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Inhärent wirkendes Abschaltsystem mit Curiepunkt-gesteuerter Sensor/ Schaltereinheit

Zusammenfassung

Im Rahmen der Arbeiten zur Sicherheit Schneller Brutreaktoren wurde ein Konzept für ein inhärent wirkendes Abschaltsystem erstellt. Kernstück dieses Systems ist eine eigens dafür entwickelte Curiepunkt-gesteuerte Sensor/Schaltereinheit. Sie unterbricht bei einem unzulässigen Anstieg der Natriumtemperatur am Brennelementaustritt ohne Hilfe von außen die Stromzufuhr zur elektromagnetischen Absorberstab-Haltekupplung und löst dadurch das selbsttätige Abfallen des Absorbers in den Reaktor aus.

Die Schaltereinheiten können unabhängig von den Abschaltelementen direkt über den Köpfen ausgewählter Brennelemente angeordnet werden. Dadurch werden sehr kurze Ansprechzeiten erreicht.

An einer Vielzahl von Schaltereinheiten wurden bei hohen Temperaturen Langzeitversuche sowohl out-of-pile als auch in-pile durchgeführt. Die Ergebnisse zeigen, daß die Abschaltung in einem sehr eng begrenzten Temperaturbereich erfolgt. Die Testschalter waren bis zum Versuchsende voll funktionstüchtig.

Abstract

Within the framework of activities devoted to the safety of fast breeder reactors a concept has been elaborated for an inherently effective shutdown system. The key element of this system is a Curie point controlled sensor/switch unit. In case of an inadmissible rise in the sodium temperature at the fuel element outlet the unit interrupts without support from outside the current supply to the electromagnetic absorber rod holding coupling and thus releases automatically the drop of the absorber into the reactor.

It is possible to arrange the switch units, independent of the shutdown elements, directly above the heads of selected fuel elements, thus achieving very short response times.

Both out-of-pile and in-pile long-term experiments have been performed on a multitude of switch units at elevated temperatures. The results show that shutdown takes place within a very narrow range of temperatures. The test switches remained fully operative until the end of the experiment.

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1 Introduction

By definition, an inherently effective shutdown system shall ensure reactor shutdown also in cases when

- all reactor protective systems fail,
- severe mechanical damage has appeared in the reactor system.

Inherently safe shutdown can be achieved by a system installed in the reactor core zone and activated by an increase in the sodium outlet temperature which directly releases the movement of an absorber without support from outside.

Moreover, an inherently safe shutdown system shall meet a number of criteria, the most significant of which being:

- The system shall operate in a fail safe mode.
- The system shall be diverse with respect to the other shutdown systems.
- The response and shutdown intervals shall be sufficiently short to be able to manage specified accidents.
- All functions of the system shall be amenable to testing at any moment.
- The components shall be suited for long service lives (at least equal to the lifetimes of the fuel elements).
- They shall be protected against human error.

An inherently effective shutdown system for fast reactors has been developed at the Karlsruhe Nuclear Research Center [1]. The key element of this system is a Curie point controlled sensor/switch unit which automatically interrupts the exciting current of a shutdown element holding coupling in case of inadmissible rise in the reactor coolant temperature. Work performed largely concerned the design and the demonstration of the performance of the switch unit. It is assumed that shutdown proper is effected by means of an articulated absorber rod unit with a large play placed in a reinforced duct tube.

2 Function and Layout of the Overall System

The system proposed consists of two parts, the absorber rod unit and a Curie point controlled sensor/switch unit (Figure 1). Similar to the concept chosen for Superphénix [2], the absorber rod unit could e. g. consist of several rod bundles interconnected through joints. It is so flexible that even in case of maximum deformation of the duct it glides into the core zone. The absorber unit is connected with the suspension system by means of an electromagnetic coupling. The joint face of the coupling in the withdrawn position lies at the upper edge level of the absorber element duct in the primary sodium. Thus, the function of the coupling is not even affected when the absorber rod suspension system gets damaged.

The sensor/switch unit is to be placed above the core in such a manner that it is directly exposed to sodium flowing out from a selected fuel element. Upon an increase in the sodium temperature at the core outlet shutdown is released by interruption of the current supply to the electromagnetic absorber rod coupling by means of the self-acting sensor/switch unit. Unlike concepts with the temperature sensitive element being a component of the coupling, this concept offers the advantage that until activation of the switching operation a much smaller mass of material has to be heated. This ensures the quickest possible response. Moreover, the electromagnetic coupling can be made of a material with a higher Curie temperature. Thus, it constitutes - independent of the prevailing operating condition - an almost constant holding force.

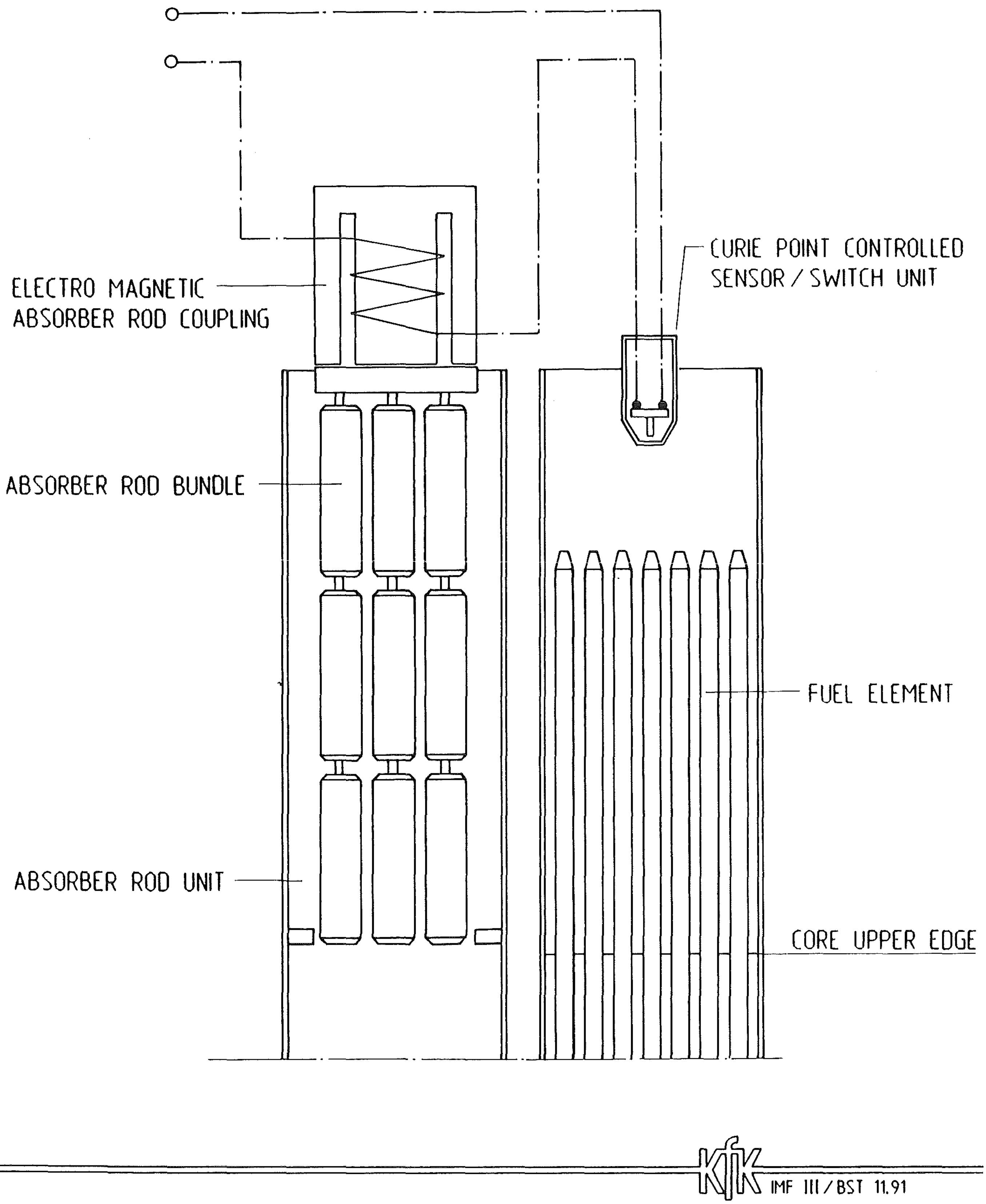

Fig. 1 : Temperature-sensitive, inherent reactor shutdown system

3 Curie Point Controlled Sensor/Switch Unit

3.1 Description

Figure 2 shows the Curie point controlled sensor/switch unit. Permanent magnets together with the magnetically soft iron yoke, the sensor element and switching weight make up a closed magnetic circuit. The switching weight is electrically insulated from the housing and in the pulled up condition it bridges the electric contacts through which the holding current of the absorber rod coupling flows. Being part of the switch housing, the sensor element is directly surrounded by the flow of reactor sodium and provided with external fins to improve heat transfer. The material used for the sensor element is a binary nickel alloy whose Curie point is at 600 °C. When the sodium temperature reaches this limit, the magnetic flux passing through the switching weight is interrupted. Most of it then flows through an appropriately sized shunt. Consequently, the switching weight drops and interrupts the current supply of the magnetic coupling which causes the absorber bundle to drop with very little delay.

An auxiliary coil installed in addition causes a secondary magnetic circuit to build up, if necessary. Its direction can be set either equidirectional with or reverse to the permanent magnetic flux by reversal of the coil polarity. If it is equidirectional with the permanent magnetic flux, the latter is intensified to the extent that the dropped switching weight is lifted again. On the other hand, by reversal of the coil polarity the switching weight can be dropped and hence the function of the shutdown device tested.

The danger of malfunction of the coil during steady-state operation is precluded by a simple safety circuit (Figure 3). The coil is supplied its load current from a capacitor with preceding resistor. Therefore, the coil can be passed in both directions by short current impulses only or, in case of malfunction, by a neglegible low steady state current.

