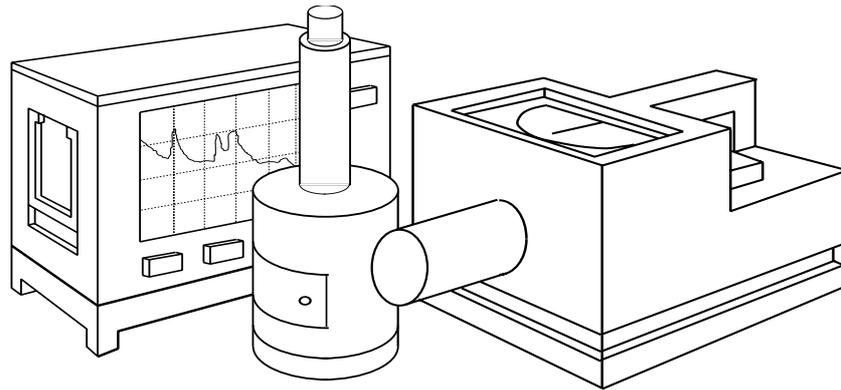
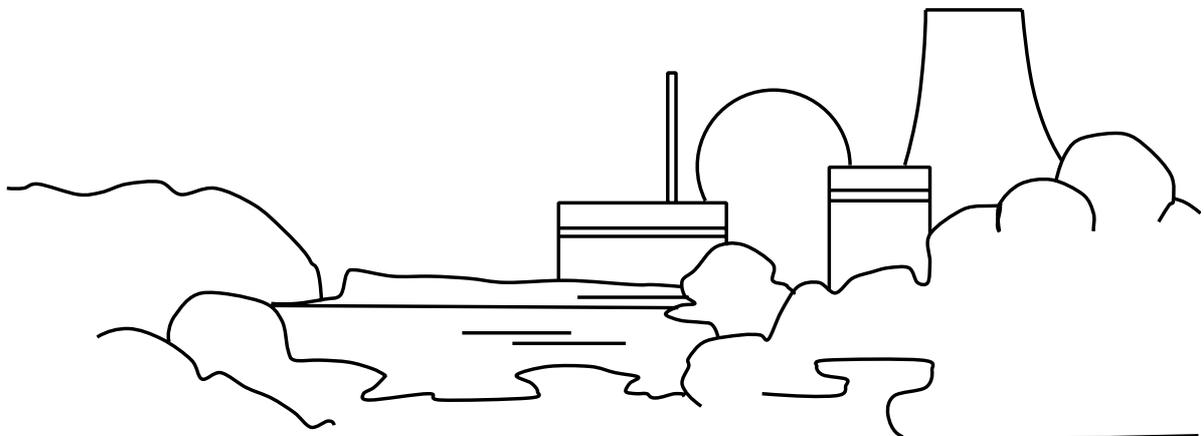


**TECHNICAL UNIVERSITY
DRESDEN**
Institute of Power Engineering
Training Reactor



Training Reactor AKR-2

Description of the Reactor Facility
Procedure of Operation



Technical Description and Procedure of Operation for the Reactor Facility AKR-2

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1. Description of the Training Reactor AKR-2

1.1. Introduction

The training and research reactor AKR-2 (from the German **Ausbildungskernreaktor**) of the Technical University Dresden is a thermal, homogeneous, solid moderated zero-power reactor with maximum continuous (thermal) power of 2 Watt.

That means:

- nuclear fission is mainly caused by thermal neutrons,
- nuclear fuel and moderator material are distributed homogeneously in the fuel plates,
- the moderator material is solid polyethylene (and not any liquid like water!),
- the extremely low nuclear power of only 2 Watt ("zero power") allows effects of temperature, fuel burnup, formation of nuclear waste, activation of structural materials, Xe-poisoning and others to be neglected.

Advantages of the design of the AKR are:

- application of low enriched uranium (LEU), i.e. U-235 content in the fuel is < 20 %,
- low absolute amount of nuclear fuel (total mass of U-235 in the reactor < 1 kg),
- desired characteristics of the reactor with respect to its inherent safety features (negative temperature coefficient of reactivity; integrity of the core maintained in case of power excursion),
- simple construction resulting in high reliability, low costs for inspections, maintenance and operation,
- strict avoidance of any liquid in the facility (no corrosion, no danger of contamination in case of leakage, no maintenance of water systems, no substitution or cleaning procedures of liquids),
- miscellaneous irradiation capabilities in the experimental channels ($\Phi_{\max} \approx 2.5 \cdot 10^7 \text{ n}/(\text{cm}^2 \cdot \text{s})$),
- free space above the core for possible installation of additional experimental equipment.

Precursor of the AKR-2 was the AKR-1. The AKR-1 training and research reactor of the TUD was put into operation in 1978 based on the concept of the proven training reactor SUR-100 from SIEMENS company. For more than 25 years, the AKR-1 was successfully used for training and education of students, for nuclear research projects, and as an information centre for the public.

In 1998, a new licensing procedure began with the goal of completing a comprehensive refurbishment of the reactor in order to update the facility concerning the current level of science and technology.

The refurbishment took place in 2004 and included civil work as well as new electrical and I&C equipment, based on the digital reactor protection instrumentation and control system TELEPERM XS (by AREVA GmbH Erlangen, Germany) and new installation of 3 channels for the neutron flux monitoring: two (logarithmic) wide-range and one (linear) power-range channel.

On the other hand, the nuclear design of the reactor itself remained the unchanged and no internal components or structures (reactor core, control rods, reflector, shielding, neutron detectors etc.) had to be replaced with the exception of a few minor details. Also the same nuclear fuel can be used furthermore for the whole reactor life expectancy.

After having successfully completed all start-up requirements (nuclear commissioning with the critical experiment on March 23, 2005), the regulatory body authorized normal operations of the new AKR-2 reactor in April 2005.

Currently, AKR-2 is the most up-to-date training reactor in Germany.

Main purpose of the AKR-2 is education and training of students in nuclear and reactor physics as well as in nuclear engineering and radiological protection. Fundamental experiments are provided and carried out in practical exercises (see chapters 3 and 4 in more detail).

According to its physical properties, the AKR is also included in specific research projects of the institute or is used as irradiation facility.

Additionally, the reactor facility and its equipment is also used as a general information centre providing practical experience in nuclear and reactor physics, nuclear energetics and radiation protection for

- interested students of all faculties of the university,
- pupils of the grammar schools of Dresden City and its surroundings or
- organised groups and individuals from the public.

1.2. Safety Features

Safe and foolproof operation of the reactor is guaranteed by a combination of

- inherent safety,
- designed safety and
- administrative procedures.

The design and operation conditions of the AKR are based upon the following considerations:

- prompt criticality must not occur at all and
- undue increase of the power must not endanger the operators, the environment or the reactor itself.

The safe nuclear operation of the reactor is secured by the following measures:

- The excess reactivity is restricted to a maximum value of $\Delta k/k \leq 0.3 \%$.
- All three control rods are designed as combined control and safety rods. The reactivity value of each of them is sufficiently high to shut-down the reactor. Thus, even in case of failure of single rods the AKR will be shut-down reliably.
- Independently on control rod movement, a separation of the two core sections by 50 mm reduces the reactivity by $\Delta k/k = - 5.8 \%$. In case of a scram this negative reactivity becomes effective within about 100 ms. It ensures a fast shut-down of the reactor and a high degree of nuclear safety in the shut-down state.
- The temperature coefficient of reactivity is negative. From measurements a value of $(2.90 \pm 0.05) \text{ } \$/\text{K}$ was found out. Estimations have shown that power excursions would be self-limiting before damages occur at the reactor itself or in its environment. This high inherent safety results from the physical properties of the fuel elements.
- By monitoring the core temperature and including the measured value into the protective logic

circuit it is prevented that additional positive reactivity could be introduced due to decreasing core temperature.

- All drives were dimensioned in such a way that the rates of reactivity changes are below 0.0001 s^{-1} .

Due to these measures, a power excursion with harmful consequences can be virtually excluded.

1.3. Radiation Protection

The reactor is designed to keep the external as well as the inner radiation exposure for the reactor operational staff and the people in the surroundings of the AKR-2 down to be negligible.

The operation of the AKR-2 as a zero-power reactor (or a so-called critical assembly) with extremely low nuclear power causes only a negligible low uranium fuel consumption and hence, a minimum production of radioactive fission products. After 30 years estimated continuous non-stop operation at 2 Watts power the resulting activity in the facility would be less than 100 GBq.

The multiple barrier concept with the capsuled core and the reactor tank as an additional subatmospheric pressure barrier guarantees that no fission products can be released into the surrounding of the reactor.

For supervising the ambient local dose rate around the reactor there are 5 gamma-ray measuring channels installed. If well defined dose rate levels would be exceeded, it would be indicated by optical as well as acoustic alarm signals and would be registered in the logfile.

1.4. Review of Technical Parameters of the AKR-2

Reactor Vessel: Total Diameter: 250 cm
Total Height: 350 cm (reactor vessel 280 cm)

Fuel Elements: Plates: ϕ 250 mm, height 2 - 23 mm
Material: homogeneous mixture from Uranium oxide (UO_2 , enrichment 19.8 %) and PE
Critical Mass: 794 g U-235

Reflector: Material: pure graphite ($\rho = 1.75 \text{ g/cm}^3$)
Thickness: 32 cm radial, 20 cm axial

Neutron Source: Am-Be: source strength: $2.2 \cdot 10^6 \text{ n/s}$

Control Rods: 3 independent combined control and safety rods
Material: Cadmium (0.5 mm thick sheets)
Total reactivity: about 37 ¢ per rod

Nuclear Instrumentation:

- 2 (logarithmic) wide-range channels with fission chamber detectors
- 1 (linear) power-range channel with γ -compensated ionisation chamber

Biological Shield:

- axial: 48 cm heavy concrete
- radial: 15 cm paraffin and 58 cm heavy concrete

Experimental Irradiation Channels:

- horizontal: 4, $\Phi_{\max} \approx 2.5 \cdot 10^7 \text{ n}/(\text{cm}^2 \cdot \text{s})$
- vertical: 2

Fast Shut-Down Possibilities: drop down of the lower core section for about 5 cm
drop down of the 3 control rods

Maximum Excess Reactivity: 0.3 %

Maximum Continuous Power: 2 W

1.5. Technical Design of the Facility

The design of the reactor is shown in Figs. 1 and 2 (vertical and horizontal cross section). The cylindrical core has a diameter of 250 mm and a critical height of 275 mm. The disk-shaped fuel elements consist of a homogeneous dispersion of polythene and uranium oxide (19.8 % enriched in Uranium-235, O/U ratio 2.27). The Uranium-235 density in the fuel elements amounts to 0.060 g/cm³.

The core is completely surrounded by a graphite reflector (density 1.75 g/cm³). The axial and radial thicknesses are 20 cm and 32 cm, respectively. Therefore, the critical mass is relatively small (about 790 g U-235). Within certain constraints the AKR is a minimum-critical-mass reactor.

For safety reasons, the core consists of two separable sections. The fuel elements of each section are enclosed in a hermetically sealed aluminium container. A second, larger gas-tight reactor tank encloses both, core sections and parts of the reflector. The pressure inside the reactor tank is lowered by (8...18) kPa compared to the ambient atmospheric pressure. This subatmospheric pressure barrier prevents an uncontrolled leakage of radioactive fission products even in the unlikely case that all the other internal retention barriers would fail. This subatmospheric pressure in the tank is continuously maintained by a pre-vacuum pump. Control is automatically performed by means of a pressure controller even when the reactor is shut down.

In the shut-down position the distance between the lower and the upper core section is about 50 mm. The lower section is lifted by means of a core drive mechanism including an electromagnetic holder of the core section. Through a tube within this mechanism the start-up neutron source (Am-Be, neutron yield $2.2 \cdot 10^6 \text{ s}^{-1}$) is moved from the source container to the bottom side of the core. The distance between the bottom side of the core and the middle of the source container measures about 800 mm.

