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OPERATIONAL CHARACTERISTICS AND RELATED DESIGN FEATURES OF SNEAK*

W. Bickel, P. Engelmann, H. Walze, and G. Wittek

Paper to be presented at the Symposium on Fast Reactor Physics and Related Safety Problems held at Karlsruhe, Germany, Oct. 30.- Nov. 3., 1967

Gesellschaft für KernforschungmbH, Karlsruhe

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1. DESCRIPTION OF SNEAK

The fast zero power reactor SNEAK has been in operation at the Karlsruhe Nuclear Research Center since December 1966. It is a tool for investigating the neutron physics of large fast reactors with uranium and/or plutonium fuel. After a series of physics assemblies, mock-ups are planned for the two 300 MWe fast breeder prototypes with sodium and steam cooling.

The SNEAK design was aimed at maximum flexibility and operational safety. Out of the various types of zero power reactors, such as horizontal split-table, vertical split-table, and vertical fixed machines, the latter was chosen. The fuel elements are suspended from a grid and the loading is performed from below.

There are points in favour of both split table and fixed assemblies. The major reasons for selecting the vertical fixed suspended version were:

1. There is no large reactivity addition such as occurs during the closing of the halves of a split-table machine.
2. The loading from below excludes fuel rod drop accidents.
3. Gravity can be used to accellerate the safety rods in case of scram.
4. The void and steel fractions can be kept very small (6.5% and 7.5% respectively) as no matrix is needed.
5. The assembly can easily be cooled by blowing air through narrow channels which are provided by the shape of the fuel element tubes.
6. The flow pattern of the cooling air is the same with the machine in loading and operating conditions which is of special importance for plutonium fueled assemblies.
7. It is relatively easy to install loops.
8. Experimental equipment can be set up immediately around the reactor, which is accessible from all sides.
9. Automatic machines were available for loading (and unloading) the plate-shaped material pieces into (or out of) the element tubes.

The reactor can accommodate assemblies up to a diameter of 3.2 m and a height of 2.7 m. It is assembled out of square elements which are suspended from a top grid plate and after completion of loading operations are fixed in their positions by 8 clamping devices at the bottom part of the circumference. The reproducibility in core geometry which can be achieved by the clamps was of major concern before the commissioning of the machine. It turned out, however, to be very good (see Chapter 3).

The design necessitates two loading machines: a lower loading machine which transports elements between the reactor and the fuel element transit lock, and an upper loading machine which hoists the elements into the reactor.

The design of SNEAK can be seen from Figs. 1, 2, and 3. Fig. 4 shows typical core and blanket material pieces. Most core materials have been fabricated into square plates 50.75 x 50.75 x 3.15 mm thick. Also available are plates of other dimensions and rods 17 x 17 x 305 mm long. Plates and rods fit into the core tubes of 51 x 51 mm inner dimensions and into the blanket tubes of 153 x 153 mm inner dimensions.

At present about 830 kg of U235, 175 kg of Pu, 50.000 kg of natural and depleted uranium and large amounts of structural materials are available.

As can be seen from Fig. 3, vertical channels for experimental purposes can be generated at any desired location. Fig. 5 shows the design of two typical elements with vertical channels. Larger vertical channels penetrating the grid plate can be formed at four locations near the core center where the top grid has square holes with side lengths 55 mm. These large channels are utilized, e.g., for insertion of a pile-oscillator tube.

Control rods may be placed at any 9th core element position. Up to 20 shim rods, 10 safety rods and 1 regulating rod can be installed.

While the generation of vertical channels is very easy, a horizontal channel has to penetrate a row of core and blanket elements. To allow this, these elements are provided with windows which give access to a rectangular tube with a cross section of 31 x 58 mm. The horizontal channel at mid-core level (north-south channel) has been used extensively for detector and material traverses, foil activiation for spectrum measurements, and for the insertion of a pulsed neutron source.

A more detailed description of SNEAK and the planned experiments was given at the Conference on Fast Critical Experiments at Argonne in Oct. 1966 /1,2/. The safety aspects were described at the Conference on Fast Reactor Safety at Aix en Provence, Sept. 1967 /3/. The experiments performed so far are reported in separate papers at this conference /4,5/. In Chapter 2 of this paper, some details are given on the safety instrumentation, controls, and experimental instrumentation. Chapter 3 deals with the operational characteristics of SNEAK.

2. INSTRUMENTATION AND CONTROL

2.1 Safety Instrumentation, Safety Rods, Shut-off Valves of the Ventilation System

The operating and safety instrumentation consists of 7 channels:

1. logarithmic counting channel for neutron flux and period measurements in the low power region (up to 0.5 watts);
2. logarithmic current channel for neutron flux and period measurements with an ionization chamber in the upper power region (from about 0.05 watts up to 1000 watts);
3. U/Pu monitoring channel for the exhaust air;
4. counting channel for monitoring the concentration of beta emitters in the exhaust air;
5. logarithmic counting channel for gamma flux measurement in the reactor building in the upper power region;

6. channel for measuring the pressure difference between the space inside each of the two steel shells and atmosphere;

7. channel for emergency shut off by hand or by the opening of certain interlocks.

The air pressure channel (No. 6) consists of two parallel measuring lines, the other channnels of three parallel lines, which work in a one-out-of-two or two-out-of-three manner respectively. These channels may be divided into three parts: analog part, digital part, and active elements.

1. Analog part:

In this part the measuring current is generated, indicated, and sometimes recorded. The analog part is terminated by limiting value indicators and comparing units which give a signal when a certain value is surpassed or when the difference of the current in two parallel lines is too large. Channel 7 has no analog part; the limiting value indicators and comparing units are replaced by switches and contacts.

2. Digital part: (Fig. 6)

The limiting value indicators and comparing units also serve as the input units of the digital part. In this part, the one-out-of-two and/or two-out-of-three selection of the signals is made. If two comparing unit signals indicate an excessive deviation in a certain measuring line, this is treated like the signal of the limiting value indicator in the measuring line in question.

The digital part is terminated by relays, which operate the subsequent safety devices, if a selection unit opens the current path. The digital part of the safety system is continuously automatically inspected for faultless operation. In cyclic progression, short check pulses are fed to the inputs of the individual limiting value indicators and the arrival of these pulses at the output of the limiting value indicators, the selection units, and the output amplifiers is checked. Thus, within two seconds the whole digital part of the safety system is checked and any defect is indicated and localized. The system distinguishes between "dangerous defects" and "non-dangerous defects".

"Non-dangerous defects" are those which without reason trigger a safety operation (e.g. scram), like a limiting value indicator giving a permament signal. "Dangerous defects" are those, which prevent a necessary safety operation, that is for example a limiting value indicator giving no signal, although the measured value is above that limit.

When a dangerous defect appears in a measuring line of a two-out-of-three channel this is automatically switched to one-out-of-two selection. In an one-out-of-two channel a dangerous defect will trigger the corresponding safety operation. In this manner a high degree of safety is guaranteed.

3. Active elements:

The terminating relays of the digital part operate various elements. They range from the safety rods to simple indicating relays and are listed below:

1. Shim and safety rods In case of scram the safety rods are shot out of the core, while the shim rods are driven out by motors. Scram is initiated by:

Channel 1, if during loading the neutron flux exceeds a certain value, or if the reactor period is less than 3 seconds or if the neutron flux exceeds the limit beyond which the pulse counters are no longer working accurately. Normally, however, the high voltage is taken off the counters before that limit is reached.

Channel 2, if the trip level of the neutron flux is reached or if the reactor period is smaller than 3 seconds.

Channel 3, if the U/Pu-concentration in the exhaust air is too large (3×10^{-12} Ci/m^3 Pu or 1.8×10^{-10} Ci/m^3 U).

Channel 4, if the concentration of ß-emitters in the exhaust air is too large (about 6×10^{-7} Ci/m^3 in case of A-41).

Channel 5, if the maximum admissible reactor power (1 kW) and the corresponding gamma-flux is exceeded.

Channel 6, if the air pressure inside the reactor building exceeds the atmospheric pressure by more than 1C mm water, or if the pressure inside the reactor building exceeds that in the space between the two shells and the latter exceeds the atmospheric pressure.

Channel 7, if the manual scram button is pushed, or if the mechanical interlock between the doors of the personnel air lock is not functioning, or if the personnel air lock is operated while the reactor is in operation, or in case of a defect in the voltage supply of the reactor instrumentation.

2. Fast acting pressure valves and ventilation of the reactor building The pressure valves in the air ducts penetrating the steel shells are closed and the corresponding blowers are switched off by channels 3, 4, and 6 in the same cases as listed above.

