Test of High Temperature Neutron Detectors(V)

−SK 400 Irradiation Tests−

April., 1976

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Abstract

One neutron detector was tested for evaluation of suitability for use in 'Japan Experimental Fast Breeder Reactor'. The tested compensated ionization chamber (Type: SK-400) from Reuter Storks, U.S.A., was selected as the test detector, for the power range neutron detector, "JOYO". Main purpose of this test was to determine the long term high temperature irradiation characteristics of the chamber. Total irradiation during the test period was 1.3×10^{16} nvt, under temperature conditions of 200 °C (normal) and 320 °C (maximum). The test result was reasonable as indicated below and showed no essential change in detector characteristics during the irradiation.

Detector insulation	10^{13} ohm
Gamma compensation	95%
Neutron Sensitivity	3.64×10^{-14} A/nv
Linearity	Deviation 2%

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1. Preface

The neutron detector SK-400, which was used in the present test, was obtained in 1972 and subjected to characteristic tests at that time. (PNC Report SJ 201 72-39) The SK-400 detector (Production No. N-2595), which showed rather large change in gamma compensation at high temperatures when tested at that time, was modified by its manufacturer, the Reuter Stokes Co. of the U.S.A., and delivered again in August 1974. After modification, it was named RS-C1-2412-401 (commonly called SK-400), simply because the manufacturer's naming had been in the meantime. The modified detector has replaced the previously used voltage compensation with volume compensation and has been so designed as to prevent the changes occurring in the characteristics of ionization gas inside the detector at high temperatures. The Reuter Storks Co. tested the detector at high temperature cycles and made certained that there occurred no characteristic changes. However, the effect of high-temperature irradiation has not yet been ascertained. The following are the main results of the short-term characteristic test that was performed last year. (PNC Report SJ 201 74-30)

Gamma sensitivity: $S_\gamma (20℃) = 1.45 \times 10^{-11}$ A/R/H
                        $S_\gamma (300℃) = 1.47 \times 10^{-11}$ A/R/H

Gamma compensation: 20℃   :   93.3%
                        300℃   :   97.8%

Neutron sensitivity: $S_n (20℃) = 3.64 \times 10^{-14}$ A/nv
                        $S_n (300℃) = 3.64 \times 10^{-14}$ A/nv

The present test was carried out in order to make certain that there occur no changes in the characteristics of the neutron detector at

high-temperature irradiation. In this test, the detector was exposed to a neutron irradiation of about 10^{16} nvt, far lower than 6×10^{16} nvt, an estimated neutron dose when it was assumed that the "JOYO" reactor would be operated at full power for two years, but enough to evaluate the high temperature irradiation effect on the detector.

2. SK-400 Irradiation Test

2-1. Introduction

The in-reactor high temperature test equipment of PNC the Power Reactor and Nuclear Fuel Development scheduled for use in this high-temperature irradiation test of the gamma compensated neutron detector under this contract went out of order immediately before the test and it was impossible to repair and therefore a new in-reactor test equipment was designed and fabricated under a separate contract. The test equipment consisted was a 7,500 mm water sealed pipe consisting of three aluminum pipes of 120 mm in outside diameter, joined together end to end, and with a lead weight of about 30 kg attached to offset its buoyancy. This heat pipe has a 400 mm detector holder for lifting the detector so that the center of the active area of SK-400 detector may be in the center of the "TTR-1" core. Since the characteristic test was to be carried out at 200 °C (normal) and 320 °C (maximum), a nichrome wire was wound round the SK-400 detector to raise the temperature. An air gap of 10 mm was provided between the detector and the water-sealed pipe in order to prevent the water-sealed pipe from rising in temperature to cause the reactor cooling water to boil. To control the temperature, three thermocouples were used to monitor the temperature and the heater power was controlled by the thyristor. A 6 mm of plastic shield mixed with boron and a 60 mm thick lead shield were used to shut off the neutrons and gamma rays coming out from the reactor through the water-sealed pipe.

The shielding effect against gamma-rays was an order of magnitude before and behind the shields. Fig. 2-1 shows a simplified representation of the heating pipe and Table 2-1 shows the inspection table of the completed heat pipe.

Using the above heating apparatus, the neutron detector to be tested was subjected to irradiation of about 10^{16} nvt at temperature of 200 °C (normal) and 320 °C (maximum). The heating was started before the normal start-up of the reactor for a high power output operation and was terminated with the end of the reactor operation. The temperature was maintained at room temperature level almost at all times except during irradiation.

2-2. Test Method

The heat pipe fitted with the heater and thermocouples was held in a fixed position near the center of the core in the TTR swimming pool to irradiate the SK-400 neutron detector. The heating method is illustrated in Figs. 2-2 and 2-3.

A scene of the TTR irradiation test is shown in Photo 2-1. The irradiation test was conducted mostly at the maximum power output of 100 kW (about 8 x 10^{10} nv). The irradiation test at 100 kW reactor operation was carried out four hours a day at the rate of two to three days a week and the test was continued for about one month. Finally the irradiation amounted to 3.32 x 10^{16} nvt.

Measurements were made of insulation resistance and gamma compensation while the reactor was shut off. The neutron sensitivity (signal current) and power output linearity were measured while the reactor was in operation.

The measurement of insulation resistance was to be made by measuring the flow of electric current but the heat pipe containing SK-400 was fixed near the center of the reactor core and therefore the ionization current which was caused by the residual gamma-rays was so large that it was impossible to make direct measurements of the

leakage current. So, we observed the plateau characteristics of the currents flowing across the electrodes and the case (actually the residual gamma current) and took their gradient as the insulation resistance. We measured the current plateau by applying a voltage ranging from 0 to 500 V across the electrode and the case. A measuring method of this cannot be said to produce a very accurate value of insulation resistance, for the deterioration of insulator in the gamma field is generally known but we accepted it as inevitable, considering the positional reproducibility because our main purpose was the measurement of the irradiation effect.

As for the gamma compensation, we determined it by measuring the dual chamber current and compensation characteristics, using the residual gamma-rays during the shut-off period of the reactor. The dual chamber current is a current that flow in the signal electrode when currents of equal potential are applied to the H.V. and Comp. electrodes. In the actual calculation, we used a value equal to one half of the dual chamber current, assuming the gamma chamber and the neutron chamber were equal in volume.

To determine the compensation characteristic, we obtained a compensation curve by applying a voltage +600 V to the H.V. electrode and a voltage ranging from 0 to -800 V to the Comp. electrode. From those values, the uncompensation can be calculated as follows.

$$\text{Uncompensation} = \frac{\text{Current of compensation curve}}{\frac{1}{2} \text{ of dual chamber current}} \times 100 \ (\%)$$

Figs. 2-4 and 2-5 show the block diagrams of the dual chamber and compensation curve measurement arrangements. These characteristics were measured at every $(1 \sim 2) \times 10^{15}$ nvt of irradiation to

observe the changes in the characteristics with the changes in irradiation.

As for the measurement of neutron sensitivity, since the detector was in a fixed position, assuming that there would be no change in the neutron flux (readings of CIC for reactor control) during irradiation, we measured the signal current and considered the changes in its value as the changes in the neutron sensitivity. All measurements, except the measurement of power output linearity, were made at the reactor power outputs of 5 kW and 100 kW and at 200 °C in most cases. The same wiring connections as in the case of compensation characteristic measurement were used in the measurement of the signal current. The plateau characteristic was obtained by varying the H.V. from 0 V to 800 V with Comp. maintained at -300 V.

The power output linearity was measured in the similar manner as in the case of the above-stated neutron sensitivity measurement: the reactor power output was increased in steps from 2 W to 100 kW and measurements were made of the output current at the different levels of reactor power. The measurements were made under such conditions that H.V. = 600 V and Comp. = -300 V.

2-3. Test Results and Review

2-3-1. Insulation Resistance

As was mentioned in "2-2 Test Method", the gradient of the plateau characteristics of the currents that are caused to flow by gamma-rays is regarded as the insulation resistance in this study. Fig. 2-6 shows that the resistance has almost the same value, that is, about 10^{13} Ω in the initial and final stages of irradiation and it is within the range between 10^{11} Ω and 10^{12} Ω in the middle stage.

This is presumably due to the fact that the gamma-ray dose in the middle stage of irradiation was 10^3 R/H or about three orders of magnitude larger than that in the initial and final stages of irradiation. In Fig. 2-6, the resistance at the termination of irradiation is split into two. The resistance at 1 R/H occurred when the detector was removed about 1.5 m away from the reactor.

From the above findings, it can be said that there will be no deterioration of the insulation due to the neutron flux of 10^{16} nvt.

2-3-2. Gamma Compensation

Fig. 2-7 shows the uncompensation characteristic at the neutron irradiations of 9.5×10^{12} nvt, 5.79×10^{15} nvt and 1.32×10^{16} nvt with H.V. being 600 V and the temperature 20 °C. Comparing the three characteristics at the compensation voltage of -300 V, the uncompensation marked with o is 7.5% at 9.5×10^{12} nvt and that marked with x at 5.79×10^{15} nvt and that marked with • at 1.32×10^{16} nvt are about 6.0%. Such differences between these values of uncompensation are related to the magnitude of between these values of uncompensation are related to the magnitude of gamma-ray dose.

