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MEASUREMENT OF FUEL PIN DEFORMATION UNDER CYCLIC POWER OPERATION (PRELIMINARY EXPERIMENT)

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Measurement of Fuel Pin Deformation Under Cyclic Power Operation (Preliminary Experiment)

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(received March 15, 1978)

The result of preliminary experiment on fuel pin deformation under cyclic power operation are described.

(1) A slight rod flattering of 30μm is observed in surface profilometry.
(2) Diametral contraction is 10μm.
(3) Increasement of temperature during constant power made 0.03mm length change (in appearance) to the rod.
(4) In the last stage of cyclic power operation elongation is 120μm at low power level and 80μm (both in appearance) at high power level. Deformation pattern is similar between low and high power levels.
(5) By metallographic observation, cracks are not parallel to the axial direction. Those reaching to pellet-pellet boundary are random in direction. Observed crack has branched.

Keywords: Cyclic Power Operation, Fuel Pin Elongation, Pellet crack, Irradiation, JMTR Capsule, Deformation

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出力サイクル運転下の燃料ピンの変形測定（予備実験）

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（1978年3月15日受理）

本報は出力サイクル運転下の燃料ピンの変形に関する予備実験の結果についてとりまとめたものである。結果は以下の通りである。

(1)　表面形状の測定から棒には30 μmの微少な偏平がみられた。

(2)　直径方向に10 μmの縮みがみられた。

(3)　一定出力中の温度上昇で0.03 mmの長さ変化が観測された。

(4)　出力サイクル運転の終わりには高出力側で120 μm，低出力側で80 μmの伸びが観測された。低出力および高出力でのピンの変形様式は非常によくにていた。

(5)　ペレットの割れは軸方向に平行でなく，ペレットとペレットの境界に達した割れの伝幡方向には一意性のない事が金相試験によって明らかになった。

観察した割れは枝分れしていた。

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1. Introduction

Recently, a capsule which enables researcher can select optional irradiation condition, especially neutron flux and gamma heating rate, for his irradiation specimen by lateral movement in the core with defined speed.

This capsule designed and instrumented in JMTR which can be used for both fissile material and non-fissile materials irradiation. Capsule is located in M-7 grid hole, which is first reflector region in JMTR and coolant system isolated from the primary coolant of reactor.

Uranium dioxide fuel pellet and Zry-2 cladding was used. Loaded instrumentation were one elongation detector and four thermocouples. The irradiation objectives are:

(1) Measurement of fuel pin deformation caused by UO_2-Zry-2 pellet clad mechanical interaction under cyclic power.

(2) Fuel irradiation rehearsal with lengthwise driven apparatus.

Aiming to study pellet-clad mechanical interaction (PCMI) under power cycle fuel operation capsule was driven periodically up and down on automatic programmed operation.

The capsule was successfully operated and in-pile characteristics of this apparatus was clarified. But fuel power estimation was failed for the incomprehensible large difference between two independent power estimation methods.

This paper describs the irradiation results of a fuel pin on power cycle condition.

2. Outline of the Irradiation

2.1 Description of the apparatus

The outlines of this apparatus are:

(1) movable stroke of a capsule shall be 500 mm

(2) coolant of apparatus shall be separated from the primary coolant of reactor

(3) moving speed shall be changeable

(4) purification system of a coolant shall be attached to the apparatus

(5) location of the in-pile tube shall be M-7 hole in JMTR.

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As the in-pile curved depending upon the geometry of JMTR, the length and diameter of the capusle are subject to restriction (32 mmϕ O.D., 270 mm length) and instrumental leads and guide tube attached to the capsule must be flexible.

The apparatus is mainly composed of capsule driving system, cooling system and control system.

When out-of-normal condition occurred to the total system, from the view of safety, capsule shall be withdrawn out to the farthest position from the core, where the neutron flux and gamma heating rate are very low level.

2.2 In-pile characteristics of the apparatus

(A) Physical characteristics of the apparatus in core region

Absolute value of unperturved thermal neutron flux was measured by the nuclear mock up in JMTRC and it is estimated about 3.5×10^{14} fiss./cm^2.sec at the peak value, gamma calorimer indicated 5.7 Watt/gram at the peak gamma heating rate.

Variations of thermal neutron flux and gamma heating rate during reaçtor operation were small.

The temperature of the coolant was low enough at the normal flow rate of 4 m^3/h and its value was nearly equal to the average temperature of reactor primary coolant. Thus in spite of the lack of secondary cooling system to this apparatus, the circulating was sufficientry cooled by reactor primary coolant and reactor pool water.

(B) Characteristics of the system effects

The reactor reactivity response with a movement of a capsule was measured. Maximum reactivity is equivalent to 0.7 mm movement of reactor control rod SR-1 estimated about 0.003 $\Delta k/k$ of reactivity. Therefore there is no significant influence to the reactor operation even if capsule of this apparatus is moved at the maximum speed (10 mm/sec).

3. Experimental Result

3.1 Gas analysis

By means of mass spectrometer, gas composition and its volume percent

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3. Experimental Result

3.1 Gas analysis

By means of mass spectrometer, gas composition and its volume percent was analysed. Result of gas analysis by mass spectrometer and the condition of the gas capturing is shown on Table 1. Volumes of 80% and 18% were occupied by helium and nitrogen and of less than 0.01% were occupied by xennon or kripton. A representative mass spectrum and gas compositions of xennon, kripton, oxygen, nitrogen and helium are shown in Fig. 1.

3.2 Dimensional measurement of the fuel rod

Fuel rod measurements as those of surface profile, diameter change and fuel bowing were performed. Temperature at the cell and fuel rod were 20°C.

3.2.1 Measurement of surface profile and diameter change

Schematic drawings of the fuel rod is shown in Fig. 2. 120 mm was the total length of the rod from top to bottom. In the rod we set two intervals of measurement. The first was interval of 77 mm in length from S to E, which was notated "interval B". Notation S and E meaned that a starting point and a ending point of the profile meter. Profile meter moved from top side to bottom side of the fuel rod. The second was a large interval than the first one, that 107 mm in length from S to E, so that notated "interval A". Interval B was about 30 mm shorter than interval A. Tracing direction of interval B was separated in 90 degrees from that of interval A. Surface profile and diameter change for each intervals were measured and obtained results were shown in Fig. 3.

From the surface profile measurement, highest part of the fuel rod and the lowest one made difference about 100 μm in high (for interval A) and about 150 μm in high (for interval B), thus the rod had the trend of a little flat in order of 30 μm.

Diametral contraction about 10 μm was obtained for both intervals with comparison to pre-irradiated rod diameter. Obtained results from the diameter measurement were shown on Table 2.

3.2.2 Measurement of bowing of the rod

To examine the fuel rod bowing was only possible for interval A and 20 μm along total length of 107 mm was observed.

3.3 Results of irradiation experiments on cyclic power capsule

Fuel pin elongation was measured during cyclic power operation. Specifications of the fuel rod is shown on Table 3. To measure the elongation of the fuel pin elongation detector (Halden type #536, differential transformer) was used.

At the beginning of the irradiation (reactor cycle of 22th in JMTR) power of the rod was about two times large with value obtained from nuclear mock up in JMTRC. From the view of safety, the capsule was not moved or fixed and keep hanging up on the top position of core center during this reactor cycle. Burnups of the fuel rod, however, advanced and fuel elongation could be measured. In this reactor cycle attained burnups were 256-480 MWd/t (estimation) and averaged linear heat ratings were 240-450 W/cm.

Figure 4 shows the fuel pin elongation behavior during this cycle. In this period, cyclic power operation was not performed because of the above reason and safety. In the figure, the position of thermocouple (T/C) are: T/C #1.....attached to thermal bond surrounding at differential transformer, T/C #2.....at top of the aluminum thermal bond, T/C #3 and #4 at middle positions of aluminum thermal bond (just above the centre of fuel).

Throughout 22th operation of JMTR, capsule kept hanging up the top position of reactor to avoid a high neutron flux. Measured temperature at all position were constant, but 20°C variation was observed between T/C #3 and #4.

In spite of the constant power operation, elongation of the fuel pin was increased gradually to the value from 0.13 mm to 0.16 mm (both in appearance). As seen from Fig. 4 at the middle of the operation, unexplained bump of the elongation curve was observed.

For the safety, guide tube of the capsule was shorten and irradiated again in 30th reactor cycle of JMTR. In this cycle the capsule was experienced the cyclic power. Thermal flux distribution at 50 MW of JMTR is shown in Fig. 5.