3. Ventilation of the operation and storage building This ventilation is switched off and the corresponding valves are closed by channels 3 and 4 in the same cases as listed above.

4. High voltage of the BF_3-counters in channel 1 The high voltage of these counters is switched off by channel 2, if the neutron flux reaches a value about 2 decades above the minimum measurable flux in channel 2.

5. Indicating relays for insufficient neutron flux A visual signal "drive in neutron source" is given by channel 1, if during reactor operation the neutron flux drops to a value about 2 decades above the minimum measurable flux.

6. Neutron source drive motor The neutron source is automatically driven in by channel 1, if during reactor operation the flux drops to a value about 1 1/2 decades above the minimum measurable flux.

7. Blocking relays for shim rods and loading machines
Channel 1 prevents driving the shim rods in and operating the loading machines if the neutron flux drops to a value about 1 decade above the minimum measurable flux.

8. Indicating relays for short reactor period The visual signal "reactor period" is given by channels 1 and 2, if the reactor period is less than 10 seconds.

Of these 8 active elements, the most important ones are the safety rods, the shim rods, and the fast acting pressure valves. The shim rods are described in detail in section 2.2. The safety rods and the pressure valves are described here.

The safety rods (Fig. 7) consist of two tubes, an outer guide tube which has the cross section of a normal core element, and a somewhat smaller tube which can be moved vertically 1 m inside the guide tube. The inner tube contains platelets of common core material and also in some cases blocks of moderated boron carbide in the upper part of the tube. The inner tube is attached to a holding magnet in the outer tube by means of a steel plate. In addition, a device is provided to accelerate the rod in a downward direction. This consists of a coil and a copper ring connected to a steel tappet. At scram, the current of the holding magnet is switched off and at the same time a capacitor (480 μF), which is loaded to 3 kV, is discharged through the coil giving a current of about 1.6 kA. The copper ring with the tappet is thrust down onto the steel plate by the induced short circuit current. This gives an impulse to the movable part of the rod which is accelerated to 1 m/sec within 1 ms /6/. When out of the core, the safety rod is decelerated by a shock absorber mounted in the lower part of the outer tube.

The reactivity reduction due to the removal of one safety rod is shown in Fig. 8 for two cases: 1. free fall and 2. accelerated with the magnetic gun. It can be seen, that the total travel time (380 ms and 470 ms respectively) differs by only 20%, the reactivity reduction, however, starts much faster in the case with acceleration.

Considerably steeper reactivity ramps can therefore be controlled by the safety system in this case /3/. With a shut down reactivity of 2.5% in the safety rods, which is the minimum required, and for an initial power of 0.01 W (1 W) reactivity ramps of up to 2.7 $/sec (5.1 $/sec) can be controlled if the rods are accelerated.

The travel time of all rods is monitored so that deviations from normal caused either by failure of the magnetic gun, sticking of the rod, or failure of the shock absorber will be discovered immediately.

In addition to the travel time monitors on each safety rod, there is a device by which the travel time of one safety rod can be measured with an accuracy of a few milliseconds.

The fast acting pressure valves close the ventilation ducts penetrating the steel shells. Ducts penetrating both steel shells have 3 valves, those which go to the interspace (penetrating only the outer shell) have 2 valves. Three different types of valves are used in order to reduce the probability of a complete failure:

1. Valves operated by an electric motor, closed within 3 seconds;
2. Pneumatic valves operated by a piston, closed within less than 1 second;
3. Spring-driven valves. These are opened by an electric motor acting against a spring which shuts the valve if the magnetic holding ratchet is released. Closed within less than 1 second.

2.2 Reactor Control

All safety rods are cocked during loading and operation of the assembly. The normal operational shut down is made with the shim rods. Their construction is similar to that of the safety rods. The shim rod (Fig. 9), filled with core material, moves in a guide tube of core element cross section and has a stroke of 1 m. The shim rod is driven by a screw and an electric motor which is placed in the upper part of the guide tube. The space around the screw may be left empty or it may be filled by a steel can filled with B_4C powder. In this case the shim rod acts as a fuel-poison rod.

The rod motor also drives a potentiometer the resistance of which is automatically compensated by a run-after potentiometer in a bridge. The position of the run-after potentiometer is used to indicate the position of the shim rod to an accuracy of ±0.15mm.

The shim rods in the SNEAK assemblies have a reactivity worth of at least 4%. Several shim rods can be moved in a bank. The maximum number which may be moved simultaneously is half the number of cocked safety rods. The maximum rate of reactivity insertion is 0.1 $/sec.

The fine control rod has a stroke of 50 cm around the core midplane in order to achieve a characteristic which is almost linear. It consists of a lower fixed part and an upper movable one. The motor and position indicator work as in case of the shim rods.

The fine control rod has a maximum reactivity worth of 0.2%, the reactivity speed is about 0.01 $/sec. It can be used in connection with the log. current channel for automatic power control. The power can be kept within ±1% of the set value.

2.3 Experimental Instrumentation

2.3.1. Linear Measuring Channels

For experimental purposes several linear neutron flux measuring channels are available. BF_3 and He^3 filled ionization chambers of high neutron sensitivity can be used with two types of amplifiers.

Type 1 uses an electrometer tube in its input, which only needs 2 x 10^{-14} ampere grid current for normal operation. Because of this, the most sensitive range is 1 x 10^{-13} ampere full scale. By means of a calibrated internal current suppression, a part of the measured neutron flux can be compensated. This is very useful for oscillating measurements. The installed model has a zero drift of about 1% of full scale in eight hours and an overall measured linearity of 0.2%. These values are relatively poor, but typical for amplifiers of the electrometer type. Type 2 uses varactor diodes in its input. By means of these voltage dependent capacitors a high frequency signal is modulated by the input current. The modulated signal drives an ac-amplifier, which is connected to a phase dependent rectifier. The most sensitive range is 1 x 10^{-11} ampere full scale. Zero drift is negligible, and the overall linearity was measured to be within 0.03%. If extremely high sensitivitiy and current suppression are not needed, the type 2 amplifier is preferred.

For easy data acquisition the output voltages of the amplifiers are digitized by voltage to frequency converters operating with an integrating capacitor.

Several BF_3- and He^3-filled proportional counters are available for linear pulse channels. Small U235, U238, and Pu239 fission chambers are used for power calibrations of the SNEAK assemblies. The output pulses of the voltage to frequency converters and those of the pulse amplifiers are counted during a certain time intervall. The countrates can serve as computer input data.

2.3.2 Deviation-Meter and Reactivity-Meter

The information from the linear ionization chamber channels can be used to operate a deviation-meter and a reactivity-meter. These instruments with display on the control desk have proven to be very useful for stabilizing the reactor power and for measuring small reactivity changes, e.g., in reproducibility experiments.

Fig. 10 shows a diagram of the linear channels and the arrangement of the equipment in the reactor building and experiment control room.

The deviation meter uses a chopper stabilized operational amplifier for comparing actual reactor power and the set power. It shows the deviation of reactor power from a set point; the most sensitive range corresponds to a 1% power deviation. The relatively high noise level in the output signal at low reactor power can be reduced by applying a R-C combination.

With the aid of a small on-line analog computer, programmed for the solution of the inverse reactor kinetic equations, it is possible to obtain continuous reacitivity information. Six ranges from 0.5 ¢ up to 5.0 $ full scale can be chosen. On the 0.5 ¢ range the reacitivity worth is obtained with an accuracy of ±0.02 ¢, if the reactor power is higher than 30 watts. Fig. 11 shows the time dependent neutron flux and the calculated reactivity for a part of a horizontal Al-probe traverse in SNEAK assembly 1.

Six chopper stabilized operational amplifiers and one servo-multiplier are the active elements in the fixed wired analog computer. The delayed neutron terms are taken into account by passive networks. Automatic switching of the source term simulator occurs simultaneously with range switching of the linear amplifier in the ionization chamber channel. Noise in the reactivity signal is reduced by applying a large time constant between reactivity meter and display unit.

3. Operational Characteristics

3.1 Temperature Behaviour with and without Cooling of the Core

For a great number of experiments it is important to minimize reactivity changes due to changes in core temperature.

Temperature variations result from the fission heat and from the decay heat of plutonium, if this is used as fissile material.

While the reactor power normally is in the range of a few watts, the decay heat of 175 kgs of Pu is about 500 watts.

