NEW MATERIAL CONTROLLED IRRADIATION FACILITY IN THE KUR

T.Yoshiie, Y.Hayashi, Q.Xu, H.Tsujimoto, K.Kamae,
K.Mishima, S.Shiroya, M.Utsuro and Y.Fujita

Research Reactor Institute, Kyoto University
Kumatori-cho, Sennan-gun, Osaka-fu 590-0494, Japan

It has been pointed out that three deficiencies exist in conventional fission neutron irradiation experiments of materials. The first deficiency is due to the poor temperature control during a high temperature irradiation. The second one is the lack of flexibility in determining the irradiation time, which is in most cases determined by the operation cycle of the reactor. The third one is the difficulty in changing the neutron energy spectrum widely in the reactor. The installation of a new irradiation facility with improved control capabilities at the KUR is scheduled in fiscal years 1996 through 1999. The irradiation temperature can be controlled by using electric heaters and by changing the helium pressure in the irradiation tube. The neutron spectrum can be adjusted by changing the irradiation position. The total irradiation dose can be controlled by moving the specimen capsule down and up during irradiation.

1. Introduction

Material irradiation by fission neutrons in nuclear reactors has been most frequently employed as a typical method to introduce defects in solids and to develop the reliability of materials used in fission reactors and future fusion reactors. For these purposes, well-controlled irradiation fields from low temperatures to high temperatures are necessary. It has been pointed out, however, that there exist three deficiencies in conventional irradiation experiments by fission neutrons.

One deficiency is due to the poor temperature control during the fission neutron irradiation at high temperatures. In most irradiation tests in fission reactors, the nuclear heating is used for the heating of specimens. The irradiation temperature deviates from that expected, typically during the start-up of the reactor where the nuclear heating is insufficient to raise the temperature up to the expected value. The important fact is that even though the neutron dose of this stage is low, the effect on the defect structure evolution is significant. This can be understood easily when one considers the general nature of the nucleation and growth of point defect clusters. The nucleation is generally enhanced at medium temperatures, whereas the growth is faster at higher temperatures.

The second deficiency is the lack of flexibility in determining the irradiation time. It is mostly determined by the operation cycle of the reactor. To understand irradiation effects, the fluence dependence of the property changes has to be studied. For this purpose, irradiations ranging widely from low to high fluences are necessary. The last deficiency is the difficulty in changing the neutron energy spectrum. It is determined by the irradiation position of the reactor. Effects of neutron spectrum on the irradiation effects are important, since understanding of irradiation effects of 14MeV neutrons by using fission neutrons is one of important subjects for the development of fusion reactor materials.

2. Temperature controlled irradiation

The irradiation experiments without these deficiencies are an urgent requirement for promotion of the study on material irradiation effects. The simplest method to maintain the specimen at the desired temperature during the irradiation is to use a heater strong enough to heat up the specimen to the designed value without any help of nuclear heating. The first time of such an irradiation with improved temperature control was performed using the JMTR (Japan Materials Testing Reactor) in the Japan Atomic Energy Research Institute at Oarai in 1988 [1], and several data which have sufficient accuracy in irradiation temperatures have been obtained [2]. The irradiations with improved temperature control at JMTR, however, can be performed only once or twice a year, and they cannot satisfy the requirement of experimenters. Further reliable short time irradiation data have not been obtained yet in spite of many efforts.

The varying temperature irradiation experiment is scheduled in an RB position of the HFIR (High Flux Isotope Reactor) in Oak Ridge National Laboratory in 1998 under the framework of the Japan-USA cooperation program (Jupiter Project) [3]. The electric heaters are included in the capsule to vary the specimen temperature during irradiation.

In these improved temperature controlled irradiation experiments, there exists another problem. As specimens are maintained at the designed temperature before the irradiation, they are exposed to low intensity neutrons during the start-up and shut-down of the reactor. The effect of irradiation intensity on the defect structure evolution is not clarified yet.