"dose variation characteristic"; At the termination of neutron irradiation (1.32×10^{16} nvt) we changed the position of the heat pipe (in-reactor high-temperature test apparatus), which had so far been held in a fixed position, thereby to vary the dose of gamma-rays remaining in the reactor and measured the gamma compensation at different level of gamma dose. As a result, we found that the value of uncompensation tended to grow smaller as the gamma dose grew larger within the range of gamma dose between 10^1 R/H and 10^3 R/H. The above characteristic is shown in Fig. 2-8.

"temperature variation characteristic"; We measured the un-compensation with H.V. being 600 V at 20 $^\circ$C, 200 $^\circ$C and 320 $^\circ$C when the neutron irradiation was 1.32 x 10^{16} nvt. Thus obtained results are shown in Fig. 2-9. Comparing the three characteristics where the compensation voltage is -300 V, the uncompensation is 6.1% at 20 $^\circ$C, 4.8% at 200 $^\circ$C and 6.5% at 320 $^\circ$C. Fig. 2-10 shows the temperature characteristics of uncompensation under such conditions that H.V. = 600 V, compensation voltage = -300 V, neutron irradiation = 1.32 x 10^{16} nvt and gamma-ray dose = 1.35 x 10^3 R/H. From this graph, it is seen that the uncompensation has the lowest value within the temperature range between 100 $^\circ$C and 200 $^\circ$C and when the temperature rises close to 300 $^\circ$C the uncom-pensation has about the same value as that at 20 $^\circ$C.

"temperature transit variations"; The values of uncompensation, which were reported in SJ-201 74-30, were 6.7% at 20 $^\circ$C and 2.2% at 300 $^\circ$C when H.V. = 800 V. That is to say that the uncompensation at 300 $^\circ$C was about one-third of that at 20 $^\circ$C. This was presumably due to the fact that measurements were made before the inside of the detector was not heated to 300 $^\circ$C as yet. In order to confirm this presumption, we used a 2-pen recorder to record the surface temperature of the detector and the signal current at H.V. = 600 V and Comp. = -300 V to measure the response the detector to temperature rises. As a result, we found that the temperature characteristics of the detector would not become stable until 1.0 to 1.5 hour after the thermocouple fixed onto the surface of the detector had reached the preset temperature. The above measurement results are graphically shown in Fig. 2-11. Such variations in the current were presumably ascribable to the fact that the SK-400

detector had three electrodes and temperature differences occurred among the three electrodes.

"irradiation characteristics"; Fig. 2-12 shows the relationship between neutron irradiation and uncompensation at 20 $^{\circ}$C and 200 $^{\circ}$C when H.V. = 600 V and Com. = -300 V. The uncompensation at 20 $^{\circ}$C was about 6.0% and it little changed when the irradiation was increased (when it reached 10^{16} nvt) and its change so negligibly small as only 4.8% even at 200 $^{\circ}$C. In Fig. 2-12, however, the uncompensation is less than 4.8% at irradiation below 8×10^{15} nvt. This was presumably due to the fact that measurements were made before the detector was properly heated as mentioned above.

In the present irradiation tests, there occurred no discharge pulse and we were able to confirm the stable operation of the detector. However, the detector alone was heated in the present tests and therefore it is possible that some different results may be obtained if the part of the cable is heated, too. As for the gamma compensation, it can be said that its value will not change even at the irradiation of 10^{16} nvt.

2-3-3. Neutron Sensitivity and Plateau Characteristic

In order to evaluated the change of neutron sensitivity with irradiation, a graph in which the values of signal current at 100 kW and 5 kW of reactor power output are plotted against the integrated neutron irradiation is shown in Fig. 2-13.

During the irradiation test, the detector was once removed away from the normal irradiation position as required by other test and for this reason the neutron flux was decreased from 8.86×10^{10} nv (100 kW) to 7.80×10^{10} nv (100 kW). The standardized value of signal current is shown in Fig. 2-13. As for the measuring

conditions the excitation voltage was 600 V and the Compensation
voltage was -300 V and the temperature was 200 $^\circ$C. As is evident
from this figure, the neutron sensitivity changed only within the
range of $\pm 3\%$ up to the irradiation of 1.3×10^{16} nvt, suggesting any
particular deterioration of neutron sensitivity due to irradiation.

The SK-400 detector uses 92% enriched boron 10 for a
neutron transforming material. The amount of reaction reduction
at 10^{16} nvt of neutron irradiation is calculated as follows.

Number of reaction boron $N = \sigma \chi \varPhi = 3.84 \times 10^{-5}$

where σ : Nuclear cross section 3837 barn

χ : Boron number

$\varPhi$: Neutron flux $= 10^{16}$ nvt

It follows that $3.87 \times 10^{-3}\%$ of boron is reduced by reaction.

It can be said that the measurement results well agree with
the calculated values.

Fig. 2-14 shows the plateau characteristic when the excitation
voltage was varied from 0 to 800 V while the compensation voltage
was maintained on a constant level of -300 V.

The saturated region was reached at 200 V when the reactor
power output was 5 kW (4×10^9 nv) but it required 600 V to reach
the saturated region when the reactor power output was 100 kW
(8×10^{10} nv). This was because the number of neutron-iron pairs
increased in a high neutron flux and there is a greater probability
of electrons and ions being recombined at a low voltage. To meas-
ure a high neutron flux of about 10^{11} nv, it is suggested to apply a
voltage higher than 600 V.

2-3-4. Power Output Linearity

The measurements of power output linearity at 20 $^\circ$C when the

neutron irradiation was about 10^{10} nvt (before irradiation) (PNC

Report SJ201 74-30) and at 200 °C when the neutron irradiation

was 7.2×10^{15} nvt (in the middle of irradiation) and 1.26×10^{16}

nvt (at the termination of irradiation) under such conditions that

H.V. = 600 V and Comp. = -300 V were equal at the neutron flux

of over 10^7 nv (about 10 W) (below 10^{10} nv).

In the present tests, measurements were made within the range

of neutron flux from 2×10^6 nv to about 1×10^{11} nv and the tested

detector showed good linearity throughout the range.

The characteristics determined in the present tests and those

obtained in the previous tests (PNC Report SJ201 74-30) are

shown in Fig. 2-15. The results of the previous tests (before

irradiation) showed that the value of neutron flux where linearity

was achieved was above 2×10^6 nv at 20 °C and above 3×10^7 nv at

300 °C. This value was about an order of magnitude worse than the

corresponding value (over 2×10^6 nv). This difference was pre-

sumably due to the differences in the heating method, particularly
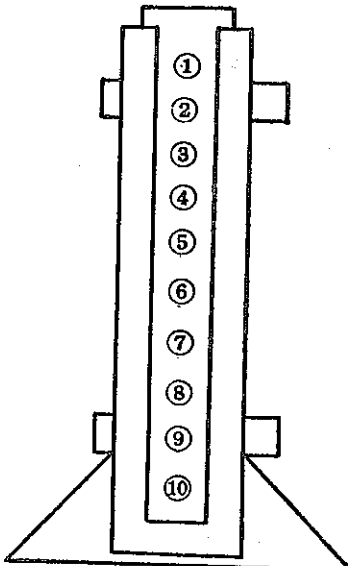
in the heated parts of the detector.

In the previous tests, the in-reactor test apparatus was larger

than that which was used in the present test and therefore not only

the probe of KS-400 but also a part of the cable was in the heated

zone so that the temperature characteristic of the cable affected the

measurement results.

In order to numerically express the evaluation of linearity,

we calculated the average characteristic from the values measured

at the measuring points from 10 W to 1 kW and extended the charac-

teristic to take the difference between thus obtained value and the

value obtained by extending the average characteristic calculated

from the values measured at 100 kW and 2 W and expressed the value in percentage against the value of average characteristic extension. As a result both characteristics obtained in the present tests were below 2%.

3. Fabrication of Disposal Cask and Disposal

The P7A capsule disposal cask, which was designed last year, was fabricated this year. The outer frame of the cask was fabricated with stainless steel plates weld together. Molten lead was poured into the cask heated to about 450 °C to 500 °C slowly and carefully so that no void might occur in it. The cask weighed about one ton by itself. The shielding effect of the cask was checked by nondestructive inspection by use of an isotope (Ra-226, 1mCi), which was moved in a longitudinal direction in the center of the cask so that the gamma rays on the circumferential surfaces of the same height could be measured at 12 points by means of a scintillation meter to make certain that there occurred no change in the measured values. No harmful void was found by this inspection. Thus we were able to complete a disposal cask having a shielding effect of two orders of magnitude as was designed. The measuring points and measured values were as given below. There were some variations in the measured values presumably due to the fact that the radiation source was deviated from the center.