In spite of the irregularity of time control circuit, holding time of low or high power level were almost in constant. Average holding time of low and high power level were 2 hours and 2.5 hours. Power increasing time was 2 hours with high power level and decreasing time was 1.5 hours with low power level. From Fig. 6 to Fig. 12 detailed operation history of cyclic power were shown. Figure 13 shows the relation between numbers of cyclic power and fuel pin elongation. From Fig. 13 the following general trend was observed:

(1) Fuel pin elongation was increased with fuel burnup.
(2) In the last stage of the cyclic power, elongations were 120 μm at low power level and 80 μm (both in appearance) at high power

level.

(3) Difference in elongation between high power level and low poer level were in same and no relation with increasing numbers of cyclic power.

Ridging was the one of the characteristics of PCMI but juding from the surface profile and measurement of diameter change, as showed in Fig. 3, non of it was observed. Only axial deformation of the fuel rod seemed to be occurred during cyclic power.

3.4 Metallographic observation

Metallographic observation were performed both on cross sectional and longitudinal area of UO_2 pellet. Schematic drawings of cutting position of the fuel rod was shown in Fig. 14. Specimen 1 shows the cross sectional part and specimen 2 the longitudinal one. Pellet to pellet boundary was included in area of longitudinal.

Photomicrograph of specimens were shown in Fig. 15. Notation A shows the cross sectional part and B the longitudinal part. From A penetrated or non-penetrated many cracks were observed. Pellet was into many small pieces. At the same time, from B it was observed that longitudinal cracks were not parallel to pellet-clad boundary or axial direction, and they were tied up at pellet-pellet boundary. All cracks were not symmetrical and complicated. Branched cracking was observed.
Pore distribution for A and B seemed to be homogeneous. Small amount of pellet fragments were disappeared at the pellet-pellet boundary.

4. Conclusion

Irradiation results of a fuel pin experienced cyclic power operations are:

(1) From the surface profilometry a little flat of the rod 30 μm was observed.

(2) Diametral contracting of 10 μm was observed.

(3) Increasement of temperature during constant power made 0.03 mm (in appearance) length change to the rod.

(4) Elongations were 120 μm at low power level and 80 μm (both in appearance) at high power level in the last stage of the cyclic

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power operation. Between low and high power level a very same deformation pattern was observed.

(5) Metallographic observation showed that crack was not parallel to the axial direction and if closed to the pellet-pellet boundary, the direction of propagation were very in random. Observed cracking was in branched.

References

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Table 1 Result of gas analysis of the capsule and the conditions of gas capturing.

Composition	Mass Spectrometer (Volume-%)
H_2	-
H_e	79.99 ± 0.13
CH_4	0.01 >
CO	-
N_2	17.57 ± 0.15
O_2	0.39 ± 0.17
A_r	2.06 ± 0.03
CO_2	-
K_r	0.01 >
X_e	0.10 >

Gas Capturing Condition	
Vacuum rate	3.8×10^{-5} mmH_g
Vol.of system	845.66 ± 0.76 cc
Leak rate	5.0×10^{-4} mmH_g/min
Balanced Pres.	43.3 mm oil
	2.76 mmH_g
Total released gas volume(STP)	2.90 cc
Room temp.	22.5 °C
Oil density	0.866

Table 2 Diameter measurement of post-irradiation examination.

(mm)

		max.	min.	average.
pre-irradiation		-	-	12.230
post-irradiation				
direction	A	12.226	12.221	12.219
"	B	12.223	12.209	12.216
diametral contraction		....	....	0.012

Table 3 Specification of the materials used in cyclic power experiment.

Specifications:

(1) Fuel:	Material	UO_2 pellets
	Density	94.34 % TD
	O.D.	10.69 mm
	Enrichment	2.6 w/o

(JPDR test assemblies NO.2 fuel segment)

(2) Clad:	Material	Zry-2
	I.D.	10.83 mm
	Thickness	0.7 mm

(3) Capsule: Lengthwise driven power cycle capsule
(single covered measuring capsule)
Thermal neutron flux 3.5×10^{14} fiss/cm^2.sec(peak)
Irradiated in JMTR M-7 hole.

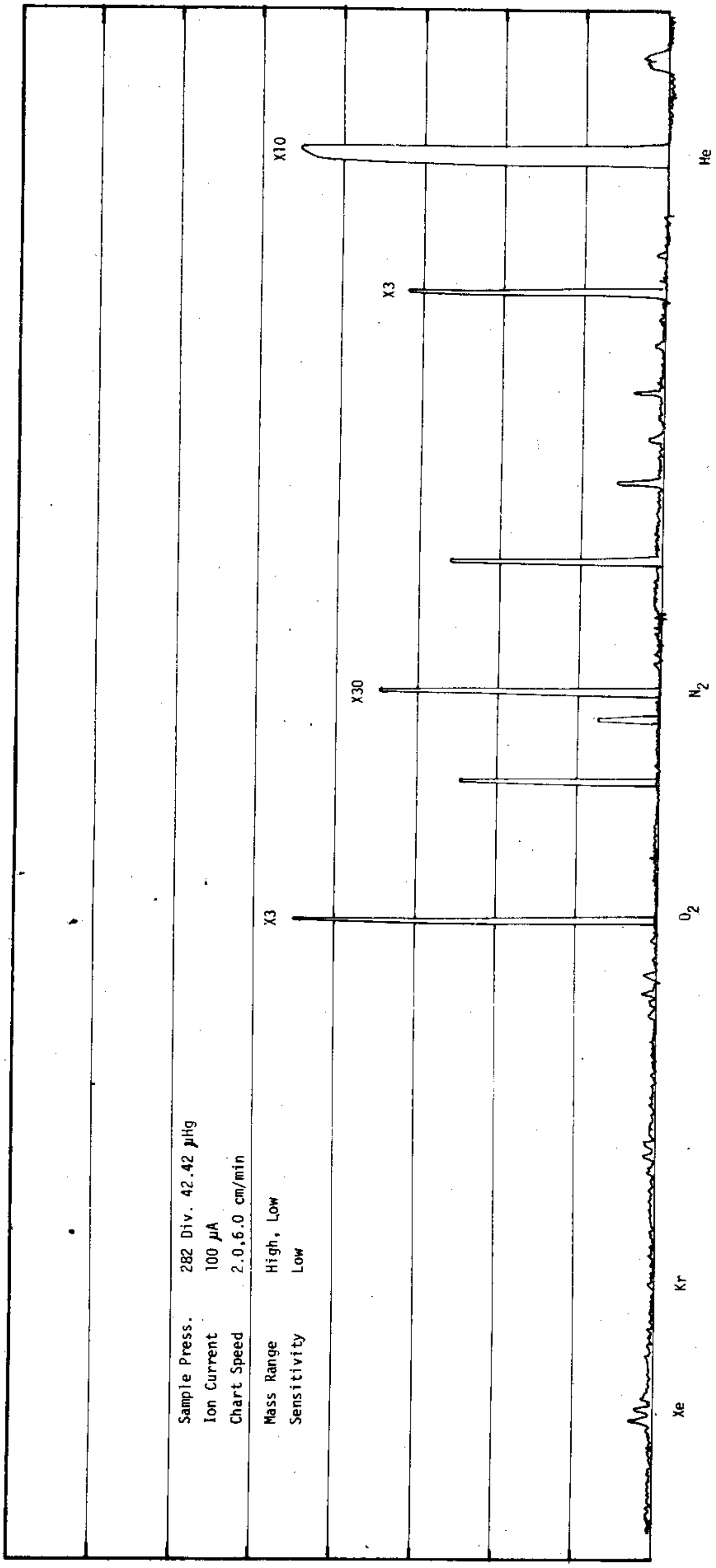

Fig. 1 Mass spectrum and gas composition.