The SNEAK core can be cooled by air blown through the gaps between the core element tubes. The air is taken from the building atmosphere and after passing through the core returns to the building atmosphere. The cooling system is also effective during loading changes.

Measurements of core temperature have been made in the U-core SNEAK-1 in order to demonstrate the efficiency of the cooling system. During a run at 650 Watts reactor power without cooling the temperature rose about linearly from $26^{o}C$ to $40.1^{o}C$ with an initial $\Delta T/\Delta t$ of $3.4^{o}C/hr$ and after 5.3 hours the temperature was still not levelling off. In a second run at 400 Watts with cooling the temperature rose from $24.3^{o}C$ to a constant level at $29.1^{o}C$ which was reached within 3 hours.

From these results it is expected that in a plutonium assembly a constant temperature will also be reached in a short time after temperature disturbances which occur during loading changes.

3.2 Measurements of Reproducibility in Reactivity

Many experiments such as void experiments and heterogeneity investigations by plate bunching require that the reactivity after unloading and reloading of fuel elements in the core, after unloading and reloading of plates in a fuel element, after position changes of the control rods and so on can be well reproduced.

A series of measurements has been made in the assemblies SNEAK-1 and SNEAK-3A-1 to investigate the reproducibility. The results of these measurements are shown in Table I.

Table I:

Operation	Measured Reproducibility in the Operation, Δk/kß*
1. Core clamping	< ±0.01 ¢
2. Un- and reloading of same element	negligible
3. Rearranging of an array of 6 fuel elements in the core	±0.014 ¢
4. Unloading of an element, un- and reloading of the plates, and reloading into the core	±0.01 ¢
5. Exchange of two elements of same kind	< ±0.25 ¢
6. Control rod positioning	±0.02 ¢
7. Regulating rod positioning	±0.02 ¢
8. Startup after scram	< 0.1 ¢

*1 ¢ ≙ 7×10^{-5} Δk/k

It can be seen from Table I, that relatively large uncertainties arise after a scram or the exchange of two elements of the same kind, but not with identically the same material plates. This has lead to the following decisions:

1. Reactivity measurements during which a scram occured are ruled out;
2. In bunching and void experiments elements are refilled with identically the same material plates and the elements are brought back to the same core position.

With these rules applied, the accuracy in reactivity measurements is very satisfactory for all kinds of experiments. It should be mentioned, that a special fine regulating rod (auto-rod) with much better reproducibility in rod position than the regulating rod is also available.

3.3 Dose Rates

In order to have free access to the reactor for all kinds of experiments, the biological shield is at the building wall. Therefore, during operation personnel are not allowed in the reactor building. The dose rate 3 meters from the outer edge of the blanket is

5 mrem/hr watt due to gamma rays and
750 mrem/hr watt due to neutrons.

Outside the biological shield the max. dose rates are

4×10^{-3} mrem/hr watt due to gamma rays and
1×10^{-3} mrem/hr watt due to neutrons.

As the reactor power is restricted to 1000 watts maximum, there is no radiation hazard outside the reactor building.

After shutdown the dose rate inside the reactor building normally drops rapidly below 2.5 mrem/hr, so that the building can immediately be entered. The highest radiation found so far was after an activation experiment in which the reactor was operated for 8.5 hours at 600 watts. In this case the 3 m dose rate was 15 mrem/hr after shut down. The dose rate dropped to 2.5 mrem/hr within 9 hours.

The radiation exposure in handling an unshielded core element or irradiated fuel plates can be appreciable. A dose rate of 500 mrem/hr was measured 10 cm from the surface of a fuel element which had been irradiated for 3.5 hours at 10 watts reactor power and had been allowed to cool for 20 minutes.

In order to avoid excessive radiation exposure to the operating crew, if possible experiments requiring relatively high reactor power are run at the end of the week, so that the assembly can cool down over the weekend. So far in only one case has a person received a dose of 50 mrem at one occasion. In this case it was necessary to do a repair job close to the reactor immediately after shut down. All other exposures could be kept below tolerance.

3.4 Operational Experience

3.4.1 Safety System

The reactor was scrammed in only one case because a safety limit had been exceeded. The reactor was on a positive period in order to raise the power. The operator was not careful, so the high power limit was reached and the reactor duly scrammed by the safety system.

In the early operation period a series of faulty scrams occurred, some of them due to failures in the safety circuitry itself, some due to perturbations in the ventilation system leading to pressure deviations. In the meantime, these perturbations to a great extent could be traced and cured.

3.4.2 Auxiliary Equipment

Most of the auxiliary equipment is performing well. Some repairs were necessary on the reactor loading machines and on the fuel element loading and unloading machines. The reactor was, however, always available for experiments.

3.4.3 Availability of the Reactor

10% of the working time (or about 8 hours per week at two-shift operation) is needed for functional tests, maintenance and repairs, the remaining 90% of the time is available for experiments and their preparation.

3.4.4 Time Requirements for Experiments and Loading Changes

The time required for set up and performance of typical zero power experiments in SNEAK is as follows:

1.	Calibration of 10 control rods and 1 regulating rod, determination of shut down reactivity of the safety rods	0,5 days
2.	Pulsed experiments	2-3 days
3.	Fission rate ratios (6 materials at core center)	2 days
4.	Spectrum measurements over the energy range 1 kev to 1 mev with a set of proton recoil spectrometers at 1 core position	2 days
5.	Spectrum measurements with Li-6 spectrometer	1-2 days
6.	Spectrum measurements in the range <3 kev by foil activation	2 x0,5 days
7.	Material worth measurements with high precision, 15 materials at core center	1 day
8.	Reaction rate and material worth measurements along a radial traverse, 7 reaction rates and 7 materials	2 days
9.	Doppler measurements, hot versus cold sample with pile-oscillator	3 days
10.	Reproducibility in control rod position (1 rod)	1 hour
11.	Unloading and loading of one core element	25 min
12.	Loading of one core element with vertical experimental channel	1 hour

The experimental program with SNEAK-1 /1/ covered a period of 4 months. In this time new equipment had to be tested and new techniques had to be checked and compared.

The experiments on SNEAK-3A-1, including the loading of the core, the critical experiment, a complete program of physics measurements and numerous loading changes in the course of heterogeneity studies required 4.5 months.

R e f e r e n c e s:

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/2/ P. ENGELMANN et al.: Initial experiments in the Karlsruhe fast critical facility SNEAK, Proc. International Conference on Fast Critical Experiments and Their Analysis, ANL-7320 (1966) p. 759

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/6/ P. DOSCH, H.J. KRAUS, H. UHRIG: Design and experimental evaluation of an electromagnetic acceleration system for fast safety rods, Proc. of the Symposium on Physics and Material Problems of Reactor Control Rods held by the IAEA, Vienna Nov. 11. - 15., 1963, p. 571