Radiation source position	Means of measured value
1	0.18 ~ 0.24 mR/Hr
2	0.12 mR/Hr
3	0.16 "
4	0.18 ~ 0.22 mR/Hr
5	0.18 ~ 0.22 "
6	0.16 ~ 0.20 "
7	0.16 ~ 0.20 "
8	0.14 mR/Hr
9	0.12 "
10	0.18 mR/Hr
11	Without shield (160 mm) 25.4 mR/Hr

The complete cask was brought to the Japan Atomic Energy Research Institute, where it was submerged in the pool of the JRR-4 reactor and P7A irradiation capsule was placed in it and the cask was covered with a top. Water was slowly withdrawn out of the cask and it was brought to the radioactive waste disposal station of the Institute.

4. Postscript

Irradiation tests were carried out on the gamma-compensated ionization chamber SK-400 (made by Reuter Storks Co.) scheduled for use as a power range detector in the experimental fast breeder reactor "JOYO".

The detector was irradiated for about one month in a Toshiba Teaching and Training Reactor with an integrated neutron flux of 1.3×10^{16} nvt, which was equivalent to about half of the neutron flux of one year when "JOYO" is operated at full power.

The irradiation caused no noticeable changes in the performance characteristics of the detector and it showed such values as given below, which fairly well satisfied the specified values.

1. Insulation resistance: 10^{13} ohm (Spec. 10^{13} ohm)
2. Neutron sensitivity: 3.64×10^{-14} A/nv (Spec. 3-x 10^{14} A/nv)
3. Gamma compensation: 95.2%, 200 $^{\circ}$C (Spec. 97 99.5%)
4. Linearity range: 2×10^{6}, 8×10^{10} nv (Spec. 10^{3}, 10^{10} nv)

5. Acknowledgement

We express our deep gratitude to the staff member in charge of JRR-4 of the Japan Atomic Research Institute for extending their very helpful services in the disposal of P7A after the irradiation test.

Radiation shield

Water sealed pipe

Water level

680

(3659)

(1746)

Detector

Holder

235^ϕ

⑨

⑩

③

②

①

⑧

⑦

⑥

⑤

④

3005

3010

1485

6600

7500
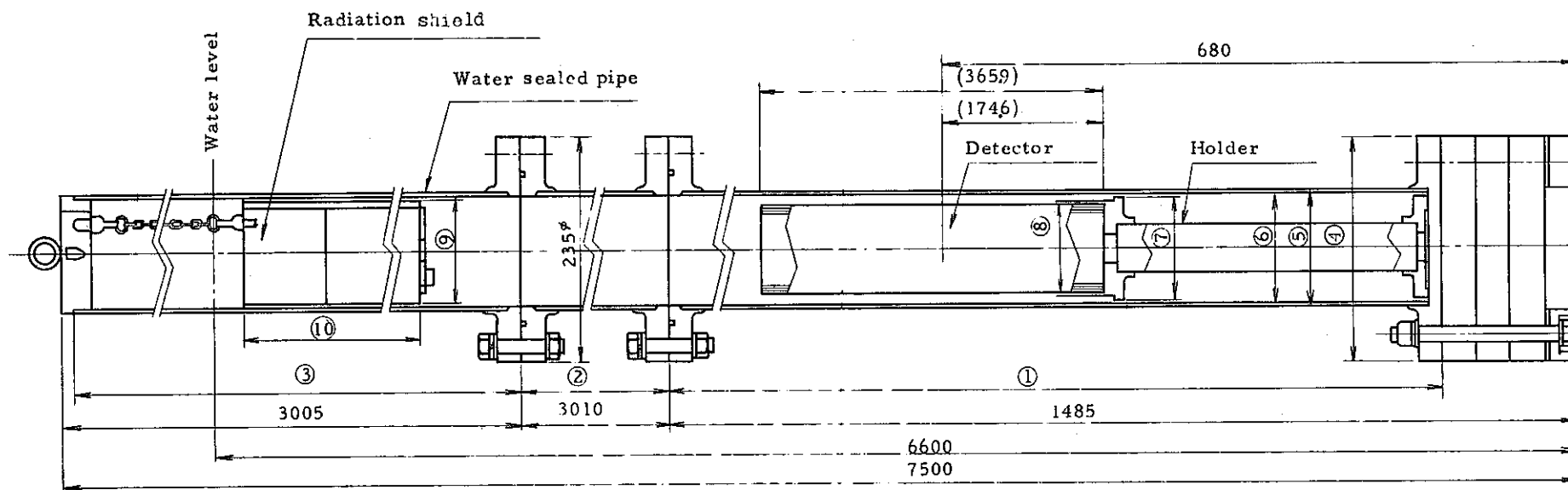
Fig. 2 - 1   Heating Pipe Outline

Table 2-1 Inspection table

(unit: mm)

measured position	Designed value	Inspected value
1	1340	1338
2	3010	3010
3	2995	2995
4	$\emptyset 235$	$\emptyset 235$
5	$\emptyset 120$	$\emptyset 120$
6	$\emptyset 114$	$\emptyset 115$
7	$\emptyset 112 \, ^{+0}_{-0.5}$	$\emptyset 111.5$
8	$\emptyset 94$	$\emptyset 94$
9	$\emptyset 112 \, ^{+0}_{-0.5}$	$\emptyset 112$
10	340	340

Glass wool

Heater   Water sealed pipe

Thermocouple

Detector
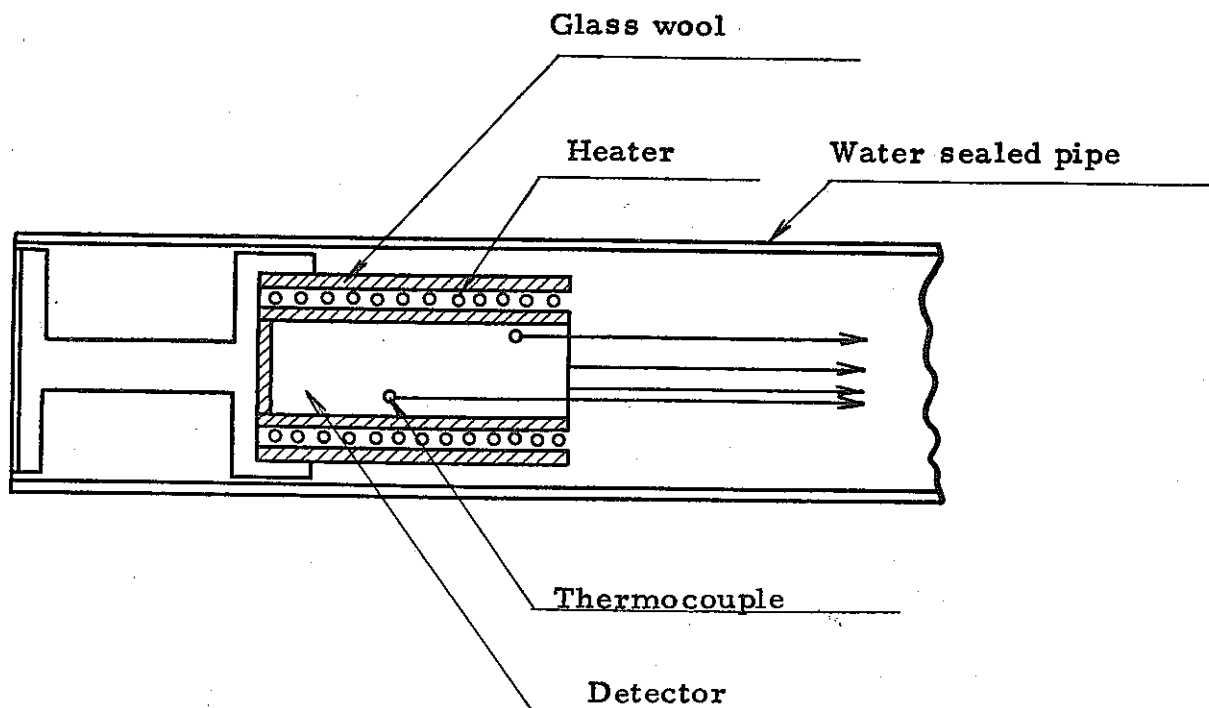
Fig. 2-2   Heater set-up arrangement

