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HIGH TEMPERATURE IRRADIATION FACILITIES IN JMTR FOR VHTR FUEL DEVELOPMENT

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Hiroharu ITAMI, Hirokatsu NAKATA
Isao TANAKA, Katsumune YAMAMOTO
Isao AOYAMA and Katsuichi IKAWA

日 本 原 子 力 研 究 所
Japan Atomic Energy Research Institute

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High Temperature Irradiation Facilities in JMTR for VHTR fuel Development

Hiroharu ITAMI, Hirokatsu NAKATA, Isao TANAKA,
Katsumune YAMAMOTO, Isao AOYAMA and Katsuichi IKAWA+

Department of JMTR Project
Oarai Research Establishment, JAERI
(Received June 9, 1983)

The VHTR is required to use fuel elements of different type from LWR and LMFBR and also heat-resisting materials, so that research and development (R&D) on fuel and material are important. In order to conduct irradiation test essential to the R&D, high-temperature irradiation facilities have been developed by JAERI. The JMTR at the Oarai Establishment has been equipped with a in-pile gas loop, OGL-1, a gas-sweep capsule facility and temperature-ramp capsules for high temperature perature irradiation on VHTR fuel samples.

The present publication intends to give general descriptions on these high temperature irradiation facilities.

Keyworks; VHTR, Irradiation Test, Irradiation Facility, JMTR, OGL-1, In-pile Loop, Gas Loop, Capsule.

+ Department of Fuels and Materials Research, Tokai, JAERI

JMTRにおける多目的高温ガス炉用燃料開発のための高温照射設備

日本原子力研究所大洗研究所材料試験炉部
伊丹宏治・中田宏勝・田中 勲
山本克宗・青山 功・井川勝市[+]

（1983年6月9日受理）

多目的高温ガス炉では，軽水炉や高速炉と異なった燃料型式を採用し，材料も高温に耐えるものを使用しなければならないことから，燃料と材料の研究開発が重要である。この研究開発に不可欠な照射試験を効率良く行うため，原研では，高温照射設備の開発と整備を進めている。
現在，大洗研究所のJMTRにOGL－1インパイルガスループをはじめ，ガススィープキャプセル照射装置，高温照射用の特殊キャプセルなどを整備し，照射試験に使用している。
本稿では，これらの高温照射設備の概要を紹介する。

＋ 燃料工学部
本稿は，昭和57年11月24日に東京で開催された「第11回多目的高温ガス炉研究成果報告会」における「高温照射設備」に関する口頭発表を英文記録したものである。

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1. Introduction

The multi-purpose Very High Temperature gas-cooled Reactor (VHTR) is required to use fuel elements of different type from LWR and LMFBR and also heat-resisting materials, so that research and development of fuels and materials are very important. High Temperature Irradiation tests are essential for effective research and development.

High temperature irradiation facilities have been developed and provided in the Japan Materials Testing Reactor (JMTR) of the Japan Atomic Energy Research Institute (JAERI). Available facilities for VHTR fuel irradiation are a in-pile gas loop (OGL-1), a gas-sweep capsule facility and temperature-ramp capsules.

The JMTR is a 50 MW high-flux reactor for various kinds of irradiation, and is located at the Oarai Establishment of JAERI.[1)] Figure 1 shows locations of the irradiation facilities in the JMTR. Irradiation samples are encapsuled and then loaded into a reactor core, or directly loaded into a in-pile tube of the loop.[2)] Out-of-pile installations are provided for recording and controlling of sample temperatures. Figure 2 is a photograph of the reactor core showing a in-pile tube of the OGL-1 and capsules.

The capsules are mainly used for verification tests and safety study of coated-fuel particles and fuel compacts, whereas the OGL-1 is used for demonstrations of full-size fuel rods. The OGL-1 is also used for study of coolant chemistry.

General descriptions are given in this paper about these high-temperature irradiation facilities.

2. In-Pile Gas Loop (OGL-1)

The OGL-1, short for the Oarai Gas Loop No.1, is a high-temperature helium-circulating gas loop installed in the JMTR. The loop is capable of conducting irradiation tests on fuels and materials under condition similar to those of VHTR coolant.[3),4)] The loop consists of a in-pile tube, a primary circuit, a purification system and so on, as shown in Fig. 3. Table 1 lists its main characteristics. The loop is considered to be a small VHTR for its structure and characteristics.

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Experiences obtained through design, construction and operation of the OGL-1 are greatly valuable, since they would be quite helpful to a construction and operation of VHTR.

The OGL-1 was put into a service operation in March 1977, and has been operated at high temperature for more than 10,000 hours so far. Six fuel-rod samples were already irradiated for their own purposes and under conditions listed in Table 2.

A structure of the 3rd OGL-1 fuel sample is shown in Fig. 4 as a example. Figure 5 shows a radial fission product distribution in a graphite sleeve of the sample obtained by post-irradiation examination.[5) It is clearly seen that metalic fission products except for Cs are effectively retained in the sleeve. A future irradiation program is presented in Table 3. A verification test will be conducted in the 9th irradiation with fuel rods, which will be fabricated in a production scale for the experimental VHTR.

The OGL-1 has also played an important role in the field of helium coolant chemistry for the VHTR. Most interested are concentrations of impurities such as oxygen and moisture which affect on integrity and life of fuel rod and high-temperature structual material.

Table 4 shows the impurities and their concentrations in the helium gas of the loop during high temperature operations.

Among the impurities, moisture, oxygen and nitrogen were detected in all irradiations, but others were not detected in some irradiations. Total concentrations of impurities were kept well below 10 vpm, which is a specification of limiting concentration for the OGL-1.