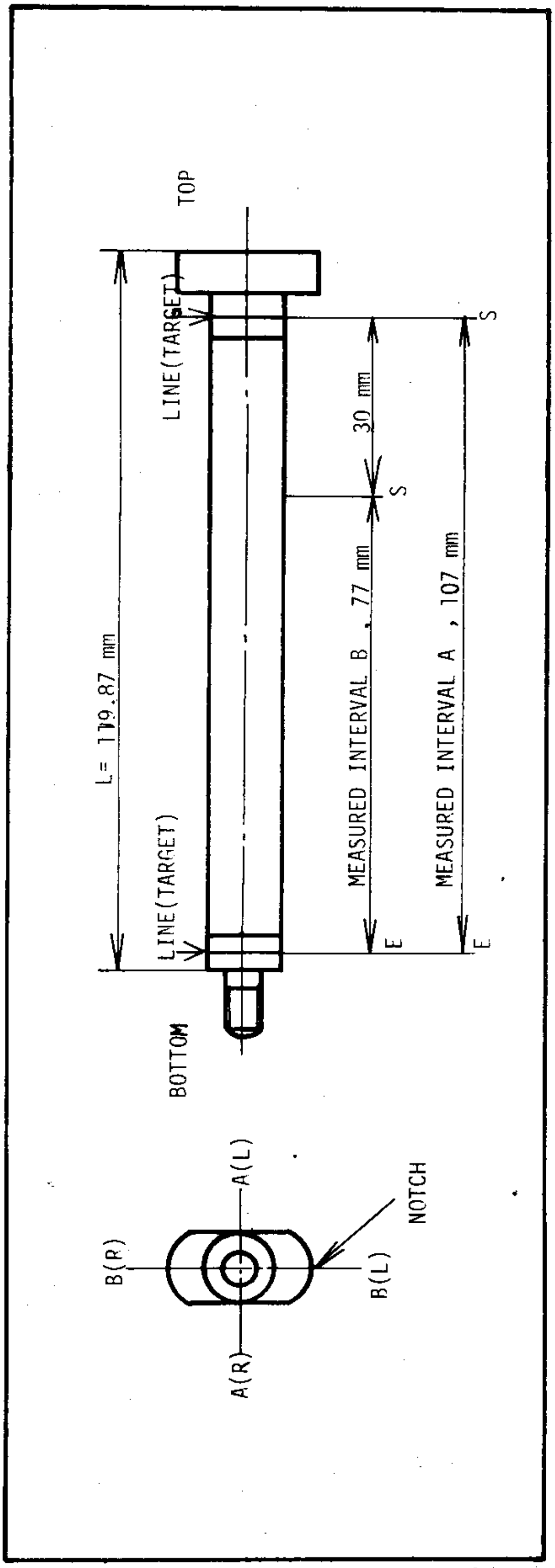

Fig. 2 Schematic drawings of the fuel rod.

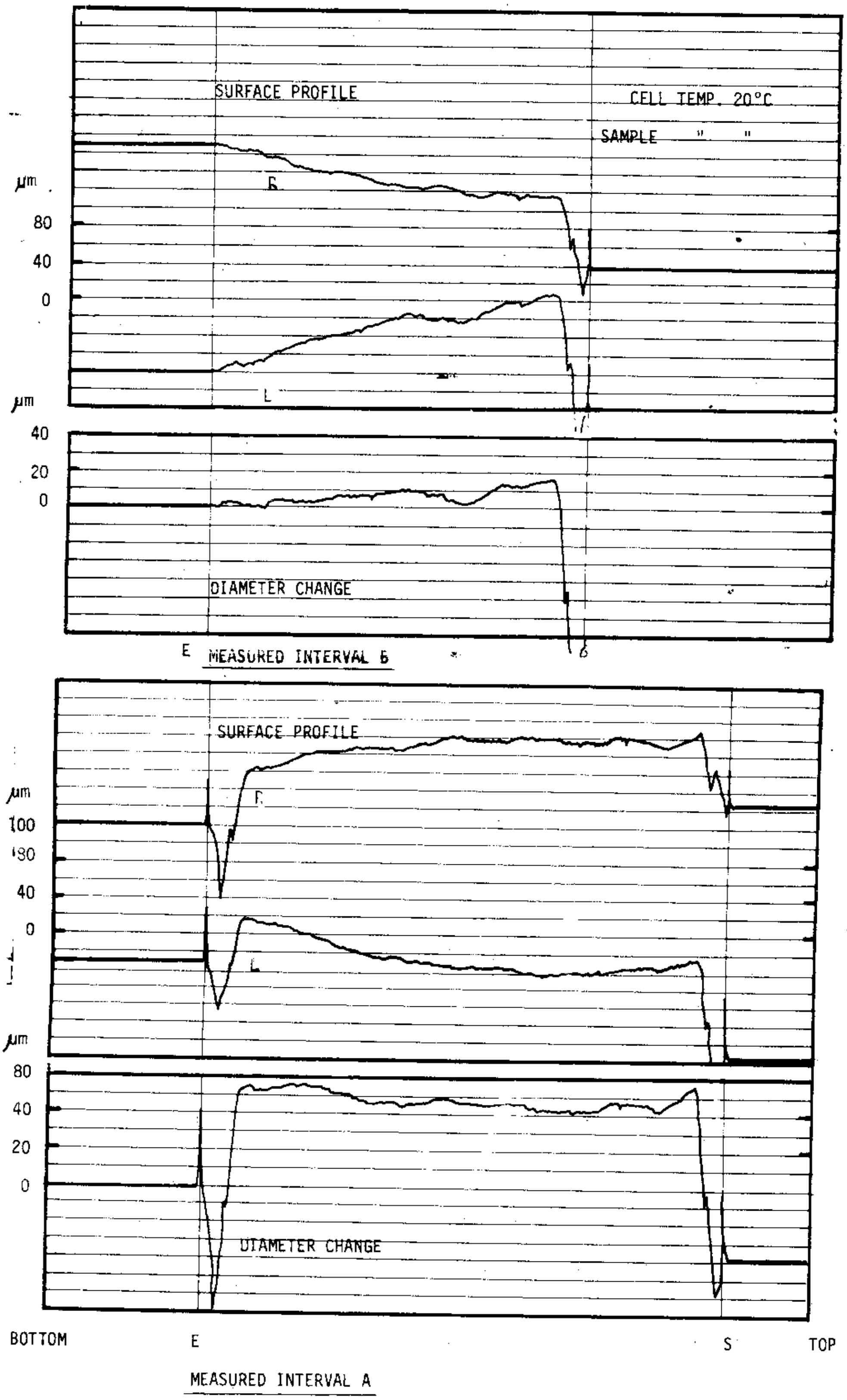

Fig. 3 Surface profile and diameter change for each intervals of the fuel rod.

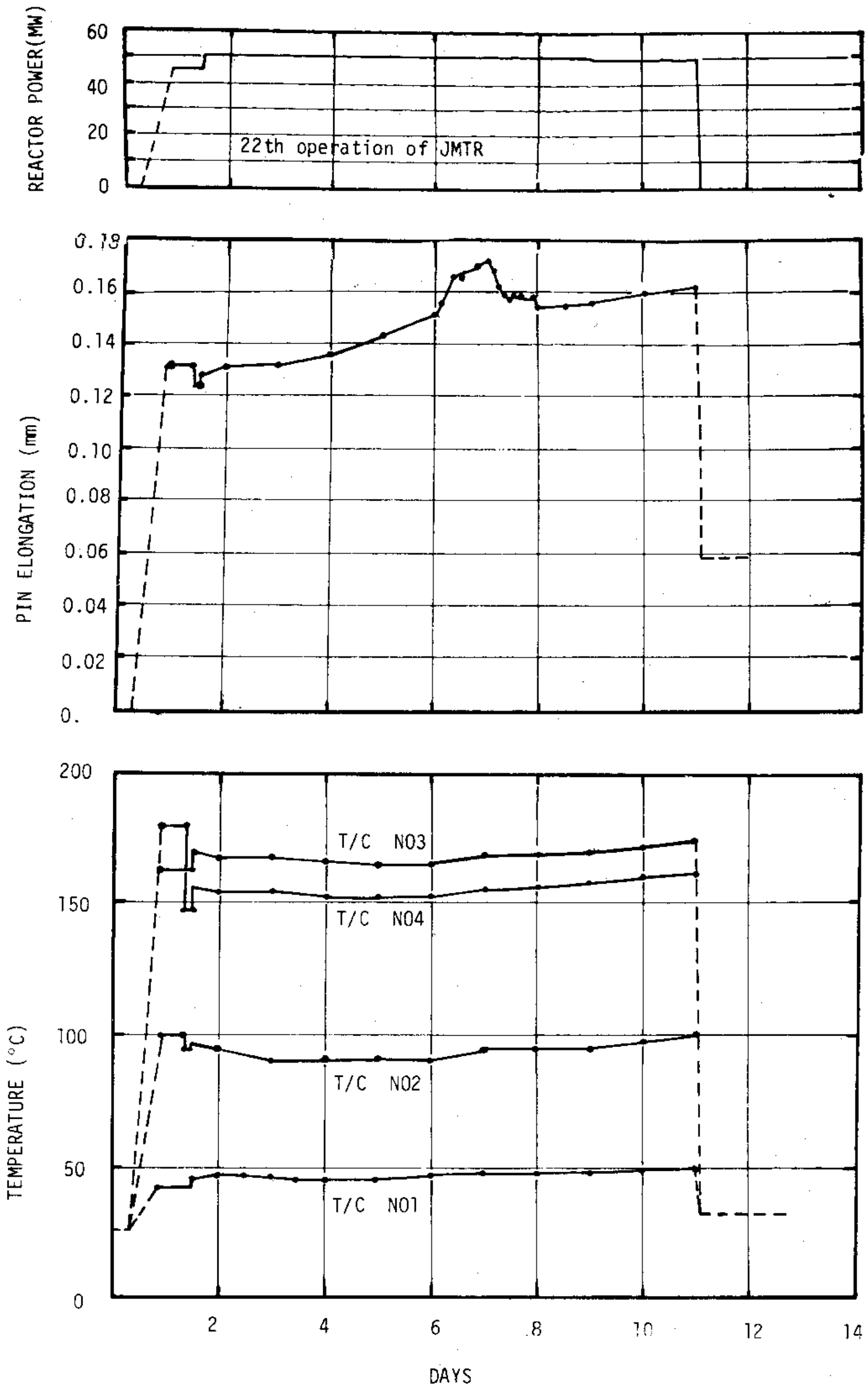

Fig. 4 Power history, pin elongation and measurement temperature of capsule, upper: power history of 22th operation in JMTR, middle; pin elongation during in that period, lower: temperature in each T/C, positions were #1:at DTF, #2-4: at aluminum thermal block.

