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GENERAL DESCRIPTION OF IRRADIATION AND
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November 1986

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and Yoshinori ICHIHASHI

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General Description of Irradiation
and Post Irradiation Examination in JMTR

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The JMTR (Japan Materials Testing Reactor) was designed to provide suitable facilities for conducting nuclear irradiation experiments necessary for the research and development of power reactor in Japan. The JMTR consists of a 50 MW high flux reactor, irradiation facilities and a multi-cell hot laboratory. The available irradiation facilities are various kinds of capsules, hydraulic rabbit facilities, high temperature and high pressure water loop, and high temperature and high pressure gas loop.

The aim of this publication is a representation of the information concerned with the irradiation facilities.

Keywords: JMTR, Irradiation Facility, High Flux Reactor, Irradiation Experiment, Hot Laboratory, Capsule, Loop

Furthermore, this publication is the revised version for JAERI-M 82-119 published, 1982.

J M T R の照射試験及び照射後試験の概要

日本原子力研究所大洗研究所材料試験炉部

露崎 典平・酒井 陽之・市橋 芳徳

(1986年10月13日受理)

J M T R (材料試験炉) は、日本における動力炉の研究開発に必要な照射実験を行うため設置されたものであり、50 MW の高中性子束炉、各種照射装置および大型ホットラボから成っている。利用可能な照射装置には、多様なキャプセル、水力ラビット装置、高温高圧水ループ、同ガスループなどがある。

本稿の目的は、これら照射装置に関する情報を提供することである。

大洗研究所：〒311-13 茨城県東茨城郡大洗町成田町字新堀3607

なお、本稿は、1982年8月に投稿したJAERI-M82-119を現時点で見直して、実体に合せ再投稿したものである。

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1. Introduction

The JMTR (Japan Materials Testing Reactor) was designed to provide suitable facilities for conducting nuclear irradiation experiments necessary for the research and developments of power reactor in Japan, and is owned and operated by the JAERI (Japan Atomic Energy Research Institute). The JMTR is located in the Oarai Establishment, which is one of the four establishments of the JAERI.

The JMTR consists of a 50 MW high flux reactor, irradiation facilities and a multi-cell hot laboratory.

The construction work of the reactor was started on June 1965. The reactor went to the first criticality on March 1968, and power operation of 30 MW for irradiation experiment started on January 1970. The reactor power was increased to 50 MW on November 1971 with a minor change of reactor core configuration.

The available irradiation facilities are various kinds of capsules, hydraulic rabbit facilities, special facilities such as water and gas loops. The capsules are loaded into irradiation holes and cooled by reactor coolant. The loops have individual high temperature and high pressurized water or gas circuit mainly for the irradiation under the similar condition to power reactor.

The hot laboratory was completed at the end of 1970, and has been continuously improved its ability. The laboratory is connected to the reactor with water canal, and is capable of conducting a wide variety of PIE (Post Irradiation Examination).

The aim of this publication is a representation of the information concerned with the irradiation facilities. After brief explanation of a configuration and characteristics of the reactor, important information are given on irradiation facilities, which are used for fissile and non-fissile materials irradiation as well as for radioisotope production. In-core instrumentation and data acquisition system, which play important role for irradiation experiments, are also described.

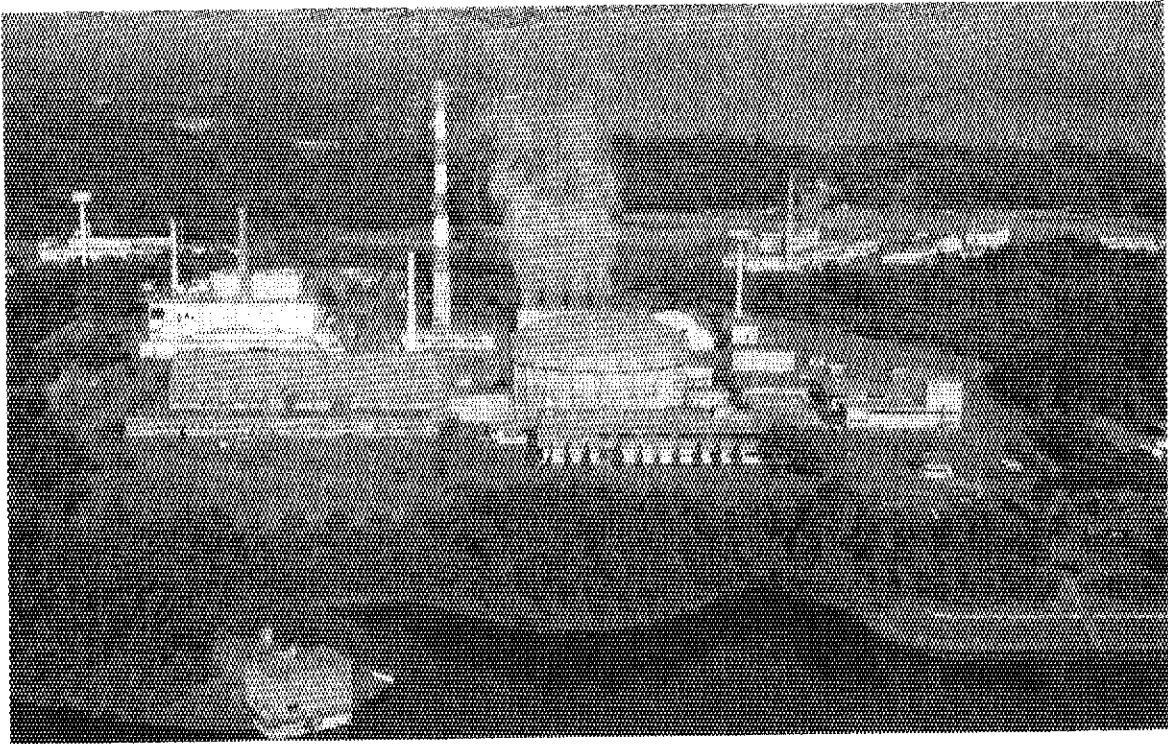


Fig. 1.1 Panoramic View of the JMTR

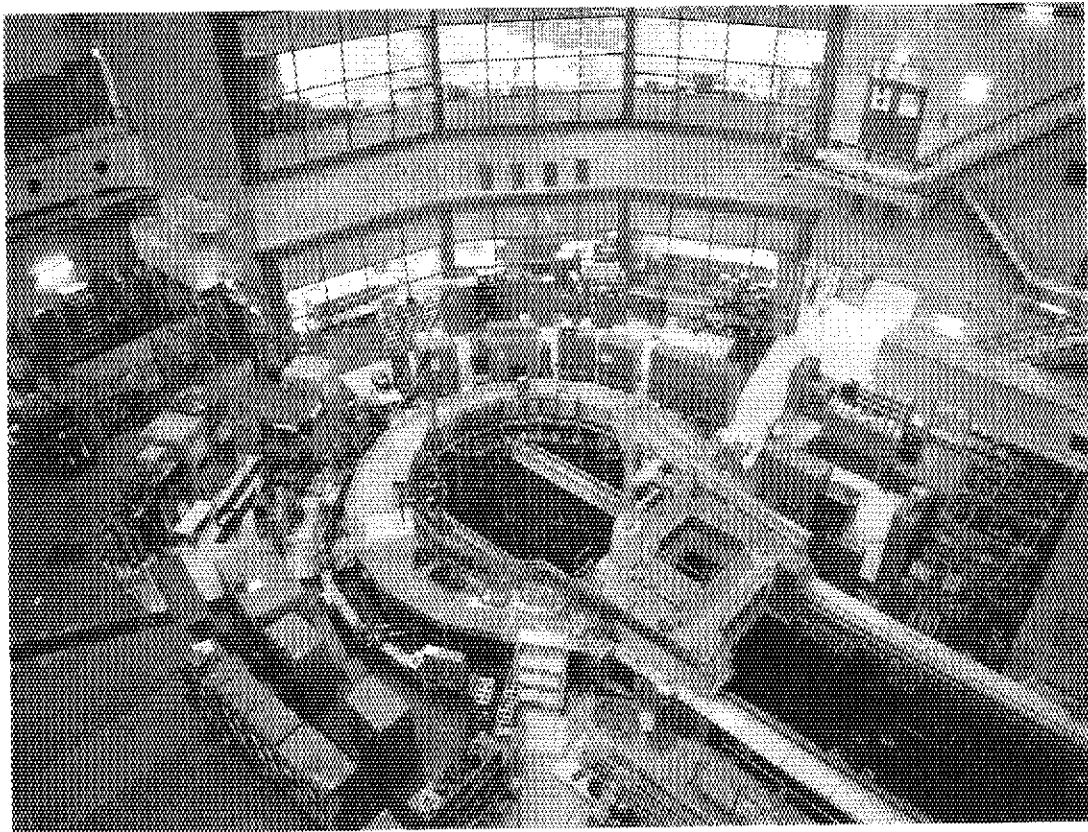


Fig. 1.2 Inside View of the Reactor Building

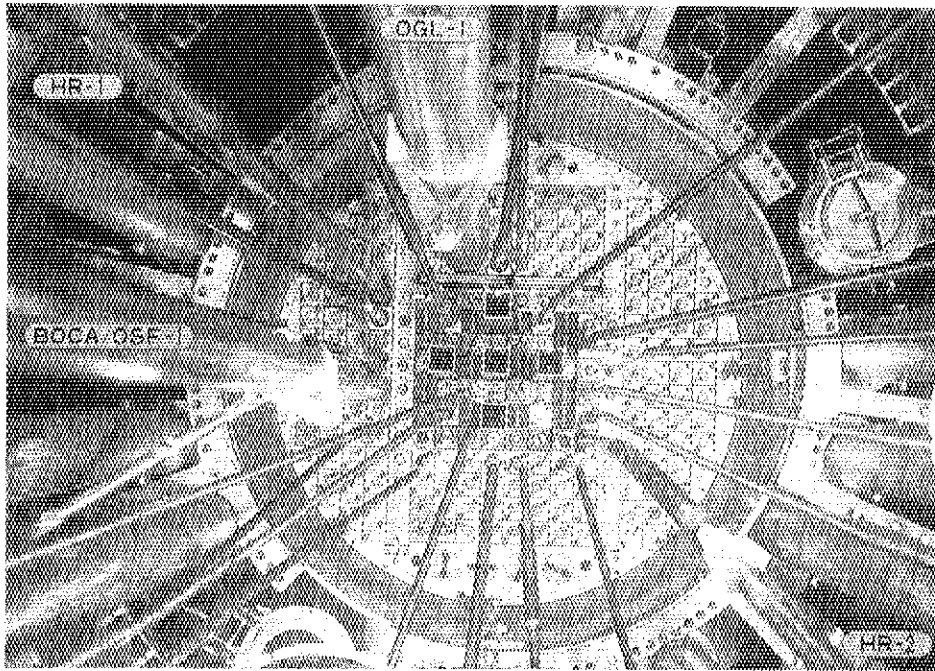


Fig. 1.3 JMTR Core

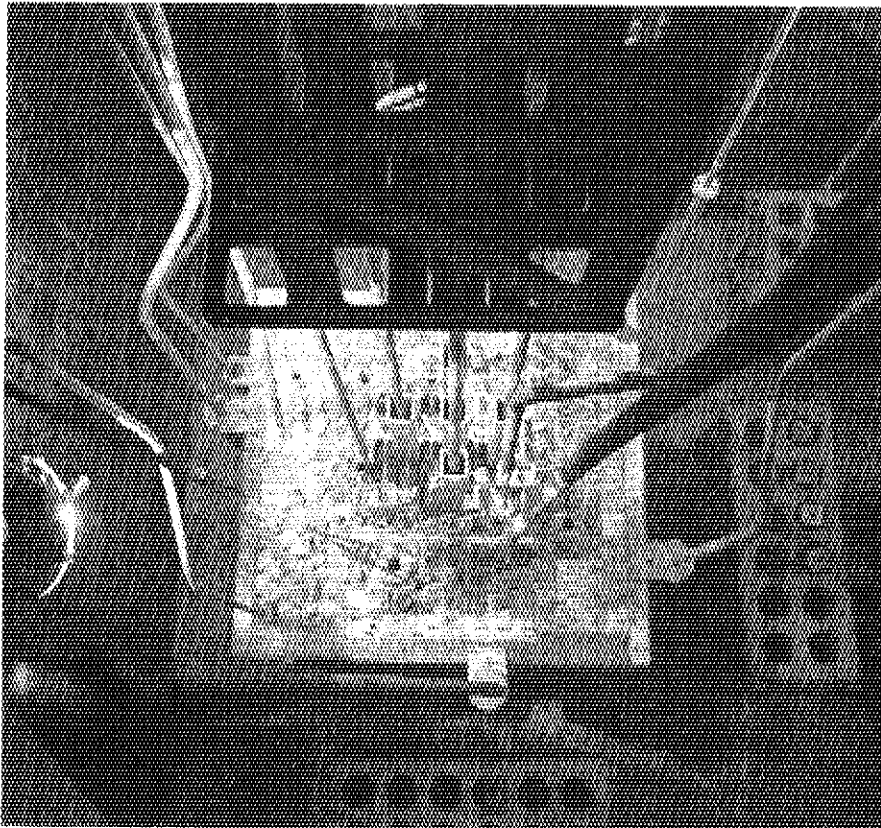


Fig. 1.4 JMTRC

2. JMTR

2.1 Reactor description

The main part of the JMTR is a 50 MW high flux reactor, which is operated by 45% enriched Uranium fuels, is cooled and moderated by light water, and reflected by beryllium.

The core, 1560 mm in diameter and 750 mm in effective height, is divided into a fuel region and reflector region. The fuel region is a 7×5 array (540 mm \times 386 mm) containing 22 fuel elements, 5 control rods and 8 experiment positions. These positions are served mainly for testing structural materials which require the irradiation of fast neutron flux. The reflector region consists of the inner reflectors of beryllium and the outer reflectors of aluminum. The reflector region, because of producing relatively constant and high thermal neutron flux during operation, is served mainly as space for irradiation of fuel materials.

About 100 capsules irradiation can be carried out in the core. However, instrumented capsules will be less than 20 due to the limited number of reactor vessel nozzles available for penetration of the instrument leads. On the grid plate, are provided 10 insertion holes for loop experiments, one in the fuel region and 9 in the reflector region. The maximum diameter of loop is 6 inches.

The JMTR was initially-designed to use the highly enriched uranium as fuel material, and the fuel elements had been used until 74th operation cycle, 1986. After then its enrichment was reduced down to 45% by the view point of international safeguards.

The fuel elements (horizontal cross section 77 mm \times 77 mm, height 1200 mm) are of the modified ETR type. Each element contains 19 fuel plate of 1.27 mm thick, 71 mm wide and 780 mm long. The fuel meat is made of about 1.6 g U/cm³ 45% enriched uranium aluminide. The content of 235-U per element is about 310 g.

Each control rods consists of a box type hafnium section on top of a fuel section. The fuel section contains 1.6 fuel plates with a total weight of 205 g 235-U. Their drive mechanism is installed on the bottom of reactor vessel. The control rods are moved on a vertical direction. When a control rod moved upwards, the fuel section moves into the core displacing the hafnium section.

All of reflector element used have a same outside dimensions as a fuel element. Each element is equipped with a irradiation hole drilled

along its axis. The hole is filled with a solid plug of same material as the element when not in use for irradiation experiment. Diameters of the holes are 32 mm, 38 mm and 42 mm for beryllium reflectors, and 32 mm, 38 mm, 42 mm, 62 mm and 67 mm for aluminum reflectors. Reflector element with desired hole could be inserted into a desired core position.

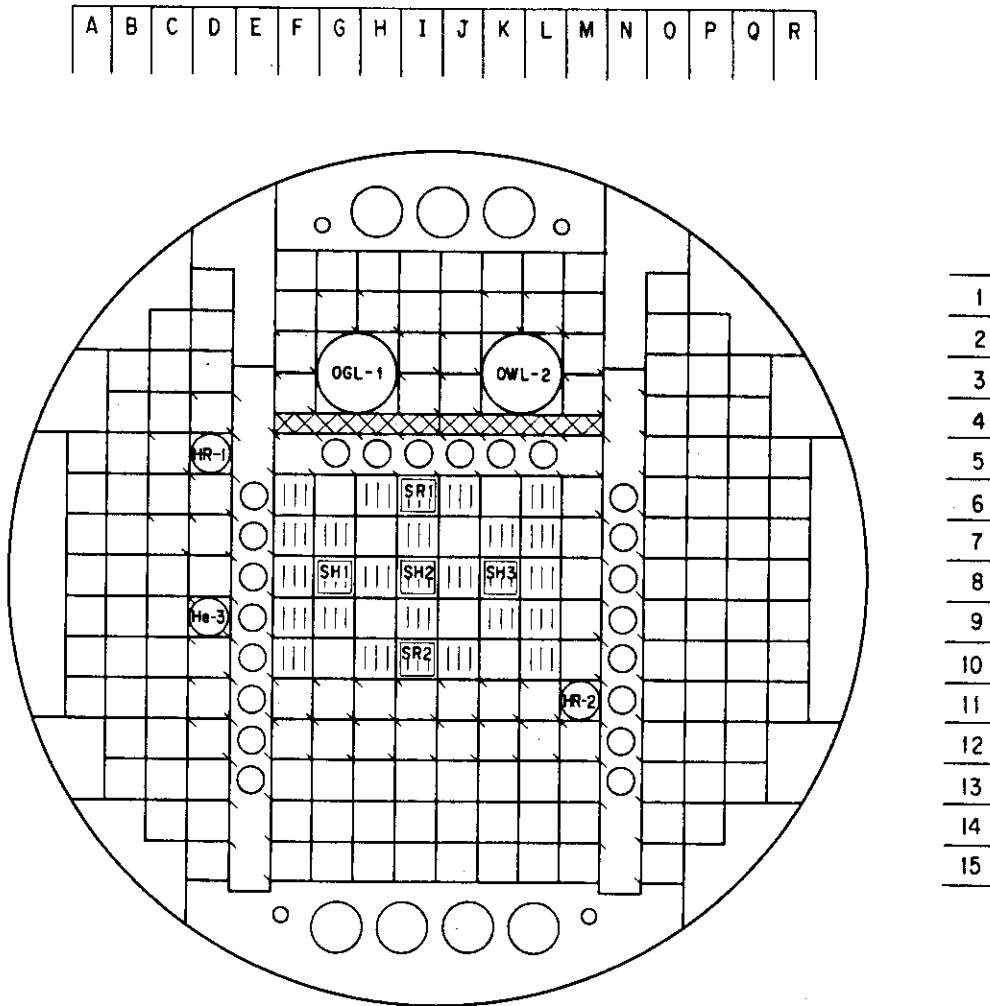
The reactor vessel is a stainless steel tank of 3 m in diameter and 9.5 m in height. Its wall thickness is 34 mm. It is designed to withstand an internal pressure of 18 kg/cm²G. The top head flanged to the shell has openings for the access to the core and many nozzles for experiments. The bottom head also provides the holes for through-loops as well as for control rods.

The reactor core is cooled by circulating water in a closed circuit. Primary cooling system is consisted of the reactor vessel, three main pumps, three water heat exchanger, and tubes. The water flows downward through the reactor core. The velocity along the fuel plates is 10 m/s. The flow rate through the core is 6000 m³/h. Max. water inlet temperature is 45°C. The corresponding outlet temperature is 56°C. In the heat exchangers the reactor power is dissipated to the secondary coolant, which is circulated over cooling towers. The flow rate of secondary water is 3900 m³/h. Number of operating fans are to be selected according to wheather condition.

The reactor vessel is situated in the reactor pool of 6 m in diameter and 13.7 m in depth. There is a water layer of 4.2 m above the reactor vessel during power operation. The water level in the pool is lowered to the top level of the reactor vessel for the handling of fuel elements and irradiation facilities during the shut down periods. Connecting the reactor pool, there is a canal of 3 m width and 6 m in depth to the Hot Laboratory adjacent to the reactor building.

Description of the JMTR

| | |
|--|--|
| Type | Tank type |
| Power | 50 MW |
| Moderator/coolant | H ₂ O (14 kg/cm ² G, 50°C) |
| Reflector | Be and Al |
| Fuel: material | Uranium Alminide Fuel (Dispersion Type) |
| enrichment | 45 % |
| loading | 7.6 Kg of 235-U |
| type | Modified ETR |
| Control rod | 5 Hf rods with 5 fuel followers |
| Neutron flux (10 ¹⁴ n/cm ² ·s), (max.); | |
| | fast (>1 Mev) thermal |
| fuel region | 4 4 |
| reflector region | 1 4 |



- Fuel element
- Be reflector with irradiation hole
- Al reflector with irradiation hole
- Control rod with fuel follower
- Irradiation holes

Fig. 2.1.1 Irradiation Facilities in the JMTR Core

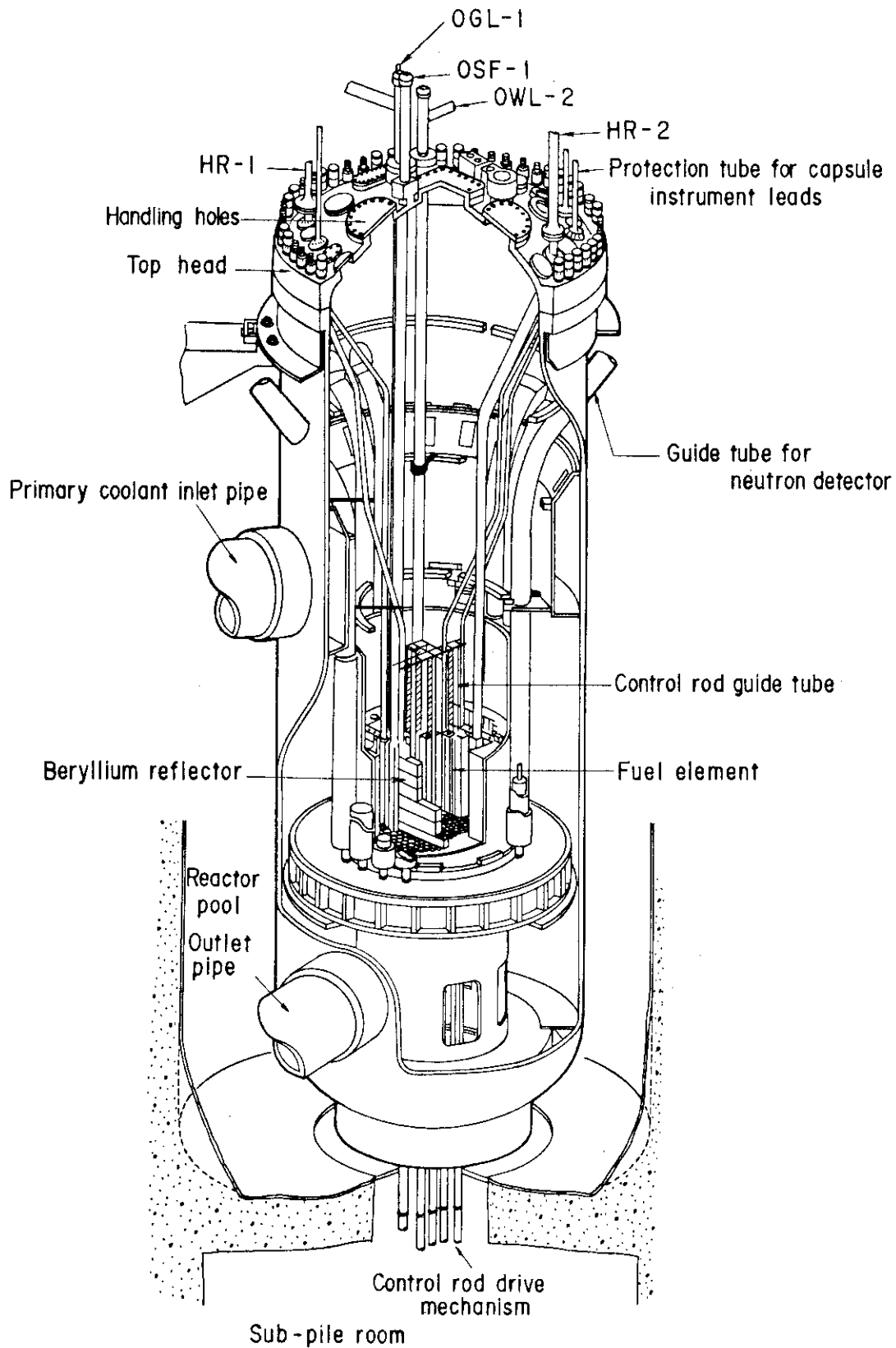


Fig. 2.1.2 Cutway View of Internals of the JMTR Reactor Vessel

2.2 Operating schedule

The operating mode of the JMTR is a 26-day operation (one cycle) followed by a shut down work.

Main shut down works are refueling, installation and reloading of the irradiation facilities, and maintenance on the reactor and the facilities. The shut down works needs 4 weeks generally. Additional 2 weeks in spring and 12 weeks in summer are required for annual inspection according to the national reactor regulation. Another 10-day shut down is scheduled for the new years holiday.

A 26-day operation, with 2-day mid shut down work for refueling, produces a integral power of about 1080 MWD.

Eight fresh elements containing 310 g of ^{235}U , ten half cycle used elements containing about 280 g of ^{235}U and four one cycle used elements containing about 250 g of ^{235}U are loaded into the core at the beginning of the operation to obtain a relatively uniform neutron flux and enough reactivity for operation. During the mid shut down, ten elements containing 280 g of ^{235}U at the beginning are replaced by fresh elements and four elements containing about 250 g of ^{235}U at the beginning are replaced by other one cycle used elements for further operation.

In case of unscheduled shut down during operation, the reactor can not restart within 40-50 hours, if a restart up within 15-30 minutes have been failed, due to a Xenon build up.

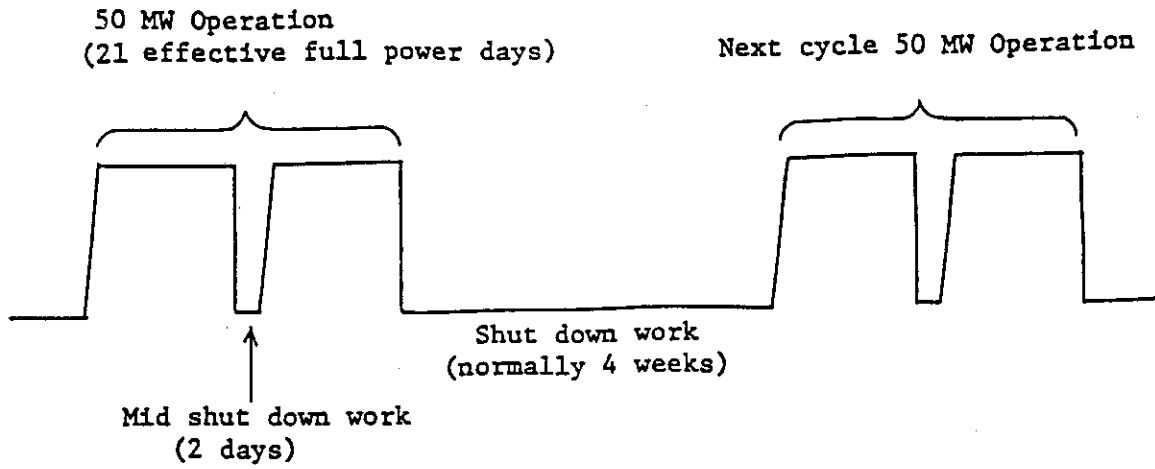


Fig. 2.2.1 Standard Operation Schedule of the JMTR

Table 2.2.1 Standard Fuel Loading in the JMTR Core

| | | | | | | |
|---|---|---|---|---|---|---|
| C | | B | F | B | | C |
| B | A | | A | | A | B |
| A | F | B | F | B | F | A |
| B | A | | A | | A | B |
| C | | B | F | B | | C |

At beginning of a cycle

| | | | | | | |
|---|----|---|----|---|----|---|
| C | | A | F* | A | | C |
| A | B | | B | | B | A |
| B | F* | A | F* | A | F* | B |
| A | B | | B | | B | A |
| C | | A | F* | A | | C |

After refueling during mid shut down work

note A; Fresh fuel element
 B; Half cycle used fuel element
 C; One cycle used fuel element
 F; Fresh fuel follower
 F*; Half cycle used fuel follower

2.3 Neutron flux and spectra

Typical thermal and fast neutron flux distribution at 50 MW are shown in Fig. 2.3.1. Neutron flux for each operation is calculated by complex neutronic code in advance to loading. Nuclear heating or neutron fluence for each experiment can be estimated with this calculated flux. Proposed loading may be changed if a results of the estimation could not satisfy a requirement of the experiment.

Neutron flux distribution is changed as the operation proceeds due to mainly control rod movement. Horizontal distribution is relatively unchanged during operation except for one day after start up. However, vertical distribution is considerably changed. Fig. 2.3.2 show a change of vertical distribution accompanied with control rod movement.

Neutron spectrum in the fuel region and beryllium reflector region are shown in Fig. 2.3.3. Neutron flux in the core is presented in energy integral basis. So-called fast neutron flux contains neutrons having energy above 1 MeV and thermal neutrons having below 0.625 eV. Table shows spectrum indices, which are used to obtain fast neutron flux having lower limiting energy below 1 MeV.

Fluence monitors, such as Fe wire for fast neutron and Co-Al alloy wire for thermal neutron are placed in irradiation facility close to specimen when exact fluence are desired.

Neutron flux measurements are carried out in the JMTRC for some special experiments, which calculation can not give precise and/or detail neutron flux distribution. The JMTRC is a nuclear mock up of the JMTR and is located in the same building.

SPECTRUM INDICES

| Region | $\frac{\phi(>0.1 \text{ MeV})}{\phi(>1.0 \text{ MeV})}$ | $\frac{\phi(>0.18 \text{ MeV})}{\phi(>1.0 \text{ MeV})}$ |
|----------------|---|--|
| Fuel Region | 2.00 | 2.02 |
| Be-1 Reflector | 2.31 | 2.08 |
| Be-2 Reflector | 2.62 | 2.29 |
| Al-1 Reflector | 2.77 | 2.44 |
| OGL-1 Loop | 2.80 | 2.48 |

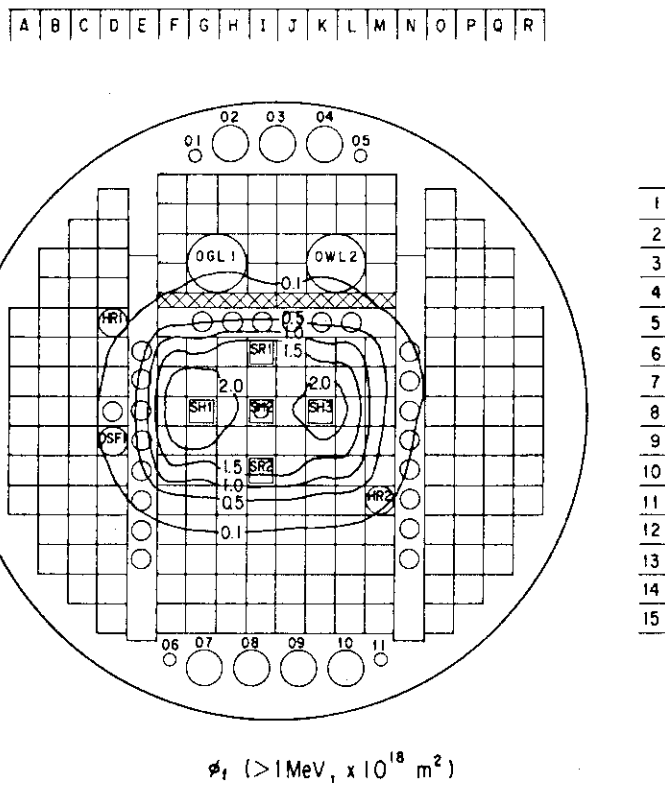
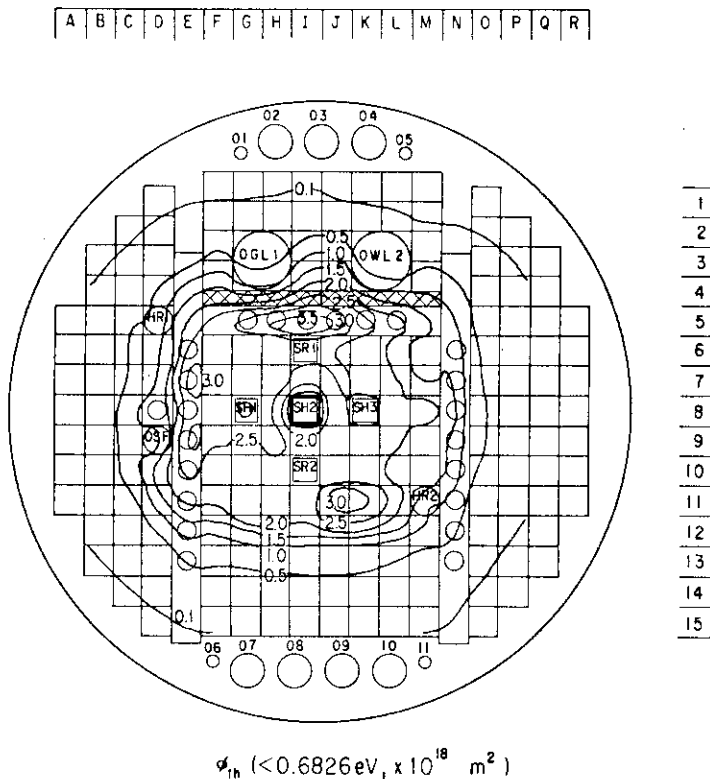
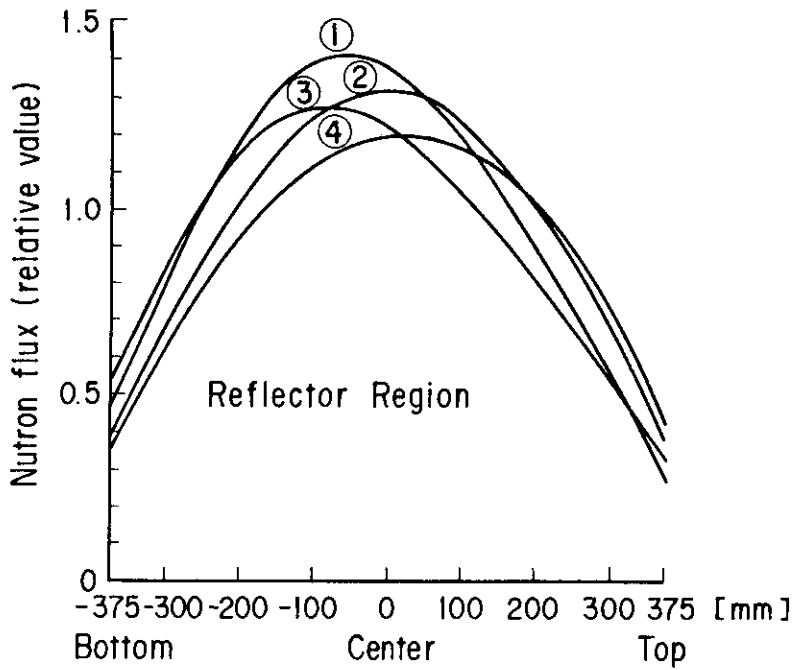


Fig. 2.3.1 Typical Neutron Flux Distribution in the JMTR Core
(Vertically Averaged)



Note

- Curve 1 : just after start up
 - Curve 2 : start of 50MW operation
 - Curve 3 : half withdrawal of center rod
 - Curve 4 : all rods full withdrawal
- All curves are nomalized to a viritically averaged value at start of 50 MW operation

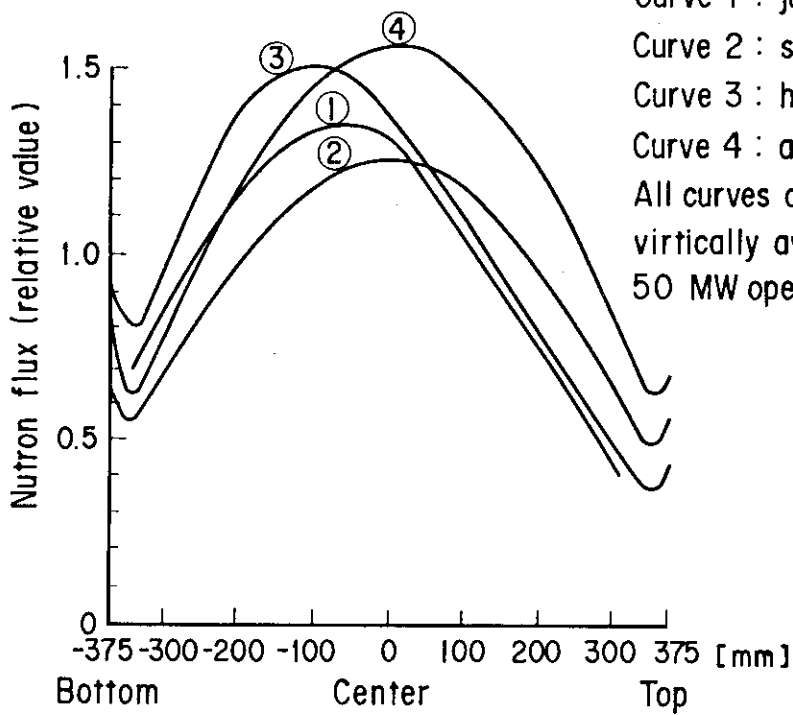


Fig. 2.3.2 Variation of the Vertical Neutron Flux Distribution During the Operation

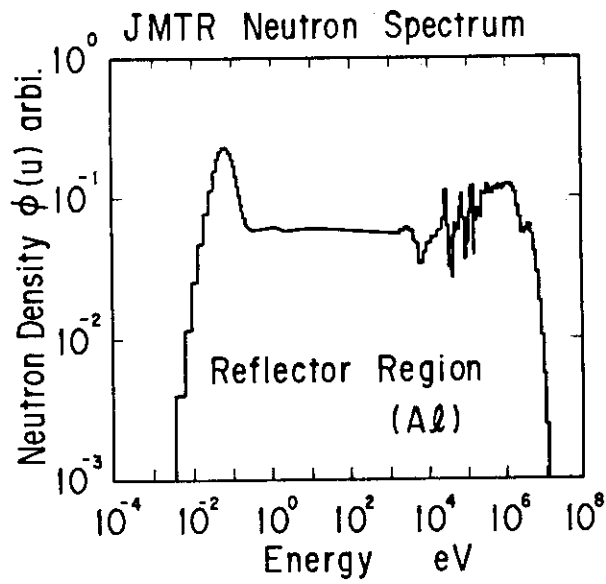
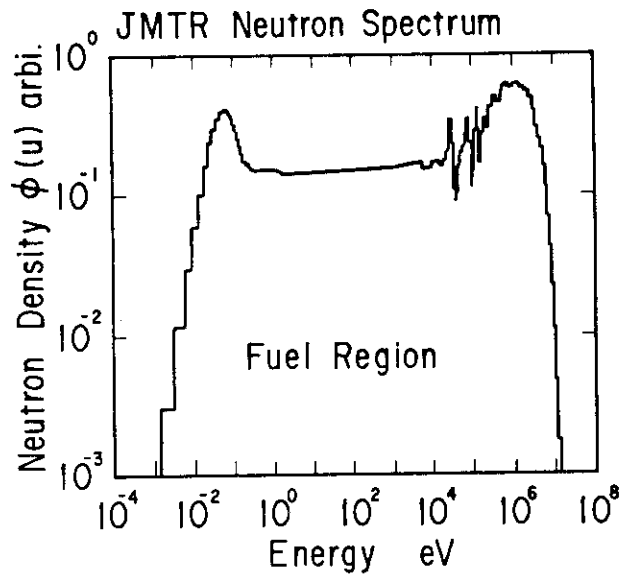


Fig. 2.3.3 Neutron Spectrum in the JMTR Reactor Core
(by calculation)

3. Capsules

3.1 Low temperature irradiation test

Some materials, such as a target for a production of neutron sources (ex. Sb-124) and surveillance test specimens, are irradiated at coolant temperature (about 50°C).