Secondly interested are concentrations of gaseous fission products, which are released into the helium gas from fuel sample during irradiation. Amounts of fission products released depend on a fabrication process and irradiation condition of a fuel sample. Noble gases such as Xe and Kr are fission products principally detected in the helium gas. Table 5 shows concentrations of typical fission products during the past irradiations. Fractional releases, R/B*, for gaseous fission products were calculated using these concentrations, and were found to be less than 10^{-4}.[6)] It has been concluded that all fuel samples irradiated had satisfied a requirement for fission-product retention. No problem has arised in a operation of the OGL-1 in connection with fission-product concentration in the helium gas.

* a ratio of release rate to birth rate

Finally interested is a phenomena known as the plate-out, in which fission products such as Cs and I are deposited at inner surfaces of primary-circuit components of the VHTR. A fission-product plate-out has been measured also at the OGL-1 along its primary circuit.[7),8)] Figure 6 shows plate-out activities of ^{137}Cs and ^{131}I measured just after reactor shut-down. It is seen that ^{131}I has a tendency to deposit at low-temperature region, while ^{137}Cs at high-temperature region. Fission-product plate-out increases dose rate at outer surfaces of primary-circuit components and makes maintenance works hard. Maintenance work on the OGL-1 however has been quite early so far, since dose rate at surface of the loop has been kept very low. Beside plate-out measurement, a fission-product filter experiment is also being conducted using the OGL-1 in cooperation with West Germany in order to establish a technique, which removes non noble geseous fission-products before plate-out.

3. Gas-Sweep Capsule Facility

The gas-sweep capsule facility has been developed in order to determine noble gaseous fission-product release-rate of fuel for a verification under high-temperature irradiation, as well as the OGL-1. The facility is however, operated in a non-through flow mode and at low pressure, unlike the OGL-1. Figure 7 shows a simplified diagram of the facility, and Table 6 lists its important characteristics. The facility is capable of irradiating two capsules simultaneously, and each of them contains three sample-holders individually swept and temperature-controlled. Gaseous fission-products released from fuel samples are swept by helium gas, and transported to the sampling station. The sampled gas are analyzed for their nuclides and concentrations. Fission-product release-rate or failure rate of samples could be calculated with analysis data.

The facility has been operated since 1976. Six capsule had been already irradiated.[9)] Figure 8 shows an example of temperature dependences of fractional releases of 85 mKr measured for loose and compacted coated-fuel-particle samples.[10)] The fractional releases gradually increase with temperature for both samples, but are less than 10^{-4}. It is beeing concluded from gas-sweep-capsule irradiations that Japanese coated-particle fuels are suitable for a VHTR application.

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The facility has been also used for a fuel failure detection experiment.[11] A part of the sweeping gas has been diluted and fed to a precipitator-type gas monitor, which is a key component of a fuel failure detection system under development for the VHTR.

4. Temperature-Ramp Capsule

The temperature ramp capsule is under development for safety study of fuel under abnormal condition. The capsule will be capable of changing a sample temperature from 1,400°C to 2,000°C in a short time.[12]

A new technique has been introduced into the capsule to realiz this wide temperature change, since a ordinary temperature control capsule would be failed during temperature ramping. Figure 9 shows a schematic structure of the capsule. A graphite thermal bond possessing two different thicknesses is connected to a pneumatic bellows assembled in the capsule. When the bellows is pressurized, the graphite thermal bond moves down as shown in Fig. 10. As a result, a thermal conductance between a fuel sample and a capsule tube is decreased, and a sample temperature is increased.

A temperature change over 500°C was achieved with a demonstration capsule by applying the thermal bond moving technique together with a ordinary vacuum-temperature-control. Figure 11 shows a temperature record during the ramping.

With a prospect obtained with the demonstration capsule, a series of temperature-ramp tests to 2,000°C are planned. It should be said that VHTR fuel safety study depends on the temperature ramp capsule.

5. Conclusions

All of the irradiation facilities described are essential to the research and development of the VHTR. The capsules are used for basic researchs, whereas the OGL-1 is used for demonstrations of fuels developed through these researchs. The operating experiences with these facilities are also useful for the development of the VHTR.

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Table 1 Main characteristics of the OGL-1

Cooling gas	Helium	
Operating pressure	max.	30kg/cm²G
Operating temperature	max.	1000°C
Mass flow	max.	100 g/sec
Fast neutron flux (>1MeV)		1.3×10^{13}n/cm²sec
Thermal neutron flux		5.9×10^{13}n/cm²sec
Limiting nuclear heat of sample		135kW
Max. dimensions of sample	80mm (diameter) × 750mm (length)	

Table 2 Results of fuel rod irradiations in the OGL-1

No. of fuel sample	1 st	2 nd	3 rd	4 th	5 th	6 th
Year of sample preperation	1975	1976	1977	1978	1979	1980
Purpose of irradiation	OGL-1 performance test	Candidate fuel low burn up	Simulation of eccentric coolant flow channel	Medium burn up	High burn up	High temperature irradiation
Max sample temp. (°C)	1380	1370	1320	1360	1350	1480
Burn up (MWD/T)	4500	8700	4500	14000	25000	3500
Duration of irradiation (H)	935	1720	976	1873	3411	525

Table 3　Future irradiation program in the OGL-1

No. of fuel sample	7	8	9	10	11
Year of sample preperation	1981	1982	1983	1984	1985
Purpose of irradiation	Comparison different origin graphite for compact matrix	Fission product transport behavior short time	Verification of mass-produced fuel	Fission product transport behavior long time	Fission product transport behavior high temperature

Table 4　Impurities and their concentrations in the helium gas of the OGL-1

Impurities	Concentrations (vpm)	Remarks
H_2O	0.05〜0.1	detected in all irradiations
O_2	less than 0.13	
N_2	0.3〜0.6	
H_2	less than 2	not detected in some irradiations
CH_4	less than 0.25	
CO	less than 0.25	
CO_2	less than 0.14	