The KUR is the only one university-owned reactor which has a MW class power in Japan, and has various irradiation facilities from low temperature to 360K. The Hydraulic Conveyor is the irradiation facility which is installed in the core center where the neutron intensity is highest in the KUR. The temperature controlled irradiation has been performed by using the Hydraulic Conveyor since 1995. Specimens are sealed in a small specimen holder and a heater is wound directly on the holder, which is in an aluminum capsule exactly of the same size as the tube, the thermal stress in the tube was analyzed with a conservative assumption that the capsule contacts with the inner wall of the tube. The heat conduction and the thermal stress in the irradiation tube were calculated by finite element calculations. Figure 5 shows the temperature profiles in the irradiation tube at 0.1sec (a) and at 7sec (b) after the contact. The linear density of heat generation in the capsule was assumed to be 100W/cm. The thermal stress at 7sec is also shown in (c) of the figure, which indicates that the stress exceeds the maximum allowable stress of A5052, 4.3kg/mm^2, near the inner wall surface. The intact region is, however, more than 15mm in thickness, which is sufficiently larger than the required wall thickness. Accordingly no failure of the irradiation tube is expected.

The seismic design was carried out according to JEAG 4601 [4], the recommended design guideline for the nuclear reactor facilities. In order to avoid the resonance with the reactor vessel, the irradiation tube was designed to have a rigid structure (20Hz < natural frequency). Static horizontal load of 0.72×W and vertical load of 0.36×W were resultantly considered as seismic forces. Here, W is a weight of the irradiation tube. The natural frequency and the maximum stress were calculated by using the finite element method. The results are shown in Tables 1 and 2, which meet the above guideline.

The irradiation tube consists of a cylindrical aluminum pipe filled with the helium gas and has 4 bending sections to avoid a significant rise in radiation dose due to the streaming of neutrons and gamma-rays through the tube. The bottom part of this irradiation tube is located at the core-reflector boundary, while the top part is located at the top shield of the reactor tank approximately 7m above the core center. The radiation dose rate at the top shield was calculated by using a continuous energy Monte Carlo code, MCNP-4A, on the basis of the JENDL-3.2 nuclear data library. Since the purpose of this evaluation was to confirm that the dose rate was suppressed in a sufficiently low level, it was assumed that fission neutrons and fission gamma-rays corresponding to 5MW operation of the KUR were homogeneously generated in the annular cylinder of 8 cm in inner diameter, 9cm in outer diameter and 60cm in height, which surrounded the bottom part of the irradiation tube. Note here that the secondary gamma-rays due to neutron reactions and the delayed gamma-rays from the fission products were taken into account in the present calculation. As a result, the dose equivalent rate at the top shield was estimated to be 13 μ Sv/h and it was found that the contribution of gamma-rays overwhelmed that of neutrons.

For the installation of the present irradiation facility, it was necessary to conduct two successive licensing procedures in accordance with the regulation of nuclear installations by the Science and Technology Agency (STA) of Japanese Government. The first procedure was for the modification of basic design of the KUR and the second was for the methods of design and construction of the irradiation facility. The licensing procedures started in June, 1994 including the pre-hearing of the STA. The licenses for the first and the second procedures were approved in December, 1995 and in October, 1996, respectively.

conventional capsule for the Hydraulic conveyor. The temperature of the specimen capsule is measured directly by a thermocouple. As the specimen capsule is inserted in the core during full power operation, the irradiation intensity is essentially constant. Various kinds of specimens have been irradiated up to the fluence of 3×10^{18}n/cm^2 and the most reliable short time irradiation data are obtained.

The Slant Exposure Tube has a low intensity and a soft energy-spectrum neutron irradiation field. The irradiation with temperature control in the Tube has been also performed since 1996. The neutron intensity of the Slant Exposure Tube is two order of magnitude lower than that of the Hydraulic Conveyor. They are expected to be used for the study of neutron intensity dependence of irradiation effects in materials.