Test pieces/specimens are held in an open-type basket made of aluminum, which is loaded in a core, and cooled directly by reactor primary coolant. This type is so called "Leaky capsule" which is the simplest capsule in JMTR. All the parts in the capsule, which comes in contact with coolant, should not be corrosive or high potential materials such as Cu, Ag, etc. in order to avoid the injury to the reactor fuels covered by aluminum and the increase of coolant activities.

Characteristics of the low temperature irradiation capsule are shown in the table.

Characteristics

| Item | Specification |
|-------------------------------|---|
| Outer diameter of capsule | 29.2, 35.2, 31.4 and 41 mm |
| Active diameter for specimens | 23.7, 36 mm |
| Active length for specimens | 750, 850 mm |
| Irradiation temperature | 50 - 100°C |
| Coolant pressure | 14 kg/cm ² .G |
| Neutron flux | max. 3×10^{14} n/cm ² .sec (<0.625 eV) max. 2×10^{14} n/cm ² .sec (>1 MeV) |

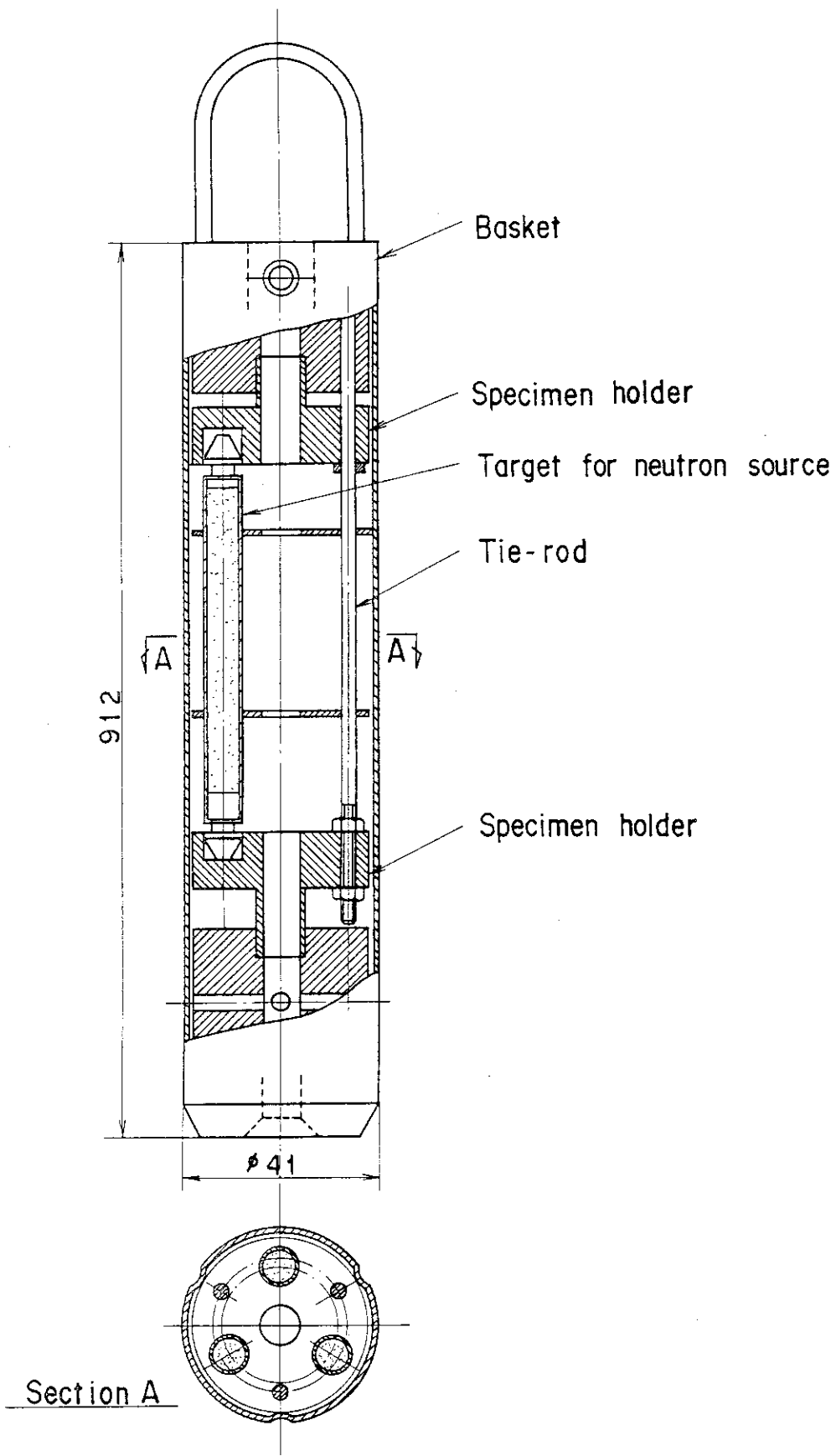


Fig. 3.1.1 Neutron source production capsule

3.2 Radio-isotope production

JMTR is a suitable reactor for production of radio-isotopes due to the high thermal and fast neutron flux. Radio-isotope production occupies about 25% of irradiations in JMTR. The following table shows radio-isotopes produced by using open baskets, aluminum capsules and hydraulic rabbits.

| Radio-isotope | Target | Reaction | Half life | |
|---------------------------|-------------------------------|------------------------------|-----------|--------------------|
| ^{32}P | S 30 g | $^{32}\text{S} (n,p)$ | 14.3 d | For medical use |
| ^{35}S | KCl 3 g | $^{35}\text{Cl} (n,p)$ | 87.9 d | |
| ^{51}Cr | Cr 5 mg | $^{50}\text{Cr} (n,\gamma)$ | 27.8 d | |
| ^{60}Co | Co 1.5 g | $^{59}\text{Co} (n,\gamma)$ | 5.26 y | |
| ^{198}Au | Au 1.5 g | $^{197}\text{Au} (n,\gamma)$ | 2.69 d | |
| ^{14}C | AlN 175 g | $^{14}\text{N} (n,p)$ | 5730 y | For industrial use |
| ^{35}S | KCl 3 g | $^{35}\text{Cl} (n,p)$ | 87.9 d | |
| ^{63}Ni | Ni 3 g | $^{62}\text{Ni} (n,\gamma)$ | 92 y | |
| $^{115\text{m}}\text{Cd}$ | Cd 0.5 g | $^{114}\text{Cd} (n,\gamma)$ | 43 d | |
| ^{170}Tm | Tm_2O_3 0.3 g | $^{169}\text{Tm} (n,\gamma)$ | 134 d | |
| ^{192}Ir | Ir 36 g | $^{191}\text{Ir} (n,\gamma)$ | 74.2 d | |
| ^{45}Ca | CaCO_3 10 mg | $^{44}\text{Ca} (n,\gamma)$ | 165 d | For other uses |
| ^{58}Co | Ni 1 g | $^{58}\text{Ni} (n,p)$ | 71.3 d | |
| ^{65}Zn | Zn 20 mg | $^{64}\text{Zn} (n,\gamma)$ | 245 d | |

a) Open basket

Middle lived radio-isotopes: such as phosphorous 32, chromium 51 and iridium 192, are produced by using the open baskets. Maximum five aluminum capsules carrying targets for radio-isotopes loaded in an aluminum basket are irradiated in the reflector and/or fuel regions. The capsules in the open type basket are cooled directly by the primary reactor coolant. Characteristics of the open basket type capsules are as follows.

Characteristics

a) Open basket in fuel regions (Figure 3.2.1)

| | |
|--|--|
| — producted radio-isotope | phosphorus 32 |
| — target nuclide | sulphur 32 |
| — outer diameter of open basket | 29.2 mm |
| — available length in open basket | 750 mm |
| — outer diameter of aluminum capsules loaded in the open basket | 25.7 mm |
| — length of aluminum capsule | 134 mm |
| — maximum number of capsules loaded in an open basket | 5 capsules |
| — center line temperature of capsules adjusted by regulation of their axial positions in the open basket | max. 444°C (boiling point of sulphur) |
| — neutron flux | 3×10^{14} n/cm ² ·sec (>1 MeV) |

b) Open basket in reflector region (Figure 3.2.2)

| | |
|---|---|
| — producted radio-isotopes : | iridium 192, chromium 51 and others |
| — target nuclide : | iridium 191, chromium 50 and others |
| — outer diameter of open basket : | 41 mm |
| — available inner length in open basket : | 850 mm |
| — outer diameter of aluminum capsules loaded in open basket : | 34 mm |
| — length of aluminum capsules : | 150 mm |
| — maximum number of capsules loaded in a open basket : | 5 capsules |
| — neutron flux : | 2.5×10^{14} n/cm ² ·sec (<0.625 eV) |

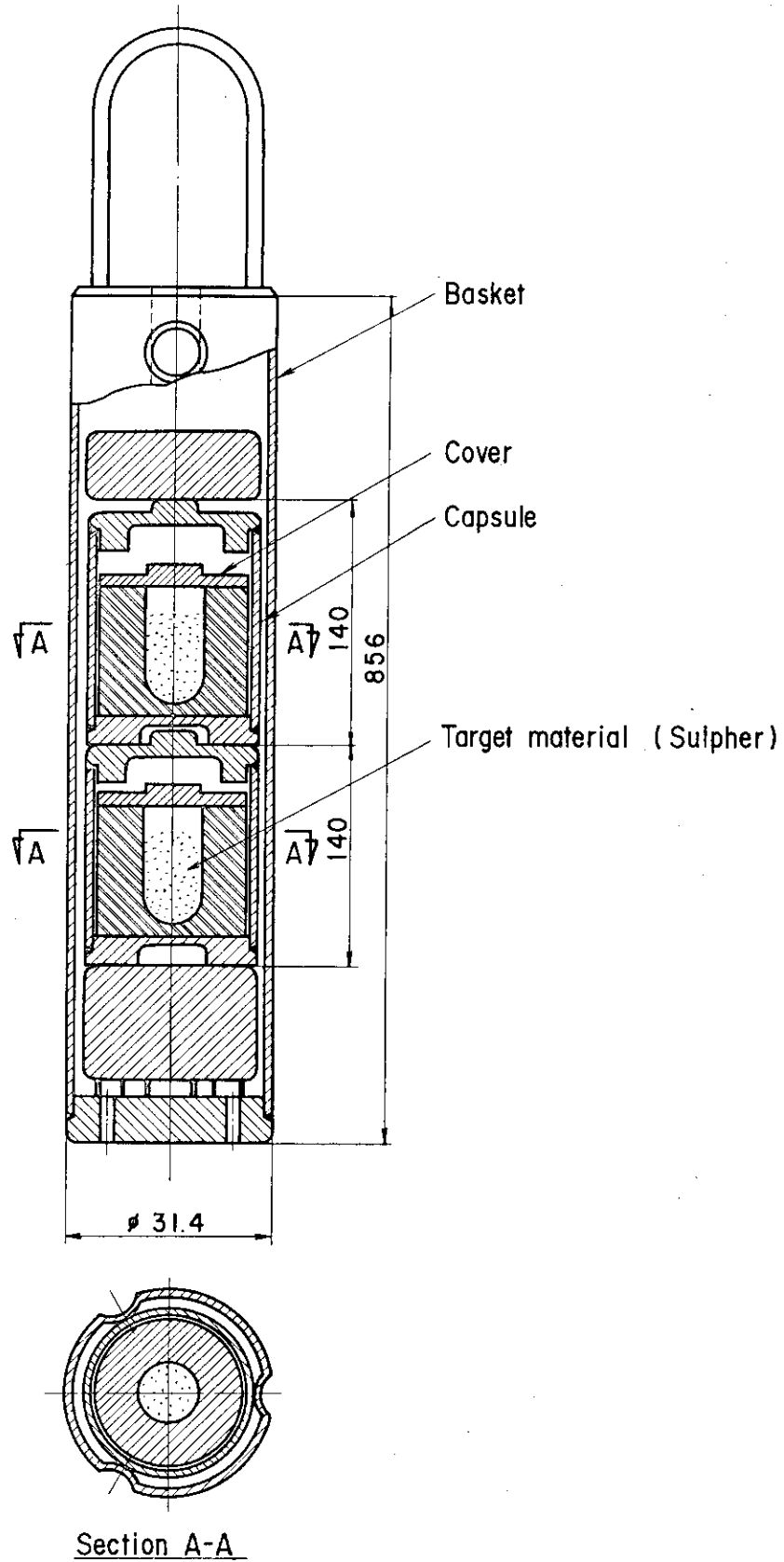


Fig. 3.2.1 Radio-isotope production capsule (open basket type)

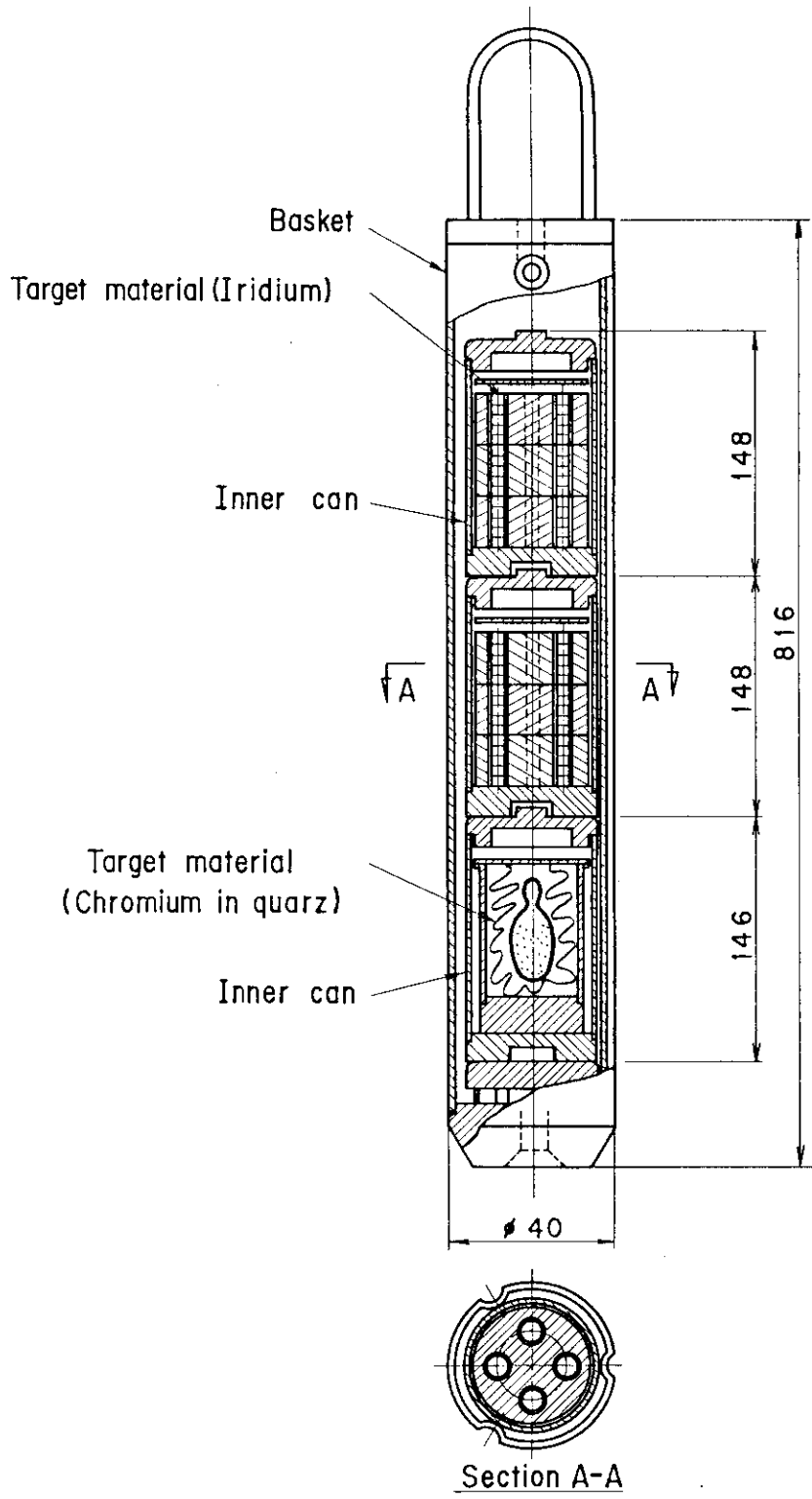


Fig. 3.2.2 Radio-isotope production capsule (open basket type)

b) Capsule type

Five aluminum inner capsules that hold pelleted targets of aluminum nitride (AlN) for production of carbon 14 are enveloped in an aluminum capsule. Capsules are irradiated in the fuel and/or reflector region in the reactor core. The inner capsules are designed to sustain sufficient mechanical strength to endure pressure increase due to gas generation from AlN during irradiation (Fig. 3.2.3). Characteristics are shown in the table.

Characteristics

| Item | Specification |
|--|---|
| Outer diameter of capsule | 30 mm (in fuel region) 35 mm (in reflector region) |
| Outer diameter of inner capsule | 23.2 mm (in fuel region) 28.2 mm (in reflector region) |
| Length of inner capsule | 134 mm |
| Number of inner capsules loaded in the capsule | 5 |
| Neutron flux | $0.5 - 2 \times 10^{14}$ n/cm ² .sec (>1 MeV) |

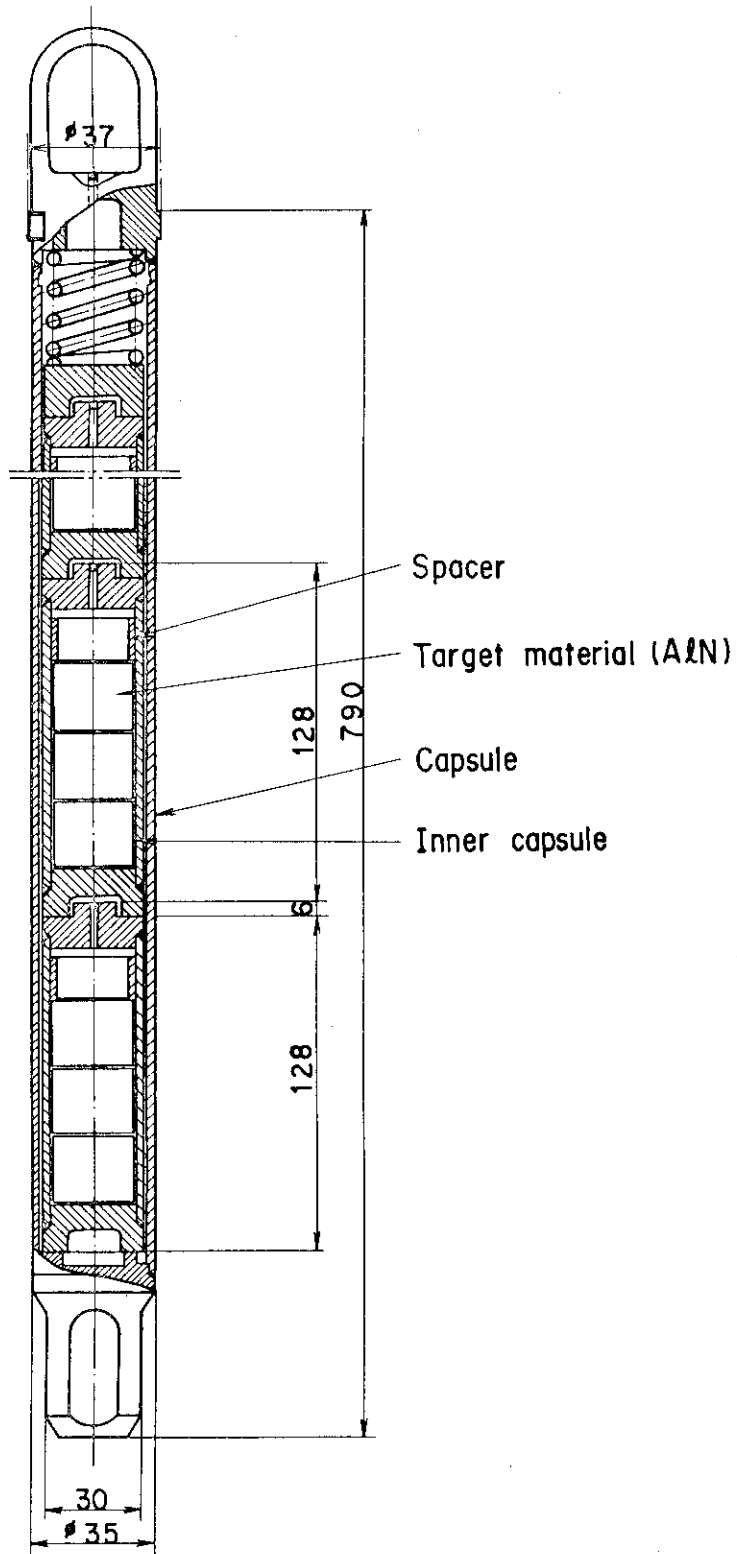


Fig. 3.2.3 Radio-isotope production capsule (capsule type)

3.3 Temperature measurement and control

The temperature of specimens in the capsules are measured by thermocouples. In the case of measuring temperature of less than about 1000°C, the sheathed thermocouples of Chromel-Alumel (CA) have been used. In the case of measuring temperature above 1000°C, tungsten-rhenium (W/Re) thermocouples are applied, but several problems are encountered, such as durability of thermocouples themselves, their compatibility with measured objectives, drifting in their outputs with the neutron exposure.

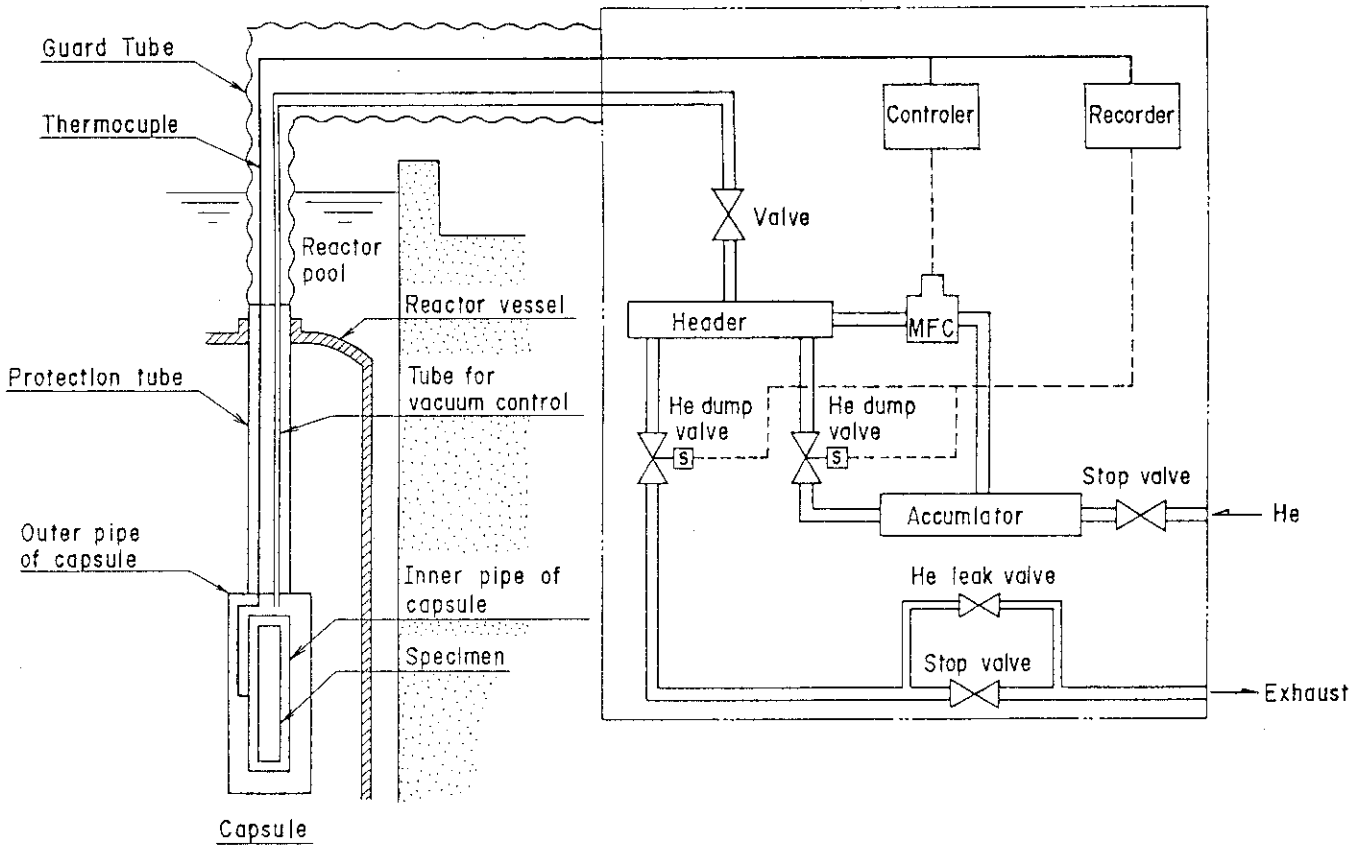
The temperature of specimens in the capsules are controlled by vacuum method, mixing gases method and/or heater method.

The temperature control by the vacuum control method is made by means of regulating the heat transfer through the gas gap by varying degree of vacuum in the capsule. The flow diagram of the out-of-pile control equipment is shown in Fig. 3.3.1(a). In some cases, the purified helium gas in a plenum volume in the capsule is directly evacuated from the surroundings of specimens through an evacuation tube connected to the out-of-pile control system. Thermocouples are inserted in the specimens or dummies for measuring and controlling temperature.

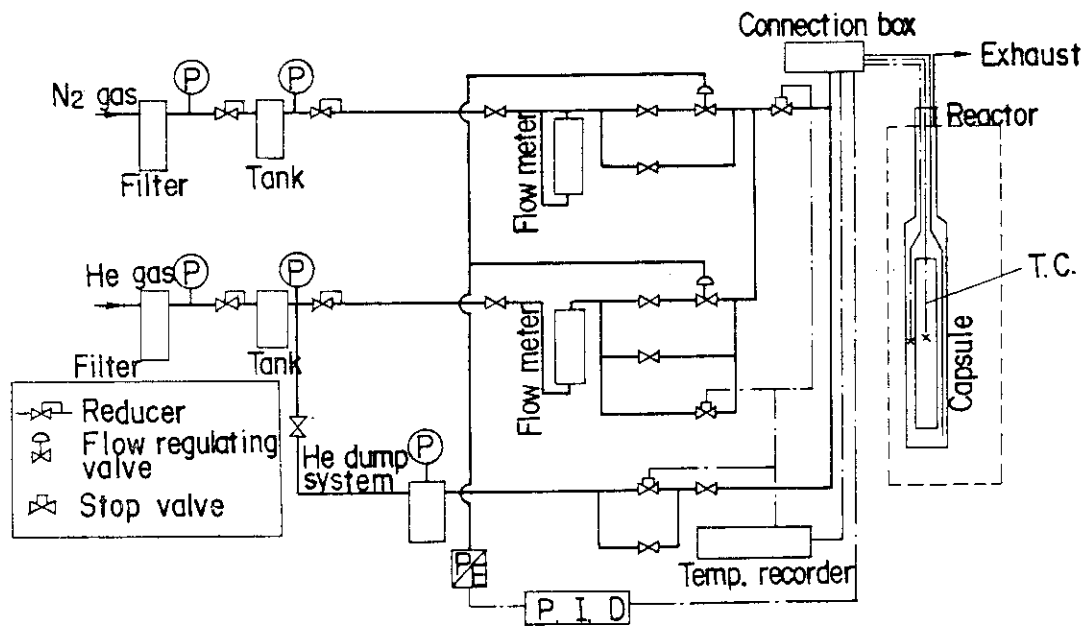
The temperature control by mixing gases is carried out similarly to the vacuum control method, by varying the composition of mixed gases of helium and nitrogen to regulate the heat transfer through the gas gap. The flow diagram of the system is shown in Fig. 3.3.1(b). This method is used not only for temperature control, but also for keeping the helium gas pure by constant sweeping of the gas during irradiation, because a capsule has sometimes special specimens, e.g. concrete blocks, which vapor gases.

The temperature control using the electric heaters are made by regulating the electric power of sheathed electric heaters wound on the heat diffuser holding the specimens in the capsule. This controlling method is occasionally used together with the vacuum controlling method in order to regulate the temperature at specimens more finely.

The vacuum temperature controllers and heater temperature controllers are shown in Fig. 3.3.2 and 3.3.3, respectively.



(a) Flow Diagram of Vacuum Controlling System



(b) Mixing gas controlling method

Fig. 3.3.1 Flow diagram of vacuum and mixing gas controlling method

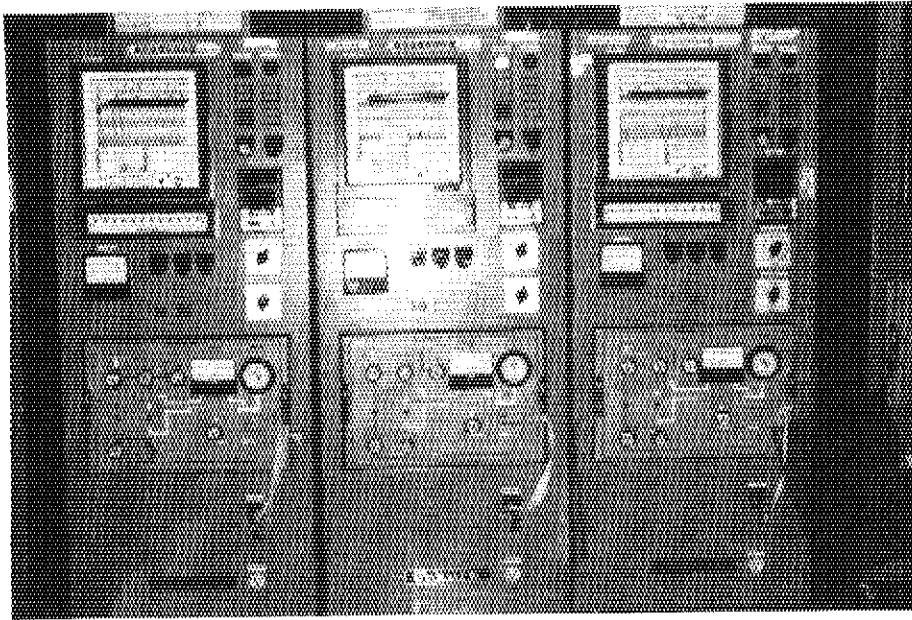


Fig. 3.3.2 Vacuum Temperature Controllers

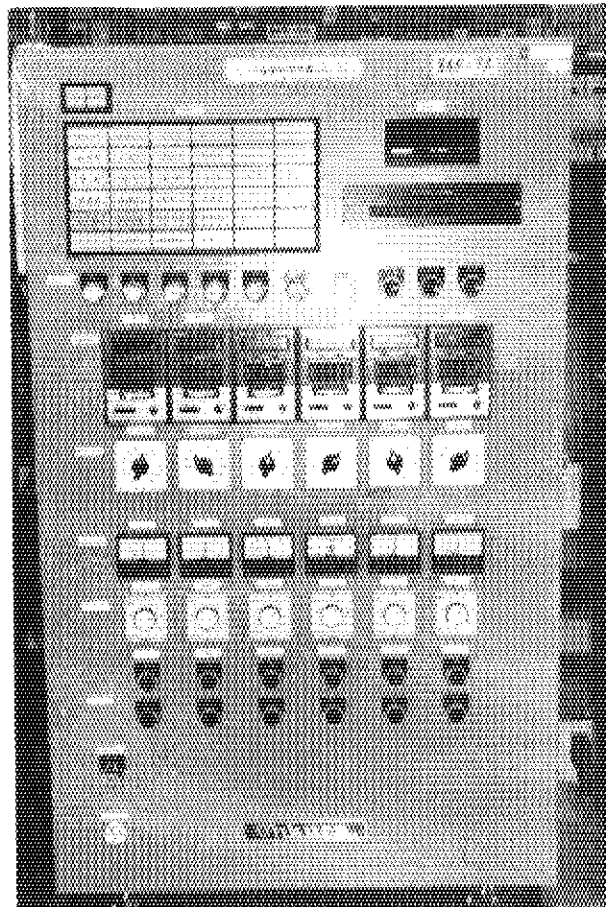


Fig. 3.3.3 Heater Temperature Controllers

3.4 Reactor vessel steel irradiation

Specimens for the Charpy impact test, tensile test, compact tension test and other tests for pressure vessel materials of light water reactors are often required to be irradiated at the temperature of about 290°C with an accuracy of $\pm 10^\circ\text{C}$. Since the axial distribution of gamma heating rate along the reactor core is not uniform and gamma heating varies during irradiation, several irradiation techniques are applied to maintain the temperature of specimens to be $290^\circ\text{C} \pm 10^\circ\text{C}$. The electric heater controlled capsule is available used in JMTR to accomplish the requested irradiation condition. A fine temperature control can be obtained to make the axial temperature distribution uniform on specimens, by regulating electric heaters arranged along axial direction of the capsule. The vacuum controlling method is often used together with the electric heaters in order to reduce a load obliged to the heaters. The configuration of the capsule is shown in Fig. 3.4.1. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|---------------------------|---|
| Outer diameter of capsule | 40 and 60 mm |
| Length of capsule | 600 mm |
| Irradiation temperature | 290°C \pm 25°C (by vacuum control only) 290°C \pm 10°C (by vacuum with heater control) |
| Neutron flux | 0.05-1 \times 10 ¹⁴ n/cm ² .sec (1 MeV) |

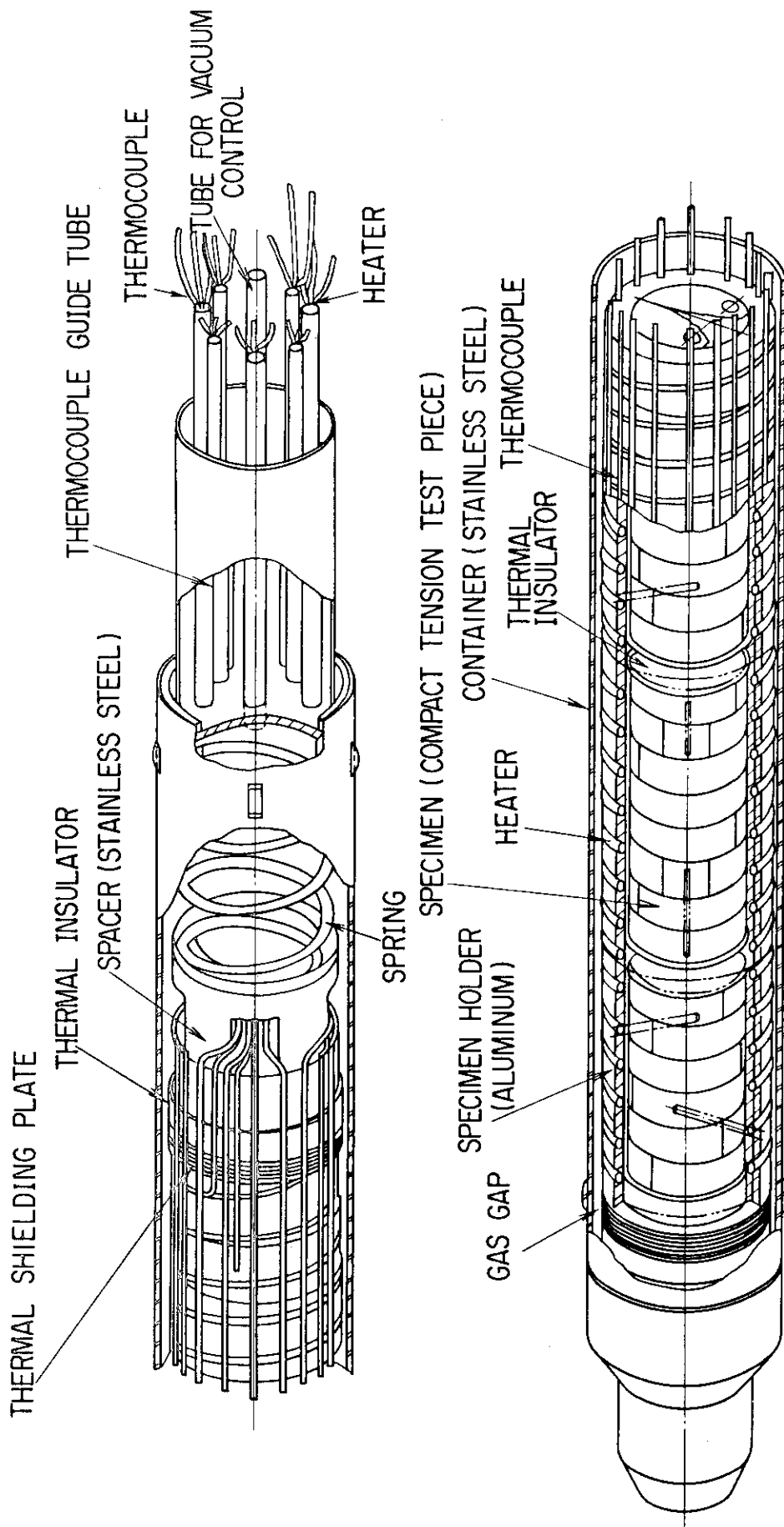


Fig. 3.4.1 The Advanced Capsule for Steel Irradiation

3.5 In-pile creep measurement

Mechanical creep rates and rupture times during neutron irradiation at elevated temperature can be measured for some reactor structural materials such as fuel cladding materials for LMFBR (ex. 304ss) and pressure piping materials (ex. Zr-2.5 % Nb) for the advanced thermal reactor (ATR).