The switch unit is 38 mm in outside diameter, 208 mm in total length and filled with helium to ensure thermal conductivity. The electric lines connecting it with the switching contacts and the auxiliary coil are routed so as to leave the switch on top.

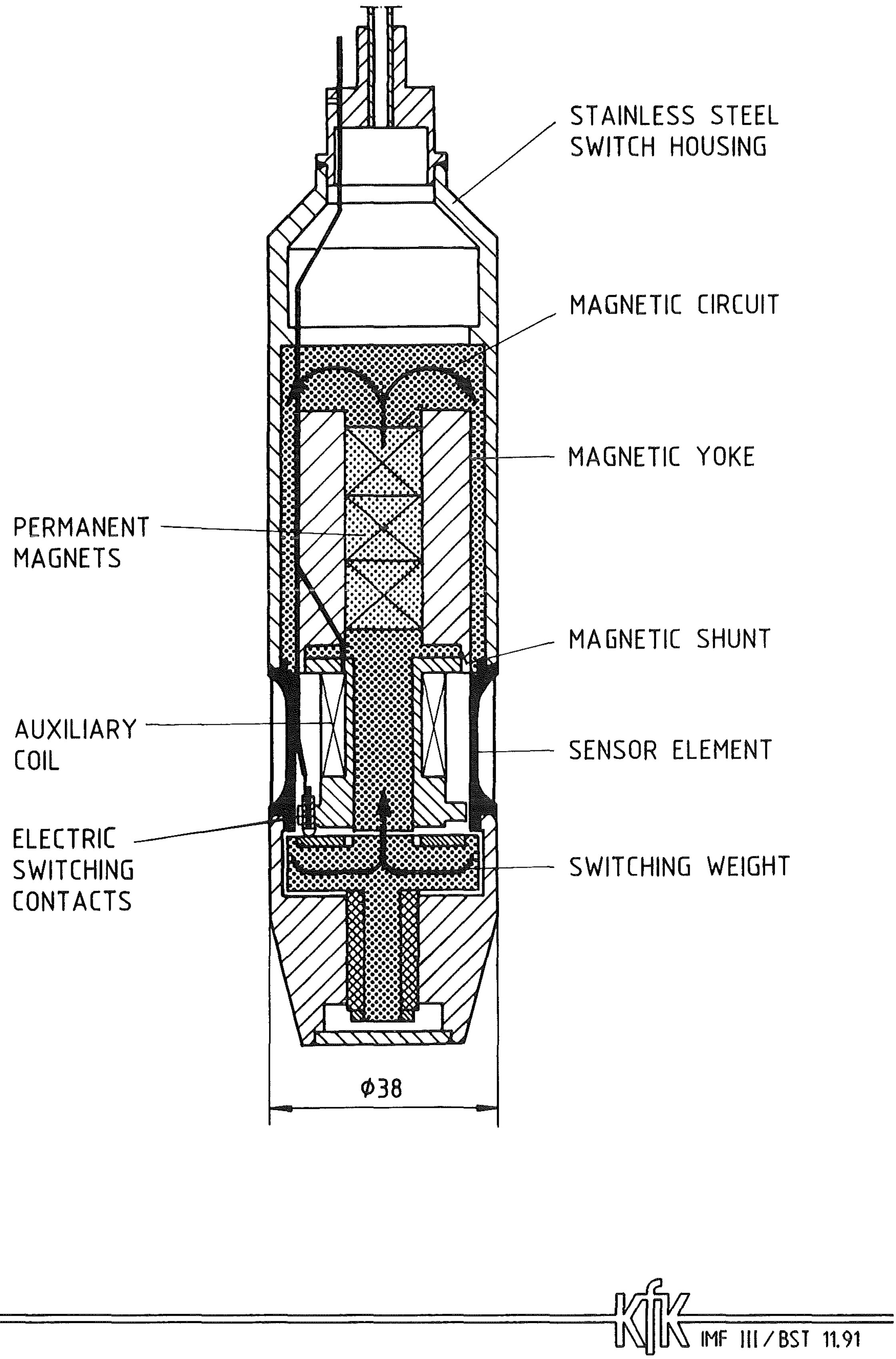

Fig. 2 : Curie point controlled sensor/switch unit

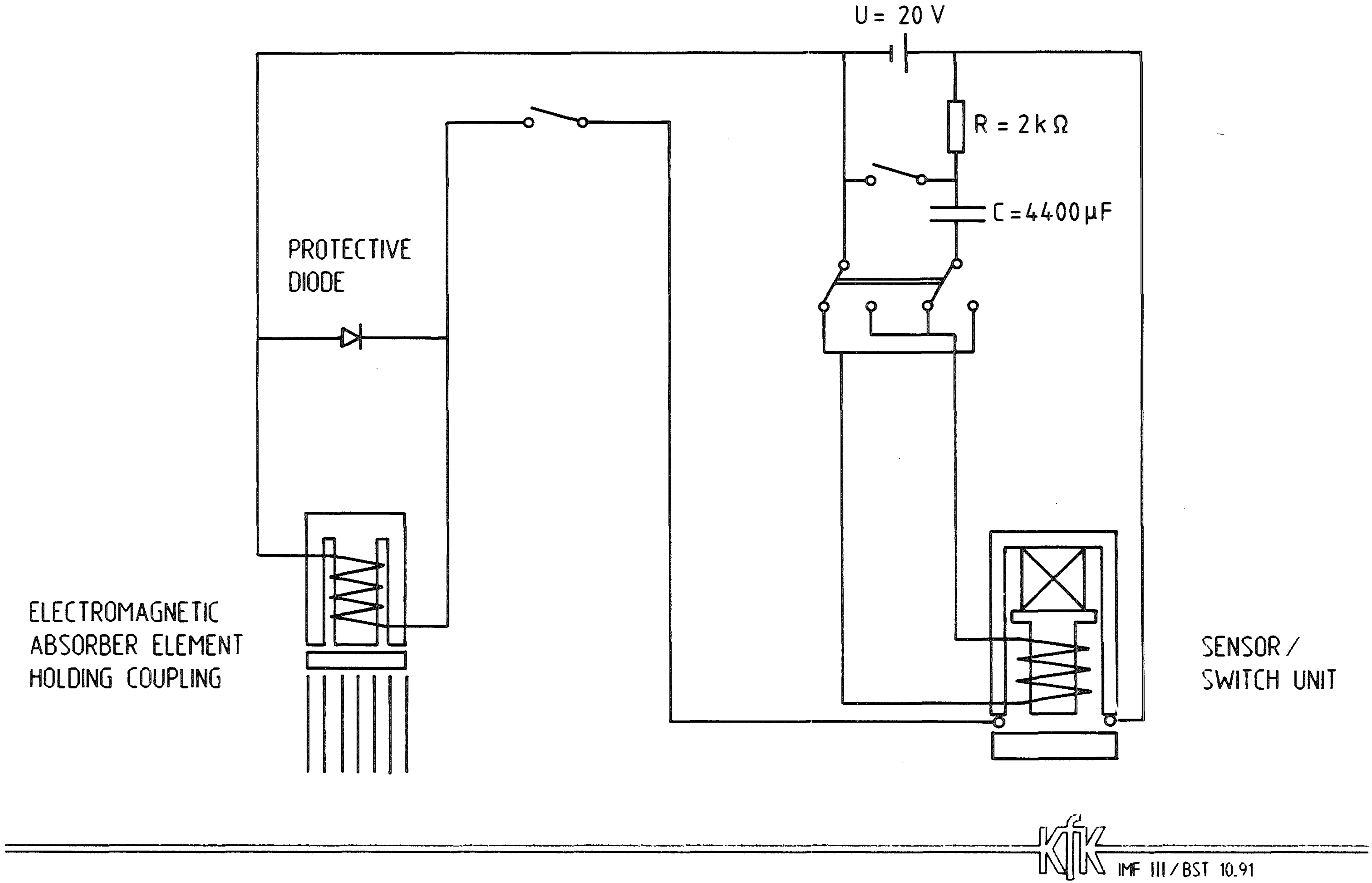

Fig. 3 : Electric circuit of the shutdown system

3.2 Magnetic Circuit Materials

In designing the magnetic circuit of the Curie point controlled sensor/switch [3] for use at elevated temperatures and in the radiation field of the reactor the choice of the magnetic circuit materials was of particular importance. These materials must be stable in their structure, keep their dimensional stability and, as to the sensor, be tolerant with respect to sodium.

Characteristic magnetic properties of the magnetic circuit components are the flux density and the permeability. The Curie temperature is of particular interest.

The material selected for the components of the magnetic yoke and the switching weight is low carbon iron and for the sensor element the iron-nickel alloy already mentioned. Their most significant magnetic data related to room temperature are:

	Armco Iron	65 Ni35 Fe
Saturation flux density	2.15 $V{\cdot}s/m^2$	1.35 $V{\cdot}s/m^2$
Initial permeability	min. 200 μ_o	min. 1200 μo
Maximum permeability	min. 3500 μ_o	
Curie temperature	1043 K (770 °C)	873 K (600 °C)

While these materials are irradiated, the properties depending on the structure, especially the permeability, may be influenced by the interferences and defects in the crystal lattice. However, no change in Curie point must be anticipated. The function of the switching unit essentially requires some constancy of the saturation flux density in the sensor material, while actually no use is made of high values of permeability.

Among the normally used permanent magnetic materials only the AlNiCo magnets are eligible for use at temperatures above 400 °C. AlNiCo 450 with the following chemical composition was selected:

Al	7 %	Cu	4 %
Ni	15 %	Ti	5 %
Co	32 %	Fe	37 %

The material has a high cobalt content and accordingly a high Curie temperature of about 1133 K (860 °C).

The long-term stability of the permanent magnet material at elevated temperatures commands special interest. Comprehensive experiments were performed at KfK within the framework of sodium flowmeter development [4]. These experiments were carried out at temperatures of 550, 575, 600 and 650 °C on AlNiCo magnets having the dimensions entered in Figure 4.

