Remote Handling in ZEPHYR

C. Andelfinger, E. Lackner
M. Ulrich, G.Weber, H.-B. Schilling

IPP 1/204 April 1982
Reprint of ZEPHYR-Report No. 11 of May 1980

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK
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Abstract

A conceptual design of the ZEPHYR building is described. The listed radiation data show that remote handling devices will be necessary in most areas of the building. For difficult repair and maintenance works it is intended to transfer complete units from the experimental hall to a hot cell which provides better working conditions. The necessary crane systems and other transport means are summarized as well as suitable commercially available manipulators and observation devices. The concept of automatic devices for cutting and welding and other operations inside the vacuum vessel and the belonging position control system is sketched. Guidelines for the design of passive components are set up in order to facilitate remote operation.

Remote Handling in ZEPHYR:

Figure Captions

1. Introduction

In the ZEPHYR experimental phases 2 and 3, when D-H, D-D and D-T plasmas will be produced, intensive neutron radiation [1] will produce activation of structure material to such an extent that access to the experiment after the discharges will only be possible for short times during phase 2, and not at all possible during phase 3. This means that one has to be prepared for remote maintenance and repair as well as remote adjustments of diagnostic devices.

To limit the necessity of remote handling the experimental area is divided by a primary neutron and γ-ray shielding around the tokamak system proper.The dimensions of this shielding must be chosen such that after an acceptable cooling time of some hours in the case of D-D discharges or some days after a longer D-T discharge phase all parts outside the primary shield can be handled hands-on. Part of this shielding is the ceiling of the basement,in which many diagnostic devices and supplements to the neutral beam injection have to be housed.

Whereever possible, remote handling should be done by relatively cheap prolonged tools which penetrate the shielding.

Work on site of the experiment will mainly be confined to assembling and dismantling of components. Attention has to be paid to adequate passive remote handling very early in the design of the total system and a compromise has to be found between the expense for passive remote handling and the time consumption for remote maintenance or repair when normal components, fittings or flanges and others are applied. Remote handling needs 10 - 100 times more time than hands-on work. This depends strongly on the question whether direct observation is possible, or only observation by TV monitor. A main subject of the philosophy of remote handling is to shift complicated maintenance or repair work to a hot cell, where direct observation through windows is possible and where power reflection of mechanical manipulators makes the job easier. Nuclear facilities have a lot of experience in hot cell technology.

Most of the devices needed for active remote handling are commercially available.

Machines capable of cutting and welding the vacuum vessel in case of defects in the vessel or surrounding coils will have to be specially developed. Development is necessary for positioning such tools and to obtain adequate television systems for obervating operation. Replacement of the heat shield or limiter also calls for special development.

Finally, consideration of remote handling must influence the organization of the building for ZEPHYR at a very early stage.

2. Conceptional Design of the Experimental Area

The experimental area of ZEPHYR is divided into 4 zones with respect to access to the tokamak and its peripheral system [2].

Zone 1: All rooms outside of the experimental hall and the hot cell and their basements, except the tritium handling room. There is unlimited access for hands-on work.

Zone 2: The basement of the experimental hall is expected to afford full access after some time for ventilation of activated air. There will be a lot of channels to the experimental hall which allow flow of activated air to the basement; furthermore, a small release of tritium will be possible. Expected activities are: Ar^{41} 10^{-7} Ci/m^3, N^{13} 10^{-6} Ci/m^3, N^{16} 2×10^{-4} Ci/m^3 and tritium 2×10^{-5} Ci/m^3. Protective clothing with oxygen apparatus could be necessary.

This basement will mainly be used for diagnostics and accessories of the neutral injection. The ventilation system should limit the waiting time to less than one hour. In the case of larger tritium release the doors will be locked until the air contamination is less than some 10^{-6} Ci/m^3.

If handling has to be done at channels to the experimental hall, local shielding and mechanical manipulators or special tools should be provided.

There is no access during the discharge.

The situation in the tritium handling area is different. Here we only have β-radiation from released tritium. Controlled personnel can enter the area when contamination is below 2×10^{-6} Ci/m^3. This will be achieved by the tritium absorption system and ventilation system. If these values cannot be achieved, full protective clothing with oxygen apparatus will be necessary. All apparatus with high tritium inventory are handled in glove-boxes.

Zone 3: The experimental hall outside the first shielding and the basement for the water cooling system of the neutral beam lines. In this area access is restricted partly by activated air or tritium contamination and partly by activated materials.

The expected activation of the air per discharge is: Ar^{41} $1-2 \times 10^{-6}$ Ci/m^3, N^{13} $1-2 \times 10^{-5}$ Ci/m^3, N^{16} 5×10^{-3} Ci/m^3 and T 2×10^{-5} Ci/m^3. The ventilation system should allow access after 1 - 2 hours with protective clothing and oxygen apparatus. More restricting will be the delayed γ-radiation in the experimental hall coming from the activated structures of the tokamak system and first shielding. The biological dose rate near the outer surface of this first shielding after one year of D-D discharges will be about 10^{-3} rem/h. After a cooling time of one hour, practically unlimited hands-on work will be allowed. However, in the case of D-T discharges, when the equilibrium of the radiation is achieved, this dose rate becomes about 30 rem/h after 1 hour and about 10^{-1} rem/h after 2 days. The latter allows only 25 hours hands-on work within a quarter of a year for a radiation worker.

This shows that in the D-T phase even outside the first shielding maintenance and replacement of components should be possible by remote handling. One should save the allowed working time for difficult handling. For longer repair intervals one would benefit from longer cooling times, but in any case the diagnostic devices in the experimental hall must be controlled and adjusted by remote elements.

In the water cooling system in the basement the isotope activated most will be N^{16} from the O^{16}. Its decay time is very short and an adequate cooling time of one hour will result. Nevertheless there is still some uncertainty about unknown contaminations in the water.

<u>Zone 4:</u> <u>Inside the primary shielding</u> there is no access for hands-on work, full remote handling having to be provided even in the D-D phase. A radiation worker could only work for a few hours.

Remote handling should be restricted to simple maintenance and replacement of components. Whenever possible, repair should be done in the hot cell with mechanical manipulators and direct observation.

Transport of the activated components has to be done with remote-controlled cranes and a railway system between the experimental hall and the hot cell.

The large boxes of the neutral beam injectors can only be dismantled in the hot cell because a large release of tritium has to be expected, and only the hot cell and the tritium handling area can be provided with an emergency tritium absorption system. Before handling in the vacuum vessel, this system must be connected with the torus.

Figures 1-3 show the conceptual design of the experimental area together with the essential crane and manipulator systems.

In addition, movable manipulator boxes and electronically controlled master-slave manipulators are foreseen.

The observation in the experimental hall should be done mainly by television systems. Special points inside the first shielding could be observed by periscopes or similar systems.

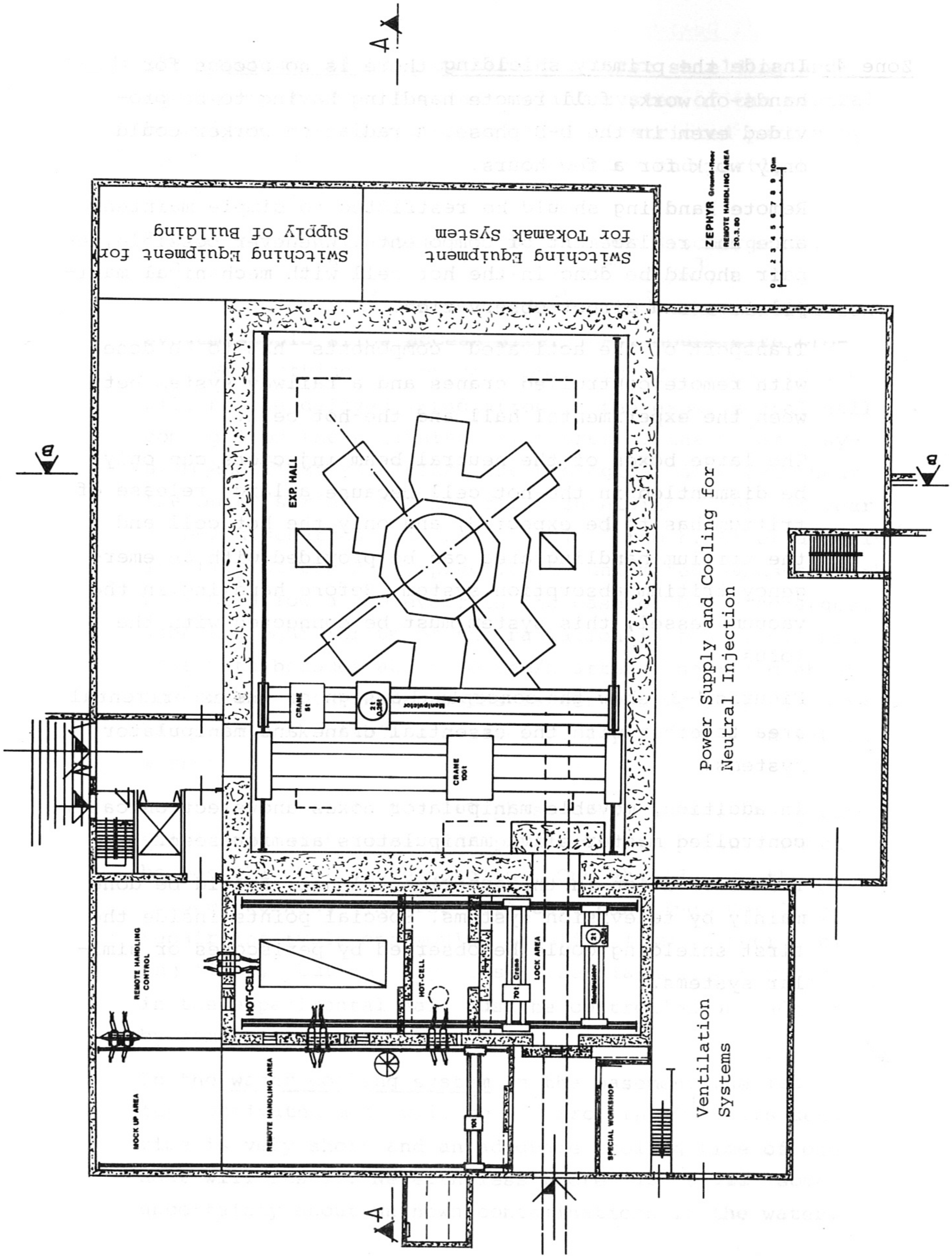


Fig.1:

ZEPHYR building concept

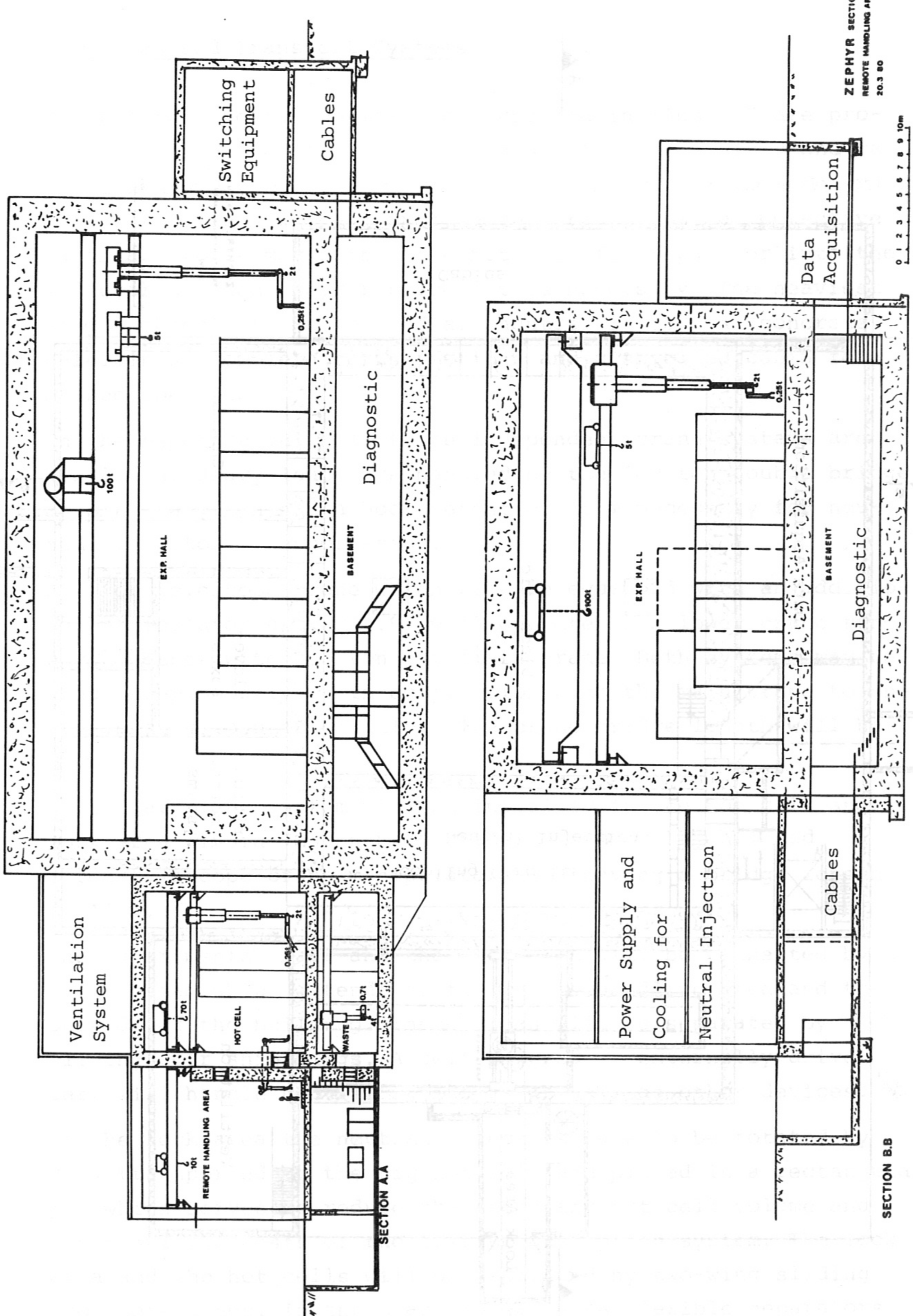


Fig.2:

ZEPHYR building concept

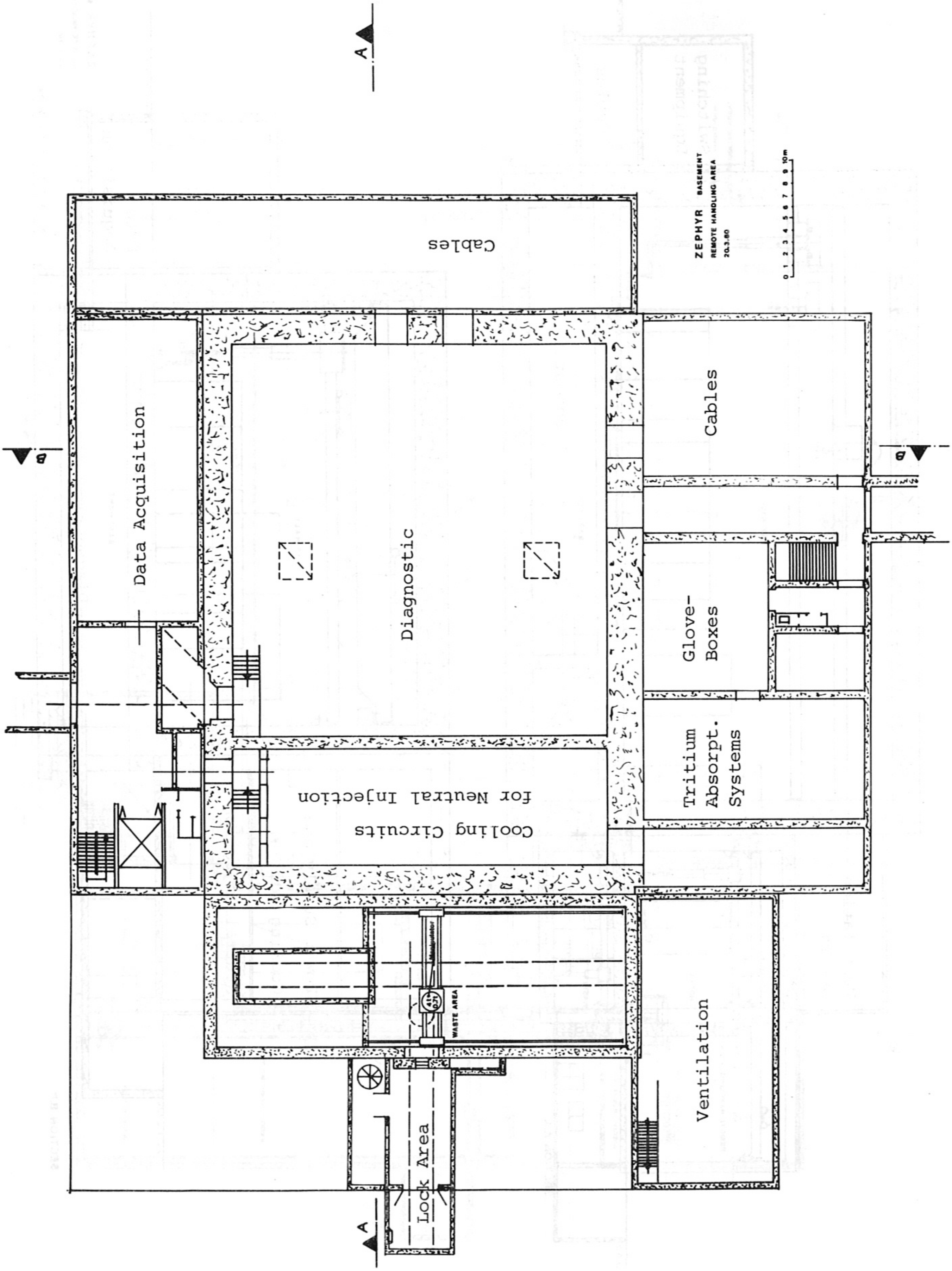


Fig.3:

ZEPHYR building concept

3. Cranes and Transport Systems

Several transportation means as sketched in Figs.1-3 are provided in order to bring manipulators,automatic devices and radiation shields into their working position and to remove defective parts or systems which cannot be repaired in place. Defective parts are to be moved into the hot cell for repair or into the waste area when their replacement is necessary. The heaviest single objects to be handled are neutral injectors, concrete shieldings, complete torus sections and a shielded cabin for manned operation.

In the experimental hall three independent crane systems are available. Heavy loads are handled by the 100 ton double bridge main crane which has a hook height of 15 m necessary for neutral injector transportation.

A 2 ton telescope crane which will be equipped with an additional manipulator arm (Fig.9) will operate on a lower crane runway together with a 5 ton auxiliary crane. Both systems may be used independently or in conjunction with the main crane to ensure proper load orientation. The crane bridge length will be 32 m.