Block diagram of measuring circuit

Water sealed pipe

Water

Nuclear reactor

Thermo controller

Detector

Heater

TTR   Thermocouple
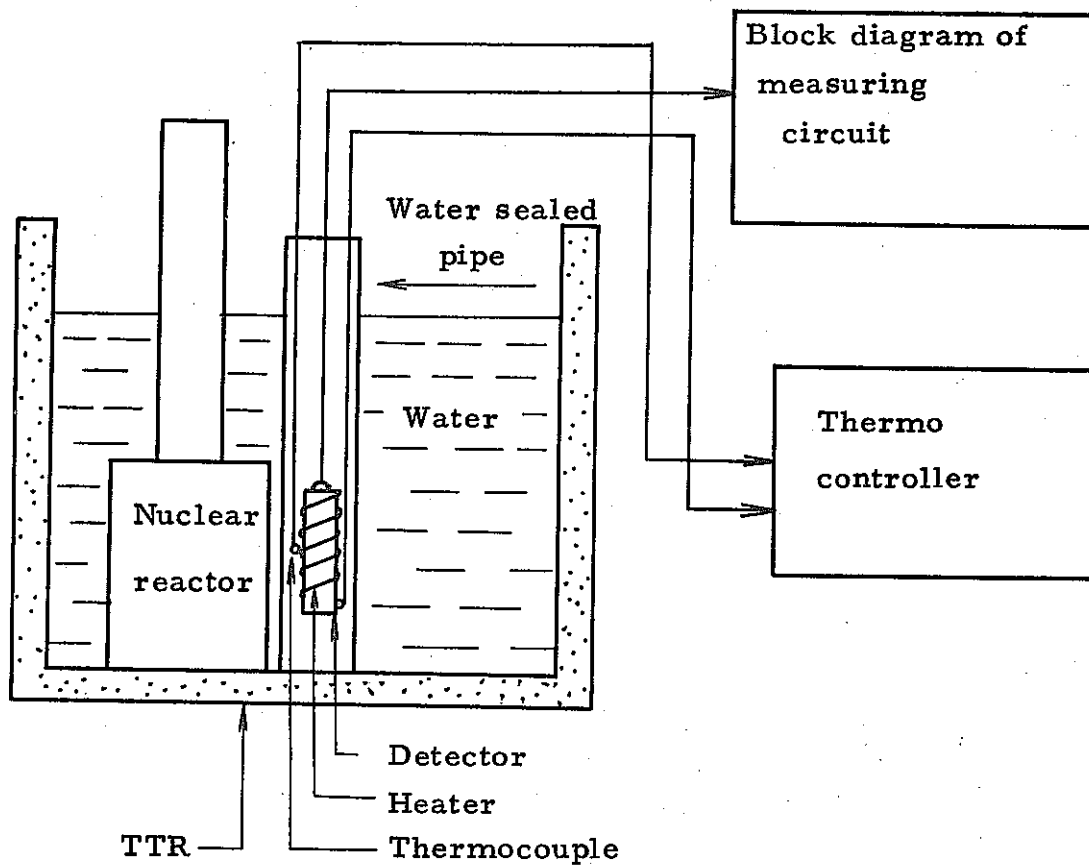
Fig. 2-3   Reactor test arrangement
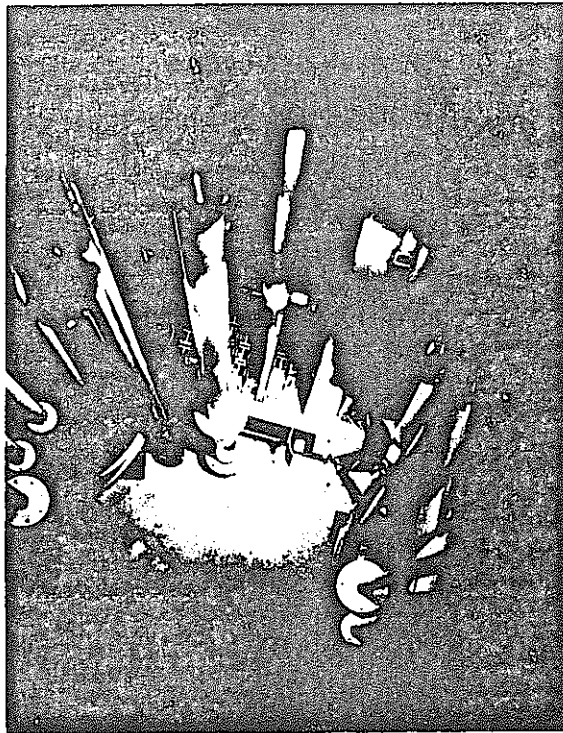
Photo. 2-1   TTR   irradiation test
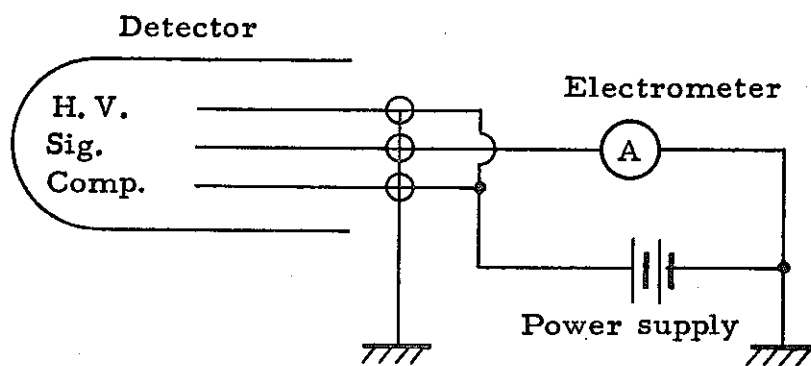
Fig. 2-4   Electrical connection for dual chamber
current measurement
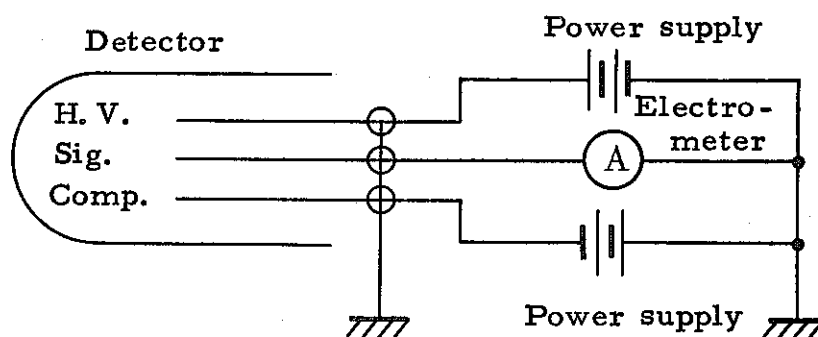