It is evident from the measured results (Figure 4) that within the range of temperatures up to 600 °C the magnetic properties of AlNiCo 450 remain rather constant for a given period and start to drop quickly thereafter.

On the other hand, the long-term behavior of the permanent magnets of the switch units is better because the geometry of the magnet (great ratio of length to diameter) and its arrangement in the nearly closed magnetic circuit are particularly favorable.

Long-term tests with this magnetic circuit configuration have shown that the permanent magnet material is still stable in its structure at 560 °C, i. e. the future temperature in steady-state operation, and that service lives of several years can be anticipated until the magnetic flux will noticeably diminish. This applies above all if it will previously be subjected to short-term aging at elevated temperature.

An influence of irradiation on the magnetic properties can be ruled out. This has been shown by in-pile experiments performed within the framework of development work on sodium flowmeters in the BR2 reactor, Mol, Belgium, with the permanent magnet material exposed to fast neutron doses up to 4×10^{21} cm^{-2}.

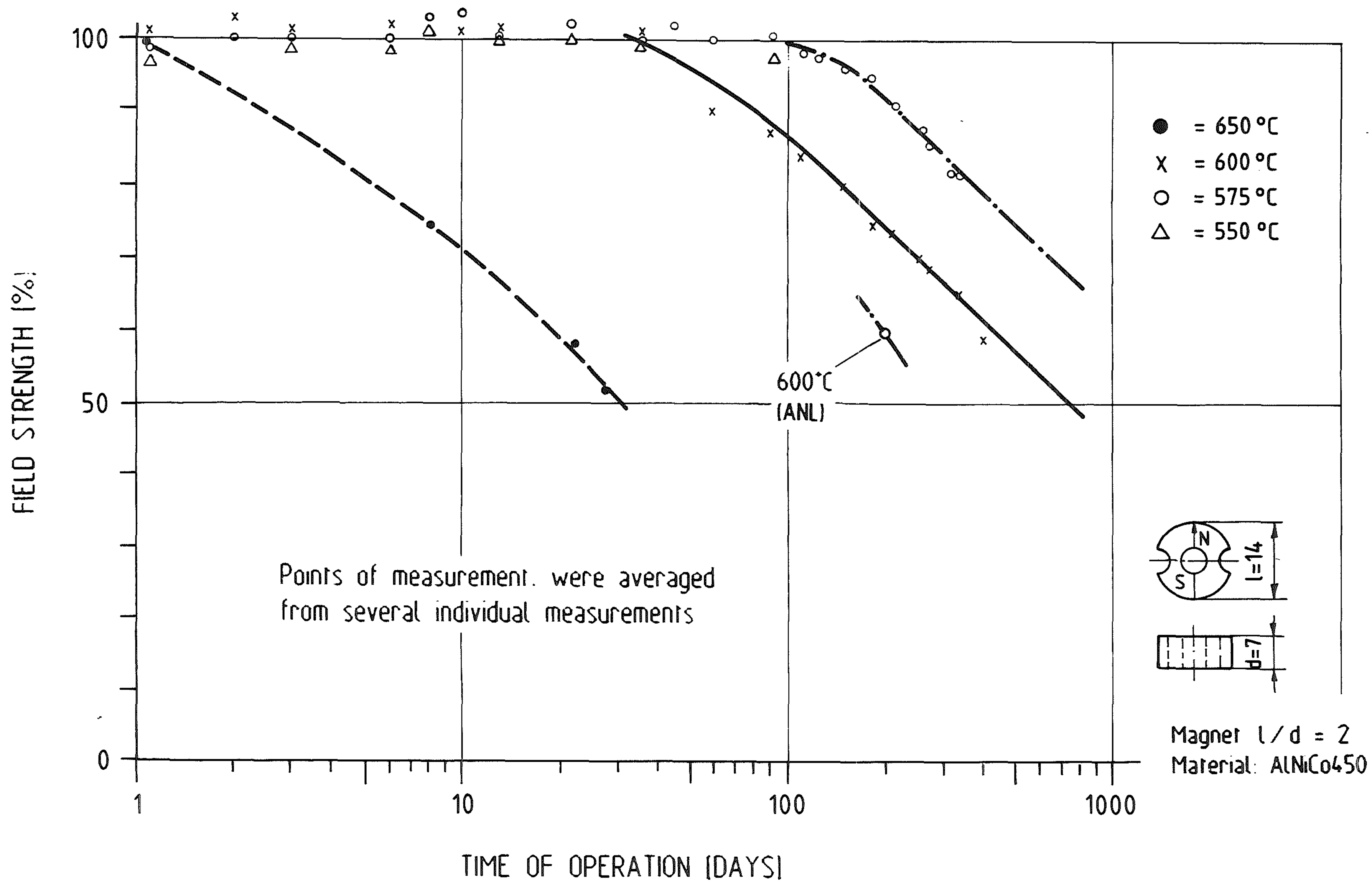

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Fig. 4 : Permanent magnet material subjected to thermal testing [4]

3.3 Shutdown Point

Figure 5 shows the magnetic circuit of the switch unit. Under the normal condition of operation, i.e. with the switch closed (left-hand side), the magnetic flux passes the external yoke made of Armco iron, the sensor made of FeNi, the switching weight separated by gas gaps, and the central part of the yoke. In parallel, a fraction of the flux θ_s is directed via a shunt. By this configuration of the magnetic circuit the leakage flux running through the switching weight and hence the undesired retention force are reduced as far as possible at the moment of shutdown (right-hand side).

These are the assumptions underlying this configuration:

• surface of the central gas gap	$A_i = 0.79 \times 10^{-4}\ m^2$
• surface of the external gas gap (cross-section of the sensor)	$A_a = 1.44 \times 10^{-4}\ m^2$
• thickness of the sensor wall	$S = 1.5$ mm
• width of the gas gap	$L_i = L_a = 0.3$ mm
• mass of the switching weight	$F_G = 70$ g

The following requirements are made with respect to the sensor design in order to guarantee the exact sequence of the shutdown function:

- The response time shall be as short as possible which means that the wall thickness of the sensor element must be small.
- On the other hand, the magnetic flux density in the sensor shall be low as compared with the saturation flux density.
  However, as will be shown later, this is important for attaining a precisely defined shutdown temperature.

Besides, the dimensions of the components of the magnetic circuit, the widths of the gaps between the magnetic yoke and the switching weight, and the mass of the switching weight must not be too small in order to keep as little as possible the influence of the tolerances in the process of manufacture and with respect to the magnetic material data.

The operating point and the shutdown point of the sensor were determined taking into account the geometry of the magnetic circuit and the specified temperatures and forces. The result has been represented in Figure 6.

The absolute values of the saturation flux density have been plotted versus the temperature for the sensor material. The saturation flux density at the absolute zero is B_{sat_0} = 1.45 V·s·m-2. When the operating temperature T_B of 560 °C is reached, it has dropped to B_{sat} = 0.5 V·s·m-2. The actual flux density in the sensor which can be determined from the chosen magnetic circuit configuration is only 0.13 V·s·m-2 and hence only about 26% of the saturation flux density.

Until dropping of the switching weight, the magnetic holding force must diminish to approximately the value of the weight force of the switching weight. Then the flux density in the sensor is reduced to 0.09 V·s·m-2. This means that the operating and shutdown points of the sensor are fixed. It is evident from the lower section of the figure that in case of a temperature rise beyond the operating temperature the magnetic flux and hence the holding force are fully maintained until the Curie temperature is almost reached. The magnetic flux decreases until shutdown within a temperature interval of about 4 K. This means that the switch is insensitive to minor temperature variations, but that shutdown takes place at a precisely defined temperature level.

The shunt gap and the magnet sizes have been dimensioned in such a manner that at the operating temperature 70% of the magnetic flux passes through the shunt and 30% through the pulled up switching weight. Figure 7 shows the forces acting on the switching weight in normal operation and at the moment of switching. The magnetic force, which is 1.4 N in steady-state operation, is reduced to 0.3 N when the point of shutdown is reached which, in any case, causes the switching weight to drop. The gap formed in this way between the switching weight and the sensor is so large that also if the Curie temperature is underrun (< 600 °C) the leakage flux is not sufficient to lift the switching weight and to build up a bridge to the contacts. This is done, as already reported, by means of the auxiliary coil whose magnetic field is made equidirectional with the field of the permanent magnet by appropriate pole reversal and, consequently, intensifies the magnet force sufficiently.