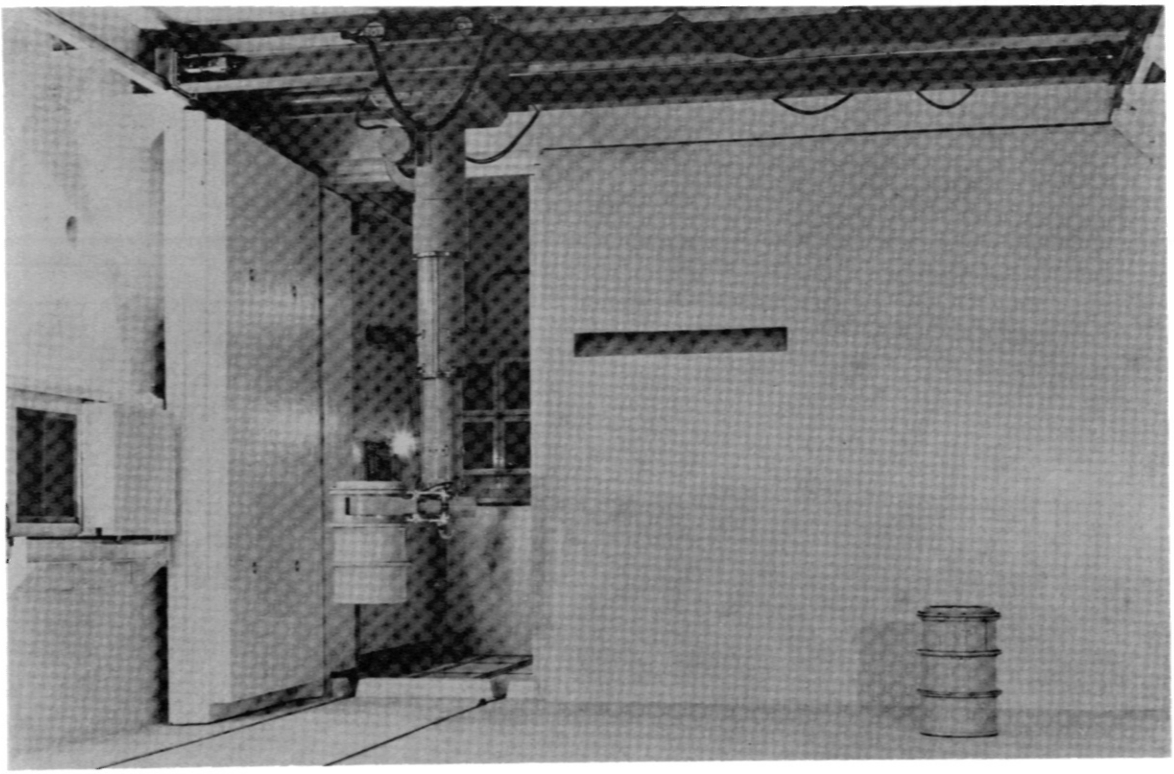
A similar crane system will be installed in the hot cell and lock area with a 70 ton main crane (8 m hook height) and 2 ton telescope crane manipulator,both having a bridge length of 12 m.

The experimental hall and the lock area will be connected by a rail system which extends to the remote handling area and the outside of the building. These areas will be separated by sliding door shieldings. A self-powered or externally driven cart will handle neutral injectors as well as other devices.

In the lock area the neutral injectors have to be rotated by 90°, transported to the big hot cell and placed in a rectangular pit which serves to reduce the necessary hot cell volume and the resulting costs of the tritium absorption system. The lock area and the hot cells will be separated by two-wing sliding door shieldings. In the crane runway area flexible separators have to be installed in order to avoid air exchange. A rail system in the basement area allows the transport of heavy waste parts from the pit into the waste area. Other waste may be disposed of through an opening in the floor of the small hot cell. The waste area will be equipped with a combined 4 ton telescope crane barrel manipulator (Fig.4). Since the waste area will not be accessible, provisions have to be taken to dismantle this crane and lift it into the hot cell for repair.

The remote handling and mock up area will have a 10 ton crane for the transport of training models, manipulators and special automatic devices. The basement area below the experiment will normally be accessible for hands-on operation. In case of removal of parts of the shielding, however, a battery powered transport cart will be used to lift a shielded manipulator cabin (Fig.7) into position. Two 3 m × 3 m openings in the experimental hall floor allow transport between the experimental hall and the basement.

Maintenance and repair of the transport systems can be performed manually after a moderate cool-off time in most cases. Duplication of components in order to achieve higher redundancy is therefore not generally recommended.



Faß-Manipulator „SM5-E"

"SM5-E" Drum Manipulator

Technische Daten SM5-E:

— 6 Bewegungsmöglichkeiten
— Tragfähigkeit in der Zange 750 kg
— Tragfähigkeit am Lasthaken 4000 kg
— Brücke für 8 m Zellen-Breite
— 5 Bewegungen mit je 2 Antriebs-Einheiten

Technical Data of SM5-E:

— Six movements.
— Load carrying capacity of tongs 750 kg
— Load carrying capacity of load hook 4000 kg
— Bridge for 8 m cell width.
— Five morements with two drive units each.

Fig.4: Hot cell barrel manipulator SM5-E (KfZ Karlsruhe)

Table of Crane Systems and Manipulators

Experimental Hall:

1 Main Crane	100 to
hook height:	15 m
bridge length:	32 m
1 Heavy load manipulator	2 to (A1001)
telescope length:	9 m
bridge length:	32 m
manipulator arm length:	1.2 m
manipulator arm load:	0.2 to
1 Auxiliary crane	5 to
bridge length:	32 m
2 Servomanipulators	25 kg (A400)

1 Shielded cabin equipped with
2 through-wall manipulators (A201)

Hot Cell:

1 Main crane	70 to
hook height:	8 m
bridge length:	12 m
1 Heavy load manipulator	2 to (A1001)
telescope length:	7 m
bridge length:	12 m
manipulator arm length:	1.2 m
manipulator arm load:	0.2 to

6 Through-wall manipulators (A100)

Waste Area:

1 Barrel manipulator telescope crane	
hook load:	4 to
barrel manipulator load:	0.75 to

Remote Handling Area:

1 Crane	10 to
bridge length:	10 m
2 Through-wall manipulators (A100)	
1 Heavy load manipulator	2 to (A1001)
telescope length:	7 m
bridge length:	10 m
manipulator arm length:	1.2 m
manipulator arm load:	0.2 to

4. Manipulators

After activation of the experiment manipulator systems have to be used for component replacement and repair, maintenance and adjustment. Ordinary commercially available manipulators are master-slave systems with an operator arm as a guiding device and a slave arm to execute the commands of the operator. A through-wall manipulator which will be installed in the hot cell-remote handling area (See Fig.1) is shown in Fig.5. Four pairs of manipulator arms will be necessary for repair, waste handling and training applications. Direct mechanical coupling of both sides of the manipulator provides adequate dexterity for difficult handling problems. Additional electrically driven axes adapt the slave arms to the restricted mobility of the operator.

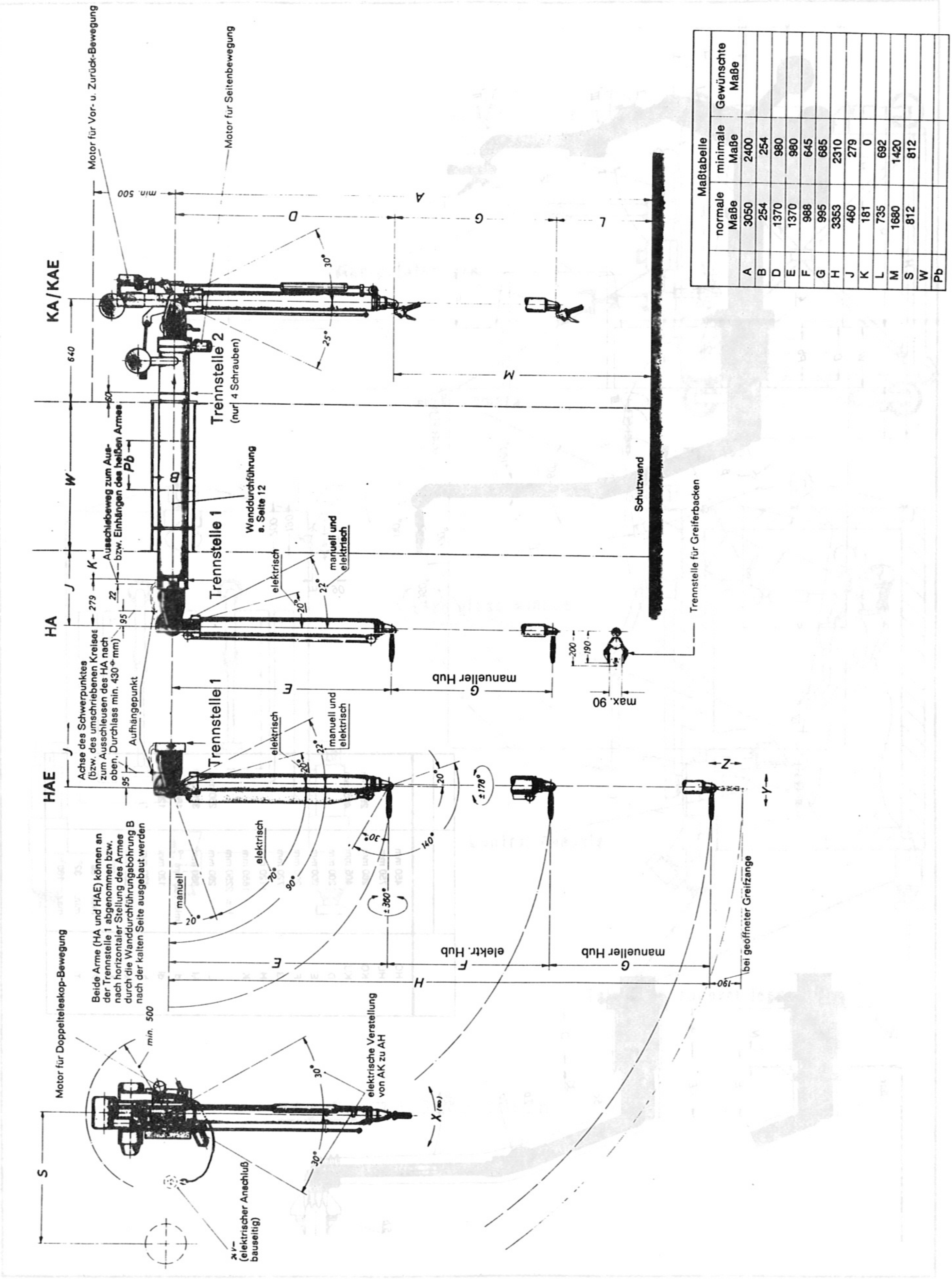
A couple of special tools will be provided for universal application.

