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Power and Particle Exhaust in TCV

A Diagnostic Proposal

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H. Weisen and R.F.Chavan

A basic diagnostic programme for the study of plasma-surface interactions in TCV is outlined, comprising the observation of plasma facing surfaces using Infra-Red camera thermography and the measurement of divertor and limiter edge parameters with arrays of Langmuir probes. The variety of IR camera equipment on the market is analysed and a particular device recommended. A programme cost estimate is provided.

Following a meeting in which the proposal was assessed, it was requested that the proposal be more widely disseminated and that a separate resumé of the costs be presented. A copy of this summary has been appended to the main proposal.

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1. Introduction

Whilst TCV was conceived as a machine with the goals of characterizing the stability, control, confinement, beta limits etc. of highly elongated plasmas, the flexibility furnished by the large number of shaping coils will also permit a variety of new and interesting divertor configurations. The many possible open configurations are particularly relevant to next step devices and, moreover, cannot be easily produced in other presently operating or planned tokamaks.

Such flexibility presents an ideal opportunity to study power and particle exhaust in diverted plasmas. Indeed, the recent ECRH Phase I proposal [1] states,

"The aim of divertor experiments in TCV is to assess the possible configurations with respect to heat load, fuelling and exhaust efficiency and to study *particle and energy transport* to and from the target plates."

Observations of this nature are long overdue but are now undertaken on all meduim and large tokamaks (eg JET [2], DIII-D [3], ASDEX-U [4], TFTR [5]) or are planned for those yet to begin operation (eg FT-U [6]).

This note will outline why such measurements are required, will describe the basic hardware elements (including cost estimates) believed to be required for a diagnostic programme to study heat and particle exhaust and show how such systems could be easily implemented in TCV.

2. Why make the measurements?

There are a number of reasons why these observations should be undertaken in any tokamak, especially those in which diverted configurations are possible:

- Machine integrity - observation of performance of first wall components during initial experiments and in more advanced diverted discharges.
- Global power balance.
- Distribution of heat flux at divertor strike zones, variation with discharge conditions, heating, X-point-tile separation, comparison of particle and heat flux strike zones.
- Observation of parallel temperature/density gradients
- Observation of non-thermal ions.

Aside from physics issues, thermography of plasma facing surfaces is becoming more necessary on modern tokamaks as a consequence of higher power densities and more complex first wall structures. Due to the flexibility and sensitivity of modern Infra-Red (IR) cameras, routine two-dimensional thermography of first wall components intercepting plasma can give the time history of the power flux density across the whole tokamak operating range Since commercially available hardware gives standard video output, the data could be presented, for example, in video form for machine operator use, whilst being stored digitally for more detailed physics analysis later.

Measurements are important during early plasma and heating system commissioning and especially in more advanced diverted configurations, where magnetic field lines may strike limiting surfaces at such glancing angles (≈ 1°) that even the very small inevitable tile misalignments (perhaps as little as 0.5 mm in TCV) beome important. Large power amplification factors have been observed in DIII-D [7] at tile edges as a consequence of misalignment. Such effects cannot be observed with visible cameras (H_α) until the temperature is already very high (eg. ≈ 1000°C).

For TCV in particular, the divertor floor will be covered with flat graphite tiles, in contrast to other machines (like JET) in which a chamfer of the order of the magnetic field line intersection angle is added to decrease sensitiviy to tile misalignments. Whilst the correct choice of angle is difficult in TCV owing to the variety of possible configurations, it would be extremely interesting to replace two tiles in the camera field of view with a pair whose surfaces are slightly chamfered. Since TCV will be sufficiently flexible to permit the field line angle at the floor to be readily varied, this would provide a unique opportunity to study the power handling capabilities of various geometries in reactor relevant configurations.

In addition to observations from the point of view of machine integrity, measurements of the total deposited power are necessary to investigate power balance. During non-diverted, ohmic plasmas and ECR heated, diverted discharges alike, it is always of importance to know if the power arriving at the plasma edge is accounted for by the difference between the total input power less that radiated. Although some toroidal averaging is always required (since a single IR camera cannot simultaneously cover the entire first wall), this is often a good approximation, even during ECRH. Using Langmuir probe arrays on DITE, good power balance was observed at medium operating densities during both ohmic and ECR heated plasmas [8]. In common with observations on JET [9], however, discrepancies appeared at low density. This may be traced to an increase in the edge plasma of the ratio T_i/T_e at low density which was observed directly on DITE [10] and indirectly on JET [9]. Heat flux measurements in combination with probe data could be used in TCV to infer the presence of high ion temperatures if they are present. In a later development of the programme, retarding field analysers could be used to measure T_i directly. In combination with IR thermography, probe studies may also be performed to evaluate the magnitude of δ, the sheath heat transmission factor, governing the power carried by each electron/ion pair crossing the sheath.

In current tokamaks utilising open divertor configurations such as those planned for ITER, measurements have shown that somewhere in the region of 30 - 60% of the total input power can be deposited on the divertor target plates (see eg. [11]). Studying the exact nature of this power deposition is of vital importance for the design of plasma facing surfaces in next step devices. For example, studies on DIII-D and JET have shown that the peak heat load does not always coincide with the separatrix intercepts (determined by magnetics). Indeed, the heat and particle deposition profiles can be quite different. No detailed study has yet been made as to how these effects scale with global parameters (eg. central density, additional heating input) or with local conditions such as changes in recycling due to wall conditioning (eg. boronization) and high power heating and variation in the X-point to wall separation.

Observations in separatrix plasmas have shown that most of the power conducted and convected to the target plates arrives at the outboard strike point if the ∇B drift is directed towards the separatrix. On reversing the toroidal field, the asymmetry disappears, as do the differences in the widths of the heat deposition profiles at the inner and outer strike points. The effect can be qualitatively explained [12] in terms of neoclassical particle drifts which lead to enhanced particle flux into the inboard divertor leg and a subsequent broadening of the profile and reduction of the heat deposition on the inner tiles. It would be particularly interesting to study the asymmetry on TCV (if it exists), where a large number of configurations and hence geometrical variations are possible.

During periods of H-mode confinement, the manner in which the divertor heat loads are modified has not been comprehensively studied. There is evidence [11] that the heat deposition profile narrows and moves closer to the strike points, but no clear experimental study of how this relates to the particle flux has been made. Detailed observations of this nature may help to identify how transport processes (for example, the balance between parallel conduction and perpendicular diffusion) are changing during the transition to high confinement. Similarly, heat and particle outflux measurements during Edge Localized Modes (if they are observed in TCV) would provide information on the nature of these instabilities. Studies are required to establish the fraction of the plasma stored energy released during a large amplitude ELM, the time over which it is released and the increase in the particle fluxes and their relation, if any, with the observed heat flux changes.

In TCV the heat flux increase due to large amplitude edge localised mode should be observable. For example, in a reference TCV ITER like discharge with $I_p = 545$ kA, $P_{tot} = 3$ MW, $\kappa = 2$ and $B_T = 1.43$ T [1], an ELM carrying 10% of the total stored energy over a period of perhaps 5 ms (as observed in DII-D [11]) over four strike zones of width 2 cm would cause a divertor tile temperature rise of $\approx$ 6°C. This should be compared with Infra-Red camera technology, described below, which can easily monitor changes of the order of 0.5°C. (The calculation assumes that the tiles may be approximated as semi-infinite solids - see section 3.1.) It is doubtful that "grassy" ELMs, should they appear, would be observable on TCV since they are high frequency and in any case are not thought to transport a significant part of the plasma energy [11]. The particle flux reaching the divertor during fast ELMs could, however, be easily observed using probes sampled at relatively low frequencies.