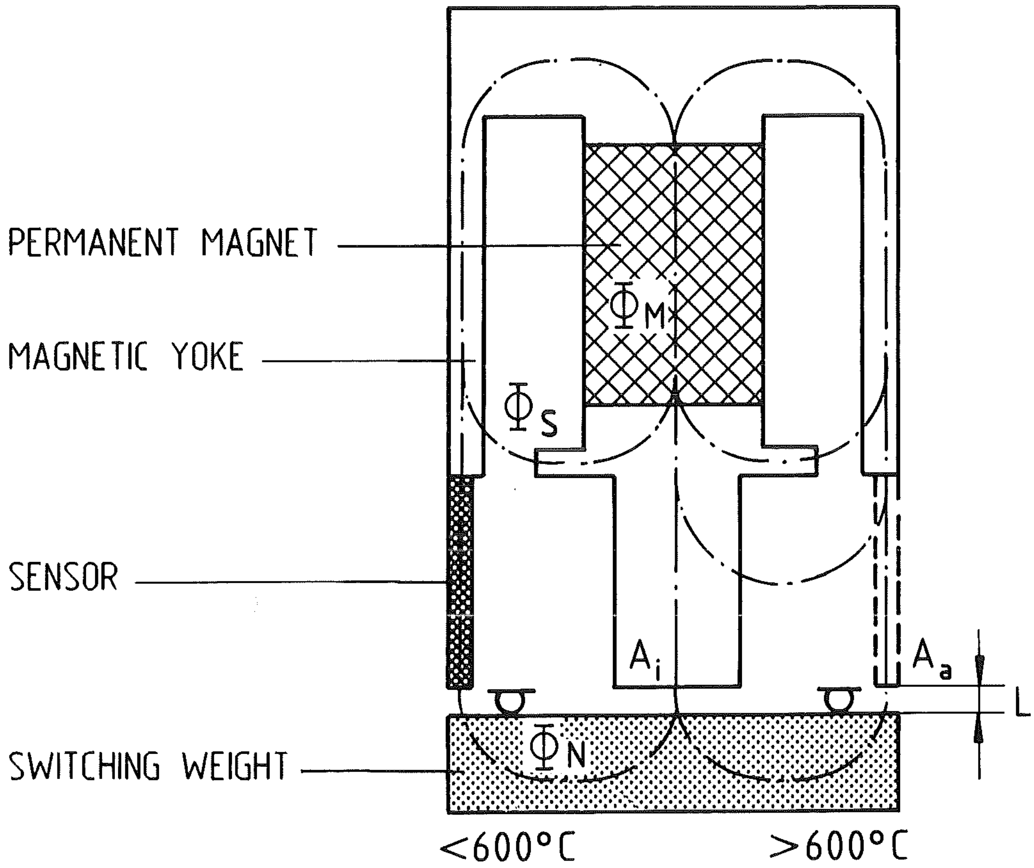

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Fig. 5 : Schematic representation of the magnetic circuit

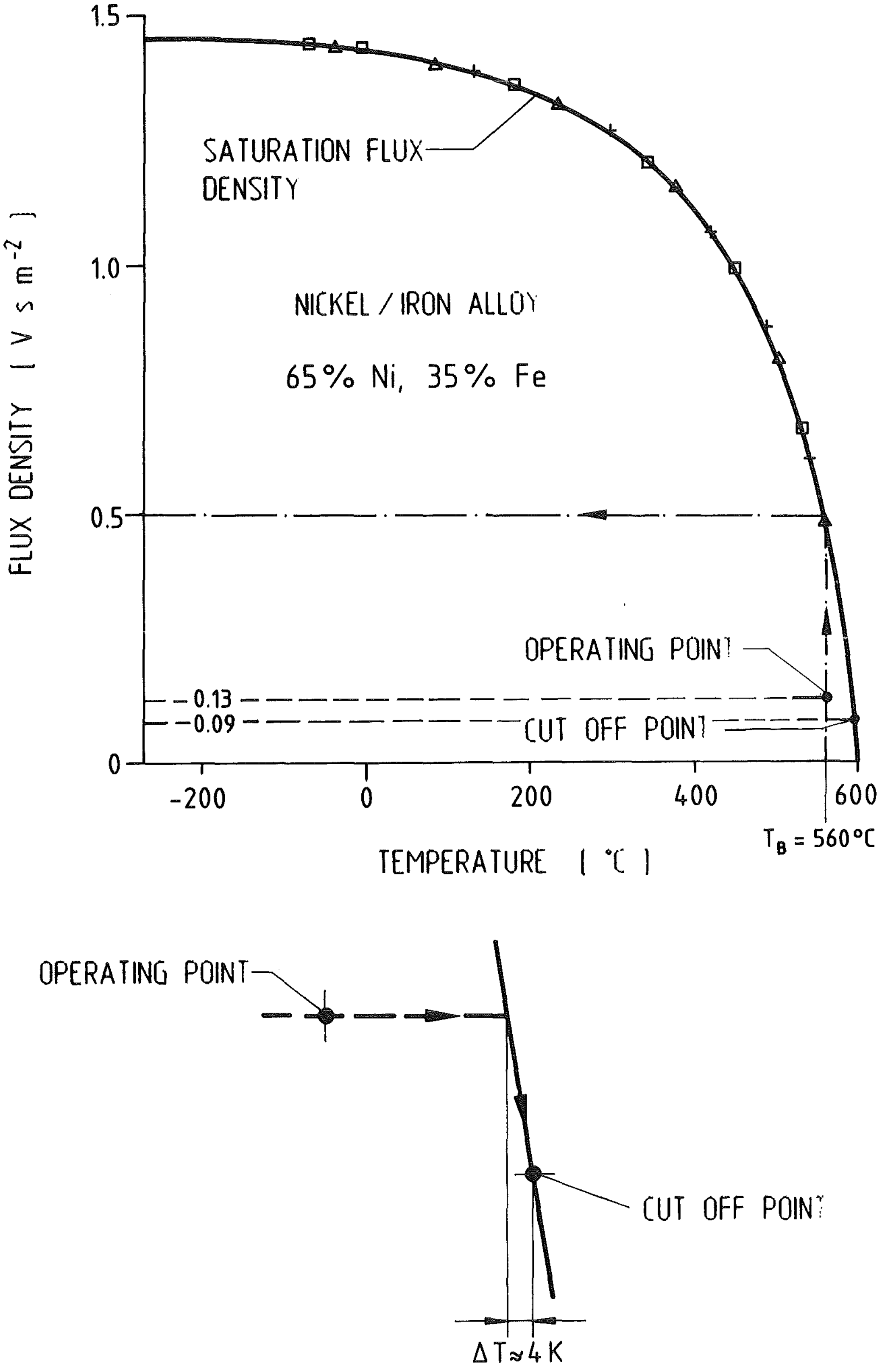

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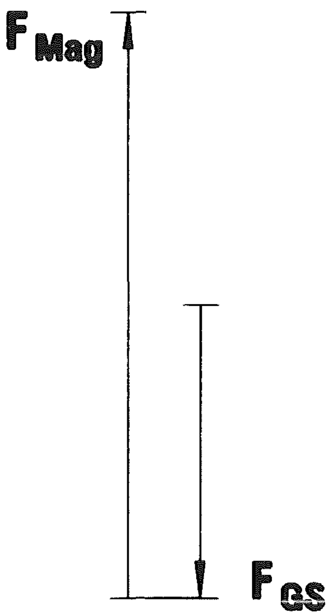
Fig. 6 : Sensor element design

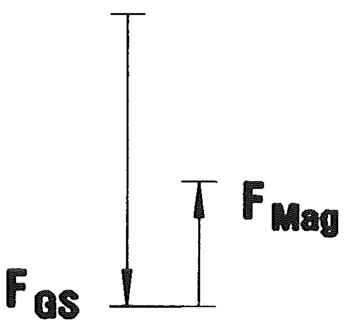
1. NORMAL OPERATION



MAGNETIC FORCE F_{Mag} = 1.4 N

WEIGHT FORCE OF SWITCHING WEIGHT F_{GS} = 0.7 N

2. MOMENT OF SWITCHING



MAGNETIC FORCE F_{Mag} = 0.3 N

WEIGHT FORCE OF SWITCHING WEIGHT F_{GS} = 0.7 N

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Fig. 7 : Forces acting in the switch unit

3.4 Response Time

The response time of the Curie point controlled sensor/switch unit, which is a part of an inherently effective shutdown system, is of particular importance in evaluating this unit. The response time is the interval between attainment of an inadmissibly high sodium temperature at the core outlet until drop of the absorber rod bundle.

This interval is determined in two steps. First, the delay in switching upon interruption of the holding current of the coupling was determined in an experiment for a potential absorber rod unit. Second, the transient temperature developments for the switch unit were calculated for a defined accident. The considerations started from requirements derived at the time from the SNR 2 design conditions.

Delay in Switching of the Absorber Rod Unit

The experiments were performed on a mockup of a coupling whose design data were compatible with those of an absorber rod holding coupling of SNR 2.

•	number of coil turns	920
•	mass of the absorber rod assembly	approx. 40 kg
•	maximum magnetic holding force	2000 N
•	coil current	0.2 A

First, measurements of the holding force were made on the mockup of a coupling. The results have been represented in Figure 8 which shows the holding force of the coupling as a function of the coil current.

Considering that the joint faces of the coupling might become polluted, the gap between the coupling and the mobile yoke was varied in the experiments. It appeared that this greatly influences the magnetic force.

Experiments were performed with the mockup of the coupling and the circuit represented in Figure 3 in order to measure the delay in switching. After opening the current switch the current is pushed forward by the self-induced e.m.f. until the magnetic energy of the coil is consumed.

Figure 9 shows the current curve and the resulting holding force under the rated conditions mentioned before. It appears that the holding force diminishes within 0.45 s from approximately 2000 N to 400 N, the force corresponding to the absorber rod weight.