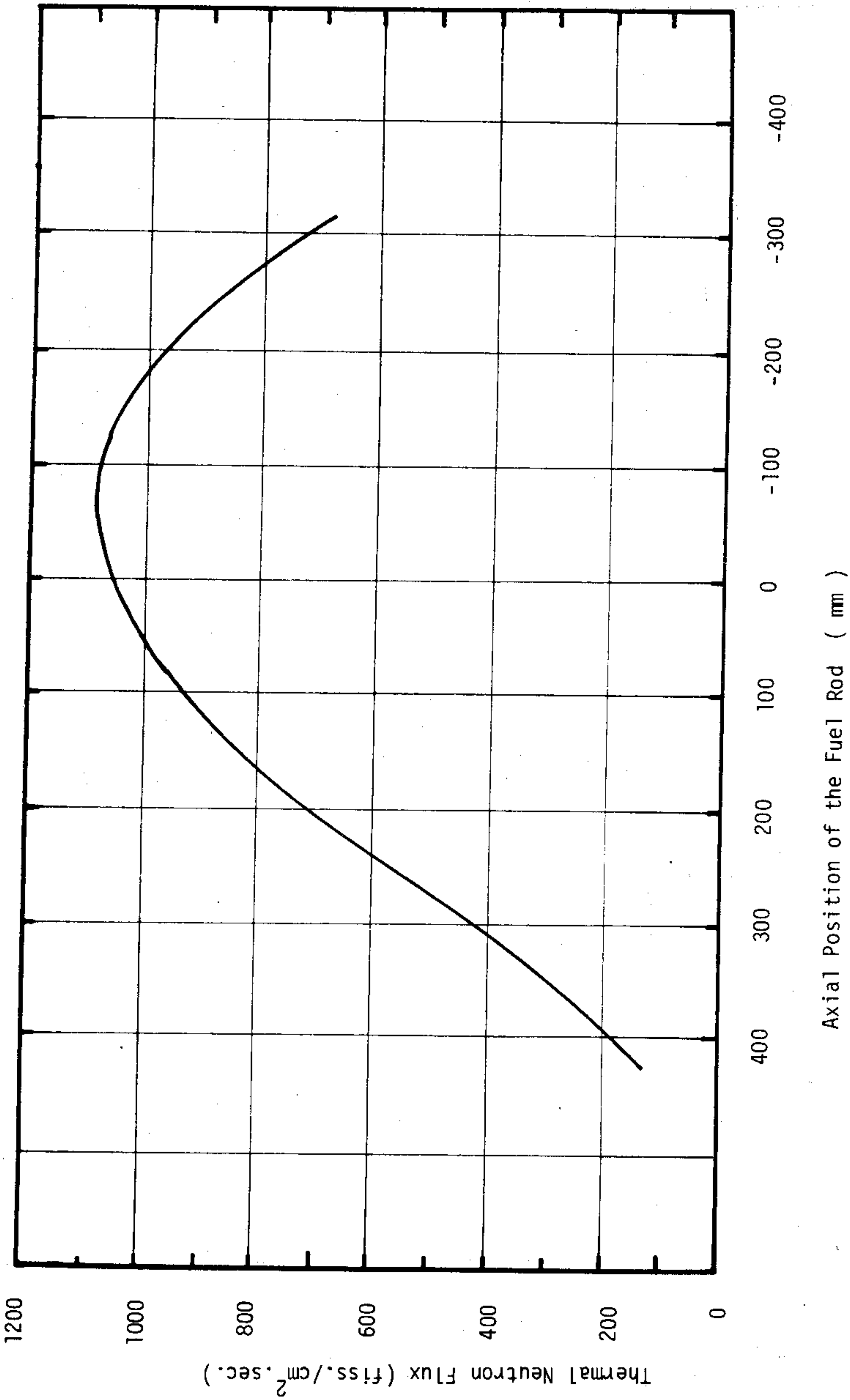

Fig. 5 Thermal neutron flux distribution at 50 MW on 30th cycle in JMTR.

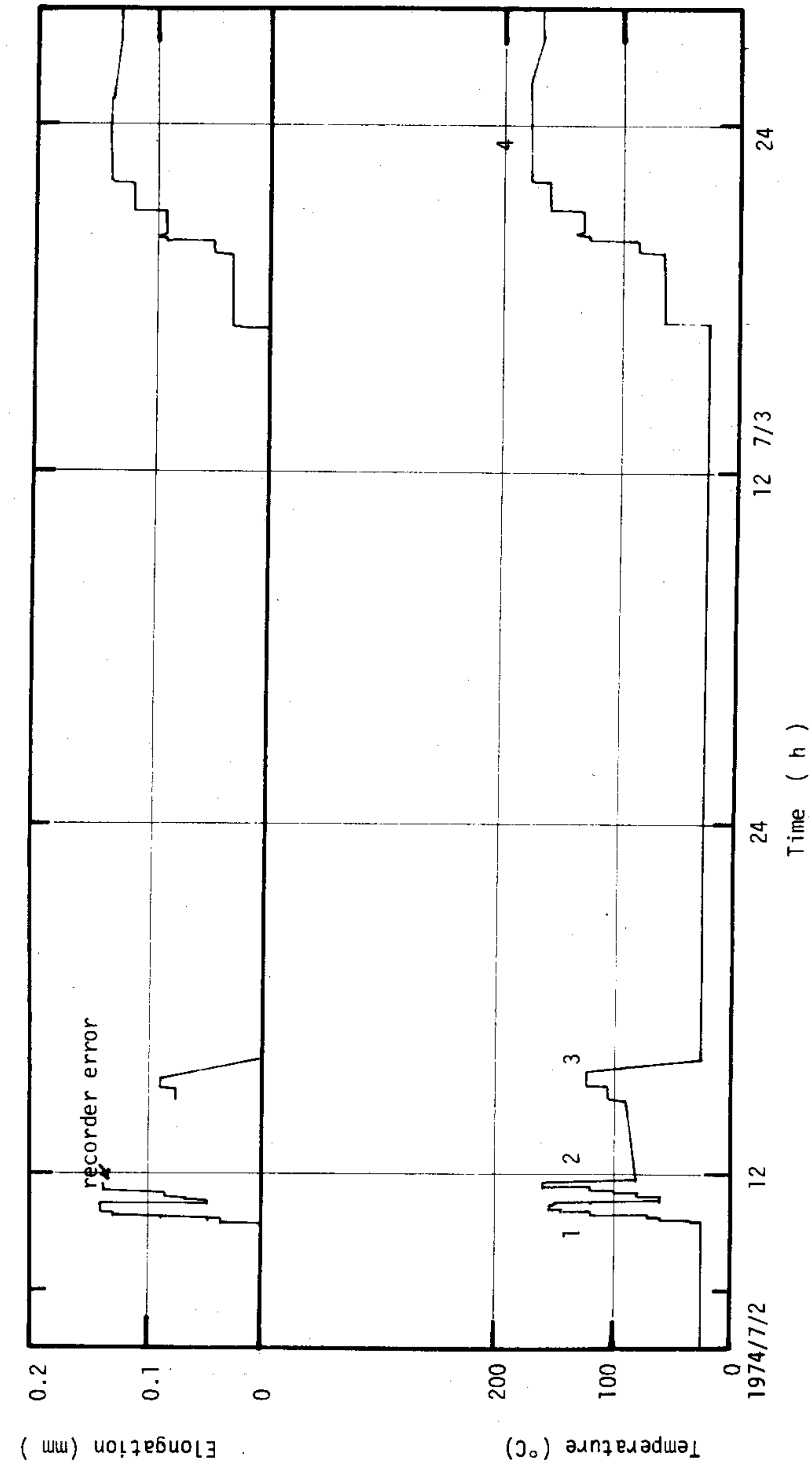

Fig. 6 Cyclic power history: relation time(h) to elongation(mm)/temperature(°C)