Fig. 2-5   Electrical connection for gamma
compensation measurement
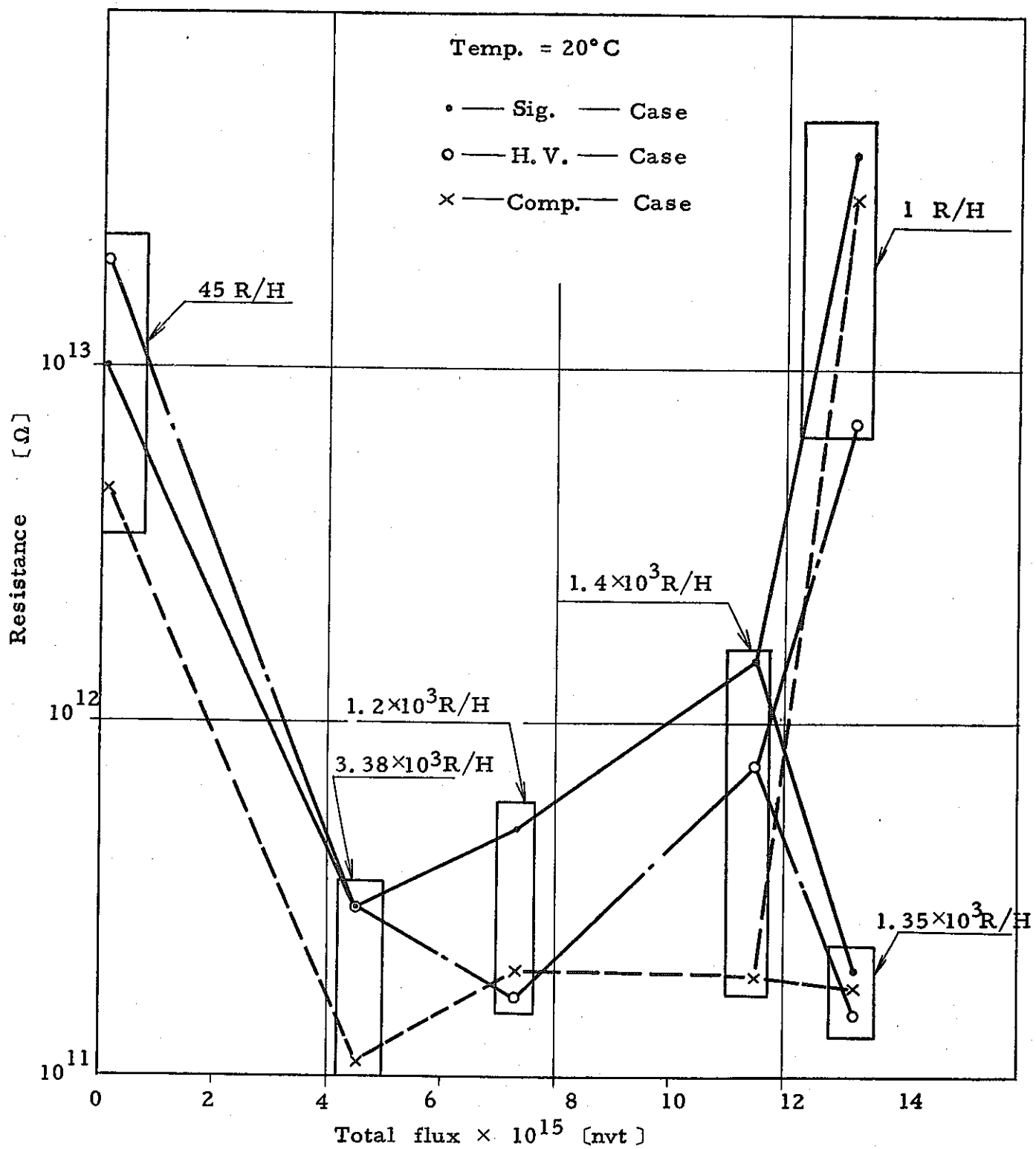
Fig. 2-6 Detector insulation
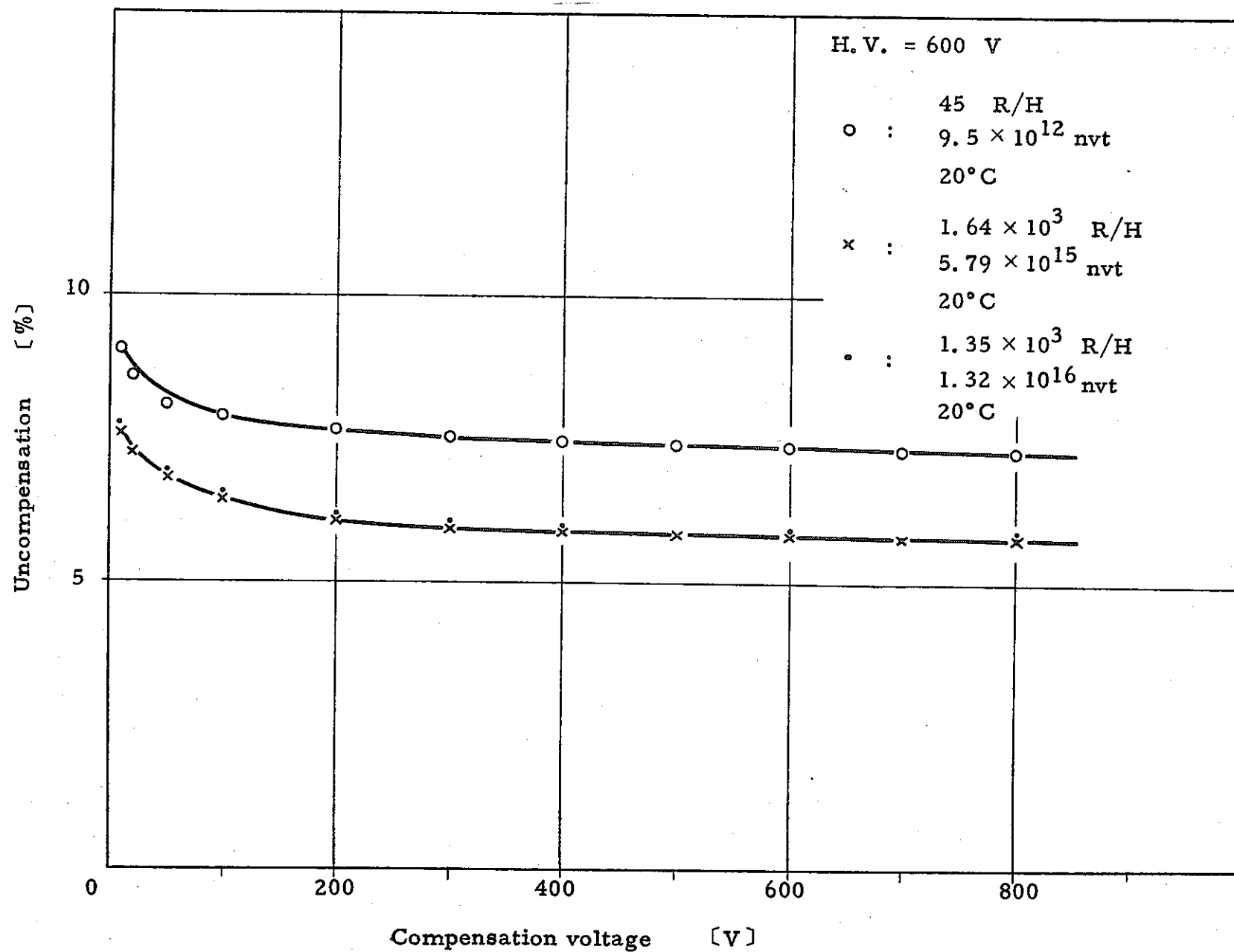
Fig. 2-7 Gamma compensation curve at 20°C
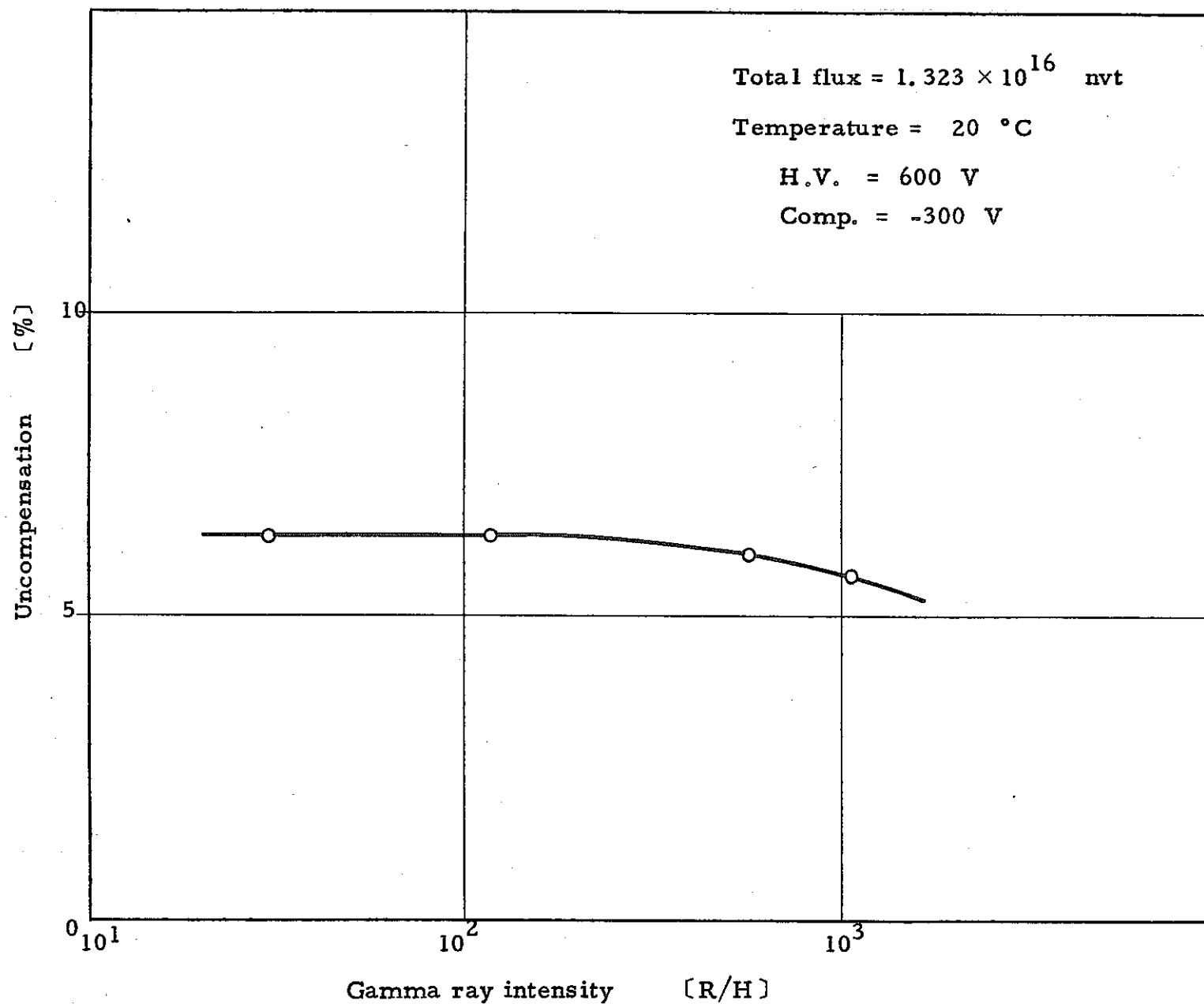
Fig. 2-8 Compensation gamma ray intensity effect
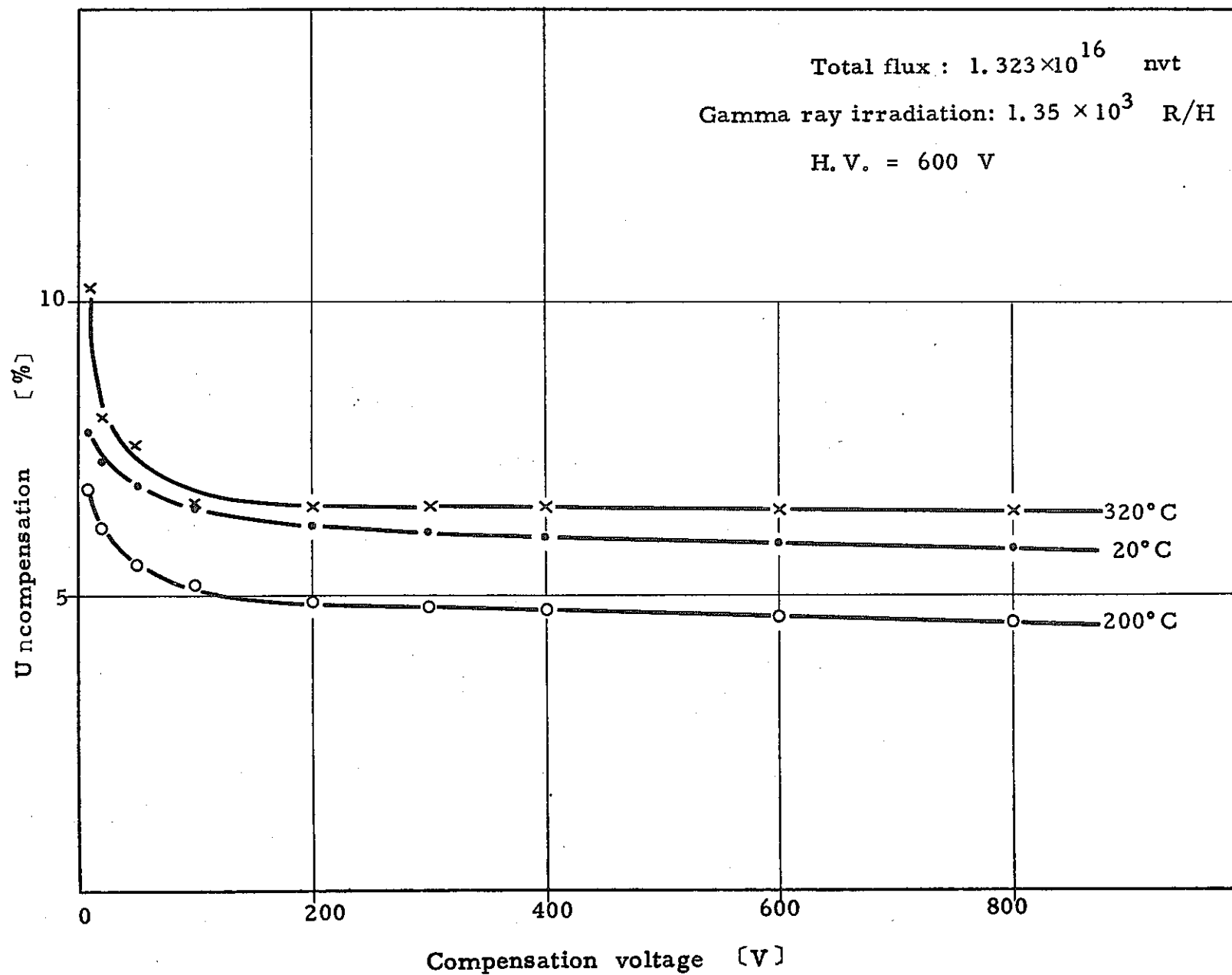
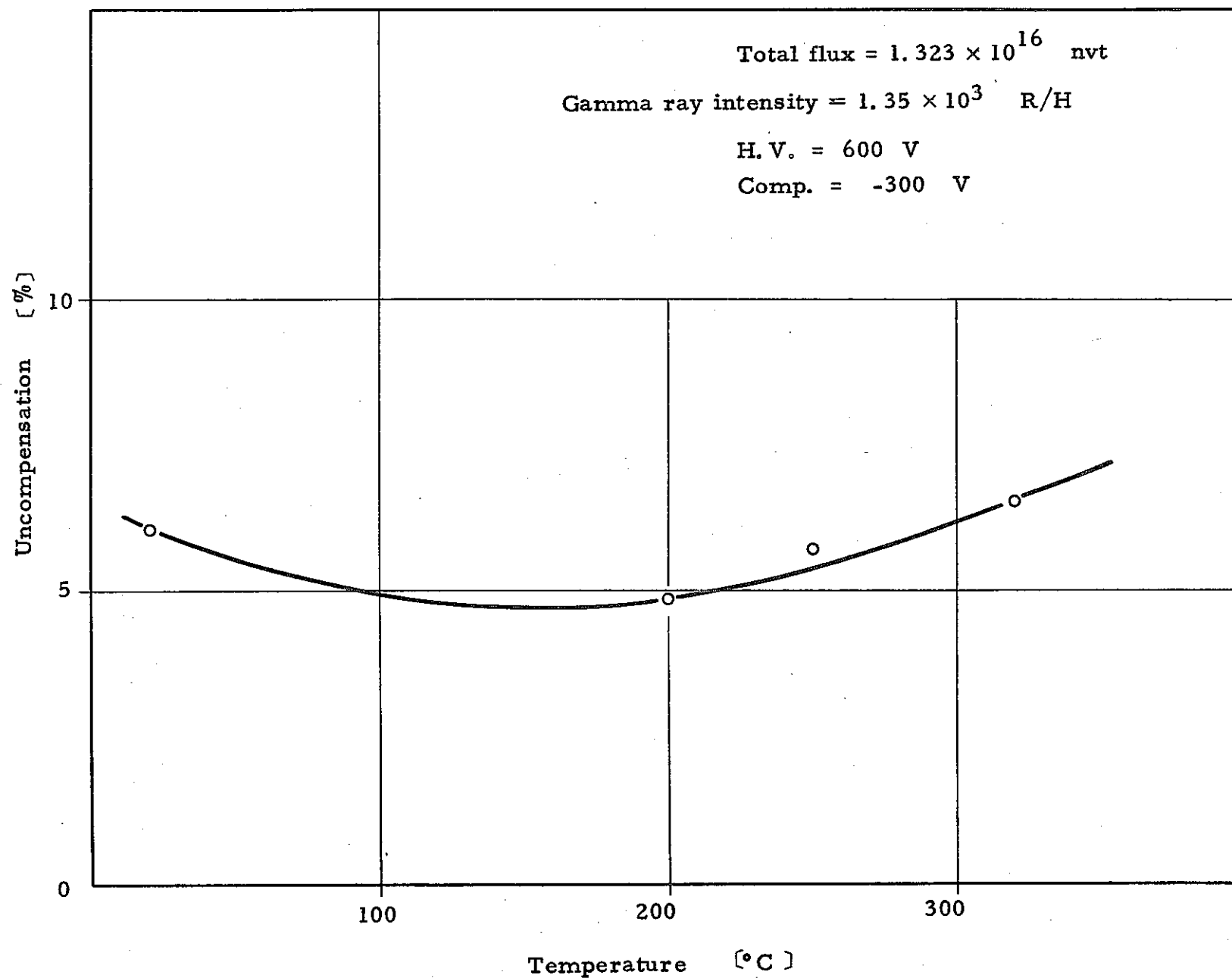Fig. 2 - 9　　Gamma compensation curve at 20°C, 200°C and 320°C