In connection with diverted plasmas, an important question which has not been studied in detail in tokamaks is that of the existence of parallel temperature and density gradients along the separatrix. Such gradients are important in determining the forces experienced by ions in the divertor region. Using simple pressure balance, parallel heat conduction and heat transmission at the divertor sheath, it can be shown [13] that an approximate condition for strong gradients in temperature to exist is that the inequality

$$\frac{Z_{eff} n_u L_c}{F_p T_u^2} \geq 10^{17}\ \mathrm{m^{-2} eV^{-2}}$$

is satisfied, where L_c is the connection length from mid-plane to divertor target, n_u and T_u are the midplane (or up-stream) values of the edge density and temperature and F_p is the fraction of the divertor power arriving at the target plates. In this context, strong gradients are taken to mean $T_u \geq 2T_d$ where T_d is the electron temperature at the divertor tiles. The quantity F_p is difficult to estimate but, for open divertor configurations is more likely to be near unity (for ITER, $F_p = 1$ is assumed). This means that gradients may only be observed in high density discharges where the edge temperature is relatively low. In TCV, measurements of the edge temperature and density near the mid-plane will be possible using the tangential Thomson scattering system. This is especially true in diverted configurations when the plasma may move away from the wall and during discharges in which the boundary density is highest (increasing the reliability of the Thomson data). Probes located in the target tiles would provide measurements of temperature and density at the divertor floor. Provided that the two measurements can be assumed to lie on or close to (compared with radial characteristic lengths in the edge) the same magnetic flux surface, and that toroidal symmetry could be assumed, it might be possible to observe parallel gradients in TCV.

Probe measurements may also be used to investigate the passage of parallel currents through the divertor target tiles near the X-point strike zones [14]. Such currents flow as a consequence of differences in the electron temperatures and densities at the two strike zones, with the thermoelectric current being dominant. If present, these currents could strongly perturb the X-point magnetic configuration, can modify the sheath voltages (and hence the degree of plasma-surface interaction) and may even modify mhd modes appearing at the edge.

3. How to make the measurements?

3.1 Heat Flux

The easiest and most rewarding method of monitoring the surface temperature is the use of Infra-Red thermography. Modern IR cameras are extremely sensitive (typically with temperature resolutions better than 0.5°C), can measure across the whole temperature range of interest (room temperature to ≈ 2000°C), can cover large surface areas and are usually internally calibrated such that the image produced may be read directly in terms of temperature. In addition, many devices on the market permit two-dimensional imaging on a relatively slow timescale (eg. 25 Hz) or extremely fast scanning along a single line (200 µs is typical). This means that integrated measurements of the power deposited over a reasonably large area would be possible for power balance and "hot spot" observations, whilst fast line scans could be made across a single line on the divertor floor to assess the response to ELMs, H-mode transitions, ECRH switch on etc. In addition, those cameras not requiring liquid nitrogen cooling are relatively small in dimension and are thus readily portable.

The power flux density arriving at a surface can be extracted analytically from a measurement of the surface temperature provided that the surface can be considered to be part of a semi-infinite solid. The condion for this to be true is [15]

$$d^2 \geq 4kt/\rho C$$

where C is the specific heat capacity, k the thermal conductivity and ρ the density of the tile material. In the case of TCV, the high thermal conductivity of the polycrystalline graphite to be used for the tiles and limiters means that this is only just valid for the timescales of interest. The criterion for the tile thickness to satisfy this approximation is d = 18mm for a 1 second heat pulse, compared with the maximum tile thickness of 19.5 mm. If the incident power flux is a function of time, P(t), then under this approximation

$$\Delta t = \frac{1}{\sqrt{\pi k C \rho}} \int_0^t \frac{P(t' - t)}{t'^{1/2}} dt'$$

Calculations to derive P(t) can be made numerically (using matrix methods [3]) and the results can be verified using finite-element codes. One such code, TOPAZ, has been used to check tile surface temperature measurements in DIII-D [11] and could be used to study TCV first wall tiles [16].

Of the diagnostic ports remaining on TCV, the central 6.0 cm port and the off-centre 10.0 cm port on the top of sector 8 are most suitable. Fig. 1 shows how vertical access is comparatively unrestricted by the vessel support structure, whilst Fig. 2 illustrates the field of view (FOV) envisaged for divertor observations. To cover the entire divertor floor, the inside wall tiles and the belt limiter requires a FOV of about 16°. Some relay optics would be required to avoid vignetting, probably including a primary objective lens at the bottom of the port together with a shutter system (similar to that planned for the soft X-ray system) to avoid coating the lens during boronization. Cooling may also be necessary in this case. From this objective, the image may be relayed horizontally or vertically depending on considerations relating to magnetic field strength (and the particular camera chosen - see below). Possible viewing scenarios for the 6 cm port are illustrated in Fig.2 although the hardware required may necessitate use of the larger adjacent window. In principle, the same camera could also be installed on alternative lateral ports (if available) to improve viewing angles for specific observations (eg. tangential viewing of the belt limiter or inner wall).

Since the emissivity of the radiating surface (in this case the graphite), can change markedly according to the surface condition (for example if impurity layers are deposited), it is important to have some method of calibration which can be implemented easily in-situ. In TCV this would be achieved by embedding thermocouples in certain tiles and using vessel bake-out to calibrate the system at low temperatures. The thermocouple design depends on the required measurements. In all cases Type K (Chromel/Alumel) thermocouples would be used, since this particular combination gives maximum sensitivity over the temperature range of interest. For calibration measurements during bake-out, simple thermocouples brazed (for good thermal contact) into a few tiles could be used [17]. For measurements during plasma operation, electrical isolation would be required to avoid erroneous voltages generated by the passage of current through the tiles. In addition, time delays would be experienced owing to the requirement that the heat pulse must propagate to the sensor. Measurements of this kind have been rarely attempted in tokamaks but could be potentially rewarding in the sense that readings of bulk tile temperature could be routinely available. Suitable sensor designs are presently being considered. Even with non-isolated thermocouples, measurements could be made before and after a discharge to evaluate the bulk temperature rise.

Since calibrated electronic thermocouple cards have already been developed in-house for other external temperature measurements on TCV, apart from the thermocouple manufacture and installation, the only additional cost would be for suitable vacuum feedthroughs. Two flanges, each carrying 21 feedthroughs for the internal magnetic coils will be located in sector 8. At present, a minimum of 50% of the capacity of each flange will be used for the magnetic feedthroughs. This leaves a possible 20 feedthroughs that could, in principle be employed for alternative use. In the case of the thermocouples, some modification of the flange may be required but this is not considered a problem. At this time, it is envisaged that a single thermocouple would be installed in each of the largest tiles in the camera field of view. This implies a maximum of 4-6 sensors (see below).

3.2 Particle Flux

In combination with the IR camera, it is proposed that an array of Langmuir probes be installed in the tiles of sector 8. The tile arrangements on the floor and lower part of the inner wall are shown in Figs.3 and 4 with the suggested Langmuir probe and thermocouple locations marked. Two possible candidate tiles with which to perform the power handling experiments described earlier are also been indicated. A maximum of around twenty probes are proposed with their disposition being determined by two factors:

1. That there be sufficient probes to obtain reasonable spatial resolution during divertor operation

and

2. That measurements be possible under the largest number of different divertor configurations. Examples of likely configurations are illustrated by the equilibrium plots shown in Fig.5

The probes must be designed such that they are robust, large enough to collect sufficient current, easy to install and remove, rigidly fixed to prevent movement during disruptions etc, easy and cheap to manufacture. A suitable design has been developed to satisfy these criteria and is shown in Fig. 6. The probe may be installed at any point in any tile and would be manufactured from the same graphite as that of the tile itself. The diameter would be 5 mm with a 0.5 mm gap all round to prevent shorting to the tile. A radius on the probe tip of 0.5 mm increases the collection efficiency while providing least sensitivity to changes in the magnetic field line angle at the tile surface [18].