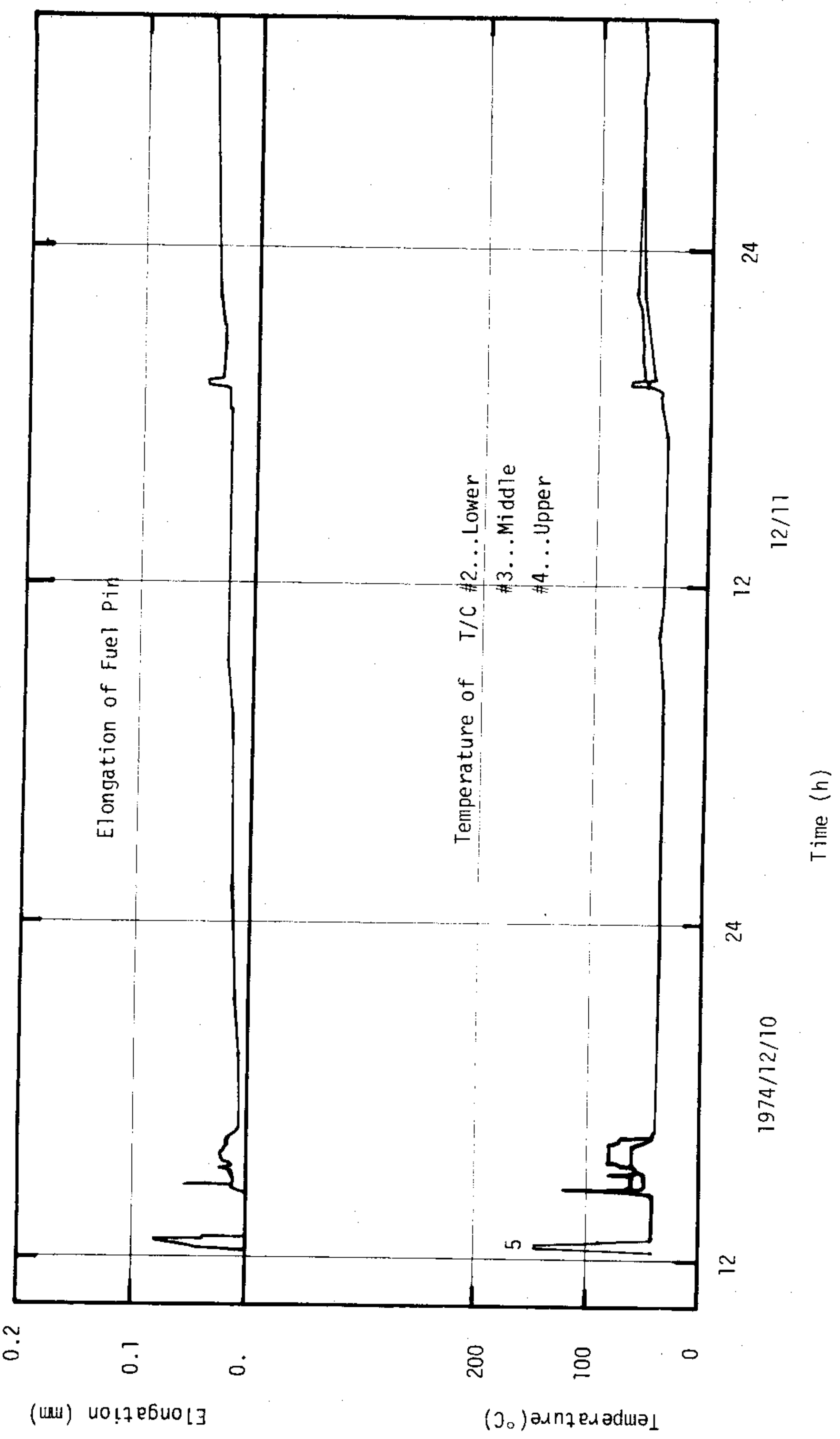

Fig. 7 (continued)

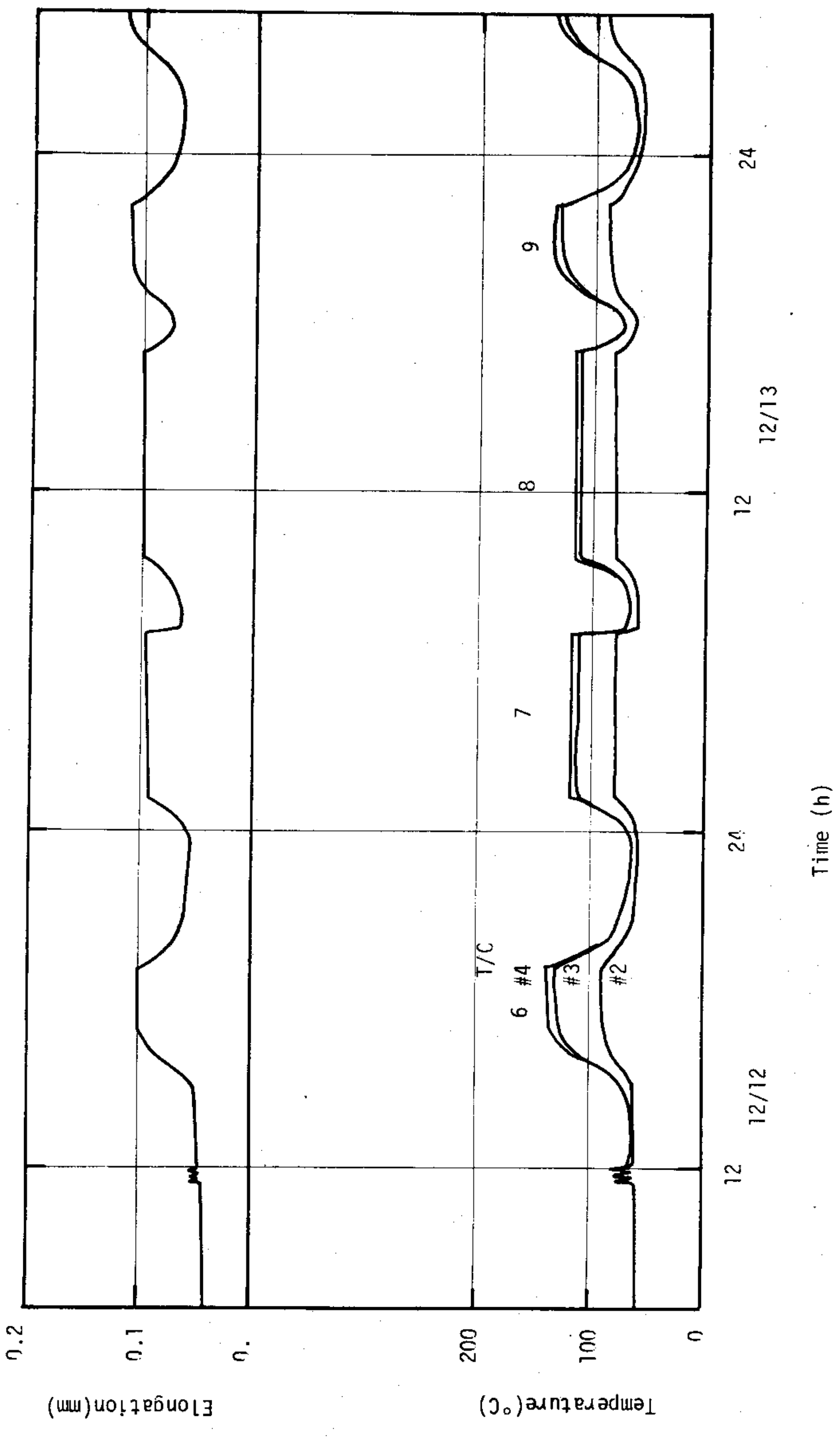

Fig. 8 (continued)