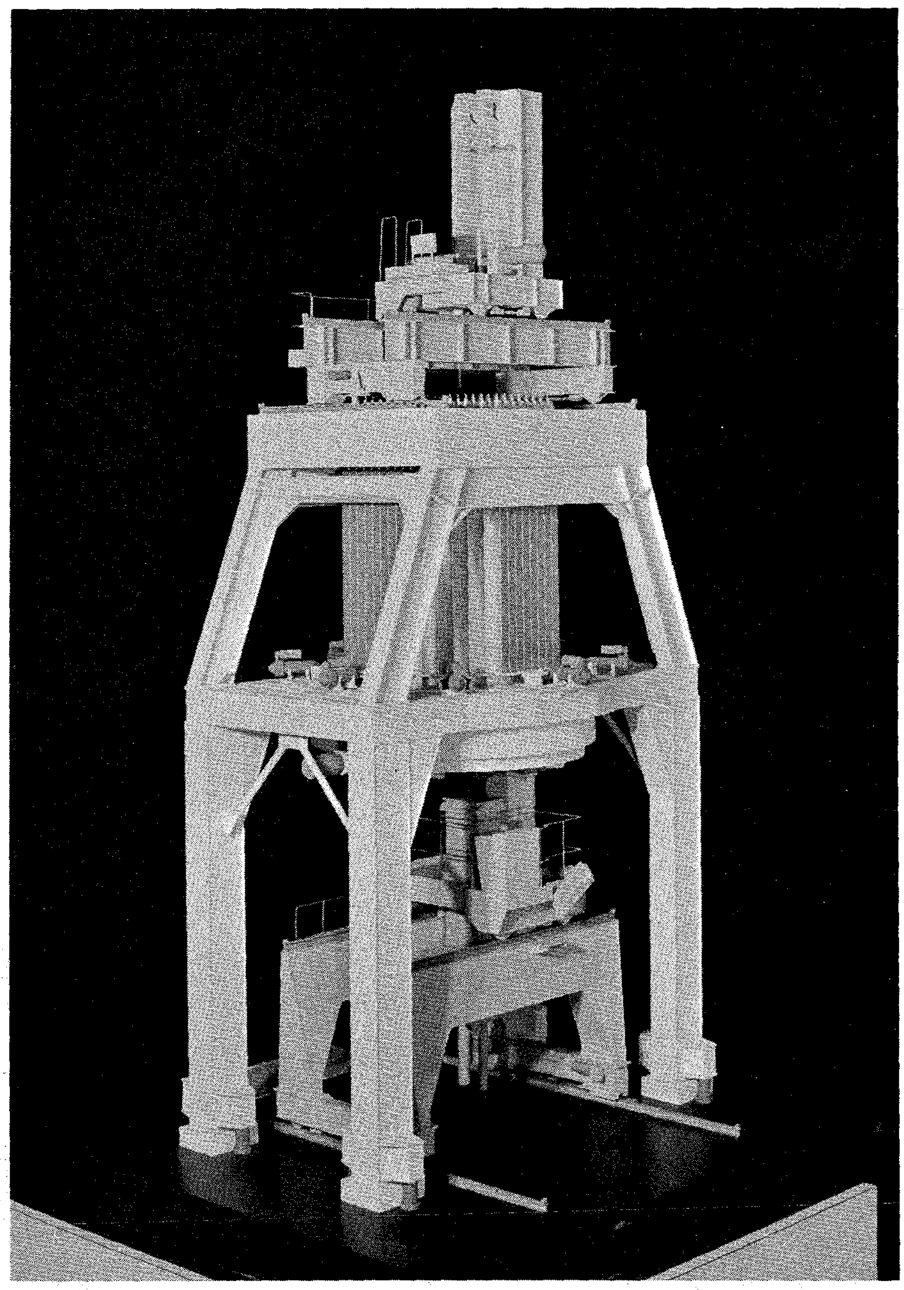


Fig. 1 Reactor, Support Frame, Upper- and Lower Loading Machines of SNEAK (model picture)

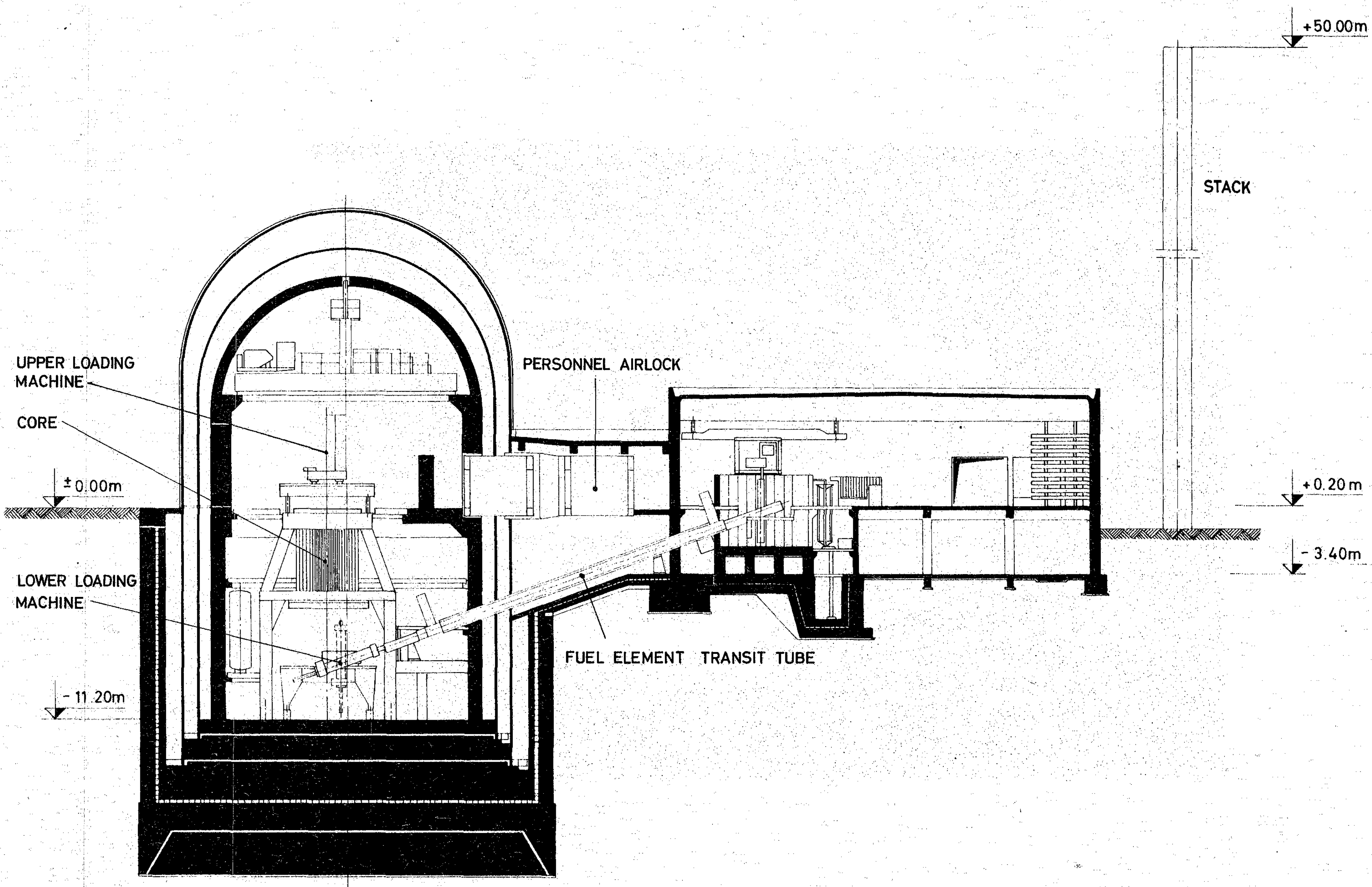
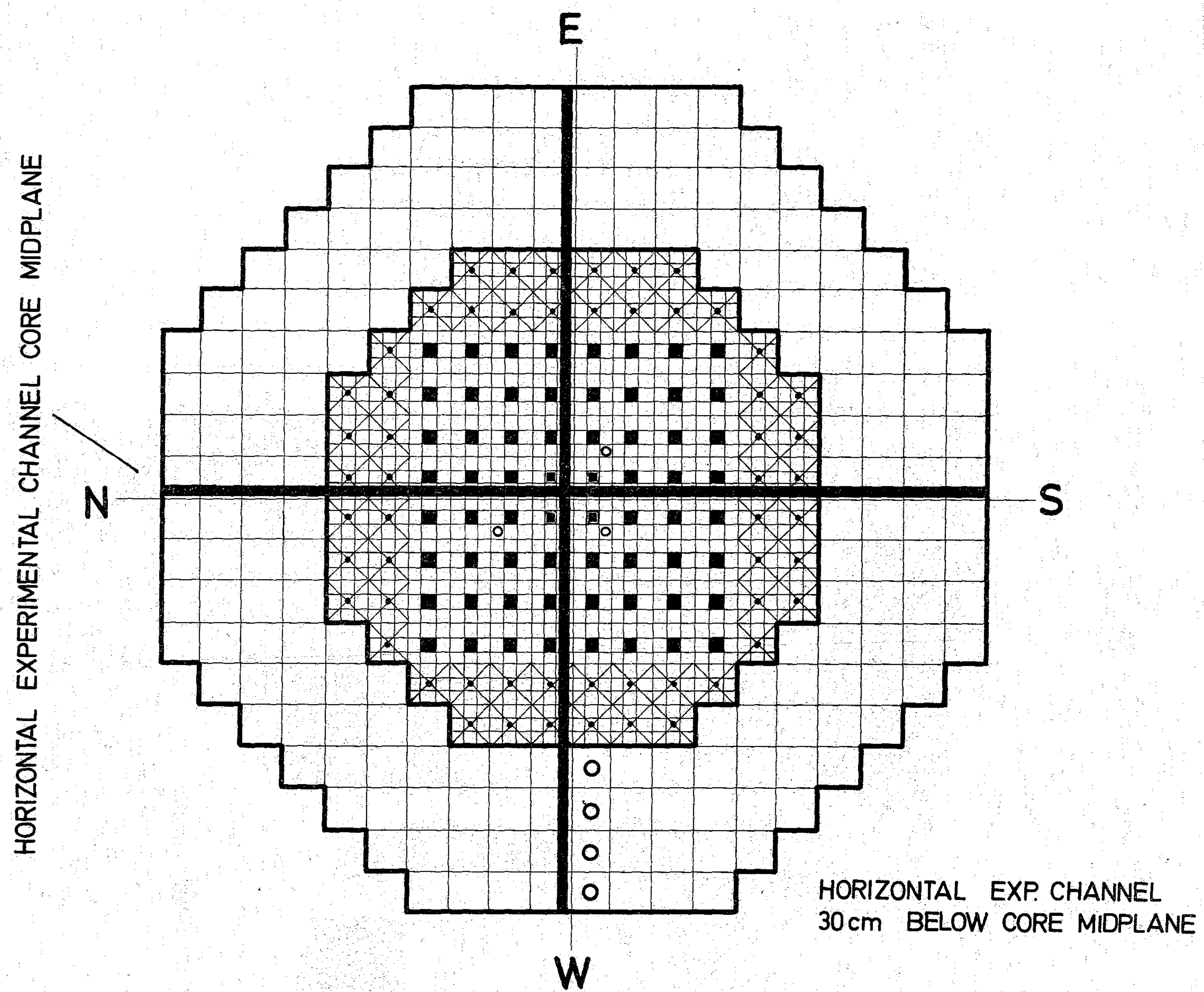