The probe is rigidly held in place by a set of insulating rings and can be positioned vertically to any required precision. It can be removed and installed easily. Signal cable connections can be brazed and the special feedthroughs adapted for the internal magnetic probes together with thermo-coax cable could probably be used. Similar probes could easily be installed in the belt limiter.

4. How much will the measurements cost?

4.1 Heat Flux

Commercially available IR cameras fall into three categories:

1. Single element, mirror scanning devices.

2. So called FPA (focal plane array) instruments consisting of a multi-element array (eg. 128 x 128) pixels, each requiring separate calibration.

3. Charge Coupled devices (CCD).

The latter are still under development and are very expensive. The focal plane arrays are more established and at the leading edge of current technology. In addition, the camera heads contain no moving parts and are thus more ideal in situations where relatively high magnetic fields may be present. However, they are expensive, especially if good spatial resolution is required (ie more pixels) and cannot be easily operated in a fast line scanning mode without additional electronics and hence additional cost. Moreover, although pixel to pixel calibration is performed automatically by the camera control electronics, the system is necessarily more complex.

Mirror scanned, single element cameras have the advantage of reasonable spatial resolution for two-dimensional viewing (ie two simultaneously scanning mirrors) and an ability to perform fast line scans with one mirror disabled. It is not clear how such cameras perform in high magnetic fields, but suitable shielding could be provided if required.

A total of seven commercial companies have been contacted at the time of writing. Six have replied giving full system details. The only enterprise from whom a reply has not been received are an organisation named PTSI in California who are the only company known to be developing IR CCD cameras.

Cincinnati Electronics (Mason, Ohio), market a (64x64) FPA array priced at around SFr. 45000, which is liquid nitrogen cooled, will not give the resolution required in TCV ($\approx$ 4 mm^2) and comes with no lens fitted. They also produce a 250 element, LN$_2$ cooled single line array which comes with no lens and no scanning equipment - the latter has to be provided by the user. It's cost is approx. SFr. 95,000. The (64x64) array will be used for IR thermography on ASDEX-U [4].

Amber Electronics (Agents, LOT GmbH) manufacture (128x128) and (256x256) InSb FPA's, each liquid nitrogen cooled and without lenses. The support electronics for calibration, temperature conversion and output in video format are included in the prices which are SFr. 133,000 and SFr. 230,670 respectively. If a fast scan option is required, the driving electronics provided with the two cameras must be replaced by an upgraded version, the Amber Series 5000. This then permits fast line scanning at $\approx$ 100 μs and a frame rate for two-dimensional images of 1000 Hz. With this upgrade the (128 x 128) array which would suffice for TCV, is being offered at Sfr. 239,000. The (256x256) array is being considered for the new instrument to replace the old system on JET [19].

The remaining companies consulted, Agema, Spectroscopy Instruments, Lambda Photometrics and Inframetrics are all producing a variety of mirror scanned, single element cameras. Each company produces a range of cameras and accessories, with costs increasing as the hardware becomes more sophisticated. The cameras have built in black-body sources so that the IR emission is converted directly to temperature. A typical package might comprise the camera head, a lens and the camera control electronics, the latter being usually in the form of a small unit which must be placed relatively near to the camera. This box produces an analogue signal containing the temperature information and may be operated remotely using, for example, an RS-232 link. Most cameras produce temperature information with an eight bit dynamic range (256 levels) but this should be adequate for the resolution required for observations in TCV (Agema manufacture a 900 Series camera giving 12 bit digitisation (4096 levels)). The video analogue signal may of course be stored on a standard recorder, perhaps for machine operator use in real time, but could also be stored digitally simultaneously using fast ADC's. In any case, because it produces a standard video signal, the camera output should be compatible with the data acquisition system under development for TCV visible and X-ray diagnostics.

For the long wavelength range required in the TCV application, each manufacturer is able to offer Peltier or Sterling Engine cooled cameras so that liquid nitrogen is not required. Most offer similar scan rates and all produce standard (eg RS-170) video output. With additional filters, most can be used from room temperature up to ≈ 2000°C. Prices are variable but are more or less similar for a given hardware package. For example, the Agema 880 series camera head (MCT detector), a single lens and the control unit will cost around SFr. 92,000 (with some discounts possible). This gives 175 points per horizontal line and 140 vertical lines at 12.5 Hz (or 70 lines at 280 Hz) and a fast line scan of 400 μs. The Agema cameras have a good reputation and are apparently easy to maintain in the sense that access can be gained to all internal components.

A far more favourable quote has been received from Micron Techniques, the UK Inframetrics agent. They market two camera series, the 600 and 700 range. The 600 series basic camera (HgCdTe detector) produces 250 points per horizontal line and 200 vertical lines at a field rate of 60 Hz or a fast line scan in 128 μs (corresponding to a scan frequency of 7800 Hz). It retails at SFr. 101,000. For a price of around **SFr. 80,000** they have offered the 600 series camera which they have been using for scientific demonstrations over the past year. The camera used routinely on DIII-D is an Inframetrics series 525 model [3].

The price includes an 8:1 electro-optical zoom, the camera control electronics, "freeze frame" capability, filters for varying frequency bands and a complete service of the system with regard to calibration of the internal black-body and the scanning mirrors. The Inframetrics 600 requires special software to evaluate temperatures in the fast line scan mode. This is quoted at SFr. 6000. Micron Techniques have given an assurance that they will hold the camera for possible purchase by the CRPP for *five weeks*. If no word is received before then (ie effectively by the end of January 1992), the equipment will be placed on general sale. It also seems that some negociation with regard to the final price may be possible. Certainly no purchase of any camera should be made without a full demonstration by the company involved.

No estimate has been made for the cost of any relay optics since it is not clear at this stage exactly what would be required. Unless the image can be relayed sufficiently far away, some form of magnetic shielding may also be required, although this was not found to be necessary on DIII-D, even with the camera relatively close to the toroidal field coils [16].

For the thermocouples, electronics are already available so that the main costs lie in the tile instrumentation itself and the vacuum feedthroughs, cabling etc. Modification to the tiles in the form of drilling and cleaning is estimated at around SFr. 150 per thermocouple. Costs of thermocouples and feedthroughs are difficult to define at this stage but will not exceed the cost of those already manufactured for the internal magnetic coils (indeed, it might be possible to use the same type of feedthrough, depending on the availability of thermo-coax thermocouple cables).

4.2 Particle Flux

Materials costs and tile modification are estimated at SFr. 8000 for an array of 20 Langmuir probes (assuming that similar feedthroughs to those to be installed for the magnetic coils can be used). This estimate assumes that all manufacture and installation will be performed in-house. If probes are to be installed in TCV, this must, of course, be performed *before* the tiles are fitted.

Amplifiers and waveform generators already exist as standard cards developed for TCV. The only remaining pieces of hardware are the probe power supplies. Depending on the number sampling plasma at any one time, a ±4A source/sink capability and a maximum voltage amplitude of 100V would suffice to provide the voltage for all the probes. Slew rates of 0.5V/µs would be required and are commercially available. For example, Kepco (USA) manufacture a fast ±2A, ±100V. Two such supplies were used during Langmuir probe experiments on TCA and would be available for use on TCV.

4.3 Total Cost

To estimate the total hardware cost of this proposal depends on the choice of IR camera, since this is by far the most expensive item. Choosing the Inframetrics series 600, ex-demonstration model, the programme can be implemented for around **SFr. 90,000**.