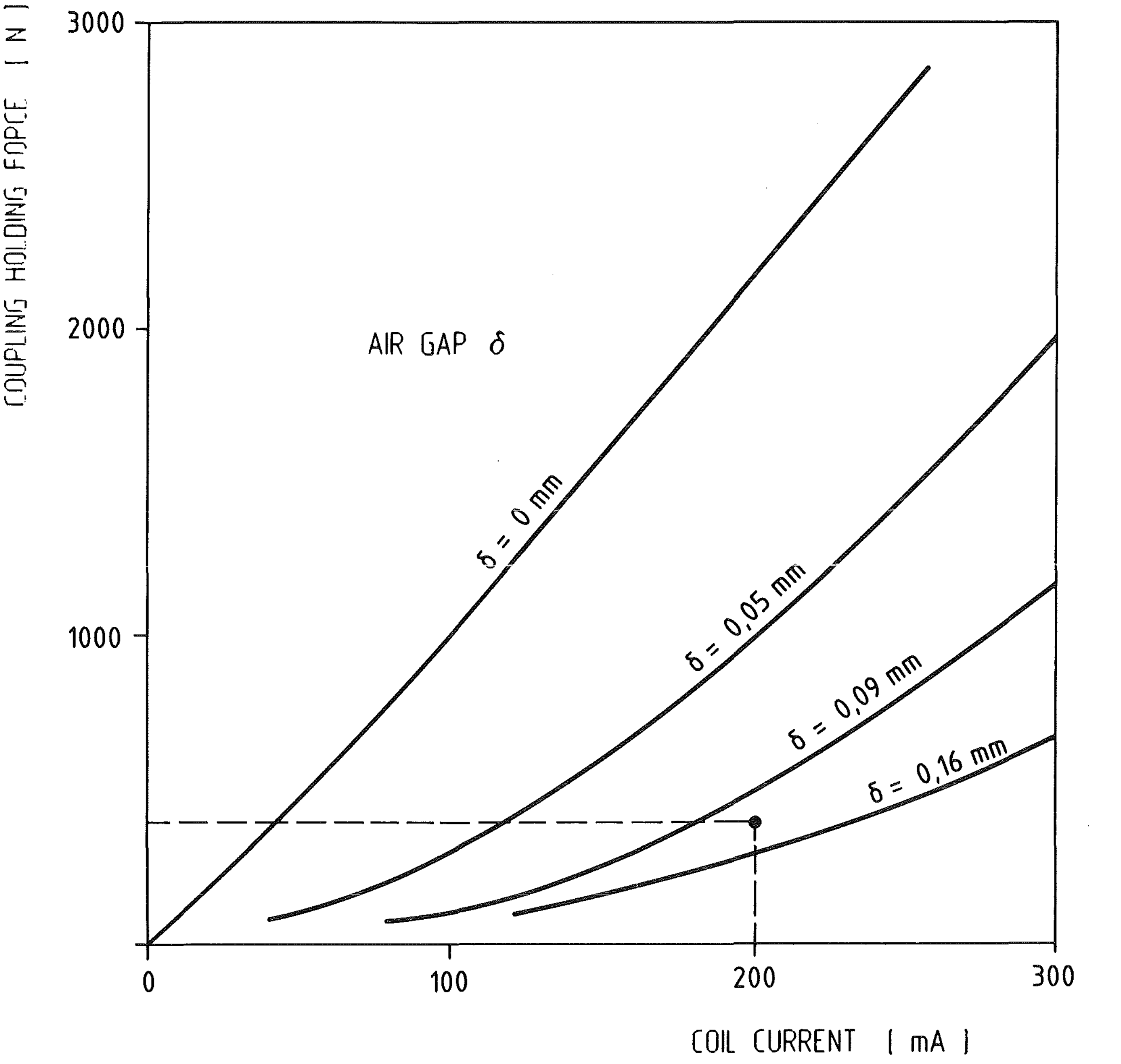

Fig. 8 : Holding force of the coupling as a function of the coil current

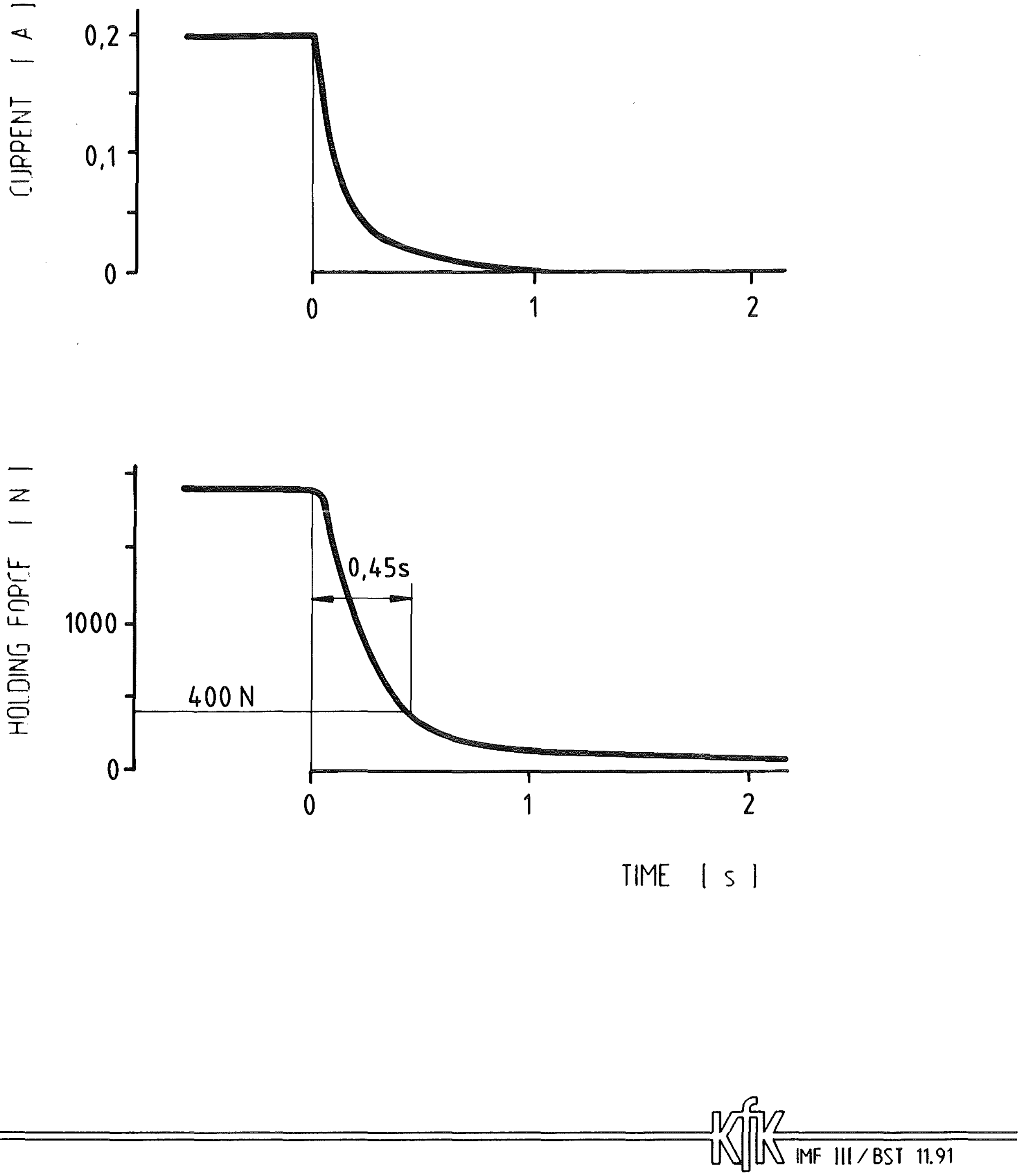

Fig. 9 : Current and holding force of the coupling after shut down

Transient Behavior of the Switch Unit

Referring to [5], the pump failure described there was assumed as the reference case in the computation of the transient temperatures in the switch unit. Accordingly, after breakdown of the energy supply, the sodium flow is reduced to half its former value within 5.7 s.

Figure 10 shows for that case the temperature versus time plot of the reactor sodium at the fuel element outlet. The sodium temperature attains after approx. 3.7 s the Curie temperature of 600 °C of the sensor material.

The temperature transient of the sensor element was calculated using the HEATING 5 computer code [6] which solves the thermal conductivity equation using the numerical difference methods:

- It was assumed that the sensor element of the switch is placed at the level of the upper edge of the fuel element.
- In determination of the initial conditions the sodium temperature at the fuel element outlet was supposed to be 562.5 °C.
- The thermal conductivity λ of the sensor material had to be estimated from the thermal conductivity of NiFe51/49 because relevant data were missing.
- The heat transfer in sodium was calculated from the expression $Nu(t,\theta) = 4.8 + 0.025[Re(t)\cdot Pr(\theta)]^{0.8}$, where t means the time and θ means the temperature.
- In line with the pump coastdown characteristic and on account of the proportionality between the Reynolds number and the mass flow it can be formulated that $Re(t) = Re_o \cdot e^{-0.122t}$.
- The Reynolds number Re_o applicable to steady-state conditions and the hydraulic diameter D_h to be taken into account were estimated for an SNR fuel element to be:
  $Re_o = 4x10^5$ and $D_h = 150x10^{-3}$m.

The result of computation is visible from Figure 11. The upper curve represents the coolant temperature at the fuel element outlet and the lower curve the temperature development at the inner wall of the sensor. Accordingly, the temperature at the sensor wall attains the value of the Curie temperature after 5.2 s. The difference with respect to the coolant temperature rise yields a 1.5 s delay in switching of the switch unit. The switching delay of the absorber rod holding coupling of 0.45 s has to be added to this value. Thus, the investigations have shown that response times of less than 2 s can be achieved. This is a very favorable value for an inherent shutdown system.