Lower end of the specimen for creep testing is fixed to the outer tube of the capsule and the tensile force is loaded on its upper end. The pressurized bellows by helium gas pulls the specimen through the yoke. The temperature of the specimen is maintained uniform by the use of electric heater rounding the specimen. The creep strain can be obtained by the buffer and the needle type of helium micrometers or can be measured by a linear variable differential transformer (LVDT) shown in Fig. 3.5.1. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|-----------------------------------|---|
| Outer diameter of capsule | 40 mm |
| Tensile load on the specimen | 10 - 120 Kg |
| Temperature at the specimen | 750°C max. |
| Number of specimens in a capsule | 3 specimens max. (for creep rupture test) |
| Temperature at bellows | 500°C max. |
| Creep strain detector | |
| (a) buffer type helium micrometer | 0 - 0.25 mm, resolution: $\pm 2 \mu\text{m}$ |
| (b) needle type helium micrometer | 0 - 10 mm, " : $\pm 10 \mu\text{m}$ |
| (c) LVDT | 0 - 10 mm, " : $\pm 25 \mu\text{m}$ |
| Neutron flux | $(0.5-1.0) \times 10^{14} \text{ n/cm}^2 \cdot \text{sec} (>1\text{MeV})$ |

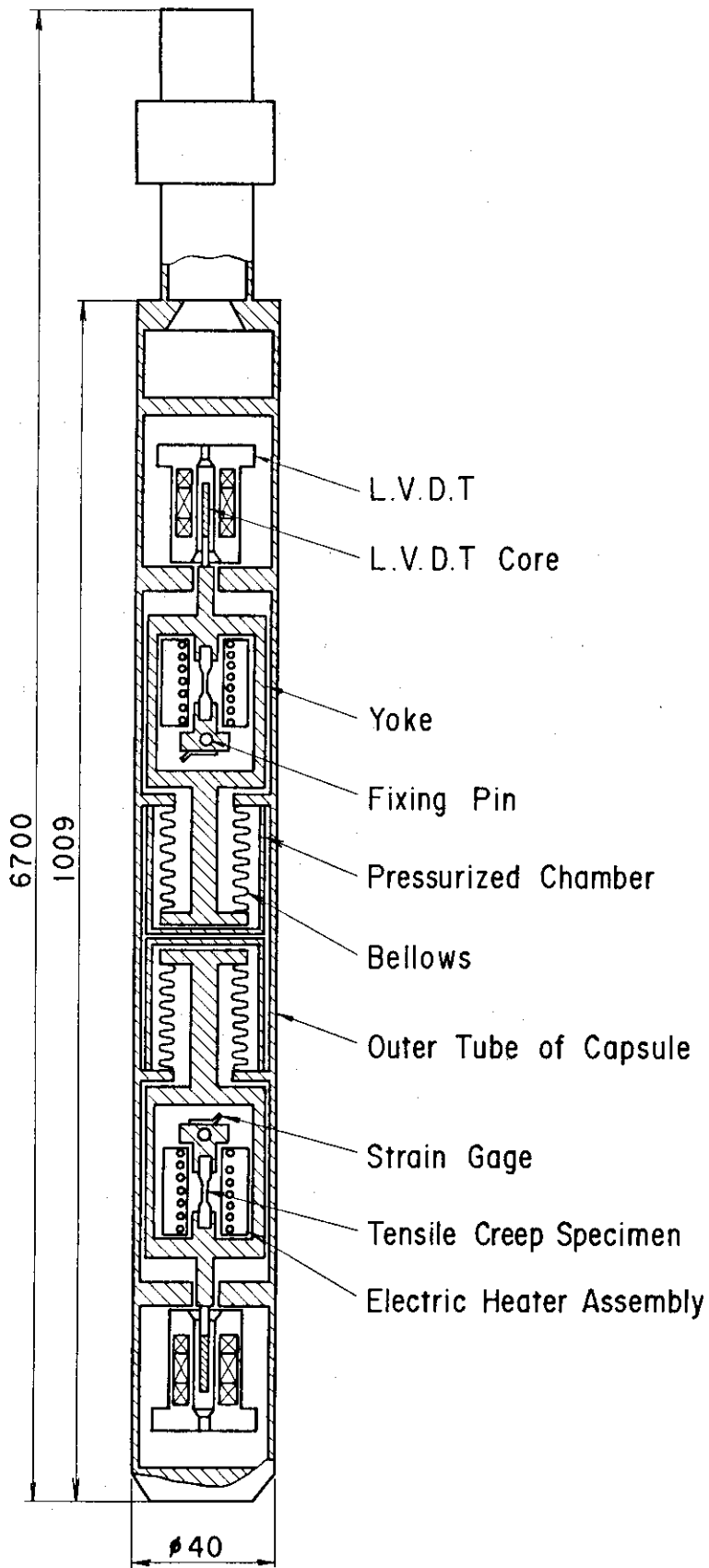


Fig. 3.5.1 In-pile Creep Capsule

3.6 Graphite irradiation

Graphite specimens for the high temperature gas cooled reactor (HTGR) are irradiated under unstressed or stressed conditions.

a) Graphite specimens irradiation capsule (Fig. 3.6.1)

The graphite thermal bonds, surrounded by rings, that hold the graphite specimens for mechanical testings, are enclosed in the inner tube. The outer tube cooled by the reactor coolant envelopes the inner tube with a co-extruded aluminum thermal bond. The rings used as the variable gamma heaters consists of materials with various densities, such as graphite, molybdenum, niobium and tungsten. This is intending that the gamma heat generated within the inner tube along the axial direction in the capsule is about uniform, accordingly the temperature of all specimens in the capsule results in uniform. The temperature of the specimens is additionally, regulated by adjusting thermal conduction through the gas gap between the outer and the inner tube by means of the vacuum control method. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|----------------------------------|--|
| Outer diameter of capsule | 40 mm |
| Available diameter for specimens | 25 mm |
| Available length for specimens | 670 mm |
| Irradiation temperature | 800 - 1200°C |
| Neutron flux | $(1.0-1.5) \times 10^{14}$ n/cm ² ·sec (1 MeV) |

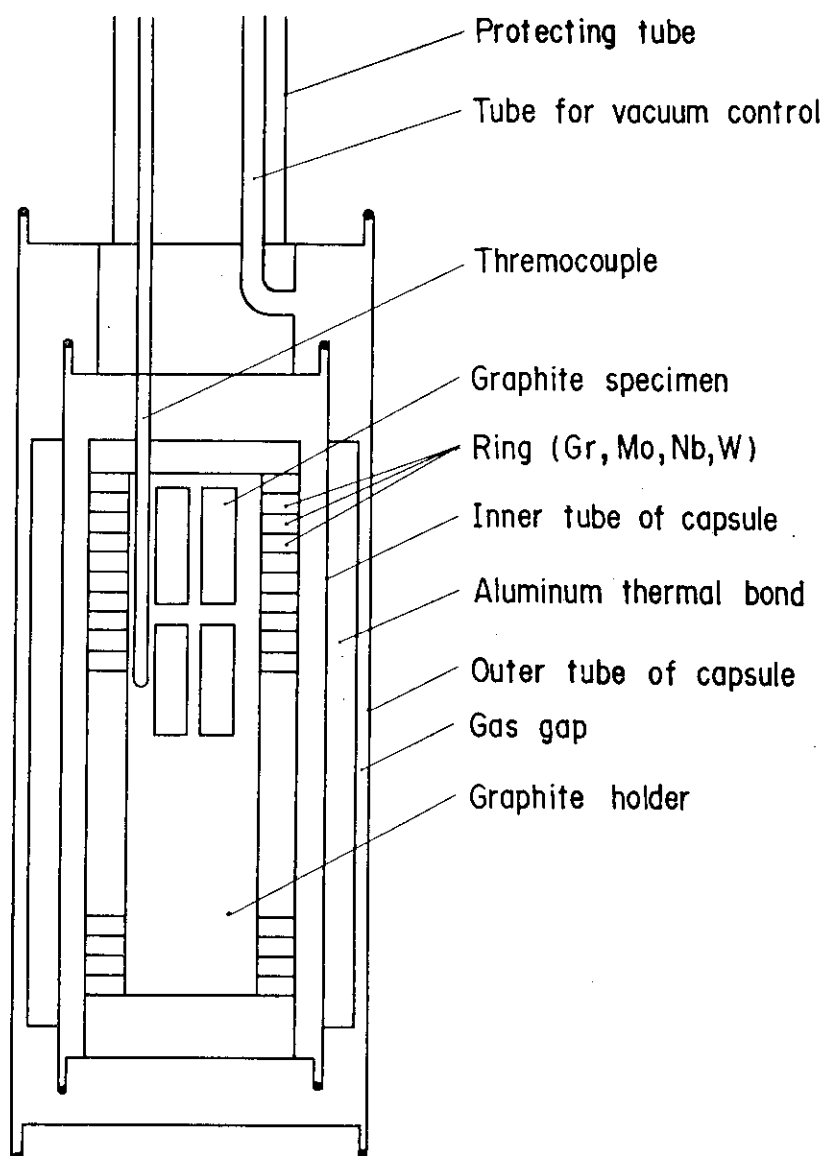


Fig. 3.6.1 Graphite irradiation capsule

b) Graphite in-pile creep capsule (Fig. 3.6.2)

Several graphite specimens pin-jointed axially with each other in a capsule are stressed by the pressurized bellows. The temperature of the specimens is controlled by adjusting the electric output of the heaters turned around the specimens. The creep strain is measured by the helium micrometer or the linear variable differential transformer (LVDT).

Characteristics are shown in the table.

Characteristics

| Item | Specification |
|-----------------------------------|---|
| Outer diameter of capsule | 40 mm |
| Tensile load on the specimens | 10 - 120 kg |
| Temperature at the specimens | 850 - 950 °C |
| Number of specimens in a capsule | 7 specimens (for creep rupture test) |
| Creep strain detector | |
| (a) buffer type helium micrometer | 0 - 0.25 mm, resolution: $\pm 2 \mu\text{m}$ |
| (b) needle type helium micrometer | 0 - 15 mm, " : $\pm 10 \mu\text{m}$ |
| (c) LVDT | 0 - 15 mm, " : $\pm 25 \mu\text{m}$ |
| Neutron flux | $(1.0-1.5) \times 10^{14} \text{ n/cm}^2 \cdot \text{sec}$ (>1 MeV) |

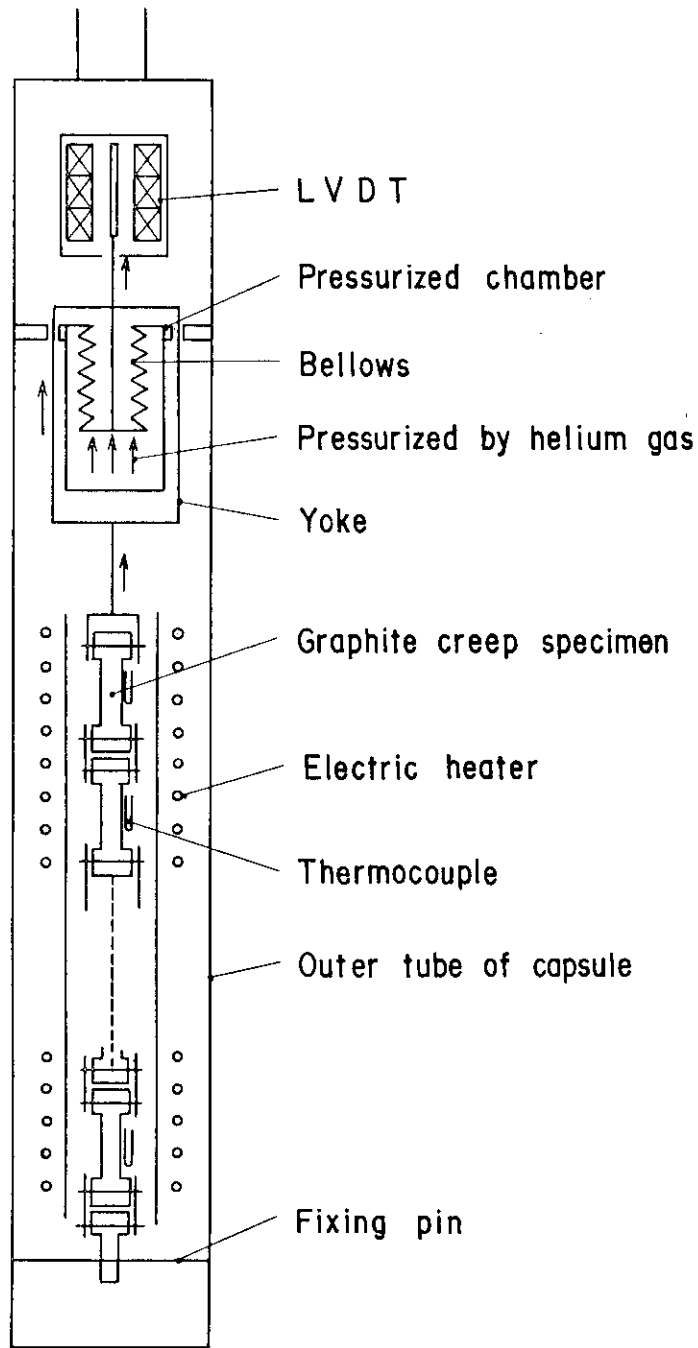


Fig. 3.6.2 Graphite in-pile creep capsule

3.7 Coated particle fuels irradiation

(a) Coated particles fuel irradiation capsule (Fig. 3.7.1)

Coated particle fuels for the high temperature gas cooled reactor (HTGR) are irradiated for investigating behaviors of the fuels at high temperature (maximum 1600°C).

The coated particle fuels or compacted coated particle fuels with graphite matrix are enclosed in the inner tube of stainless steel that is contained in the outer tube also of stainless steel. The high temperature is obtained at the specimens by the large temperature gradient across the gas gap between the inner and outer tube by means of the vacuum control method. The tungsten-rhenium thermocouples are used for measuring and controlling the temperature of specimens. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|---|---|
| Outer diameter of capsule | 40 and 65 mm |
| Available length for the specimens | 600 mm |
| Outer diameter of compacted coated particles fuel | 12, 24 and 36 mm |
| Irradiation temperature | 1000 - 1600 °C |
| Neutron flux | max. 2.5×10^{14} n/cm ² ·sec (<0.625 eV) max. 1.5×10^{14} n/cm ² ·sec (>1 MeV) |

(b) Gas sweep capsule (Fig. 3.7.2)

Coated particle fuels for HTGR are irradiated to measure activities of gaseous fission products released from the fuels during irradiation.

The compacted coated particle fuels are placed in the double walled inner capsule of niobium-zirconium alloy (Nb-1 % Zr). The irradiation temperature of maximum 1600 °C is obtained by adjusting the temperature gradient across the gas gap between the double walls of the inner capsule by using the vacuum control method.

The purified helium gas sweeps the fuels and carries fission products released from the fuels to the gas analyzing system. The gas sweep capsule holds three inner capsules and the each sweeping gas from each inner capsule is independently carried and analyzed. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|--|---|
| Outer diameter of capsule | 65 mm |
| Outer diameter of compacted coated particle fuels | 24 mm |
| Available length for specimens in an inner capsule | 80 mm |
| Irradiation temperature | 1000 - 1600 °C |
| Number of inner capsules in a capsule | max. 3 capsules |
| Material of inner capsule | (a) Nb-1 % Zr 1) (b) ss-316 2) |
| Neutron flux | max. 2.5×10^{14} n/cm ² .sec (<0.625 eV) max. 1.5×10^{14} n/cm ² .sec (>1 MeV) |

- 1) Irradiation time is limited to be less than about 5000 hrs, and temperature at each inner capsule is adjustable independently.
- 2) There are no limitations for irradiation time, and temperature at an inner capsule of three ones can be controlled.

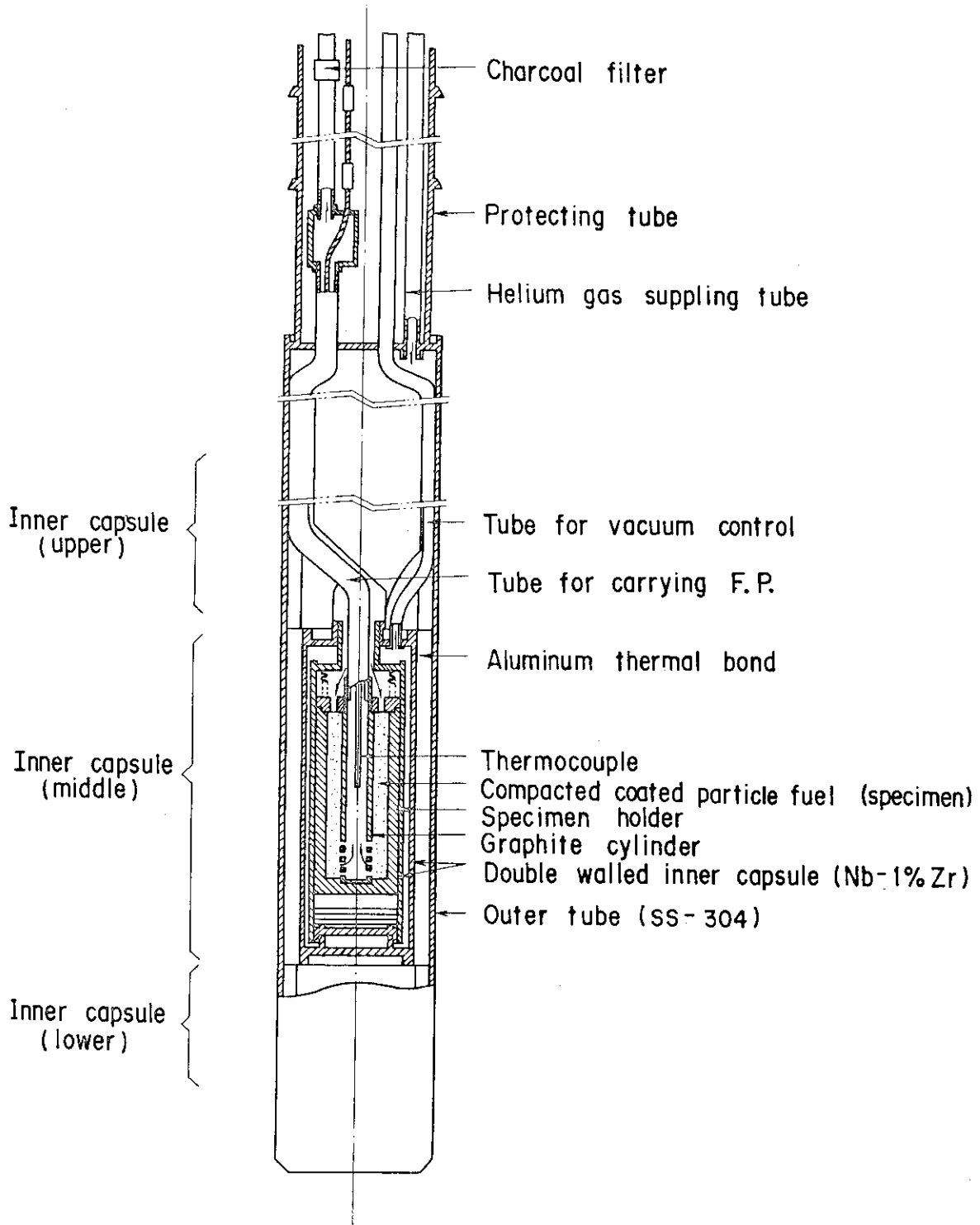


Fig. 3.7.2 Gas sweep capsule for coated particle fuel

(c) Temperature ramping capsule (Fig. 3.7.3)

Coated particle fuels for HTGR are irradiated to investigate transient behaviors of the fuels at very high temperature (above 2000°C) by temperature ramping.

The compacted coated particle fuels are held in the graphite holder, which is placed in the inner capsule. The fixation of the graphite holder is made by being hanged on the upper plug of the inner capsule, by three tie-rods, the guide tube and the pressurized chamber. The holder is surrounded by the graphite thermal bond which has the high thermal conductance during stationary irradiation condition of from 1000 to 1600°C.

The temperature ramping to above 2000°C is performed by changing the gas gap size between the graphite thermal bond and inner tube of capsule. The change of the gap size is made by displacing the thermal bond by means of pressurizing the bellows in the pressurized chamber. The displacement of the thermal bond is detected by means of the output of LVDT and the gas pressure of gas supplying system. The temperature of the specimens is monitored by the thermocouple placed in the center hole of the specimen. The inner capsule is enveloped by the outer capsule cooled by the reactor coolant and temperature regulation is made by adjusting the temperature gradient across the gas gap between the outer and inner capsule. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|---|---|
| Outer diameter of capsule | 40 mm |
| Outer diameter of compacted coated particle fuels | 12 mm |
| Irradiation temperature | 1000 - 1600 °C (before temperature-ramping) max. 2200°C (after temperature-ramping) |
| Temperature at bellows | max. 500°C |
| Neutron flux | max. 2.5×10^{14} n/cm ² ·sec (<0.625 eV) max. 1.5×10^{14} n/cm ² ·sec (>1 MeV) |

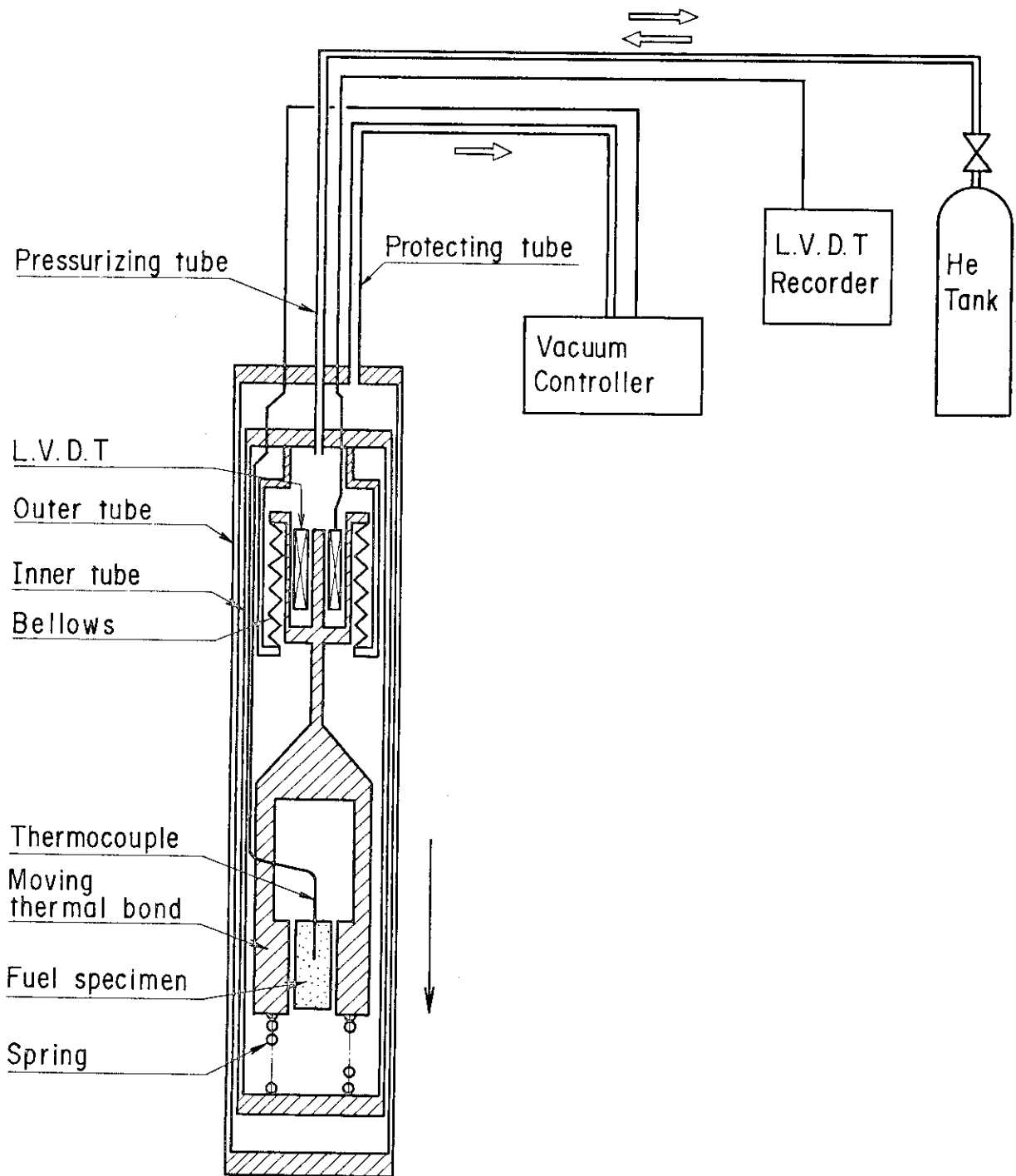


Fig. 3.7.3 Temperature ramping capsule

3.8 NaK bonded capsule

Some materials such as mixed-oxide fuel rods (fuel pellets of $\text{PuO}_2\text{-UO}_2$ with 316 stainless steel cladding) and tensile test specimens of 316 stainless steel are irradiated in NaK bonded capsule.

The mixed-oxide fuel rods are enveloped in the inner capsule with NaK which forms the thermal bond between the fuel rods and the inner capsule. The NaK has a good thermal conduction and a high boiling point, consequently the removal of the high heat rate is possible to perform the high power test for LMFBR fuel rod. The outer capsule envelopes the inner tube with co-extruded aluminum thermal bond. The outer capsule prepares the second shell for NaK to the reactor coolant. The temperature of the fuel cladding is regulated by varying the heat transfer through the gas gap between the outer capsule and the aluminum thermal bond with the inner capsule. Characteristics are shown in the table.

Characteristics

| Item | Specification |
|-----------------------------------|--|
| Fuel rods | |
| Outer diameter of capsule | 40 mm |
| Available fuel rod length | 500 mm |
| Cladding temperature | 500 - 750°C |
| Power of fuel rod | max. 800 w/cm |
| Neutron flux | $(0.1-1)\times 10^{14}$ n/cm ² ·sec (<0.625 eV) |
| Non-fissile materials | |
| Outer diameter of capsule | 40 mm |
| Available diameter for test pices | 29 mm |
| Available length in capsule | 600 mm |
| Nak temperature | max. 800 °C |
| Neutron flux | 1×10^{14} n/cm ² ·sec (>1 MeV) |

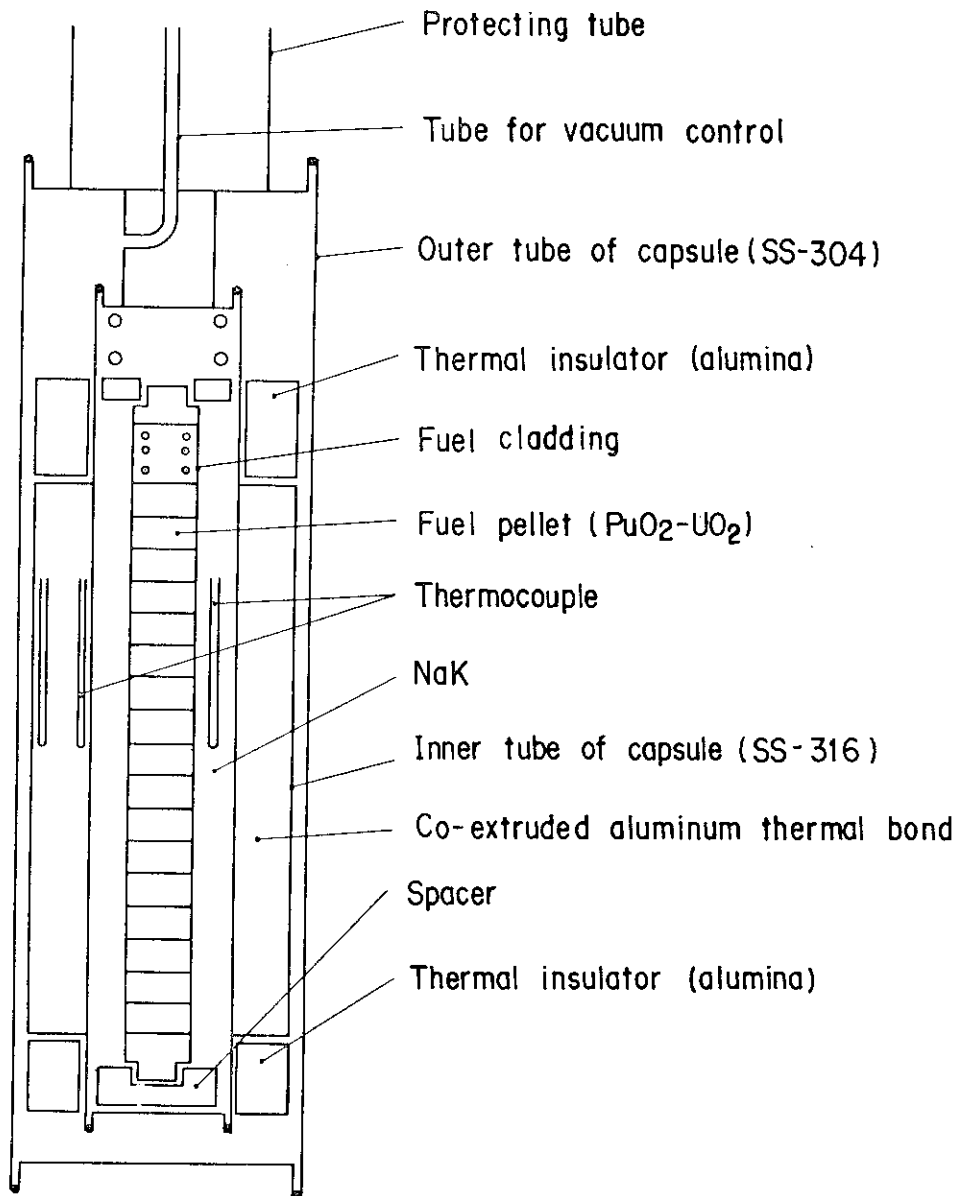


Fig. 3.8.1 NaK bonded capsule

3.9 Boiling water capsule

The BOCA (Boiling water capsule) has been recently developed for a irradiation test of fuels under the conditions of LWR.

A fuel pin to be tested is placed in a capsule filled with water. The water is pressurized by a out-pile pressurizer. The nuclear heat produced in the fuel pin is dissipated through the pressurized water and a capsule pressure tube, and is removed by the JMTR cooling water or the shroud cooling water. The surface temperature of the fuel pin is almost constant over a wide range of linear heat rate because of a subcool boiling at the surface.

The fresh demineralized water is continuously supplied to the capsule at very small flow rate for maintaining the water quality. The draining water from the capsule is monitored for fission products to detect fuel pin failure. Some equipments of the out-pile control circuit for the capsule is shielded with leads and is installed in a glove box for radioactive materials treatment. An automatic reactor power reduction system acts in case of pressure decrease in the capsule.

Some self-powered neutron detectors and/or micro-fission chambers and a LVDT type fuel pin elongation detector are equipped in the capsule for fuel pin power estimation and elongation behavior measurement.

A specially designed boiling water capsule is able to accept a pre-irradiated fuel pin. The fuel pin is loaded into the capsule in the hot laboratory.

The capsule is usually inserted into a gas screen of He-3 power control facility for power ramp and/or power cycling test.