5. Figure captions

Fig.1 Plan view of TCV, showing the ports in sector proposed for viewing the divertor floor

Fig.2 Cross-section of TCV sector 8. A possible viewing scenario for the divertor tiles is illustrated.

Fig.3 Divertor floor tiles in TCV sector 8. Possible locations for Langmuir probes and thermocouples are marked along with two suggested tiles for modification to enable power handling studies

Fig.4 Inner wall tiles and suggested probe and thermocouple positions.

Fig.5 Selected TCV equilibria, showing X-point strike locations.

Fig.6 Prototype Langmuir probe design for TCV.

6. References

[1] A. Pochelon, J. M. Moret, H. Weisen et al., Internal Report Dec. 1991

[2] D. D. R. Summers, Varenna 1987 Vol 3. 825

[3] D. N. Hill et al., Rev. Sci. Instr. **59** (1988) 1878

[4] A Herrmann, Electron Physics Institute, Berlin, private communication

[5] M. Ulrickson et al., J. Nucl. Mater. **176&177** (1990) 44

[6] C. Ferro, Association EURATOM-ENEA, Frascati, private communication

[7] M. Ali. Mahdavi et al., J. Nucl. Mater **176&177** (1990) 32

[8] B. Lloyd, R.A.Pitts et al., ibid 245

[9] S. K. Erents, et al., ibid 301

[10] G. F. Matthews and R.A.Pitts, Nuclear Fusion **31** (1991) 1495

[11] D. N. Hill, et al., Nuclear Fusion **28** (1988) 902

[12] G. H. Staebler, GA report GA-A19796

[13] P. C. Stangeby and G. M.McCracken, Nuclear Fusion **30** (1990) 1225

[14] A. Chankin, abstract submitted to the 10th PSI, Monterrey, CA, 1992

[15] H. S. Carslaw and J. C. Jaeger, "Conduction of Heat Solids", Oxford Univ. Press, (1959) 401

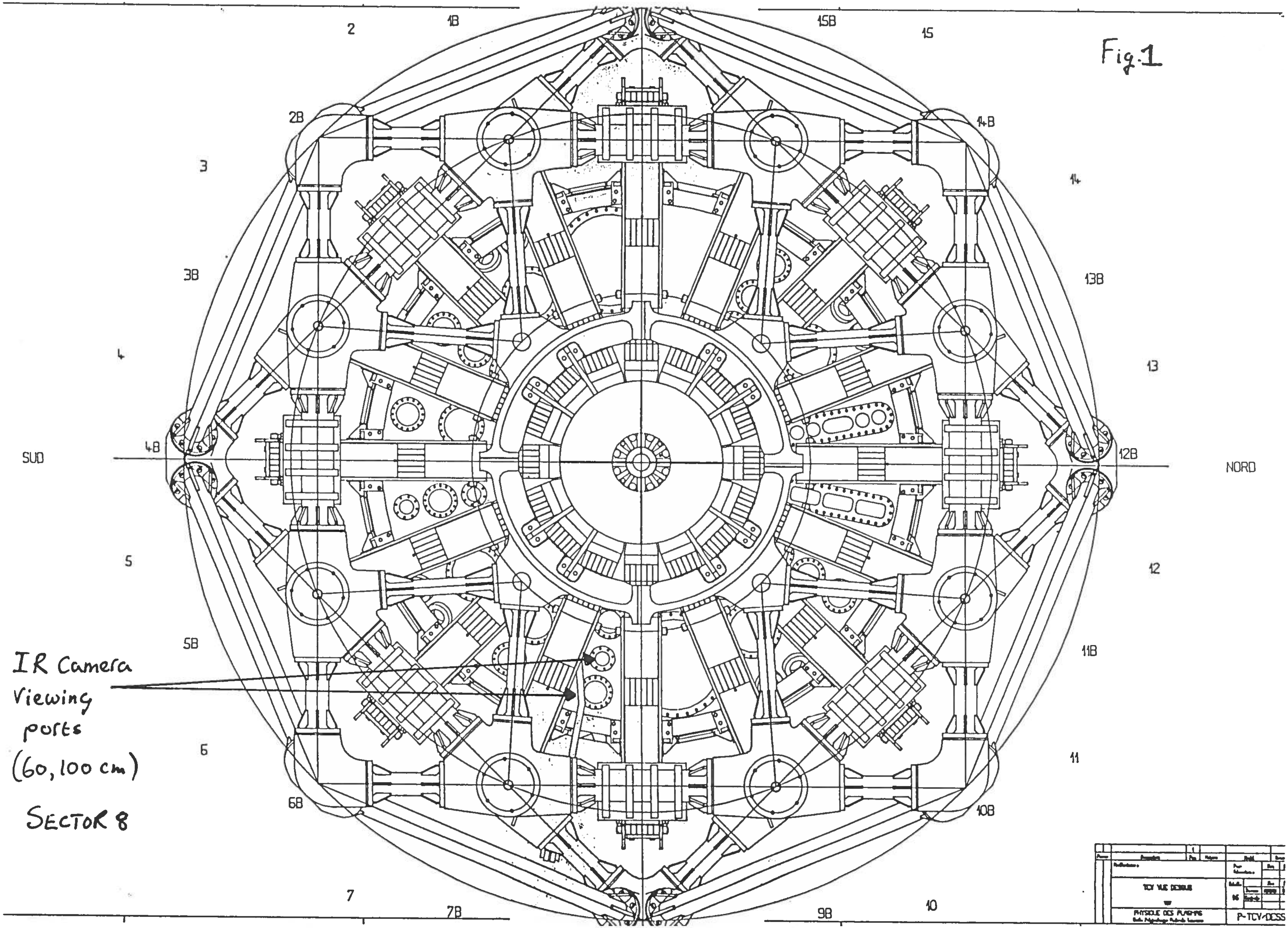
[16] D. N. Hill, Lawrence Livermore National Laboratory, California, private communication

[17] M. Brossa et al., Fusion Technology 1990 p.283

[18] D. Buchenauer et al. Rev. Sci. Instr. **61** (1990) 2873

[19] A. V. Chankin, JET and I.V. Kurchatov Institute, Moscow, private communication

Fig.1



IR Camera viewing ports (60, 100 cm)