3. New material irradiation facility

To install a facility for the exclusive use of controlled irradiation in the KUR is an urgent task to be accomplished in this research area. The installation of the irradiation facility, the Material Controlled Irradiation Facility, which has improved control capabilities of irradiation conditions, is scheduled in the KUR during fiscal years 1996 through 1999. Figure 1 shows the schematic drawing of the facility. It consists of three parts, i.e., the irradiation tube, the specimen loading chamber and the system control unit. The irradiation tube is a pipe of aluminum alloy, A5052, of 8m in length, 8cm in diameter and 2cm in thickness. The specimen loading chamber is mounted on the top shield of reactor tank. Specimen are inserted from the chamber. The system control unit measures and controls the irradiation conditions. The position of the facility in the reactor is shown in Fig. 2 for the schematic vertical view of the reactor tank and in Fig. 3 for an example of the core configuration. The irradiation tube is possible to insert in 'b-7', 'b-8' or 'b-9' in the core.

The neutron-temperature history is controlled by using an electric heater in the irradiation capsule and by changing the helium pressure in the irradiation tube. An example of the irradiation capsule is shown in Fig. 4. The neutron spectrum is adjusted by changing the irradiation position and further by changing the combination of fuel and reflector elements. Any irradiation dose can be chosen by moving the specimen capsule down and up during the irradiation.

4. Safety aspects

To maintain the integrity of the irradiation tube, the following design criteria were adopted: 1) the temperature of the specimen capsule should be below 500C, 2) the heated specimen capsule should not cause excessive thermal stress in the irradiation tube, 3) an appropriate seismic design should be applied to the irradiation tube, 4) the irradiation tube should not increase the radiation dose rate at the top shield.

Although the specimen capsule is supported by a spacer to isolate it from the irradiation

5. Future plans

The irradiation tube was successfully installed in March, 1998. Although it will take another two years to attach other auxiliary equipments for bringing the present irradiation facility to completion, preliminary irradiation experiments will start within calendar year 1998.

Data acquisition by using the irradiation facility makes it possible to examine whether the previous irradiation data were reliable or not. If we can succeed to observe the effect of neutron spectrum on the radiation effects, it would become possible to compare correctly the irradiation data obtained in different reactors with each other. These studies will contribute to thorough understanding of the irradiation effects caused by fission neutrons.

References

[1] M.Kiritani, T.Endoh, K.Hamada, T.Yoshiie, A.Okada, S.Kojima, Y.Satoh and H.Kayano, J. Nucl. Mater. 179-181, 1991, 913-916.

[2] M.Kiritani, T.Yoshiie, S.Kojima, Y.Satoh and K.Hamada, J. Nucl. Mater. 174, 1990, 327-351.

[3] A.L.Qualls and T.Muroga J. Nucl. Mater. in print.

[4] Technical Guideline for Ascetic Design of Nuclear Power Plants, Japan Electric Association, 1987.

Table 1

Natural period and natural frequency

Model	b-7		b-8	
Mode	Natural Period (sec)	Natural Frequency (Hz)	Natural Period (sec)	Natural Frequency (Hz)
1	0.044	22.9	0.042	24.1
2	0.039	25.7	0.039	26.0
3	0.032	31.1	0.032	31.6

Table 2

Evaluation of stress

Model	b-7	b-8
	Maximum Stress (kg/mm^2)	Maximum Stress (kg/mm^2)
Internal Pressure	0.1	0.1
Weight	0.2	0.2
Earthquake	0.3	0.3
Total	0.6	0.6
Maximum allowable Stress	5.6	5.6