FIG. 2 SECTION THROUGH REACTOR BUILDING AND LOADING AREA



CORE SECTION		▣	■	□
PILE OSCILLATOR	▣	X		
SAFETY RODS	■		X	
SHIM RODS	■	X	X	
REGULATING ROD	■	X	X	
CORE ELEMENTS WITH VERT. EXP. CHANNELS	⊡	X	X	X
CORE ELEMENTS	□	X	X	X

BLANKET SECTION		⊡	□	⊠
BLANKET ELEMENTS WITH VERT. EXP. CHANNELS	⊡	X	X	X
BLANKET ELEMENTS	□	X	X	X
CORE - GROUP - ELEMENTS	⊠	X	X	X

FIG. 3 SNEAK LOADING PLAN

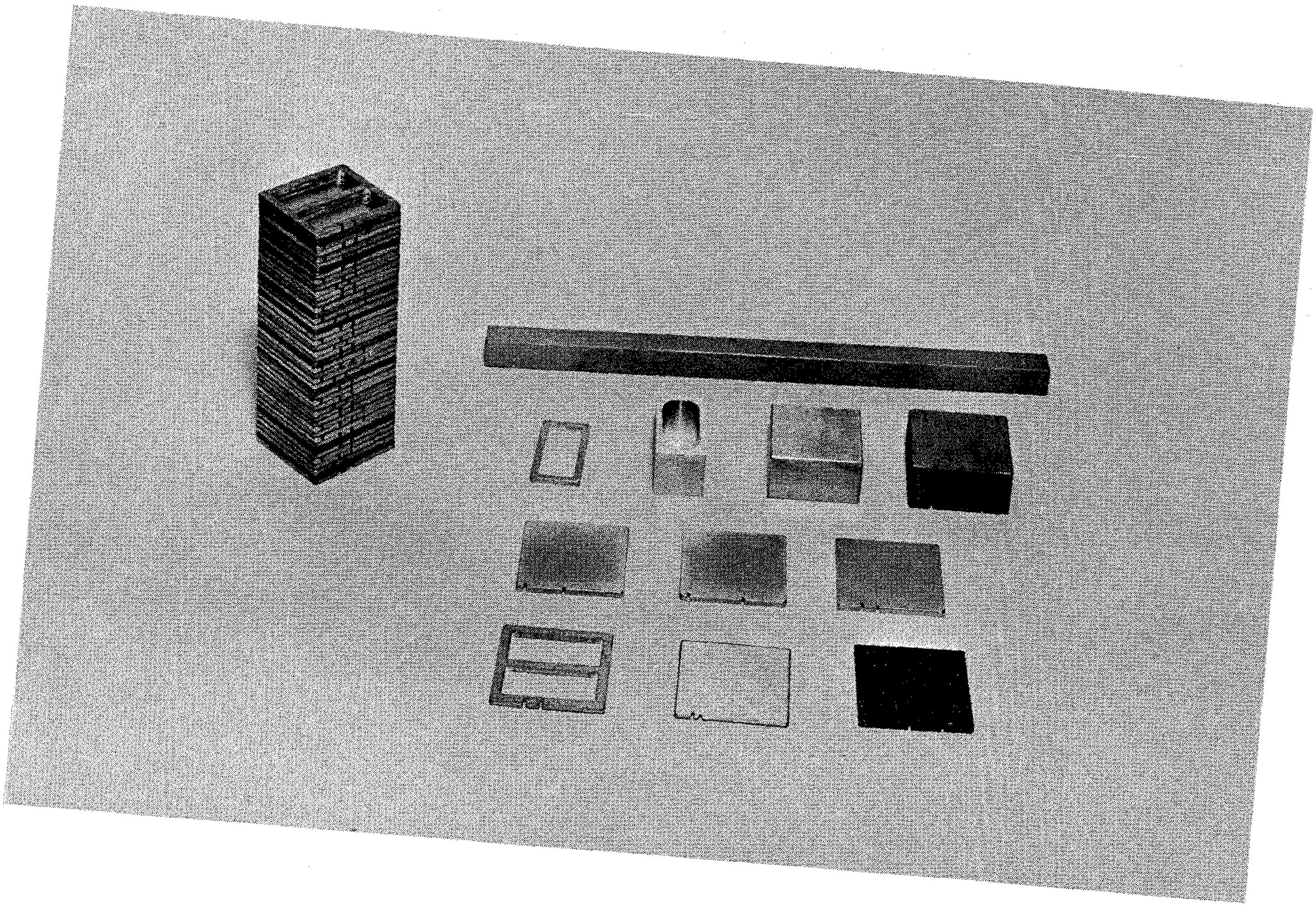


Fig. 4 Core and Blanket Material Pieces

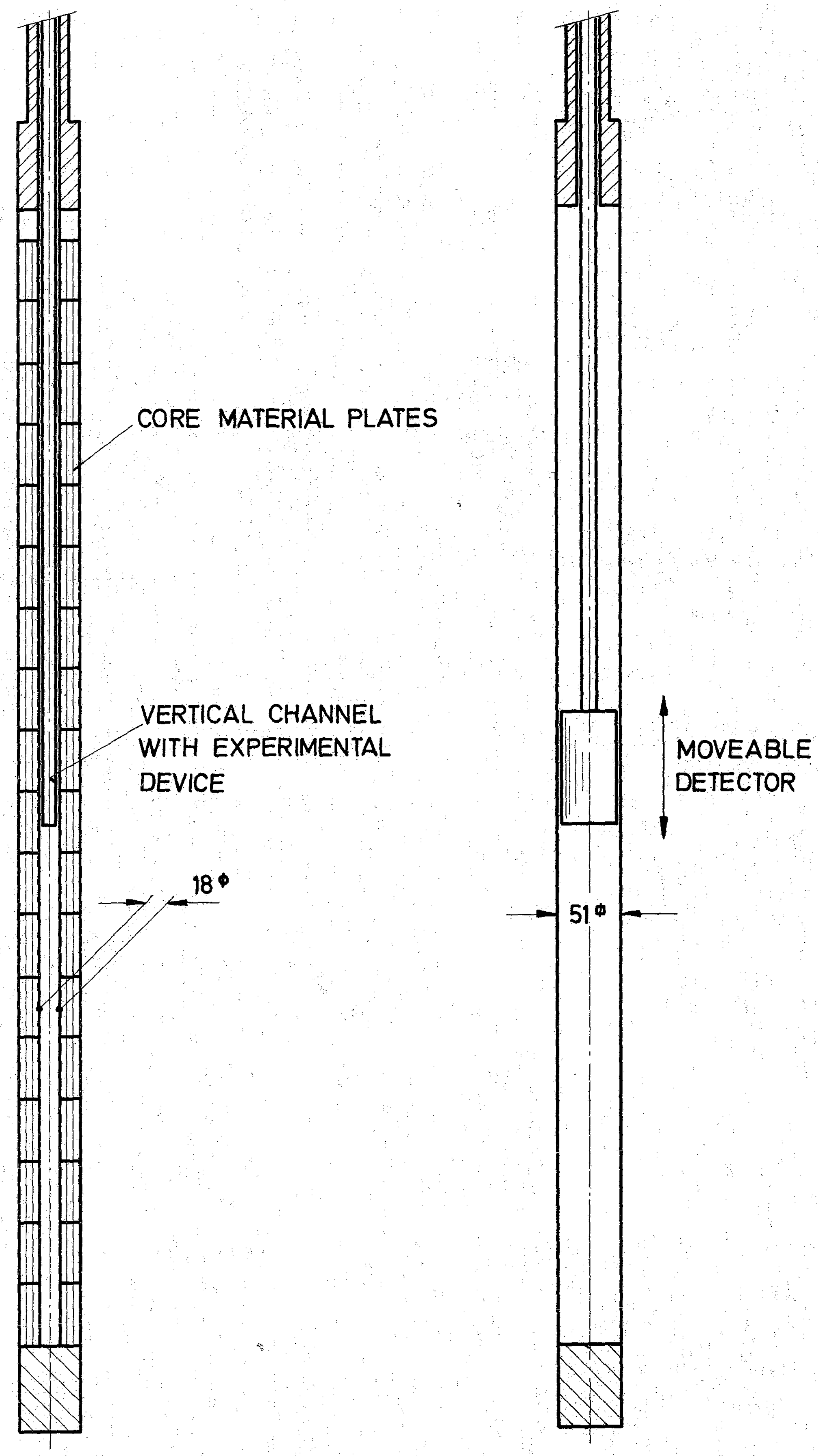


FIG. 5 CORE ELEMENTS WITH VERTICAL CHANNELS

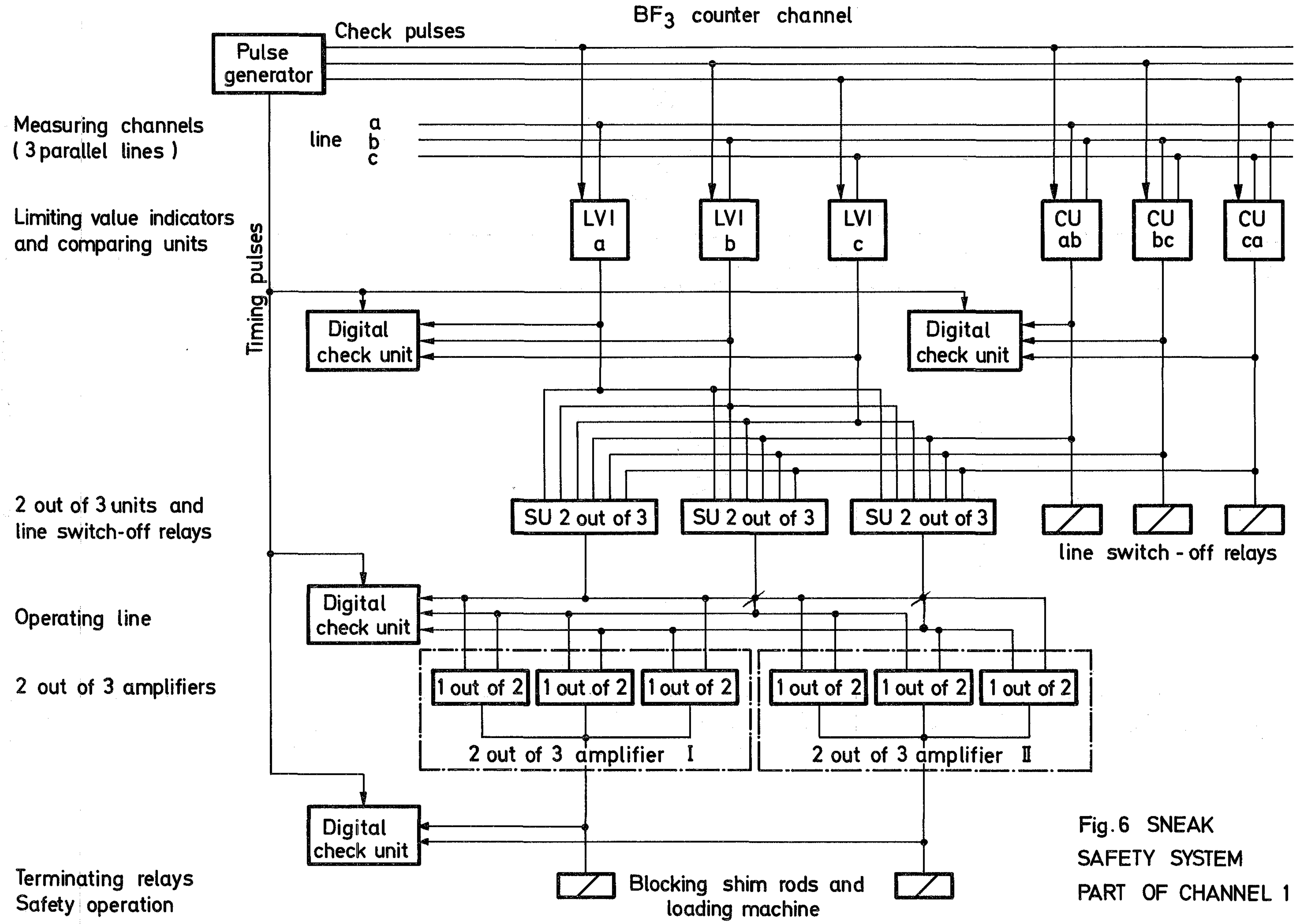


Fig. 6 SNEAK SAFETY SYSTEM PART OF CHANNEL 1

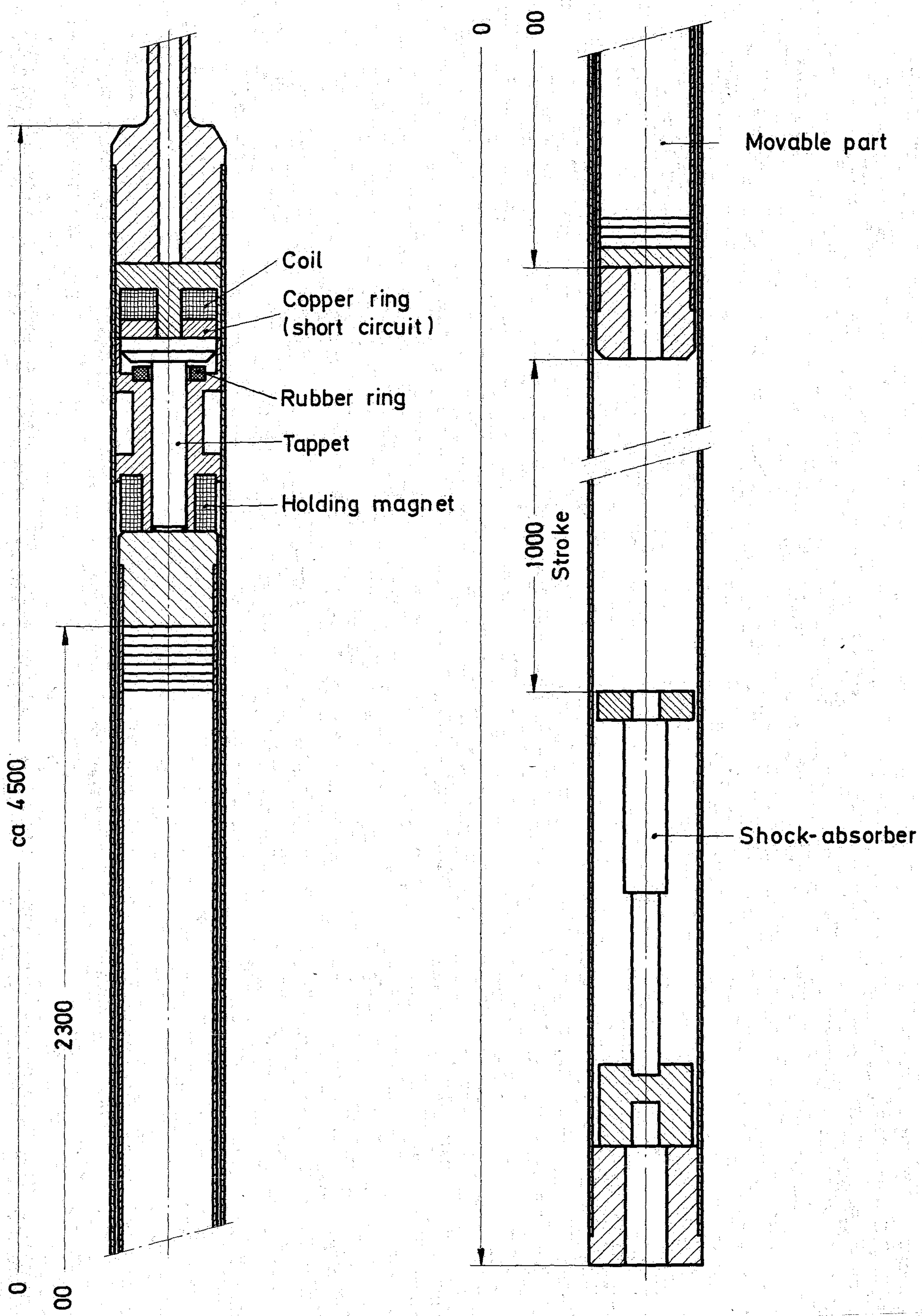