(See section 5.2)

Characteristics of the boiling water capsule

| | |
|-------------------------------------|--|
| Max. fuel rod power | 590 W/cm |
| Usual fuel rod enrichment | 2.8% for BWR size fuel 4.5% for PWR size fuel |
| Fuel rod diameter | 9 to 12.5 mm |
| Max. active fuel rod length | 400 mm |
| Coolant pressure | 73 kg/cm ² G |
| Cladding temperature | approximately 295°C |
| Rinsing rate of capsule water | 1 cc/s. |

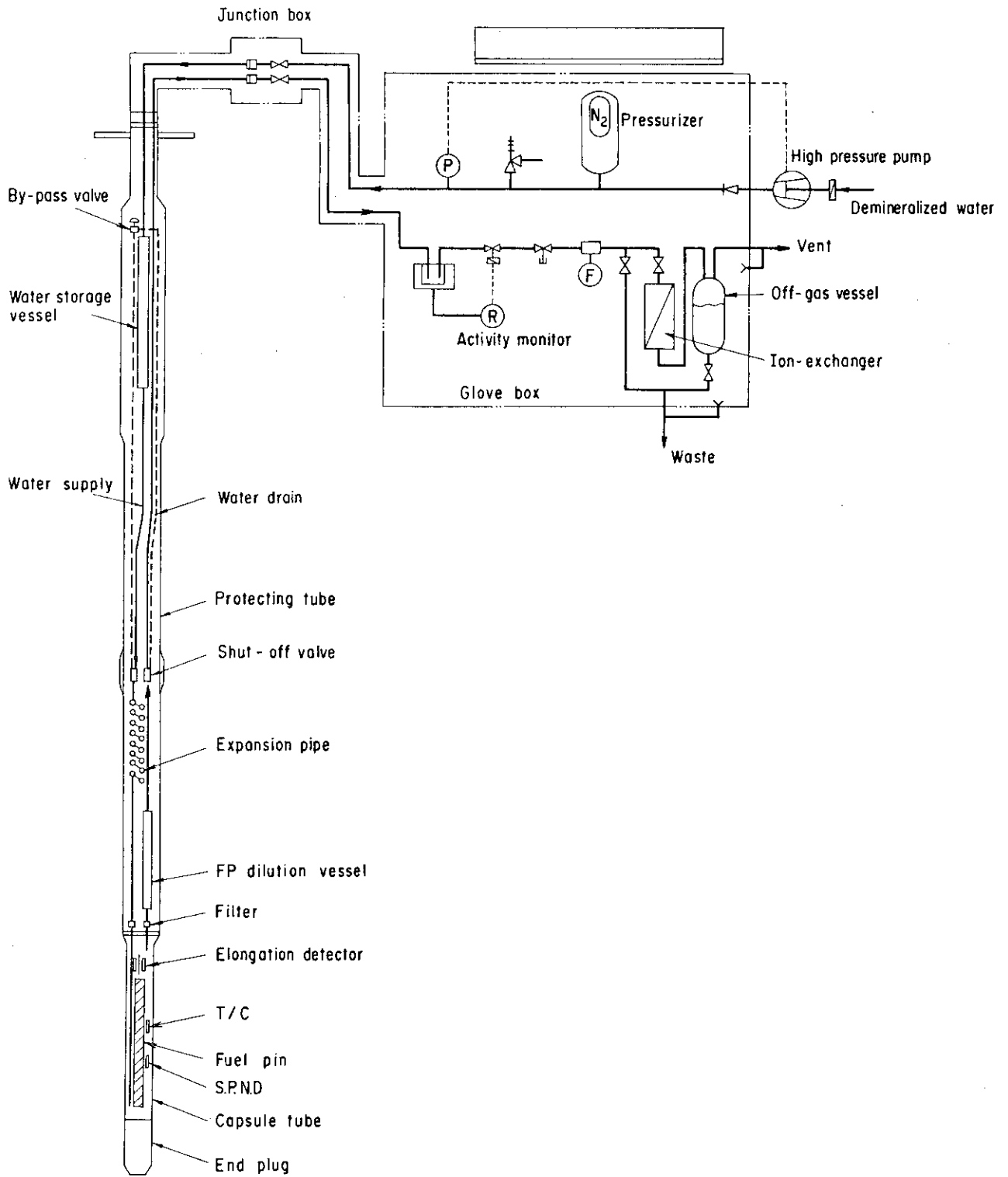


Fig. 3.9.1 Boiling Water Capsule and its Controller

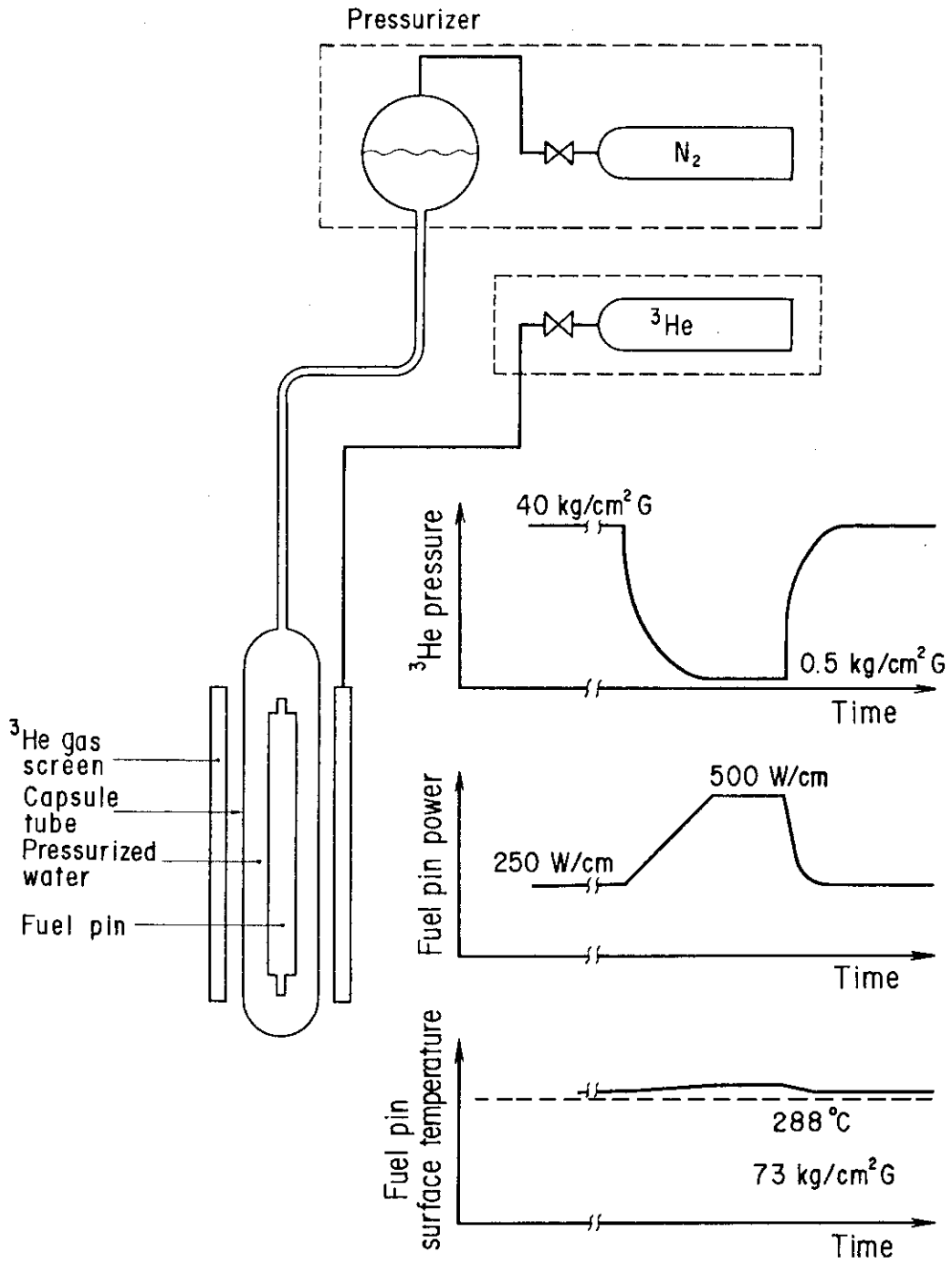


Fig. 3.9.2 Power Ramp Test using Boiling Water Capsule and 3He Power Control Facility

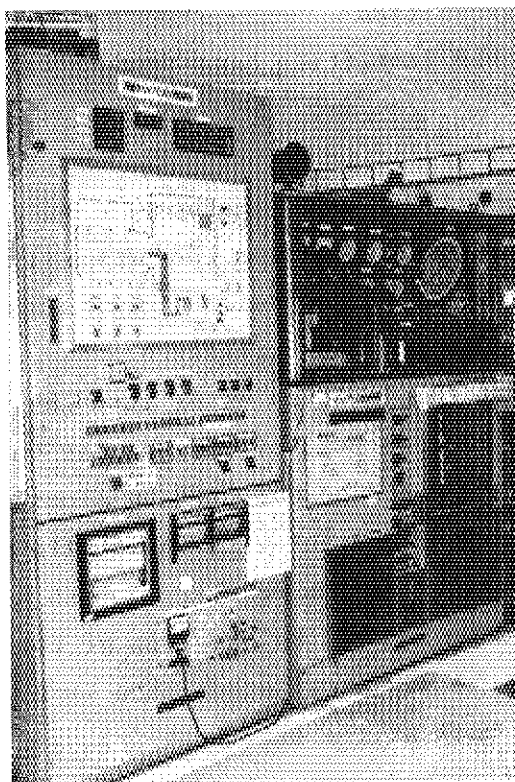


Fig. 3.9.3 Controllers for Boiling Water Capsule

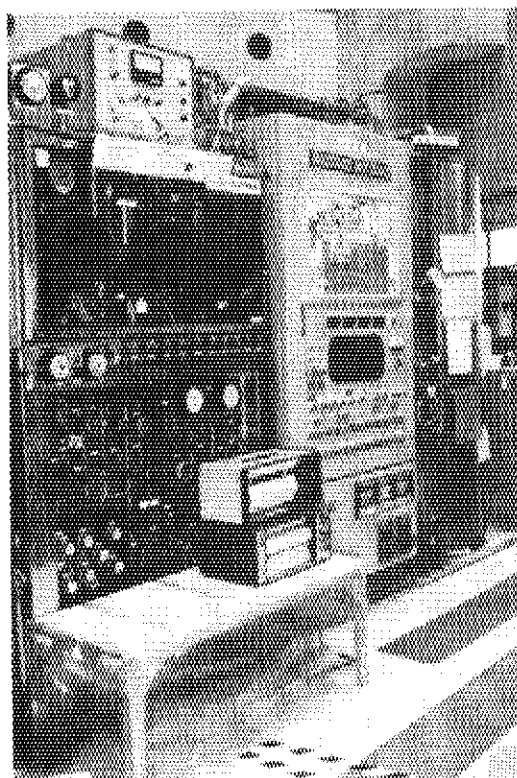


Fig. 3.9.4 He-3 Power Control Facility

4. Hydraulic rabbit facilities

Two hydraulic rabbit facilities have been installed in the JMTR; HR-1 and HR-2.

The facilities are hydraulic transfer devices for small capsule, rabbit. The rabbit containing test specimens is of 32 mm in outer-diameter and 150 mm in length. As the specimens can be easily inserted and removed during reactor operation, it is convenient for the short term irradiation of radioisotope production and basic research.

The in-pile tube of the facility enters into the reactor core through the nozzle provided in the top head of the reactor vessel. Their in-core parts are double concentric and housed with an aluminum block having the same outer shape as the fuel elements. Both in-pile tubes of the facilities are in the reflector region and can be charged with up to 3 rabbits.

The rabbit station is located by the side of the canal. The rabbit is sent to the reactor core and irradiated, then sent back to the canal or put into a transfer cask at the station.

The facility is of closed water circuit. The flow of demineralized water assures simultaneously the cooling of the rabbits and the injection and return (by flow inversion) of the rabbits. Two pipes connect the terminal station with in-pile tube; one for conveying the rabbits and the other for circulating the water.

Characteristics of the hydraulic rabbit facilities

| | HR-1 | HR-2 |
|-------------------------------------|--|---|
| Core position | D-5 | M-11 |
| Thermal neutron flux | 1.1×10^{14} n/cm ² ·s .. | 1.3×10^{14} n/cm ² ·s |
| Fast neutron flux | 8.8×10^{12} n/cm ² ·s .. | 2.1×10^{13} n/cm ² ·s |
| Gamma heating | 1.1 W/g | 2.2 W/g |
| Coolant flow rate | 11 m ³ /h | 8.4 m ³ /h |
| Coolant temperature | 40°C | 40°C |
| Max. heat generation per rabbit ... | 20 KW | 9 KW |

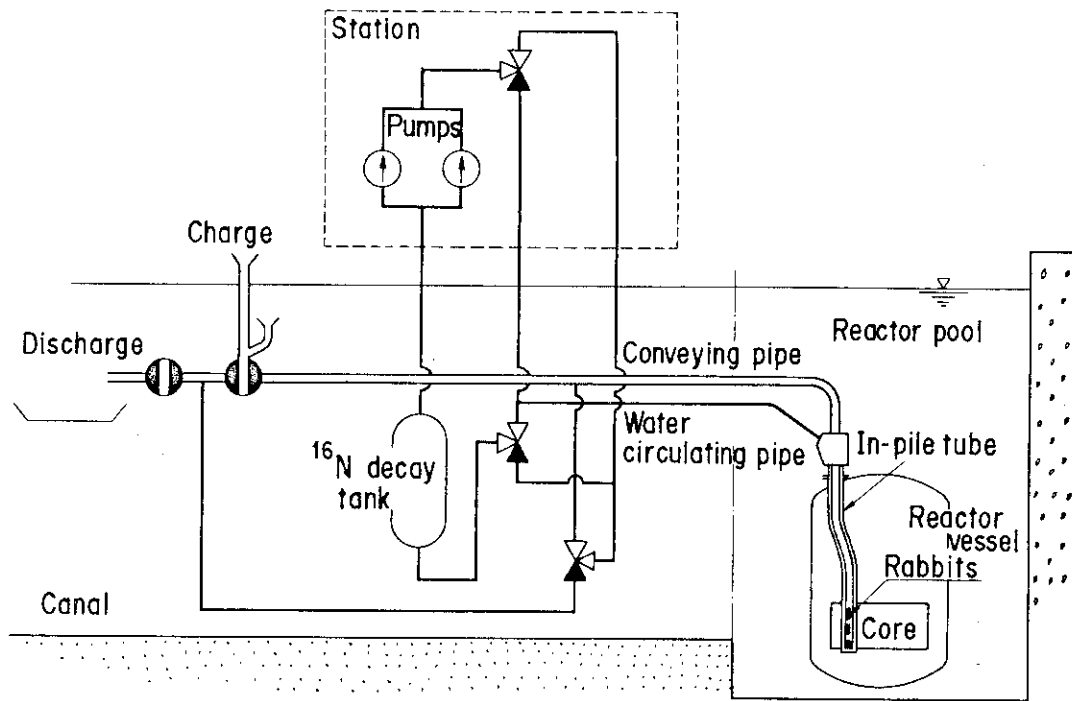


Fig. 4.1 Simplified Flow Sheet of the HR-2

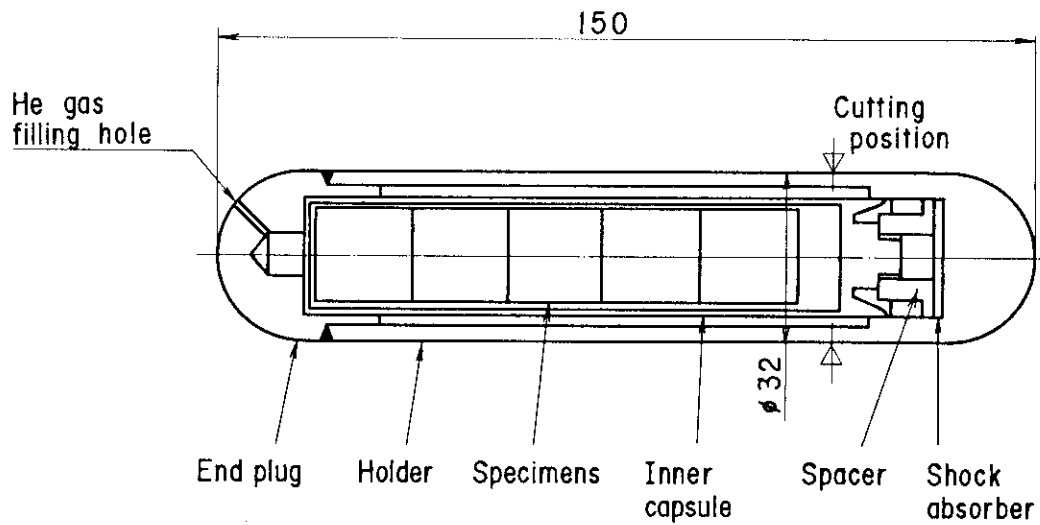


Fig. 4.2 Longitudinal Cross Section of a Rabbit

5. Special facilities

5.1 He-3 power control facility

The He-3 power control facility, recently developed for power ramp test of LWR fuels, consists of a in-pile gas screen and a out-pile pressure controller. The He-3 gas screen has an annular gap between two concentric tubes filled with He-3 gas which possesses an important absorption cross section for thermal neutrons. By varying the He-3 gas pressure, the neutron flux in the capsule loaded into the central hole of the screen can be changed. A small gas flow is maintained through the annular gap for purifying the He-3 gas from Tritium produced by neutron capture.

The gas pressure is varied by means of a pressurizer equipped with a super flexible metal bellows. The He-3 gas screen is connected to the one-side of the bellows, and Nitrogen pressurizing gas is supplied to the other side. The He-3 gas pressure in the screen can be varied by charging or discharging Nitrogen gas into/from the pressurizer. The bellows pump applying to all pressure range is used for a circulation of He-3 gas through the gas screen and the Tritium trap. The Tritium trap is a column of Titanium grain heated to a operating temperature of 400°C. Max. Tritium production rate in the gas screen is estimated to be 60 Ci a day.

Characteristics of the He-3 power control facility

| | |
|---|----------------------------|
| Range of He-3 pressure variation | 0.029 - 4 MPa |
| Range of neutron flux depression factor | 2.8 |
| Required time for pressure variation; | |
| 4 to 0.029 MPa | 80 s. - 100 h. |
| 0.029 to 4 MPa | 5 min. - 1 h. |
| Rate of power ramp | 1 % of max. power/s. (max) |
| | 1 % of max. power/h. (min) |
| Flow rate of He-3 gas | 1 cc/s. |

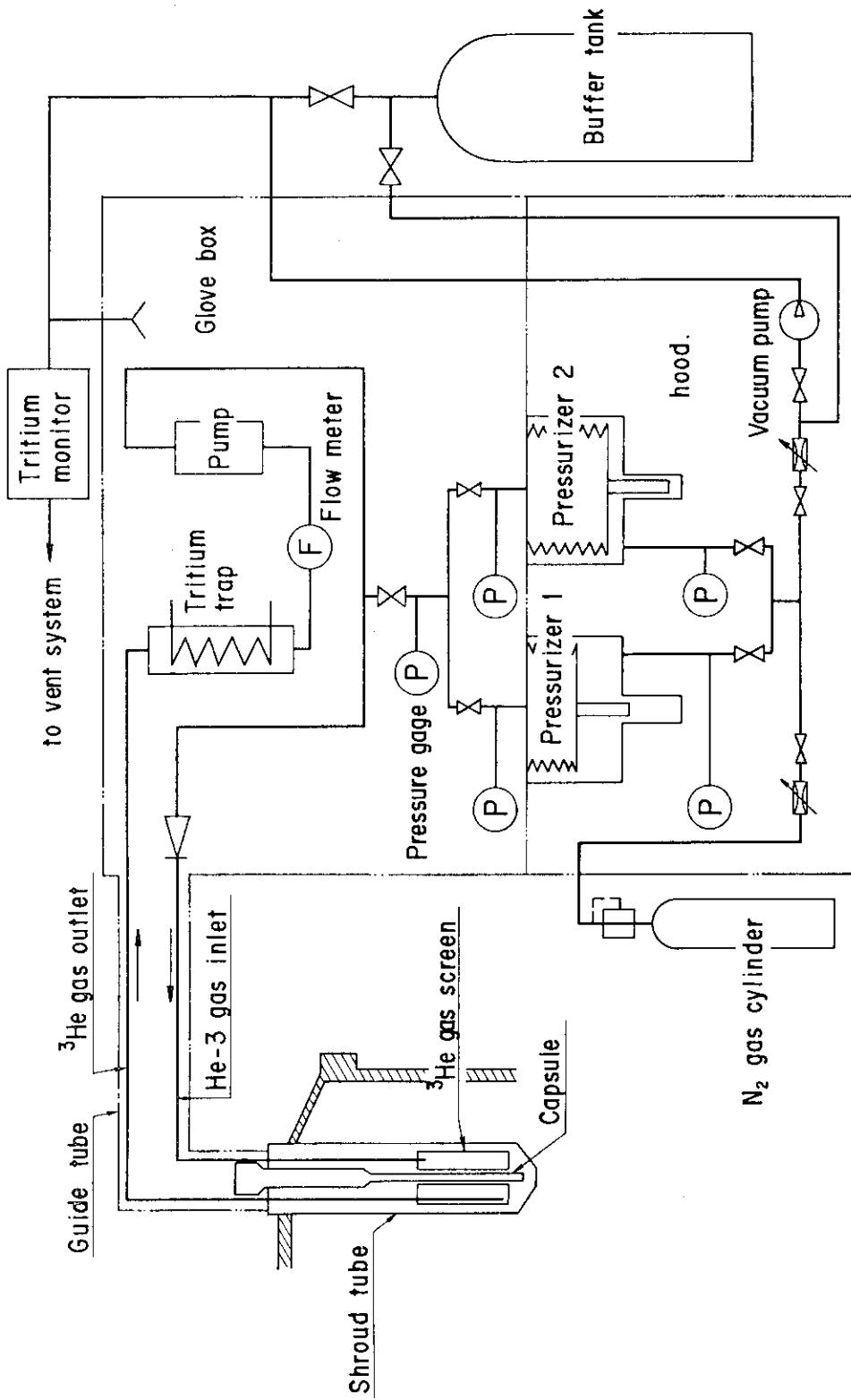


Fig. 5.1.1.1 ³He Power Control Facility

5.2 Shroud facility (OSF-1)

The facility has a straight in-pile tube open to the reactor pool and a individual cooling water system. A heavily instrumented or complicated capsule such as a boiling water capsule can be charged into or discharged from the in-pile tube even during reactor operation. Charging or discharging is carried out with remotely operated capsule exchanger.

Flow separator of the in-pile tube has a He-3 gas screen on its core region. Power ramp tests are to be carried out for fuel pins contained in boiling water capsules combining with a pressure controller of the He-3 power control facility.

The facility was completed in 1983.

Characteristics of the shroud facility

| | |
|---|--|
| Core position | D-9 |
| Thermal neutron flux | 2.6×10^{14} n/cm ² ·s (max.) |
| Fast neutron flux | 2.2×10^{13} n/cm ² ·s |
| Gamma heating | 2.2 W/g |
| Coolant flow rate | 2 m ³ /h |
| Coolant temperature | 40°C |
| Max. heat generation in a capsule | 30 KW |
| He-3 gas screen dimension | 34 mm I.D.×540 mm L |

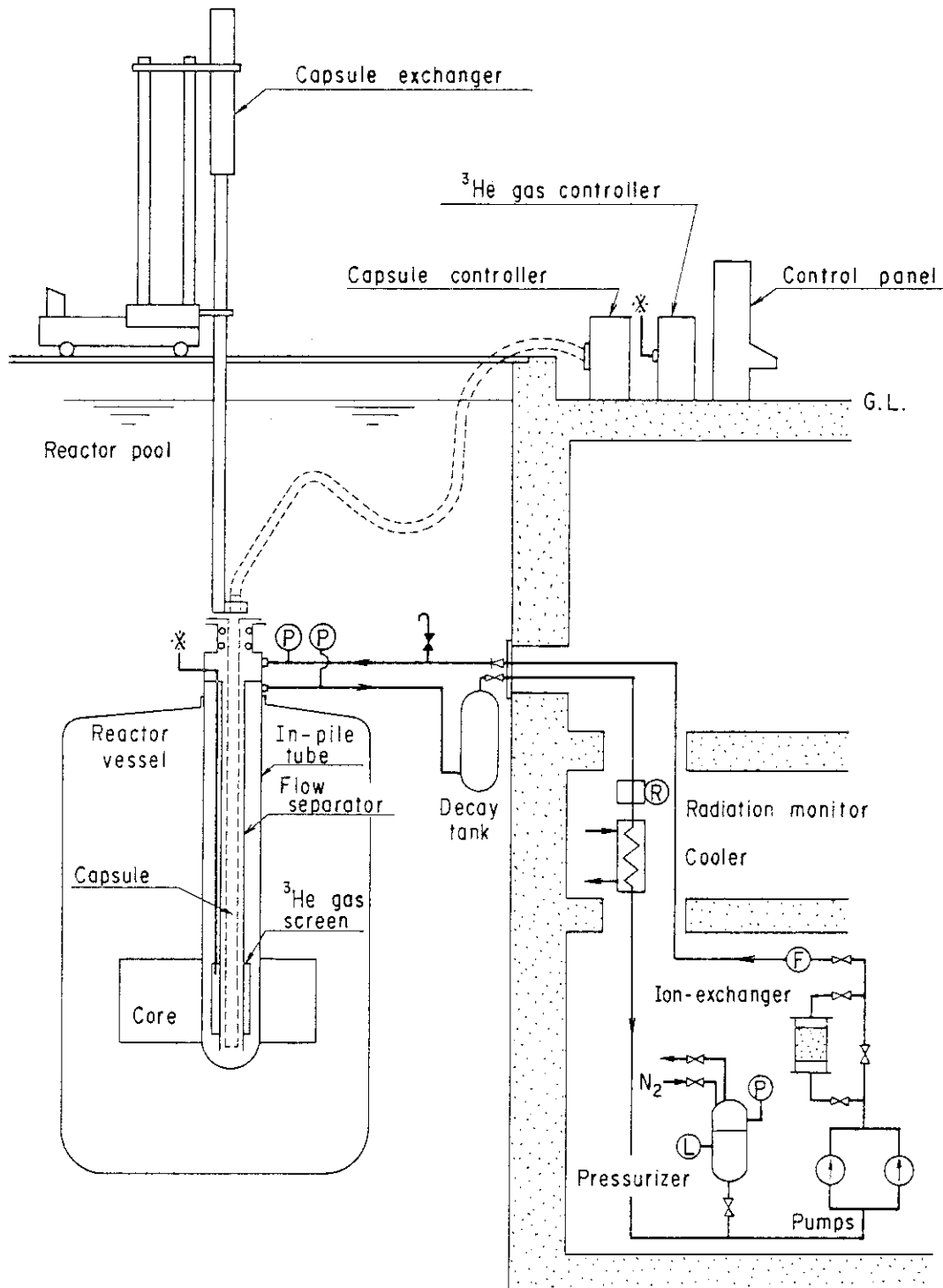


Fig. 5.2.1 Scheme of the Shroud Facility

6. Loops

6.1 OWL-2

OWL-2 (Oarai Water Loop No.2) was installed in JMTR on 1971, this facility is mainly used for the irradiation experiments of fuel element and component materials for a light water cooled reactor.

OWL-2 is consisted with primary cooling system, secondary cooling system, safety and control system. Both primary and secondary cooling system are closed-circulating system, and heat exchanger for heat transfer is placed between the primary cooling system and secondary cooling system. Secondary coolant is cooled by the water of utility cooling line (UCL) through the heat exchanger.

In-pile test section (tube) is the straight tube passing through the reactor core from the top of reactor pressure vessel to the bottom as shown in Fig. 6.1.3. The stream of primary coolant is up-flow type, and the irradiation test specimen is inserted from the top closure to the core position. An outline flow sheet of OWL-2 is shown on Fig. 6.1.1.

According to the experimental purpose, an inside atmosphere of test section is formed by out-pile equipments (electric heater and high pressure injection pump, etc.).

Out-pile equipments of this facility has been installed in the loop cubicle (room) that was consisted with thick biological shielding concrete.

OWL-2 has three out-pile test sections in the primary cooling system. The No.1 test section has been installed in the inlet of the in-pile tube the No.2 test section has been installed in the outlet of in-pile tube, and the No.3 test section has been installed in the steam line. These test sections are located in the loop cubicle, and are usually used for a corrosion test.

Table 6.1.1 summarizes the pertinent OWL-2 design and operating parameters.

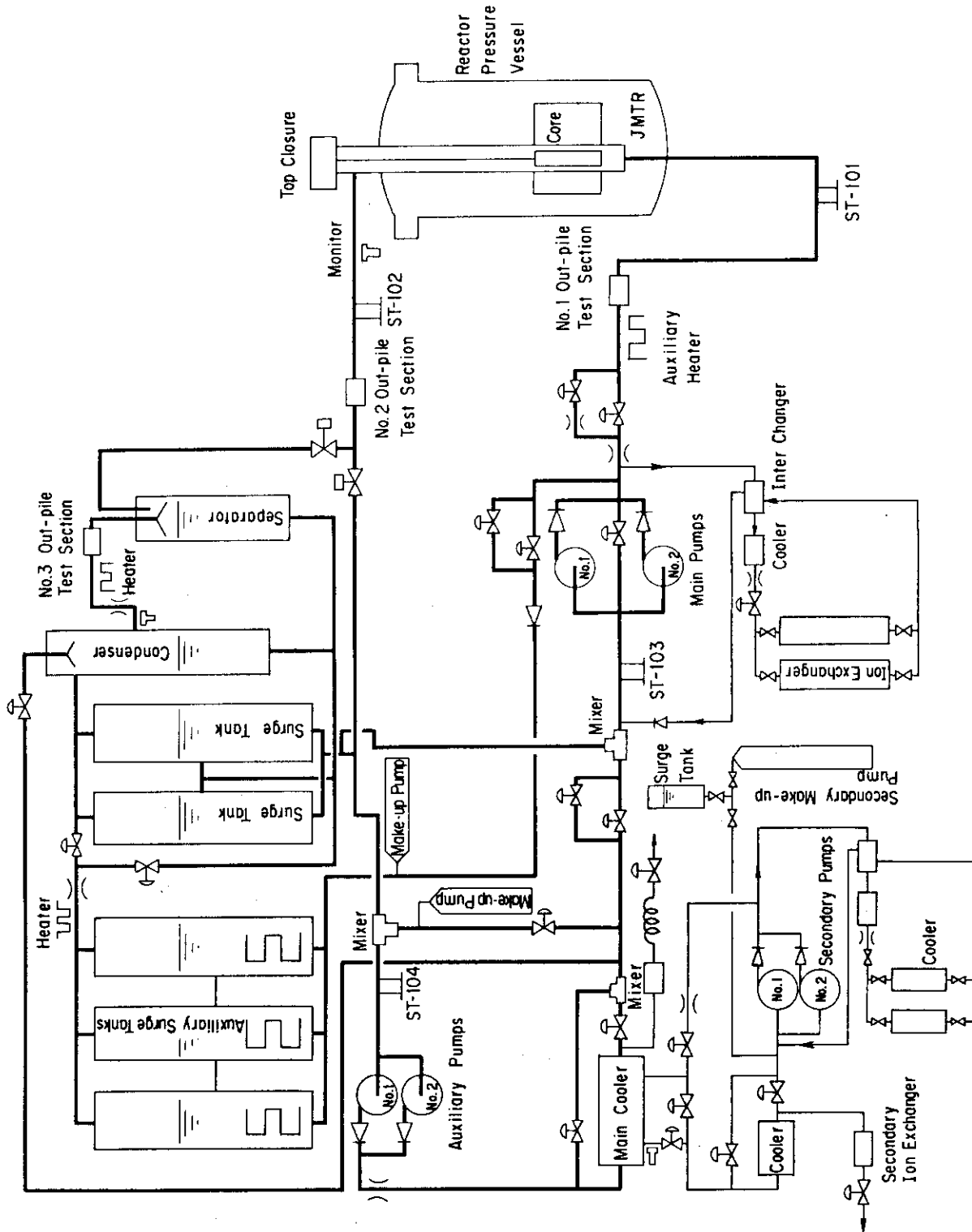


Fig. 6.1.1 Flow Diagram of OWL-2

Table 6.1.1

OWL-2 LOOP

| | |
|-----------------------------------|--|
| Loop Type | Pressurized Water Through Type |
| Core position | K,L-3,4 |
| Thermal Flux | 5.4×10^{13} n.cm ⁻² .s ⁻¹ (max) |
| Fast Flux | 5.5×10^{13} n.cm ⁻² .s ⁻¹ (max) |
| Heat Generation of Specimen | 850 KW (max) |
| Test Section (in-pile tube) | |
| Material | Stainless Steel |
| Effective Length | 750 mm |
| Diameter | 117.8 mm |
| Coolant | Water |
| Operating Condition | |
| Pressure | 73 Kg/cm ² .G |
| Flow | 1,100 Kg/min. |
| Temperature | 270°C in P-mode Operation 285°C in B-mode Operation |
| Steam Quality in B-mode Operation | 20 % (max) |

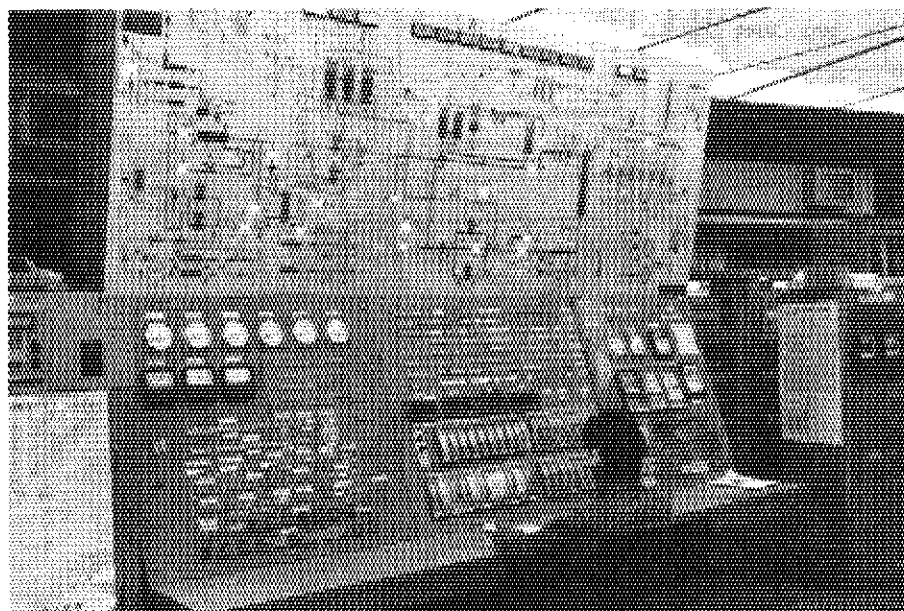


Fig. 6.1.2 Control Desk for OWL-2

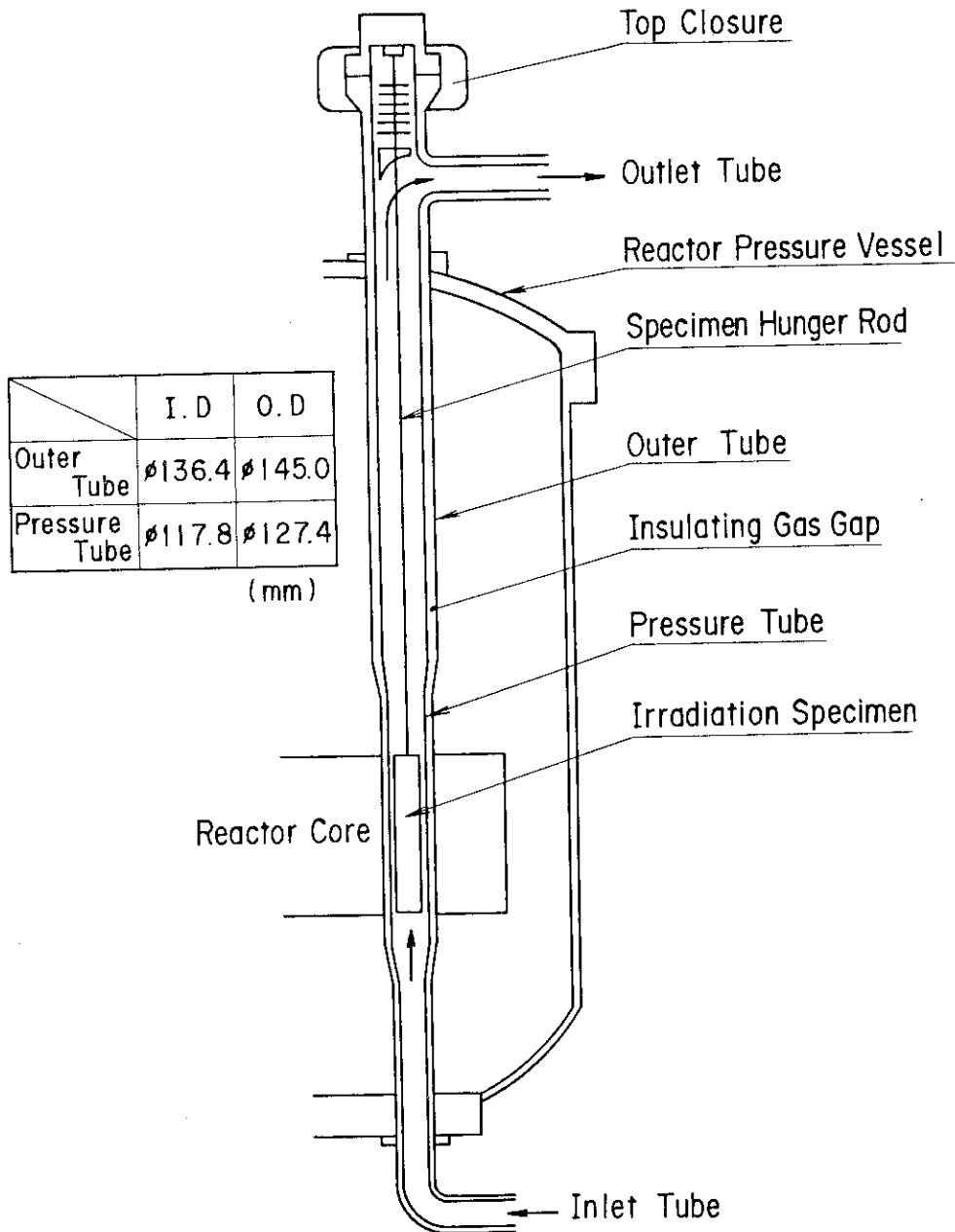


Fig. 6.1.3 OWL-2 In-Pile Tube

6.2 OGL-1

OGL-1 (Oarai Gas Loop No.1) is a high temperature in-pile gas loop which was developed as a testing facility for the multipurpose high temperature gas cooled reactor (VHTR), especially designed to make irradiation test of coated particle fuel and graphite under the helium flow condition of 1,000°C. This loop is not only an irradiation facility but also a pilot plant of VHTR, and was installed in JMTR on 1977.