The reactor is controlled by three cadmium absorber plates. These plates are moved vertically in a gap within the reflector outside the reactor tank. They are designed as combined control and safety rods.

The lower core section and the control rods are held by electromagnets in their "working" positions. Any scram signal opens the direct-pull holding magnets allowing the rods and the lower core section to fall down in the shut-down position simply by influence of gravity.

Reactor core, reactor tank, graphite reflector and control rods are arranged on a horizontal steel plate (diameter 1000 mm, thickness 30 mm) inside the reactor vessel. This is a cylindrical double-walled vessel containing the biological shield and having an outer diameter of 2500 mm and a height of 2800 mm.

The top cover of the reactor is removable. The free space above the core could be used for e.g. installing a thermal column or a subcritical assembly.

There are four horizontal and two vertical experimental channels with different diameters and shapes. They provide adequate inpile irradiation volume with different neutron spectra.

The permissible power level is limited only by the effectiveness of the biological shield. It consists of paraffin and baryte heavy concrete with an overall thickness of 75 cm inside the reactor vessel. Proceeding from the condition, that the dose rate equivalent just outside the shield should not exceed 10 $\mu\text{Sv/h}$, a continuous 2 Watt operation is possible. At 2 Watt power level the maximum flux density of thermal neutrons in the central experimental channel amounts to about $2.5 \cdot 10^7 \text{ n}/(\text{cm}^2 \cdot \text{s})$.

The reactor vessel is arranged on the ground floor of the building on a separately grounded fundament as additional shock protection e.g. for the unlikely event of an earthquake. The drives for lower core or start-up neutron source movement and the control rods are accessible from the basement.

An overview of the plan of the reactor hall is given in Fig. 3.

The control desk (Fig. 4) and the separate cabinet with the reactor protection system are also located in the reactor hall in about 6 m distance from the reactor. The cabinet hosts the modules of three redundant channels for neutron flux measurement and the computers of the digital reactor protection system (TelepermXS by AREVA GmbH, Erlangen, Germany) whereas the operational units are hosted in the control desk.

The control desk holds all operating elements, signal displays and operational instruments required for the control of the reactor. It has an operation and signal panel with conventional display and operational elements (Fig. 5) and 3 monitor screens for reactor control and supervising. On each of these 3 different screens all operational soft-buttons and parameters (Figs. 6, 7 and 8) can be displayed. Alternatively, I&C system announcements or alerts (example in Fig. 9) or different graphic presentations of reactor parameters can be shown. User access permits are possible by means of key-switches on the conventional operation and signal tableau. The reactor control is done by point-and-click on the corresponding soft-buttons on the screens. In order to avoid unwanted reactivity change (especially positive reactivity rise) all corresponding operations

has to be chosen first and then confirmed by a second mouse-click.

Signals of peripheral technical units (ventilation system, subatmospheric pressure in the reactor tank, local dose rate limits etc.) are displayed on an independent signal panel in the reactor hall next to the control desk (Fig. 10) even in the case of shut-down reactor.

1.6. Instrumentation and Control (I&C) System with TELEPERM XS

1.6.1. Architecture of the I&C System

The I&C system of the reactor comprises

- the nuclear instrumentation and
- the operational instrumentation with the safety and control system (German abbreviation: SUS) and the control and display units on the control desk.

Purpose of the measuring channels for neutron flux density (nuclear instrumentation) is to control the reactor in its shut-down subcritical state as well as to supervise the conditions for reactor start-up and operation in the whole power range.

For this purpose, it provides

- a signal, which is proportional to the reactor power and which quickly follows temporary changes,
- a signal, which is proportional to the relative neutron flux exchange speed and thus proportional to the reciprocal reactor period (the so-called RELFAEG signal).

These signals are input parameters for the safety and control system (SUS) and for the control and display units on the control desk. They are used by the safety and control system (SUS) as shut-down criteria or for prevention of reactor start-up in case of reactivity irregularities or malfunction of instrumentation units. Furthermore, these signals are used in the operational instrumentation in order to allow only permitted operations by the operators.

The digital safety system TELEPERM XS (by AREVA GmbH Erlangen, Germany) serves as the basis for the technical solution (reactor protection as well as operational instrumentation).

1.6.2. Nuclear Instrumentation

The nuclear instrumentation consists of three independent redundant channels for neutron flux measurement (digital system TK250, MGP Instruments GmbH Munich, Germany):

- two (logarithmic) wide-range channels (DAK 250-i, pulse measurement with fission chamber detectors),
- one (linear) power-range channel (DAK 250-g, DC measurement with γ -compensated ionisation chamber detector).

The neutron flux channels of the TK250 system were developed for BWR and PWR applications and are designed and certified according to the requirements of the German KTA-3501 safety standards.

1.6.2.1. Wide-Range Channels (Start-up/Middle/Power Range)

The logarithmic wide-range (start-up/middle/power range) monitors with two redundant measuring channels DAK 250-i cover 6 decades (approx. $2 \dots 2 \times 10^6 \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$) of neutron flux density at the measuring location outside the graphite reflector. Fission chambers (type 9R100) are used as detectors.

In the safety system, the absolute fission chamber signals and the so-called RELFAEG signals (being reciprocal to the reactor period) are evaluated for the following limits (prevention of the reactor start-up as well as release SCRAM):

- minimum neutron flux required for reactor start-up (1∪2 logic),
- SCRAM signal for exceeding maximum reactor power (1∪3 logic together with the signal of the power-range channel,
- SCRAM signal for too small reactor period (1∪2 logic) or too high relative neutron flux exchange speed (RELFAEG), respectively.

1.6.2.2. Power-Range Channel

The linear power-range channel, DAK 250-g, measures the upper 2 - 3 decades (approximately $5 \times 10^3 - 2 \times 10^6 \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$) of the neutron flux density at a detector position outside the graphite reflector. A γ -compensated ionisation chamber is used as a neutron detector. In the safety system, the chamber signal is evaluated for following limits (release SCRAM):

- SCRAM signal for exceeding maximum reactor power (1∪3 together with the signals of the wide-range channels).

1.6.3. Safety and Control System

The safety and control (German: SUS) system should protect the facility from inadmissible demands and shall minimize the effects on the staff, the surroundings and the reactor in case of accidents. The safety and control system causes automatic reactor shut-down (SCRAM) in the following cases:

- malfunction of drives of control rods, neutron source or core,
- too fast power increase (reactor doubling time $< 10 \text{ s}$, warning signal at 20 s),
- too high absolute reactor power ($> 2.4 \text{ W}$, warning signal at 2.2 W),
- too low moderator temperature ($< 18^\circ\text{C}$),
- too high pressure in the reactor tank ($> -8 \text{ kPa}$),
- in case of malfunctions in the safety and control system,
- non-availability of the I&C computer,
- in case of malfunction in an external experiment (optional),
- in case of malfunctions in the I&C rack,
- an implicit SCRAM is initiated in case of a safety computer failure (fail-safe by closed-circuit connection).

1.6.4. Safety Relevant Protective Logic

1.6.4.1. Protective Logic for Reactor Start-up

The protective logic for reactor start-up (Fig. 11) guarantees that reactor operation is only possible in the case that all initial requirements are fulfilled and the correct command sequence is maintained.

Initial conditions are:

- no SCRAM signal, no warning signal, no alarm signal,
- neutron start-up source is in its container AND position signalisation works correctly,
- lower core section is in lower end position AND position signalisation works correctly,
- all control rods are in their end position (shut-down position) AND position signalisation works correctly,
- key-lock for RESA-Reset (SCRAM) was triggered.

If all conditions are fulfilled, the start-up neutron source drive will be released.

The lower core section drive mechanism is released for lifting, if

- start-up neutron source is in its upper end position AND required minimum count rate at the neutron instrumentation was measured (about 2-3 cps).

The drive mechanism for control rod withdrawal is released, if

- lower core section is in its upper end position (upper and lower core sections close together) AND minimum required neutron count rate at the neutron instrumentation was measured (about 2-3 cps) AND key-lock for reactor start-up is in its ON-position.

An interlock circuit guarantees that not more than only one control rod can be withdrawn from the core at the same time.

At a reactor power >0.25 W the start-up neutron source can be driven back down into the container.

1.6.4.2. Protective Logic for the Critical Experiment

In the critical experiment it must be possible to withdraw the control rods even in that case that the lower core section is not in its upper end position.

At first, initial conditions are the same as in 1.6.4.1.:

- no SCRAM signal, no warning signal, no alarm signal,
- neutron start-up source is in its container AND position signalisation works correctly,
- lower core section is in lower end position AND position signalisation works correctly,
- all control rods are in their end position (shut-down position) AND position signalisation works correctly,
- key-lock for RESA-Reset (SCRAM) was triggered.

If all conditions are fulfilled, the start-up neutron source drive will be released.

If the start-up neutron source is in its upper end position AND required minimum count rate at the neutron instrumentation was measured (about 2-3 cps) AND, additionally, the key-lock "Simulation KHZ" was triggered, than the control rods can be withdrawn even in the case that the lower and upper core sections are not connected. Also in this case, the interlock circuit for control rod movement is active, that only one control rod after the other one can be withdrawn.

1.6.5. Operational Functions

1.6.5.1. Automatic Reactor Power Control

At AKR-2, an automatic reactor power control is available with following properties:

- preset of a desired value of reactor power on the monitor screen of the control desk,
- selection of control rod for automatic power control (on the screen of the control desk),
- switch for manual/automatic power control (on the screen of the control desk),
- in the case that the selected control rod could go to its end position without obtaining the desired power value, the next control rod is automatically used for control,
- manual movement of a non selected rod is possible in the automatic mode, too, unless the end position has been reached.

1.6.5.2. Control Rod Drop

The possibility exists, to switch off manually the holding magnets of any single (or all together) control rods via soft-buttons on the monitor screens of the control desk. In that case, the control rod(s) drop into the shut-down position very fast only by gravity. For quality assurance, the drop down time is measured and can be displayed on the monitor screen of the control desk (Fig. 8).

1.6.5.3. SCRAM

Fast reactor shut-down (SCRAM, or in German: RESA) is activated in case of according criteria of the safety and control system (SUS). Additionally, SCRAM is possible at any time by manual activation (red button "Hand-RESA" on the conventional operation and signal panel left on the control desk, see Fig. 5), which has to be released after activation.

For fast reactor shut-down (SCRAM), there are two shut-down systems available in diversity:

- drop-down of the control rods (triple redundancy) and
- disconnection of the two core sections (drop-down of the lower core section)

Both shut-down mechanisms are effective only by gravity, i.e. no any additional energy supply is required.

For quality assurance, the drop-down time of the control rods and of the lower core section to reach their shut-down positions are measured and can be displayed on the monitor screen of the control desk (Fig. 8).

1.6.6. System Messages

1.6.6.1. Reactor Signalisation System

Three categories of signals are initiated according to their safety-related relevance:

- Status signals (Zustandsmeldungen) are messages, which inform the operator about the status of the system (drive ON/OFF, release of any action available / not available). At AKR-2 status signals are shown on the screens of the control desk.
- Fault signals (Störmeldungen) indicate a not specified abnormal operation in the operational or (as far as this signal is integrated in a safety alarm signal (see below)) in the safety system. At AKR-2 fault signals are shown on the monitor screens of the control desk (list of system messages, see Fig. 9) and have to be acknowledged by the operator on the screen. Fault signals will be saved in the reactor log datafile.
- Safety alarms (Gefahrenmeldungen) indicate a not specified abnormal operation in the safety system with audible and/or visual signals and must be prompted by the operator to clear the malfunction.

Safety alarms are displayed at the conventional operation and signal panel on the control desk as follows:

- | | |
|---|-----------------|
| - incoming or newly excited signal (unconfirmed): | fast flashing |
| - still existing signal (confirmed): | permanent light |
| - going signal: | slow flashing |
| - deleted signal: | dark (no light) |

Both, the safety alarms itself as well as the single alarms, from which they are generated, are additionally displayed on the screens of the control desk and filed and saved in the operational instrumentation.

