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IRRADIATION OF AN EMITTER ELEMENT FOR A THERMIONIC CONVERTER EXPERIMENT DICOM-01

by

H. HAUSNER, R. KLERSY,
A. SCHÜRENKÄMPER and O. SIMONI

1971

Joint Nuclear Research Centre
Ispra Establishment - Italy

Materials Department

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ABSTRACT

The irradiation of a vented emitter element for a thermionic conventer is described. This emitter type could be used in a thermionic fuel element, in which the converters are connected in parallel. The irradiation device is discussed and the irradiation conditions together with the results of the post-irradiation examination are presented.

KEYWORDS

THERMIONIC CELLS
IN PILE LOOPS
CAPSULES
IRRADIATION
RADIATION EFFECTS

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1. INTRODUCTION x)

In a thermionic fuel element the single converters can be arranged in different ways. In many designs they are located one upon another and connected in series electrically (Fig. 1). Other proposals foresee an arrangement of the single cells side by side, with a parallel connection (Fig. 2). A cell of this type is shown schematically in Fig. 3 . The emitter consists of the fuel material, a tungsten or molybdenum cladding, a thermal shield above the fuel and the top cover plate. Fission gases can be vented through a hole in the top in order to relieve stresses on the cladding and to ensure its dimensional stability.

The purpose of this experiment was to investigate such a cell under irradiation. It was of special interest to test the effectiveness of a baffle system acting as a thermal shield and preventing the escape of UO_2 without preventing the fission gas release. In addition it was necessary to obtain information on a possible relocation of the fuel at the high temperatures being present in a thermionic fuel cell of this type.

2. DESCRIPTION OF THE IRRADIATION DEVICE.

The irradiation rig consisted of a water cooled capsule, a suspension tube and a shielding plug on top (Fig.4). The water cooling circuits and the He-Ar circuit for the temperature regulation of the fuel element are indicated in Fig.5.

The main parts of the irradiation capsule were the fuel element, a thermal barrier and the outer container. A longitudinal and a cross section of the capsule are shown in Fig. 6.

2.1 Fuel element.

Five UO_2 pellets (20% enriched) with an external diameter of 6.9 mm and a total length of 30 mm formed the active part of the element.

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x) Manuscript received on July 12, 1971

A 2 mm high natural UO_2 pellet, on top of the enriched fuel, was used for thermal insulation. All pellets had a 1 mm central hole. A small molybdenum cylinder (OD 12 mm, ID 6.9 mm, Length 100 mm) contained the UO_2 pellets. Above the fuel the baffle was located, which had been machined from molybdenum in form of a helix. The remaining free space of the molybdenum cylinder above the baffle acted as a fission-gas plenum. End closures were made by electron beam welding. In order to reduce axial heat losses the wall thickness of the molybdenum container was reduced from 2.55 to 0.5mm between the fuel containing part and the fission gas plenum over a length of 10 mm. The different parts of the fuel element are shown inFig.7, the dimensional data are

2.2 Thermal barrier.

The fuel element was centered within a thermal barrier consisting of three concentric tubes of Zr-2. The two annular gaps between the tubes were filled with molten magnesium under pressure. The measurement of the temperature difference across the thermal barrier was used for the determination of the fuel heat rating. Fig. 8 and 9 show the fuel element and the thermal barrier before and after the assembly stage.

2.3 Outer container.

The outer part of the capsule was a double wall, finned aluminium container, in which the cooling water circulated. At the lower part a centering piece of aluminium ensured the proper position of the capsule in the channel.

2.4 Temperature measurement.

The cladding temperature of the fuel element was measured with three WRe 26/WRe 5 thermocouples of 1.5 mm diameter which were positioned in the cladding wall (2.5 mm thickness). They are indicated in Fig.6 as 1A, 2A and 3A. The ΔT across the Zr-2 barrier was determined by coaxial chromel-alumel thermocouples of 0.5 mm diameter.

These thermocouples were located in small stainless stell tubes (OD 0.9mm, ID 0,6 mm). The SS tubes had been positioned in their proper place prior to the magnesium filling (see Fig. 10). Seven thermocouples were provided in the inner annulus, formed by the concentric Zr-2 tubes and seven in the outer one. In Fig. 6 they are indicated as B or C thermocouples respectively. The filling with magnesium ensures that the thermocouples are located in an almost isothermal region and that the accuracy of the measurement is better. The inlet and outlet water temperature of the capsule was measured with four chromel-alumel thermocouples.

2.5 Temperature control.

The interspace between the fuel element, the thermal barrier and the outer container was filled with He. By using He-Ar mixtures of different composition the cladding temperature could be adjusted to a desired value.

2.6 Neutron flux measurements.

Three Al/Co and Al/Ag flux wires with a diameter of 0.5 mm and 50 mm length were fixed at 120° intervals at the outer wall of the capsule. In addition three continuous neutron flux monitors were provided at the outer wall of the capsule.

2.7 Water-leak detectors.

Three water-leak detectors were foreseen at the capsule bottom. They consisted of three stainless-steel sheathed chromel-alumel thermocouples (Ø 2mm) with MgO insulation. The lower end of the sheath was removed. A water leak is indicated by a decrease in the insulation resistance of the magnesium oxide.

3. IRRADIATION

The capsule was irradiated in the ISPRA-1 reactor for 25 full power days. After the first reactor start-up the measured linear power was 238 W/cm resulting in a molybdenum cladding temperature of 1300°C. This power was approximately 30 % lower than expected, caused by a lower neutron flux than used in the design calculations. Fig. 11 shows the radial temperature distribution calculated with the design heat rating of 347 W/cm and the measured rating of 238 W/cm. The results of the temperature measurements are also indicated in Fig. 11. They are in good agreement with the calculated values using the actual heat rating of 238 W/cm. Since the temperature requirements of this experiment were more important than the achieved power it was decided to raise the cladding temperature to higher values by applying He-Ar mixtures instead of pure He. After five days of operation at a cladding temperature of 1300°C, the temperature of the molybdenum container was increased to 1635° and after an irradition period of 10 days to 1700°C. Under these conditions the irradiation continued for other 10 days. In Fig. 12 the average sheath temperature is indicated which has been measured during the total irradiation period.
The calculated maximum fuel surface and central temperaturer s and the burn-up are listed in Table 1. Gas samples which have been taken during irradiation did not reveal the presence of fission gases indicating that the molybdenum container had remained intact.

TABLE I

Fuel and cladding dimensions and irradiation conditions.

Fuel	
Material	UO_2
Enrichment	20% U-235
O.D	6.9 mm
I.D	1 mm
Length	30 mm
Heat rating	238 W/cm.
Specific power	67 W/g_u
Max. fuel center temperature (calculated)	2280°C
Max. fuel surface temperature (calculated)	1770°C
Burn-up	1800 MWD/Tu
Cladding	
Material	molybdenum 99.93%
O.D	12 mm
I.D.	6.9 mm
Max. surface temperature	1700°C
Surface heat flux	62 W/cm^2

4. POST-IRRADIATION EXAMINATION.

The post-irradiation examination included the following operations :

- dismantling of capsule
- gamma-scanning of fuel element
- examination of baffle
- metallographic investigation

The dismantling of the capsule was performed without any major difficulties. Fig. 13 and 14 show the capsule partially dismantled.
The axial distribution of the gamma-activity along the fuel element is shown in Fig. 15. The curve indicates the total γ activity in the energy range 5O KeV to 2.5 MeV obtained with a NaI crystal. One observes a rapid decrease above the position of the enriched pellets but a pronounced activity peak is present at about the middle of the baffle. Detailed examination of the spectra obtained with a Ge-Li detector at different parts of the fuel element gave the following results. The activity of the fuelled part is mainly caused by Zr, Nb and Ru which is in accordance with the irradiation and cooling time. The gamma spectrum from the part of the baffle opposite the $U0_2$ revealed the presence of the same fission products and gave therefore a strong indication that $U0_2$ had been deposited there. A confirmation of this result has been obtained by visual examination (Fig. 16) but the deposited amount of $U0_2$ is rather small. The general appearance of the baffle is very good, no plugging by the $U0_2$ can be observed (Fig. 17). The activity peak in the middle of the baffle is caused mainly by Cs and can be explained by the volatility of this element. No fission products could be detected which could give an indication for the presence of $U0_2$, when compared with the gamma-scanning results of the fuelled part of the Mo-container. A spectrum obtained from the fission gas plenum revealed the presence of Cs only. The gamma autoradiography of the baffle (Fig. 18) revealed also the presence of fission products at the part opposite to the fuel and partially in the middle, which confirms the results of the gamma-scanning. The puncture-test for the determination of fission gases could not be carried out successfully since the Mo-container broke in the clamping

device of the puncture equipment due to the strong embrittlement of the molybdenum during the high temperature irradiation. Fig. 19 shows a metallographic section of the fuel; no fuel relocation has been observed.