FIG. 7 SAFETY ROD

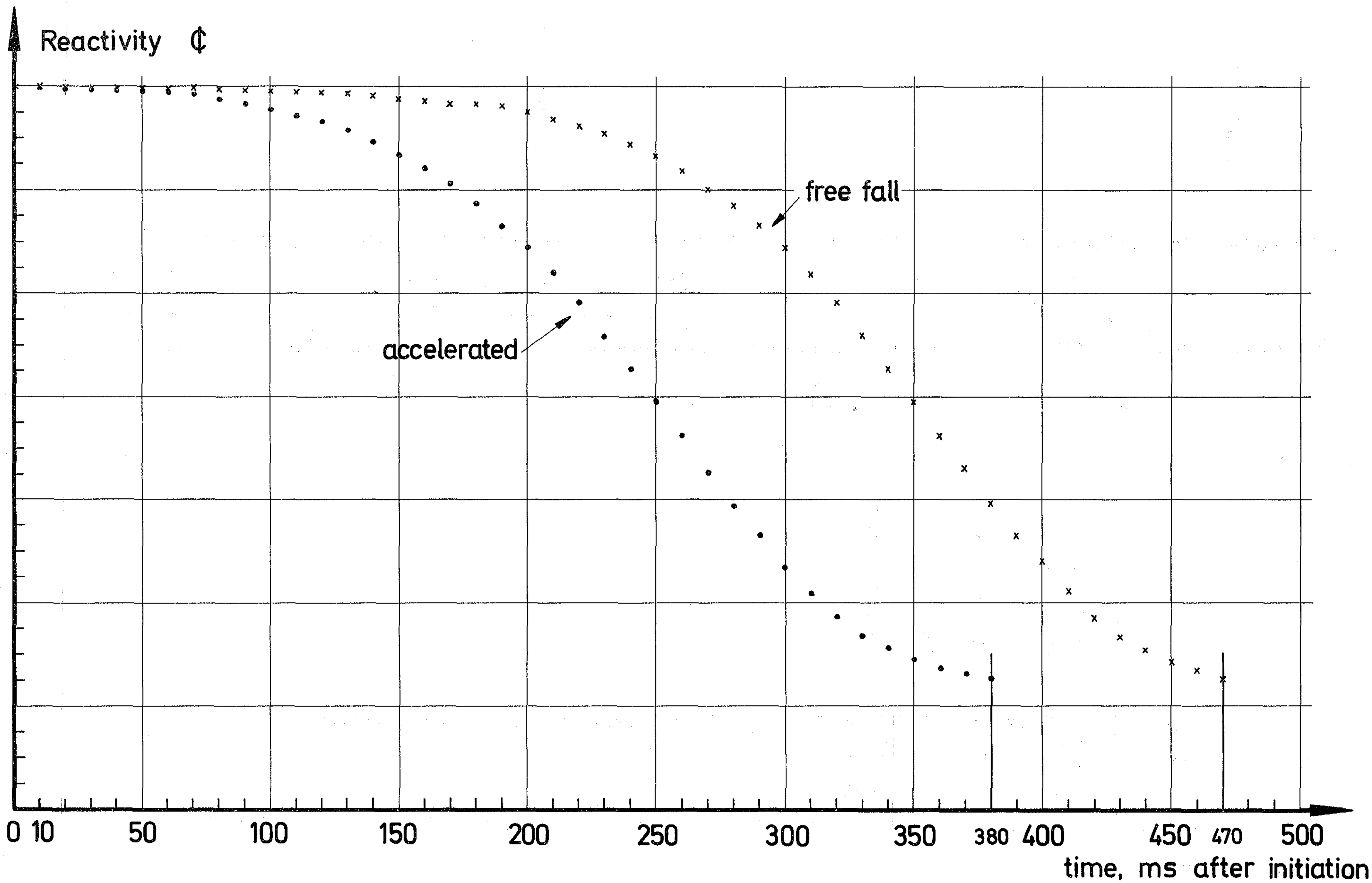


FIG. 8 REACTIVITY REDUCTION VS. TIME AT REMOVAL OF SAFETY ROD NO. 12, SNEAK 3A-1

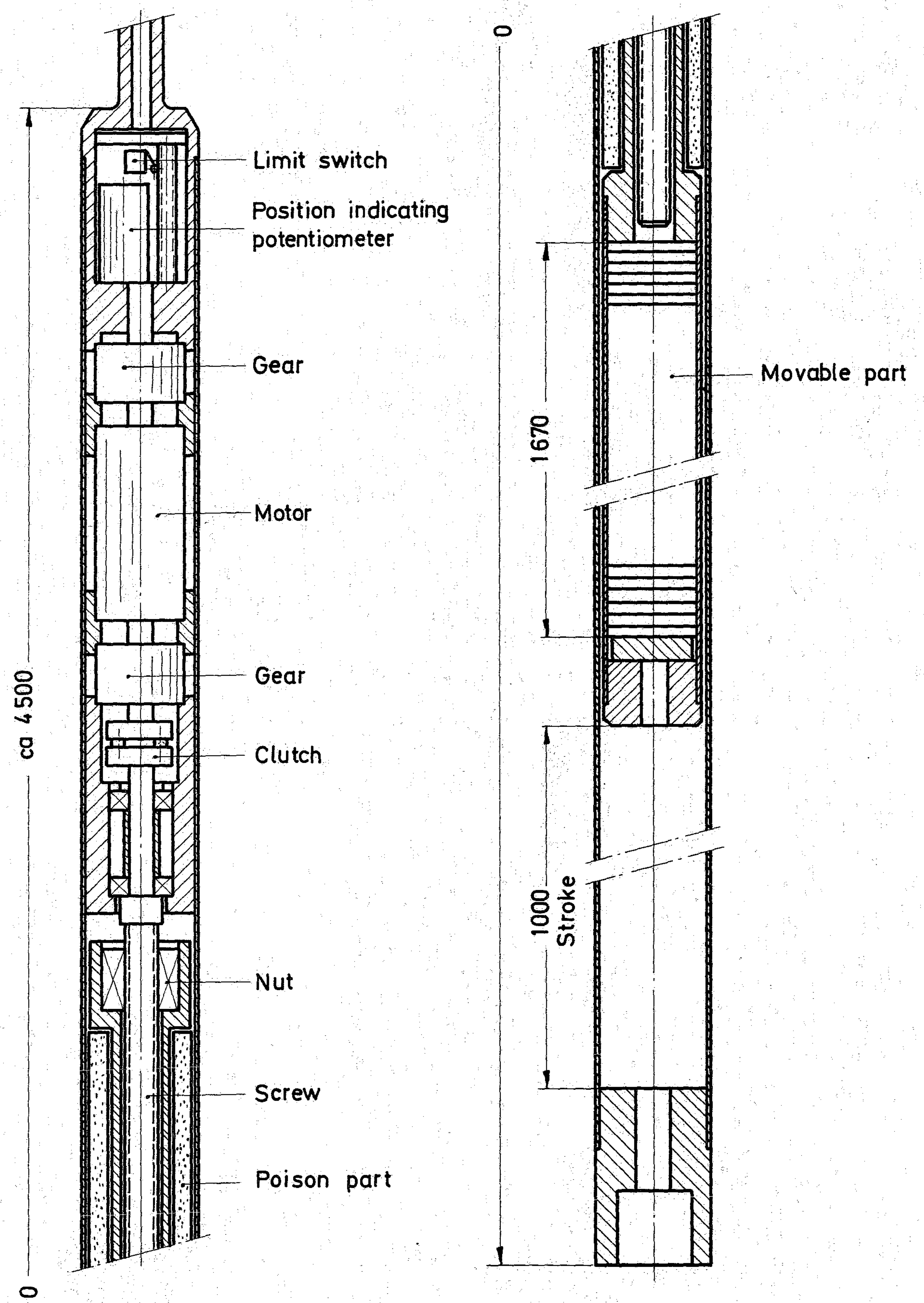
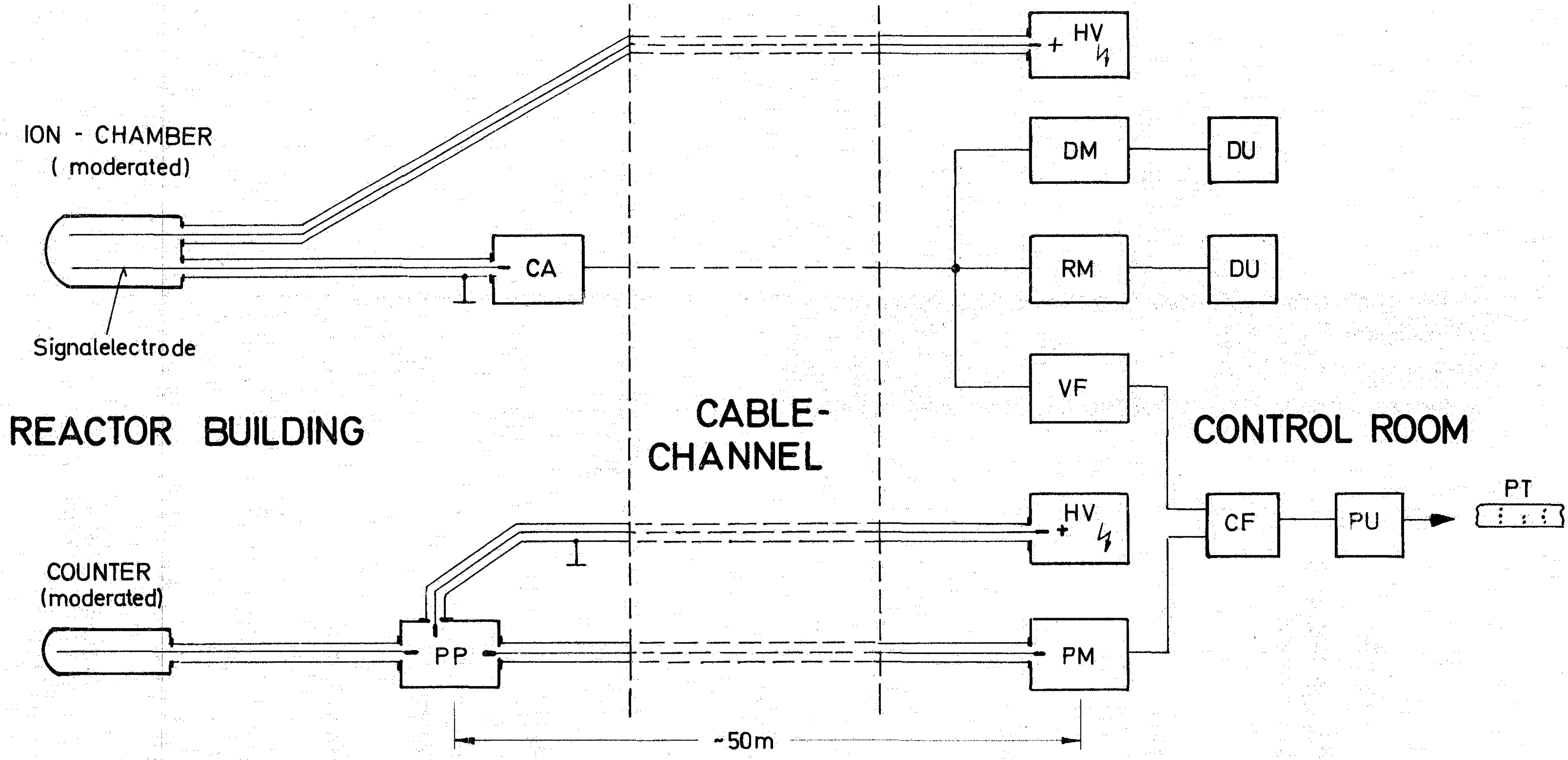


FIG. 9 SHIM ROD



CA = Current amplifier
DM = Deveation meter
RM = Reactivity meter
VF = Voltage to frequency converter