1.6.6.2. Safety Alarms

1.6.6.2.1. Process-Orientated Safety Alarms

As process-orientated safety alarms all those criteria are summarised, which result in a reactor SCRAM due to exceeding specified safety thresholds or malfunctions of drives:

- "Neutron flux density > max"
(1∪3 link of the thresholds in the wide-range channels WB1/WB2 and power-range channel LB)
- "doubling time < min"
(1∪2 link of the thresholds in the wide-range channels WB1/2)
- "moderator temperature < min"
(1∪2 link of the thresholds of the temperature 1/2 moderator < min)
- "reactor tank subatmospheric pressure > max"
- "any drive working without control signal"
(contactor of a control rod OR of the lower core section OR of the neutron start-up source)

closed AND accordant control signal is not available).

For any of these safety alarms reactor SCRAM (RESA) is initiated. This is displayed on the screens of the control desk as a status message. After the activation of SCRAM it is checked that all addressed units have reached their intended shut-down position (control rods and lower core section in accordant end position). If not, the collective message "Rückmeldung nicht vollzählig" (response incomplete) will be displayed.

1.6.6.2.2. Safety Alarms of I&C Units

Safety alarms of I&C units are collective messages, which combine all detected malfunctions in supervised parameters of I&C hardware and software.

- **"Schrankstörung"** (malfunction in the I&C cabinet)
This alarm is initiated by (at least) one of the following single events:
 - "Störung Schrankstromversorgung" (malfunction in I&C cabinet power supply) - Fuse activated as a collective message for the whole cabinet. This can (depending on the fuse) result in reactor SCRAM or in non-availability of the control system or of single binary signals.
 - "Einstecküberwachung" (Plug-in supervision) - (unit(s) in the cabinet are pulled out / removed as a collective message for the whole cabinet). This can (depending on unit) also result in a SCRAM.
 - "Temperatur-/Lüfterüberwachung" (temperature and cooler supervision) - cooler failure or temperature in the TXS units too high). This results automatically in a shut-down of the corresponding computer (and furthermore to reactor SCRAM, if the computer of the reactor safety system is concerned, or to the non-availability of the control system).
 - "BASP/WDG angesprochen" ("BefehlsAusgabeSPerren/WatchDoG") - failures of the computer hardware / cycle time exceeded). This results automatically in the shut-down of the corresponding computer (and furthermore to reactor SCRAM, if the computer of the reactor safety system is concerned, or to the non-availability of the control system).
- **"Schranktür offen"** (door of the TELEPERM XS cabinet open)
The operator is caused to close the door(s) of the cabinet, because they have to keep closed during operation due to EMC-reasons.
- **"Leittechnikstörung 1"** (malfunction in I&C system 1)
Summary of all malfunctions as collective message, which are recognised within the computer of the reactor safety system.
 - missing antivalence in binary changeover contacts
 - errors in signal input or output in I/O-units
 - errors in sending or receiving signals via computer bus-system.Additionally integration of the message that the computer of the operational instrumentation is not on cyclical operation.
- **"Leittechnikstörung 2"** (malfunction in I&C system 2)
Summary of all malfunctions as collective message, which are recognised within the computer of the operational instrumentation.

- missing antivalence on binary changeover contacts
- errors in signal input or output in I/O-units
- errors in sending or receiving signals via computer serial bus system.

Additionally integration of the message that the computer of the reactor safety system is not on cyclical operation.

The detailed localisation of malfunctions for the last mentioned two messages is preferably possible by means of the service computer. The messages which originate in the cabinet additionally activate a lamp at the top outside of the cabinet.

1.6.6.3. Fault Signals

Fault signals give detailed information on the current status of the I&C system. Fault signals are displayed on the monitor screens of the reactor control desk and visualised, logged and saved in the computer-aided operational and supervising system.

1.6.6.4. Releases / Status Messages

The information on the reactor control desk offers a wide overview about the general status of the I&C system, partly with conventional equipment technology (operation and signal panel) and partly with screens (3 monitors).

The operation and signal panel (Fig. 5) with conventional equipment technology includes:

- safety alarms class 1,
- key-switches for release and simulation "Kernhälfte in oberer Endlage" (lower core section in upper end position),
- pushbutton to confirm and delete safety alarms and to check lamps,
- analogous panel meters "Neutronenflussdichte Weitbereich" (neutron flux density wide range), "Verdopplungszeit" (doubling time),
- digital display of "Temperatur Moderator" (moderator temperature) and "Unterdruck Reaktor" (subatmospheric pressure in reactor tank).

Additional control elements in conventional techniques on the control panel:

- covered latching button for manual reactor SCRAM ("Hand-RESA"),
- key-switch for RESA-Reset,
- key-switches for releases to change operational modes of the computers.

The reactor facility is controlled and supervised by means of 3 monitor screens on the control desk, on which messages and facility pictures are displayed (Figs. 6 to 9). These pictures provide all information for reactor control and displaying of process parameters.

1.6.7. Service Equipment (Diagnostics Interface)

The service equipment is used for planning, configuration, monitoring, maintenance and modification of the reactor safety system such as:

- diagnostics,
- modification of I&C components,
- modification of parameters,
- documentation and saving of hardware and software specifications.

It can be distinguished between services without required communication with TELEPERM XS and those with access to the safety units. The following properties characterise the service equipment:

- It is not part of the safety I&C; therefore, it can be switched off.
- It is never used for reactor operation process management.
- A hierarchically arranged operating surface is provided for user prompts.
- Unauthorized access protection to the service equipment is given by administrative measures (login/logout function) and additionally by key-operated switches.
- The software is protected against modifications by setting read-only features and additionally by backup procedures on data storage (CD-ROM).
- The service computer is located in the reactor control desk behind a locked door.

1.6.8. Gateway Interface Computer

The gateway computer sends information from the reactor safety and protection system to the control and monitoring system (and never in the opposite direction!). The gateway computer is located in the reactor control desk behind a locked door.

1.6.9. Interconnection between I&C Units

Communications between the reactor protection and the operational computers in the TELEPERM XS cabinet to the gateway and service computers in the reactor operator control desk takes place via a fiber optic cable. In a media converter, the signals are converted into electric signals and transmitted to the gateway and service computers via an Ethernet switch. Normally, all three monitor screens of the reactor control desk are connected to the gateway computer. Optionally, the monitor on the right hand side of the control desk can be swapped by a switchbox to the service computer (Fig. 12).

2. Instruction for Reactor Start-up Procedure

2.1. General Remarks

1. In the operation of the AKR-2 three modes of reactor start-up procedures are to distinguish:
 - Wiederholungsstart (normal restart),
 - Anfahrexperiment (comprehensive start-up experiment),
 - kritisches Experiment (critical experiment).

The normal restart is the start-up procedure in routine reactor operation. Restarts are possible, if nothing has changed since last reactor operation with effect on the reactivity properties of the facility, neither in the reactor itself nor in the internal experimental arrangements. The reactivity characteristics and the control rod positions in the critical state of the reactor are known.

A comprehensive start-up experiment is necessary for a safe reactor start-up after small material or geometry changes (e.g. new installation of internal experimental arrangements), which do not require a critical experiment. The behavior and the reactivity properties of the reactor are known, i.e. the fuel loading, the reflector properties and the reactivity characteristics of the control rods.

A critical experiment has to be carried out, if the physical parameters (e.g. critical mass, reactivity characteristics of the control rods, excess reactivity etc.) are only known from calculations. That applies in any case to the first start-up of a newly build reactor and to any further start-up after all such variations of the assembly when considerable change in the reactivity behavior is expected.

2. For any reactor start-up a valid written service instruction (BA) signed by the director of the AKR (Leiter AKR) and the radiation protection commissioner (SSB-AKR) or the corresponding deputies is required.
3. An experiment can be carried out with the same service instruction (BA) several times under the same conditions if it fits the period of validity of the BA.
4. Before each reactor start-up, a check of the proper function of the units is mandatory.
5. The preparation, the functional check of the equipment and the progress of the starting-up procedure have to be recorded in the operation logbook of the AKR-2. For that purpose a given flowchart of the checking and start-up process has to be used (Fig. 13).
6. In the comprehensive start-up experiment and in the critical experiment, the loading of the experimental channels in the core and in the reflector area as well as the measured pulse rates have to be recorded in the operation logbook.
7. When the reactor is in the supercritical state, the values of the doubling time, the corresponding control rod positions and after being in the critical state the critical control rod positions have to be recorded in the operation logbook according to the given flowchart.

8. At all changes in and at the reactor, especially
 - adding of extra fuel,
 - changes in the experimental channels,
 - movement (upwards) of the lower core section,
 - withdrawal of the control rods,
 - movement of the start-up neutron sourcethe displays (especially doubling time and reactor power) have to be watched carefully.

In case of fast power increase (in connection with constant doubling times below 30 s) the reactor has to be down-regulated. At doubling times below 10 s the reactor has to be shut-down instantly (unless automatically happened).

9. If in the critical experiment and the comprehensive start-up experiment only low pulse rates (i.e. < 5 cps) are measured, then for each pulse channel all pulse rates have to be determined as the average from at least 3 single measurements. A valid pulse rate, which shall be measured only once, must have at least 15 cps.
10. The correct sequence of operational steps in the start-up procedure is assured by the protective logic (Fig. 11). By means of soft-buttons on the screens of the control desk first step is to move the start-up neutron source to its upper end position, afterwards to do the same with lower core section. The successful execution of these steps is required to let the reactor safety system give release for withdrawing the control rods. This is possible not earlier until the start-up neutron source AND the lower core section have reached their respective end positions AND a pre-defined minimum count rate is measured at the neutron flux channels AND the key-lock "Anlassfreigabe" (start-up release) on the control desk is activated. Thus, operation errors, which affect the safety of the reactor, are impossible.
11. Too fast power increase (i.e. too short doubling time) or too high absolute power in the start-up procedure result in an automatic shut-down of the reactor by the safety system.
12. The pictures on the monitor screens of the control desk show a symbolic illustration of each drive and each control command, which can be addressed by mouse click on soft-buttons. At the same time (according to the context of the picture), releases, current positions and end positions of the drives as well as measured doubling time or pulse rates are displayed in order to see the success and the consequences of the action.
13. All operations have to be done on the control desk manually. Operational elements are conventional keys and pushbuttons as well as the computer-aided operational and supervising system which requires actions by keyboard or mouse on soft-buttons on the screens. Only the (operative classified) power control and the (safety related) fast reactor shut-down (SCRAM) as well as the optical and acoustical alarm signals in cases of failures work automatically.
14. On one of the control desk screens, the list of system messages can be displayed as a message sequence (example see Fig. 9). All fault and alarm signals are listed in this table in the order of their appearance (and disappearance). Coming as well as going messages are registered. Coming messages are announced also acoustically, they have to be confirmed by the reactor operator.

Additionally, alarm signals are displayed on the conventional alarm and signal panel of the control desk and are acoustically announced. Confirmation also of these signals by the reactor operator is mandatory. Normally, all alarm signals result in a SCRAM initiated by the reactor safety system.

15. Since the delay of the subatmospheric pressure control in the ventilation system in the reactor hall can be up to 20 min, the reactor operation may start not earlier than having passed this delay time after switching on the ventilation, and if, additionally, LED H13 on the signal panel does not indicate any failure.

2.2. Start- and Stop-Procedure of the Safety and Control System

For starting the safety and control (SUS) system, there is a combined mains switch on the control desk to switch on the power supply for the TELEPERM XS cabinet and the control desk of the reactor. The gateway computer (located in the control desk of the reactor), which connects to the safety and control system, and in which the operation and supervising system is integrated, has to be started afterwards manually. The computers in the TELEPERM XS cabinet boot automatically when connected to the power supply. After booting, the reactor protection is in a state, in which the signal "Reaktor abschalten (RESA)" (= SCRAM) is activated and the electro-magnets for the control rods and the lower core section are disconnected. The reactor is shut down.