Table 5 FP gas concentrations in the helium gas of the OGL-1

(μci/ml)	Fuel samples					
	1st	2nd	3rd	4th	5th	6th
^{85m}Kr	2.55×10^{-6}	2.8×10^{-6}	1.2×10^{-4}	3.5×10^{-6}	2.2×10^{-4}	5.5×10^{-6}
^{87}Kr	5.3×10^{-6}	8.3×10^{-6}	2.8×10^{-4}	1.5×10^{-5}	6.6×10^{-4}	3.8×10^{-5}
^{135}Xe	9.7×10^{-7}	4.9×10^{-6}	4.7×10^{-4}	6.8×10^{-6}	3.8×10^{-4}	2.6×10^{-5}
^{135m}Xe	9.2×10^{-7}	8.6×10^{-6}	5.0×10^{-4}	8.4×10^{-6}	5.0×10^{-4}	3.4×10^{-5}

Table 6 Main characteristics of the Gas Sweep Capsule Facility

Sweeping Gas Operating pressure	Helium max. $3kg/cm^2G$
Coated particle fuel loading Limiting sample nuclear heat Limiting fission gas release rate (R/B)	66g/ capsule 830W/cm of sample holder 1.0%

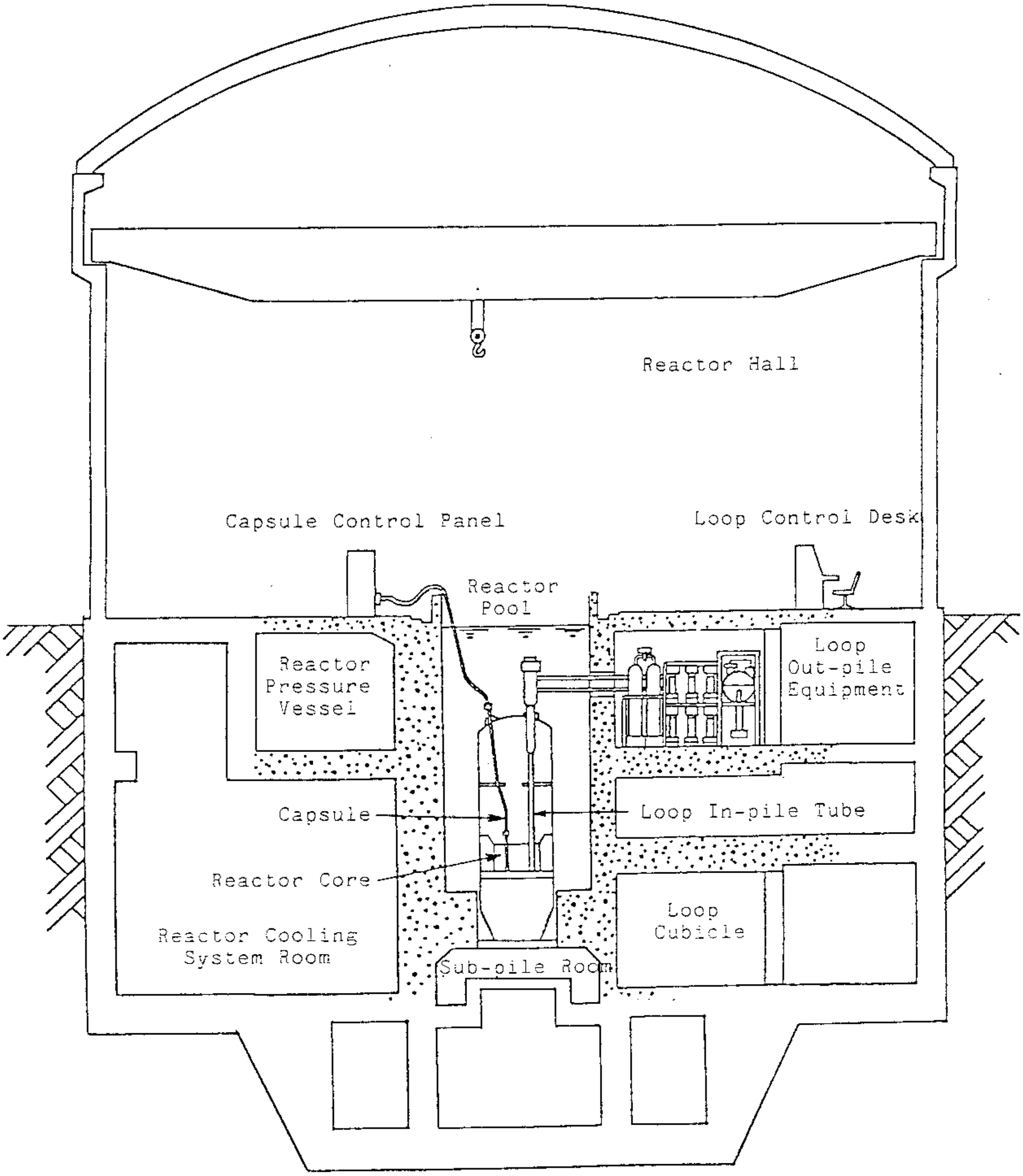

Fig. 1 Locations of the Irradiation Facilities in the JMTR