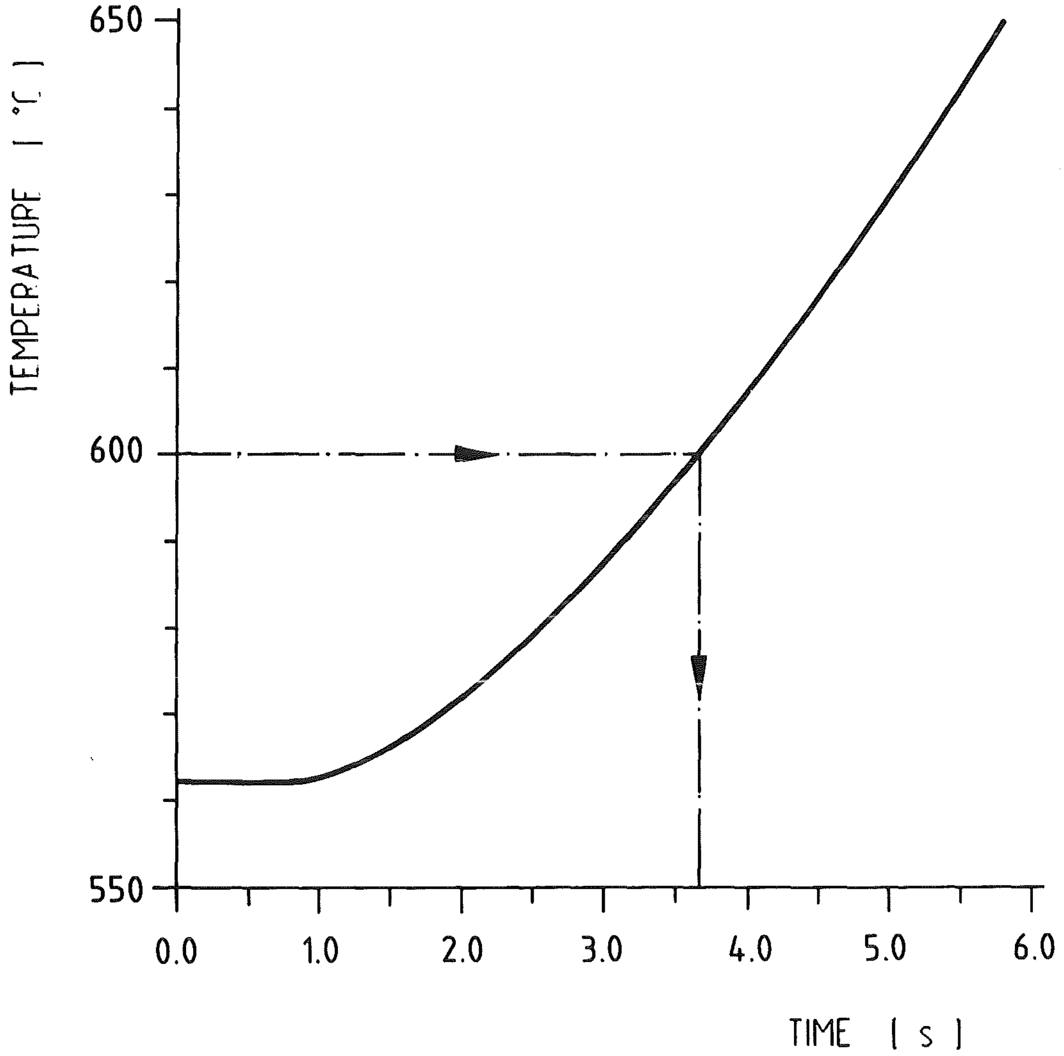

Fig. 10: Coolant temperature at the fuel element outlet in an LOF-accident [5]

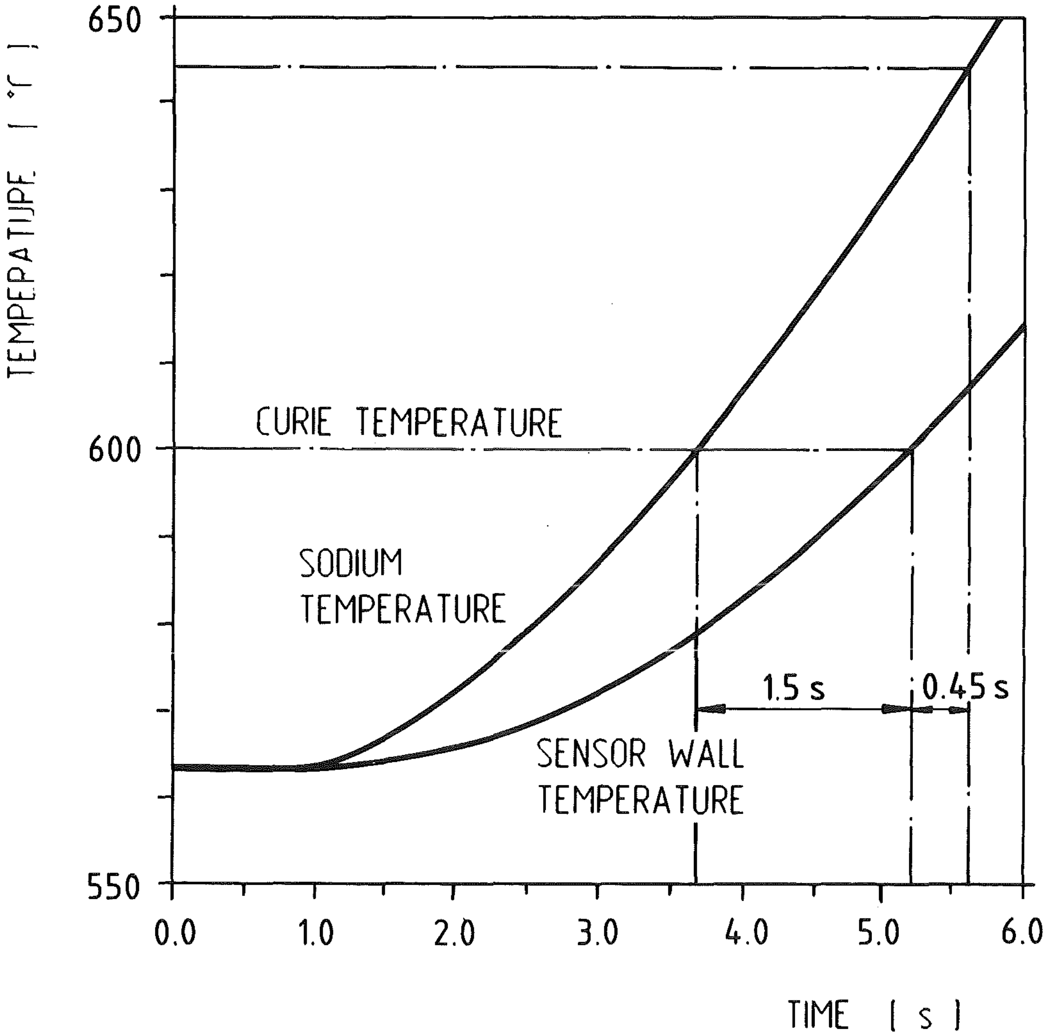

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Fig. 11 : Sensor wall temperature in an SNR LOF–accident

4 Experiments

4.1 Experiments Paralleling Design Work

Preparatory work for the experiments started early and served as a basis and for the validation of the magnetic circuit design of the Curie point controlled sensor/switch unit. A test bench was built in which a first test switch was operated under cover gas at temperatures from 550 to 600 °C. The switch was passed by a coil current of a simplified absorber rod coupling.

The experiments served in the first line to optimize the magnetic circuit gaps in terms of the impact of forces on the switching weight in steady-state operation and at the moment of shutdown. This was accompanied by improvements in the design of the mobile switch components and switch contacts. Also various material pairs suited for bridging to the absorber rod holding current had been tested until molybdenum was found to be the most suited contact material.

Operating experience gathered in all these experiments finally led to a fully performing switch concept. On that basis a prototype switch was operated successfully for 440 days under cover gas at approximately 560 °C and heated at irregular intervals until the switching point was attained.

No measurable changes of the magnetic forces have been found. Also the mean value of the shutdown temperature remained constant. Its bandwidth was approx. 1.5 K under exactly the same external conditions.

Experience accumulated in this long-term experiment resulted in the detailed design of a reference concept for the switch unit whose main data have been compiled once more in a table shown in Figure 12. This concept served as a basis for the irradiation of several switches in a KNK II in-pile experiment.

1	**Dimensions** - length - diameter	 208 mm 38 mm
2	**Materials** - permanent magnet	AlNiCo 450 Al 7 wt.% Cu 4 wt.% Ni 15 wt.% Ti 5 wt.% Co 32 wt.% Fe 37 wt.%
	- yoke components - switching contacts - magnet supports and bobbins - sensor - external parts - auxiliary coil and leads to the switching contacts • jacket • wire • insulation	Armco iron Mo 1.4541 NiFe 6535 1.4571 1.4306 Cu/Zr stainless steel coated MgO
3	**Cover Gas in the Switch**	helium
4	**Forces** - weight force of the switching weight - magnetic force acting on the switching weight • normal operation • moment of switching	 0.7 N 1.4 N 0.3 N
5	**Temperatures** - operating temperature - shutdown temperature (Curie temperature of the sensor material)	 560 °C 600 °C

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Fig. 12 : Principal data of the Curie point controlled sensor/switch unit

4.2 In-pile Testing in KNK II

The magnetic circuit of the Curie point controlled sensor/switch unit is made of materials which, normally, are not used in the radiation field of a reactor at elevated operating temperatures. This is true above all for the magnetically soft components such as the iron yoke, the switching weight and the sensor. Major changes in these components exposed to irradiation and likewise the mechanical behavior of the mobile components and the switching contacts made of molybdenum could exert an influence on the function of the shutdown system and might set limits on their useful lives.

As an investigation of individual material properties in the hot cells would have been too expensive and, moreover, not effective enough, the in-pile experiment at KNK II was conceived and performed as an integral function test. It was devised to demonstrate that the additional influence exerted by the radiation field has no adverse effect on the operating behavior of the switch unit.

When specifying the irradiation conditions it was assumed that the switch units in SNR 2 are placed near the upper edges of the fuel elements, directly above the heads of selected fuel elements so that interferences could be recorded as quickly as feasible. In that zone the fast neutron flux (E>0.1 MeV) is 3×10^{13} cm$^{-2} \cdot$s^{-1}. The desired service life was 1200 full power days (FPD).

This resulted in the following irradiation conditions for in-pile testing in KNK II:

- fast neutron dose (E>0.1 MeV): approx. 3.1×10^{21} cm^{-2};
- irradiation temperature: 560 °C in the steady-state mode (controllable temporarily up to 610 °C).

Starting from these conditions and the performance of the experiments in the second KNK II reactor core the reflector position 511 was selected as the point of irradiation. In the area of the reactor top this position possesses penetration so that the measurement and supply lines needed for the experiment can be introduced from outside. The maximum fast neutron flux at position 511 is approx. 3.3×10^{14} cm$^{-2} \cdot$s^{-1}. The duration of irradiation was fixed at 180 FPD.