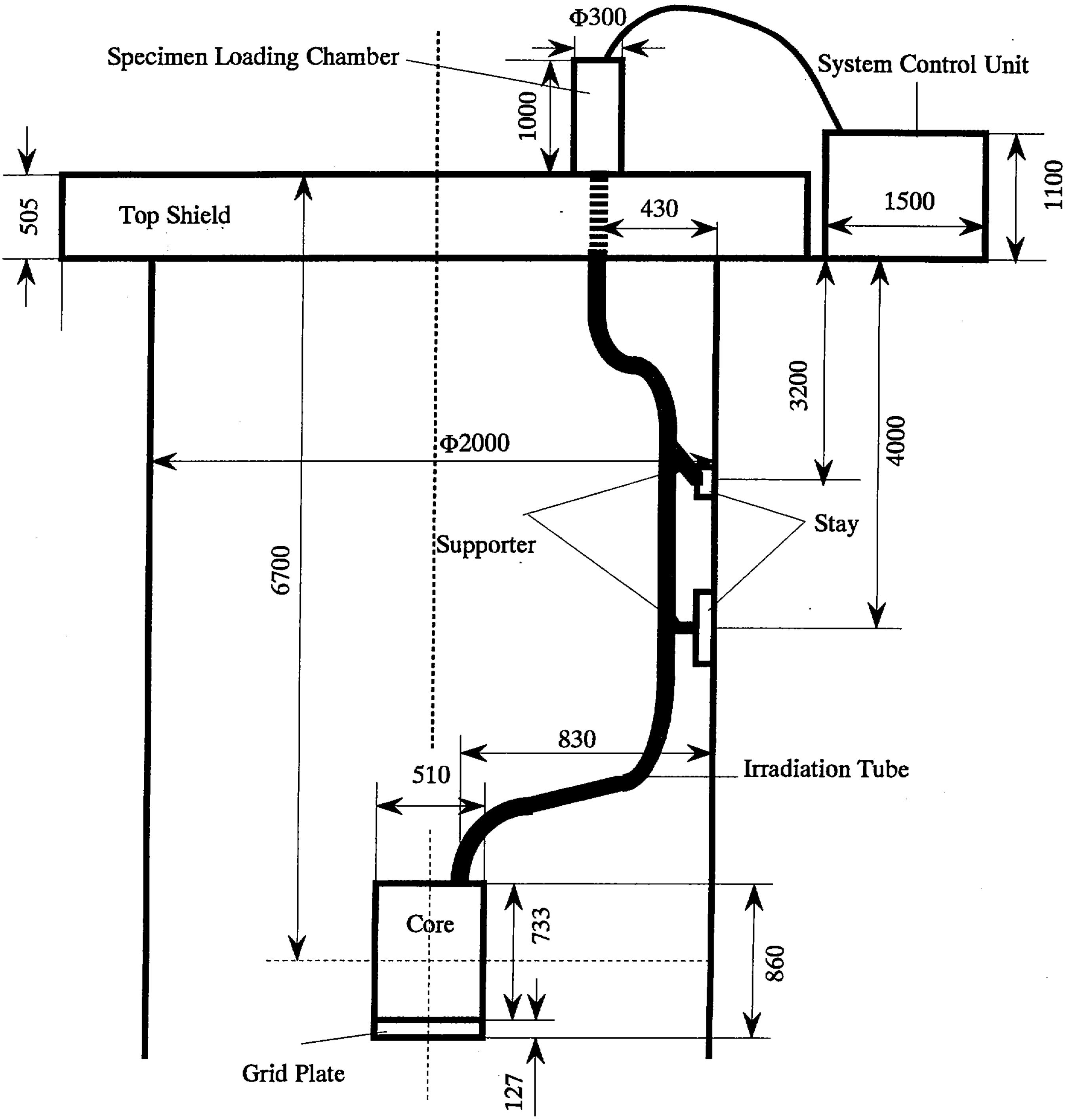


Figure 1. The Material Controlled Irradiation Facility.