A pair of similar through-wall manipulators (Fig.6) will be installed in a transportable shielded cabin (Fig.7) which will be used for manned operation after the removal of shielding elements. The cabin weighing about 30 tons will be positioned by the main crane and can be supported by telescope legs to avoid oscillations. A thick lead glass window allows visual contact for complex manipulations.

For operations in the experimental hall without direct visual contact servo-manipulators (Fig.8) will be used. The master and slave units of a servo-manipulator are connected electrically and may be located at distant positions. The electrical system provides force reflection and adjustable force amplification to facilitate operation. A computer-controlled guidance system may replace the manual control.

Maintenance, adjustment and other universal operations will be typical applications.

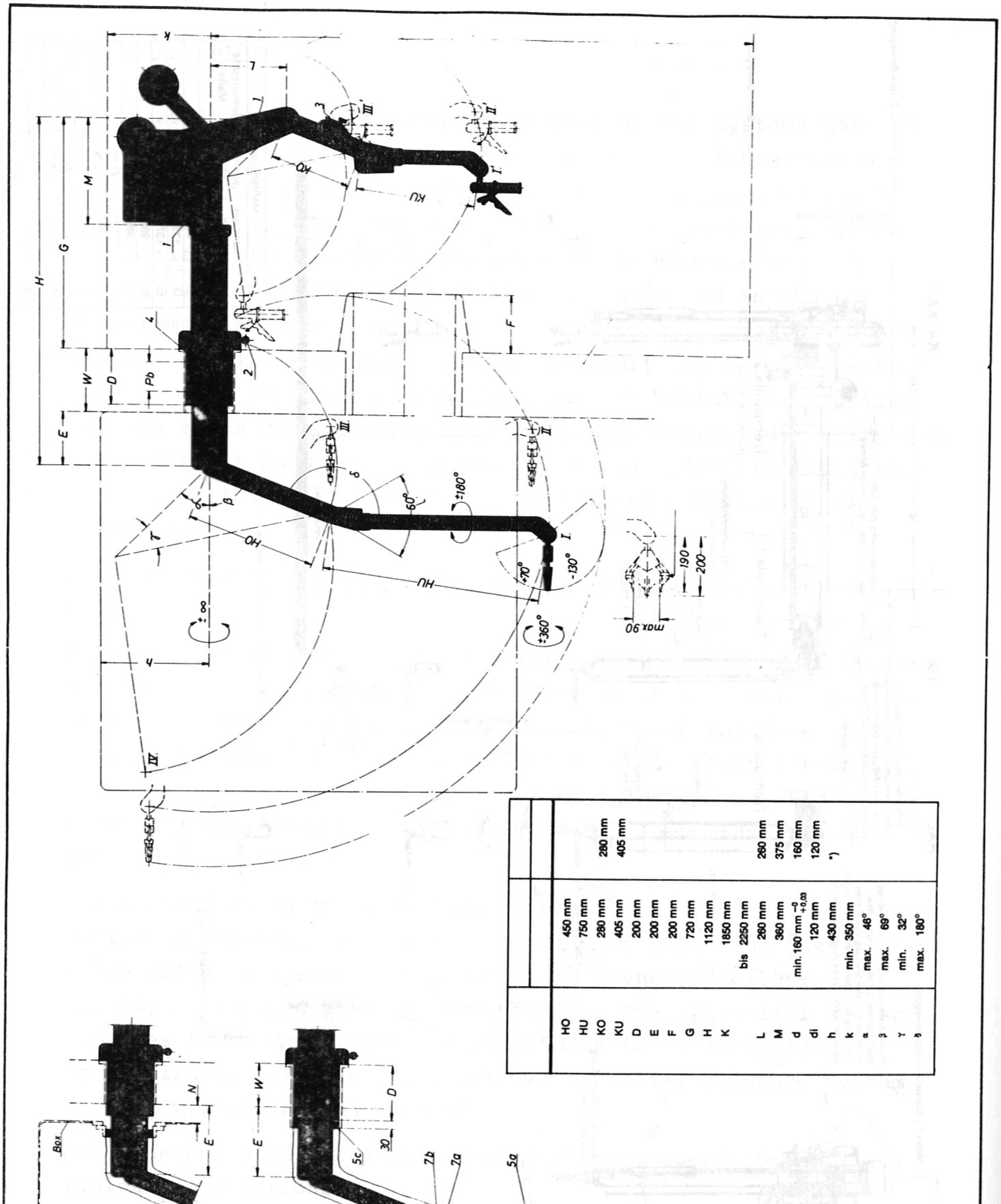
Heavy load manipulators mounted on a telescope crane (Fig.9) will be installed in the experimental hall and the hot cell to handle crane hooks and heavy tools and to position auxiliary devices.



Maßtabelle

	normale Maße	minimale Maße	Gewünschte Maße
A	3050	2400	
B	254	254	
D	1370	980	
E	1370	980	
F	988	645	
G	995	685	
H	3353	2310	
J	460	279	
K	181	0	
L	735	692	
M	1680	1420	
S	812	812	
W			
Pb			

Fig.5: Through-wall manipulator A100 (Wälischmiller)



HO	450 mm	
HU	750 mm	
KO	280 mm	280 mm
KU	405 mm	405 mm
D	200 mm	
E	200 mm	
F	200 mm	
G	720 mm	
H	1120 mm	
K	1850 mm	
	bis 2250 mm	
L	260 mm	260 mm
M	360 mm	375 mm
d	min. 160 mm $^{-0}_{+0,03}$	160 mm
di	120 mm	120 mm
h	430 mm	*)
k	min. 350 mm	
α	max. 46°	
β	max. 69°	
γ	min. 32°	
δ	max. 180°	

Fig.6: Through-wall manipulator A201 (Wälischmiller)