The software of the computer-aided operational and supervising system of the AKR-2 is programmed in the programming language WinCC.

In detail the safety and control system is put into operation as following:

1. Switch-on the main switch on the right-hand side of the control desk (no. 10 in Fig. 4). Hereby, the power supply for both the I&C cabinet (24V DC) and the computers in the control desk (230V AC) is switched on.
2. The TELEPERM XS system in the cabinet starts running automatically.
3. The computers (gateway and service device) have to be switched on manually. The gateway computer runs automatically until WinCC software is executed. The plant video display is shown on all three monitor screens.

While WinCC is running the access to the operating system level (Taskmanager, Windows-Explorer etc.) and to quit WinCC by unauthorised action is blocked. This is only possible after entering a pre-defined username and a password and is only permitted to the staff. When clicking a click button the message "Keine Berechtigung" (no authorisation) is displayed. Pressing <STRG+Tab+n> an entry mask appears, in which the login and the password is to enter (only permitted to the staff). With the correct entry the click buttons are unblocked for two minutes.

4. Push the <STRG>-key of the right-hand keyboard on the control desk twice quickly in order to switch the right monitor screen to the service device.
5. Login at the service device (any user but root).
6. Start the Service-Monitor-Server (SMS) by double click on the button "Start SMS". This is required, because TXS, while booting, checks the communication to the gateway and to the service device. The connection is accepted to be correct not earlier than confirmation signals from the computers (via the SMS) arrive the TXS processing units. Without successful confirmation the RESA(=SCRAM)-signal cannot be reset.

7. Afterwards the SMS could be stopped and the service device could be shut down. But reasonably the SMS should be left running in order to have available possible failure messages (e.g. telegram failure), which are recorded in the log-datafile of the SMS, for a long term analysis.
8. Press the <STRG>-key on the right-hand keyboard twice quickly to switch the right monitor screen back to the gateway.

The safety and control system is switched off like following:

1. Press the <STRG>-key on the right-hand keyboard twice quickly to switch the right monitor screen to the service device.
2. Quit the SMS (i.e. enter <q> into the window of the SMS + <return>)
3. Quit WinCC:
By pressing <STRG+Tab+n> an entry mask appears, in which the username and the password has to be entered (only permitted to the staff). With the correct entries the click buttons are unblocked for two minutes.
4. Shut down the gateway interface computer and the service device in the reactor control desk (any order).
5. Switch off the mains switch on the right side of the reactor control desk.

2.3. Preparation for Reactor Start-up

For starting the reactor, the signal “Reaktor abschalten (RESA)” (fast reactor shut-down (SCRAM)), which is saved in the safety system, has to be reset. This is done with a key-switch on the conventional operation and signal panel of reactor control desk, and only successful in that case if no shut-down criteria, no alarm signals or operational related failures are queued. After successful reset of the RESA (SCRAM) signal, the holding magnets for the control rods and the lower core section are supplied with power and are coupled.

The pre-defined operation actions required for starting the reactor are effected by soft-buttons on the monitor screens (Figs. 6 and 7) on the reactor control desk. The required and possible sequence of the reactor operator’s actions is pre-defined technically by the protective logic (Fig. 11) and administratively by a check list for reactor start-up and operation procedure (Fig. 13) in the operation logbook and is supervised by the reactor safety system. Operation systems are blocked until the accordant release conditions are existent.

The preparation for the reactor start includes the check of the radiation protection equipment:

- proper function of the hand-foot-clothes-contamination-monitor (HFK),
- personal equipment with film batches and/or dosimeters for direct reading,
- availability and proper function of the gauged portable, battery-powered X-ray and gamma dosimeter,
- availability and proper function of the portable, battery-powered neutron dose rate meter,
- operational reliability of the stationary gamma local dose rate devices in the reactor hall (green panels lighting).

2.4. Safety Check of the Fast Shut-down System

- The reactor facility is started according 2.2. and prepared for start-up according 2.3.
- The neutron source is lifted to its upper end position at lower core section. The position of the source is displayed on the monitor screen, additionally the arrival at the end position is signaled.
- The lower core section is lifted out of its lower end position. The position of the lower core section is displayed on the monitor screen. The movement has to be stopped, when the lower core section has left its lower end position, which is signaled on the monitor screen.
- On the conventional operation and signal panel of the reactor control desk, RESA (=SCRAM) signal is initiated manually by pressing the red pushbutton "Hand-RESA".
- On the monitor screen, it has to be checked that the lower core section has dropped down reliably (confirmation by showing the light signal for reaching the lower end position).

For the critical experiment, another extended safety check is necessary:

- The proper shut-down function of the lower core section is checked by the described safety check according 2.4.
 - Additionally to the previous procedure, also the correct drop of the control rods has to be checked. For this purpose, the protective logic signal "Kernhälften zusammen" (core sections joined) has to be simulated by turning the key-switch "Simulation KHZ" (simulation of core sections in joined state) on the conventional operation and signal panel of the control desk. This key-switch administratively ensures that switching over to this operating state can only be done consciously.
 - All three control rods are moved out from their internal end position one after another. The movement has to be stopped, when the corresponding control rod has left its end position, which is signaled on the monitor screen.
 - On the conventional operation and signal panel of the reactor control desk, RESA (SCRAM) signal is initiated manually by pressing the red pushbutton "Hand-RESA".
 - On the monitor screen, it has to be checked that all control rods have dropped down reliably (confirmation by showing light signals for reaching their end positions).
- After this safety check, the facility must not switched off until finishing the critical experiment.

2.5. Normal Restart of the Reactor

1. Before beginning any restart, the reactor facility has to be prepared according chapters 2.2. and 2.3., and the safety check has to be done according to chapter 2.4. The results of the safety check have to be recorded in the operation logbook according the flowchart stamp print (Fig. 13). If all required conditions are met, the reactor can be started.
2. The neutron source is lifted to its upper end position at lower core section. The position of the source is displayed on the monitor screen, additionally the arrival at the end position is signaled (end position about 800).
3. After the source is completely in its upper end position and the required neutron flux is measured, the lower core section is lifted. The position of the lower core section is shown on the monitor screen. While lifting the lower core section, the displays of the doubling time and the power meter channels have to be watched carefully. The arrival at end position is signaled (end position about 506).
4. With the key-switch of the starting release the drives of the control rods are unblocked. The rod drives are connected in such a way that only one single rod can be selected and moved

in pull-out direction. The sequence of pulling out is arbitrary (if not indicated different administratively in the service instruction), because each rod approximately has the same reactivity equivalent.

5. By pulling out the control rods the reactivity change has to be limited. If the control rod characteristic is not known, a rod must not be lifted more than 5 cm (about 500 digits) at a time. Between each step a break for at least 1 min must be maintained. The power and doubling time meters have to be watched carefully at any time.
6. In case of a constant doubling time combined with a permanent power increase the reactor is supercritical. Now, the rod position may only be changed in such a way that the doubling time does not fall shorter than 30 s (acoustic alert at 20 s, automatic RESA (SCRAM) at 10 s).
7. The start neutron source can be run out manually at a power exceeding 0.25 W. A small influence on the reactor behavior has to be expected. The possibly resulting reactivity change must be compensated by adequate movement of the control rods, so that the reactor power still increases with a doubling time >30 s.
8. When the intended reactor power given in the service instruction is approaching, the doubling time is to control to "infinite" (i.e. display of the doubling time at 1000 s) to adjust the critical state at the required power.
9. The restart is finished by writing the values of the control rod positions, the reactor power and the time of reaching the critical state into the flowchart stamp in the operation logbook (Fig. 13).

2.6. Protocol Records in the Operation Logbook

Detailed records of all operations at nuclear facilities are mandatory. These records are important documents. All entries into the operation logbook have to be done well legible and with ink or ball-point pen. The sequence of all operations must be reproducible by means of the logbook. Therefore, all actions at the facility have to be instantly registered with date and time (according the clock at the reactor facility) and signature.

This is relieved by the pre-defined algorithm of a flowchart control stamp in the operation logbook (Fig. 13). Entries, which are not pre-defined in the stamp, are written down formlessly and manually in chronological order below the stamp in the operation logbook with date and signature of the reactor operator.

For each experiment at the reactor, a corresponding service instruction (BA) with the respective date is required, from which the number of the instruction, the name of the experiment and the name of the responsible person for the experiment have to be copied into the flowchart stamp in the operation logbook.

Before any operation of the AKR-2, the dosimeter equipment of the staff and all other participating persons as well as the proper function of the instruments and the systems necessary for fast reactor shut-down (SCRAM) have to be checked. The result is to be noted in the stamp (time of check and in case of the positive result "i.O." (= o.k.)) and signed by the reactor operator.

Also the core temperature displayed on the conventional operation and signal panel (Fig. 5) has to be checked and noted in the logbook. All steps of reactor start-up procedure are recorded during or instantly after their execution.

Usually, the end of any reactor experiment is the shut-down of the facility. The time of this action has also to be recorded in the logbook. The log is finished with the signature of the operator.

3. Fields of Application of the AKR-2

3.1. Education and Training

The main purpose of AKR-2 and its design basis was and is the education of students in nuclear and reactor physics, in nuclear engineering as well as to teach fundamental knowledge and rules in radiation protection and radiation dosimetry (see chapter 4).

3.2. Application in Research Projects

Due to its physical characteristics, a zero power reactor as the AKR-2 offers only limited possibilities for research. However, it can be used for all those projects where high neutron fluxes are not required but variable operational conditions and low costs are requested, e.g. investigations on sophisticated neutron detectors, development of radiation measuring techniques, radiation spectrometry in mixed neutron-photon fields.

3.3. Information Centre for the Public

One of the great advantages of small, low power training reactors on the campus of a university is their central location and that not such strict admittance restrictions exist as in many other nuclear installations. Hence, it is suitable for using these facilities also as information centres for groups or individuals of the interested public. Besides the transfer of fundamental knowledge, it is of high importance to enhance the quality of the public discussion about nuclear energy.

4. Examples of Typical Fundamental Training Experiments at AKR-2

A variety of exercises in fundamental neutron, reactor, nuclear and radiation physics as well as in radiation protection were developed at AKR. For any exercise, scripts are available and can mostly be downloaded from the AKR-website describing the theoretical basis of the experiment and providing practical procedures, values to be determined, evaluation procedures as well as how to discuss results etc. In advance of any practical work, the preparation of the students to the special exercise is tested by means of a PC-based check list. Results of these tests are used by the lecturer to identify deficiencies in knowledge or in preparation and to correspondingly concentrate efforts in colloquia.

4.1. Reactor Start-up Procedure

This is the basic exercise for all programs at the reactor and in most cases the first contact of the students with the facility. The exercise comprises start-up of the reactor, the adjustment of the critical state at various power levels, changes of the power level (increasing, decreasing), various inspections and safety checks of the instrumentation and control units.

Included in that part is the study of fundamental reactor physics effects as:

- correlation between reactivity, reactor period (or doubling time) and reactor power,
- subcritical multiplication of the neutron start-up source,
- prompt reactivity steps,
- stable positive reactor period with exponential power increase in supercritical reactor state,
- correlation between prompt and delayed neutrons,
- control of stable reactor power,
- independence of control rod position in critical reactor state on absolute power level (if effects of temperature and fuel burnup are negligible as in a zero power reactors),
- influence of the neutron start-up source on the critical reactor,
- dependence of neutron and gamma dose rate on the reactor power and on the distance from the reactor.

Usually, this part is also the first close contact of the students with the special rules of radiation protection measures (changing clothes, wearing overshoes and dosimeters, rules of conduct according to the ALARA-principle, check of contamination when leaving the radiation protection area etc.).

4.2. Control Rod Calibration

For safe operation of a nuclear reactor it is of high importance to know:

- reactivity values of all control rods in dependence on their position,
- excess reactivity,
- shut-down reactivity brought about by the control rods.