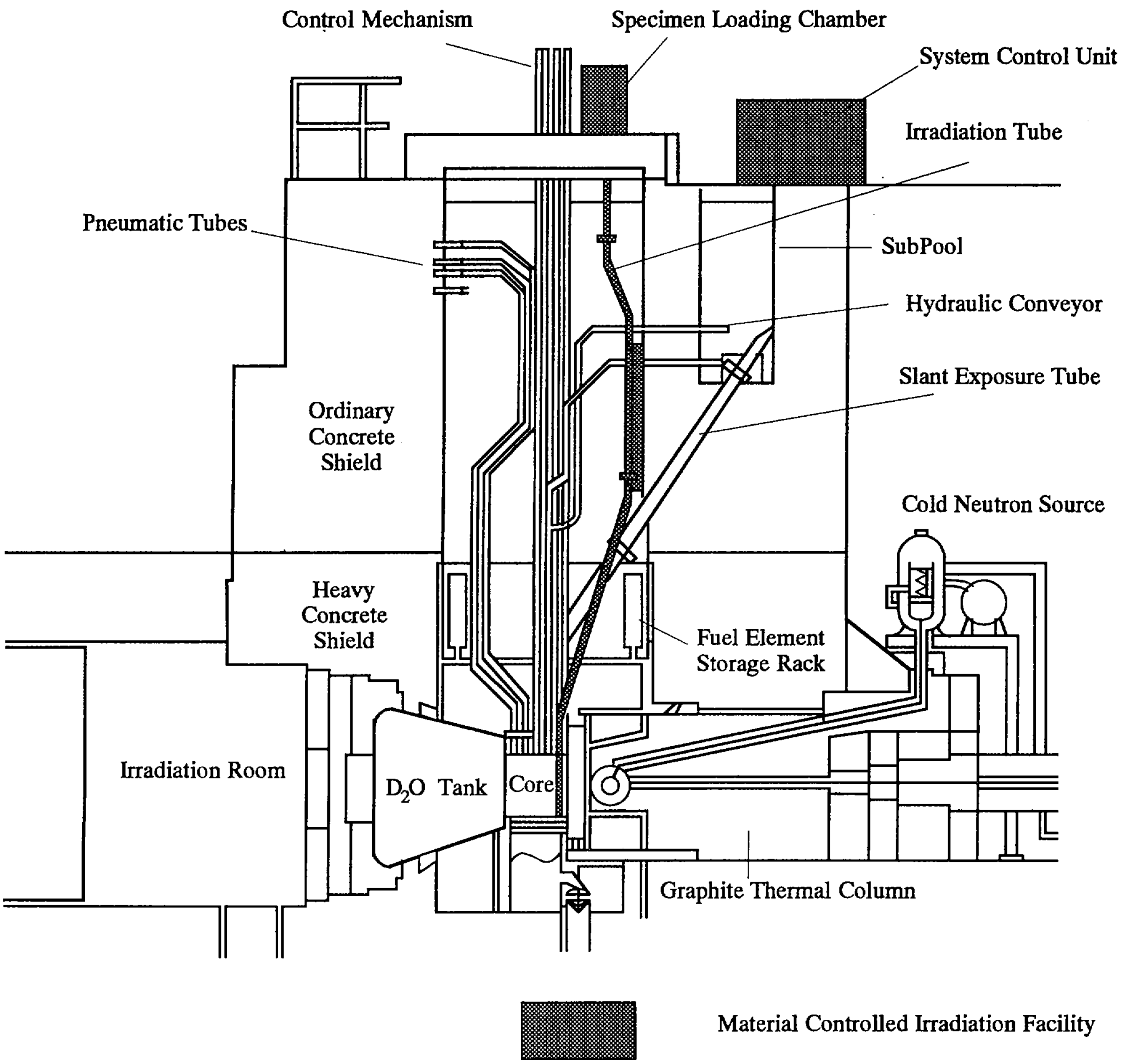