Figure 13 shows the axial plot of the fast neutron flux above the core height for position 511. The three test switches have been entered at their respective points of irradiation. Due to the axial neutron flux distribution the switches receive the following irradiation doses after 180 FPD:

- switch 1: 5.1×10^{21} cm^{-2}
- switch 2: 3.3×10^{21} cm^{-2}
- switch 3: 8.6×10^{20} cm^{-2}

For reasons of thermodynamics the test switches had been placed in a sodium cooled irradiation capsule. Figure 14 is a schematic representation of the capsule layout. A double tube system with a gas gap served as heat barrier. Making use of gamma heating and by installation of additional electric heaters, the temperatures of the individual switches could be set and controlled individually between 540 and 610 °C. Test switches and electric heaters were embedded in sodium to improve the heat transfer. The space above the sodium level was filled with helium. Neon was used as the isolating gas in the gap between the capsule tube and the jacket tube. The electric lines of the test switches, the heaters and thermocouples - a total of 39 lines of 1 mm diameter - were routed gastight out of the top of the capsule.

The capsule had been placed at the bottom end of an approx. 7 m long test plug penetrating into the reactor down to the lower edge of the core and through which the measurement and supply lines entering the reactor top were routed (Figure 15). The irradiation device was completed by a current supply for activating the switch units, a temperature control device and a measured data acquisition system [7,8].

Eight test switches based on the reference concept were manufactured completely at the KfK central workshop in context with the in-pile experiment. During the individual steps of assembly work examinations were made on the magnetic circuit, the electric lines and the welds. Finally, the performance of each switch unit was examined. All switch units behaved perfectly in switching operation. The bandwidth of the cut-off temperature of each switch was < 1 K.

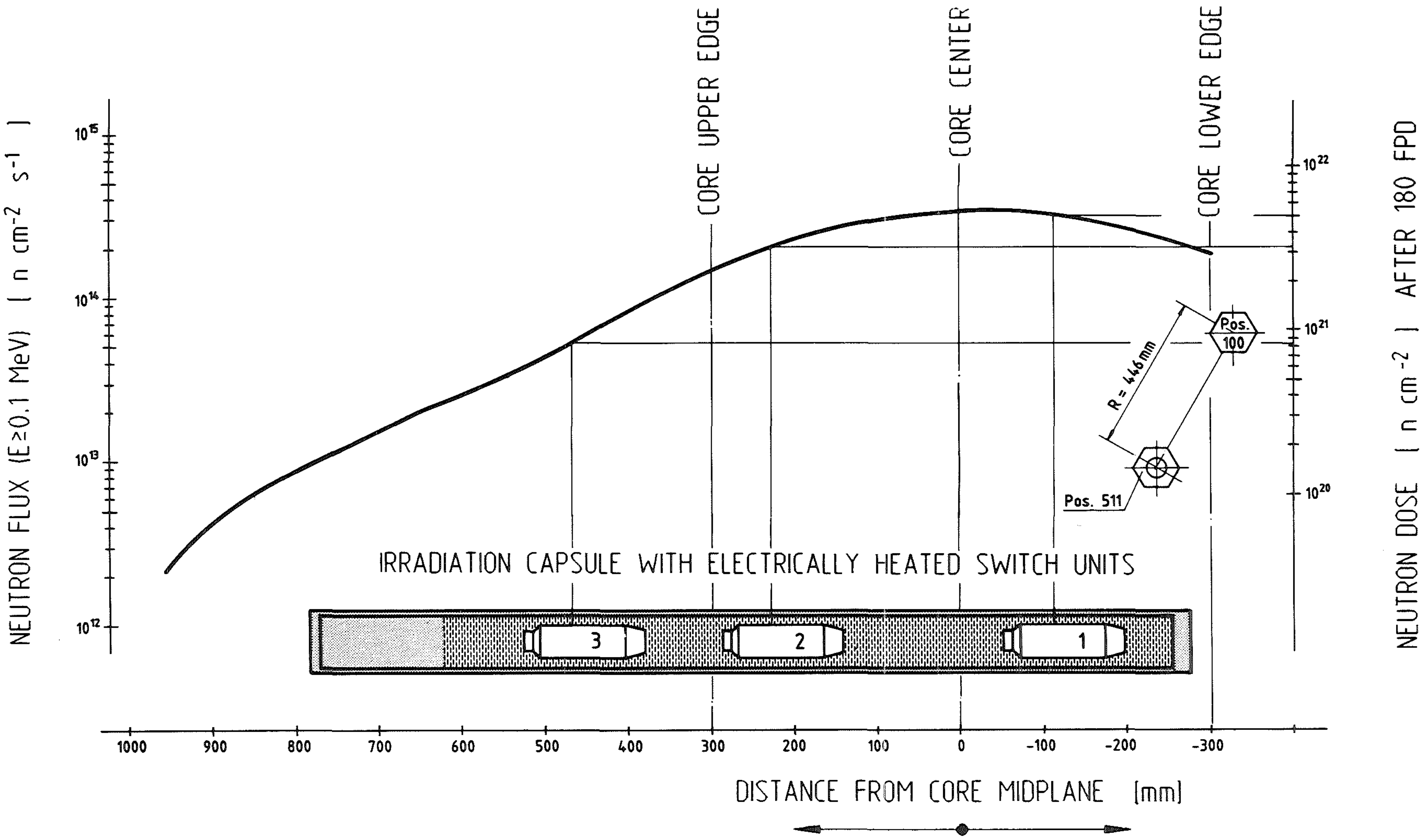

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Fig. 13 : Development of axial neutron flux (E ≥0.1 MeV) at reflector position 511