In the exercise position-dependent reactivity values of all control rods are determined by measurements of the stable reactor period in combination with the reactivity compensation method. Physical background of the evaluation method is the INHOUR-equation.

Results of the exercise are the integral reactivity curves (total reactivity) as well as the differential reactivity curves (characterisation of the efficiency of a control rod in a given position). Furthermore, the excess reactivity is calculated as the maximum available reactivity to be released by withdrawal of all control rods, starting from the critical core. In contrary, the shut-down reactivity of the control rods is calculated as the negative reactivity value when all control rods are in their shut-down positions.

4.3. Critical Experiment

The critical experiment is a check of proper fuel loading (critical mass) and core configuration of a nuclear reactor. At AKR-2 with its well sealed core no exchange of fuel elements is feasible in student's exercise. Instead, a stepwise variation of the distance of both core sections is carried out leading to a corresponding variation of the subcritical multiplication of the neutron source. For any step, the multiplication factor k of the reactor and the corresponding reactivity ρ of the system are iteratively calculated. The result of this kind of critical experiment is the critical distance between both core sections.

4.4. Adjoint Flux Function

The intention of the exercise is to investigate influences on reactivity by introducing samples of different materials (e.g. PVC as a neutron absorber, PE or graphite as typical neutron scattering materials) into the central irradiation channel of the reactor. The samples are shifted stepwise inside the channel and the reactor response is measured. The reactivity $\rho(x)$ is evaluated in dependence on the distance x of the sample from the core centre and compared to calculations.

4.5. Measurement of Radial Neutron Flux Distribution

The knowledge of space dependent radial and axial neutron flux distribution $\Phi(r)$ and $\Phi(z)$, respectively, is of high importance in any reactor facility, e.g. in research reactors as entry value for many experiments (neutron source strength in irradiations) or in power reactors as heat source distribution. In the experiment, the flux distribution of thermal neutrons $\Phi_{th}(r)$ is measured in radial direction over the diameter of the reactor in the horizontal plane of the central experimental channel by means of neutron activation technology in Mn activation samples.

4.6. Pile-Oscillation Experiment

While the exercise "control rod calibration" and "adjoint flux function" are based on the measurement of the stable reactor period (i.e. in the equilibrium state between prompt and delayed neutrons) pile oscillation experiments require a more detailed way of looking at the theoretical basics of reactor kinetics including the solution of point kinetic equations for time dependent reactivities $\rho(t)$. By means of a mechanical pile-oscillator fitted to the central experimental channel of the reactor the function $x(t)$ as sample position in dependence on time is measured using a multichannel analyser which is operated in multi-scaling mode. This function is weighted with the result of the adjoint flux function $\rho(x)$ in order to get $\rho(t)$. The experimental result will be compared with an independent calculation.

4.7. Demonstration of Neutron Activation and Decay of Various Radioisotopes

The production of radionuclides by neutron capture is one important application of many research reactors. Of course, in the low neutron flux density of a zero power training reactor no real production of nuclides is possible in industrial scale, but the effect of the production of radioactive nuclei itself can be demonstrated as well. Activation, saturation and subsequent decay can be investigated in dependence on reactor power (i.e. neutron flux density), time, capture cross section, half live time, sample size etc. Students get the experience that materials are activated in the neutron field but they acknowledge in the same way that activity decreases subsequent to the irradiation according to the law of radioactive decay. Experimental results are compared to calculations on relative and absolute scale.

4.8. Identification of Radionuclides by means of High Resolution Gamma Spectroscopy

High resolution gamma spectrometry is one of the mostly used techniques for non-ambiguous identification of radionuclides. Physical properties of different kinds of detectors (e.g. simple traditional NaJ-scintillator/photomultiplier-combinations with their high efficiency but comparably poor energy resolution and actual HPGe semiconductor detectors) and required features of amplifiers and multichannel analysers are investigated. The HPGe-spectrometer is calibrated in its energy scale as well as with respect to absolute energy dependent efficiency using a set of well known calibration sources. The procedure of neutron activation analysis (NAA) is demonstrated by activation of "unknown" samples in an irradiation channel of the reactor and subsequent identification of the isotopic composition qualitatively and quantitatively. Traces of radionuclides can be measured and identified in samples taken from natural environment (e.g. K-40) or industrial goods (e.g. ancient tiles or watches). Another issue of NAA is the use of activation foils for the determination of absolute neutron flux densities in different energy ranges at nuclear facilities according to the conversion of the formula for activation with respect to the neutron flux as unknown value.

4.9. Radiation Protection and Shielding

In this experiment, the students obtain knowledge of dosimetric units and of dosimetric limits defined in the German Radiation Protection Ordinance. Characteristics of ionising radiation are highlighted and from these characteristics essential principles of radiation protection are derived and deepened. The student gets experience in the correct use of suitable kind of measuring devices for the different types of radiation and measuring conditions as well as in the evaluation of measured values. Fundamental rules of radiation protection according to the ALARA-principle are demonstrated experimentally such as: keep distance, use shieldings, shorten time in radiation fields.

The fundamental physical dependences of dose rates or of total doses on these parameters are explored. Efficiencies of several shielding materials as Pb, Fe or different qualities of concrete are investigated and shielding coefficients are derived and compared with data in literature. Using these data, required thicknesses of shieldings can be calculated and experimentally verified in order to get defined dose rates meeting given conditions at the reactor.

4.10. Radiation Measurement Techniques

Fundamental characteristics of different kinds of radiation detectors are explored with special attention to gas-filled ionisation detectors like ionisation chambers, proportional and Geiger-Mueller-counters. The dependence of the counting rate on high voltage is measured and discussed with reference to the adjustment of suitable parameters for proper application. Students become familiar with the statistical character of any measured value being essential for assessment of accuracy (Gaussian-distribution of measured data, arithmetic mean value, statistical uncertainties, standard deviation). Attenuation curves are measured for different materials and linear as well as mass attenuation coefficients are determined and discussed.

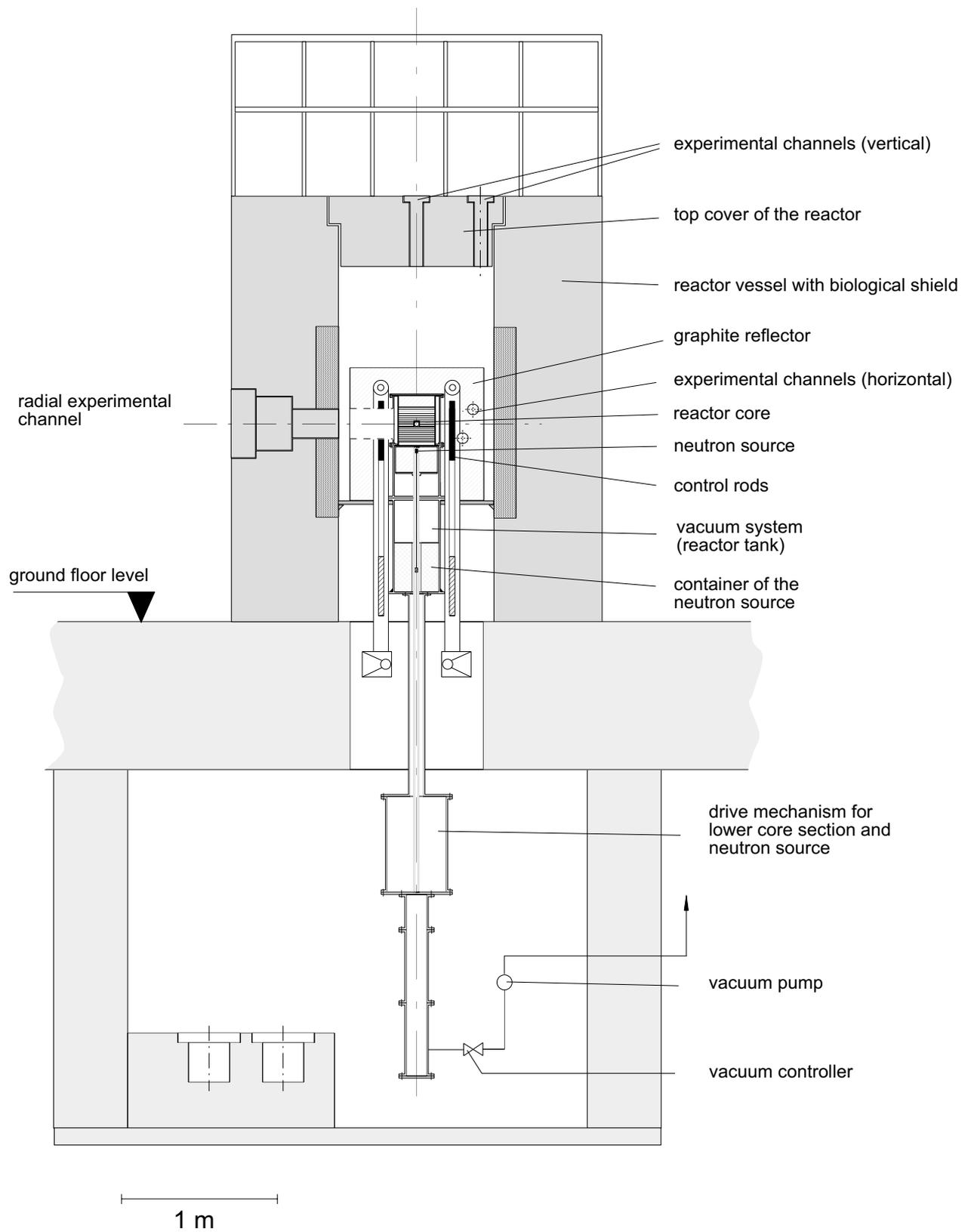


Fig. 1, Vertical Cross Section of the Training and Research Reactor AKR-2

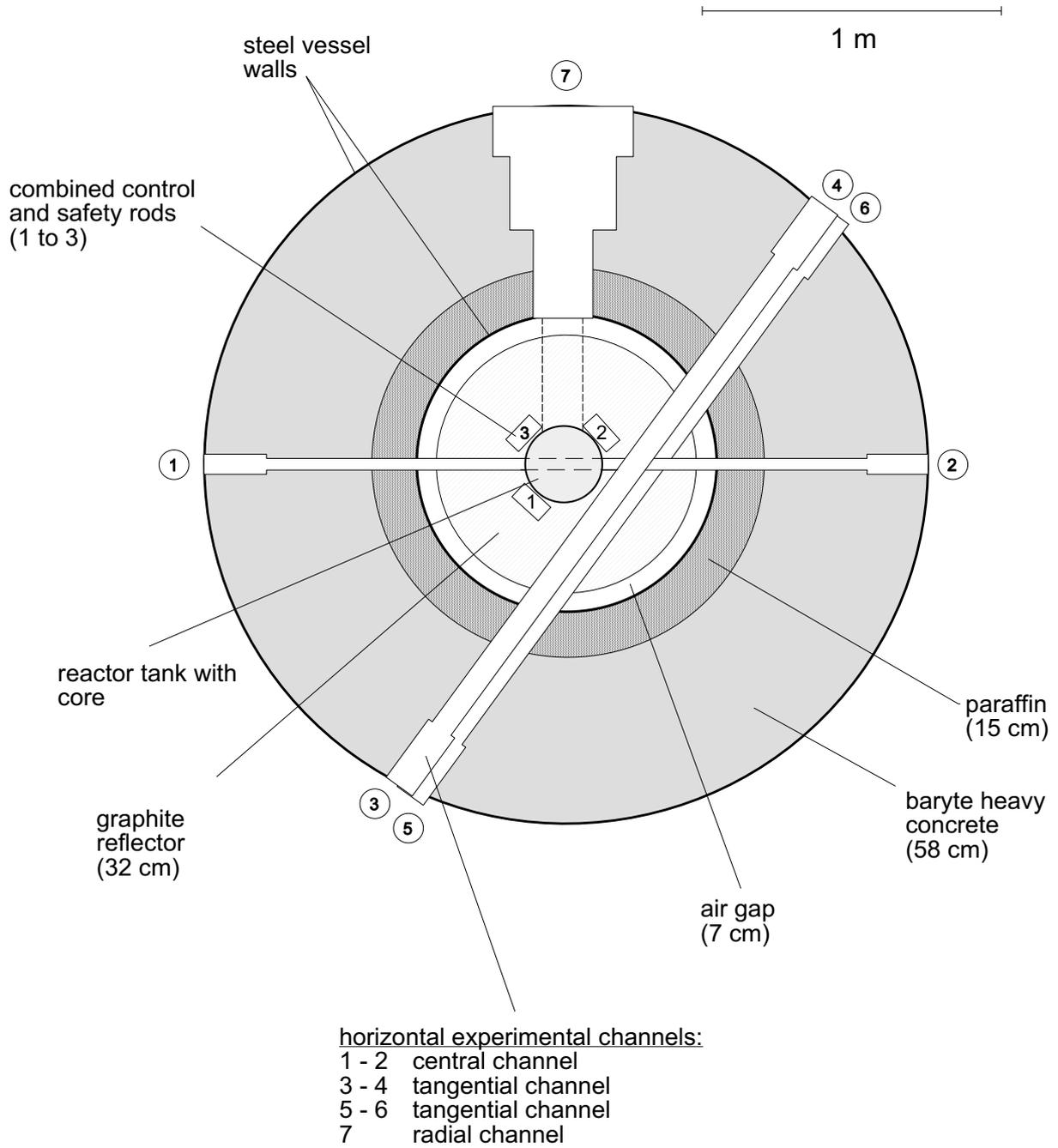


Fig. 2, Horizontal Cross Section of the Training and Research Reactor AKR-2 at Core Level