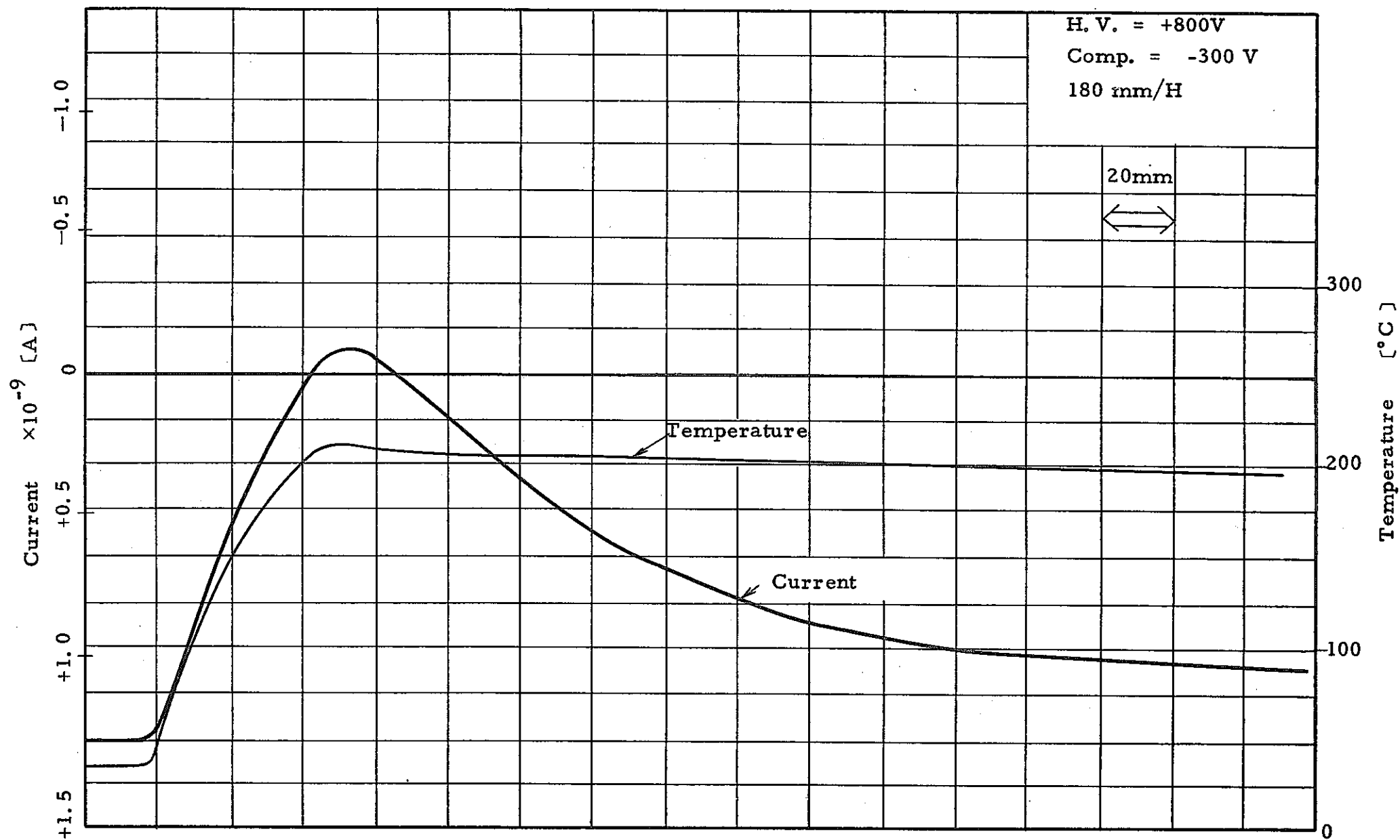Fig.   2-10   Compensation temperature effect