SECTOR 8

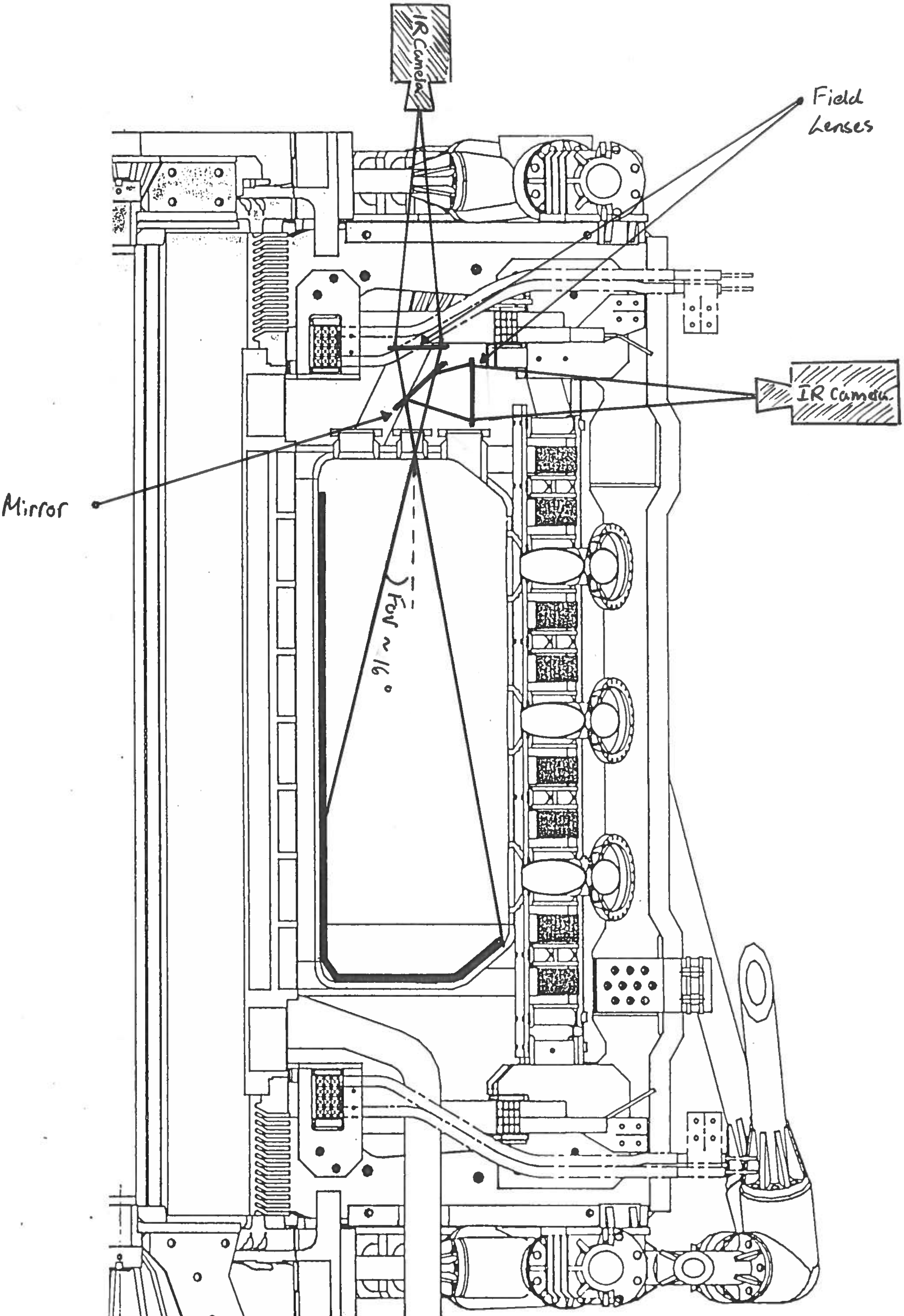


Fig. 2.
Sector 8

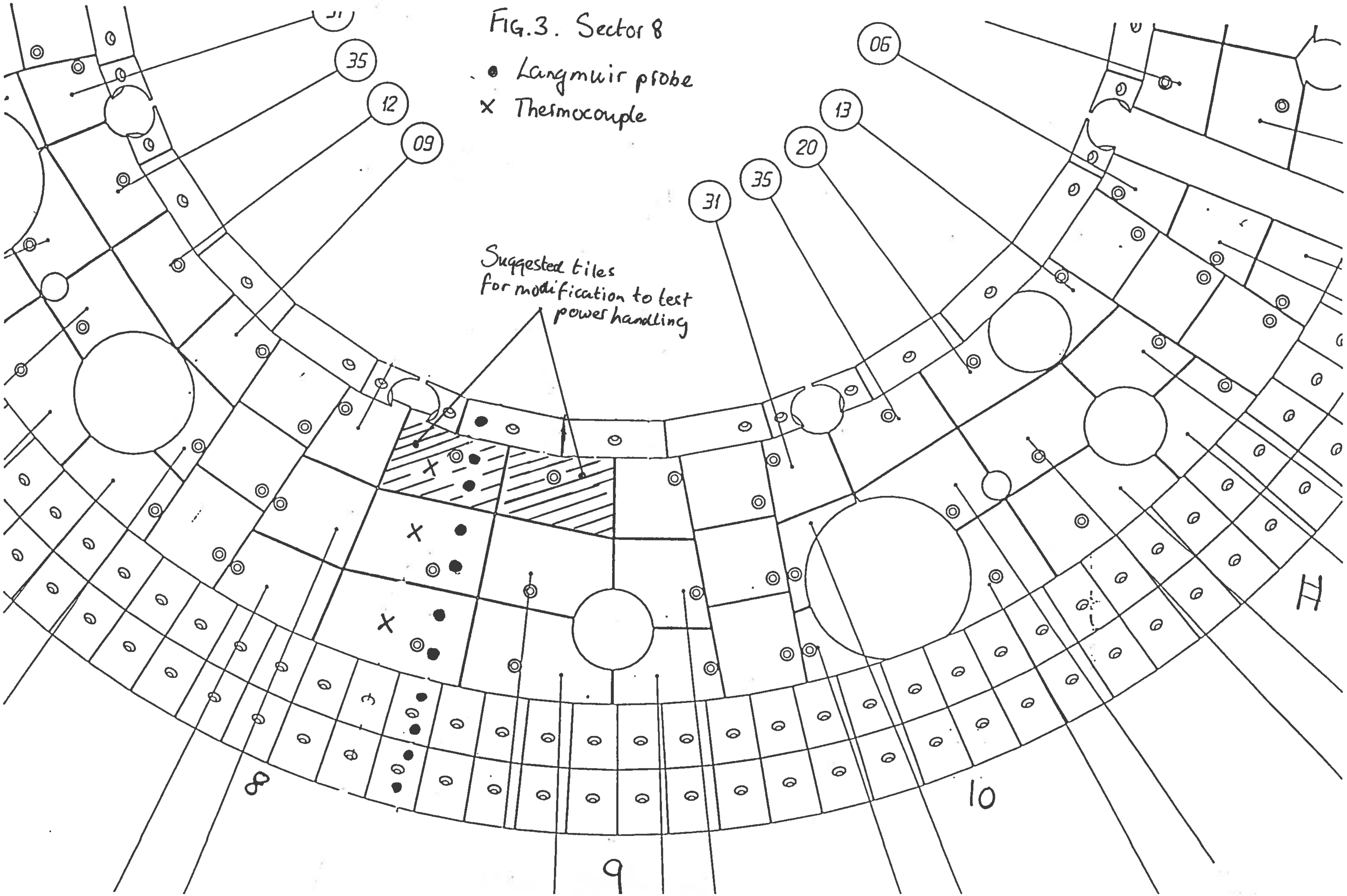


Fig. 3. Sector 8

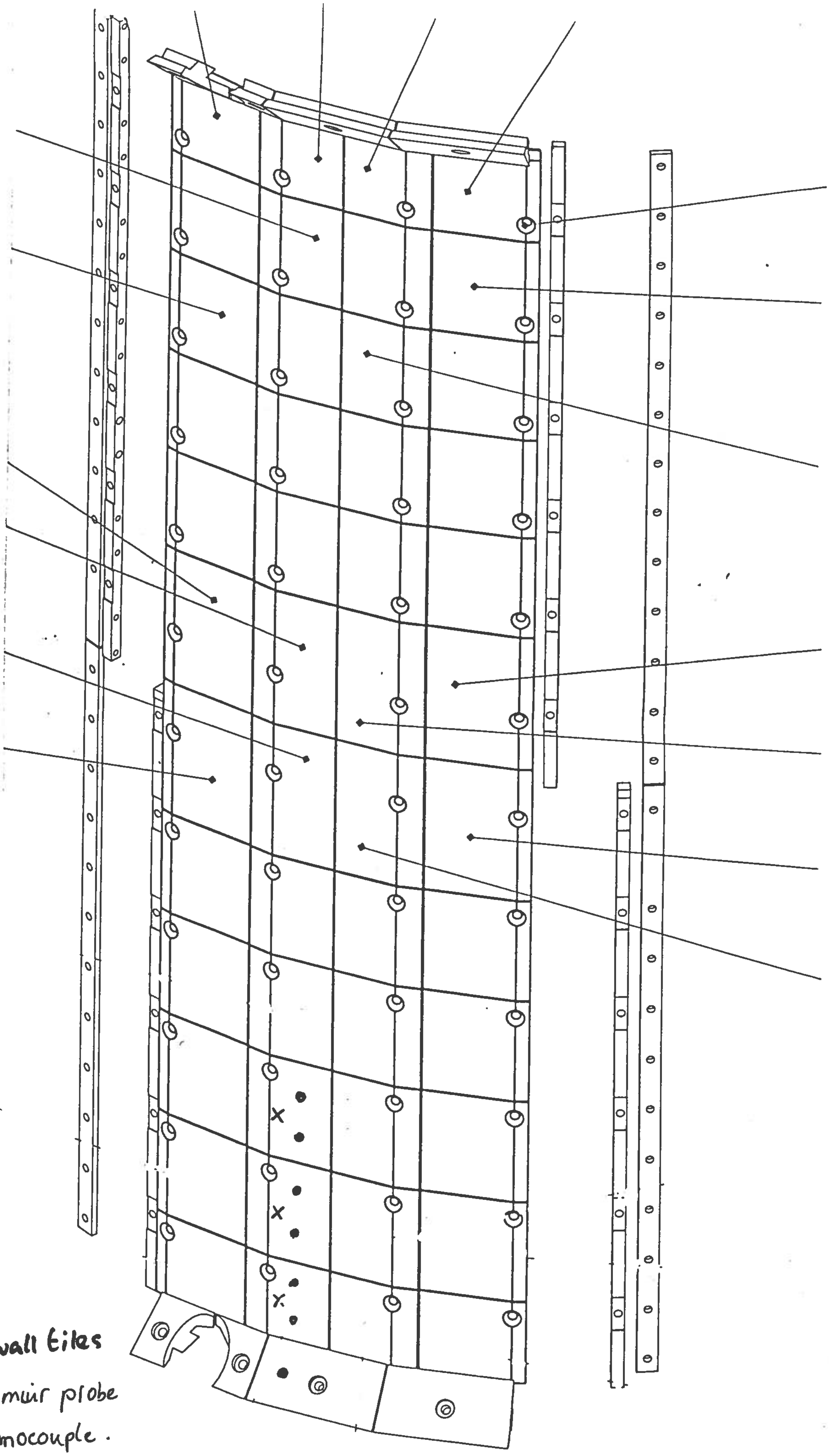