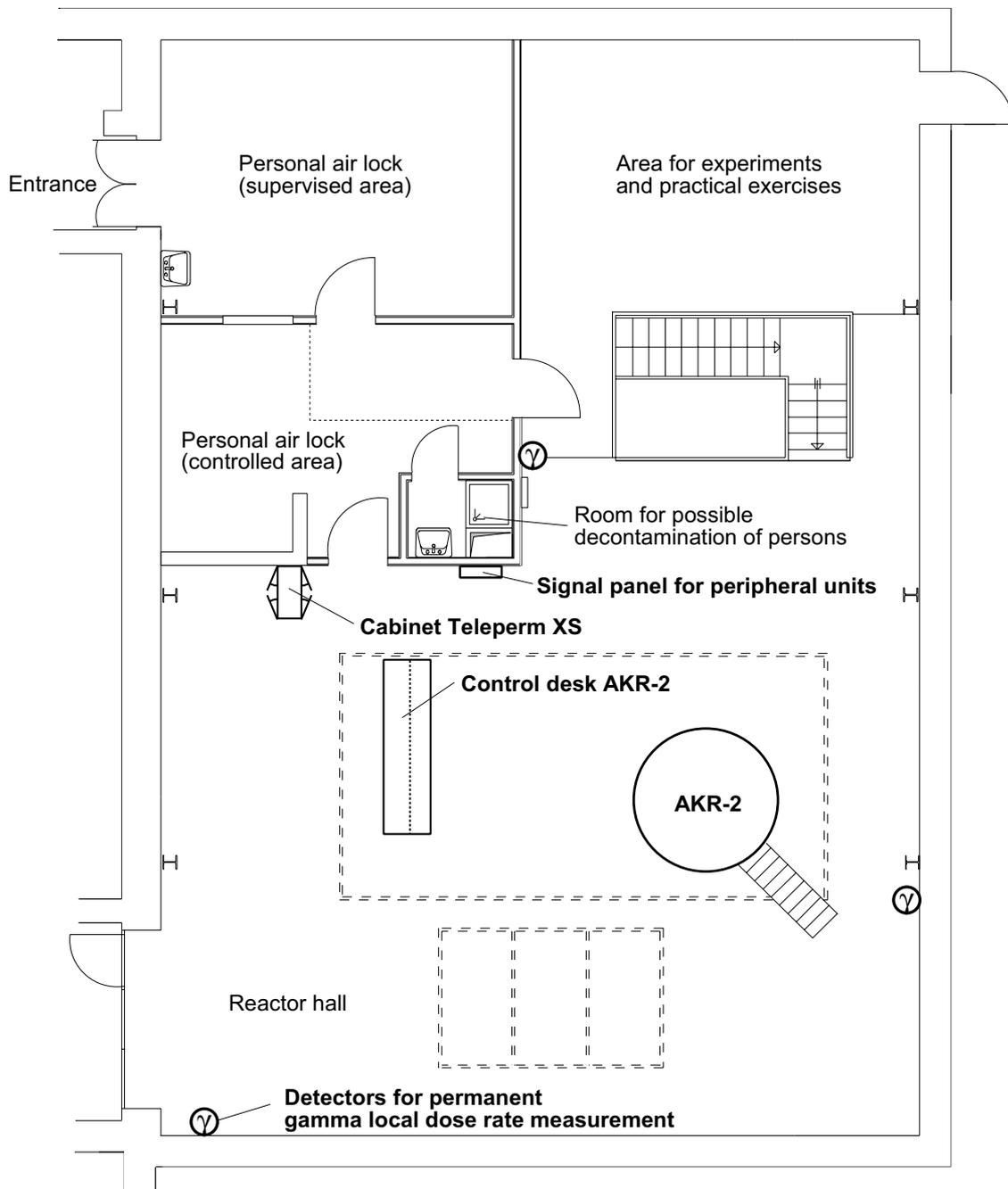
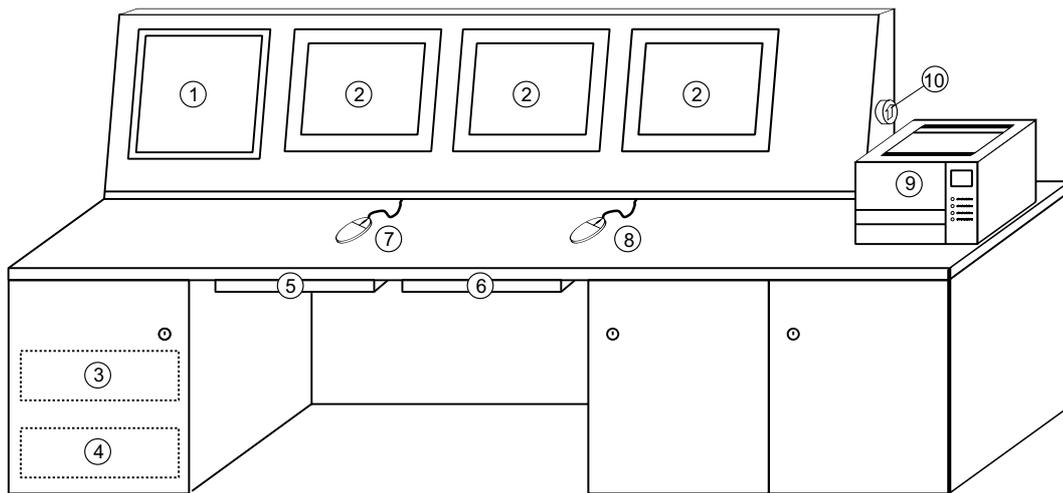


Fig. 3, Cross Section of the Reactor Hall AKR-2



- 1 Conventional Operation and Signal Panel
- 2 Monitor screens
- 3 Service computer (Diagnostics Interface)
- 4 Gateway Interface Computer
- 5 Keyboard for Gateway Interface Computer
- 6 Keyboard for Service Computer
- 7 PC-Mouse for AKR-2 Control
- 8 PC-Mouse for Service Computer
- 9 Hardcopy Printer
- 10 Mains Switch (for Electrical Power Supply of Reactor)

Fig. 4, Control Desk of AKR-2

	JRE90 EG300 XD07 LT Störung RSS JRZ90 EG300 XD07 LT Störung BLT	JRE90 EG300 XD15 SchrankStö CLE01 JRE90 EG300 XD16 Tür offen CLE01		JRE90 EG300 XD11 NeutrFI > max2 JRE90 EG300 XD12 T2 WB < min2	JRE90 EG300 XD13 T Mod < min1 JRE90 EG300 XD14 P ReaktTk > max1	JRE90 EG300 XD19 Antr ohne StSig	
	Temperatur Moderator (°C)	-18888		Reaktorleistung (W)			
	Druck Reaktortank (kPa)	-18888		Verdopplungszeit (s)			
	Lampenprüfung 				Meldung quittieren 	Meldungen löschen 	
NeutrFI WB1 		0 	0 		JRE10 ER001 XE02 RkMid RESA	JRZ03 ER150 XE01 RSS zykl Betr JRE03 ER150 XE01 BLT zykl Betr	
NeutrFI WB2 		JRY80 CH801 Freig PARAM	JRY80 CHB02 Freig TEST/DIAG				
NeutrFI LB 							
RELFAG WB1 						JRY11 CH801 Hand RESA ein	
RELFAG WB2 							
		0 	0 		0 		
		JRY10 CH802 Simulation KHZ	JRY10 CH801 Anlassfreigabe		JRY11 CH802 RESA Reset	JRY11 CH801 Hand-RESA	