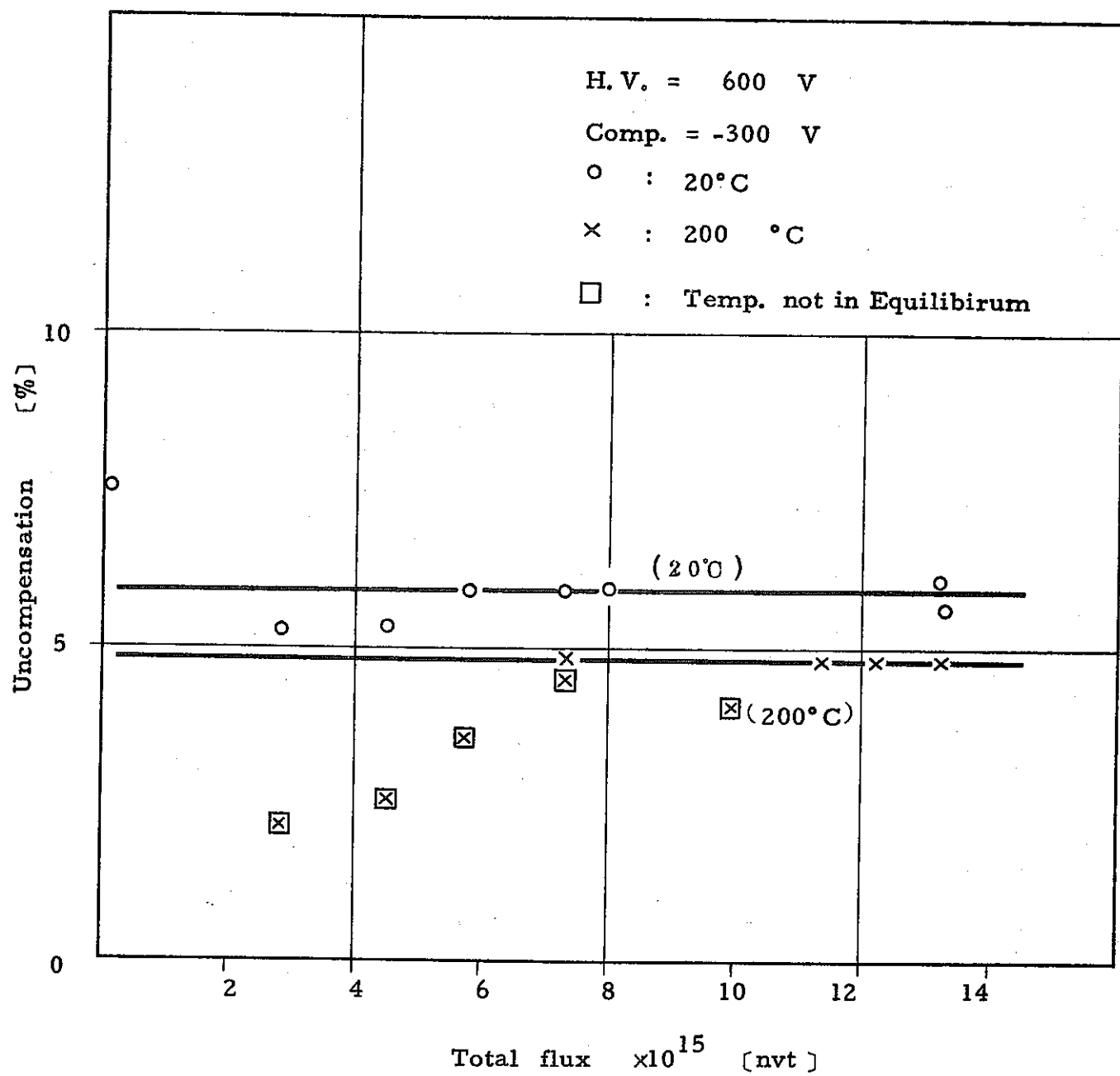Fig. (2-11)   Signal current temperature dependency

Fig. 2-12   Compensation irradiation effect
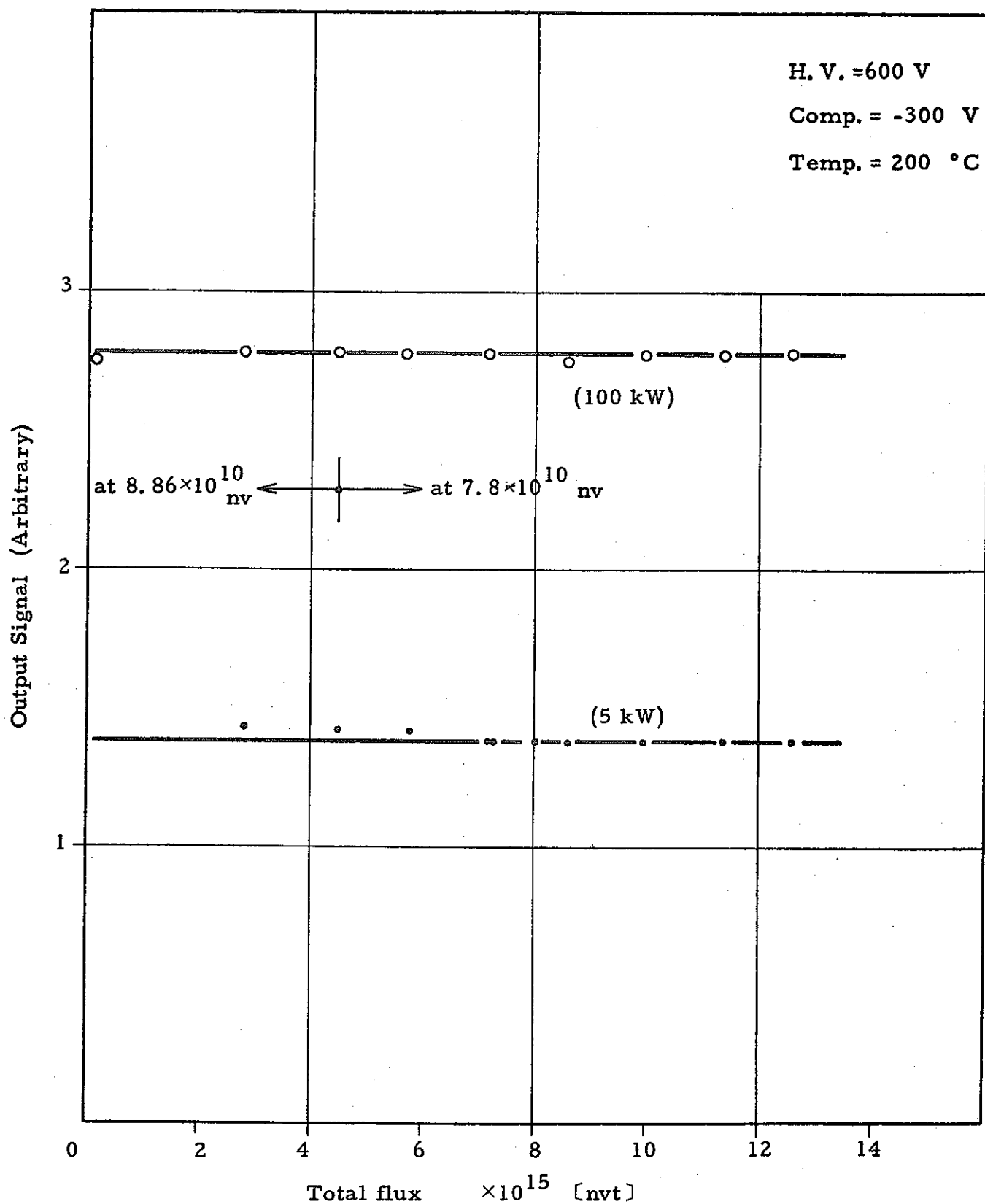
H. V. =600 V