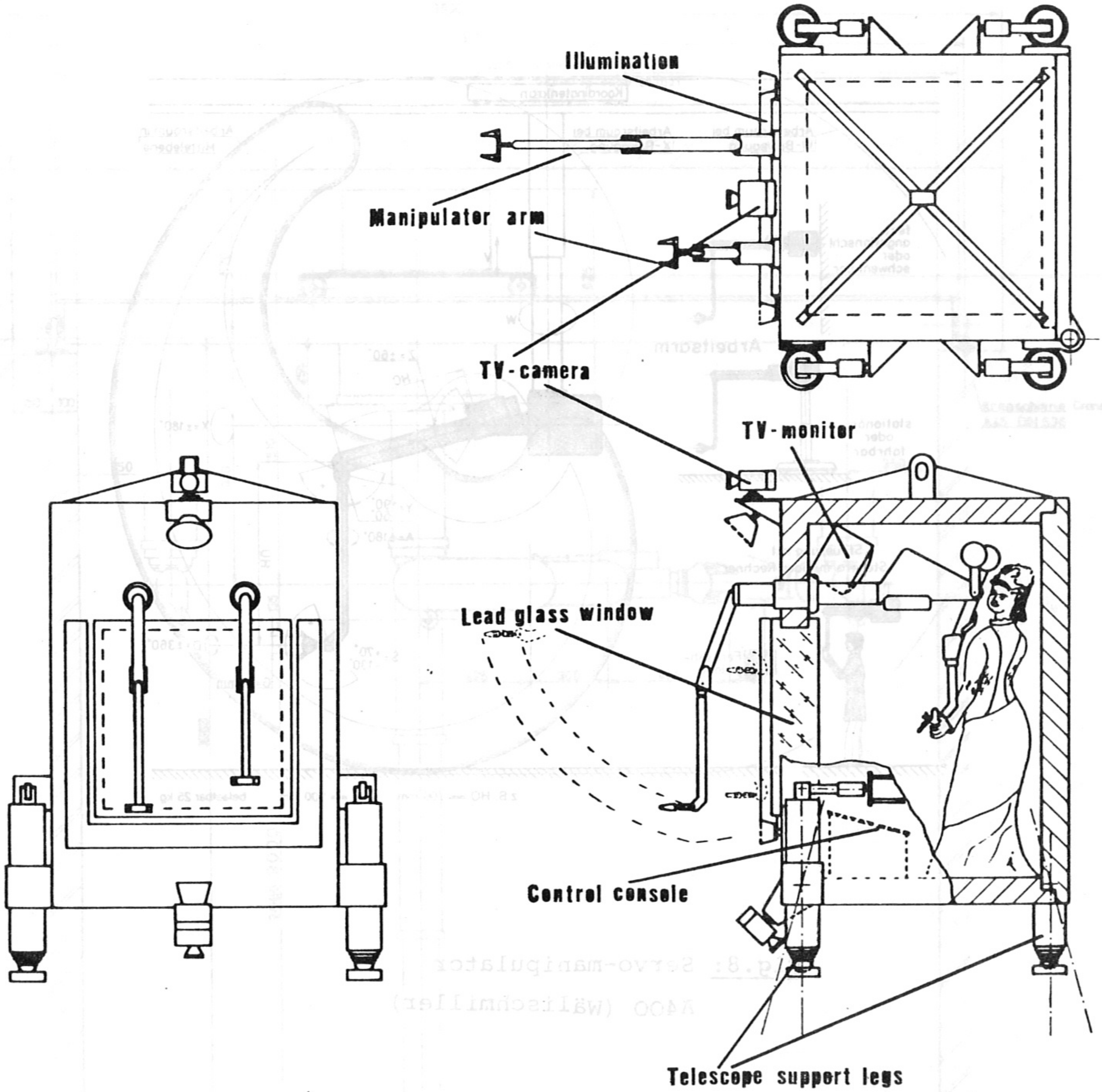


Fig.7: Shielded cabin

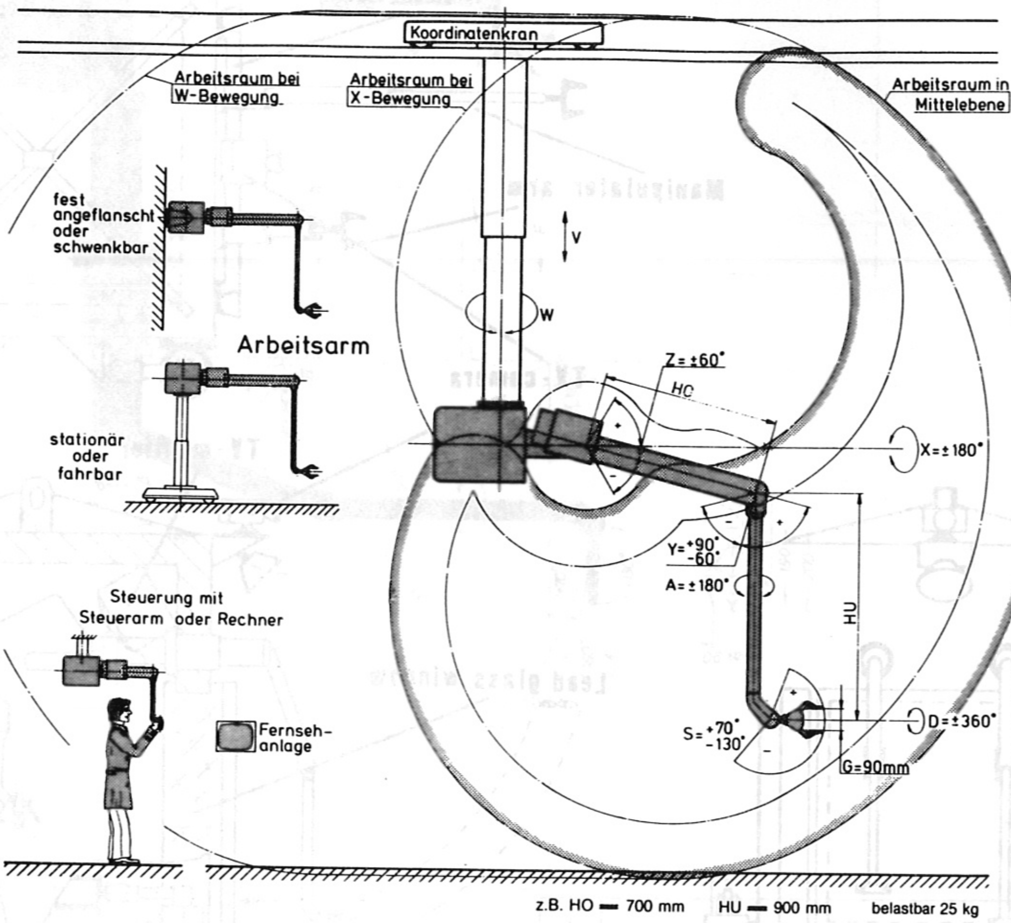


Fig.8: Servo-manipulator A400 (Wälischmiller)

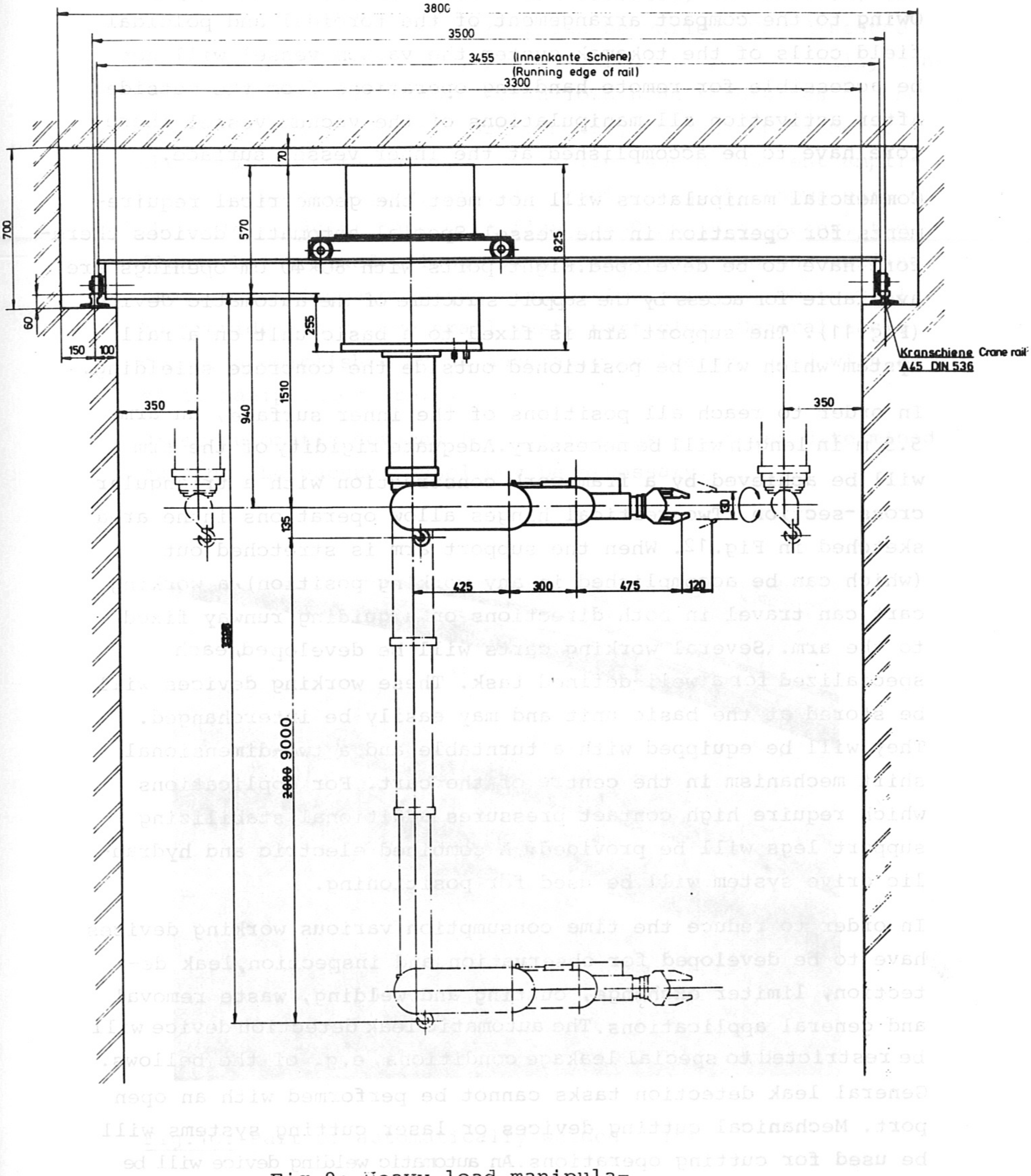


Fig.9: Heavy load manipulator A1001 (Wälischmiller)

5. Automatic Devices

Owing to the compact arrangement of the toroidal and poloidal field coils of the tokamak system the vacuum vessel will not be accessible for remote handling operations from the outside. After activation all manipulations of the vacuum vessel therefore have to be accomplished at the inner vessel surface.

Commercial manipulators will not meet the geometrical requirements for operation in the vessel.Special automatic devices therefore have to be developed.Eight ports with 80×40 cm openings are available for access by the support structure of the automatic device (Fig.11). The support arm is fixed to a basic unit on a rail system which will be positioned outside the concrete shielding.

In order to reach all positions of the inner surface, an arm 5.5 m in length will be necessary.Adequate rigidity of the arm will be achieved by a framework construction with a triangular cross-section. Two vertical hinges allow operations in the area sketched in Fig.12. When the support arm is stretched out (which can be accomplished in any working position), a working cart can travel in both directions on a guiding runway fixed to the arm. Several working carts will be developed, each specialized for a well-defined task. These working devices will be stored at the basic unit and may easily be interchanged. They will be equipped with a turntable and a two-dimensional shift mechanism in the centre of the cart. For applications which require high contact pressures additional stabilizing support legs will be provided. A combined electric and hydraulic drive system will be used for positioning.

In order to reduce the time consumption various working devices have to be developed for observation and inspection, leak detection, limiter exchange, cutting and welding, waste removal and general applications. The automatic leak detection device will be restricted to special leakage conditions, e.g. of the bellows. General leak detection tasks cannot be performed with an open port. Mechanical cutting devices or laser cutting systems will be used for cutting operations. An automatic welding device will be available from a recommended manufacturer. This welding trolley is guided by a steel ribbon and carries an electrode head which can be shifted axially and radially; in addition, the angle of the welding electrode can be varied. The distance between the joint and welding electrode is automatically controlled by the arc drop. This allows high tolerances of the workpiece. All functions are remotely controlled, some of them being programmable, e.g. trolley speed, current amplitude, pulse frequency, etc. The photo (Fig.10) shows part of the welding joint made on a flange 650 mm in diameter, the flange being fixed (flange axis horizontal) and the welding trolley running around the flange. A suction automate will be provided to remove small waste particles. General tasks can be accomplished by an automatic device equipped with a small manipulator arm.

Other automatic devices for special tasks not yet determined outside the vacuum vessel may be necessary.