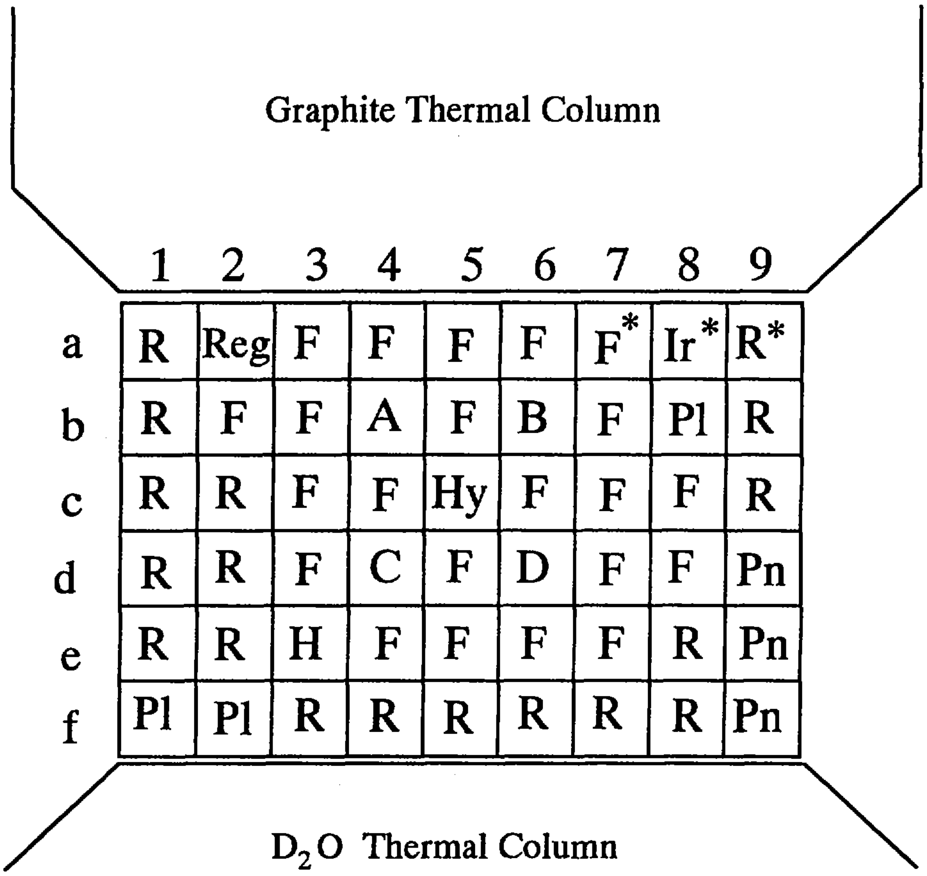