The OGL-1 facility consists of an in-pile tube, primary circulating system, secondary circulating system, purification system and auxiliary system. Fig. 6.2.3 shows the OGL-1 in-pile tube. The in-pile tube is of the re-entrant type, and consists of four coaxial tubes to keep He gas temperature sufficiently high.

Direct resistance heating of the primary piping is used for the heater. The helium purification system consists of a precharcoal trap, molecular sieve trap to remove moisture and carbon dioxide, a cold charcoal trap to remove the fission-produced noble gases, and hydrogen removal section including titanium sponge as the getter. Secondary coolant is the air. An outline flow sheet of this loop is shown on Fig. 6.2.1.

An irradiation test specimen is inserted from the top closure to core position.

Out-pile equipments of this facility has been installed in the loop cubicle (room) that was consisted with thick biological shielding concrete.

Table 6.2.1 summarizes the pertinent OGL-1 design and operating parameters.

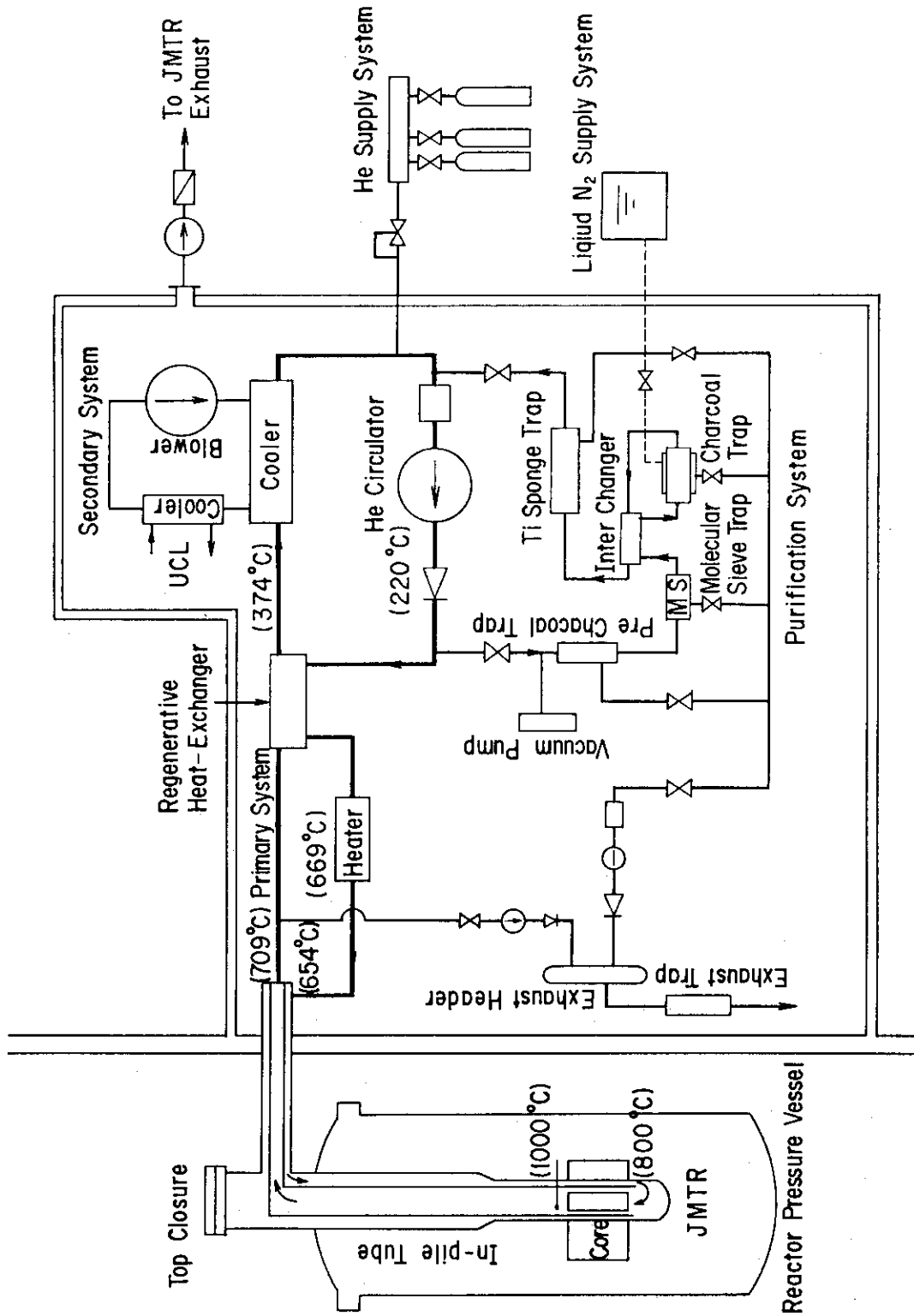


Fig. 6.2.1 Flow Diagram of OGL-1

Table 6.2.1

OGL-1 LOOP

| | |
|-----------------------------|---|
| Loop Type | Pressurized Gas Re-entrant Type |
| Core position | G,H-3,4 |
| Thermal Flux | $5.9 \times 10^{13} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ (max) |
| Fast Flux | $1.3 \times 10^{13} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ (max) |
| Heat Generation of Specimen | 135 KW (max) |
| Test Section (in-pile tube) | |
| Material | Hastelloy-X (Flow Tube and Inner Barrier Tube surrounded by high temperature Helium Gas) |
| Effective Length | 750 mm |
| Diameter | 82 mm |
| Coolant | Helium Gas |
| Operating Condition | |
| Pressure | $30 \text{ Kg/cm}^2 \cdot \text{G}$ |
| Flow | 6 Kg/min. |
| Temperature | $1,000^\circ \text{C}$ (at Test Section) |
| Impurity | less than 10 vpm |
| Out-pile Test Section | None |

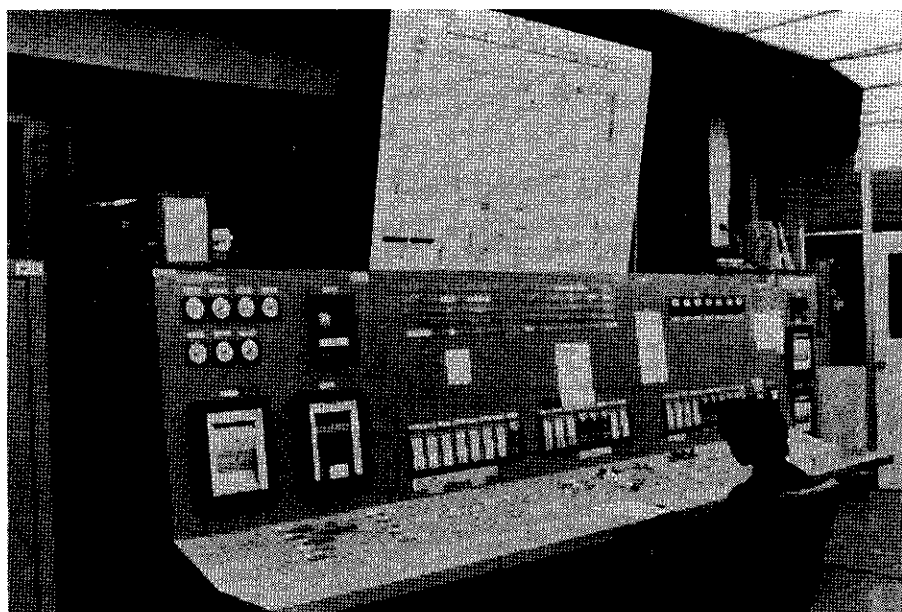


Fig. 6.2.2 Control Desk for OGL-1

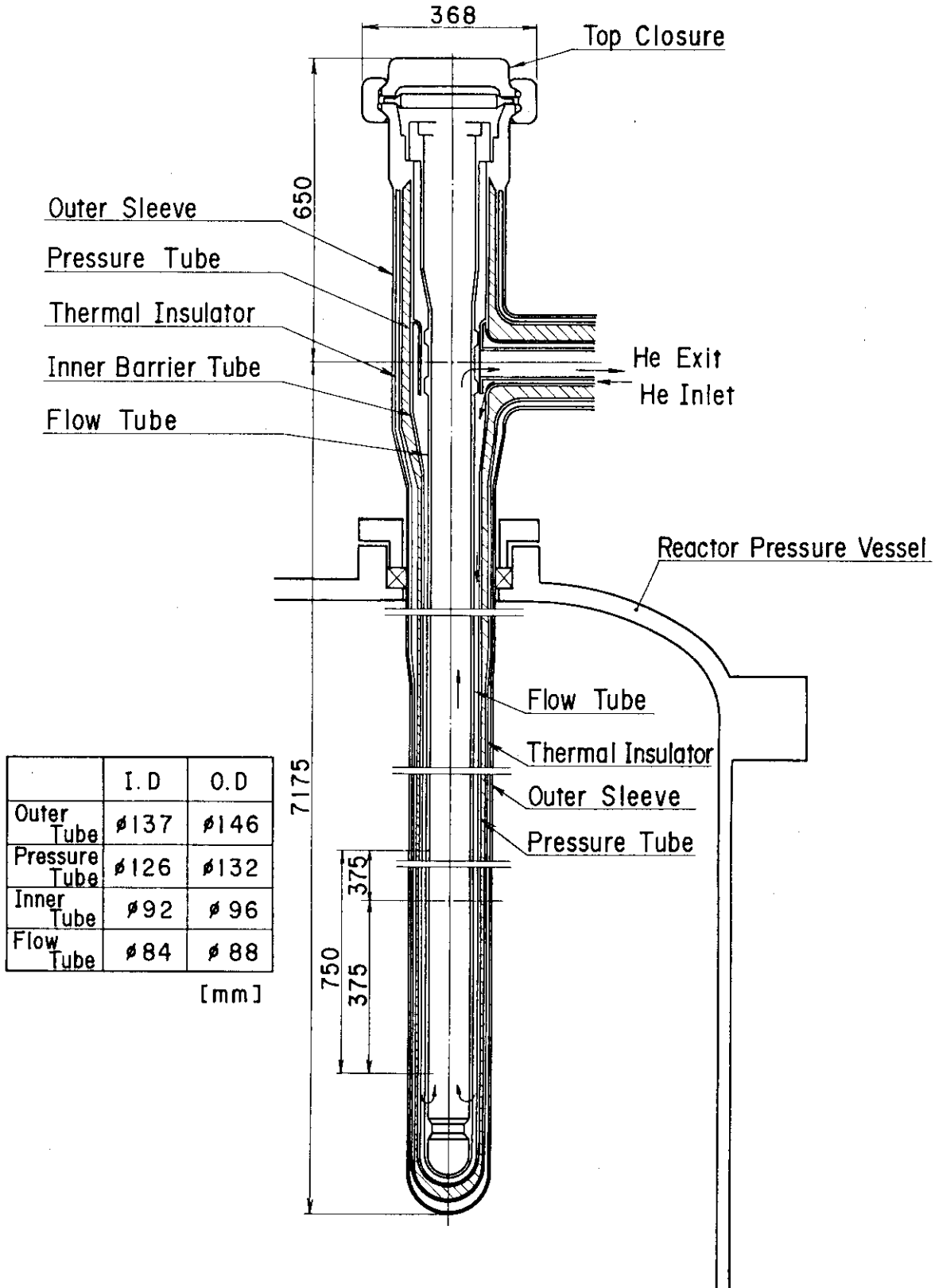


Fig. 6.2.3 OGL-1 In-pile Tube

7. In-core instruments and devices

7.1 Thermocouple

The Chromel-Alumel (CA) thermocouples are available to measure temperature of specimens in a capsule up to about 1100°C and tungsten-rhenium thermocouples are used for measuring temperature from about 1100 to about 2100°C, occasionally 2300°C. The Nb-1 % Zr sheathed high temperature thermocouples are mostly applied to measure the temperature of coated particle fuels specimens for HTGR up to about 1600°C, occasionally 1900°C. The molybdenum sheathed thermocouples are utilized for measuring center line temperature of fuel rods for LWR. High temperature thermocouples with hafnia insulation and sheath of W-augmented rhenium are being developed for measuring temperature above 2100°C. All thermocouples used in JMTR are un-grounded type (Fig. 7.1.1). Specifications are shown in the table.

Specifications

| Specification of thermocouples | Temperature range |
|--|---------------------|
| Chromel-Alumel (CA) thermocouples, MgO insulation, ss-316 or inconel sheath, 0.5, 1.0 and 1.6mm O.D. | up to 1100°C |
| W-5 % Re/W-26 % Re thermocouples, BeO insulation, Nb-1 % Zr or Mo sheath, 1.6 or 1.8mm O.D. | from 1100 to 1900°C |
| W-5 % Re/W-26 % Re thermocouples, BeO insulation with Ta barrier tube, W-22 % Re sheath, 2.0mm O.D. | from 1100 to 2100°C |

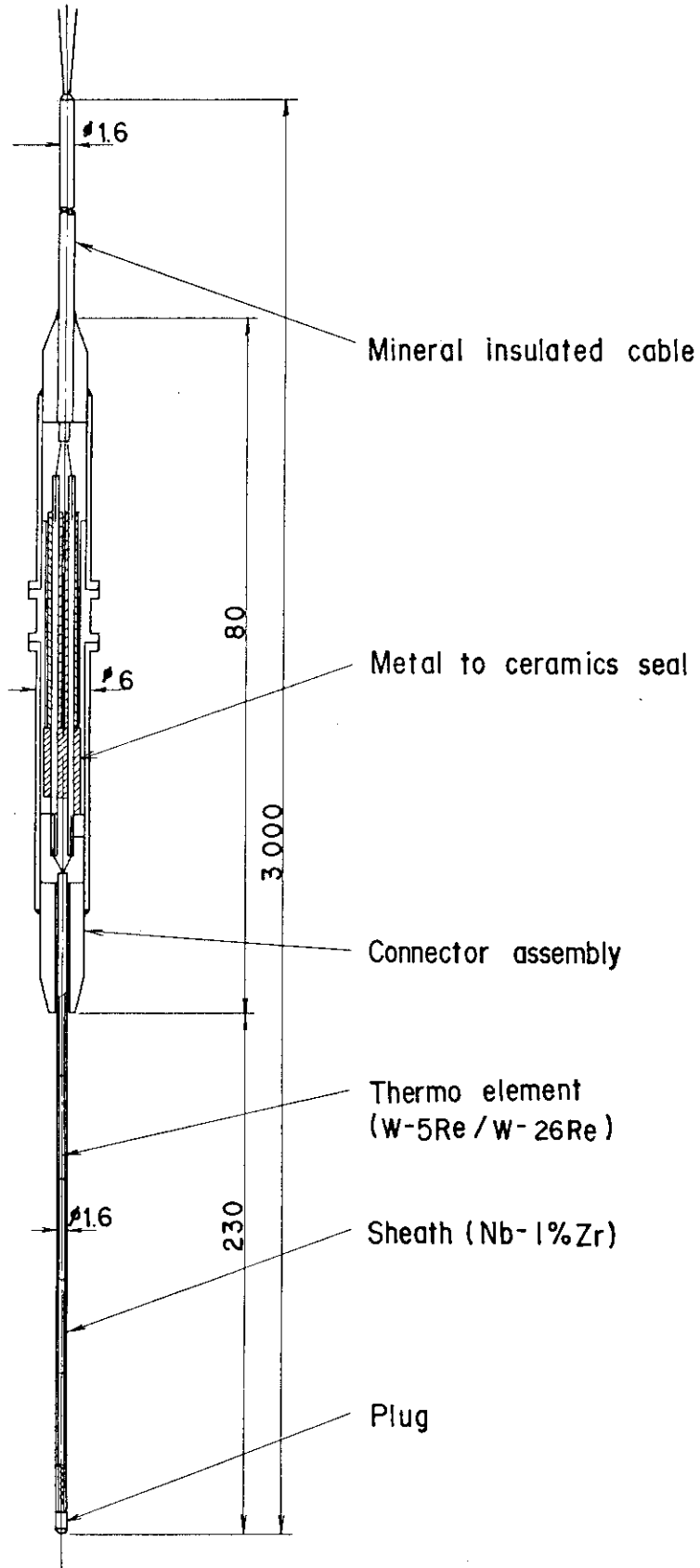


Fig. 7.1.1 High temperature thermocouple

7.2 Linear variable differential transformer (LVDT)

The linear variable differential transformer (LVDT) is available as an in-pile detector of displacement in the capsule. The combined elongation and failure detector with the LVDT shown in Fig. 7.2.1 is loaded in the boiling water capsule (BOCA) to measure elongation of fuel pin and also to detect failure of the pin when occurred.

The LVDT is applied as an extention-meter for various purposes in the capsule, for example, to measure the creep strain of the stressed specimen in the in-pile creep capsule. Another application of the LVDT is a detector for displacement of the actuating bellows for moving the thermal-bond in the temperature ramping capsule. Specifications are shown in the table.

Specifications

| Item | Specification |
|--|---|
| a) Combined elongation and failure detector | |
| Linear range | ± 3 mm |
| Sensitivity | 0.01 mm |
| Service temperature | 350°C for continuous usage, 460°C for short term usage |
| Minimum operating pressure of bellows | 0.2 kg/cm ² |
| Exciting current | 50 mA |
| Exciting frequency | 400 Hz |
| b) Extention-meter for temperature ramping capsule | |
| Measuring range | 0 - 80 mm |
| Accuracy | ± 3 mm for stroke of 80 mm |
| Service temperature | 350°C |
| Exciting current | 30 mA |
| Exciting frequency | 500 Hz |
| c) Extention-meter for in-pile creep capsule | |
| Measuring range | 0 - 10 mm |
| Sensitivity | 0.01 mm |
| Service temperature | 350 °C |
| Exciting current | 50 mA |
| Exciting frequency | 400 Hz |

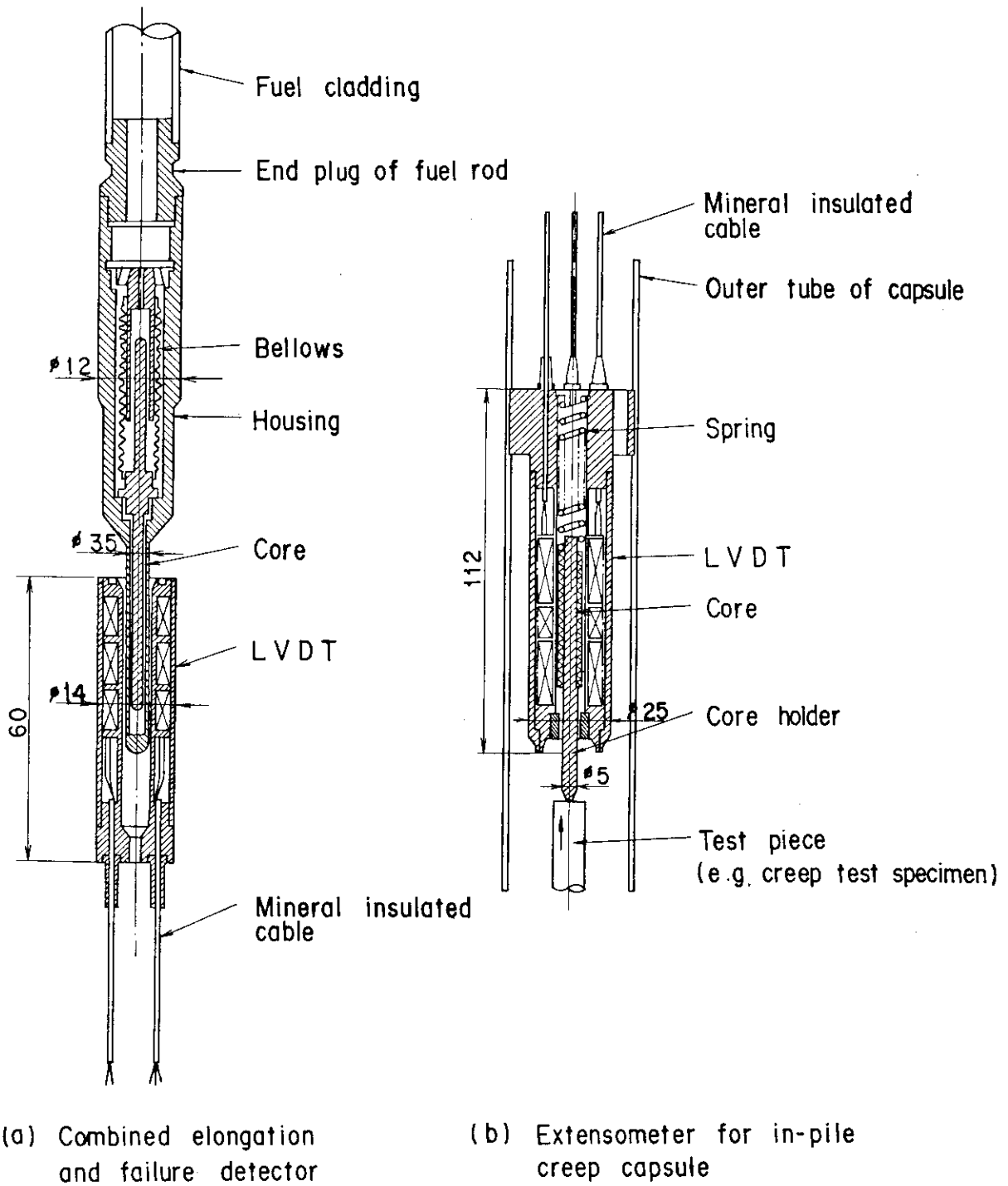


Fig. 7.2.1 Linear variable differential transformer (LVDT)

7.3 Pressure transducer

Two types of pressure transducer used for measuring fission gas pressure inside fuel pins and other gas pressure are available in JMTR.

(1) Null-balanced ON-OFF type (Fig. 7.3.1 (A))

A bellows of stainless-steel that withstands the pressure of 70 kg/cm^2 is placed in the center of the transducer as the element for detecting gas pressure. A moving electrical contact-point is fixed at the top of the bellows. An another electrical contact-point is fixed to the housing of transducer. The fixed contact-point is insulated with the transducer by alumina washer. Gas pressure is obtained as a balancing pressure between the inside and outside of bellows by measuring the back pressure from out-of-pile system. Specifications are shown in the table.

Specifications

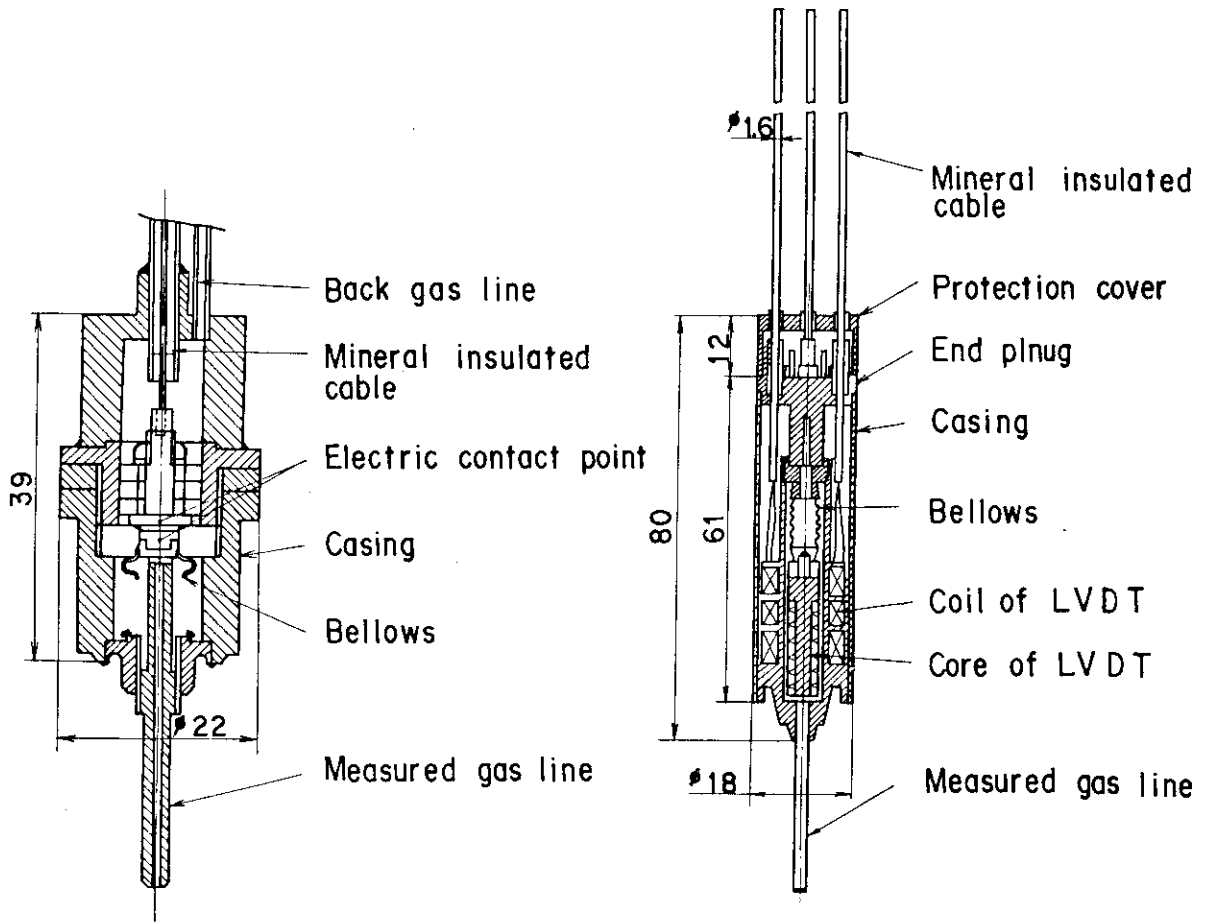
| Item | Specifications |
|-------------------------|---|
| Measuring range | 0 - 70 kg/cm^2 |
| Accuracy | $\pm 1.5 \%$ of full range |
| Operating temperature | 450°C max. |
| Dimension of transducer | $\phi 22 \times 39 \text{ mm}$ |
| Dimension of bellows | $\phi 8 \times \phi 5 \times 0.1 \text{ mmt}$ |

(2) Differential transformer type (Fig. 7.3.1(B))

The ferritic core of 4.3 stainless-steel located in the center of the variable differential transformer (LVDT) is connected to the bellows of Inconel 718 for detecting the pressure that withstands the pressure of 50 kg/cm^2 . The voltage induced in the secondary coil of the LVDT due to displacement of the core resulted from deformation of the bellows is calibrated with helium pressure.

Specifications

| Item | Specifications |
|-------------------------|---|
| Measuring range | 0 - 50 kg/cm^2 |
| Accuracy | $\pm 1.5 \%$ of full range |
| Operating temperature | 350°C max. |
| Dimension of transducer | $\phi 18 \times 80 \text{ mm}$ |
| Dimension of bellows | $\phi 4 \times \phi 5 \times 0.1 \text{ mmt}$ |



(A) Null-balanced ON-OFF type pressure transducer

(B) Linear variable differential transformer (LVDT) type pressure transducer

Fig. 7.3.1 Pressure transducer

7.4 Bellows

Bellows are used in the capsule for the purpose of stressing the specimens in the in-pile creep measuring capsule, moving components in the temperature ramping capsule and so on. The bellows are also utilized as a sensing element for gas pressure in the fission gas pressure transducer. Specifications of the bellows used in the capsules and transducers are described in the following. The molded or welded bellows is used properly depending on each objective for application.

(1) Molded bellows

A) for sensing element in pressure transducer

| | |
|-------------------------|---------------------------------------|
| — material | Inconel 718 |
| — dimension | $\phi 6 \times \phi 4 \times 0.1$ mmt |
| — number of plys | 8 |
| — operating pressure | 70 kg/cm^2 |
| — operating temperature | 400°C |

B) for stressing specimen in in-pile creep capsule

| | |
|-------------------------|---|
| — material | Inconel 718 |
| — dimension | $\phi 34 \times \phi 21.5 \times (0.15 + 0.15)$ mmt, double wall |
| — number of plys | 54 |
| — operating pressure | 30 kg/cm^2 |
| — operating temperature | 400°C |

(2) Welded bellows

A) for stressing specimen in in-pile creep capsule

| | |
|-------------------------|---|
| — material | ss-304 L |
| — dimension | $\phi 35 \times \phi 22 \times (0.15 + 0.15)$ mmt, double wall |
| — number of plys | 135 |
| — operating pressure | 28 kg/cm^2 |
| — operating temperature | 400°C |

B) for displacing a thermal-bond in temperature ramping capsule

| | |
|-------------------------|--|
| — material | ss 304 L |
| — dimension | $\phi 24 \times \phi 12 \times 0.15$ mmt |
| — number of plys | 312 |
| — operating pressure | 10 kg/cm^2 |
| — operating temperature | 400°C |

7.5 Fluence monitor

Fluence monitors for measuring the neutron dose exposed on the irradiated specimens are loaded with the specimens in the capsule and/or loop assembly. The monitor of ^{54}Fe sheathed in the tube of pure alumina or aluminum are applicable to measure the fast neutron flux dose of above 1 MeV. The neutron dose is obtained by detecting the gamma ray from ^{54}Mn produced by the reaction of $^{54}\text{Fe}(n,p)^{54}\text{Mn}$ using Ge-detector. The wire of 0.17 w/o Co-Al sheathed in the tube of pure alumina or aluminum are applied to measure the thermal flux dose, and the flux dose is also obtained by detecting the gamma ray from the reaction of $^{60}\text{Co}(n,\gamma)^{60}\text{Co}$. Positions of the fluence monitors loaded in the capsule are arranged, in order to obtain both radial and axial distributions of flux dose.

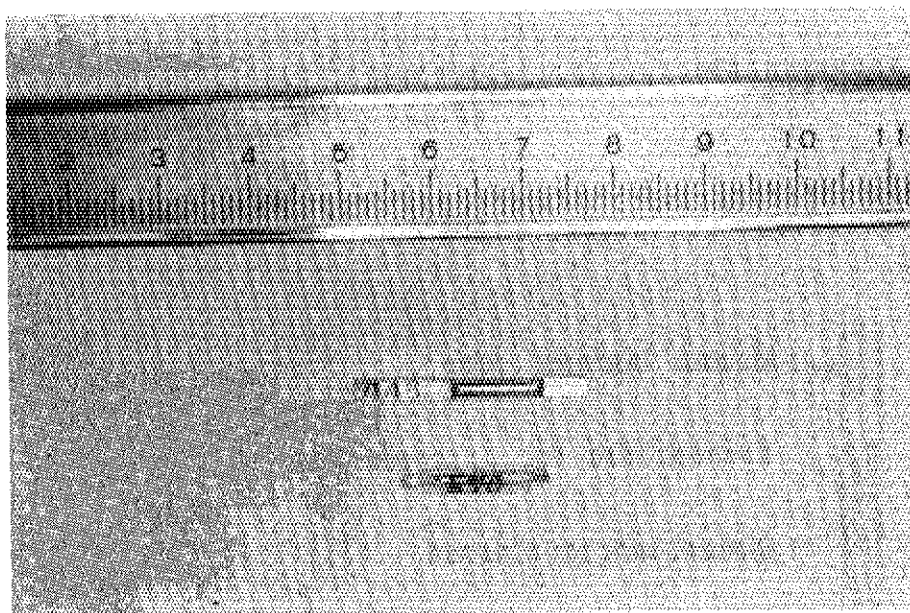


Fig. 7.5.1 Fluence Monitors

7.6 Self powered neutron detector

Self powered neutron detectors (SPND) are used in order to obtain the power of the fuel pin irradiated in the capsule and/or loop by continuous measurement of the thermal neutron flux during irradiation. The SPND with gamma compensation used in JMTR is shown in Fig. 7.6.1. Specifications are shown in the table.

Specifications

| Item | Specification |
|-----------------------|--|
| Emitter | $\phi 0.5$, ^{51}V , ^{103}Rh and ^{59}Co |
| Insulator | Al_2O_3 |
| Sheath (Collector) | $\phi 1.6$ and $\phi 2.0$, ss-316 |
| Sensitivity | 7.7×10^{-23} A/nv·cm (^{51}V) 1.2×10^{-21} A/nv·cm (^{103}Rh) 1.7×10^{-23} A/nv·cm (^{59}Co) |
| Response time | 5.4 min (^{51}V) 68 sec (^{103}Rh) <1 sec (^{59}Co) |
| Operating temperature | 400°C max. |

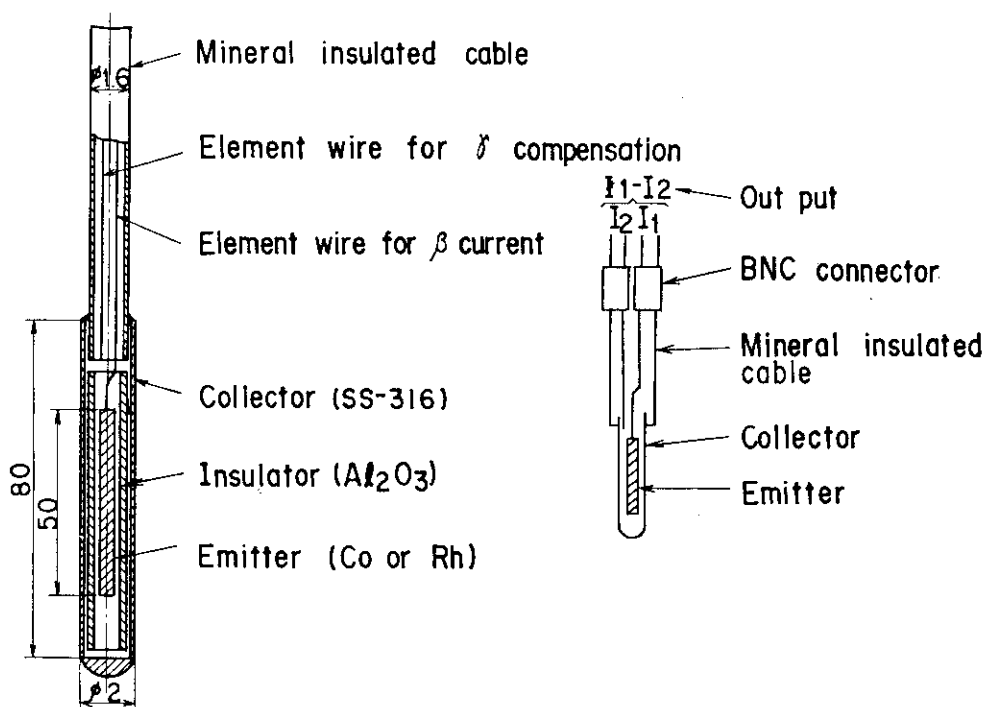


Fig. 7.6.1 Gamma compensated self powered neutron detector

7.7 Turbine flow meter

The turbine flow meter is applied to measure the mass flow rate of water which gives the power of fuel pins loaded in the water loop together with temperature rise of the coolant. The mass flow rate is obtained by measuring electric pulse induced in the pick-up coils with the permanent magnets by rotation of the rotor with blades made of 17-4 PH. The hard metal is used for the bearing on the shaft. The configuration of the flow meter is shown in Fig. 7.7.1.

Specifications

| Item | Specification |
|---------------------------|------------------|
| Dimension of flow meter | $\phi 40$ 116 mm |
| Outside diameter of rotor | 25 mm |
| Number of blades | 4 |
| Number of pick-up coils | 2 |
| Measurable flow range | 100 - 200 l/min |
| Accuracy | ± 1 % F.S. |

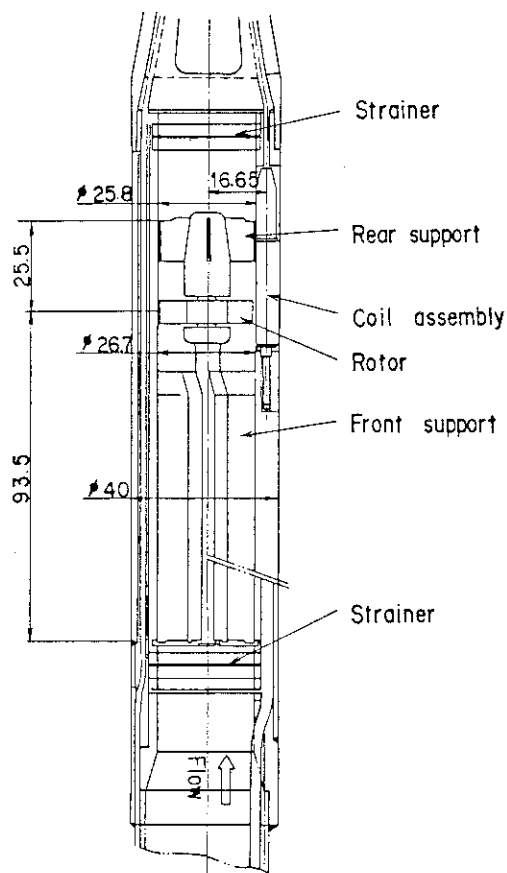


Fig. 7.7.1 Turbine flow meter

8. Data acquisition system

8.1 Hardware

The system is able to handle 529 irradiation data from 24 capsules (including He-3 power control facility), 2 hydraulic rabbit facilities, neutron control facility and 2 loops. 467 of them are analog-type and 62 of them are digital. A high speed 16 bit central computing unit (C.P.U.) processes these data. Main out put devices are a printer, a x-y plotter and two CRTs. Disk memory unit has a sufficient capacity for data storage during 40-day-operation. Data stored in disk are transferred into magnetic tape after operation for permanent storage. An operator can access to the system through an operator console.