DU = Display unit
CF = Counting facility

PU = Punch unit
PT = Paper tape
PP = Pulse preamplefier
PM = Pulse mainamplifier
HV = High voltage supply

FIG. 10 LINEAR CHANNELS

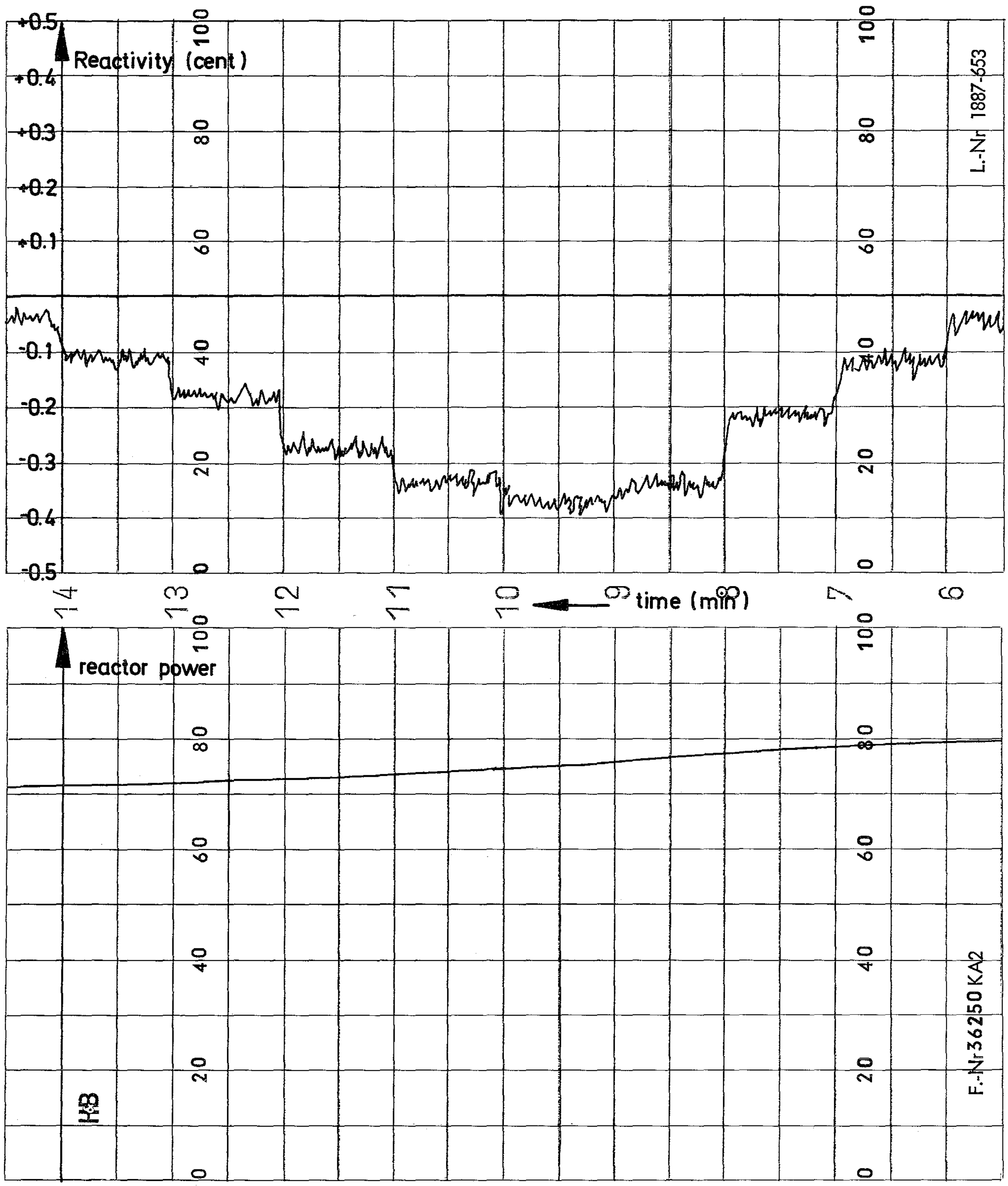


FIG. 11 REACTIVITY TRAVERSE OF AN AL - SAMPLE IN SNEAK - 1 AS CALCULATED BY THE REACTIVITY METER FROM THE TIME DEPENDENT REACTOR POWER