Fig. 5, Conventional Operation and Signal Panel

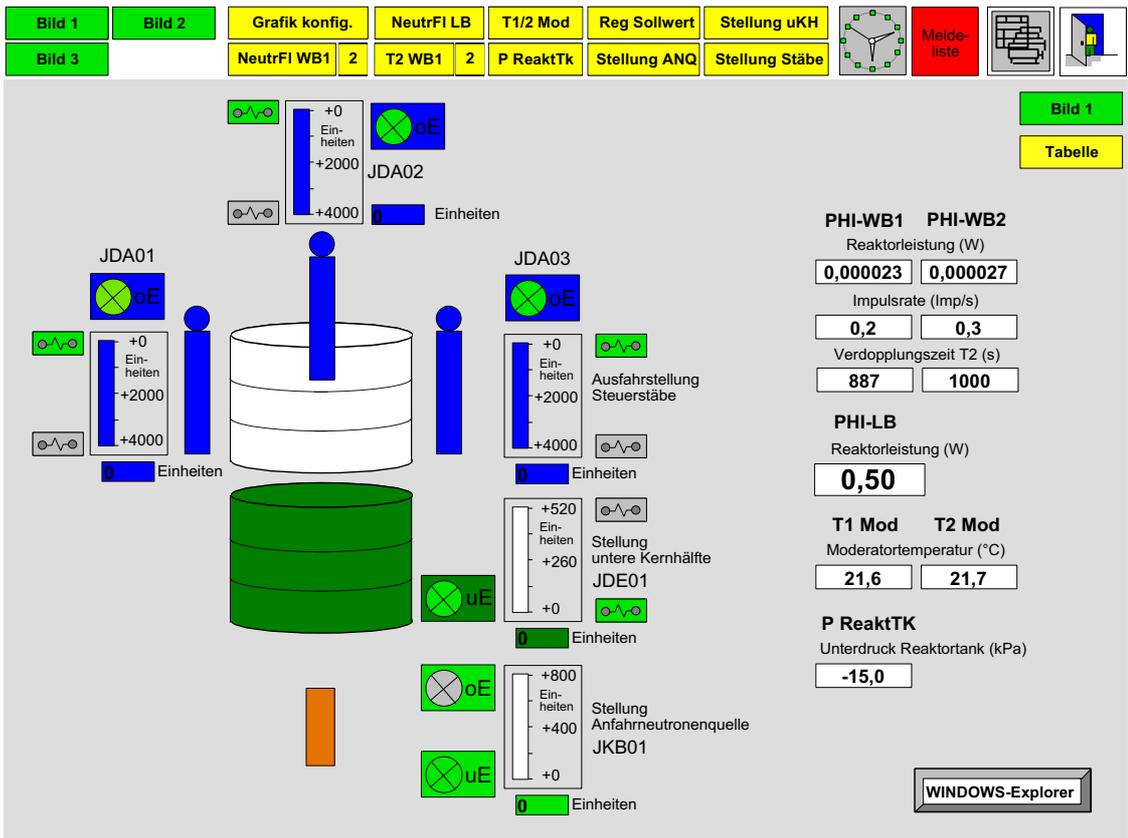


Fig. 6, Monitor Screen, Picture 1

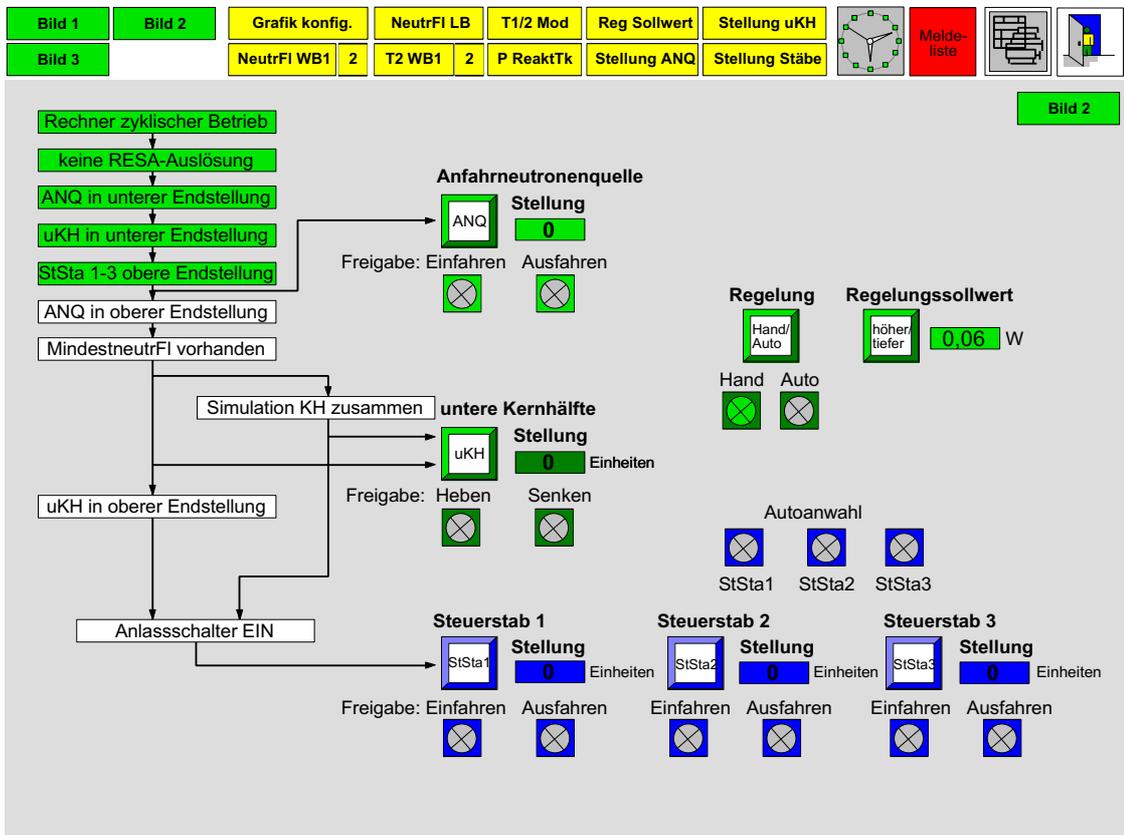


Fig. 7, Monitor Screen, Picture 2

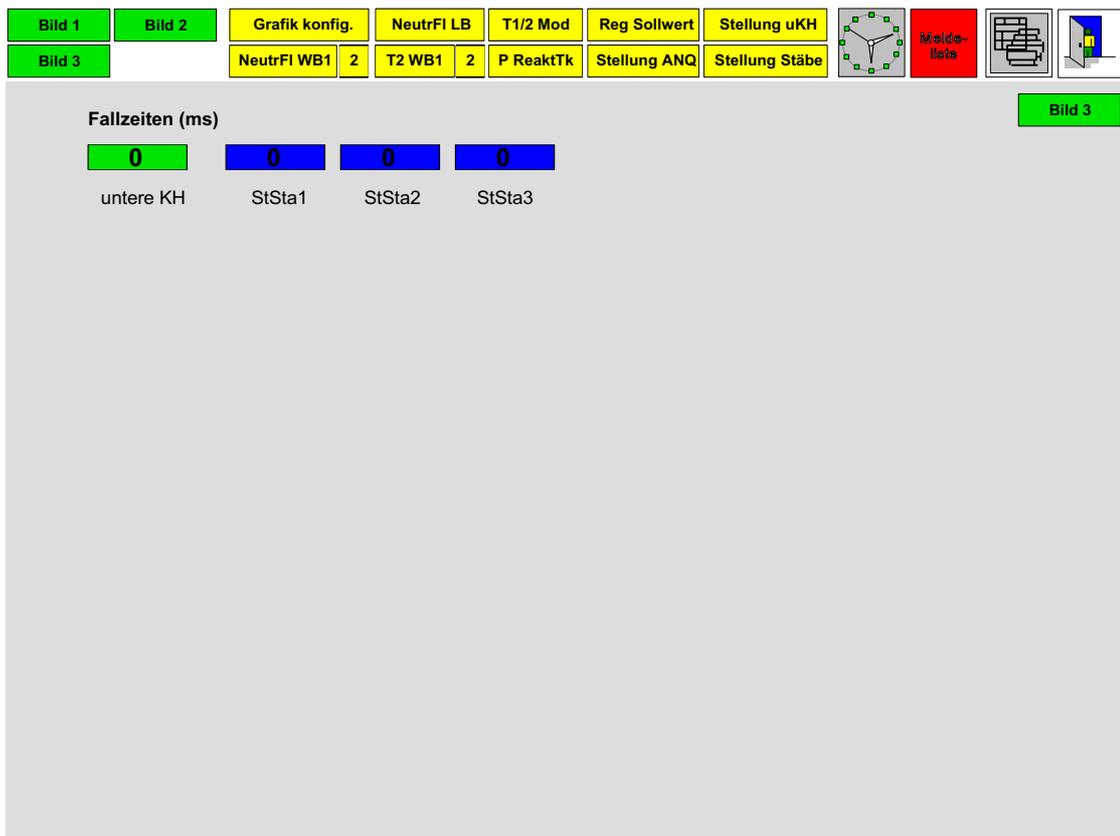
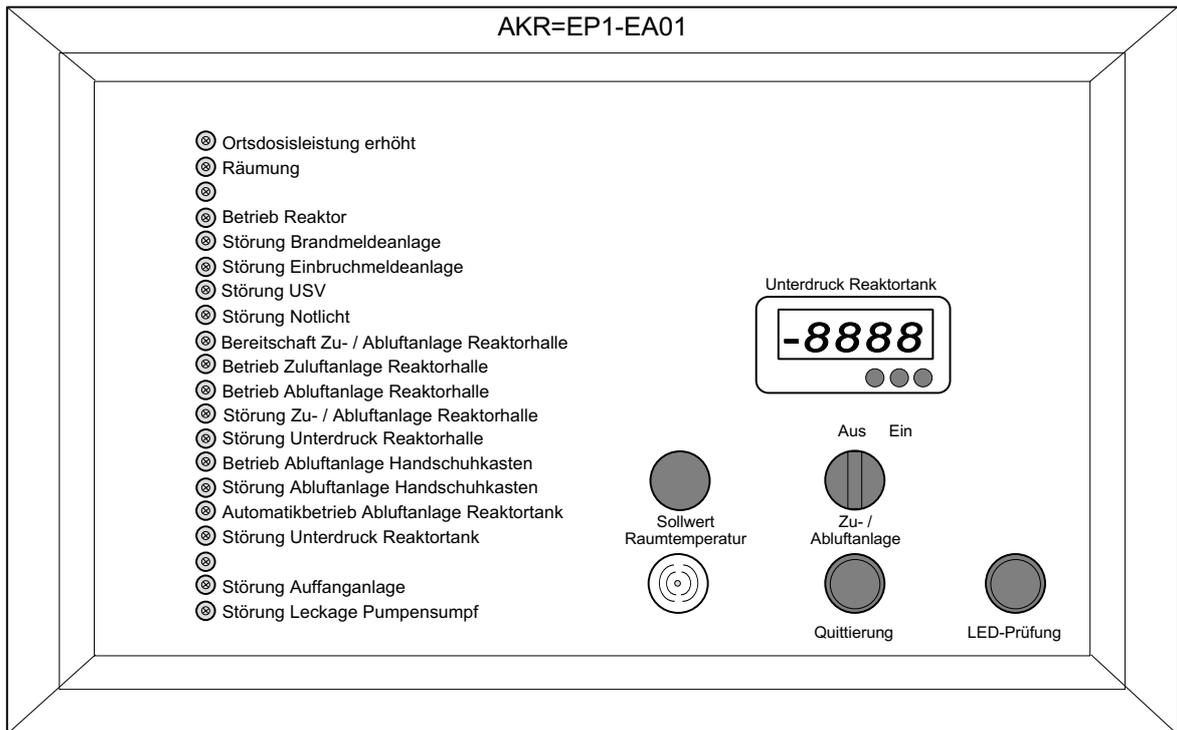


Fig. 8, Monitor Screen, Picture 3

...	Art	Variable	Meldetext	Grenzwert/Funktion	Zustand	Datum	Uhrzeit
1	Status	JRG00EG360XD42	BLT zyklischer Betrieb		angesprochen	19.07.05	11:21:45
2	Status	JRG10ER200XE13	Neutronenfluss WB1 < min1	2 Imp/s	angesprochen	19.07.05	11:21:45
3	Status	JRG10ER200XE23	Neutronenfluss WB2 < min1	2 Imp/s	angesprochen	19.07.05	11:21:45
4	Status	JRG00EG360XD51	ANQ uE		angesprochen	19.07.05	11:21:45
5	Status	JRG00EG360XD53	untere KH uE		angesprochen	19.07.05	11:21:45
6	Status	JRG00EG360XD54	Steuerstab 1 oE		angesprochen	19.07.05	11:21:45
7	Status	JRG00EG360XD55	Steuerstab 2 oE		angesprochen	19.07.05	11:21:45
8	Status	JRG00EG360XD56	Steuerstab 3 oE		angesprochen	19.07.05	11:21:45
9	Status	JRG00EG360XD57	Steuerstäbe1-3 oE		angesprochen	19.07.05	11:21:45
10	Status	JRG00EG360XD43	RSS zyklischer Betrieb		angesprochen	19.07.05	11:21:45
11	Status	JRZ10ER211XE01	Antrieb untere KH uE		angesprochen	19.07.05	11:21:45
12	Status	JRZ10ER212XE11	Antrieb Steuerstab 1 uE		angesprochen	19.07.05	11:21:45
13	Status	JRZ10ER212XE11	Antrieb Steuerstab 2 uE		angesprochen	19.07.05	11:21:45
14	Status	JRZ10ER212XE31	Antrieb Steuerstab 3 uE		angesprochen	19.07.05	11:21:45
15	Status	JRZ10ER902XE61	ANQ einfahren	Freigabe	angesprochen	19.07.05	11:21:45
16	Status	JRZ52DX107XE12	Hand-Reaktorregelung	ein	angesprochen	19.07.05	11:21:45

Alle Meldungen quittieren

Fig. 9, Monitor Screen, List of System Messages (example)



Indicators:

Ortsdosisleistung erhöht	Local dose rate above threshold
Räumung	Evacuation
Betrieb Reaktor	Reactor in operation
Störung Brandmeldeanlage	Fault in fire alarm system
Störung Einbruchmeldeanlage	Fault in alarm system for detection of un-authorized access
Störung USV	Fault in uninterruptible power supply
Störung Notlicht	Fault in emergency light
Bereitschaft Zu-/Abluftanlage Reaktorhalle	Standby of ventilation in reactor hall
Betrieb Zuluftanlage Reaktorhalle	Operation of supply air system in reactor hall
Betrieb Abluftanlage	Operation of extracted air system in reactor hall
Störung Zu-/Abluftanlage Reaktorhalle	Fault in ventilation system in reactor hall
Störung Unterdruck Reaktorhalle	Fault in subatmospheric pressure in reactor hall
Betrieb Abluftanlage Handschuhkasten	Operation of extracted air system in glove box
Automatikbetrieb Abluftanlage Reaktortank	Automatic operation of subatmospheric pressure system in reactor tank
Störung Unterdruck Reaktortank	Fault in subatmospheric pressure system in reactor tank
Störung Auffanganlage	Fault in drain pan for possibly contaminated water
Störung Leckage Pumpensumpf	Fault in pump sump on basement floor
Unterdruck Reaktortank (kPa)	Value of subatmospheric pressure in reactor tank (kPa)

Keys / Switches:

Sollwert Raumtemperatur	Desired value of room temperature in reactor hall
Zu-/Abluftanlage Ein/Aus	Ventilation system in reactor hall ON/OFF
Quittierung	Acknowledgement of signals
LED-Prüfung	Functional check of LED-lights

Fig. 10, Signal and Key Panel for Peripheral Units

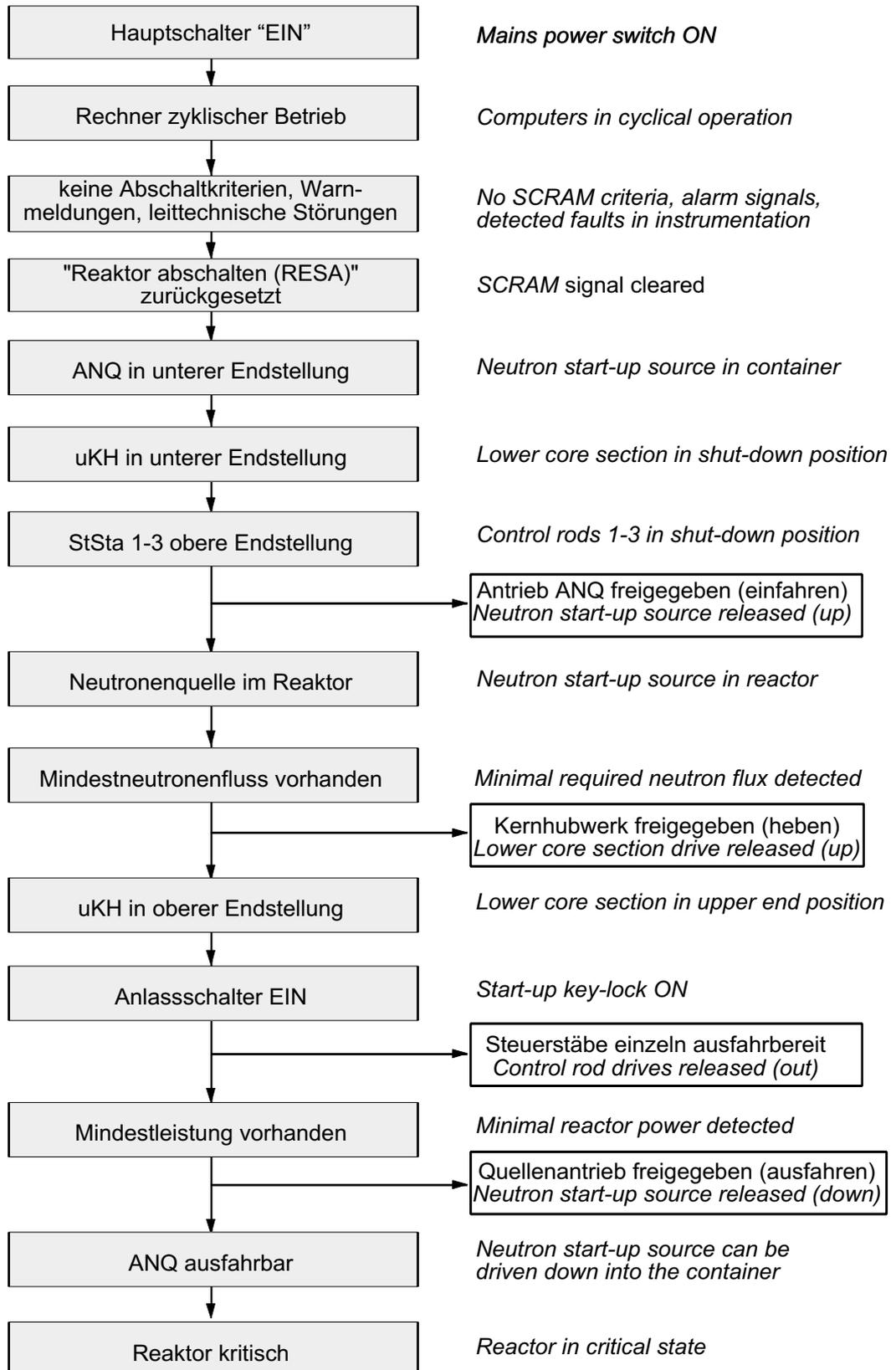
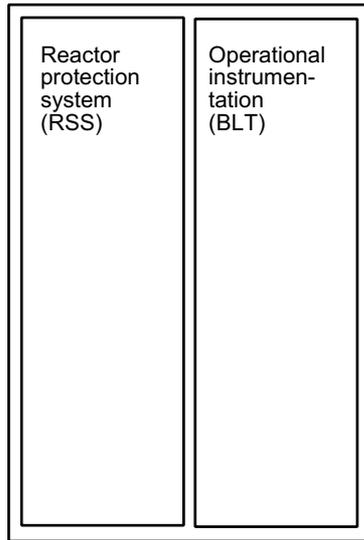


Fig. 11, Protective Logic for Reactor Start-up Procedure

TXS cabinet
CLE01



Reactor control desk
CWA01

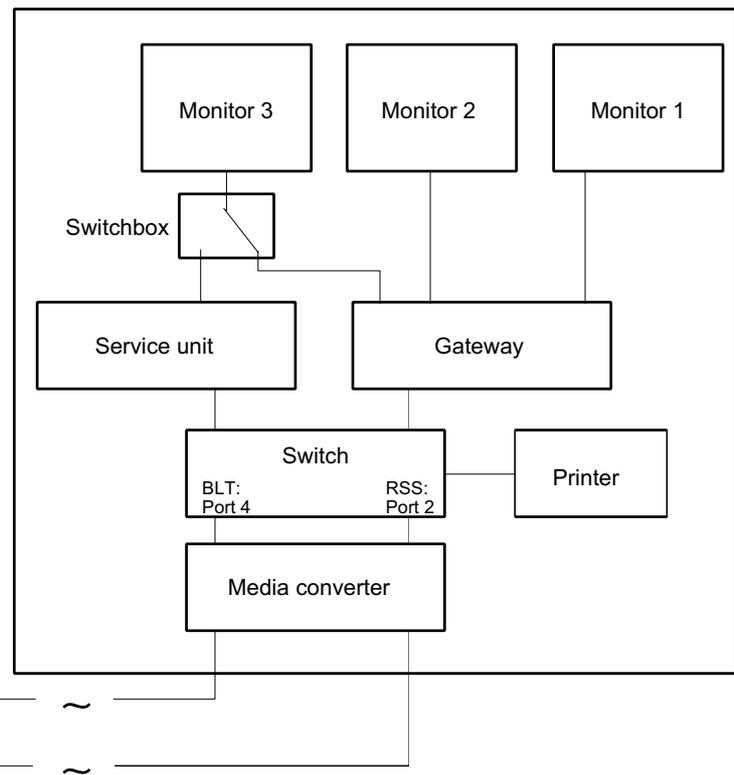


Fig. 12, Combination of the Safety and Control System (SUS)

Datum:		BA:	
Versuch:		Versuchsleiter:	
Überprüfung dosimetrische Einrichtung:		Uhr	
Überprüfung nichtnukleare Einrichtung:		Uhr	
Quellenantrieb:	Kernhubwerk:	Totalabschaltung:	
Beladung Brennstoff vom:		Experimentierkanäle vom:	
Bemerkungen:		Unterschrift:	
Temperatur Spaltzone:			
Quelle eingefahren:	Uhr	Kernhälften zusammen:	Uhr
Reaktor überkritisch:	Uhr	Verdopplungszeit::	s
Stab 1:		Stab 2:	
Stab 3:			
Reaktor kritisch:	Uhr	Leistung:	W
Stab 1:		Stab 2:	
Stab 3:			
Abschaltung:	Uhr		
Anlage AUS:	Uhr	Unterschrift:	

Fig. 13, Check List for Reactor Start-up and Operation

Comments to the check list of start-up procedure and reactor operation

(translation of and remarks to Fig. 13)

<i>Datum :</i>	actual date
<i>BA :</i>	no. of actual service instruction
<i>Versuch :</i>	experiment to be carried out (according to operational instruction)
<i>Versuchsleiter :</i>	person being responsible for the experiment
<i>Überprüfung dosimetrische Einrichtung :</i>	availability and proper operation of dosimetric devices
<i>Überprüfung nichtnukleare Einrichtung :</i>	availability and proper operation of conventional instrumentation
<i>Quellenantrieb :</i>	test of proper operation of neutron source drive (o.k.)
<i>Kernhubwerk :</i>	test of proper operation of drive and fast shut-down actions for lower core section (o.k.)
<i>Totalabschaltung :</i>	test of manual fast total shut-down action (SCRAM), released by pressing the red button on control desk (o.k.)
<i>Beladung Brennstoff vom :</i>	date of last fuel reloading in the core
<i>Experimentierkanäle vom :</i>	date of last change in configuration of the experimental channels
<i>Bemerkungen :</i>	remarks (optional)
<i>Unterschrift :</i>	signature of the operator
<i>Temperatur Spaltzone :</i>	measured temperature inside the core
<i>Quelle eingefahren :</i>	neutron source in core (time), digital position 800
<i>Kernhälften zusammen :</i>	lower core section lifted (time), digital position 506±1
<i>Reaktor überkritisch :</i>	reactor in supercritical state (time) (characterised by constant doubling time $< \infty$)
<i>Verdopplungszeit :</i>	measured constant doubling time in supercritical state
<i>Stab 1, 2, 3 :</i>	digital positions of control rods S1, S2, S3
<i>Reaktor kritisch :</i>	reactor in critical state (time) (characterised by constant doubling time $= \infty$)
<i>Leistung :</i>	corresponding reactor power, in Watt
<i>Stab 1, 2, 3 :</i>	digital positions of control rods S1, S2, S3
<i>Abschaltung :</i>	reactor shut-down (time)
<i>Anlage AUS :</i>	mains off (time)
<i>Unterschrift :</i>	signature of the reactor operator

Glossary (German / English)

Alarmmeldung	alarm signal / safety alarm
Betriebliche Leittechnik	operational I&C system, operational instrumentation
Betriebsanweisung (BA)	service instruction
Betriebsfunktionen	operational functions
Betriebsjournal	operation logbook
Freigabe	release
Gateway	Gateway interface computer
Leistungsmesskanal	(linear) power-range channel
Meldeliste	list of system messages
Meldetableau	(conventional) operation and signal panel
Nukleare Instrumentierung	nuclear instrumentation
rechnergestütztes	
Bedien- und Beobachtungssystem	computer-aided operational and supervising system
RESA	fast reactor shut-down (SCRAM)
Schlüsselschalter	key-lock
Service-Gerät	service equipment (diagnostic interface)
Sicherheitsleittechnik	reactor protection
Steuerpult	control desk
Störmeldung	fault signal
SUS	safety and control system
Systemsignalisation	system messages
Verriegelungskreis	protective logic
Weitbereichsmesskanal	(logarithmic) wide-range channel
Zustandsmeldung	status signal / status message