5. CONCLUSIONS.

For the conditions investigated the baffle proved to be effective for the retention of the $U0_2$. No major redistribution of $U0_2$ could be observed outside the fuelled region. Volatile fission products, e.g. Cs have been migrated up to the middle of the baffle. Cs was also found in the fission gas chamber above the baffle region. Further tests would be of interest to determine the behaviour during longer irradiations. Design studies should reveal how systems of this kind can be incorporated into the thermionic converters.

Acknowledgements

The authors acknowledge the assistance and very useful contributions of F. Farfaletti Casali and N. Mariani for the design, J. de Greef and R. Pagani for the assembly of the capsule, A. Frigo for the instrumentation and E. Ghezzi, J. P Meerschman, J. Loens and M. Herold for the post-irradiation examinations.

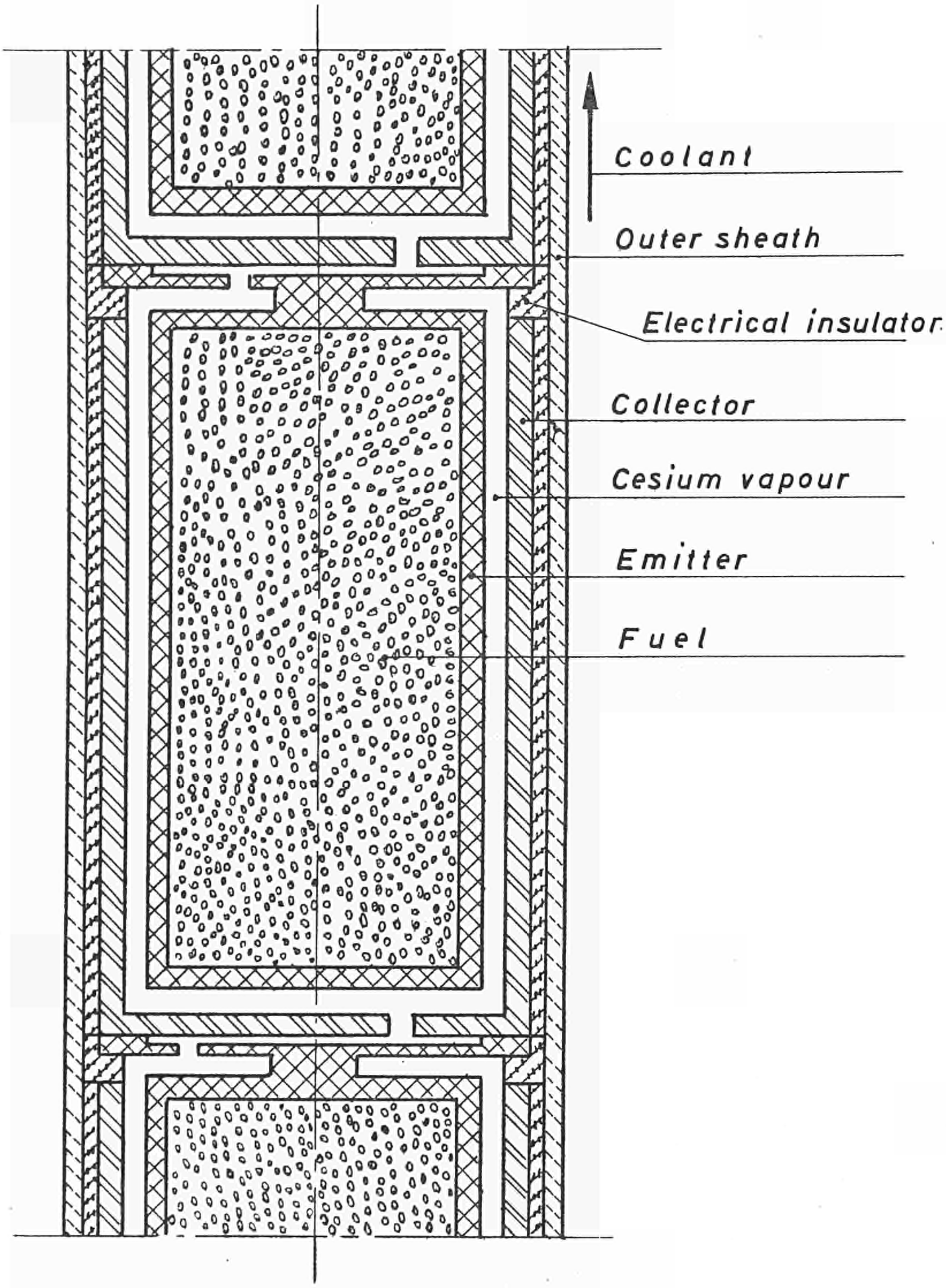


Fig.1 – Thermoionic fuel element with converters connected in series

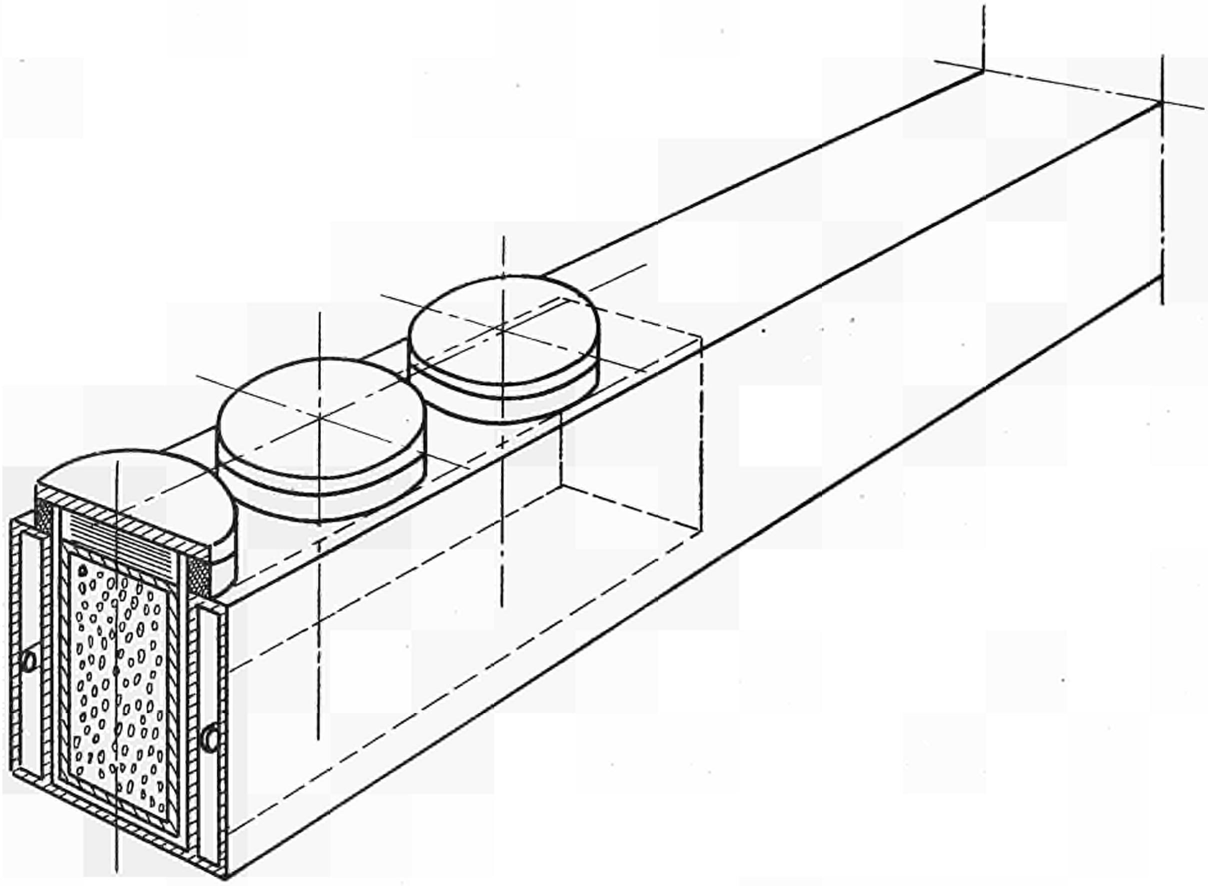


Fig. 2 – Thermoionic fuel element with converters connected in parallel

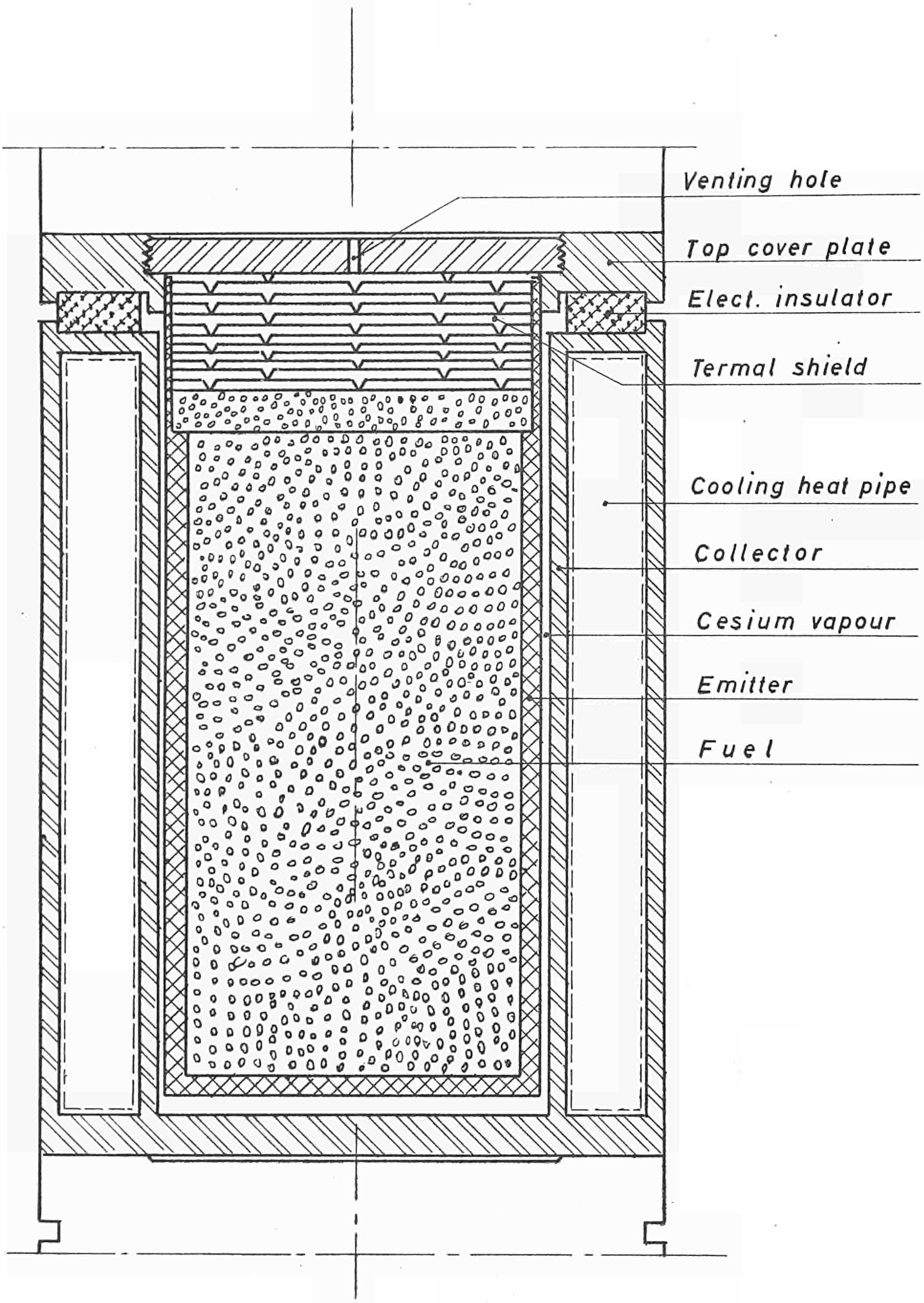


Fig.3 – Single termoionic converter cell

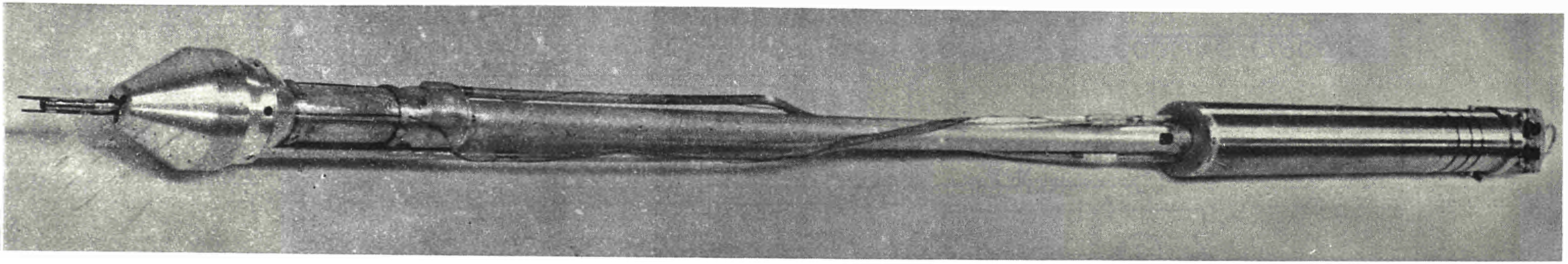
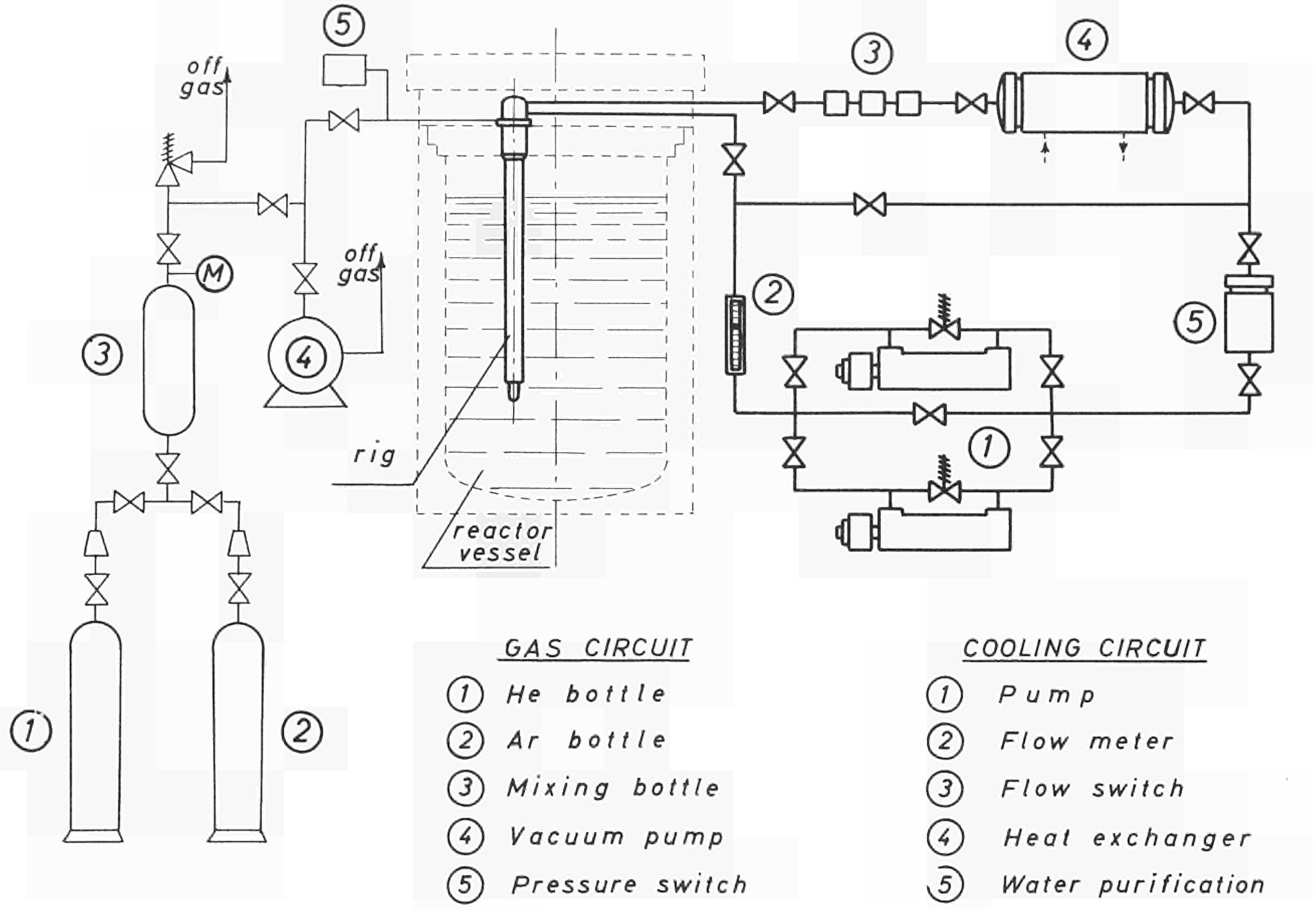