Fig. 4

Inner wall tiles

● Langmuir probe

X Thermocouple.

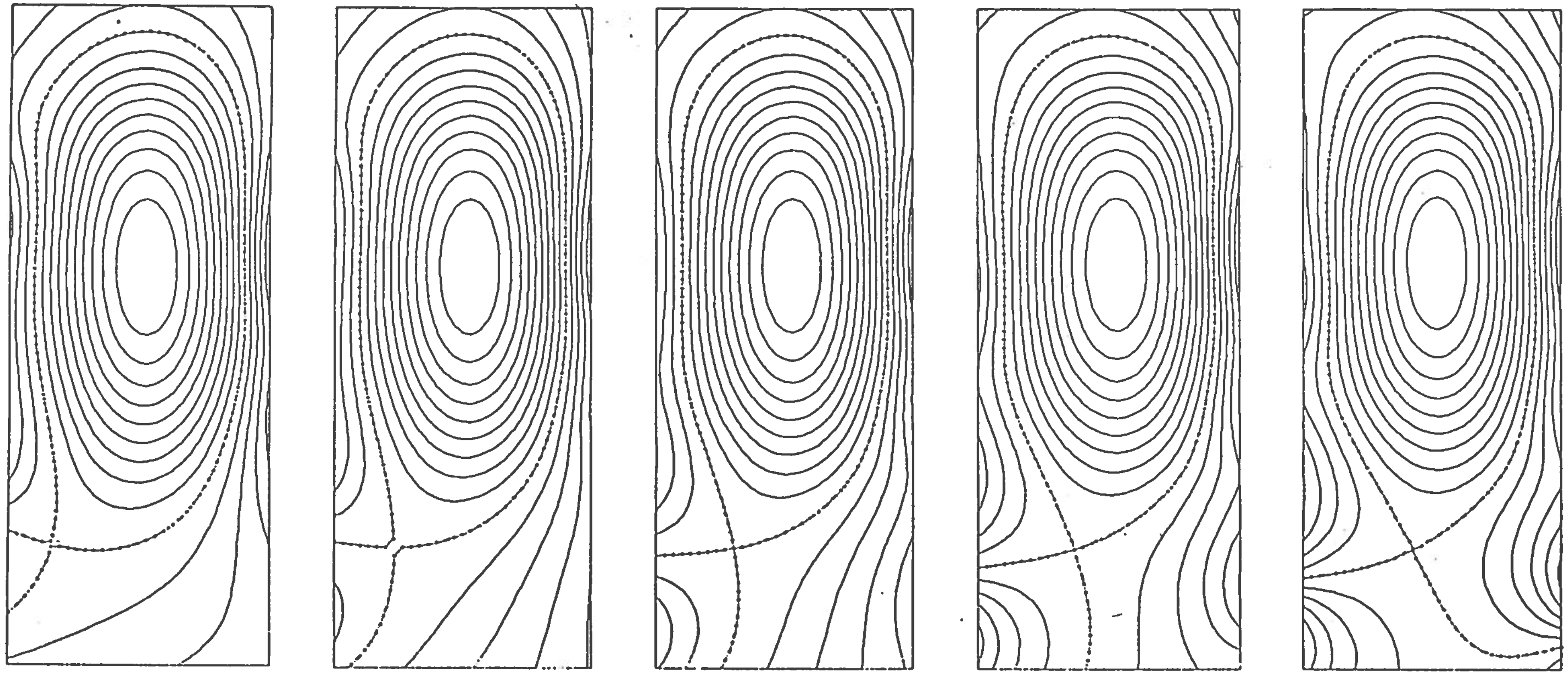
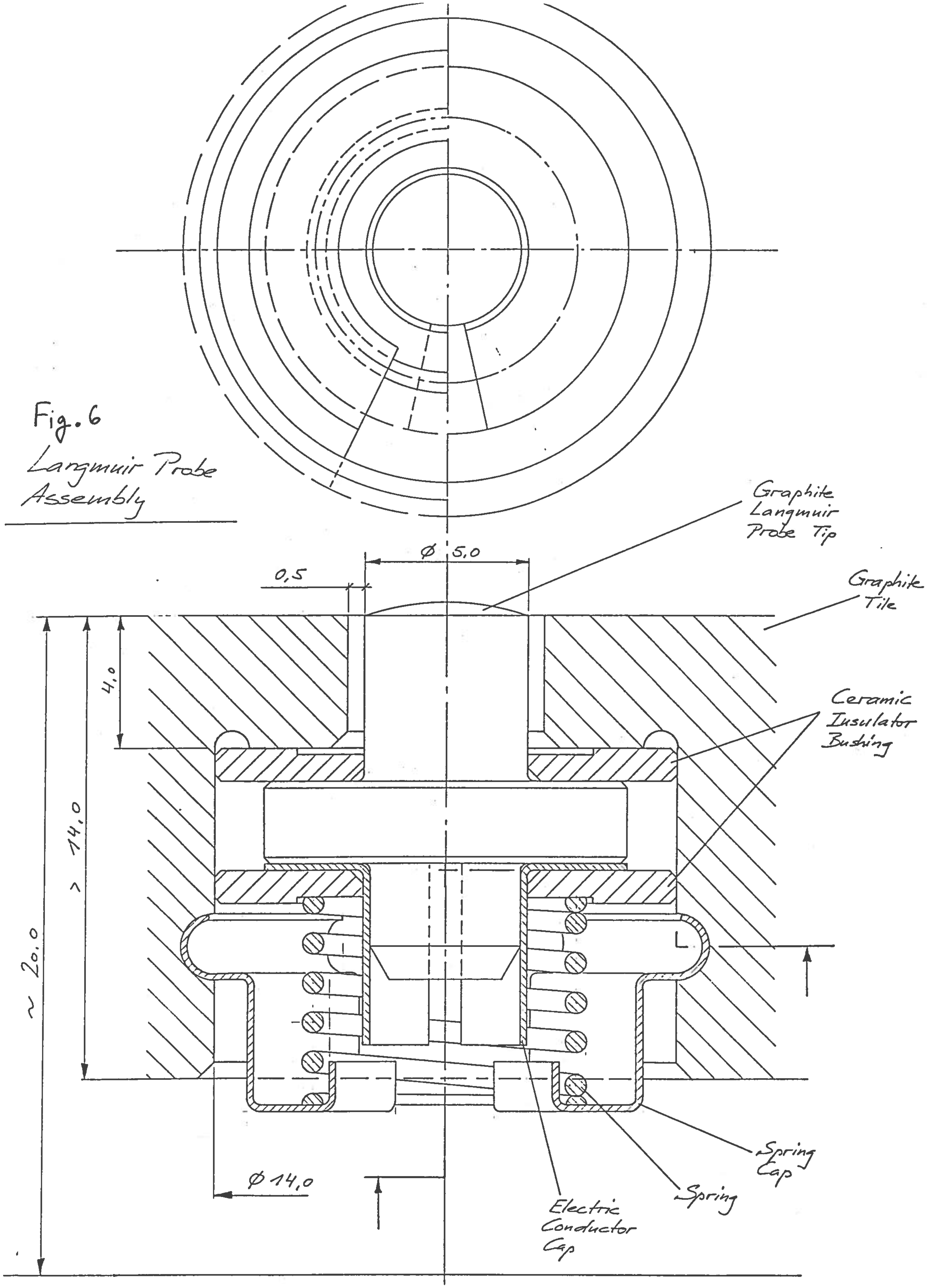