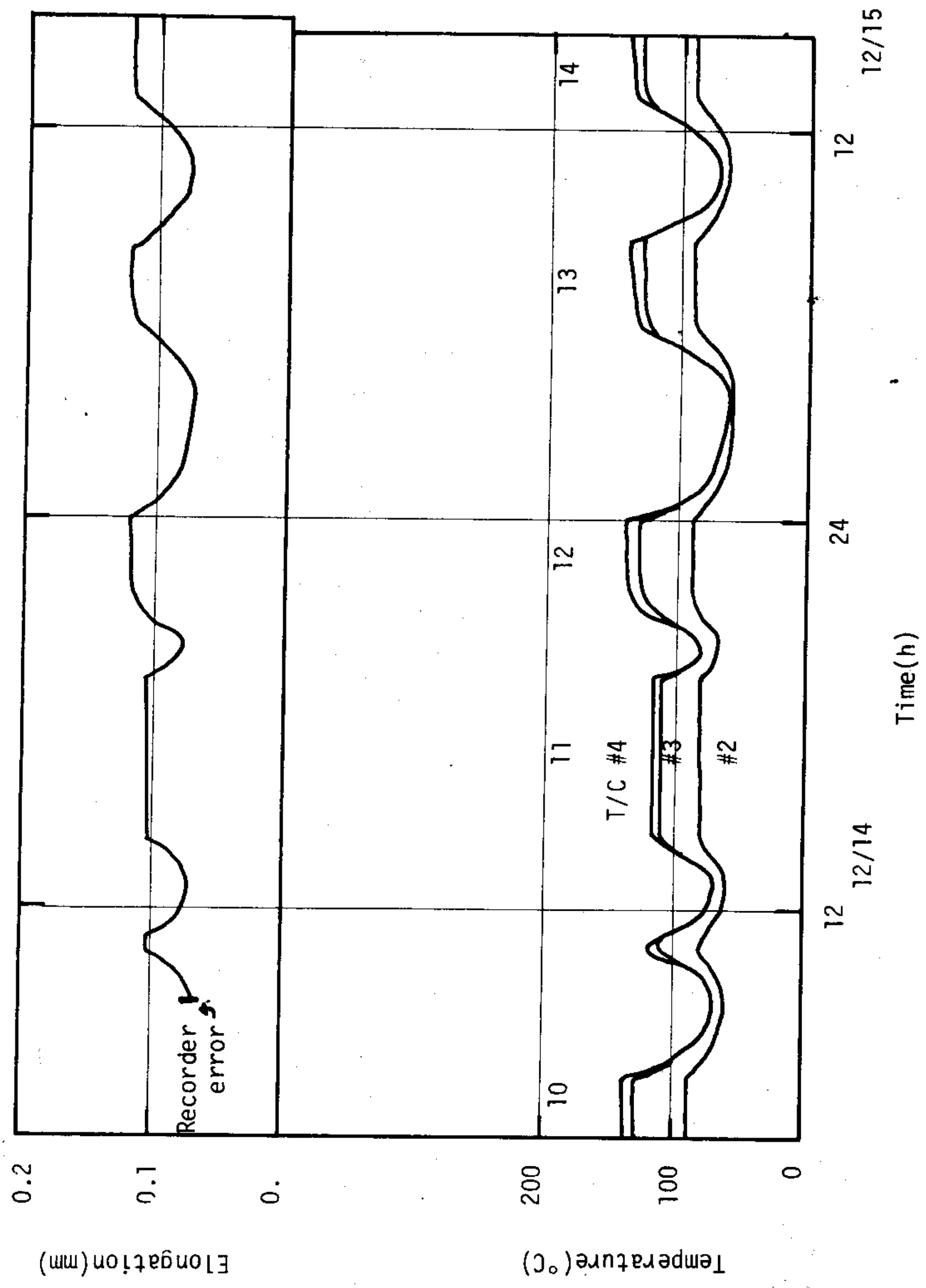

Fig. 9 (continued)

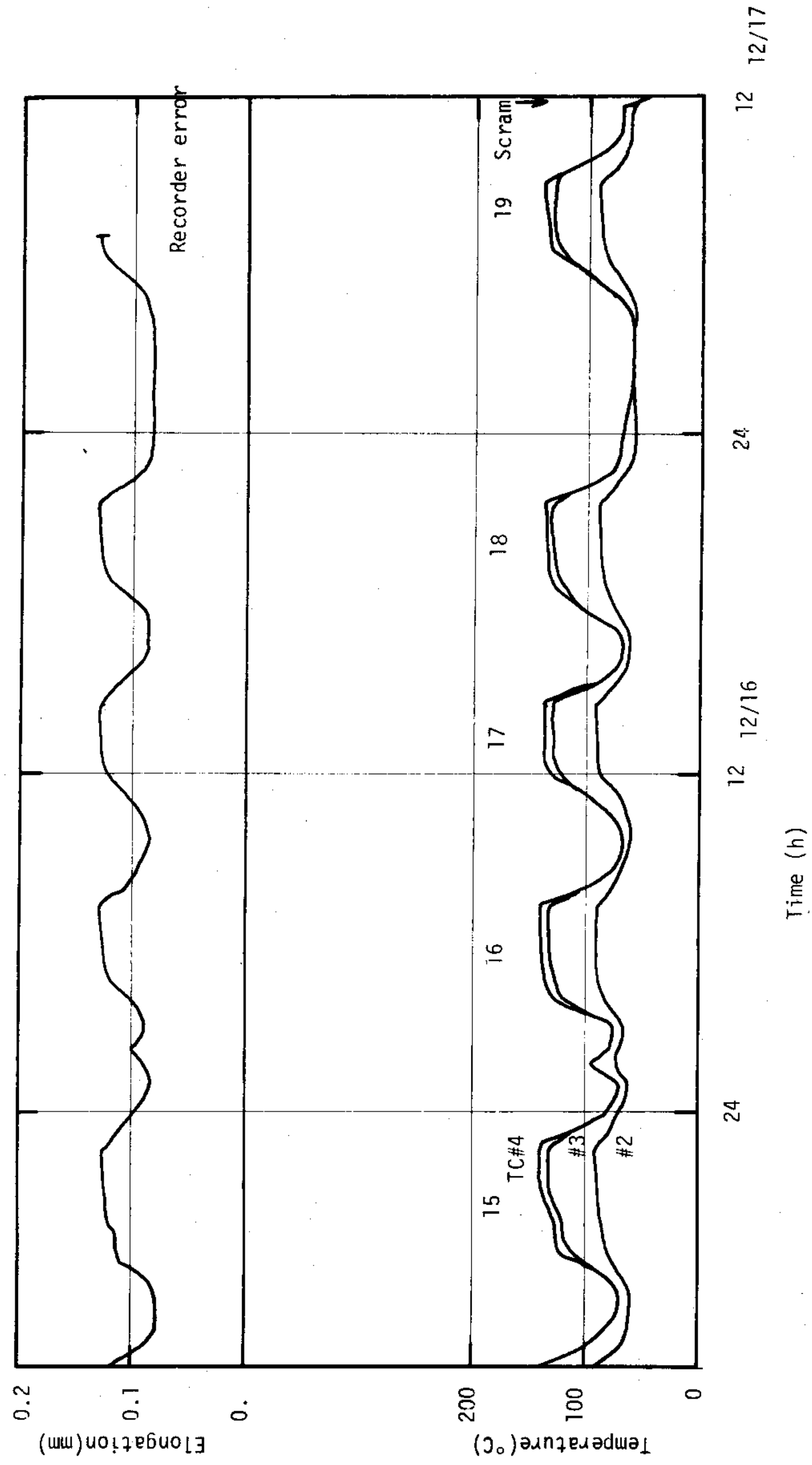

Fig. 10 (continued)