Fig. 4 - Irradiation rig



GAS CIRCUIT

① He bottle
② Ar bottle
③ Mixing bottle
④ Vacuum pump
⑤ Pressure switch

COOLING CIRCUIT

① Pump
② Flow meter
③ Flow switch
④ Heat exchanger
⑤ Water purification

Fig.5 - Cooling and inert gas circuits

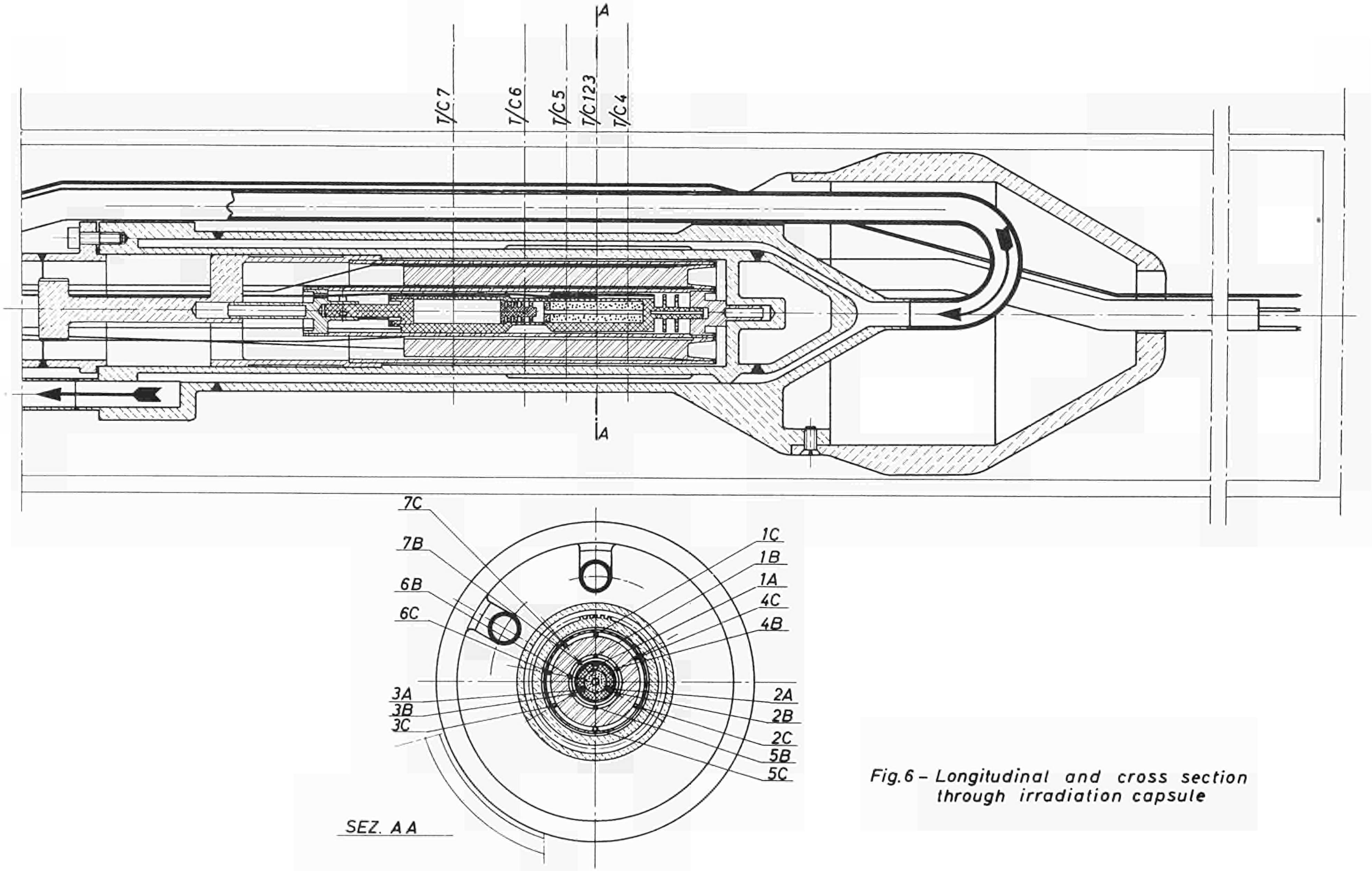


Fig. 6 – Longitudinal and cross section through irradiation capsule

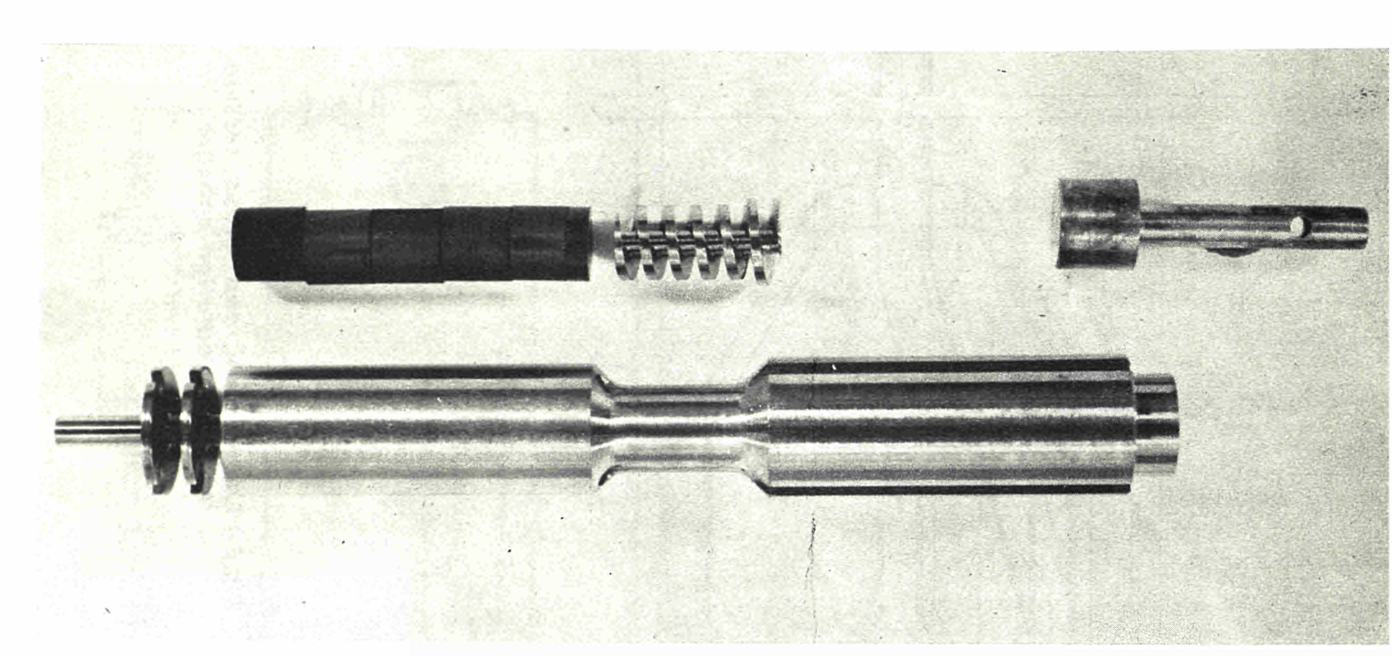


Fig. 7 - Parts of fuel element

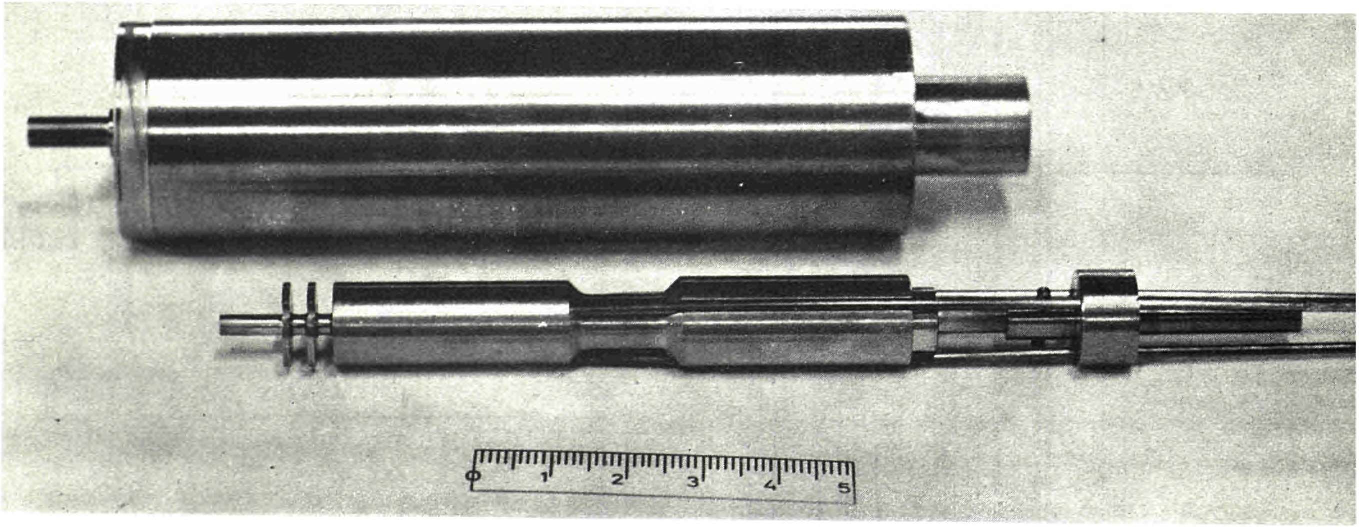


Fig. 8 - Fuel element and thermal barrier before assembly stage