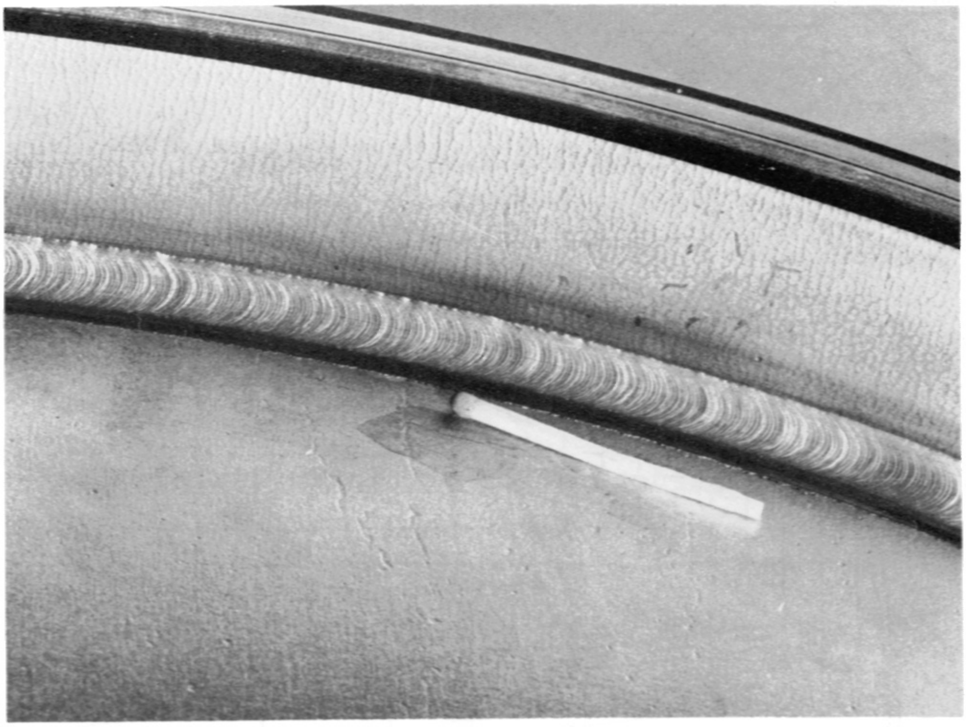


Fig.10: Part of automatically welded joint

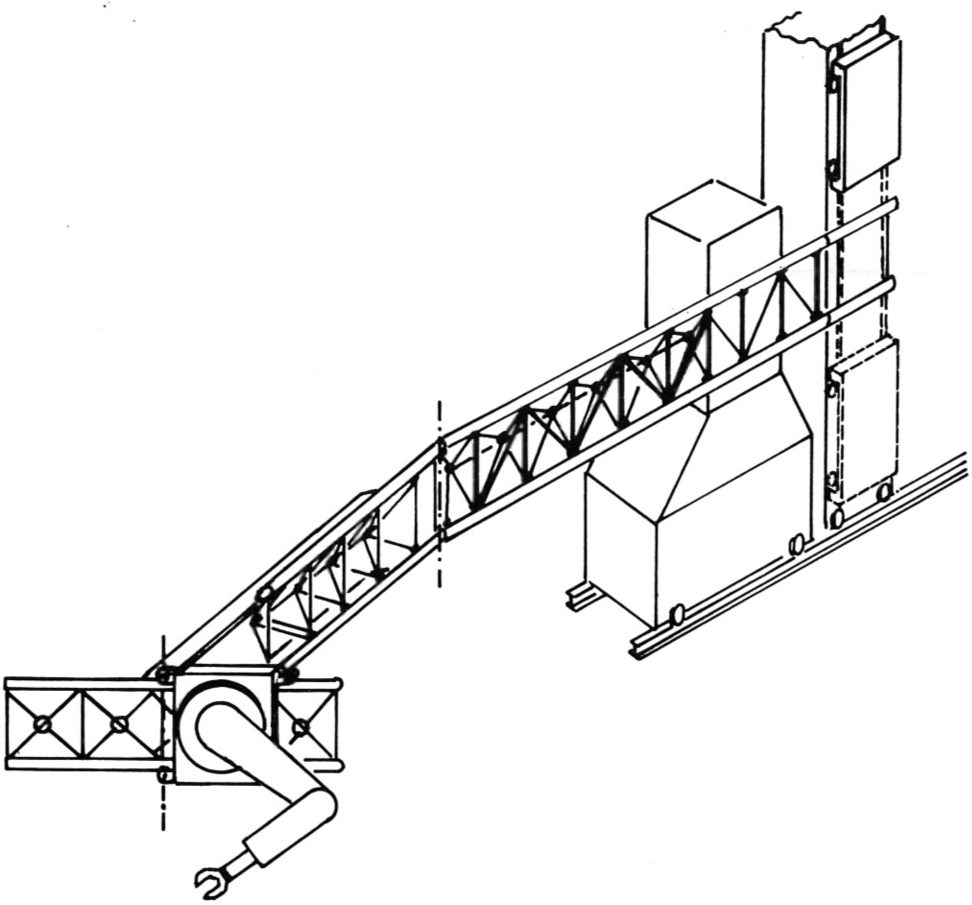


Fig.11: Support structure for automatic devices

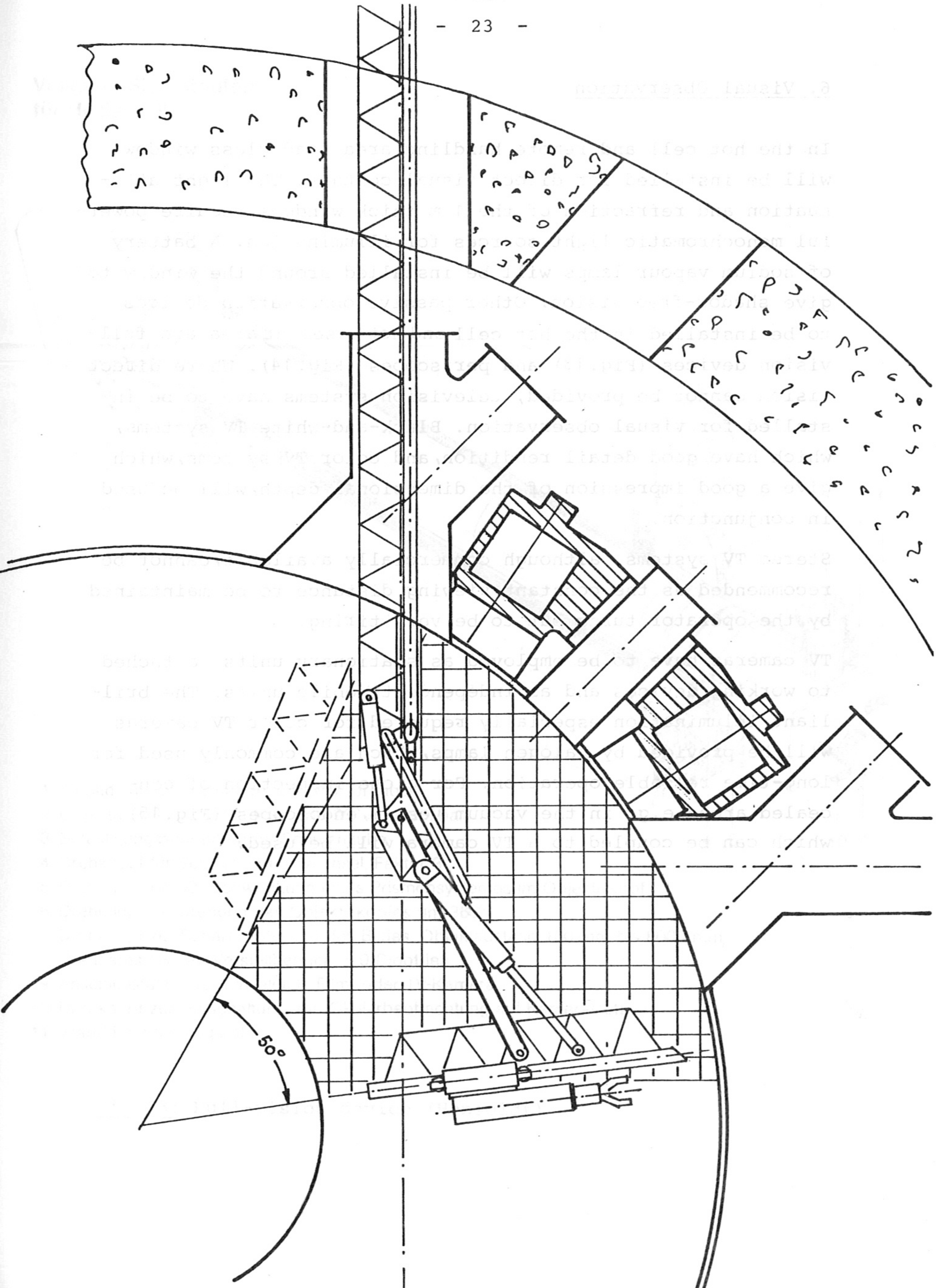


Fig.12: Working space of the automatic device

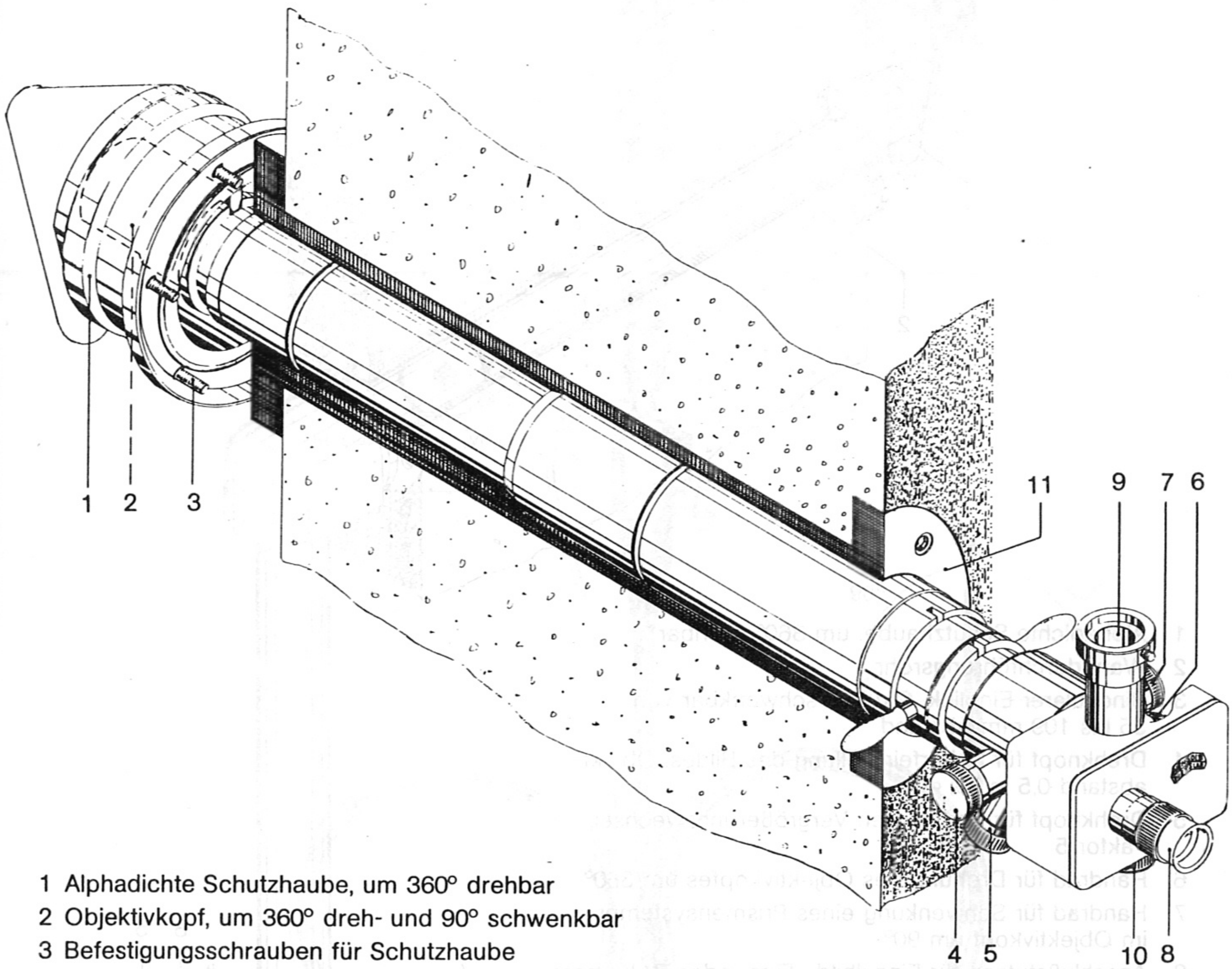
6. Visual Observation

In the hot cell and remote handling area lead glass windows will be installed for direct visual contact. The light attenuation and refraction of the 1 m thick windows require powerful monochromatic light sources for illumination. A battery of sodium vapour lamps will be installed around the window to give shadow-free vision. Other passive observation devices to be installed in the hot cell and hot basement area are full-vision devices (Fig.13) and periscopes (Fig.14). Where direct vision cannot be provided, television systems have to be installed for visual observation. Black-and-white TV systems, which have good detail rendition, and color TV systems, which give a good impression of the dimensional depth, will be used in conjunction.

Stereo TV systems, although commercially available, cannot be recommended as the constant viewing distance to be maintained by the operator turns out to be very tiring.

TV cameras have to be employed as stationary units attached to working devices and as independent mobile units. The brilliant illumination especially required for color TV cameras will be provided by halogen lamps, which are commonly used for long-time reliable operation. For close inspection of concealed areas, e.g. in the vacuum vessel, endoscopes (Fig.15) which can be coupled to a TV camera will be used.