8.2 Data collection and monitoring

All signals are sampled at 10 sec interval, filtered, corrected, scaled and stored into designated memory locations in data files. Each data is to be compared with preset values every sampling. Alarm is given to operators if data exceeds limit value. Two standard data files are provided, one is a 24-hour file, in which all data are stored every 1 minute for 24 hours, and other is a reporting file, in which data are stored every 30 minutes with calculated heat generation of loop specimens for 40-day-operation. Another special file, such as a reactor scram transient file for all data and a transient file for specified data, are also provided. All transient files have capacities for 2 hour-storage at 10 sec interval.

During a reactor power up, all data are stored in the start-up file at every power level.

8.3 Display and printing

Irradiation data processed in the system can be displayed in two colour CRTs, one for character and one for graphic. The data also can be printed out in table form and plotted in graphical form for reporting. 08:30, 16:30 and 23:00 hour data of several important operating parameters are to be printed out every next morning for operation records. Desired interval data of selected parameters during the operation can be printed out after the operation for reporting. The whole data of selected parameters during the operation also can be plotted. If required, 1 minute interval data of selected parameters for past 2 hours, 6 hours or 24 hours can be displayed or plotted. Data in transient files also can be displayed or plotted. Power-up-data are displayed with predicted value at 50 MW in course of power up.

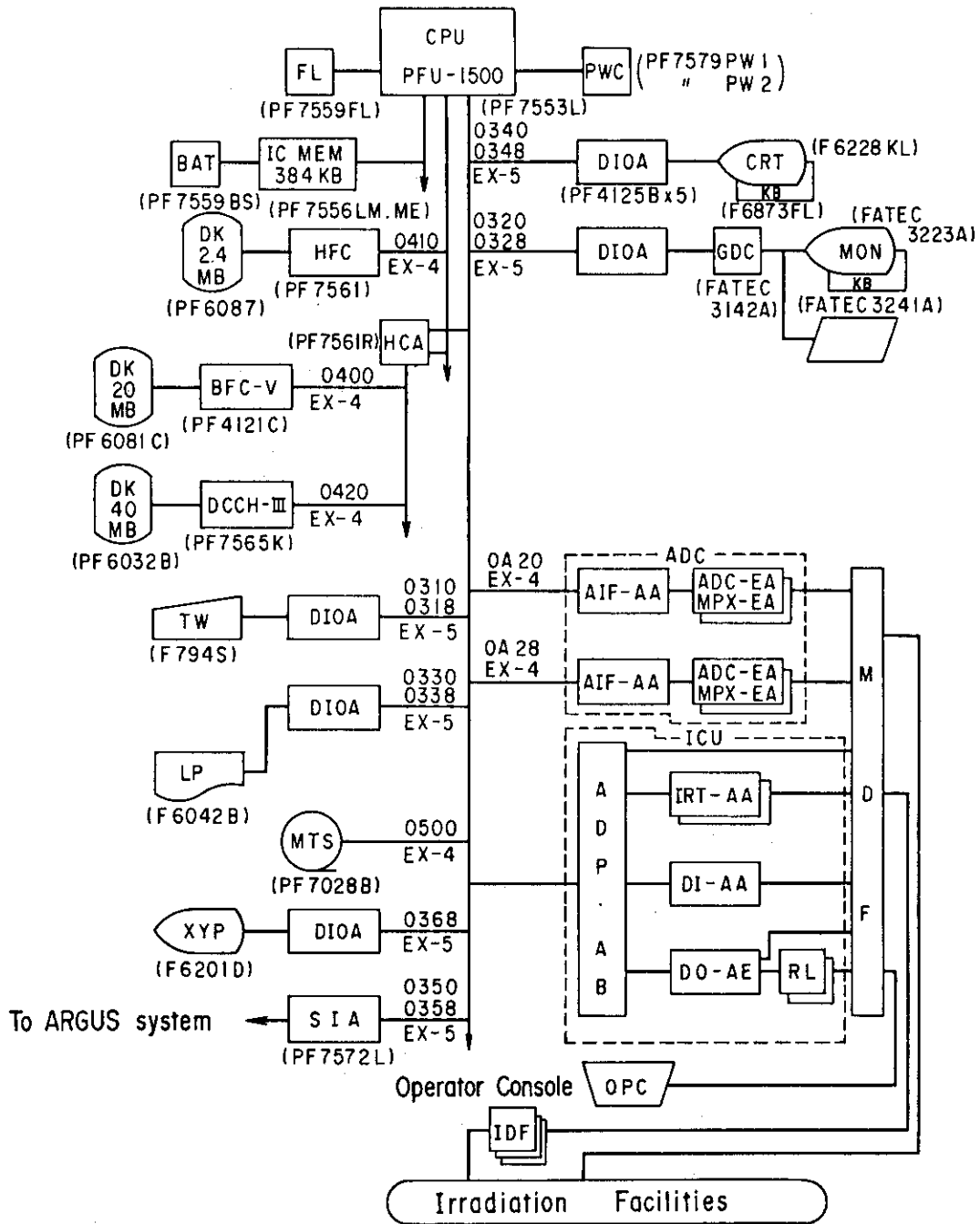


Fig. 8.1 Lay Out of JMTR Irradiation Data Aquisition System

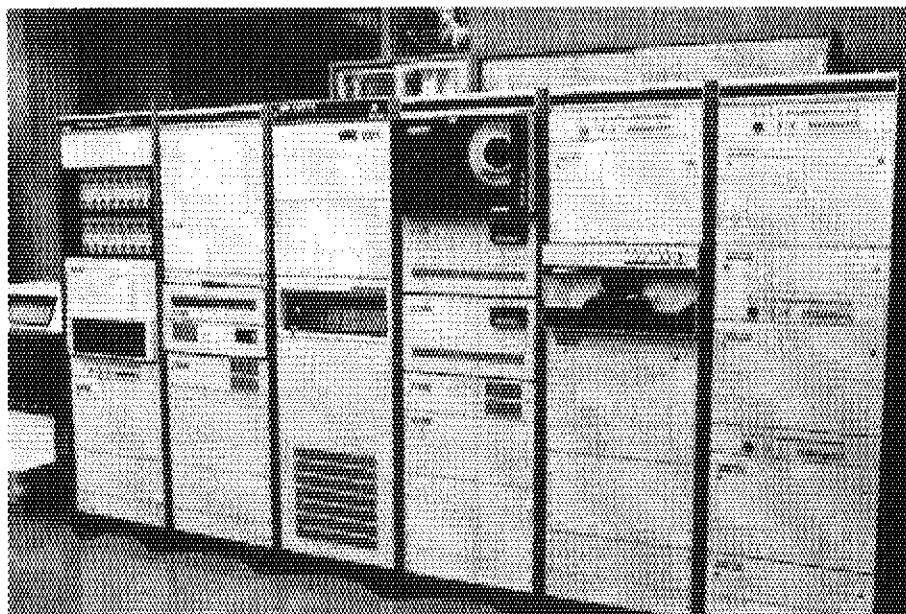


Fig. 8.2 Irradiation Data Acquisition System

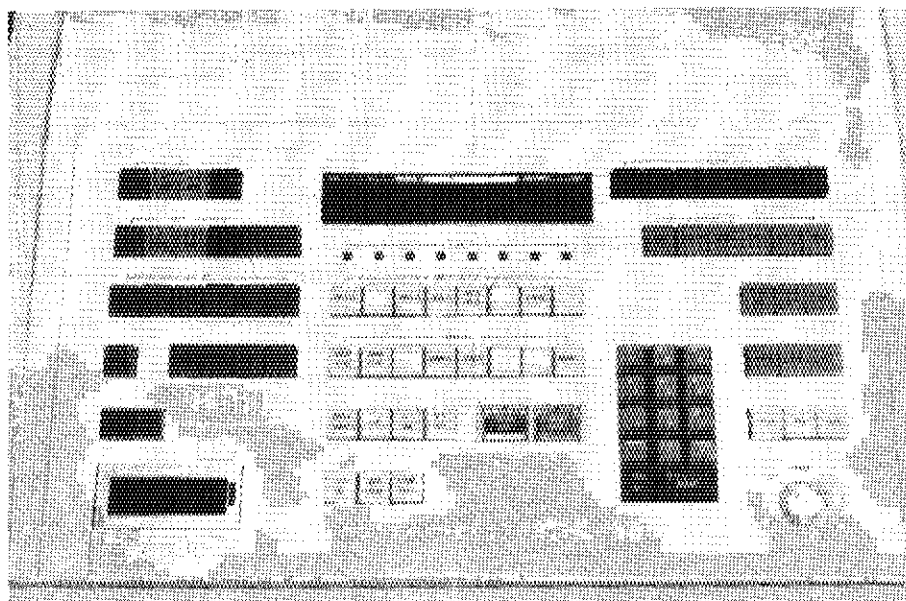


Fig. 8.3 Operator Console

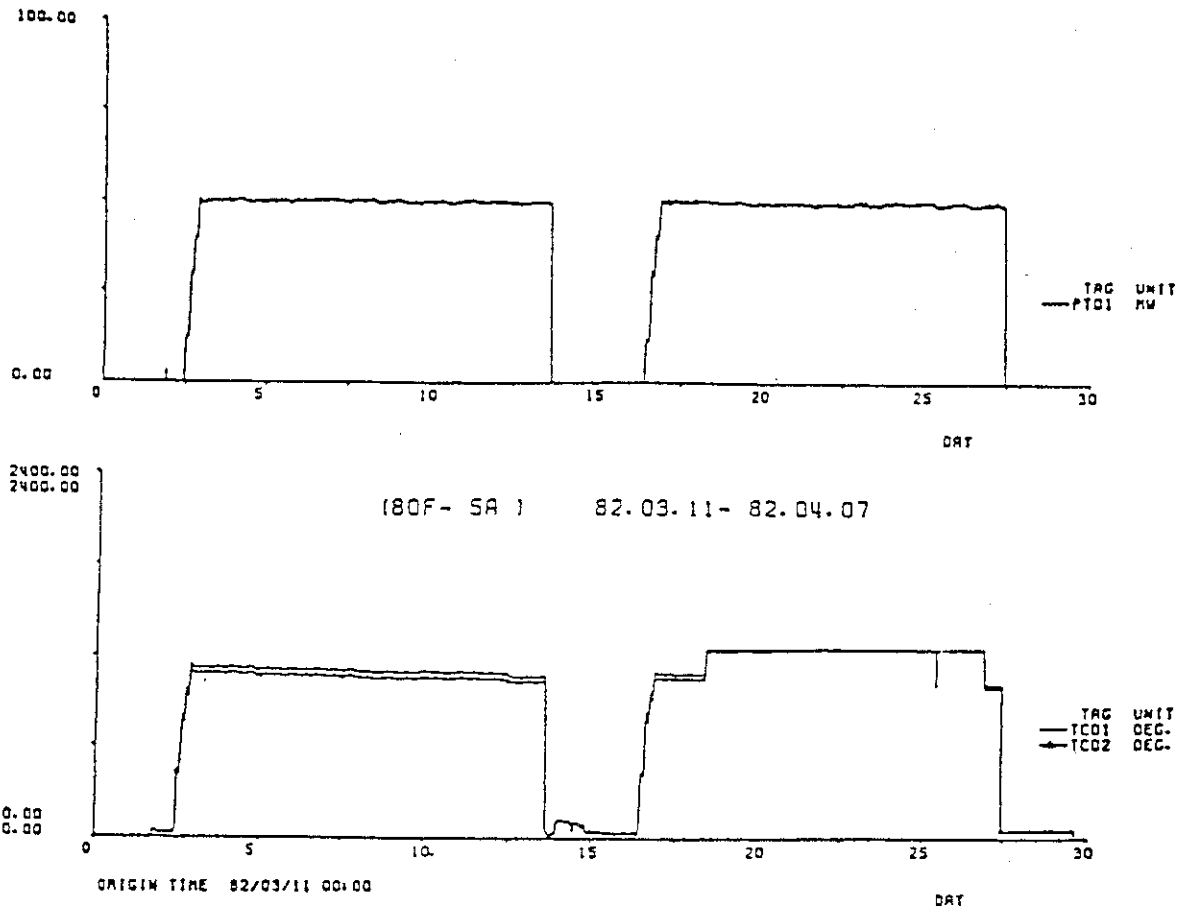


Fig.8.4 JMTR-58CYCLE CAPO2 HISTORY TREND

Table 8.1 Printed Out-Put, Data

| JMTR 58 7126 ***** 7855.7871.7855 777*58 7777 #07 ***** 58-11 | | 1982 03/20 7777 7777 | | |
|---|-------------------|----------------------|------------|------------|
| TAG.NO | UNIT | 1 8:30 | 2 16:30 | 3 23:00 |
| 7777 77777777 | PT01 MW | 49.2 | 48.5 | 49.4 |
| 80F- 5A | 7855.80-3 TC01 °C | 1094 MAN | 1082 MAN | 1097 MAN |
| 80M-21J | 7855.80-4 TC04 °C | 878 MAN | 873 MAN | 883 MAN |
| 77F- 5A | 7855.77-2 TC03 °C | 962 MAN | 955 MAN | 965 MAN |
| 80M-30U | 7871. 4-1 TC08 °C | 607 | 602 | 611 |
| 80M-18A | 7855.80-2 TC02 °C | 1144 AUT | 1163 AUT | 1143 AUT |
| 80M-31U | 7855.80-1 TC07 °C | 1020 AUT | 1006 AUT | 1015 AUT |
| 80F- 3A | 7855.79-3 TC03 °C | 1179 MAN | 1174 MAN | 1182 MAN |
| 78M- 6U | 7855.79-2 TC05 °C | 648 AUT | 648 AUT | 649 AUT |
| 79M- 3A | 7855.79-4 TC06 °C | 891 MAN | 882 MAN | 895 MAN |
| 78M- 9A | 7855. 7-1 TC03 °C | 1065 AUT | 1066 AUT | 1066 AUT |
| 80M-16A | 7855. 7-2 TC07 °C | 881 MAN | 875 MAN | 885 MAN |
| 777*58 77777777 | M001 CPH | 0.15E 04 | 0.14E 04 | 0.14E 04 |
| 77777777- 77777777 | V001 TORR | 0.11E 01 | 0.11E 01 | 0.12E 01 |

9. Hot Laboratory

The hot laboratory of JMTR, adjacent to the reactor building and connected with a water canal, has been in operation since 1971. The laboratory has a capability with a wide variety of work such as dismantling of irradiated capsule and loop assembly, post irradiation examination (PIE) of fuels, and mechanical and physical property test of structural materials.

The concrete cells, mainly used for dismantling and fuel examination, are equipped with cutters, saws, milling machine, welder, leak locator, apparatus for dimensional measurement, peri-scope, stereo-scope, X-ray apparatus, gamma scanner, liquid metal disposer, FP gas analyzer, eddy current tester, balance polisher and microscope.

The lead cells, used for material testing, are equipped with tensile, compression and bend test machines, Sharpy impact tester, apparatus for dimensional measurement, hardness tester, microscopes and furnace for heat treatment. An shielded X-ray microanalyzer (XMA) has been also installed in the hot laboratory.

The five cells shielded with steel were completed in 1982 and were equipped with PCI-SCC* tester for LWR fuel cladding, apparatus for electric resistivity measurement and dimension measuring device.

The hot laboratory can accept materials irradiated not only in JMTR but also in other reactors. The materials to be transported from/to outside of the hot laboratory are loaded through the top opening of cell.

The specimens finished PIE, capsule structural materials and high activity waste are packed in steel container and transferred to the waste management facility.

In addition to the conventional examination methods, several new techniques were developed and operated in the hot laboratory. The apparatus installed in recent several years are as follows:

1. Fuel rod endplug welding machine for circumferential helium arc weld and pressurized seal weld up to 3 MPa for the irradiated fuel rods.
2. Retained pellet-cladding gap measuring machine used for the measurement of diametrical gap between fuel pellet and cladding.
3. Panorama camera system for taking the photograph of cylindrical specimen surface of a fuel rod.

4. Shielded X-ray microanalyzer (XMA) for X-ray analysis of all elements between boron and americium and for taking the scanning image with resolving power of 200 \AA in the radioactive specimen.
5. Instrumented Sharpy impact tester for automatic data analysis on the energy absorption and the correlation between load and deflection.
6. Compact tension test system used for evaluation of fracture toughness. It consists of tensile testing machine, temperature regulating bath and clip gauge to measure the change of crack aperture.
7. Boiling water capsule assembling apparatus by which the irradiated fuel rod is inserted into capsule and helium leak test and pressure test is performed for the ramp test in JMTR.
8. Two kinds of PCI/SCC* tester. Tensile type tester is used for the ring tensile test in iodine atmosphere. Internal pressure type tester is used for the cyclic internal pressure test by iodine.
9. Electric resistance measuring apparatus used for measurement of shape memory alloy at $-190^{\circ}\text{C} \sim +150^{\circ}\text{C}$.

* PCI Pellet-Cladding Interaction
 SCC Stress Corrosion Cracking



Fig. 9.1 Concrete Cells

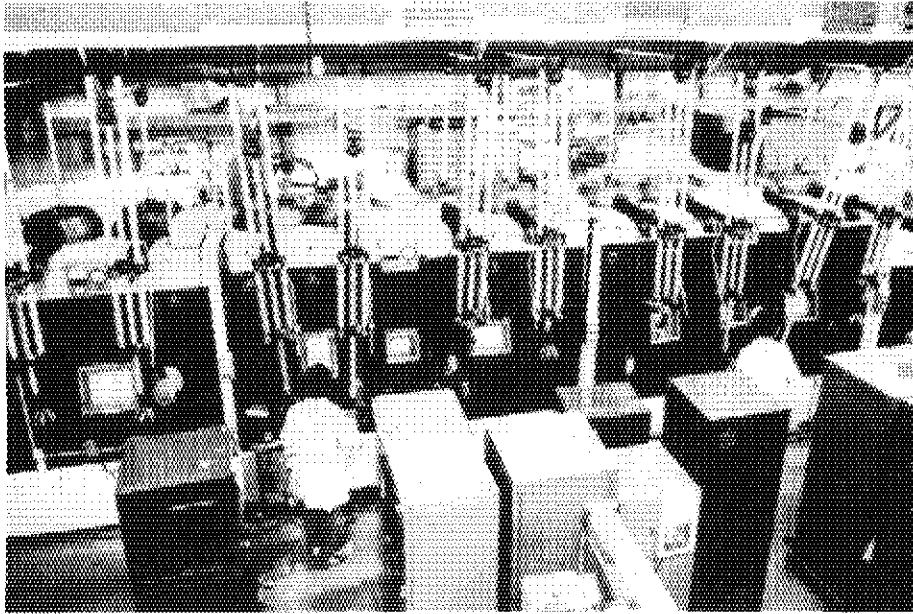


Fig. 9.2 Lead Cells

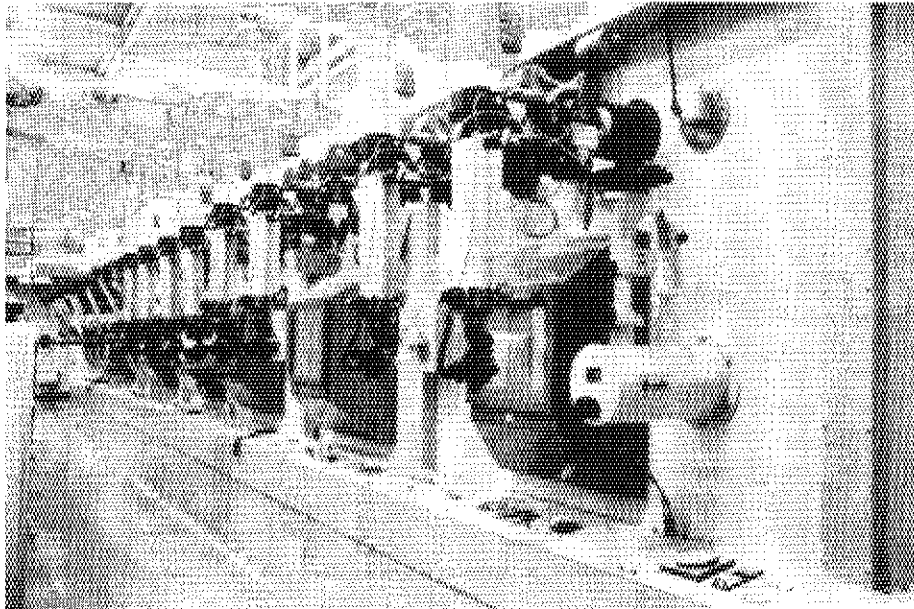


Fig. 9.3 Steel Cells

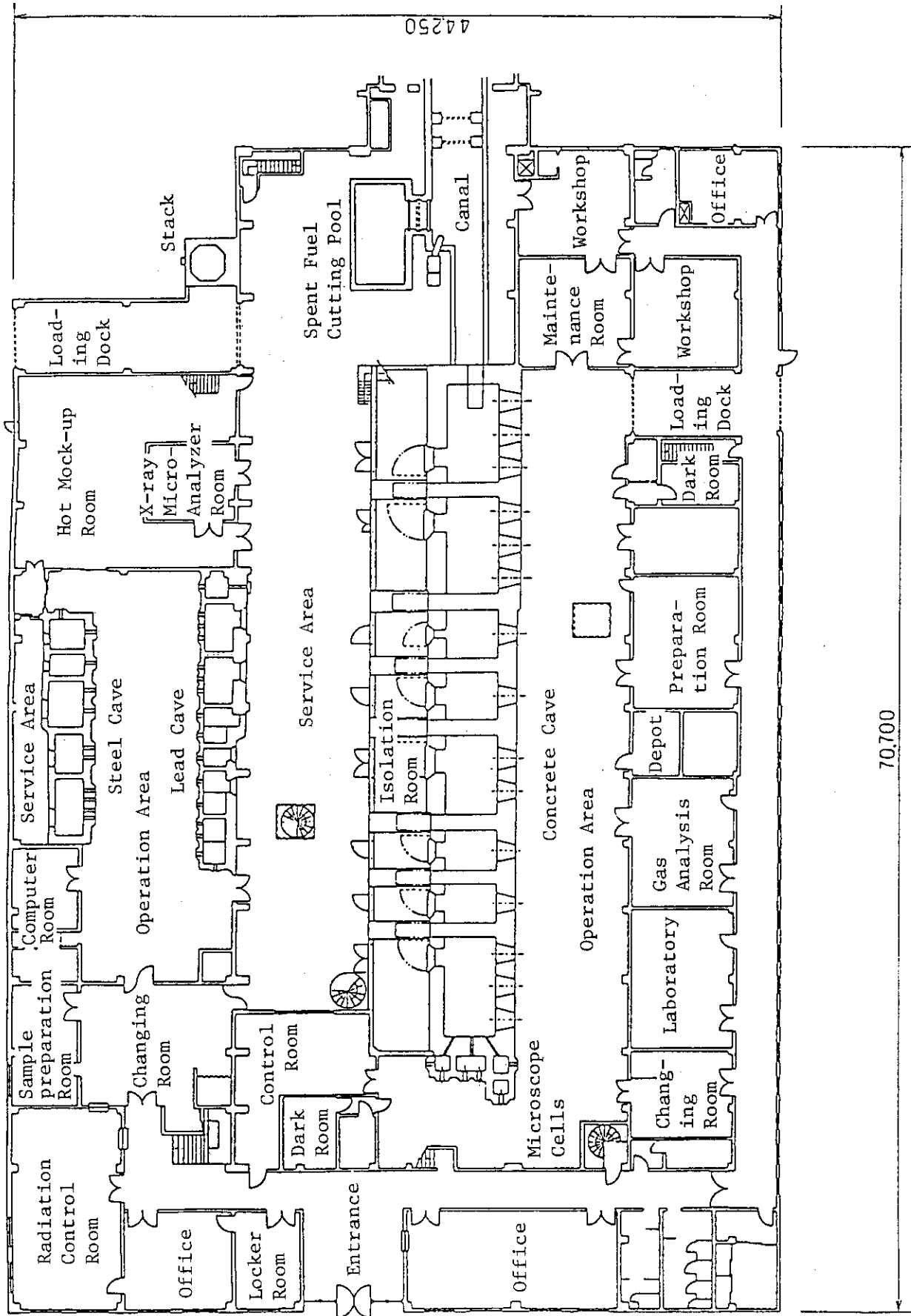


Fig. 9.4 Arrangement of JMTR Hot Laboratory

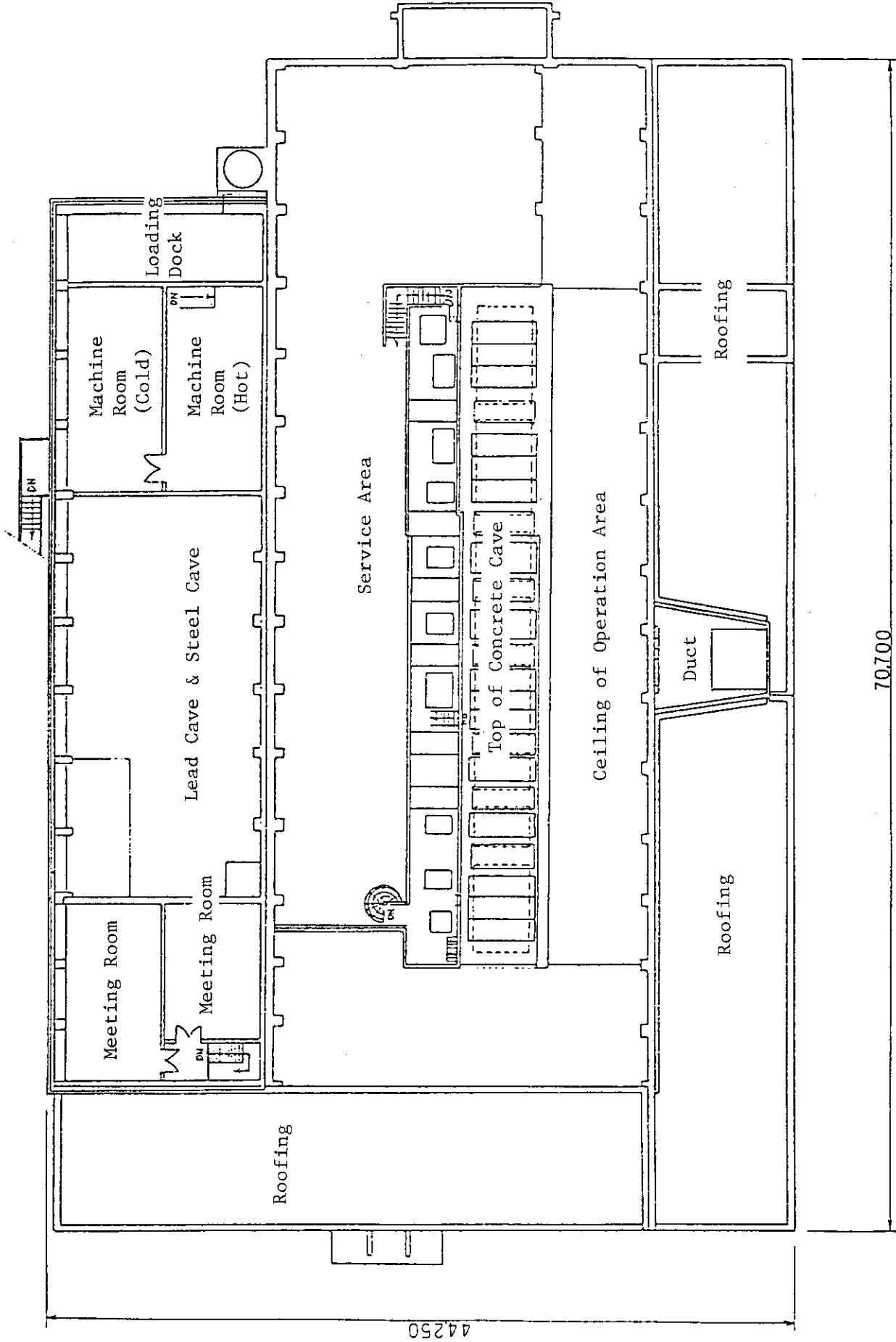


Fig. 9.5 Arrangement of 2nd Floor

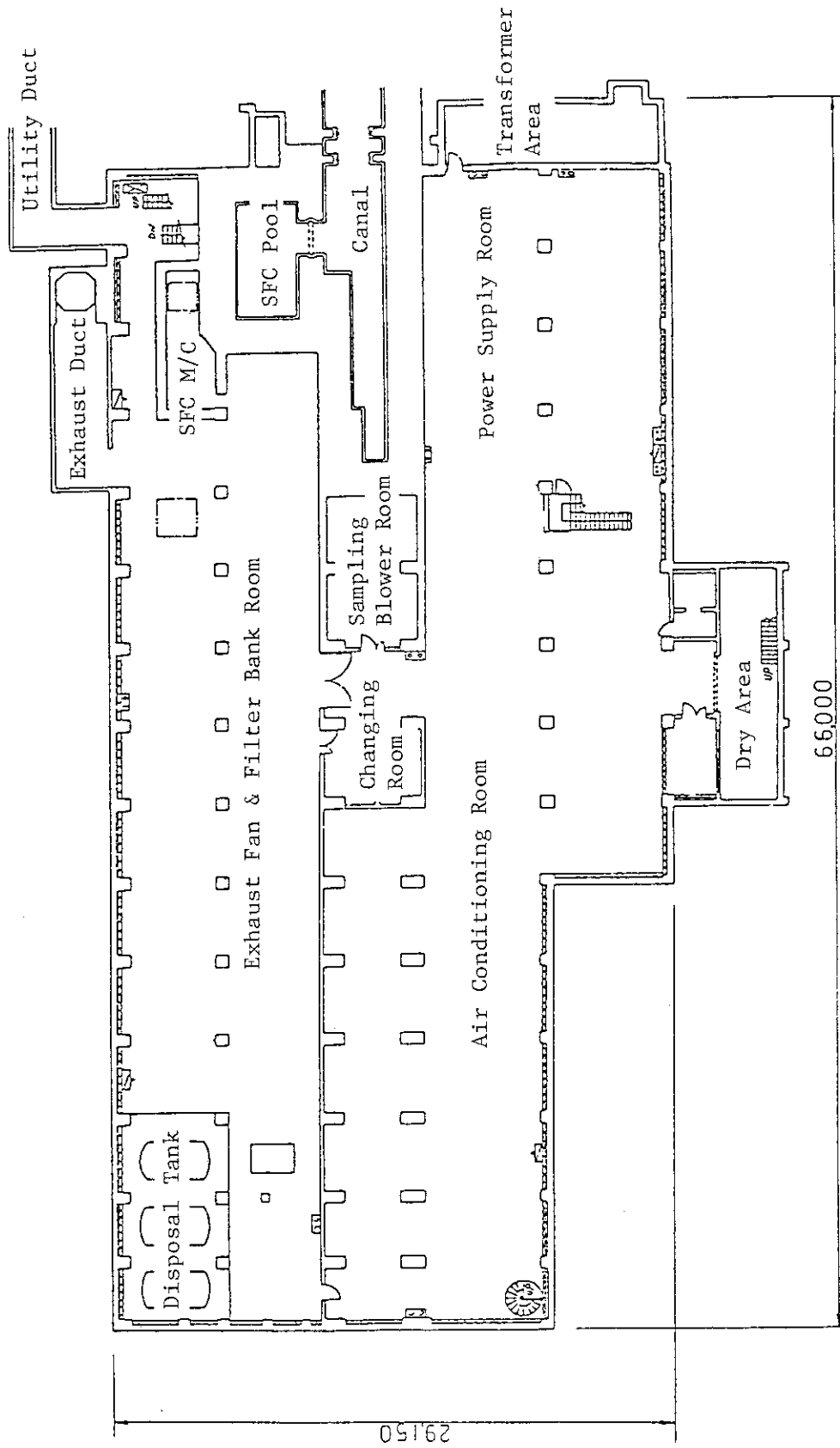


Fig. 9.6 Arrangement of Basement Floor

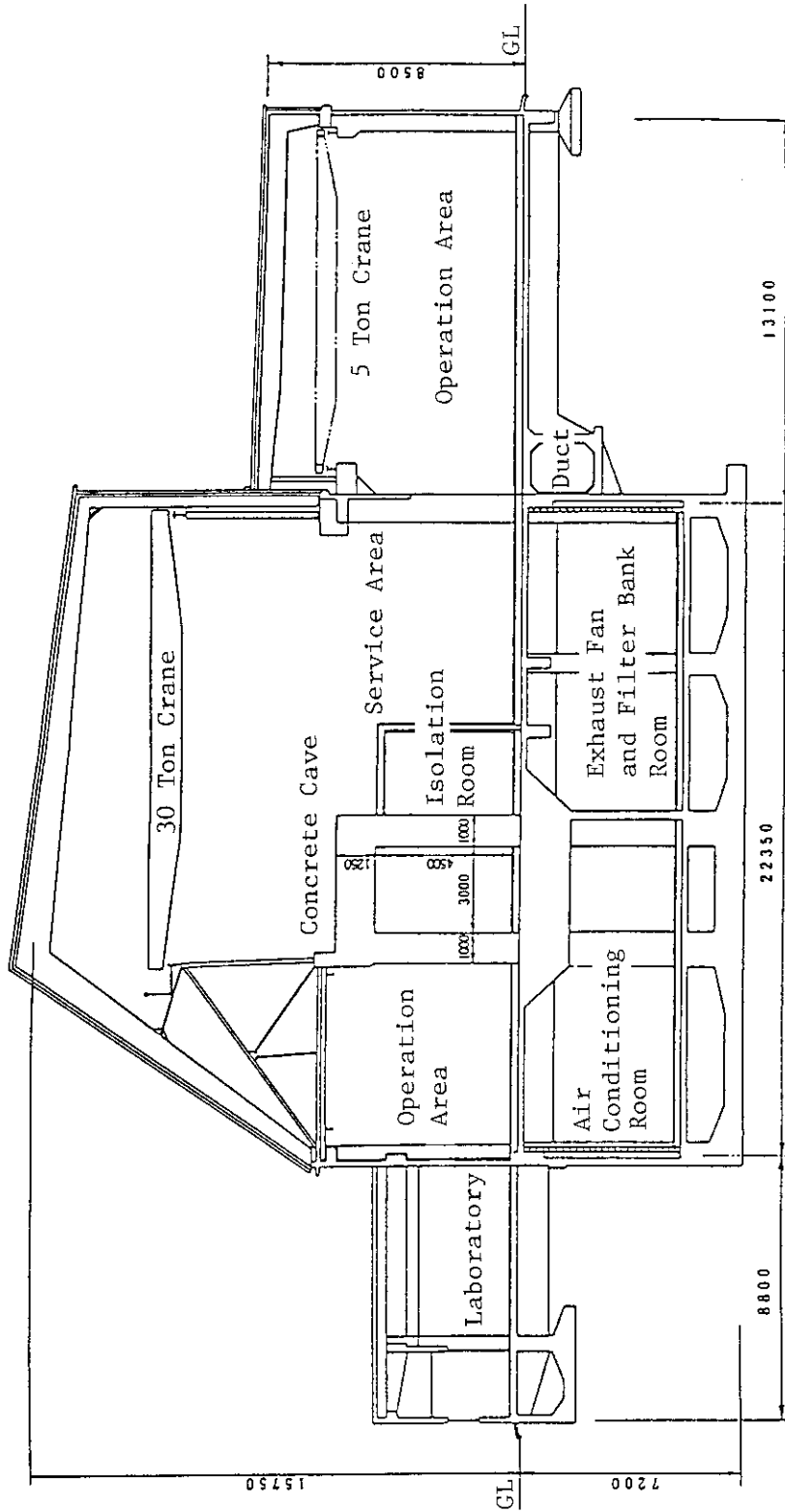


Fig. 9.7 Cross Sectional View of JMTR Hot Laboratory

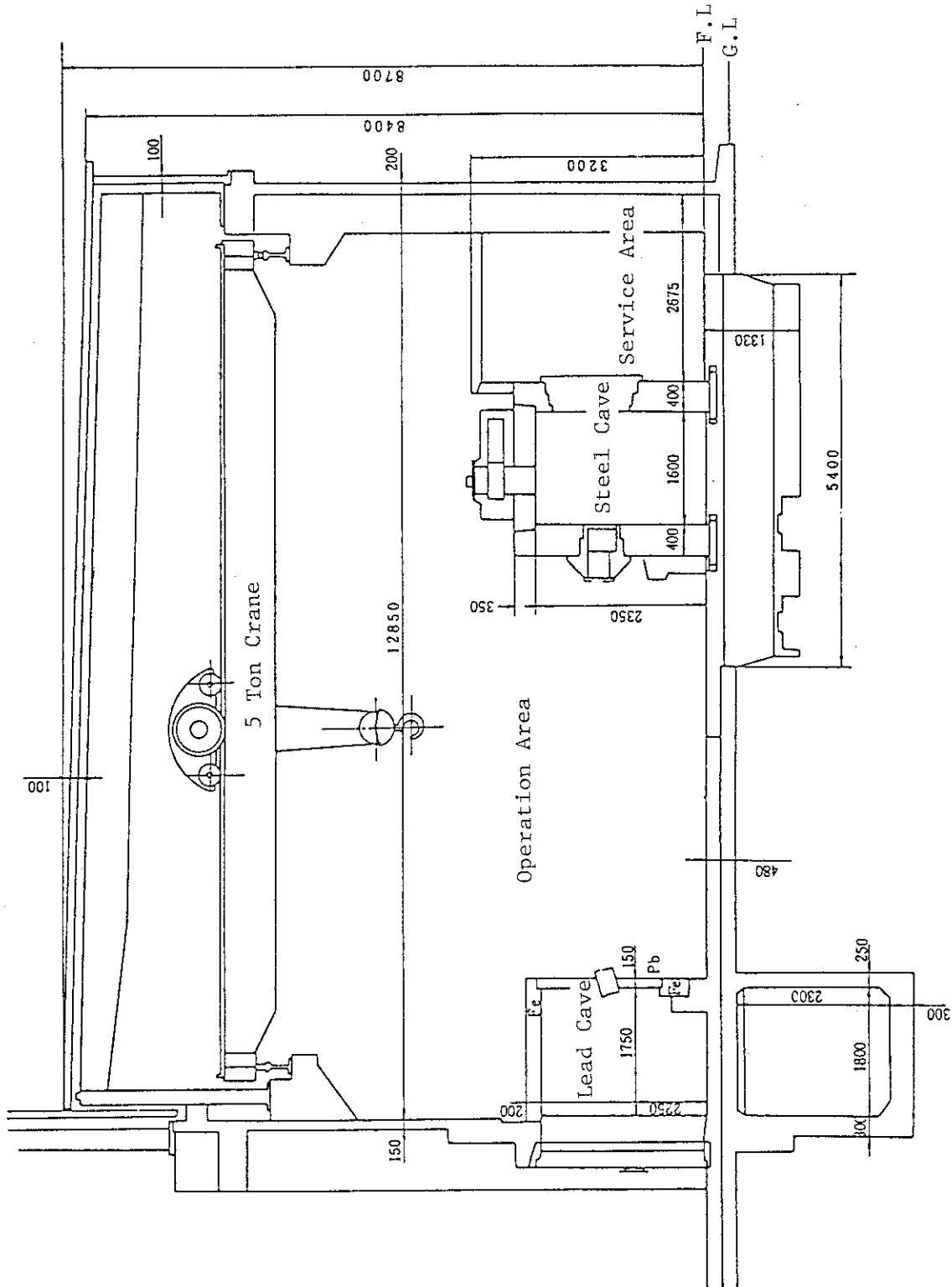


Fig. 9.8 Cross Sectional View of Operation Area installed Lead Cave and Steel Cave