Fig. 5 Example TCV Equilibria for Diverted Discharges

Fig. 6

Langmuir Probe Assembly



Summary

Power and Particle Exhaust in TCV

Financial Summary
&
Further Comments

R.A.Pitts

Following the recent appraisal of my proposal for an edge diagnostic programme on TCV, this note is intended to serve as the summary requested during the meeting in which it was considered. The proposal suggested the use of Infra Red thermography both for basic machine integrity observations and studies of the power fluxes arriving at the first wall under the various TCV operating scenarios. Such observations, it was proposed, should also be augmented by Langmuir probe measurements of the local edge conditions, particularly in diverted discharges.

With some slight modifications, the budgetry requirements specified in the original proposal remain valid, but are specified in detail below along with additional information and comments concerning some features not specified earlier.

Infra-Red Camera

Of the various cameras studied, the mirror scanned devices are least expensive and, of those, the most favourable option turned out to be an 'ex-demonstration' Inframetrics series 600 model offered at considerable price reduction by the UK agents Micron Techniques. The camera is complete with all accessories necessary for our application, excluding data acquisition requirements (see below). The full quote is appended to this note and amounts to: **£32,262.50** or ≈ **SFr. 80,000.** This represents a saving of nearly SFr. 25,000 on the same system bought new. The equipment is to be refurbished and recalibrated in the next two weeks and will be retained thereafter in London pending a final decision by the CRPP. In the event of purchase, it would seem appropriate, given the cost, to make a short visit to London to see the equipment in operation. Such a demonstration will be organised by Micron Techniques on request.

The data acquisition aspects of an IR system on TCV were not considered in detail in the proposal. This was, and remains, a consequence of no progress having yet been made on the full specification of a generic acquistion system for all video based TCV diagnostics (ie X-ray and visible CCD cameras).

In common with all IR camera suppliers, Inframetrics offer their own dedicated PC based acquisition system ('ThermaGRAM'), a full quote for which is also appended to this note. Only items 1 and 4 on this list are of interest and amount to ≈ SFr. 38,640. This is rather expensive, particularly since it appears to be simply a video frame grabber with associated software allowing a multitude of operations on the temperature data which would probably not be required for the purposes of operation on TCV. The output video signal does, however, contain encoded information regarding the radiometer settings which are used by the software to produce accurate temperature data. Understandably, the manufacturers are reluctant to reveal the nature of this coded data, which is in any case not of interest to most users of these systems. The UK agent has promised to furnish us with the information so that we may be in a better position to decide.

From the point of view of the camera and the data acquisition system as a whole, since submitting the original proposal, I discovered that the Inframetrics series 600 cameras are used extensively on TEXTOR for limiter viewing. I contacted the physicist responsible, Dr. K. Finken, for more information and he invited to me to visit the KFA to see the cameras operating and discuss data acquisition (letter of invitation attached). This would be particularly useful since the TEXTOR group also use the Inframetrics ThermaGRAM package as part of their data acquisition system and this would be an ideal opportunity to evaluate is applicability to TCV. In addition, Dr. Finken has developed numerical analysis codes to extract power flux densities from measured temperatures and has also offered assistance in this direction.

Whilst it is not possible at present to specify the details of an IR data aquisition system, a reasonable price estimate may be compiled by considering the likely components. These would include a standard frame grabber (VMEbus) with memory extension for multiple image store, a PC and a monitor. The total cost of these items would not exceed ≈ **SFr. 18,000**. It remains to evaluate the necessity of this equipment within the framework of all other TCV video based diagnostics.

Relay optics will also be required for IR viewing but this again is difficult to specify owing to the variety of locations at which one might wish to install the camera and the requirement that the camera itself be not too close to high magnetic fields. In principle, a single objective lens, a suitable vacuum window and a mirror should suffice for most applications. Depending on the materials chosen (eg high quality ZnSe or lower quality NaCl, KCl lenses), it seems that each viewing location could be established for a *maximum* cost of ≈ **SFr. 10,000** and probably considerably less, especially in cases where field lenses are not required. There are also possibilities to use existing IR optics from previous experiments on TCA. A modest amount of technical drawing and workshop effort would probably also be required to design and construct basic support elements for the camera and optical components.

Thermocouples and Langmuir probes

As suggested in the original proposal, it now seems possible that the system of Thermocoax and special vacuum feedthroughs developed by M. Rage for the internal magnetic probes can be used also for tile (or limiter) thermocouples and Langmuir probes. A prototype Langmuir probe based on the design described in the previous report will be manufactured and tested to check that the proposed method of connecting the Thermocoax to the probe is satisfactory under vacuum and at elevated temperatures. Such tests would be performed in parallel with those planned by M. Rage for the magnetic probes. The cost remains as specified in the first proposal, namely ≈ **SFr. 10,000** for an array of around twenty probes including materials and manufacture, with the latter being performed in house.

It also appears that type K thermocouples are also available in self-contained units similar to the Thermocoax cables. Costs here would be limited to purchase of the cable and installation in the tiles or limiter elements. This is likely to be several hundred francs. Again, the same feedthroughs can be used as for the magnetic probes.