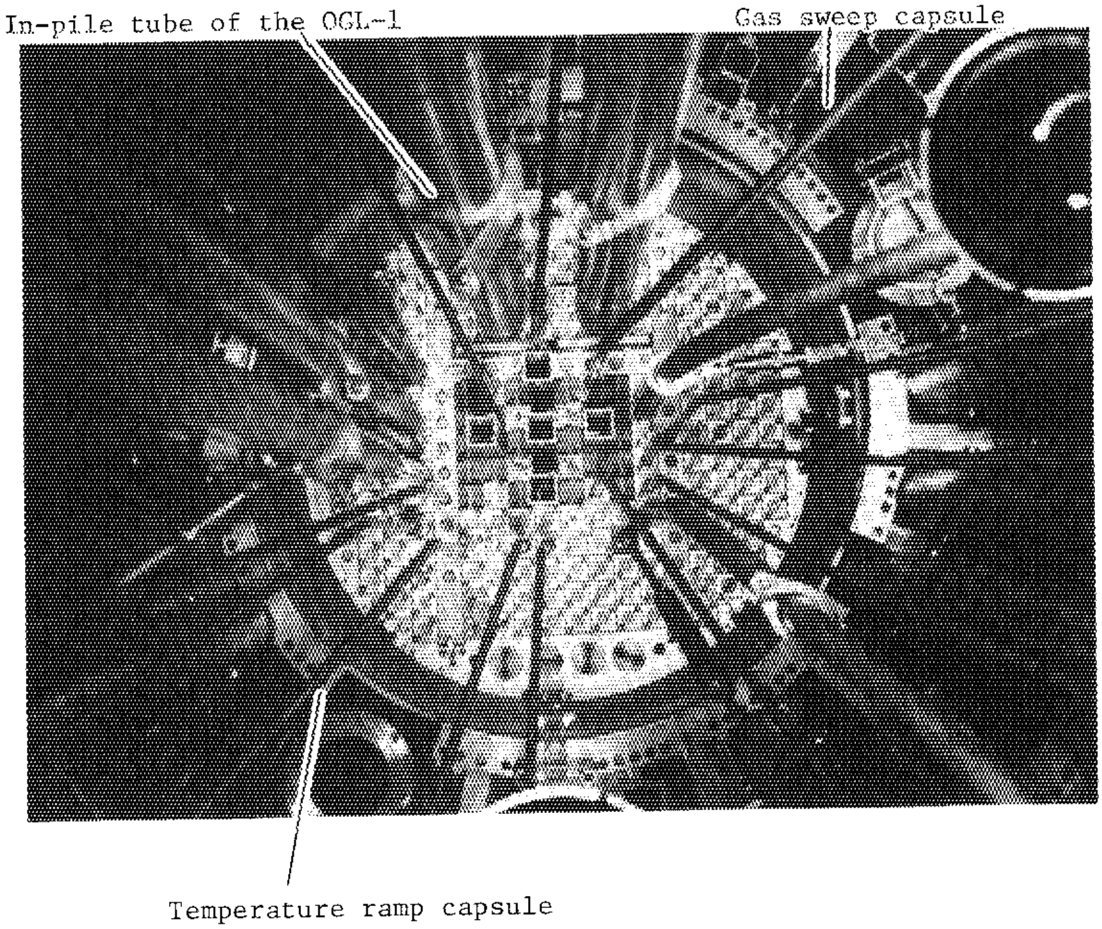

Fig.2 Vertical view of the JMTR Core

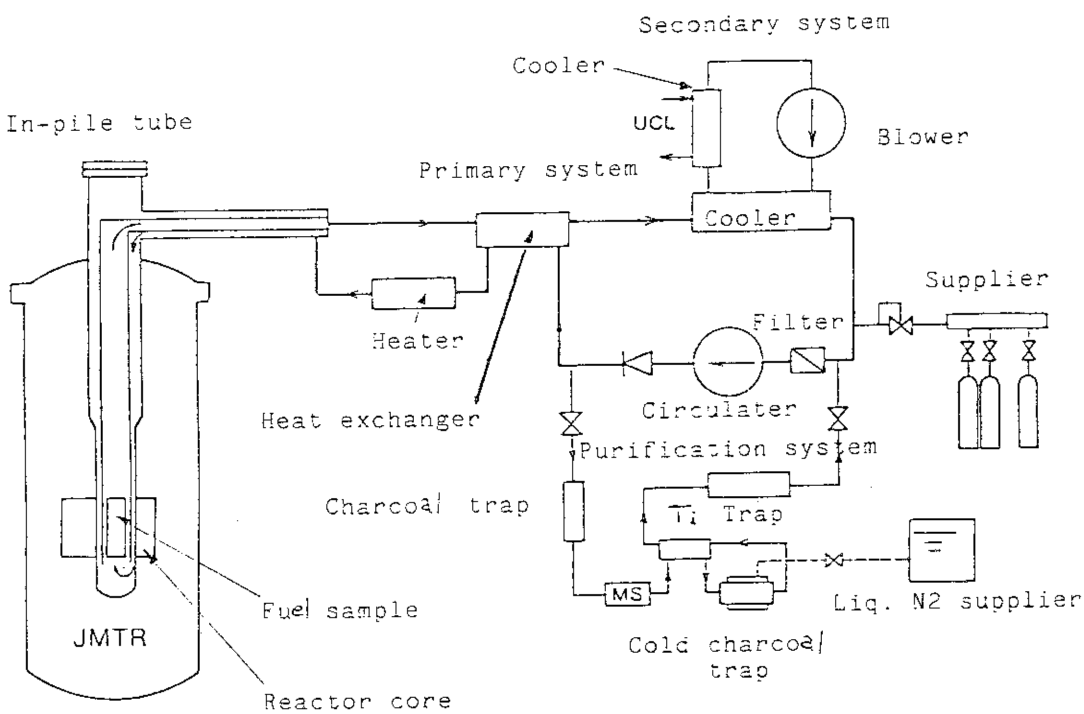

Fig.3 Simplified flow sheet of the OGL-1

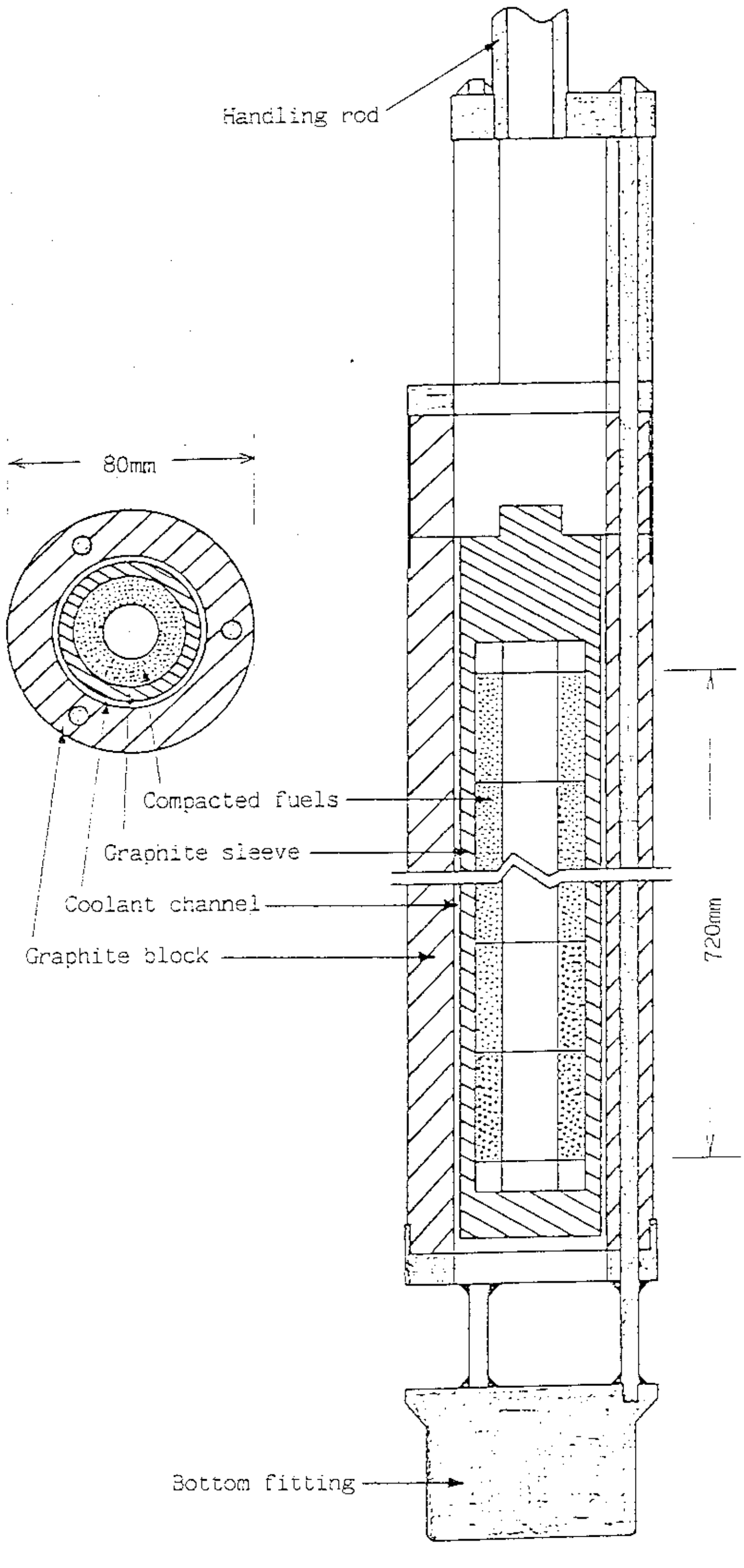

Fig.4 Schematic structure of the OGL-1 3rd fuel sample

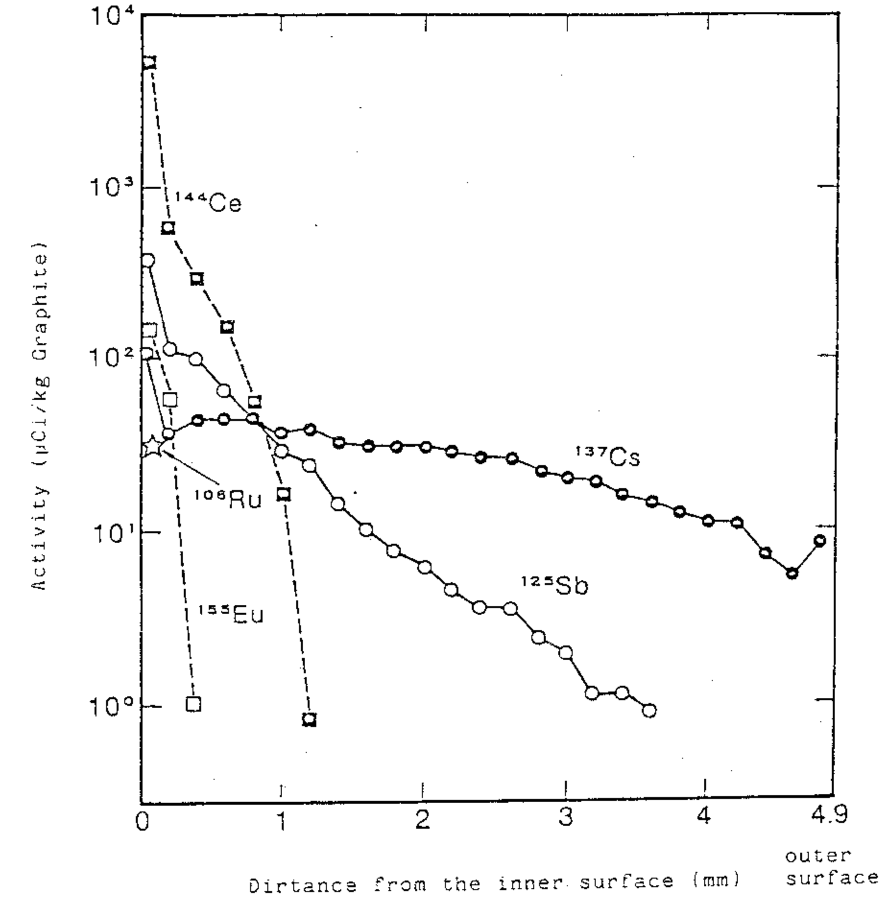

Fig.5 Radial Fission-Product Distribution in the graphite sleeve of the 3rd fuel sample