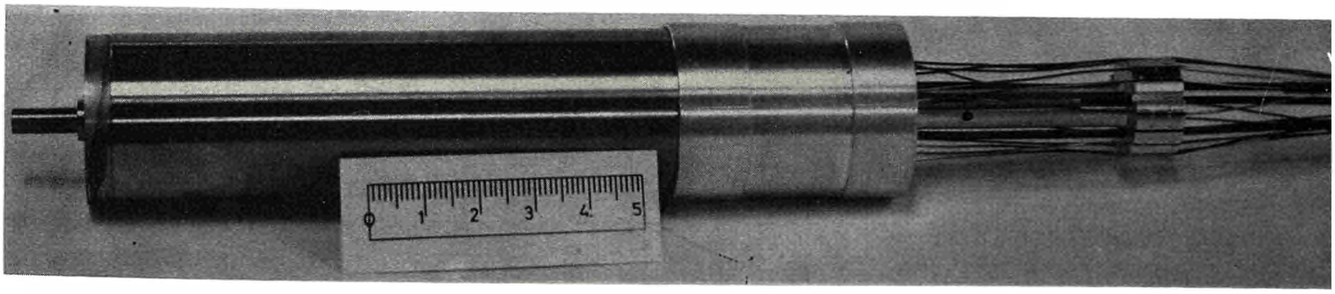


Fig.9 – Fuel element and thermal barrier after assembly stage

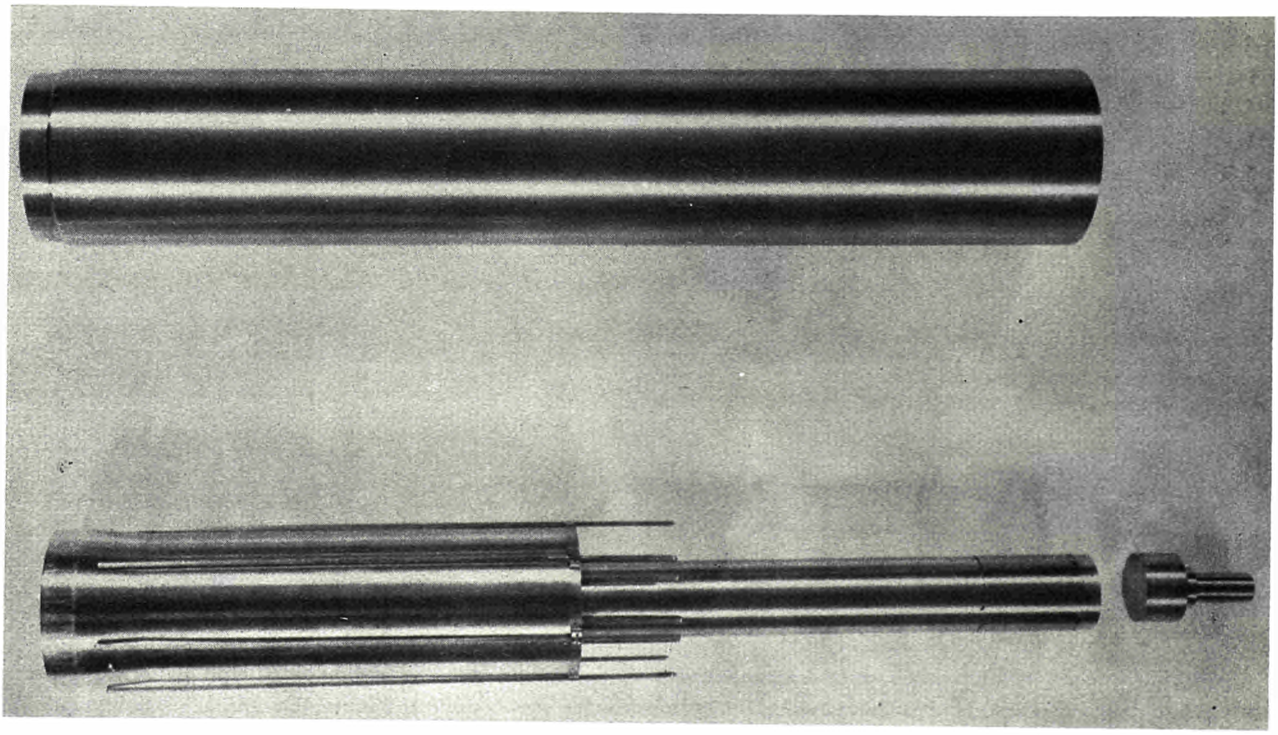


Fig.10 – S.S. tubes in the thermal barrier before magnesium filling

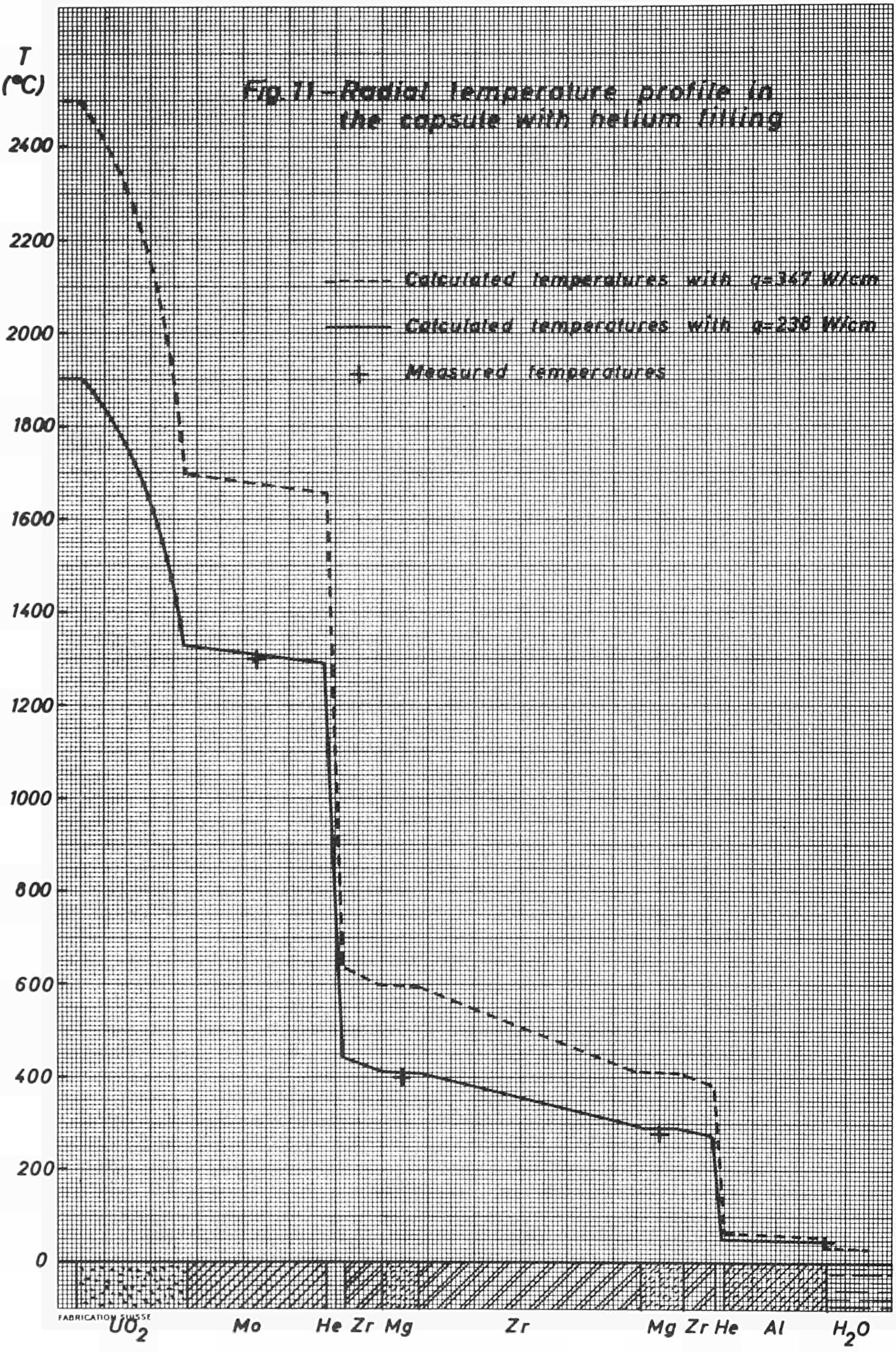


Fig.11 – Radial temperature profile in the capsule with helium filling
Calculated temperatures with q=347 W/cm
Calculated temperatures with q=238 W/cm
Measured temperatures
T (°C)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
FABRICATION SUISSE
UO_2
Mo
He
Zr
Mg
Zr
Mg
Zr
He
Al
H_2O