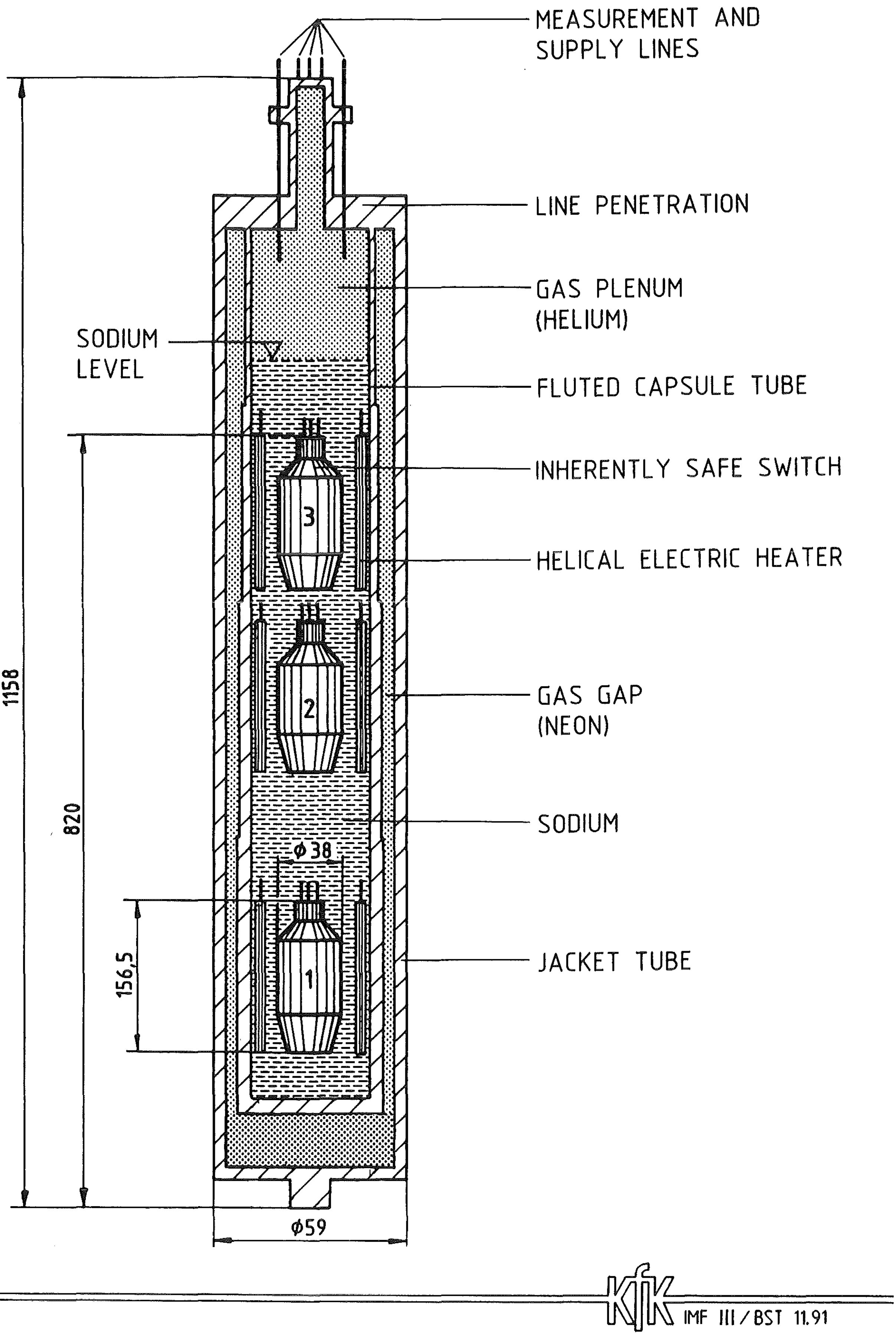

Fig. 14 : Electrically heated capsule with three switch units

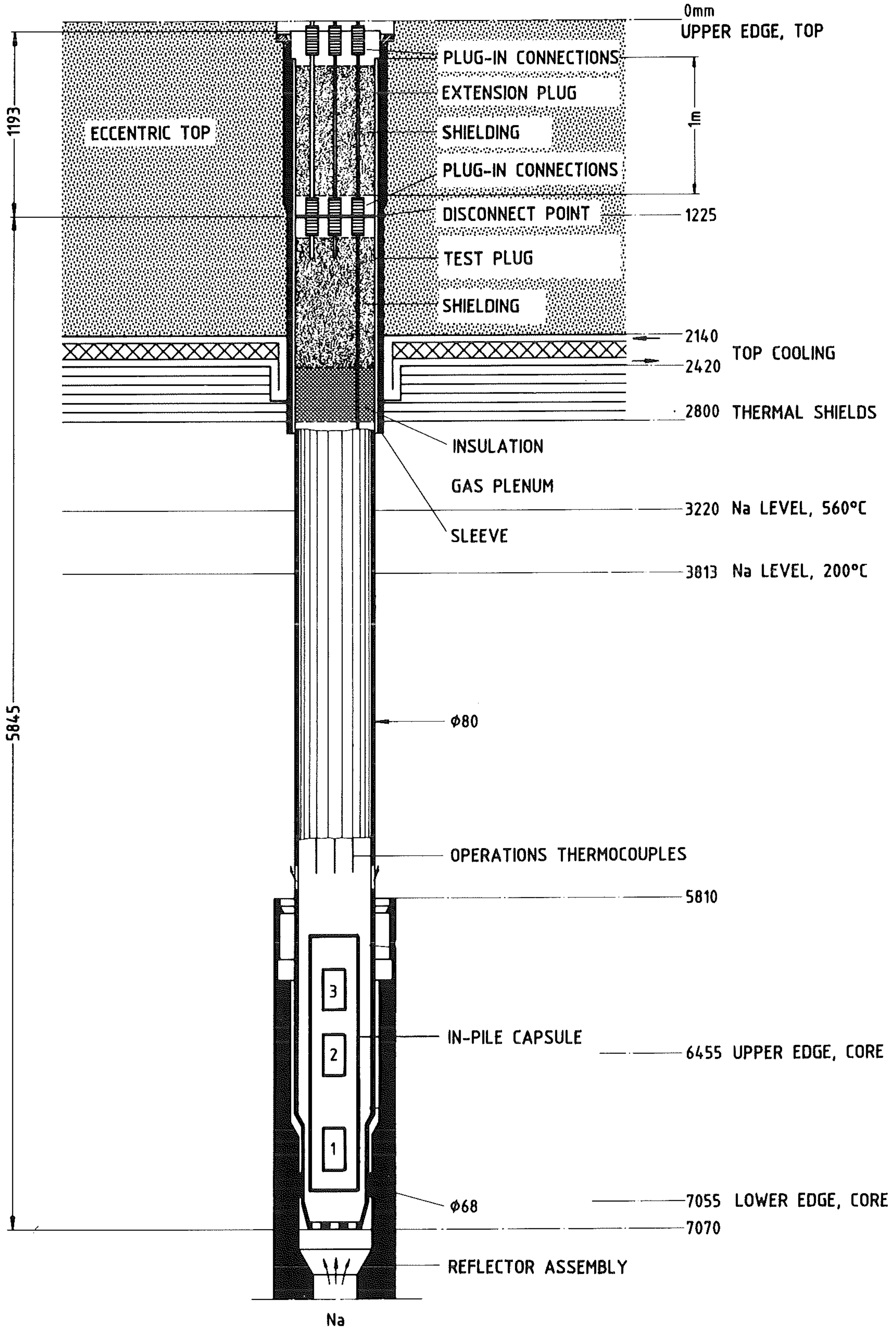

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Fig. 15 : Test plug in the irradiation position

The in-pile experiment was performed during the period of extended KNK II/2 operation. As the reactor was operated during most of that period at 60% of its nominal power, although the irradiation capsule had been designed for operation at full power thermodynamically, the heating powers of the electric tracing heaters were not sufficient for the switch in the lowest position to heat it up to its cut-off point (600 °C). For the other two test switches adequate electric power reserves were available to compensate for the lack of gamma heating. Till the end of KNK II operation the irradiation extended over a total of 120 FPD. Converted to the conditions prevailing in SNR 2 this means for the switch in the central position about 77% of the specified irradiation dose and for the upper switch about 19 %. It must be taken into account here that due to the distribution of the neutron flux in the reflector position 511 only about 27% of the specified dose would anyway have been achievable for the upper switch.

The switches remained fully operative until the end of testing. During the time of irradiation their switching temperature remained almost constant. The scatter band of the switching points ranged from 2.5 K for the central switch (Figure 16) to 4 K for the upper switch.

Two irradiation capsules were manufactured for use in the in-pile experiment. The standby capsule was operated at the laboratory for about twelve months in an endurance test. The test was performed in the same way as the in-pile experiment. Also these three switches remained operative during the whole period of testing. The bandwidth of the cut-off temperature was < 1.5 K.

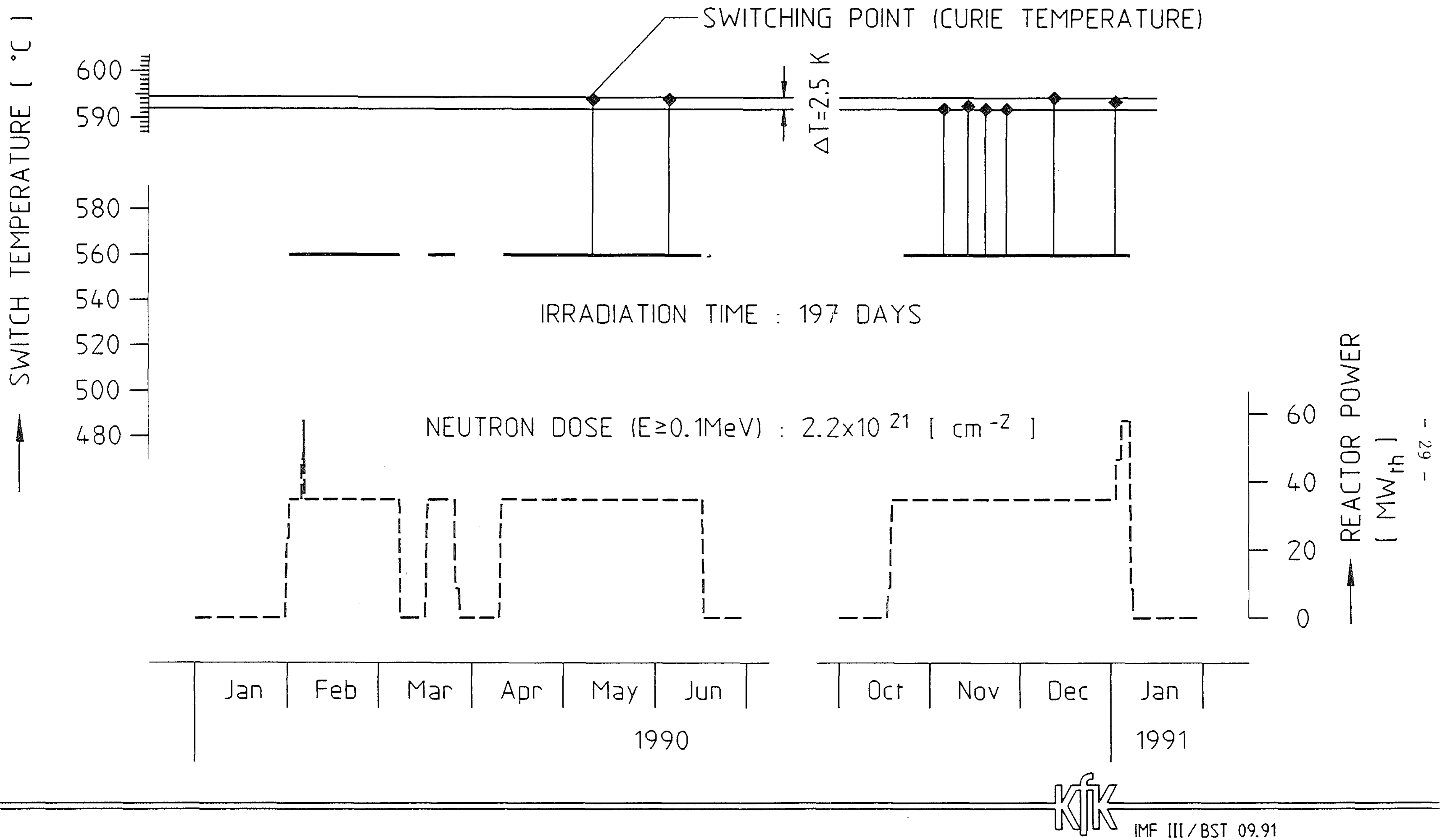

Fig. 16 : Irradiation diagram for test switch No. 2 (center)

5 Concluding Remarks

The inherent shutdown system proposed is to shut down the reactor upon inadmissible rise in the sodium temperature at the core outlet through automatic interruption of the current of one - or several - shutdown rod holding couplings by a Curiepoint controlled sensor/switch unit. It is assumed that the absorber drops safely into the reactor core, even in case of maximum deformation of the duct.

Development work largely concerned the Curie point controlled sensor/switch unit. To be able to evaluate the sensor/switch unit and the proposed system as a whole, it must be examined to which extent the requirements mentioned at the beginning are satisfied:

- Fail safe behavior:
  The principle according to which the switch unit is operated implies that the reduction in magnetic flux due to aging would cause the current to be interrupted. Penetration of sodium into the switch housing would cause short circuit to ground and, consequently, likewise shutdown. According to experience derived from the out-of-pile and in-pile tests with a multitude of switch units, obstruction of the motion of the switching weight can be excluded. Other possible defects such as the failure of the auxiliary coil do not exert an influence on the switching function.

- Protection against errors in manipulation:
  Erroneous switching of the auxiliary coil would be critical if during operation the coil were passed by a current unnoticed in such a manner that the magnetic holding force would be intolerably enhanced. It has been shown that this can be excluded by a simple electric circuit.

- Possibilities of testing:
  All mechanical functions of the system - dropping the switching weight and dropping the absorber - can be tested with the auxiliary coil provided.

- Long-term operation:
  The materials used should allow the switch unit to attain a service life of several years. The assumption has been confirmed in long-term experiments performed at elevated temperatures on a laboratory scale and by irradiation under reactor design conditions. In these integral tests the switches remained fully operative until the end of testing. Their switching temperatures remained nearly constant during the entire period of testing.

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