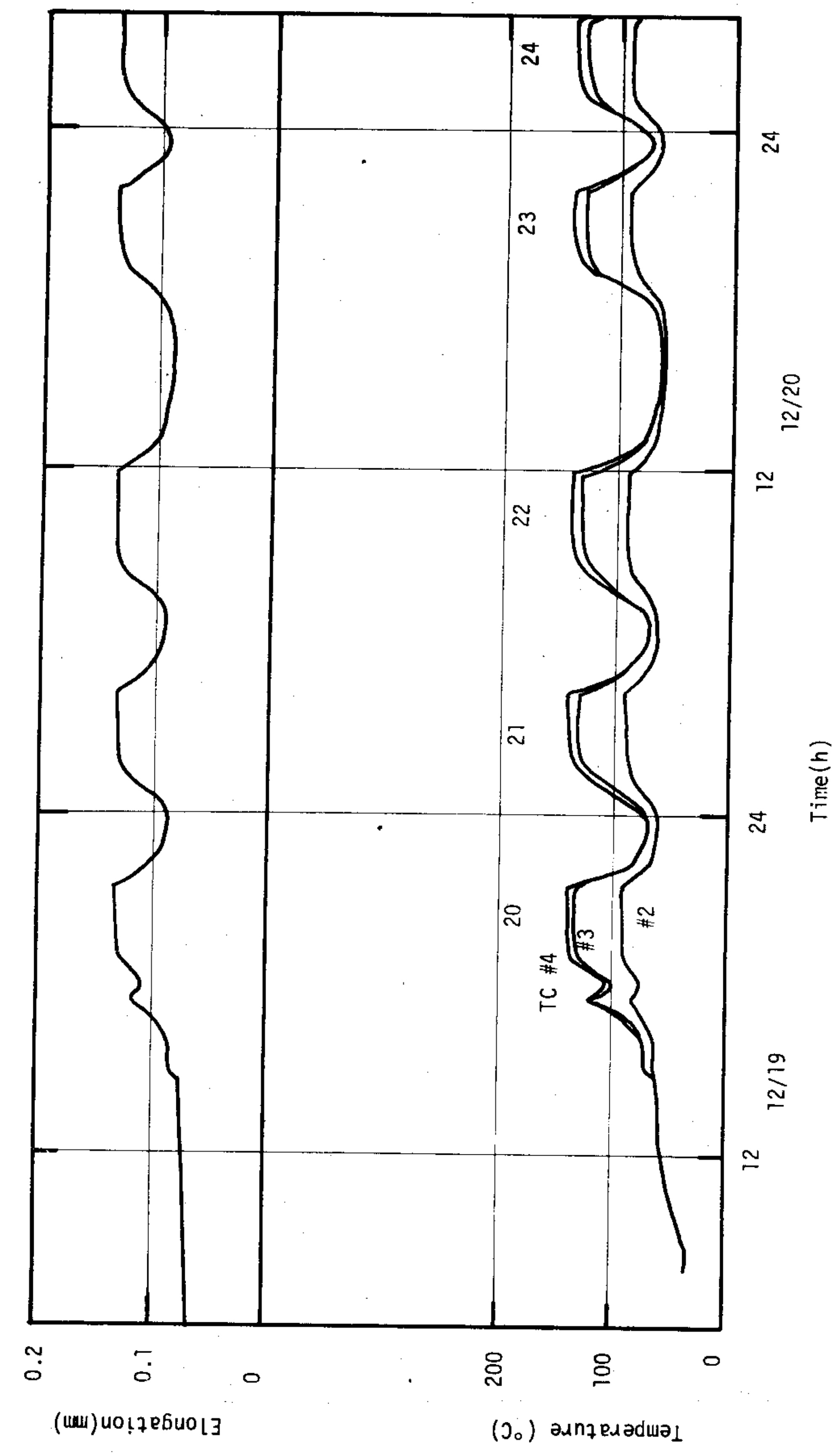

Fig. 11 (continued)

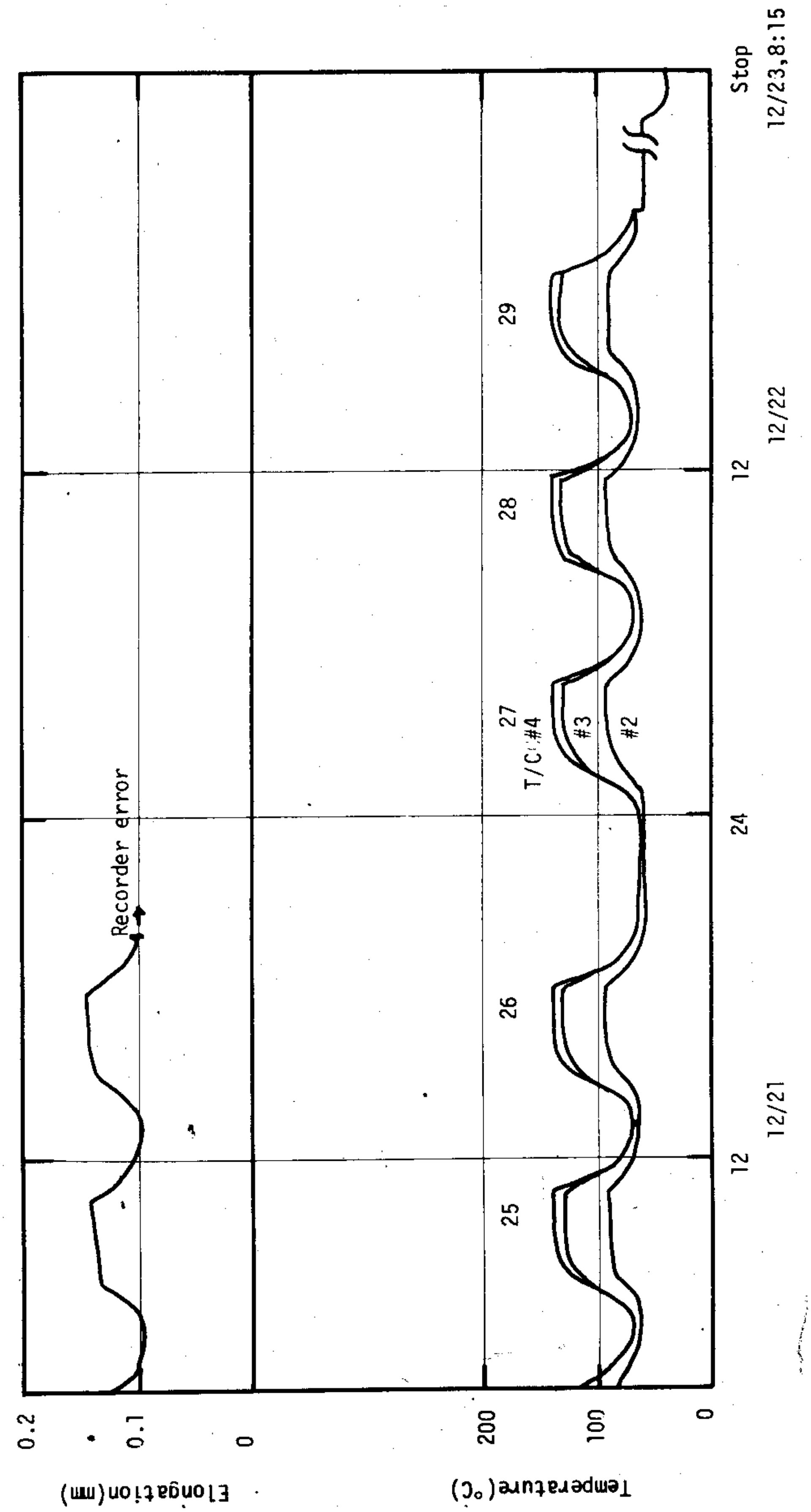

Fig. 12 (continued)

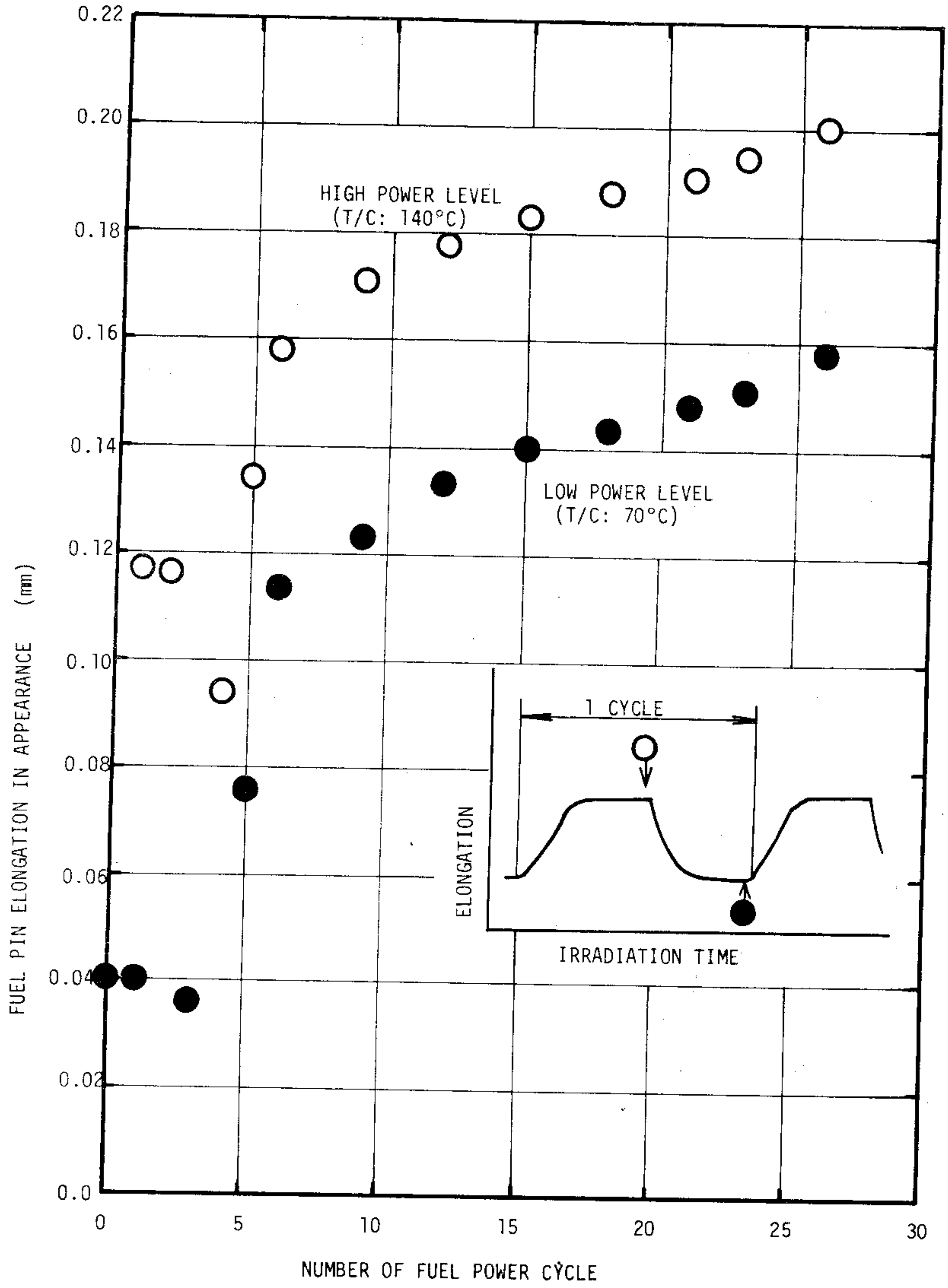

Fig. 13 Fuel pin elongation in appearance as a function of numbers of cyclic power.