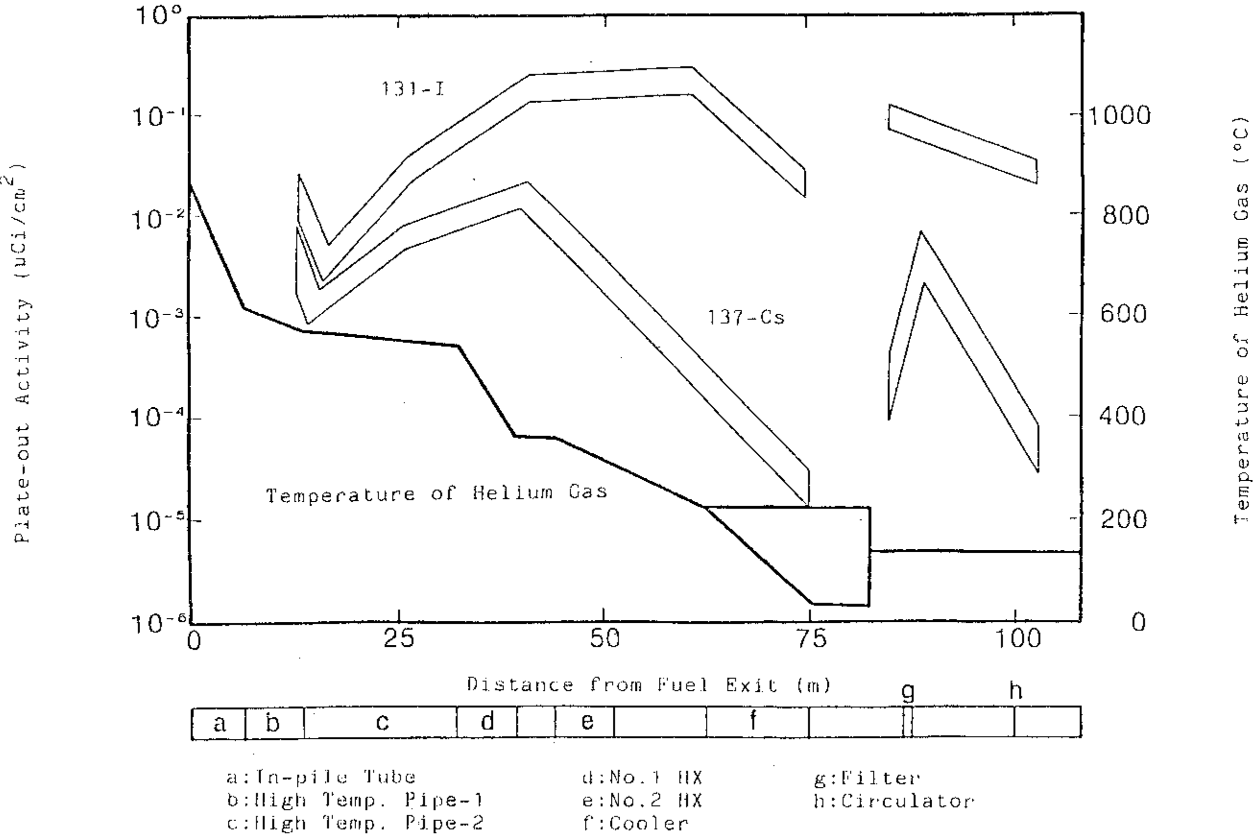

Fig.6 Plate-out Distribution of 131-I and 137-Cs in the OGL-1 Circuit

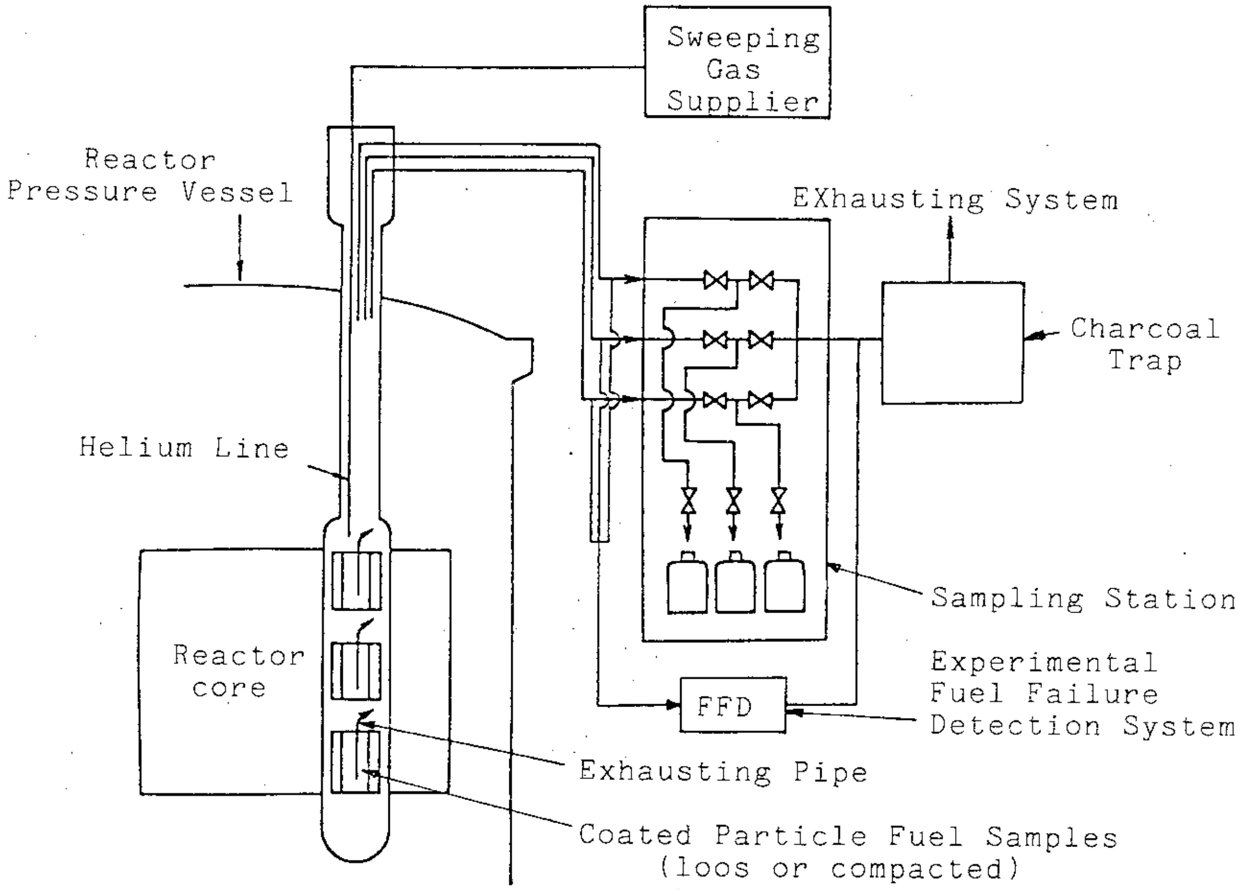

Fig.7 Simplified Diagram of the Gas Sweep Capsule Facility