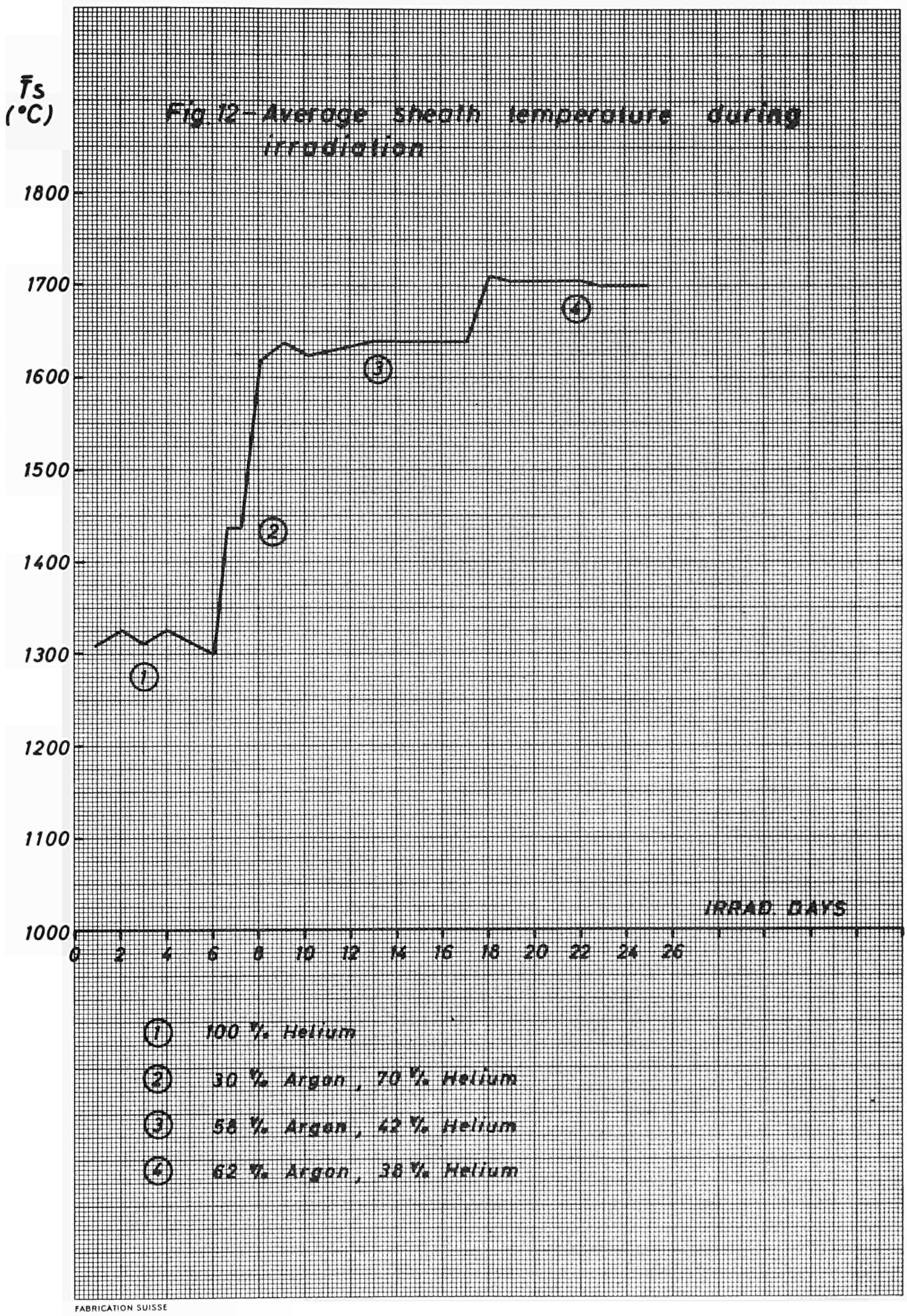


Fig. 12 - Average sheath temperature during irradiation

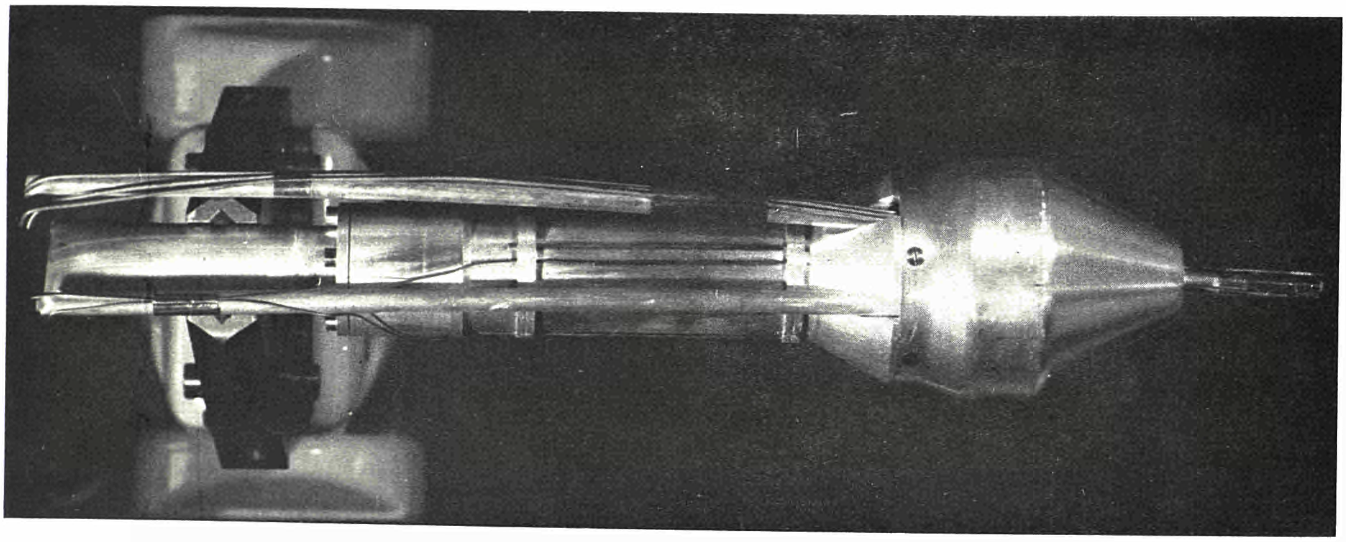


Fig.13 – Fuelled part of capsule after irradiation

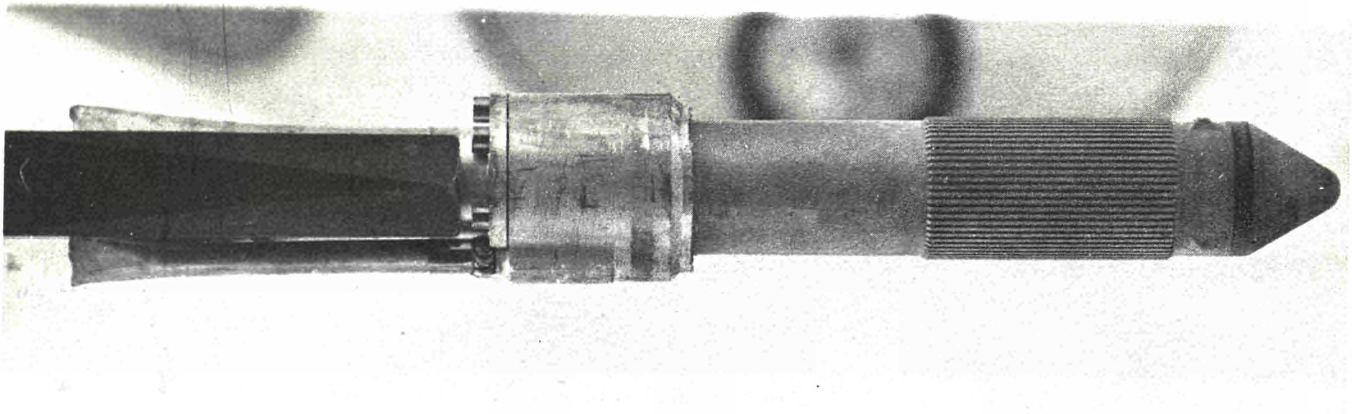
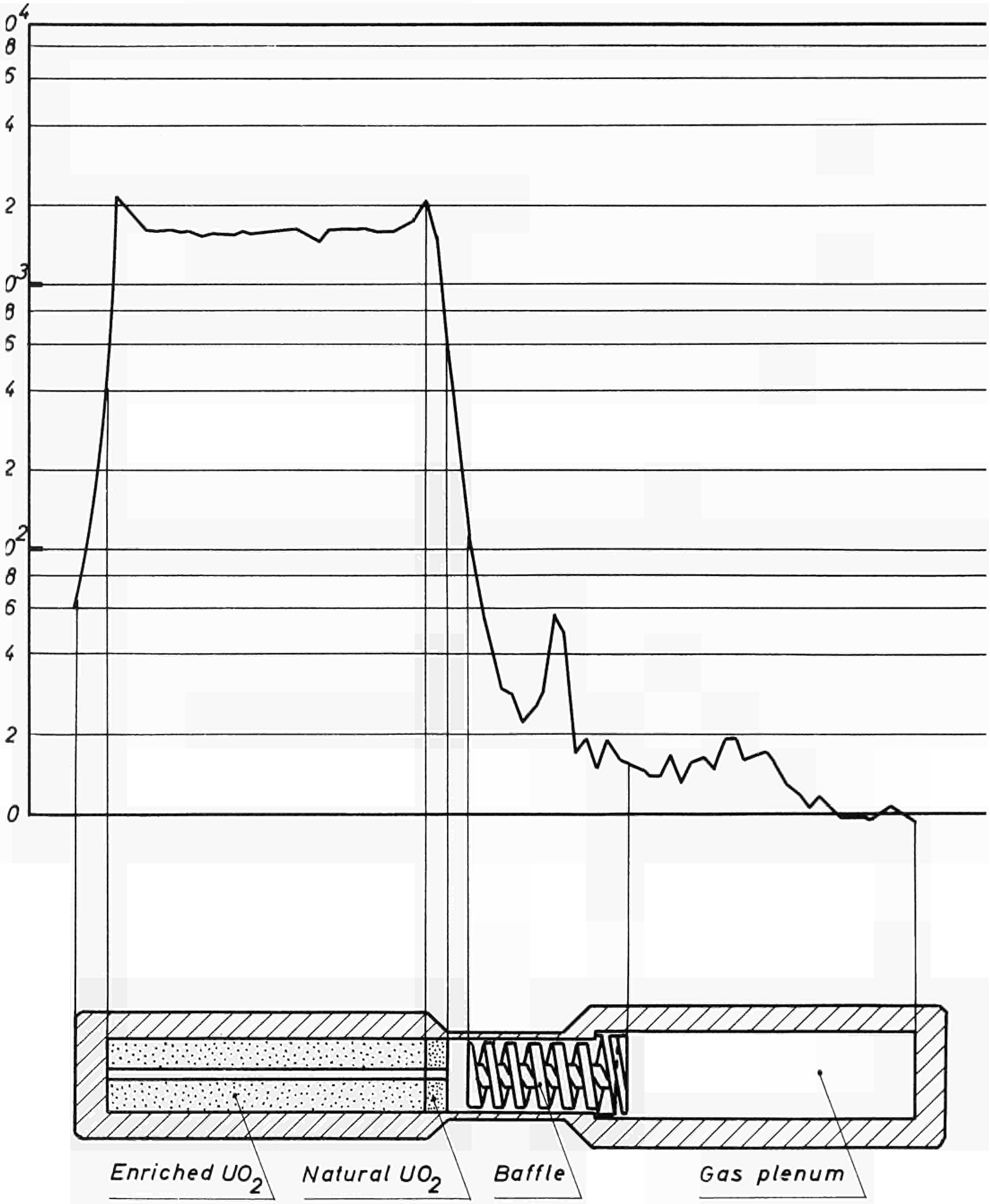