Cost Summary

The table below compiles the various cost estimates summarized in this note. As discussed above, the camera data acquisition system may turn out not to be unique to IR measurements with the consequence that this aspect of the cost may born by all TCV diagnostic systems using video output. Each amount represents the maximum likely cost.

Item	**Cost (SFr.)**
IR Camera	80,000
Data acquisition	18,000
Relay Optics	10,000
Thermocouples & Langmuir probes	10,000
Total:	**118,000**

MICRON

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MICRON TECHNIQUES LIMITED
~~15 RIVERSIDE PARK WIMBORNE MINSTER DORSET BH21 1DU~~
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QUOTATION

Ecole Polytechnique Federale de Lausanne
Centre de Researches en Physiques des Plasmas
Association Euratom - Suisse
Bassanges/TCV
CH - 1015, Lausanne
Switzerland
For the attention of Dr. Richard A Pitts.

QUOTE NUMBER:	MT/Q/871
DATE:	January 20, 1992
YOUR REF:	Specific Request
QUOTE VALID FOR:	60 Days
IMPORT DUTY:	Not Applicable
EST. DELIVERY:	1-2 Weeks,after refurbishment
DELIVERY:	Landed, Zurich
PAYMENTS TERMS:	~~NET MONTHLY ACCOUNT~~ Letter of Credit

No.	Qty	DESCRIPTION	UNIT	AMOUNT
		To Supply the ex-demonstrationand refurbished Inframetrics Model 600 Thermal Imager to the published specification, consisting of Items 1 to 6.		
1	1	Model 600 "EC" Thermal Imaging System with an electric Sterling Cycle detector cooler, to operate the detector at 77° K. Ouput is standard TV PAL CCIR format, giving 128 grey scale image and 8 colour palettes up to 20 colours. Built in microprocessor provides many facilities, including on-screen temperature measurement, isotherms, normal and fast line scan, remote focus and electro-optical zoom. Consists of an optical head with built-in lenses, control console, cable and accessories, and a 5" JVC TV monitor, installed in a rugged transit case. Full technical operation described in the Micron Specification sheet "Model 600 'EC' High Performance Imaging Radiometer".	32,000.00	32,000.00
2		Filter mechanism, to fit up to four filters to define a specific bandpass . Remotely operated from the control console.		
3		3-5 micron bandpass filter, including calibration into software. Sensitivity reduced compared to the 8-12 μ band below 100°C.		
4		8-12 micron bandpass filter, including calibration into software. Minimum measurable temperature is -20°C.		
5		10.8 micron flame suppression filter, including calibration into software.		
6		"Image averaging and freeze frame" system.		
		Carriage, Insurance and Freight Charge...		262.50
		The quoted prices are in £ Sterling. 15 Day Letter of Credit required.		
		The current BRAND NEW price of this system is £41,450.00		
		VALUE ADDED TAX IS NOT INCLUDED IN THE QUOTED PRICES		
		APPROVED BY: E. & O. E.	TOTAL	£

This quotation is issued subject to our Terms and Conditions of Sale, available on request.

MICRON

MICRON TECHNIQUES LIMITED

[redacted]

22, Ashley Walk, Mill Hill, London, NW7 1DU
Telephone:- 081-343 4836
Fax:- 081-343 4286

QUOTATION

QUOTE NUMBER: MT/Q/872
DATE: January 20, 1992
YOUR REF: Specific Request
QUOTE VALID FOR: 60 Days
IMPORT DUTY: Is Included
EST. DELIVERY: 1-2 Weeks
DELIVERY: Landed, Zurich
PAYMENTS TERMS: ~~NET MONTHLY ACCOUNT~~ Letter of Credit

Ecole Polytechnique Federale de Lausanne
Centre de Researches en Physiques des Plasmas
Association Euratom - Suisse
Bassanges/TCV
CH - 1015, Lausanne
Switzerland
For the attention of Dr. Richard A Pitts.

No.	Qty	DESCRIPTION	UNIT	AMOUNT
		To supply the ThermaGRAM 600, Version 3.0 Thermal Image Processing System.		
1	1	ThermaGRAM 600. Consists of a specifically designed Image Processor Board and software for installation into a IBM, Compaq, or other approved computer. See Micron Specification sheet "Computer requirement for ThermaGRAM" for computer specification. Software includes all device drivers, printer drivers and calibration data for a Model 600 with a specific serial number. Accepts live images from any Model 600 Thermal Imager, or images from any VHS VCR, with a specifiction equal to or better than a National Panasonic NV-180.	9,995.00	9,995.00
2	1	Optional PLOT, time versus temperature software. Captures and analyses up to three channels of transient thermal data from individual points or areas on a thermagram. Accepts data at 'normal' rates from one per second or at 'snapshot' rates of one per digitized video frame.	1,790.00	1,790.00
3	1	Optional 'PictureBase', an image archive and retreival system for ThermaGRAM images. Data base can be searched for a specific record or a	3,220.00	3,220.00
4	1	'RedSTAR', Real time Digital Storage and Retreival software. Stores consecutive video fields (or fast line scans) from the Imager into virtual Full ThermaGRAM software analysis available on each data field (or line).	5,461.00	5,461.00
5	1	Sony KX14-CP1, RGB analogue/digital high resolution monitor**.	660.00	660.00
		The quoted prices are in £ Sterling. 15 Day Letter of Credit required. 5)**Accepts CCIR TV signals from the Model 760 thermal imager, and required to accept the 'Thermagram' from the Image Processor in RGB format.		
		Item (1) is the complete 'ThermaGRAM' system, with full comprehensive software. (2) enable up to 3 points on a ThermaGRAM to be time analysed. (3) stores ThermaGRAM (and video) pictures, as a true data base. (4) stores to virtual disc, and all software facilities are available for analysis. VALUE ADDED TAX IS NOT INCLUDED IN THE QUOTED PRICES		
		APPROVED BY: E. & O. E.	TOTAL	£

This quotation is issued subject to our Terms and Conditions of Sale, available on request.

Institut für Plasmaphysik
GESCHÄFTSFÜHRENDER DIREKTOR
PROF. DR. G. H. WOLF
FORSCHUNGSZENTRUM JÜLICH GmbH

KFA

Dr. K.H. Finken

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Dr. Richard Pitts
Centre de Physique des Plasmas
Ecole Polytechnique Federal
21 Avenue des Bains
Ch 1007 Lausanne

Ihre Nachricht vom / Zeichen   Bei Beantwortung bitte angeben   Telefon-Durchwahl (02461) 61   Telefax (02461) 61   JÜLICH

Dear Richard,   Jülich, Jan. 17th 1992

I saw your mail message that you are interested in thermography. We have meanwhile a few years experience in this field and are willing to transfer all our knowledge to you. It is of course difficult to explain everything over this distance and if you would like I can show the details of our system if you may visit us next time.

We are using the Infrarmetrix 600 system with a video recorder for the data storage and the thermogram card for the analysis. Meanwhile there may be other systems for the data readout; the advantage of this system is, however, that it is optimized to the IR scanner and it reads the data at a given position already as temperature. More important even may be that in the first 21 lines of the IR image information about the scanner is stored such as the recording time and the setting of the camera (temperature range, central temperature and so forth). It will be difficult to recover these - necessary - data with a normal frame grabber.

Up to now we have made measurements concerning the heating of the limiters, but also more sophisticated things like the analysis of the power decay length and the ratio of electron to ion temperature (I'm preparing there something for the PSI). Additionally we have measurements from synchrotron radiation from run-aways and of the heat distribution during the disruptions (I'll send you a copy of this as soon as it is accepted).

I will be glad to give you all Information and discuss all question if you would make a visit to Jülich. Best regards

K. H. Finken

(K.H. Finken)