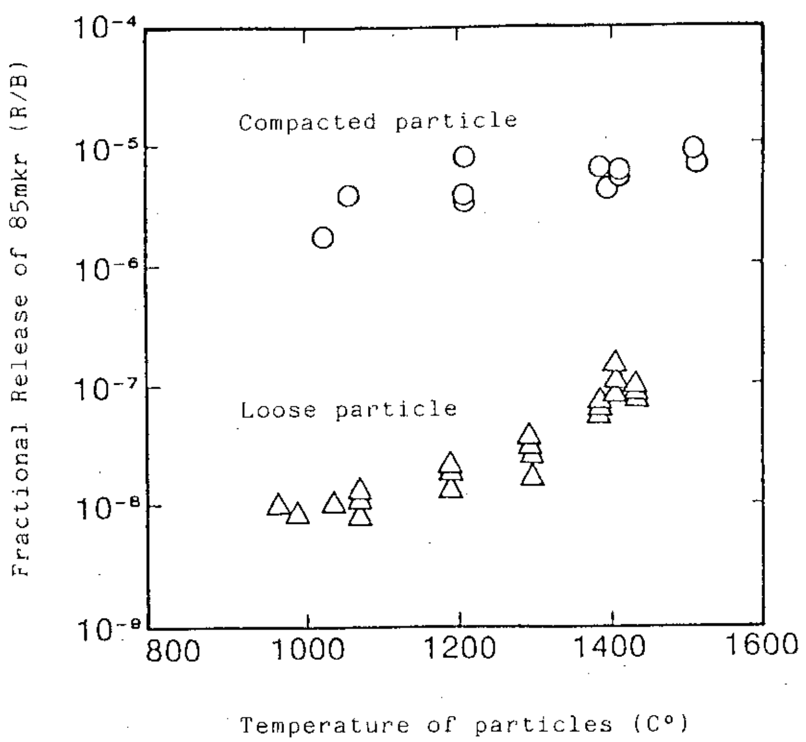

Fig.8 Typical Example of Fission Product Release Characteristics

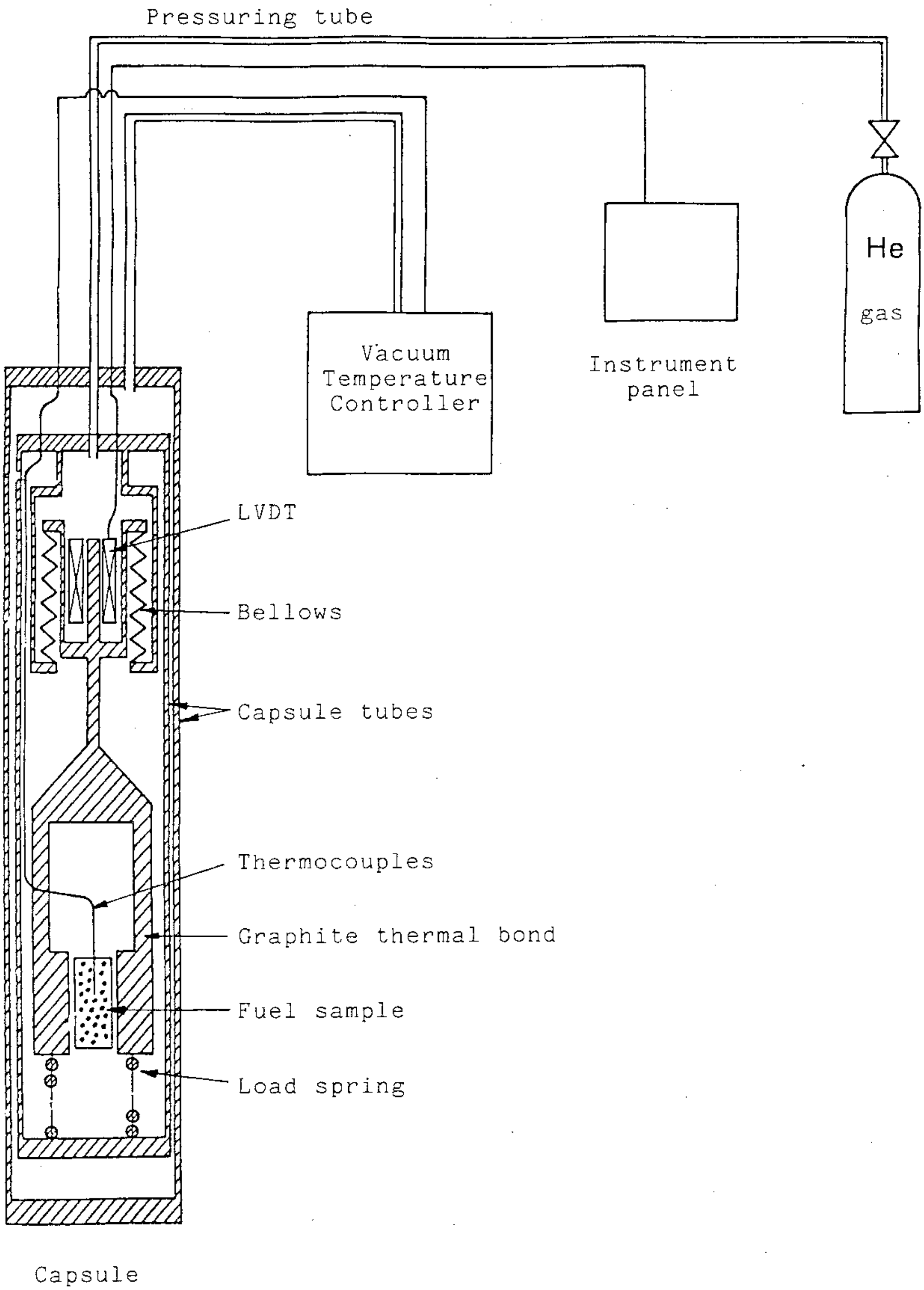

Fig.9 Schematic structure of a temperature ramp capsule