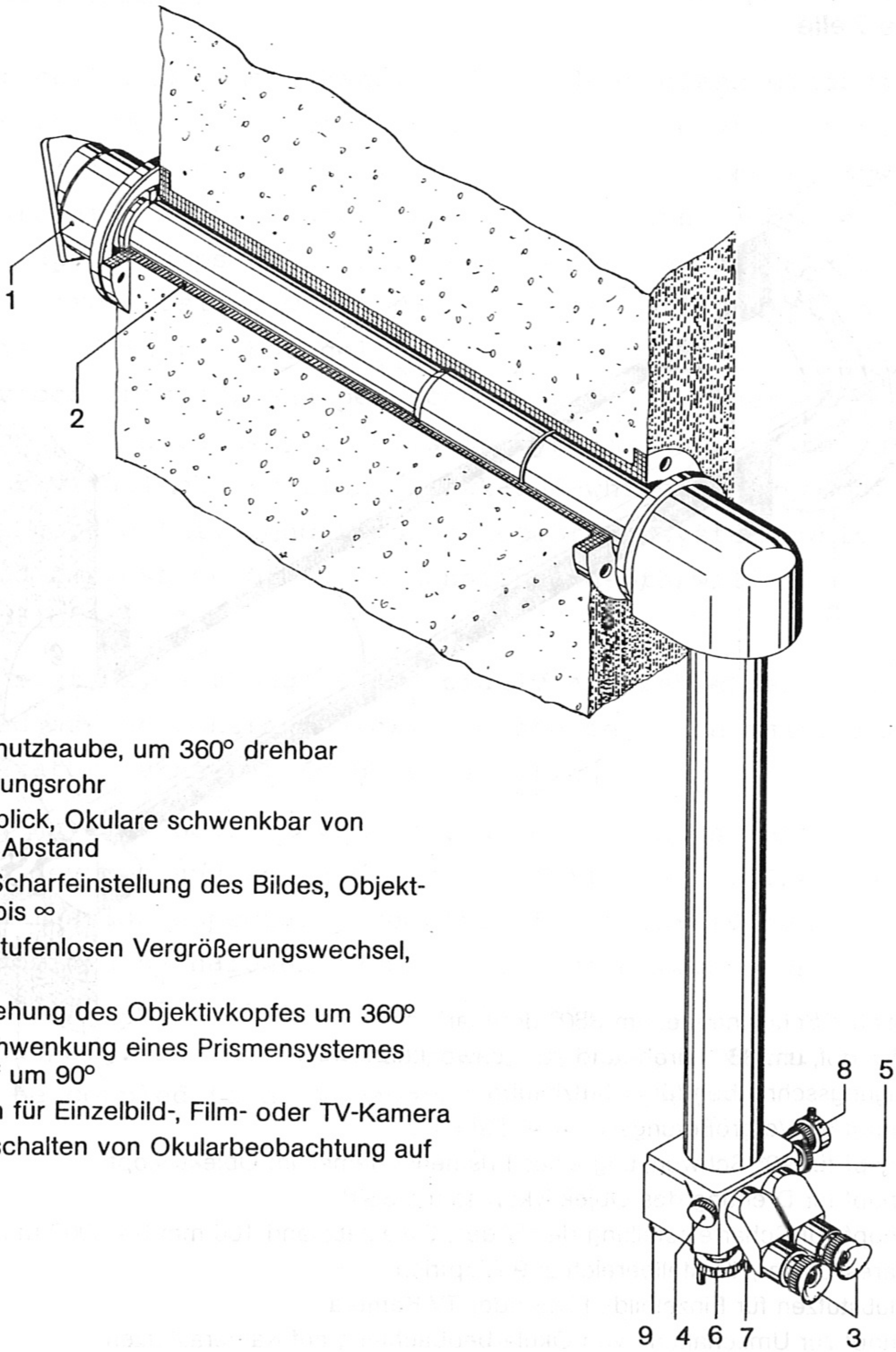
Vollraum-Sichtstopfen
für Heiße Zelle



1 Alphadichte Schutzhaube, um 360° drehbar
2 Objektivkopf, um 360° dreh- und 90° schwenkbar
3 Befestigungsschrauben für Schutzhaube
4 Drehknopf für Vergrößerungswechsel, Faktor 3
5 Drehknopf für 90°-Schwenkung eines Prismensystemes im Objektivkopf
6 Drehknopf für Drehung des Objektivkopfes um 360°
7 Drehknopf zur Scharfeinstellung des Bildes, Objektabstand 100 mm bis 8000 mm
8 Drehbares Okular, Verstellbereich ± 9 Dioptrien
9 Anschlußstutzen für Einzelbild-, Film- oder TV-Kamera
10 Drehknopf zur Umschaltung von Okularbeobachtung auf Kamerastutzen
11 Wanddurchführungsrohr

Fig.13: Full-vision device (Hensoldt)

Vollraumsicht-Periskop für Heiße Zelle



1 Alphadichte Schutzhaube, um 360° drehbar
2 Wanddurchführungsrohr
3 Binokularer Einblick, Okulare schwenkbar von 55 bis 109 mm Abstand
4 Drehknopf für Scharfeinstellung des Bildes, Objektabstand 0,5 m bis ∞
5 Drehknopf für stufenlosen Vergrößerungswechsel, Faktor 5
6 Handrad für Drehung des Objektivkopfes um 360°
7 Handrad für Schwenkung eines Prismensystemes im Objektivkopf um 90°
8 Anschlußstutzen für Einzelbild-, Film- oder TV-Kamera
9 Hebel zum Umschalten von Okularbeobachtung auf Kamerastutzen

Fig.14: Periscope (Hensoldt)