Table 9.1 Specifications of Concrete Cells and Microscope Cells

| Concrete Cell | Inside Dimension W×D×H (m) | Shielding Wall Thickness and Density | | Number of Window | Maximum Activity (Ci) (1 MeV) |
|---------------|----------------------------------|---|------------|---------------------|--|
| | | (m) | (ρ) | | |
| 1 | 6 × 3 × 5.5 | 1.1 | >3.8 | 3 | 9×10^5 |
| 2 | 6 × 3 × 5.5 | 1.1 | >3.8 | 3 | 9×10^5 |
| 3 | 3 × 3 × 5.5 | 1.0 | >3.8 | 1 | 1×10^5 |
| 4 | 3 × 3 × 4.5 | 1.0 | >3.8 | 1 | 3×10^4 |
| 5 | 5 × 3 × 4.5 | 1.0 | >3.8 | 2 | 3×10^4 |
| 6 | 2.5 × 3 × 4.5 | 1.0 | >3.1 | 1 | 2.3×10^3 |
| 7 | 2.5 × 3 × 4.5 | 1.0 | >3.1 | 1 | 2.3×10^3 |
| 8 | 6 × 3 × 4.5 | 1.0 | >3.1 | 3 | 2.3×10^3 |
| | | | | | |
| Lead Box | (m) | (cm) | | | |
| 1 | 1 × 1 × 1.1 | 17.8 | Lead | 1 | 100 |
| 2 | 1 × 0.85 × 1.1 | 17.8 | " | 1 | 100 |
| 3 | 1.59 × 1 × 1.1 | 17.8 | " | 2 | 100 |
| 4 | 1.5 × 1 × 0.95 | 17.8 | " | 2 | 100 |

Table 9.2 Specifications of Lead Cells

| Cell | Inside Dimension W × D × H (m) | Shield Wall Thickness (cm) | Number of Window | Maximum Activity (Ci) Equivalent Co-60 |
|------|--------------------------------------|-------------------------------|------------------|---|
| 1 | 1.5 × 1.3 × 1.95 | 20 | 1 | 35 |
| 2 | 2.9 × 1.75 × 2.25 | 15 | 3 | 1 |
| 3 | 2.9 × 1.75 × 2.25 | 15 | 3 | 1 |
| 4 | 1.2 × 1.75 × 1.8 1.2 × 1.25 × 1.8 | 15 | 2 | 1 |
| 5 | 1.2 × 1.25 × 1.8 | 15 | 1 | 1 |
| 6 | 2.8 × 1.25 × 1.8 | 15 | 2 | 1 |
| 7 | 2.75 × 1.25 × 1.8 | 15 | 4 | 1 |

Table 9.3 Specifications of Steel Cells

| Cell | Inside Dimension W × D × H (m) | Shield Wall Thickness (cm) | Number of Window | Maximum Activity (Ci) Equivalent Co-60 |
|------|--------------------------------------|-------------------------------|------------------|---|
| 1 | 2 × 1.7 × 2.4 | 35 | 1 | 18 |
| 2 | 1.3 × 1.6 × 2.35 | 40 | 1 | 160 |
| 3 | 3.2 × 1.7 × 2.4 | 35 | 2 | 18 |
| 4 | 2.2 × 1.25 × 2.4 | 35 | 2 | 18 |
| 5 | 4 × 1.25 × 2.4 | 35 | 4 | 18 |

Table 9.4 Capacity of Remote Handling Device

| Remote Handling Device | Cells | Handling Capacity |
|--------------------------|--------------------|-------------------|
| Master-Slave Manipulator | | |
| Model 9 | C-1, 2, 4 cells | 13.6 kg |
| Model 8 (UD, UE, CRL) | C-1, C-3 ~ 8 cells | 5 kg |
| Model 7 (HB) | L-1 ~ 7 cells | 5 kg |
| Model G | S-1 ~ 3 cells | 4.5 kg |
| Model MA 11/80 | S-1, 4, 5 cells | 7 kg |
| Ball Socket Manipulator | L-5 ~ 7 cells | 1.3 kg |
| | M-1 ~ 4 cells | 1.3 kg |
| Power Manipulator | | |
| TP 5 | C-1, 2 cells | 50 kg |
| TP 6 | C-3 ~ 8 cells | 25 kg |
| In-Cell Hoist | | |
| TH-3 | C-1 ~ 3 cells | 2.5 ton |
| TH-5 | C-4 ~ 8 cells | 1 ton |

C : Concrete cells

L : Lead cells for materials test

S : Steel cells for materials test

M : Microscope cells

Table 9.5 Operation and Apparatus of Concrete Cells

| Cell | Operation | Apparatus |
|--------------------|--|--|
| Concrete Cell 1 | Loading, Unloading Optical viewing Dose measurement Assembling of fuel rod Assembling of capsule | Loading lift, Loading cask Periscope, View camera, Panorama camera Dose measuring device Welding machine End-plug tightner, Shielding container |
| Cell 2 | Dismantling of capsule, Waste disposal | Milling machine, Hacksaw, Diamond cutter |
| Cell 3 | X-ray radiography Gamma scanning Optical viewing | X-ray radiography system Gamma scanning system Stereoscope |
| Cell 4 | Eddy current test Gap measurement Dismantling of NaK capsule | Eddy current tester Gap measuring Apparatus Cutter, NaK treatment bath |
| Cell 5 | Dimension measurement Leak test Fission gas collection Preparation for XMA sample | Demension measurement apparatus, Linear scale Leak locator Rod puncture device, Gas collector Vacuum evaporator |
| Cell 6 | Weight and density measurement | Balance and densimeter |
| Cell 7 | Preparation for metallography | Micro-cutter, Vacuum impregnation device |
| Cell 8 | Preparation for metallography | Grinding polisher, Vibratory polisher, Electrolitic etcher, Ultrasonic cleaner, Stereoscope |

Table 9.6 Operation and Apparatus of Microscope Cells

| Cell | Operation | Apparatus |
|------------|----------------------|-------------------------------|
| Microscope | | |
| Cell 1 | Metallography | Microscope |
| Cell 2 | Metallography | Microscope |
| Cell 3 | Metallography | Low-magnification microscope |
| | Hardness test | Micro-Vickers hardness tester |
| Cell 4 | Micro gamma scanning | Micro gamma scanning system |

Table 9.7 Operation and Apparatus of Lead cells
and Steel Cells

| Cell | Operation | Apparatus |
|--------|---|--|
| Lead | | |
| Cell 1 | Specimen storage Specimen classification | Storage pits Periscope |
| Cell 2 | Tensile and compression test Impact test | Instron-type tensile tester, High temperature vacuum furnace Charpy impact tester |
| Cell 3 | Tensile and compression test Instrumented impact test | Instron-type tensile tester, Furnace Charpy impact tester |
| Cell 4 | Heat treatment Dimension measurement | Vacuum furnace, Gas furnace Dimension measuring device |
| Cell 5 | Specimen preparation | |
| Cell 6 | Preparation for metallo- graphy | Grinding Polisher, Vibratory polisher, Electrolitic etcher, Ultrasonic cleaner, Microscope |
| Cell 7 | Hardness test Metallography | Vickers hardness tester, Micro-Vickers hardness tester Microscope |
| Steel | | |
| Cell 1 | Dimension measurement | Periscope, Dimension measuring device |
| Cell 2 | Specimen storage | Storage pits |
| Cell 3 | PCI/SCC test Electric resistance measure- ment | Tensile type tester Electric resistance measuring apparatus |
| Cell 4 | PCI/SCC test | Internal pressure type tester |
| Cell 5 | Under planning | |

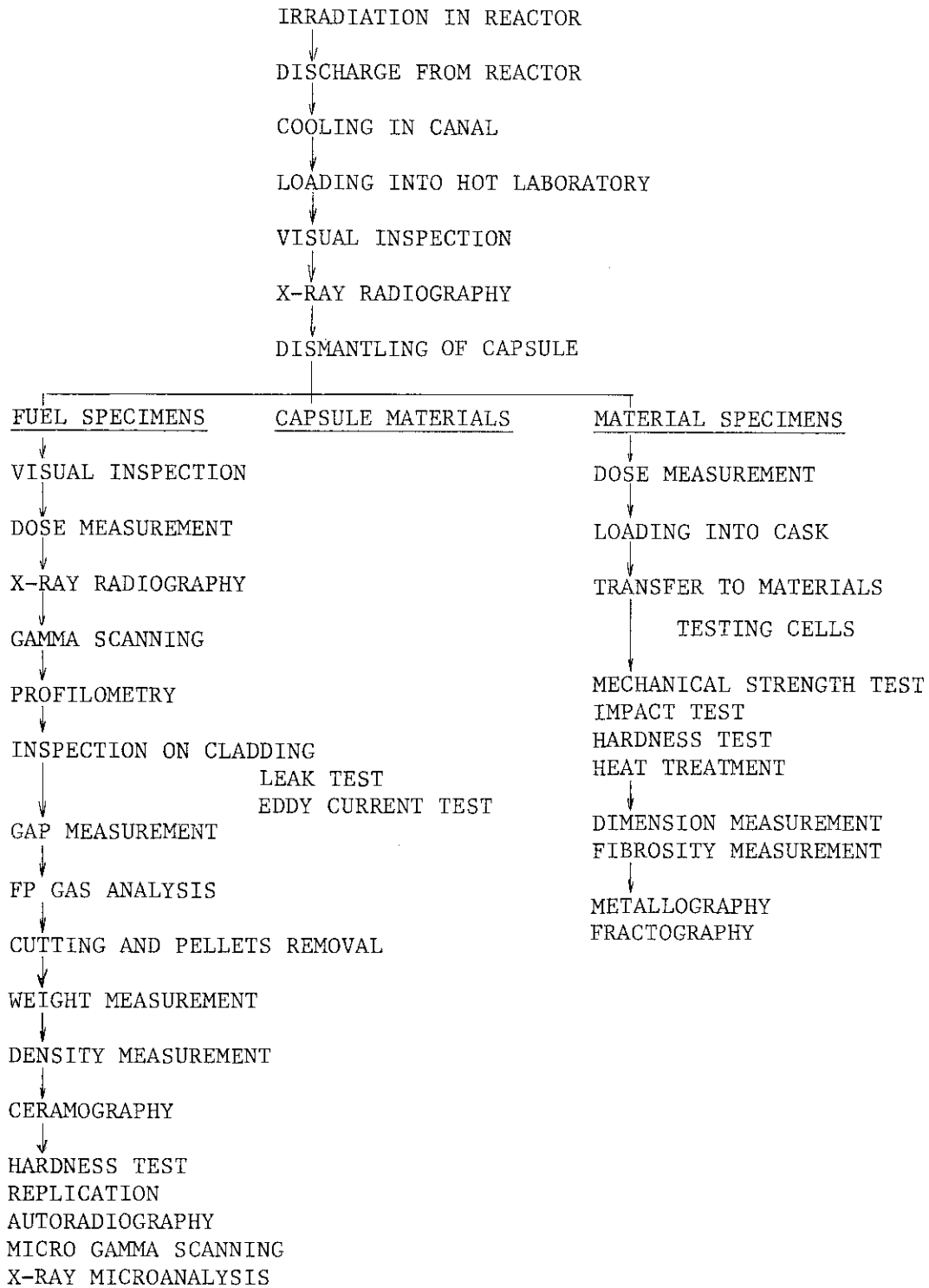


Fig. 9.9 Working Flow Diagram of PIE

Table 9.8 PIE of Fuel Specimen

| Examination | Apparatus | Specification |
|-------------------------------|------------------------------|--|
| 1. Optical Viewing | Periscope | Magnification $\times 2, \times 10$ |
| | Stereoscope | Magnification $\times 8 \sim 45$ (Zoom) |
| | View Camera | $f = 320, F = 5.6$ and $f = 640, F = 11$ Film $4" \times 5"$ |
| | Panorama Camera | Photograph of Cylindrical Specimen Surface |
| 2. Dose Measurement | RADOCN II, Model 555 | Dose $3 \text{ mR} \sim 10,000 \text{ R}$ Doserate $0.1 \text{ mR/min} \sim 1000 \text{ R/min}$ Energy $35 \text{ keV} \sim 1.2 \text{ MeV}$ |
| | IONEX Type 2500/3 | Dose $10 \text{ mR} \sim 1000 \text{ R}$ Doserate $0.1 \text{ mR/min} \sim 1000 \text{ R/min}$ Energy $40 \text{ keV} \sim 3 \text{ MeV}$ |
| 3. Dismantling of capsules | Milling Machine | Maximum Diameter 90 mm Maximum Length 800 mm Accuracy of Cutting 0.01 mm |
| | Pipe Cutter | Maximum Diameter 90 mm Minimum Length 70 mm Blade Width 1.5 mm |
| | Diamond Cutter | Maximum Diameter 60 mm Minimum Length 20 mm Blade Width 1.5 mm |
| | Hacksaw | Maximum Diameter 76 mm Minimum Length 30 mm Blade Width 0.6 mm |
| 4. Dismantling of NaK Capsule | Pipe Cutter in Kerosene Bath | Capsule Diameter $15 \sim 50 \text{ mm}$ Capsule Length $150 \sim 800 \text{ mm}$ |
| | NaK Treatment Bath | Capacity 13 l NaK Volume 200 cc |

| Examination | Apparatus | Specification |
|---------------------------|---|---|
| 5. X-ray Radiography | X-ray Apparatus for High Activity Specimen | 150 kVp X-ray Tube Small Focus 1.5 mm Max. 400 mA, 1.0 sec Large Focus 3 mm 300 kVp X-ray Tube Small Focus 1.5 mm Max. 4 mA continuous Large Focus 4 mm Film Size 140 mm × 990 mm |
| 6. Gamma Scanning | Scanner | Scanning Speed 5 ~ 250 mm/min Rod Fuel: Axial and Circumferential Movement Plate Fuel: X-Y Movement |
| | Collimator | Hole: 0.3, 0.75, 1.5 mmD Slit: 0.2 × 20 mm, 1 × 15 mm |
| | Multi-Channel Analyzer (CANBERRA 40) Computer (PDP11/23) | Data Memory 4096 Channel Storage Mode Pulse Height Analysis Multi-Channel Scaling CPU 128 KB Disk 1 MB × 2 Code SPECTRAN-F |
| 7. Micro Gamma Scanning | Scanner | Step-scanning: 0.25 mm |
| | Collimator | Hole 0.2 ~ 0.5 mmD |
| | Detector | Ge-NaI Anticoincidence Ge 50 cc, 2.5 keV |
| 8. Assembling of Fuel rod | Welding Machine | Current 0 ~ 300 A (Automatic Changeable) Welding Time 0.1 ~ 100 sec Pulse Ignition 0.1 ~ 1 sec |
| | Welding Chamber | Capacity 20 ℓ Sample Diameter PWR, BWR Seal Welding and Circumferential Welding |

| Examination | Apparatus | Specification |
|--|---|--|
| 9. Assembling of Boiling Water Capsule | End-Plug Tightener (with Helium Leak Test Chamber) | Torque 7 kg·m Tightening Distance 0.7 mm Dimension: Length 123 cm Width 60 cm |
| | Shielding Container (out of cell) | Capacity : 10,000 Ci Materials: Lead, Stainless Steel Lining Dimension: Length 903 cm Diameter 81 cm |
| | Transfer Carriage | Transfer on No.3 Canal Motor 200 V, 1.5 kW and 0.4 kW |
| 10. Dimension Measurement | Dimension Measuring Apparatus | Diameter Measurement Range 5 ~ 20 mm ϕ Accuracy ± 0.005 mm Bowling Measurement Range ± 3.0 mm Accuracy ± 0.02 mm Length Measurement Range 150 ~ 1000 mm Accuracy ± 0.05 mm Record Digital, Analogue, Floppy Disk |
| | Linear Scale | Whole Length Measurement Range 10 ~ 1000 mm Accuracy ± 0.02 mm |
| 11. Eddy Current Test | Fuel Cladding Tester | Cladding Diameter 4 ~ 17 mm Length 100 ~ 1000mm Test speed 5 ~ 30 mm/sec |

| Examination | Apparatus | Specification |
|------------------------|-------------------------|--|
| 11. | | Failure Detection Coil Encircling and Probe Frequency (kHz) 16, 32, 64, 128, 256, 512, 1024 Detection Limit 5% of thickness, 0.1mmD Oxide Layer Measurement Coil Probe Frequency (kHz) 1024 Range 5 ~ 100 μ m Accuracy \pm 5 μ m |
| 12. Leak Test | Leak Locator | Cladding Diameter 5 ~ 20 mm Length 100 ~ 800 mm Vacuum Chamber filled with White Spirit Degree of Vacuum 1×10^{-2} Torr |
| | Helium Leak Detector | Detection Sensitivity 5×10^{-11} atm·cc/sec Measuring Range $10^{-6} \sim 6 \times 10^{-4}$ Torr Evacuation Speed (Rotary Pump) 300 ℓ /min |
| 13. Gap Measurement | Gap Measuring Apparatus | Cladding Diameter 5 ~ 20 mm Length 50 ~ 1000mm Residual Gap Measurement between Cladding and Pellet Gap Range 1 mm Accuracy \pm 5 μ m |
| 14. Weight Measurement | Mettler Balance | (1) Maximum Weight 160 g Accuracy \pm 0.0001 g (2) Maximum Weight 1200 g Accuracy \pm 0.01 g |

| Examination | Apparatus | Specification |
|---|---------------------------------------|--|
| 15. Density Measurement | Densimeter | Sample weight Max. 150 g Substitution Liquid Metaxylene Accuracy ± 0.01 g/cc |
| 16. Gas Volume and Pressure Measurement | Rod Puncture Device and Gas Collector | Rod Diameter 6.5 ~ 20 mm Length 30 ~ 1000 mm Vacuum Chamber $1 \sim 10^{-6}$ Torr |
| 17. Gas Analysis | Mass Spectrometer | Analyzing Element Kr, Xe, H ₂ , He, Ar, CH ₄ , N ₂ +CO, CO ₂ Isotopic Ratio of Kr and Xe Detection Limit 0.01 volume % |
| 18. Preparation for Metallography | Micro-Cutter | Maximum Diameter 32 mm Diamond Blade Width 0.6 mm Cutting Width 1 mm |
| | Grinding Polisher | 3 Sets Abrasive Paper #180 ~ #1000 |
| | Vibratory Polisher | 3 Sets Diamond Paste 7 ~ 1 μ m |
| | Electrolytic Etcher | LECTROPOL |
| | Ultrasonic Cleaner | Power 100 W Frequency 28 kHz |
| 19. Metallography and Ceramography | Microscope | Magnification $\times 50 \sim \times 900$ |
| | Low-magnification Microscope | Magnification $\times 5 \sim \times 10$ (Zoom) |
| 20. Autoradiography | High Resolution Plate | HRP 2" \times 2" |
| 21. Hardness Test | Micro-Vickers Hardness Tester | Load (g) 50, 100, 200, 500, 1000 Measuring Magnification $\times 400$ |
| | REICHERT Micro Hardness Tester | Load (g) 10 ~ 50 Measuring Magnification $\times 1000$ |

| Examination | Apparatus | Specification |
|--|---|---|
| 22. Electron-Probe Micro-Analysis (EPMA) | Shielded X-ray Micro-Analyzer | Acceleration Voltage 0 ~ 50kV Analyzing Element WDS ${}^5\text{B} \sim {}^{95}\text{Am}$ EDS ${}^{11}\text{Na} \sim {}^{95}\text{Am}$ |
| 23. Scanning Electron Micro- scopy (SEM) | | Scanning Image Secondary Electron Back Scattering Electron Absorbing Electron |
| 24. Shipping | Irradiated Fuel Shipping Cask (JMHL-78Y15T) | Type BM Capacity Uranium 2000 g Radioactivity $5.8 \times 10^4 \text{Ci}$ Dimension $2.0\text{m}^{\text{D}} \times 3.7\text{m}^{\text{L}}$ |
| | Radioisotope Shipping Cask (RIC-D-1501) | Type BM Capacity Ir 6,540 Ci P 188 Ci Dimension $1.3\text{m}^{\text{D}} \times 1.37\text{m}^{\text{L}}$ |

Table 9.9 PIE of Materials

| Examination | Apparatus | Specification |
|---|--|---|
| 1. Tensile Test 2. Compression Test 3. Bend Test 4. Fracture Toughness Test | Instron-type Tensile Tester with High Temperature Furnace | Capacity 10 Ton Test Speed 0.05 ~ 50 mm/min (1) Furnace R.T. ~ 800°C (2) Vacuum Furnace 400 ~ 1300°C 7×10^{-8} Torr |
| 5. Impact Test | Charpy Impact Tester | Capacity 30 kg-m Temperature -197°C, -120 ~ 200°C Instrumented Tester |
| 6. PCI/SCC Test | Tensile Type Tester | Capacity 5 Ton Atmosphere Iodine Temperature R.T. ~ 300°C Test Speed 0.05~500 mm/min. |
| | Internal Pressure Type Tester | Maximum Pressure 450 kg/cm ² G Internal Gas Ar + Iodine Temperature R.T. ~ 500°C Constant and Cyclic Pressure |
| 7. Heat Treatment | Gas Furnace | Temperature 100 ~ 800°C |
| | Vacuum Furnace | Temperature 450 ~ 1200°C Degree of Vacuum 1×10^{-5} Torr |
| 8. Dimension Measurement (after Test) | Dimension Measuring Device | (1) Periscope and Pulse Encorder Measuring Range X-50 mm, Y-50 mm Accuracy 40 μm |
| | | (2) Periscope and Linear Scale (Pulse Encorder) Measuring Range X-100 mm, Y-50 mm Accuracy 20 μm |

| Examination | Apparatus | Specification |
|---|--|---|
| 9. Optical Viewing (after Test) | Periscope | Magnification $\times 1 \sim \times 5$ |
| 10. Preparation for Metallography | Grinding Polisher | 3 Sets Abrasive Paper #180 \sim #1000 |
| | Vibratory Polisher | 3 Sets Diamond Paste 7 \sim 1 μm |
| | Electrolytic Etcher | LECTROPOL |
| | Ultrasonic Cleaner | Power 100 W Frequency 28 kHz |
| 11. Metallography | Microscope | Magnification $\times 50 \sim \times 900$ |
| | Low-magnification Microscope | Magnification $\times 5 \sim \times 10$ (Zoom) |
| 12. Hardness Test | Vickers Hardness Tester | Load (kg) 1, 2, 5, 10, 20 Measuring Magnification $\times 130$ |
| | Micro-Vickers Hard- ness Tester | Load (g) 50, 100, 200, 500, 1000 Measuring Magnification $\times 400$ |
| | REICHERT Micro Hardness Tester | Load (g) 10 \sim 50 Measuring Magnification $\times 1000$ |
| 13. Electric Resistance Measurement | Electric Resistance Measuring Apparatus | Temperature $-190^{\circ}\text{C} \sim +150^{\circ}\text{C}$ (85 K \sim 423 K) |

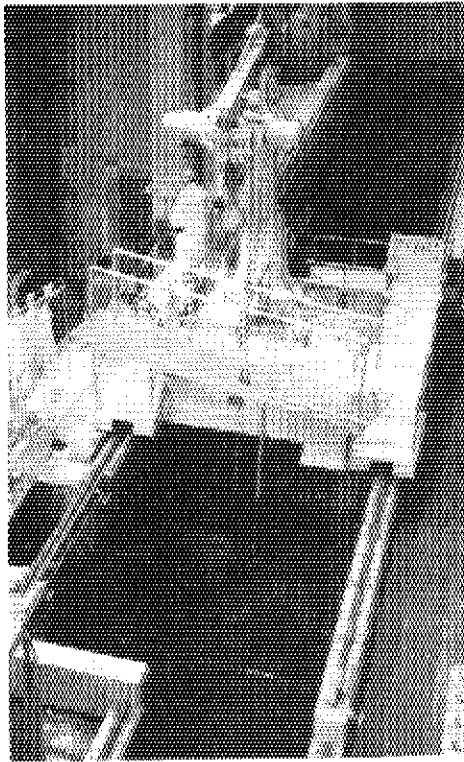


Fig. 9.10 Transfer Carriage
on Canal

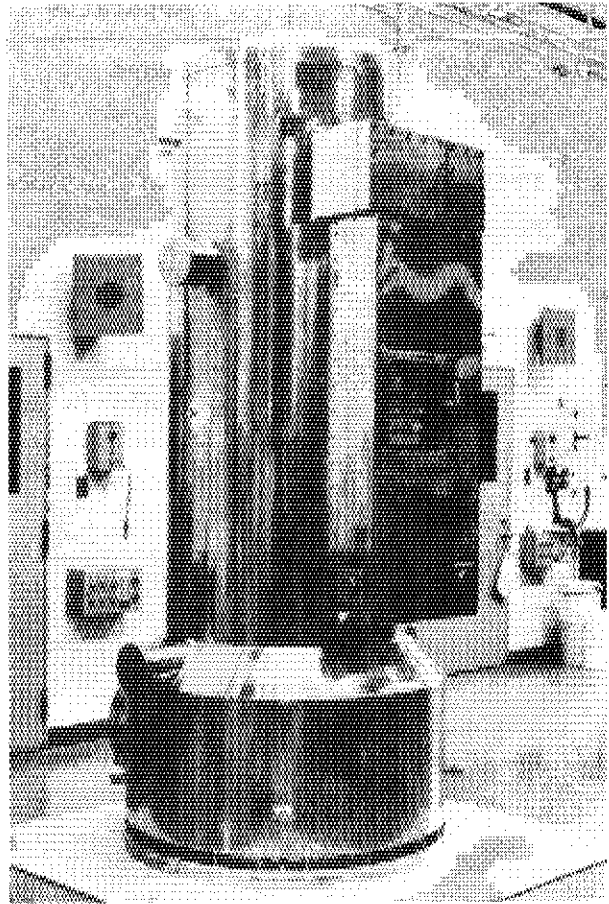


Fig. 9.11 Irradiated Fuel
Shipping Cask

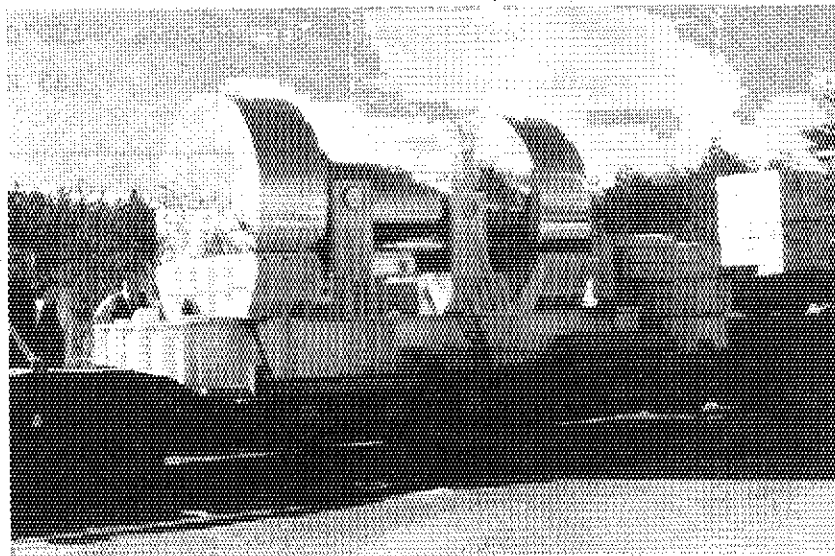


Fig. 9.12 Shipping Cask on Trailer

Fig. 9.13
Endplug Tightner
for Boiling Water
Capsule

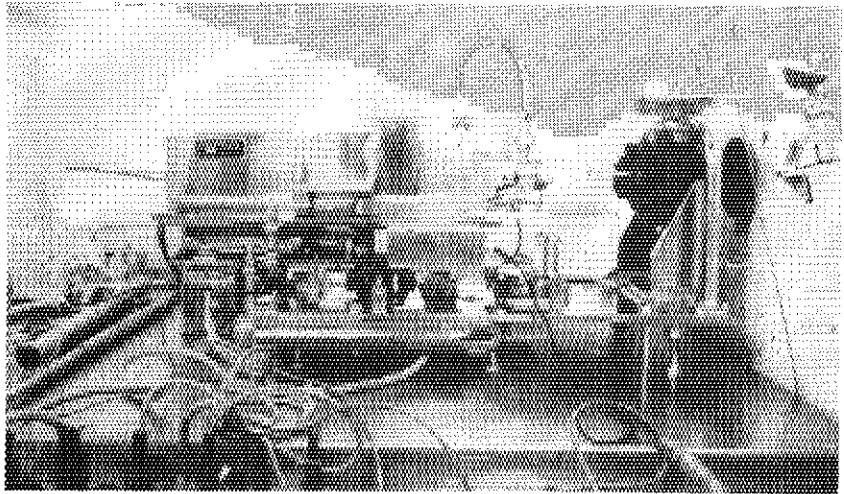


Fig. 9.14
Shielding Container
for Boiling Water
Capsule

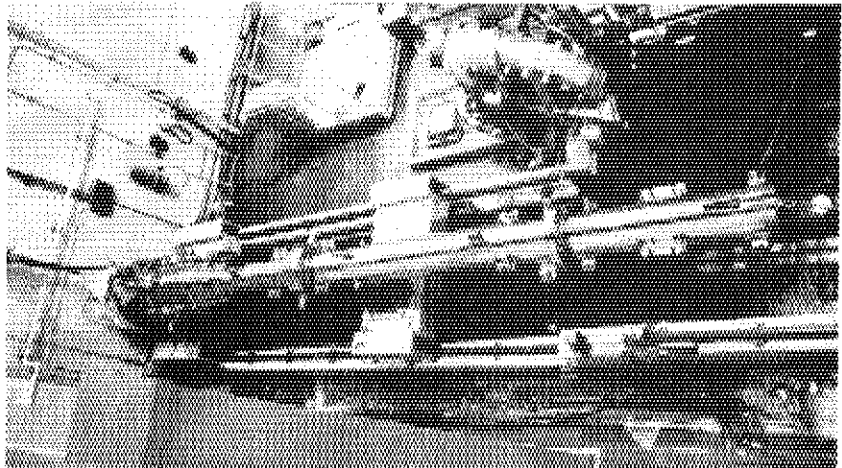
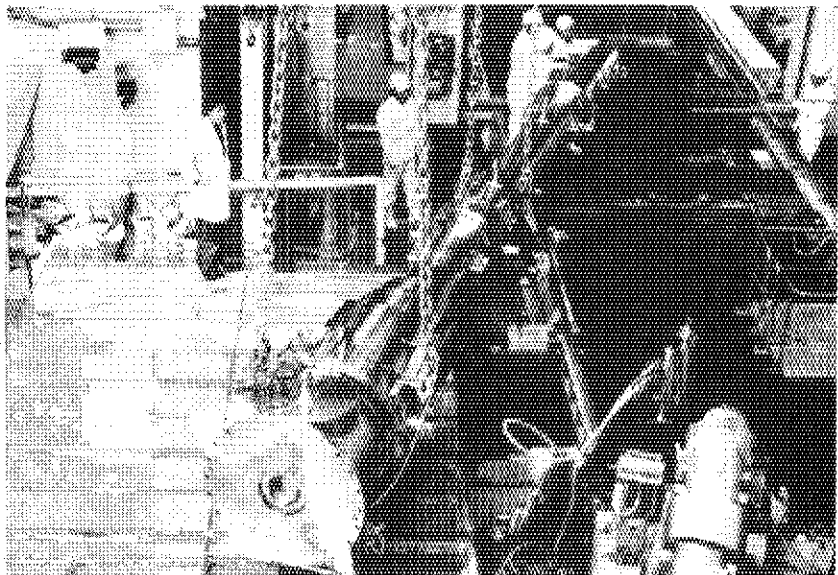


Fig. 9.15
Handling of
Shielding Container



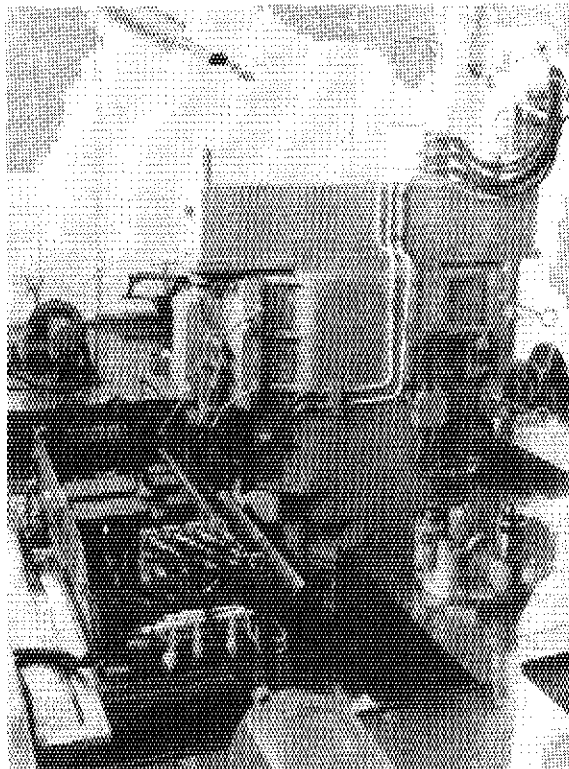


Fig. 9.16
Milling Machine
for Capsule Dis-
mantling

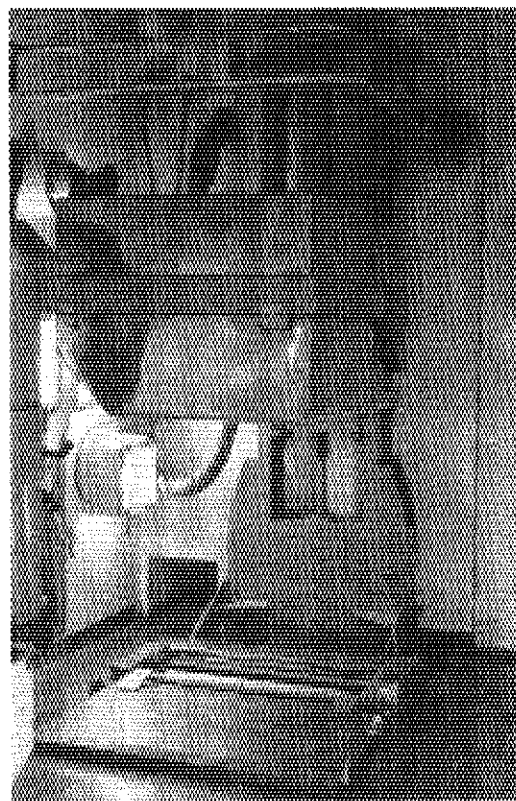
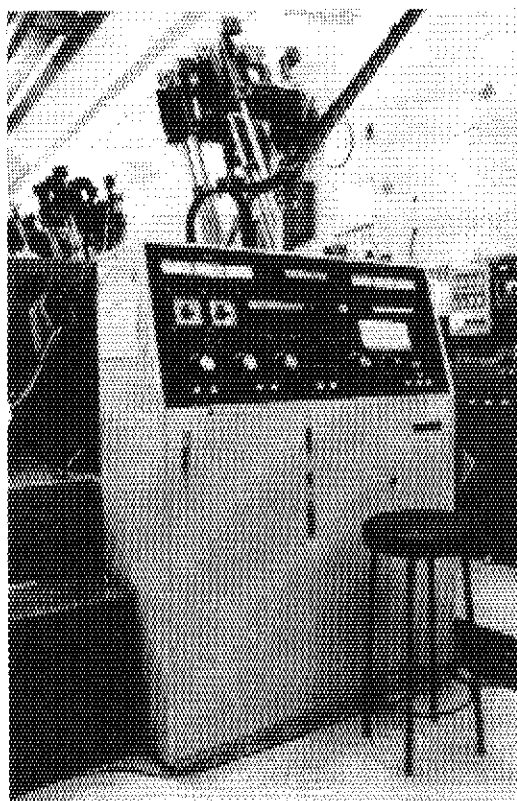