Fig.14 – Capsule partially dismantled

Fig. 15 - Total γ activity distribution along the fuel element



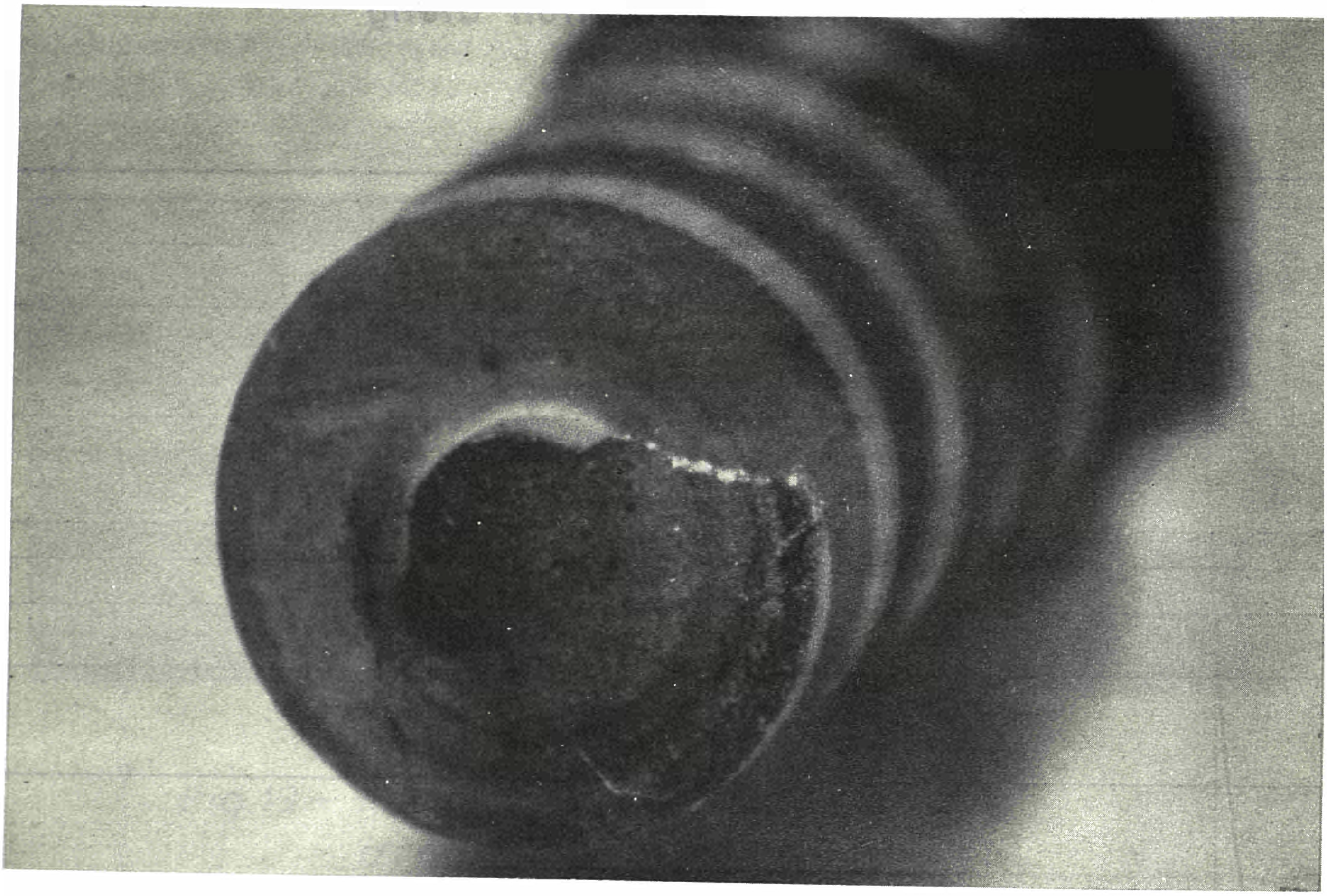


Fig. 16 – Surface of baffle opposite to the UO_2

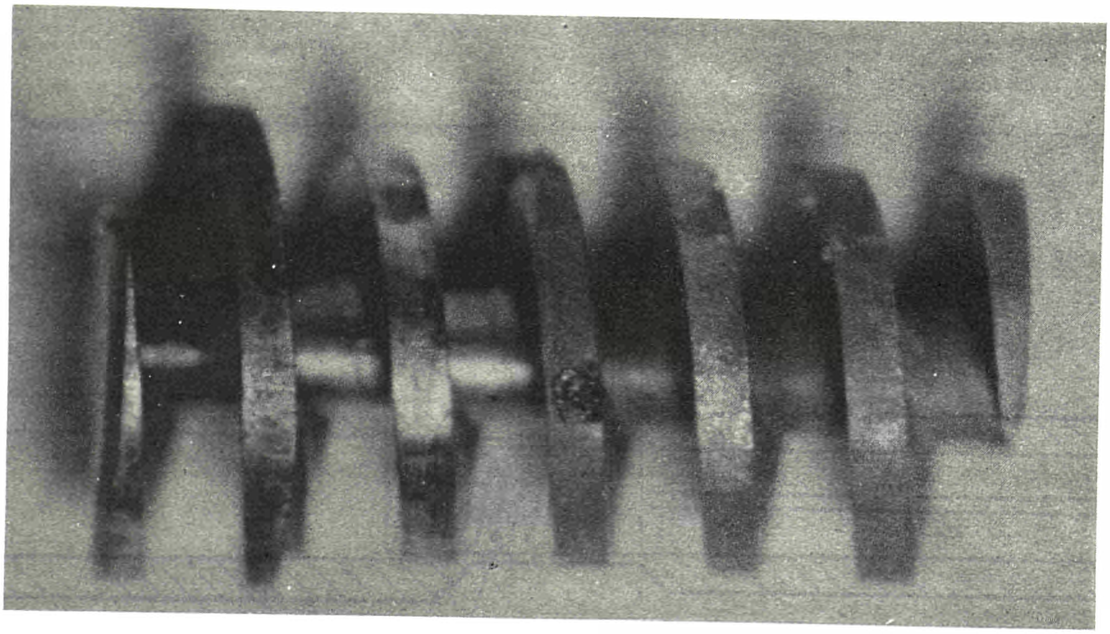


Fig. 17 – Baffle after irradiation