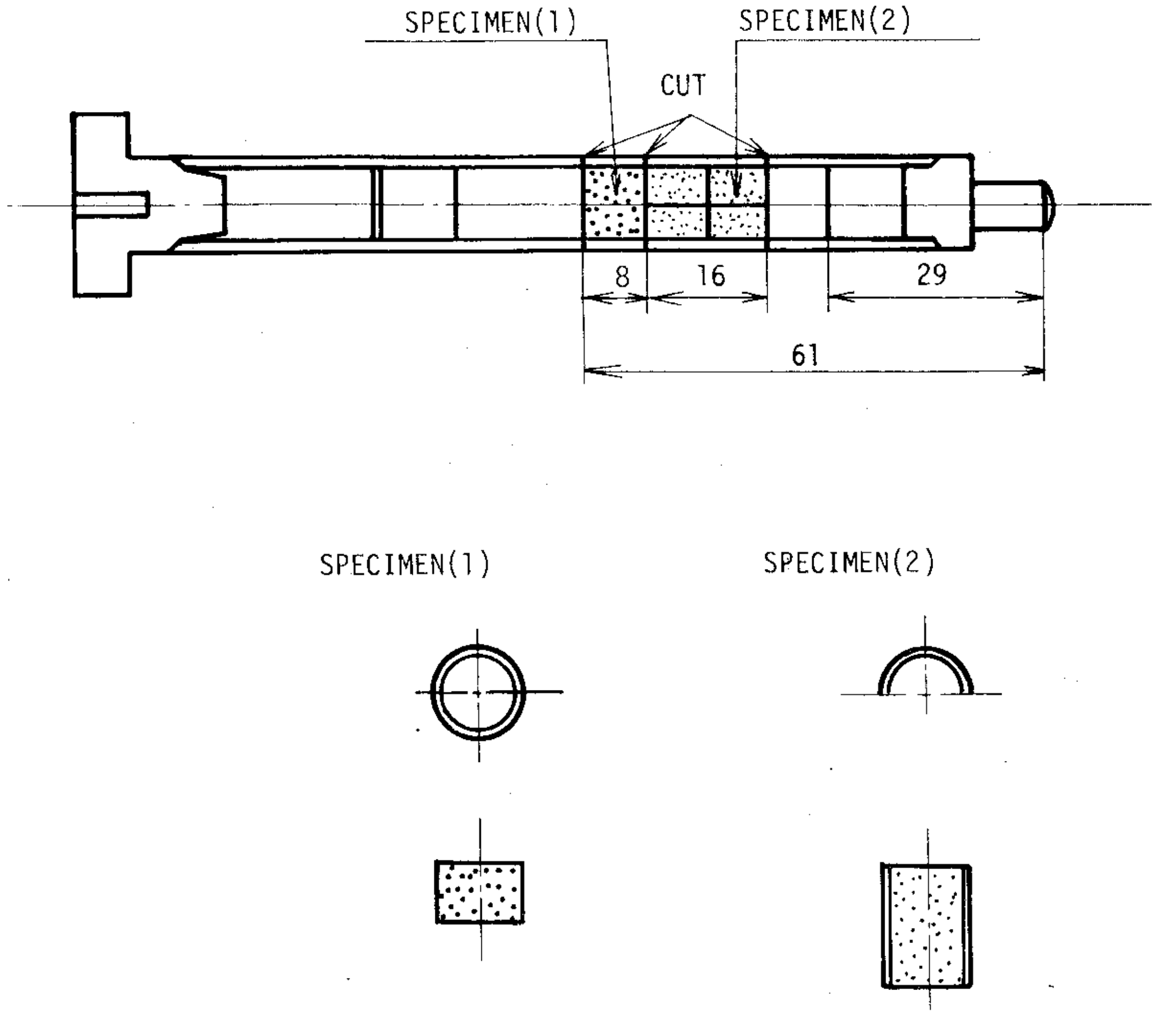

Fig. 14 Schematic drawings of cutting position of fuel rod, used for metallographic observation.

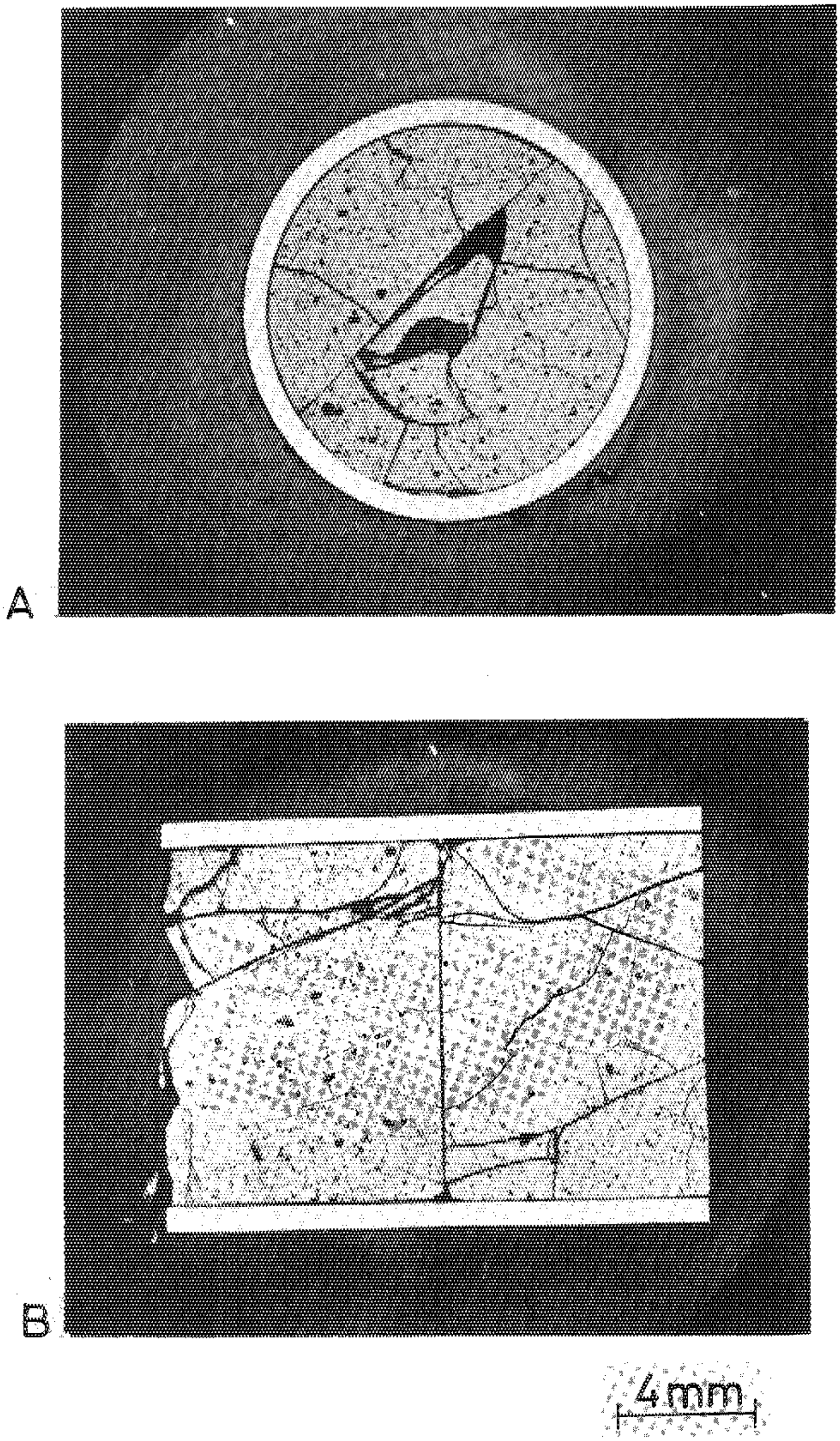

Fig. 15 Photomicrograph of power cycled UO_2 pellet, upper: cross sectional area of pellet and lower: longitudinal area of pellet.