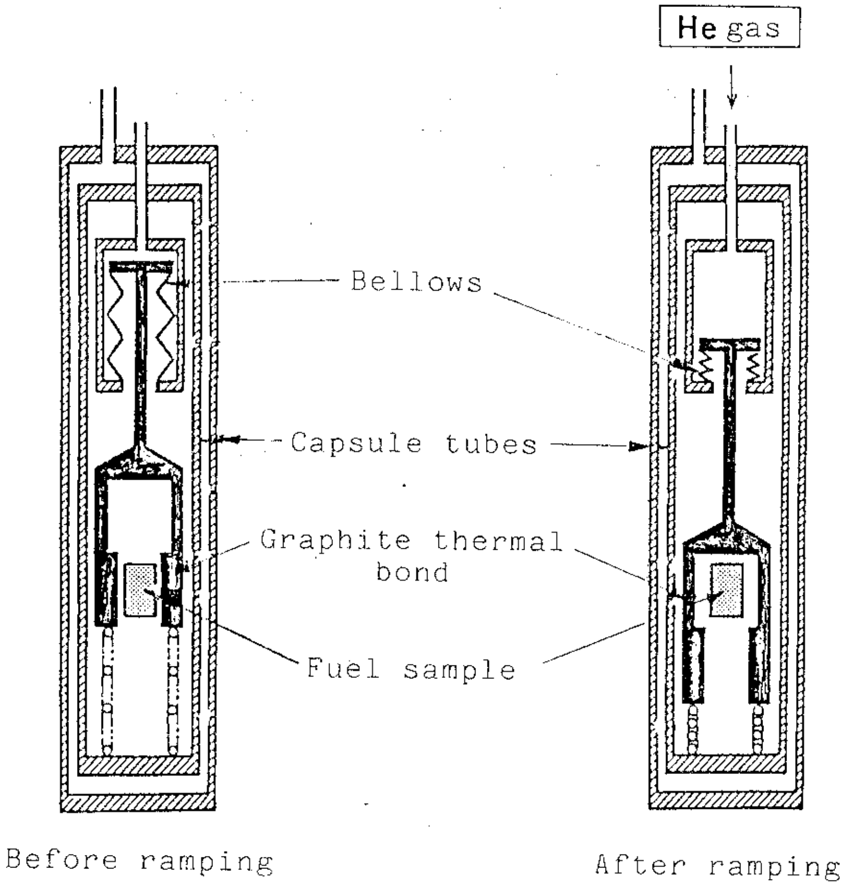

Fig.10 Movement of a graphite thermal bond in a temperature ramp capsule

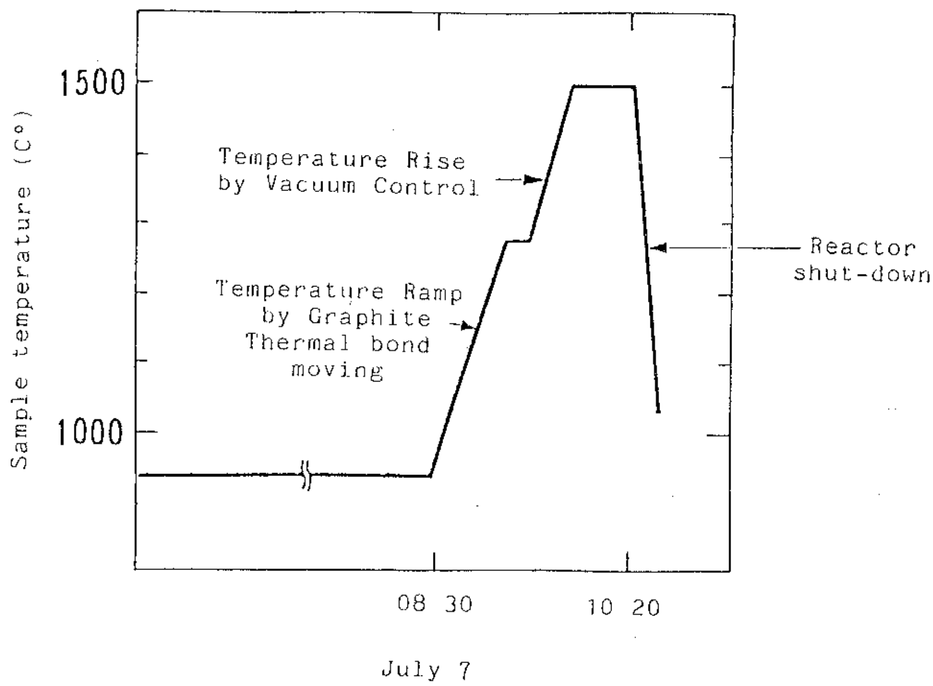

Fig.11 Result of temperature-ramp demonstration using the lead test capsule