Figure 2. Vertical cross section of the KUR.



	1	2	3	4	5	6	7	8	9
a	R	Reg	F	F	F	F	F*	Ir*	R*
b	R	F	F	A	F	B	F	Pl	R
c	R	R	F	F	Hy	F	F	F	R
d	R	R	F	C	F	D	F	F	Pn
e	R	R	H	F	F	F	F	R	Pn
f	Pl	Pl	R	R	R	R	R	R	Pn

F	Fuel Elements
H	Half Loading Fuel Elements
Reg	Special Fuel Elements for Regulating Rod
A B C D	Special Fuel Elements for Shim Rod
D	Graphite Reflector
D	Plug
Hy	Hydraulic Conveyor
Pn	Pneumatic Tube
Ir	Material Controlled Irradiation Tube

(*shows possible positions of the material controlled irradiation tube)

Figure 3. An example of the core configuration.

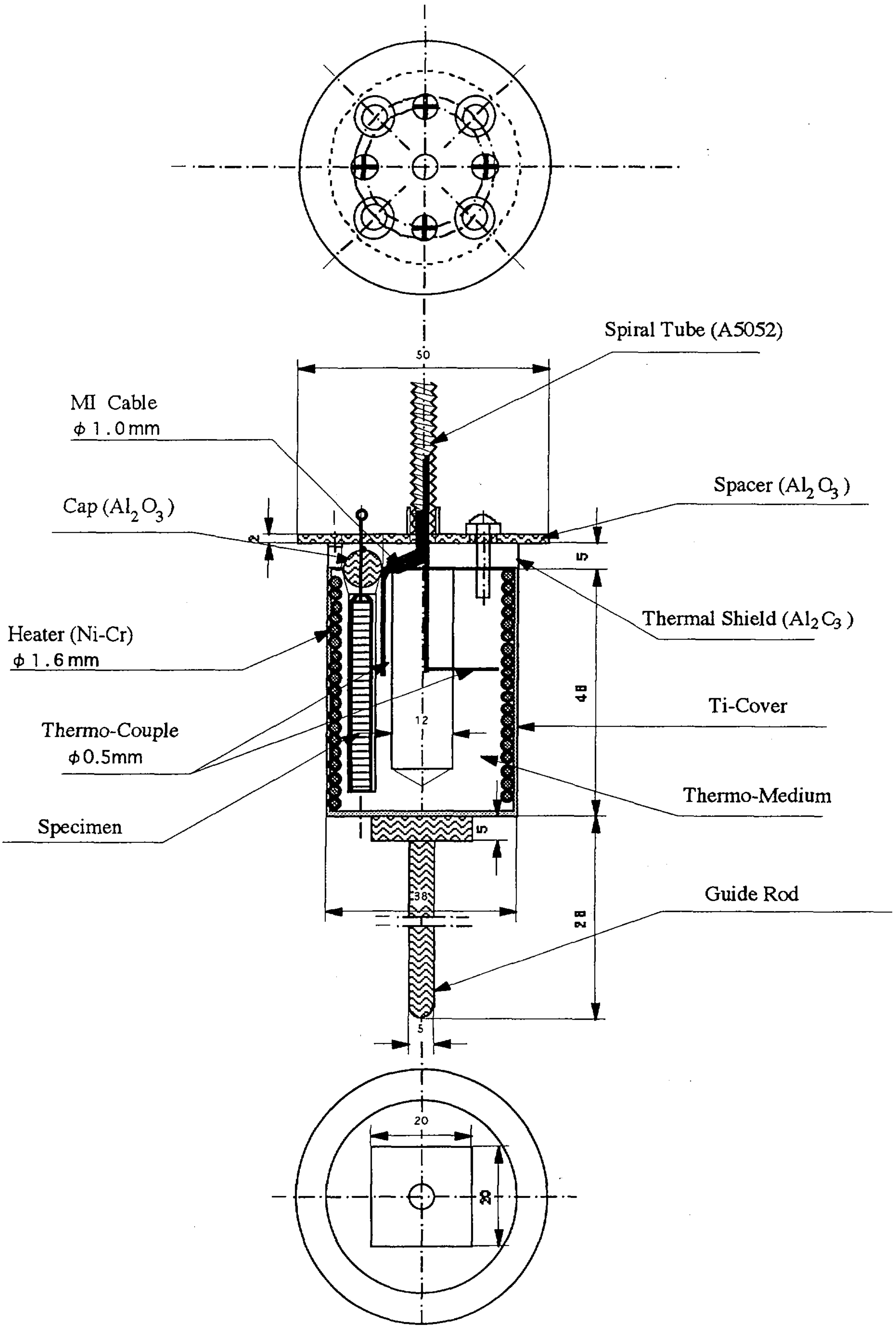


Figure 4. An example of irradiation capsule.