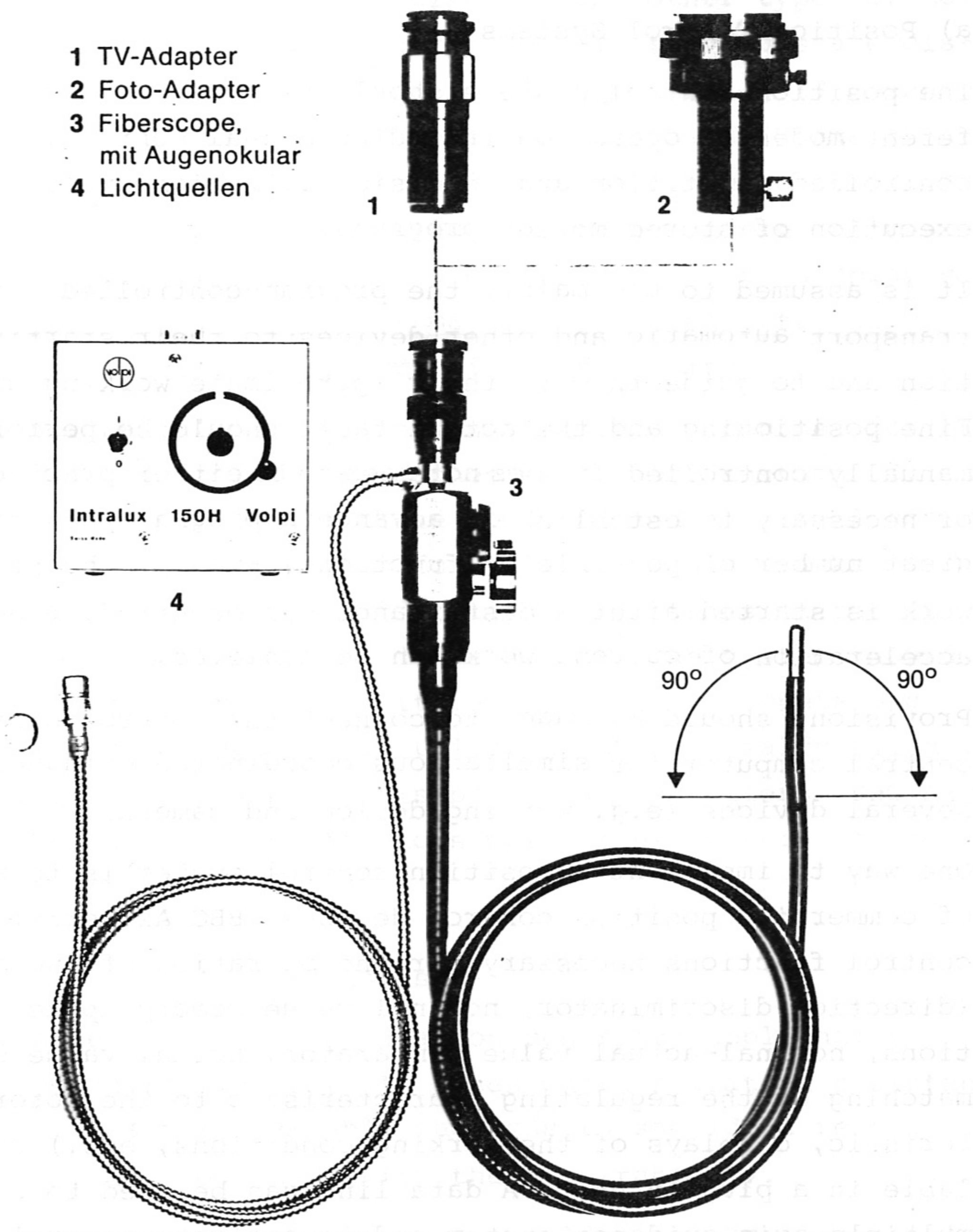


Fig.15: Endoscope (Volpi)

7. Position Control and Monitoring

a) Position Control Systems

The position control systems should be able to perform different modes of operation including manual control, computer-controlled repetition and inversion of motion cycles and the execution of stored motion programs.

It is assumed to use mainly the program-controlled mode to transport automatic and other devices to their starting position and to guide them to their approximate working position. Fine positioning and the actual tasks should be performed manually controlled.It does not seem to be either practicable or necessary to establish in advance a program pool for a great number of possible malfunctions. Even if the programming work is started after a disturbance has occurred, essential acceleration of current work can be achieved.

Provisions should be made to connect the control system to a central computer for simultaneous coordinated guidance of several devices (e.g. working device and camera).

One way to implement a position control system is to make use of commercial position control devices (BBC Axumerik). All control functions necessary for the operation of one axis (direction discriminator, nominal value memory up to 64 positions, nominal-actual value comparator, actual value display, matching of the regulating characteristic to the motor characteristic, displays of the working conditions, etc.) are available in a plug-in unit. A data line can be used to connect a multiple-axis guidance system and to activate several operational functions (manual control, zeroing, absolute or relative reference system, selection of one out of four preadjustable velocities). Since the guidance system has to be developed by the user, considerable development times and costs have to be expected especially with complicated positioning systems.

Complex positioning systems with up to 6 axes can be realized by computerized numerical control devices which are also commercially available (Siemens Robot Control, Güttinger Gipsy-400).

They are designed for simultaneous operation of several axes in order to generate linear, circular and other types of motion. For monitoring purposes the coordinate values are displayed simultaneously (Güttinger) or sequentially (Siemens). Electro-optical sensors (Güttinger) or synchros (Siemens) are used as position indicators. Manual control, keyboard programming, playback and the execution of programs stored on magnet tape are provided. A tape recorder and a data display scope are integrated (Güttinger) or may be connected externally (Siemens) to facilitate programming and editing.

Several peripheral devices and an additional computer for multiple device control can be connected to both systems. It is recommended to use one of these computerized numerical control systems as a standard system for all positioning tasks. Preliminary information indicates slight advantages of the Güttinger system in performance and costs. Only one system should be introduced in order to facilitate training of operating personnel and replacement of units in case of malfunctions. The application of single axis position controllers (BBC Axumerik) should be restricted to simple problems such as the manual control of few axes.

b) Measuring Tasks and Sensors

An environment of strong radiation restricts application of many measuring devices. In cases where radiation resistance information is not available the sensors should be tested under radiation load to verify their suitability.

Linear displacement measurements should - as far as possible - be reduced to angular measurements using rack and pinion or spindle drives. Here the sensors can be positioned in zones of reduced radiation. Additional sensor shielding should be employed whereever possible.

Linear transducers are less suitable owing to their physical dimensions and the subsequent restrictions on the device mobility. Electro-optical transducers, precision potentiometers on synchros should be suitable for angular measurement.

Whereas no information about the radiation resistance is available for potentiometers and synchros, electro-optical shaft encoders (Heidenhain) have been exposed to 10^8 R without damage. High-resolution displacment sensors should also be employed with the crane systems to enable slow motions and jerk-free operation. Mercury or electrolytic inclination sensors may be used to measure the crane rope inclination in order to avoid oscillations of the load after lifting. Since the cable drum diameter varies during operation, the crane hook height is a non-linear function of the cable drum rotation. If mechanical solutions (measuring the rope length by means of a friction wheel) are not practicable, linearization of the measurement of the cable drum rotation by electronic means can be applied.

In some applications it might be necessary to explore contours using tactile sensors. These have to withstand strong radiation for a limited time. Inductive tactile sensors with external electronics are supposed to be suitable for this purpose.

Collisions between working devices and the experimental setup generally cannot be avoided in case of errors by the operator. Collision detectors (tactile sensors at critical locations, microphones) are not expected to provide sufficient protection. Therefore additional criteria for collision detection should be utilized, e.g. sudden changes of driving torques or a tilt of the crane rope. Moreover, it should be part of the programming work to restrict the driving torques to values necessary for the special task.

Automatic devices which will be transported into their working position by cranes or other transport means first have to approach a well-defined starting position. It is proposed to attach optically detectable crossmarks to the ground which can be found by a straightforward search routine when the originating quadrant is known. Crossmarks have, compared with coordinate grids, the advantage of being unambiguous and avoid difficulties when intersections have to be crossed. When the starting position is obtained the further motions will be controlled by position transducers.

8. Passive Systems

Objects to be handled by remotely operated transport systems, manipulators and automatic devices require special design considerations in order to achieve effective operation.

Components and assemblies are to be equipped with transport elements (suspension gears, lugs or hooks) which have to be adapted to facilitate pick-up by crane hooks. The transport elements have to be mounted above the centre of gravity. If necessary,the weight has to be balanced by additional loads.

Guiding skids and rails, fishing bolts, conical rings and other devices will be useful for component positioning. Fixed position operating elements will be equipped with removable control linkages which find their way using similar positioning aids.

It is intended to use standardized commercially available fastening elements as far as possible. Special tools as well as the application of nut cages and screws with retaining rings will be necessary. For pipe connections conventional solutions such as metal seals with conical sealing surfaces and flat gasket rings with sealing disks and screw caps are considered to be the most reliable. Their application requires specially contructed grip and clamping tools. It is intended to use a central pipeline system for oil changes of the vacuum pumps.

Flexible hose connections can be implemented by commercial snap closures (Gardena, Legris) which will be adapted to remote operation by minor modifications.

Electrical contacts shall be concentrated so that very few multiple contact connector units are needed.

Conventional vacuum flanges are not well suited to remote handling. A flange system has therefore been developed which makes use of an easy to handle clamping mechanism. Measures have been taken to protect the sealing surfaces and rings against damage by rough handling. A pair of these flanges were tested with an aluminum ring as seal. The same seal was used several times, the leakage always being below $1 \cdot 10^{-9}$ $mb \cdot l \cdot s^{-1}$. The pressure necessary to seal the system was always well below one half of the value that could have been applied. Even after several cycles of cooling one of the flanges to LN_2 temperature and then warming it up to room temperature the seal was still tight but the pressure upon the seal was slightly reduced by this procedure.

A separate report on these remote-handled flanges is being prepared.

The above mentioned design considerations are also valid for remotely operable diagnostic systems.

9. Items for Further Development

During the design phase the following items must be investigated in a more detailed manner:

- The support structure of the automatic devices working inside the vacuum vessel,
- Modification of commercial welding automatic devices and testing under the conditions of real geometry and material combination,
- Development of an automatic cutting machine for possible separation of parts of the vessel,
- Further tests with remote-handled vacuum flanges,
- Modification of quick disconnects for electrical and cooling lines,
- Design of railway systems in the lock area,
- Design of remotely movable television systems,
- Development of the software for computer controlled positioning of transport systems, automatic devices and observation systems,
- Analysis of the market for power devices adjusting the final control element of diagnostic equipment.

[1] H. Brockmann, H. Krause, U. Ohlig: 1D radiation analysis for the ZEPHYR fusion ignition experiment, Internal ZEPHYR Report No.5, IPP Report No.1/173

[2] C. Andelfinger, M. Mahl: ZEPHYR experimental complex, Internal ZEPHYR Report No.12