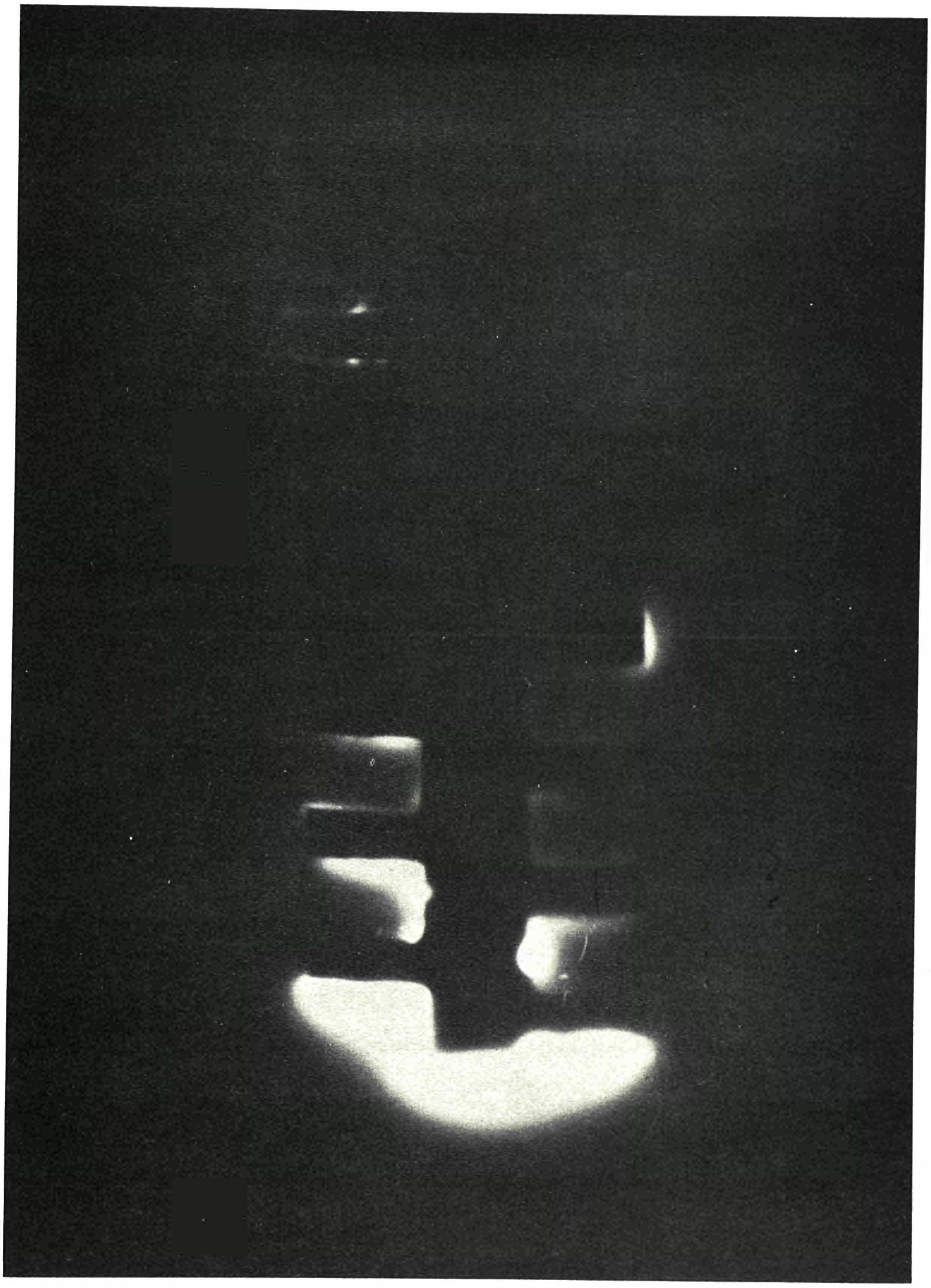


Fig. 18 – Gamma autoradiography of baffle

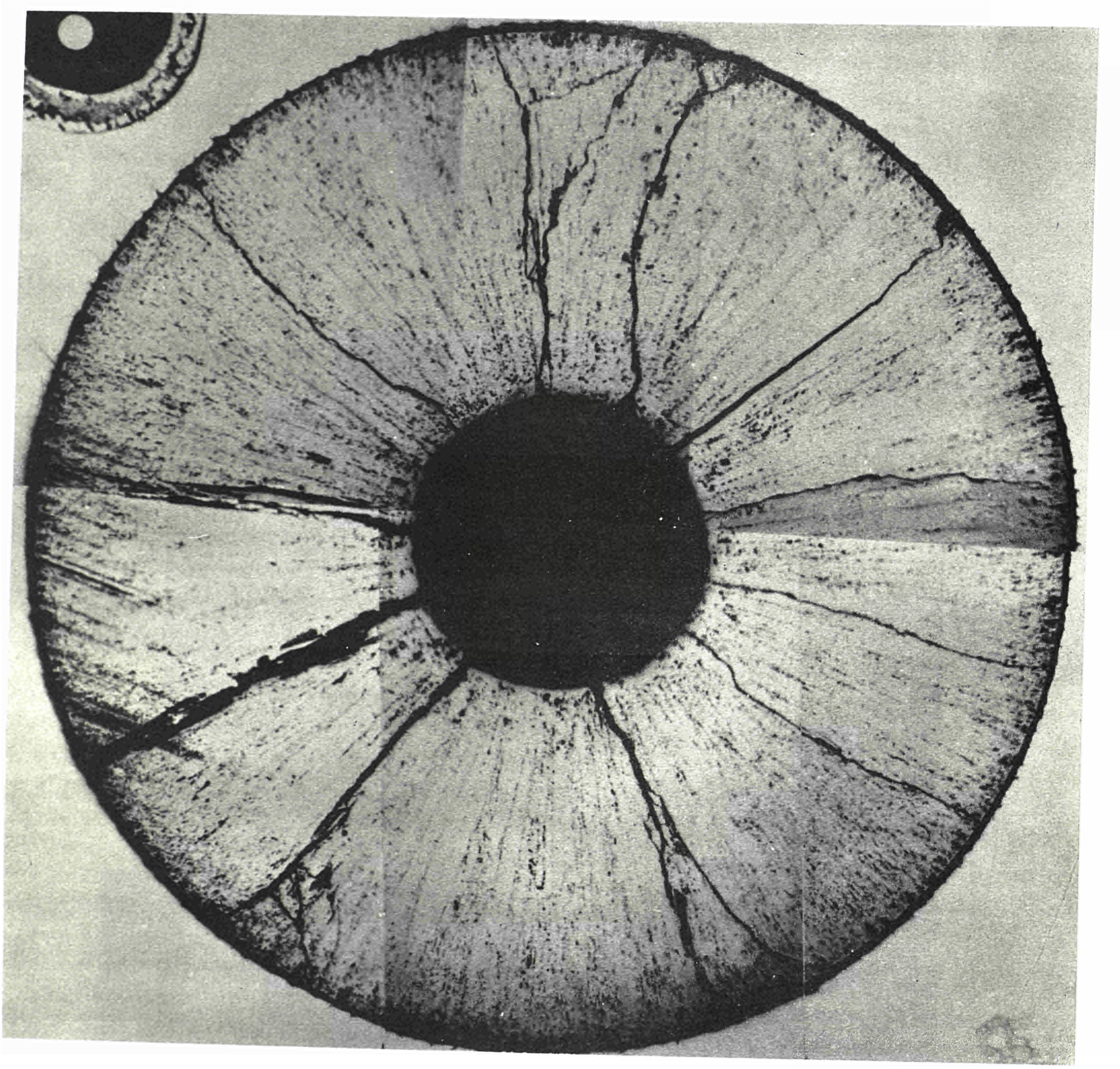


Fig. 19 – Metallographic cross section of fuel

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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