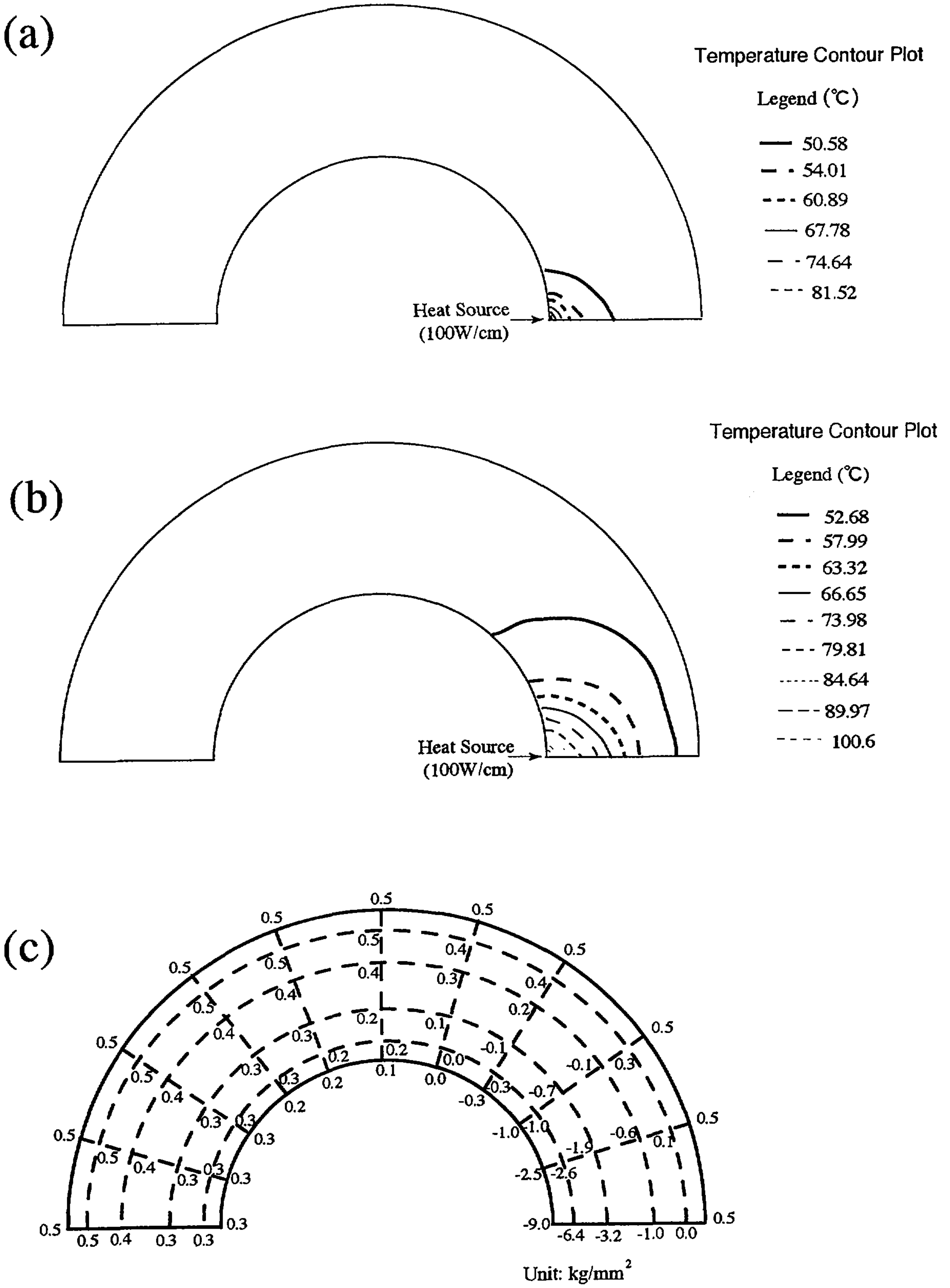


Figure 5. Temperature profiles in the irradiation tube at 0.1sec (a) and 0.7sec (b), and the thermal stress at 7sec (c) after the contact of specimen capsule with the tube.