Comp. = -300 V

Temp. = 200 °C

Output Signal (Arbitrary)

(100 kW)

at 8.86×10^{10} nv $\longleftarrow$ $\longrightarrow$ at 7.8×10^{10} nv

(5 kW)

3

2

1

0   2   4   6   8   10   12   14

Total flux $\times 10^{15}$ [nvt]
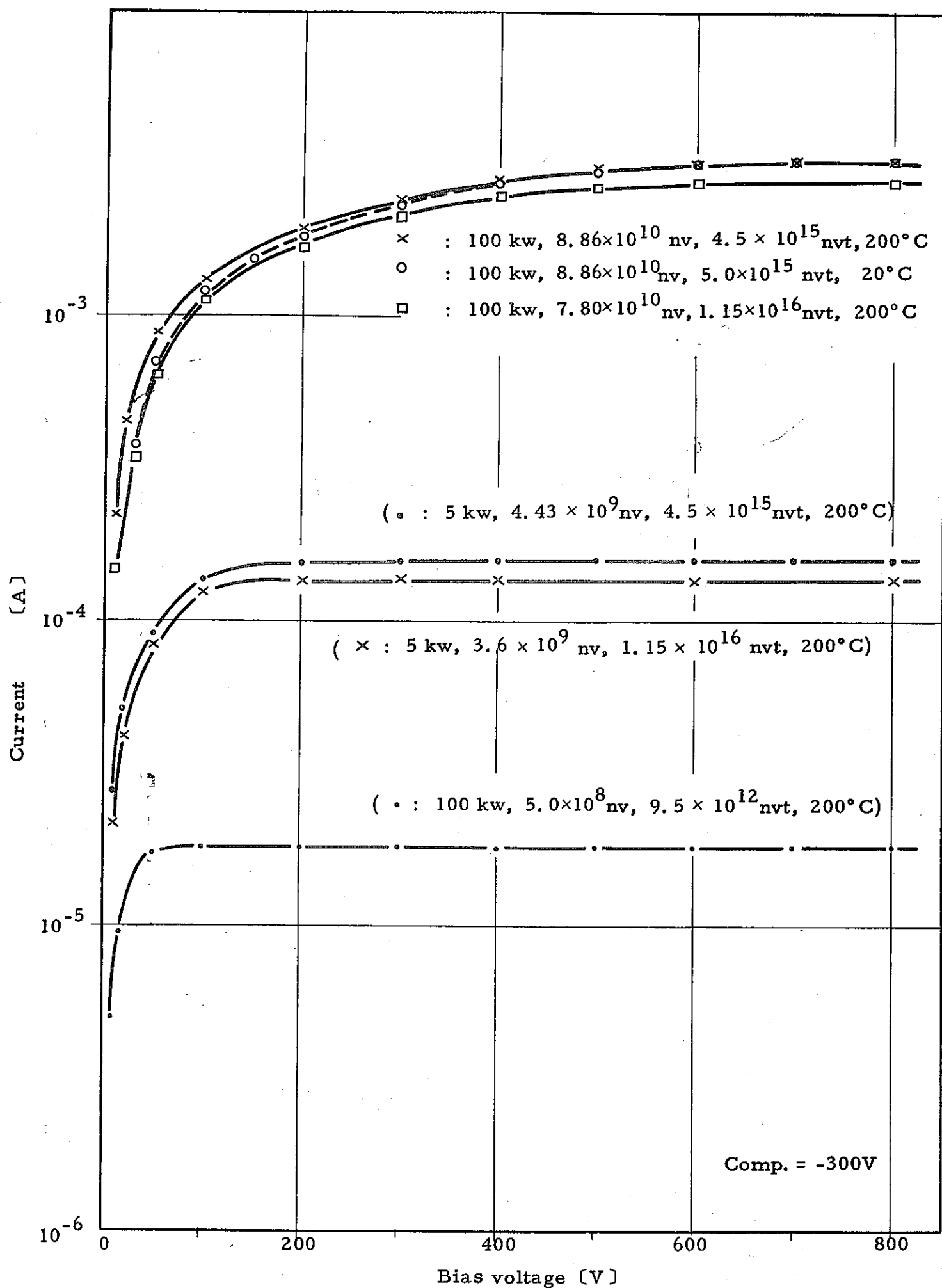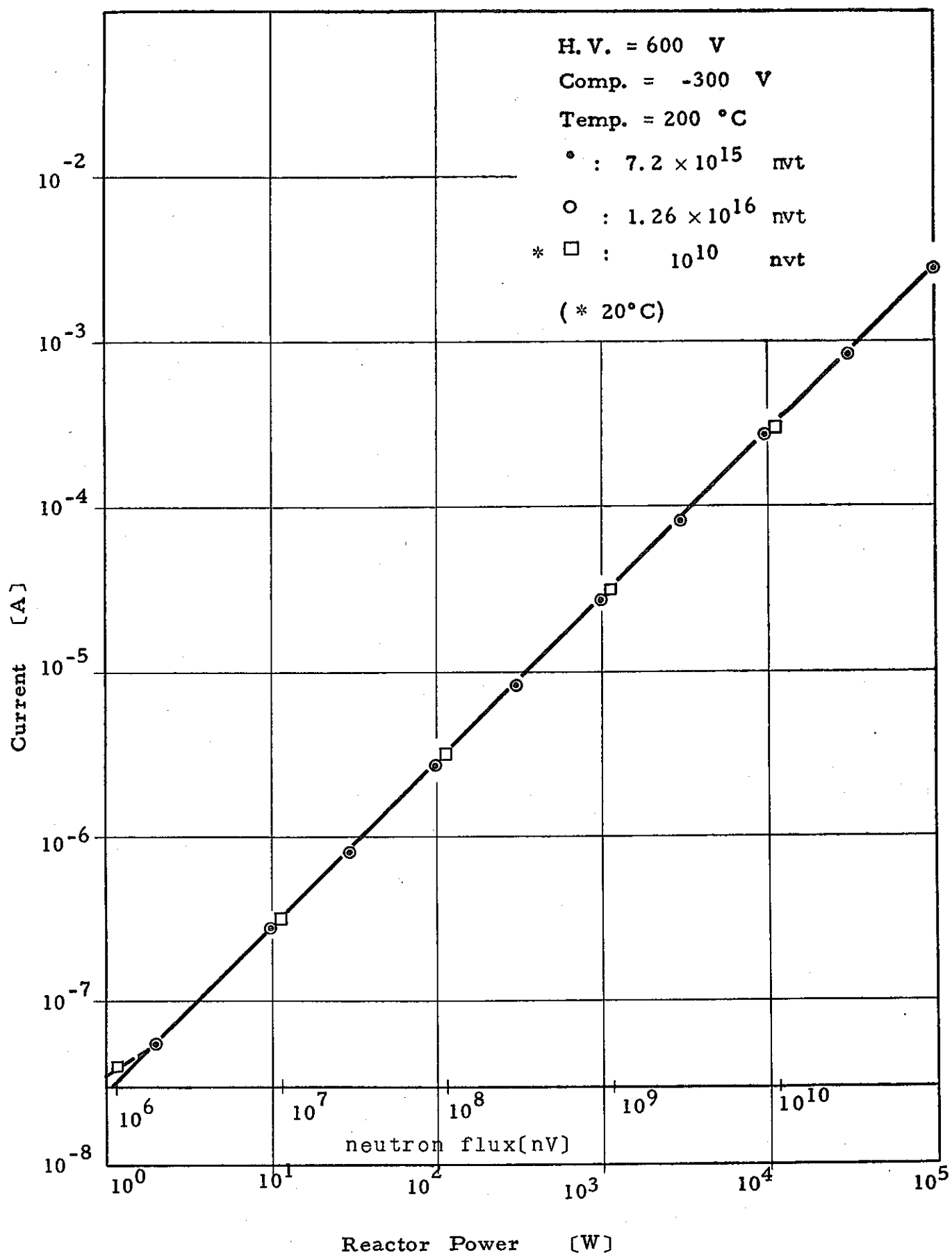
Fig. 2 - 13   Neutron sensitivity irradiation effect

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Fig. 2 - 14   Signal current plateau

Fig. 2 - 15 SK-400 linearity at TTR