Fig. 9.17 X-ray Radiography System

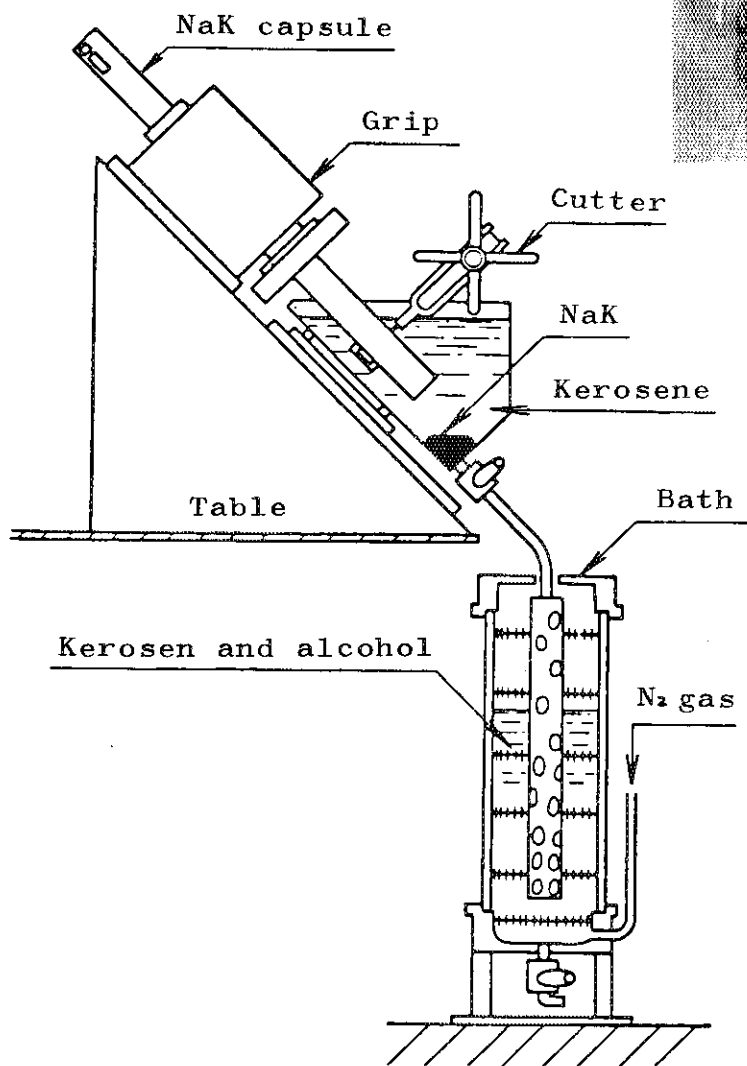
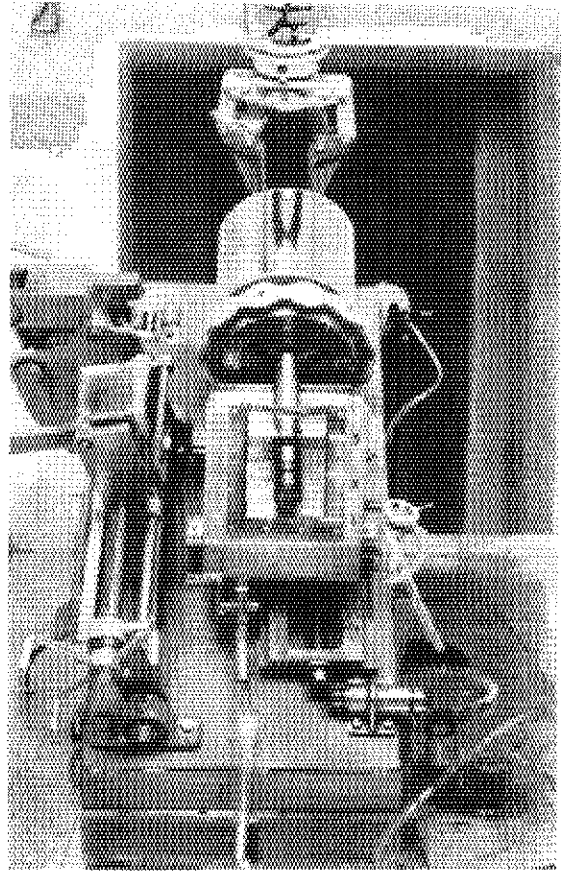


Fig. 9.18 Dismantling Apparatus for NaK Capsule

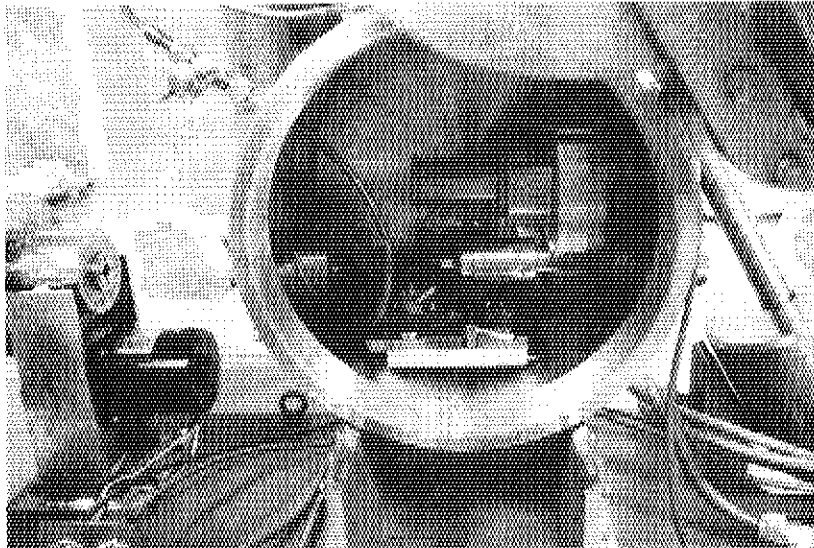
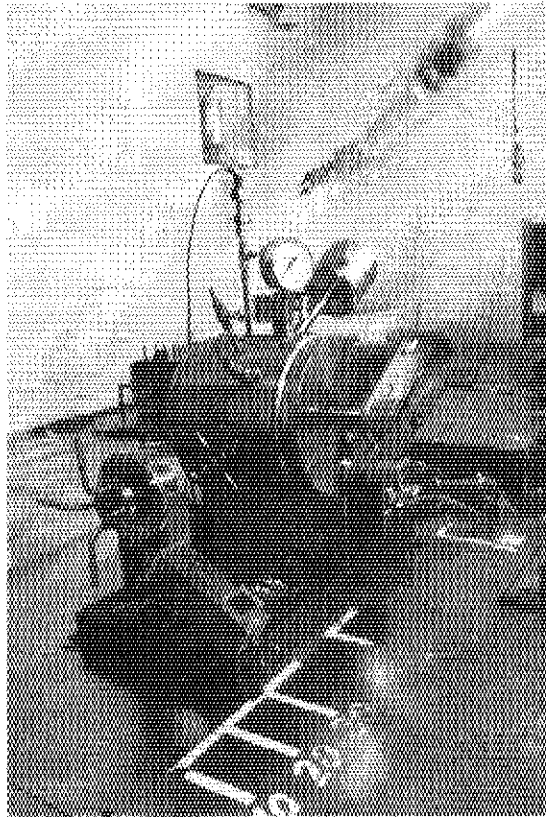
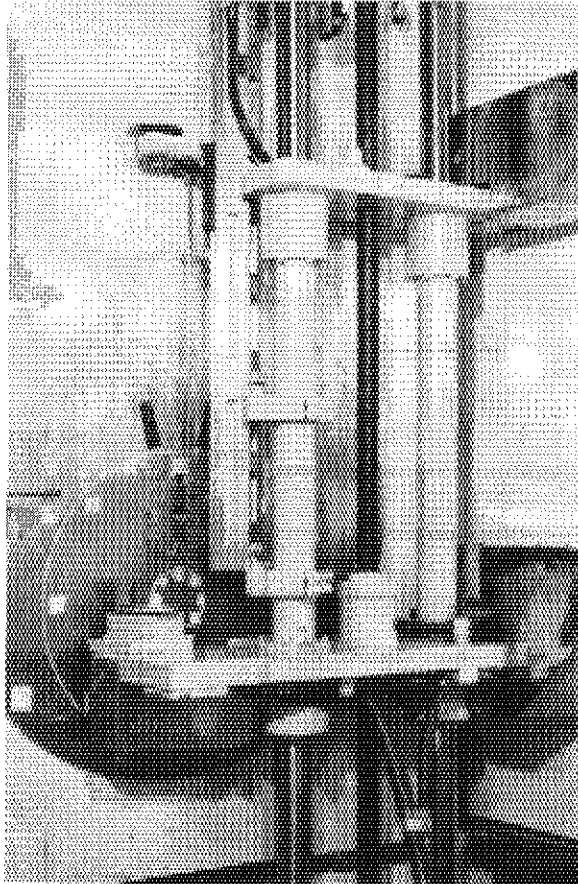


Fig. 9.19 Welding Machine for Fuel Rod



- 1 Fuel rod specimen
- 2 Fuel assembly (or fuel plate)
- 3 Collimator (hole, slit)
- 4 Ge detector
- 5 Lead shield
- 6 Pre-amplifier

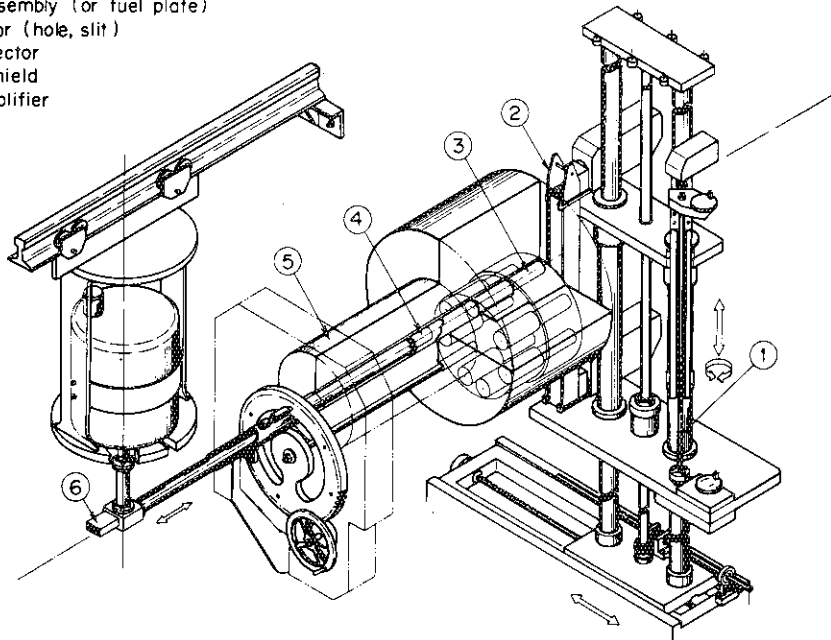


Fig. 9.20 Gamma Scanning System

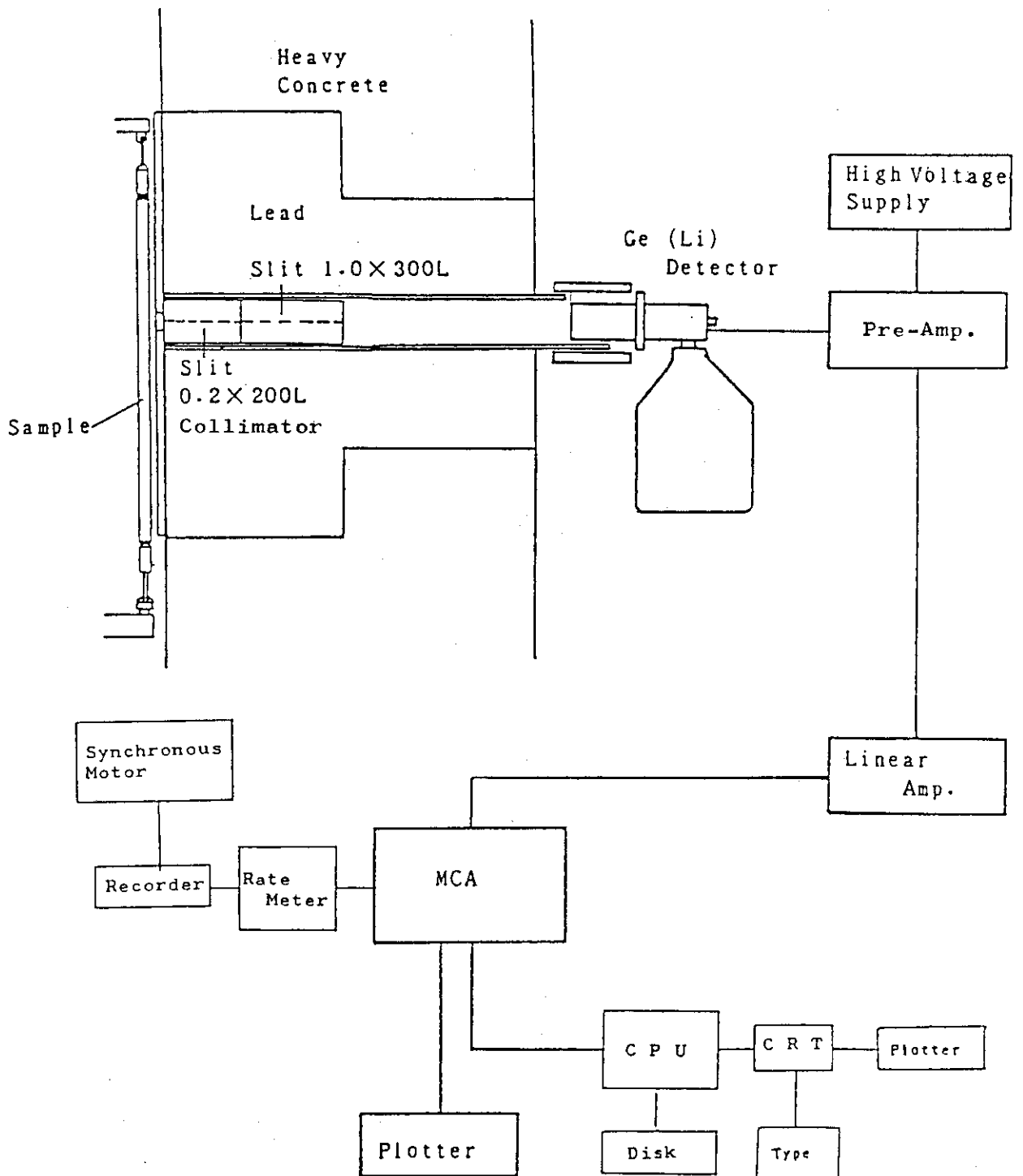


Fig. 9.21 Gamma scanning system for the fuel rod

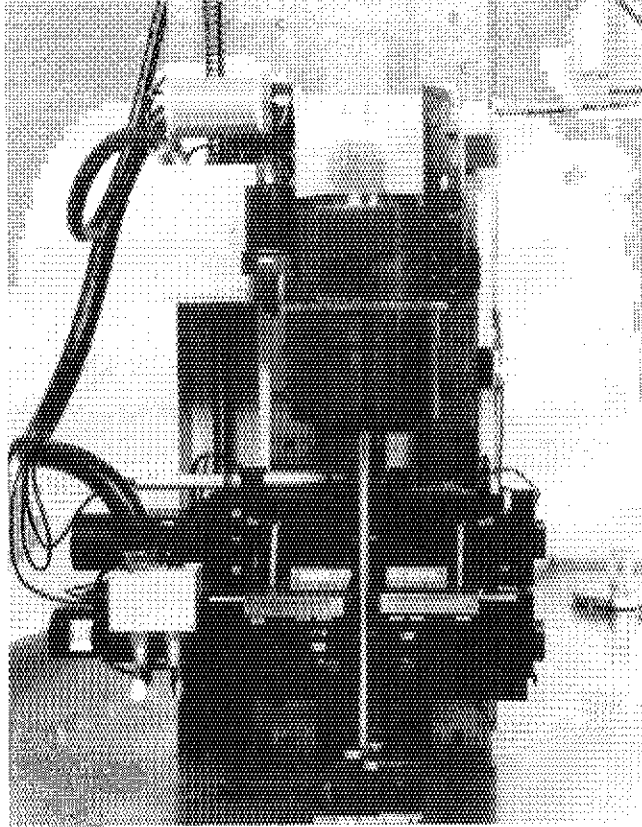


Fig. 9.23 Dimension Measuring Apparatus

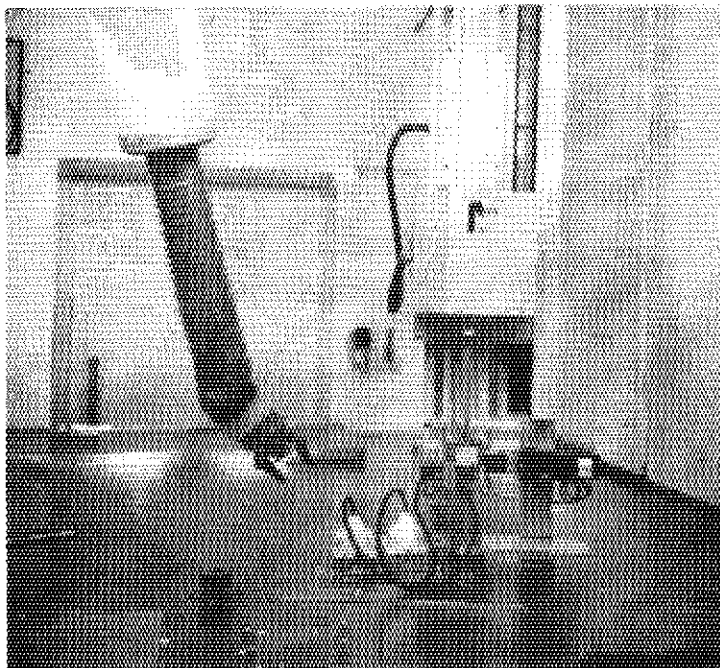


Fig. 9.22 Eddy Current Tester

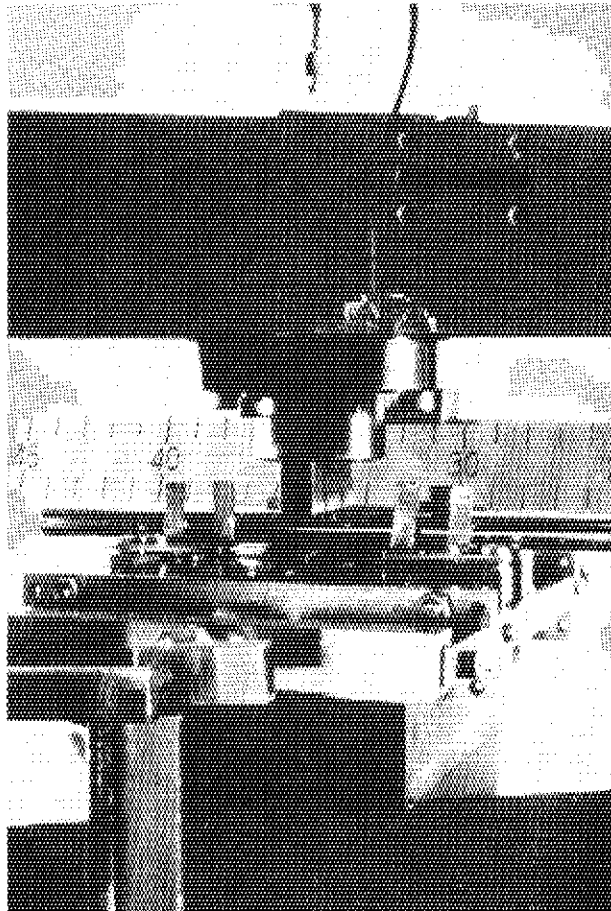
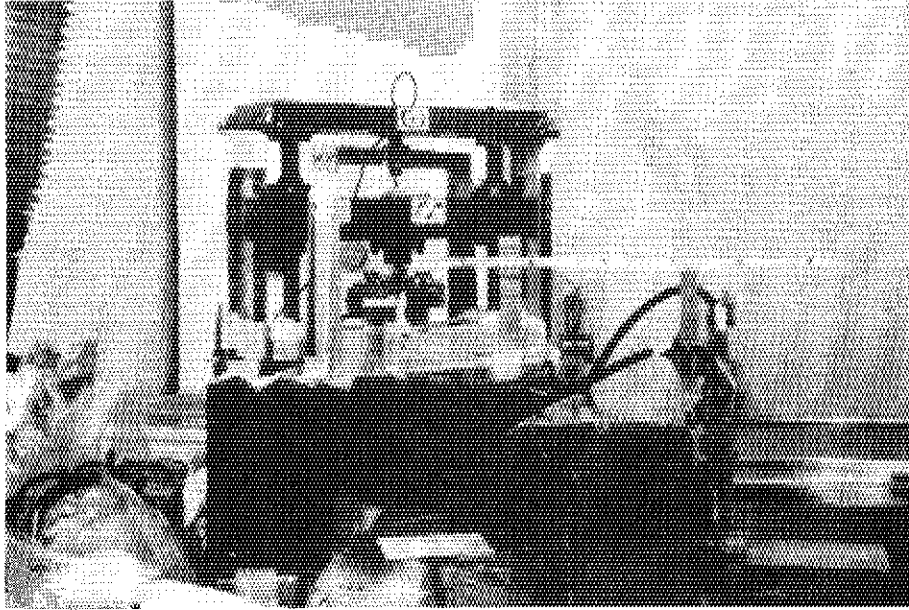


Fig. 9.24 Gap Measuring Apparatus

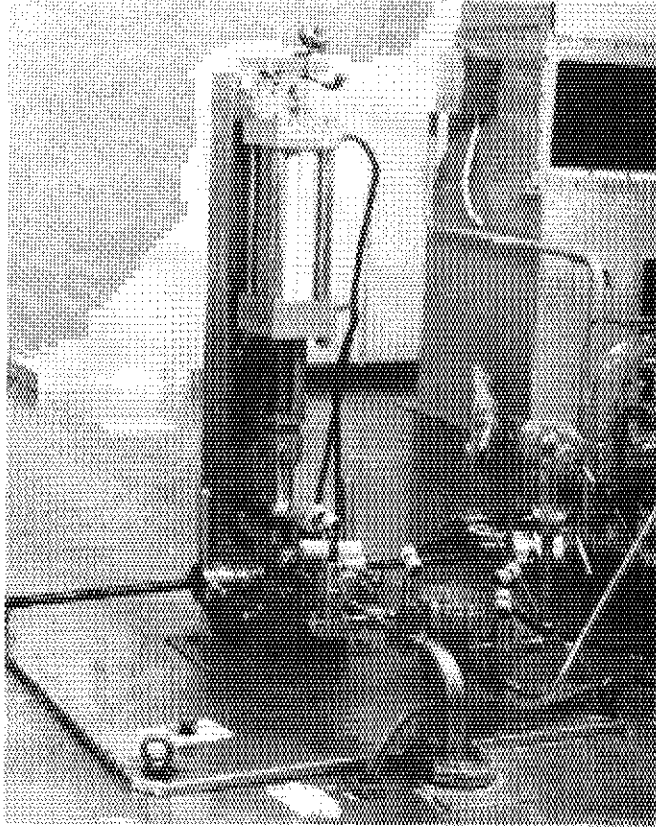


Fig. 9.25 Rod Puncture Device

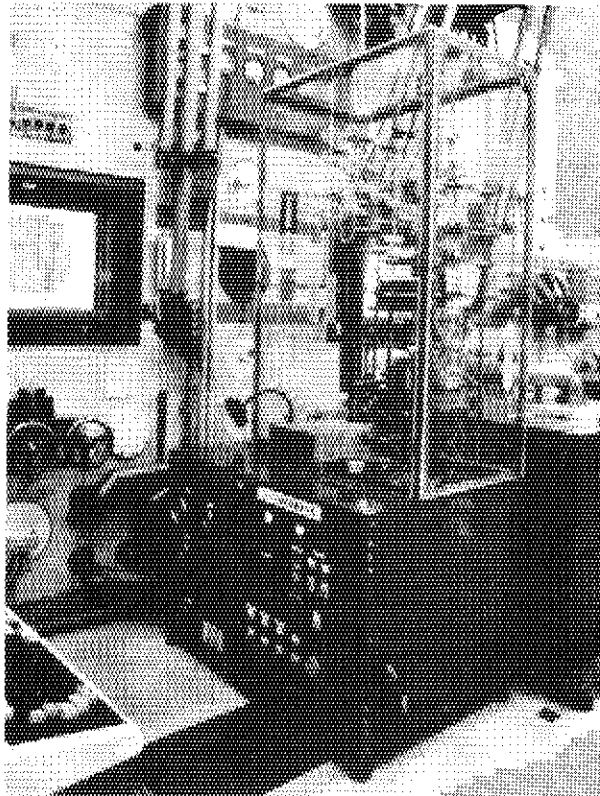
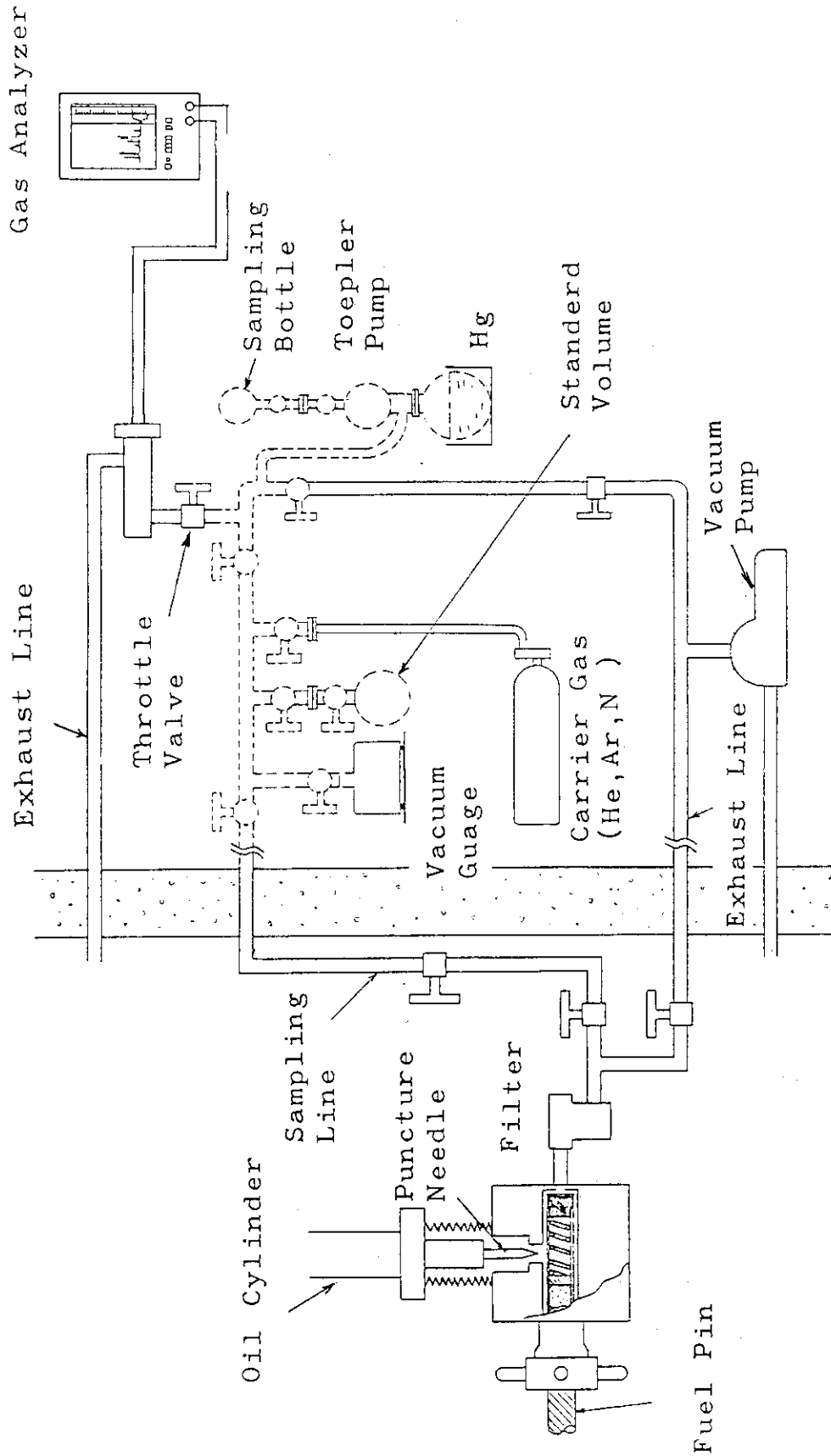


Fig. 9.26 Fission Gas Collector



Note: Dotted line shows the parts made of glass.

Fig. 9.27 FP Gas Sampling of Fuel Pin

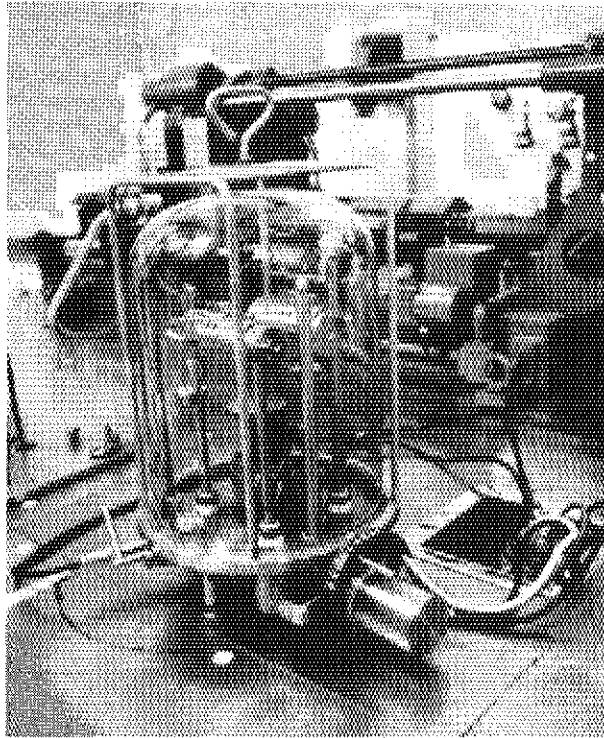


Fig. 9.28 Vacuum Evaporator for XMA Specimen

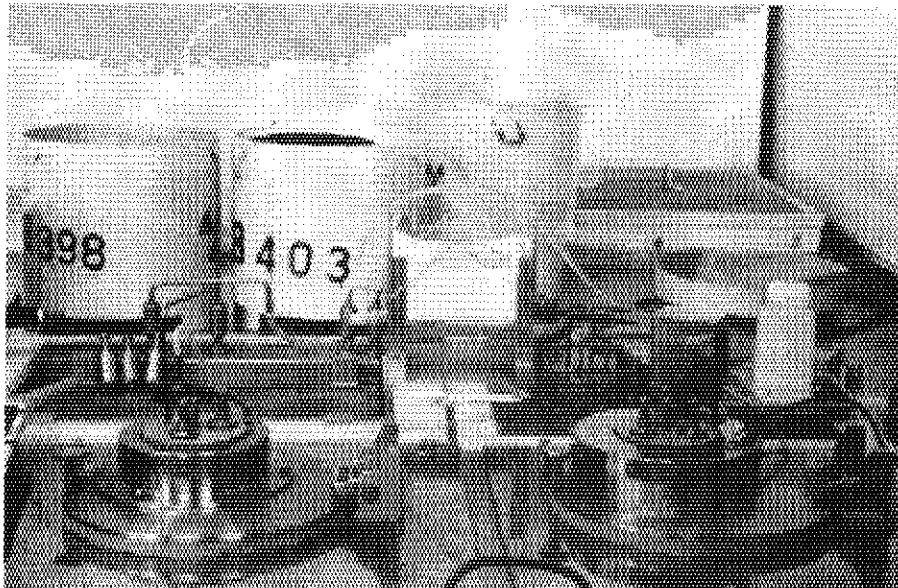


Fig. 9.29 Rotary Polisher for Metallographic Specimen

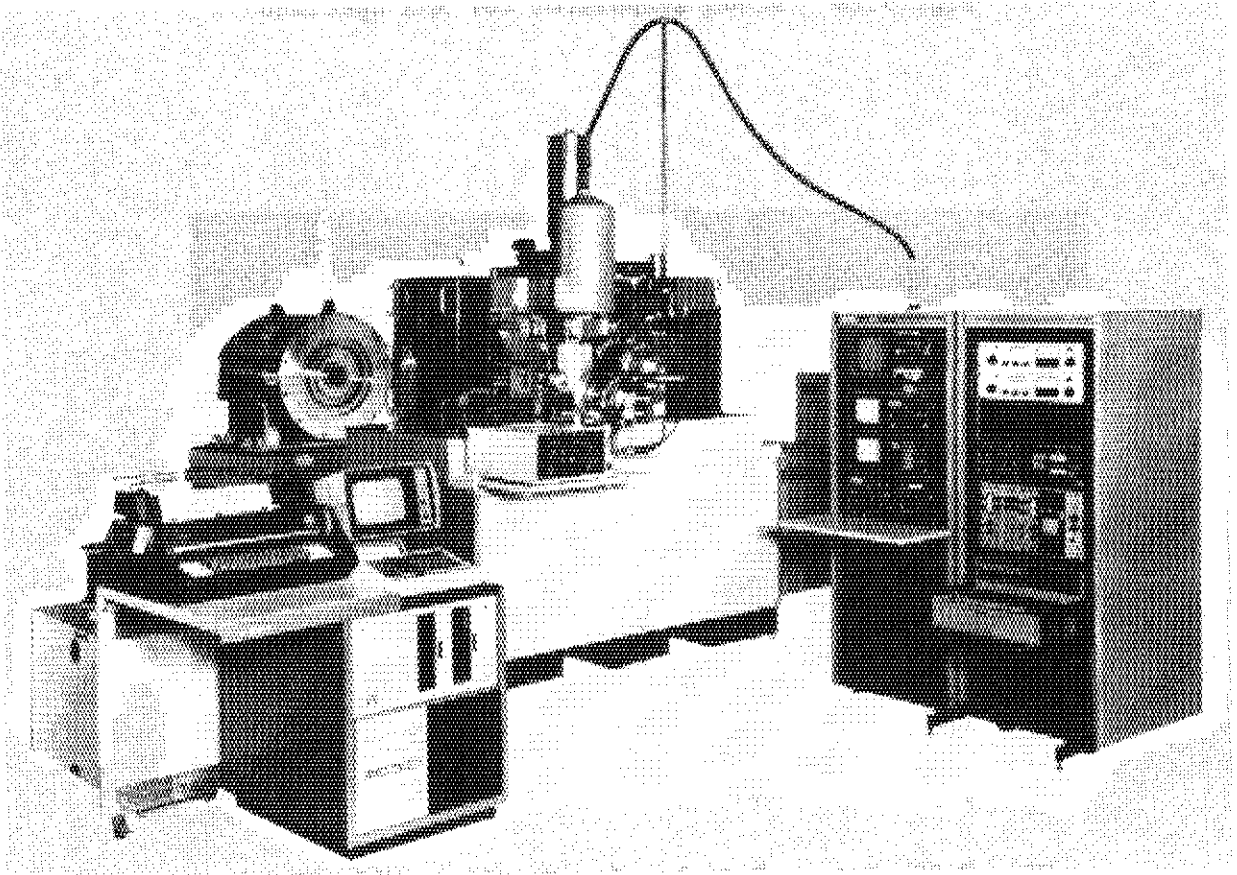
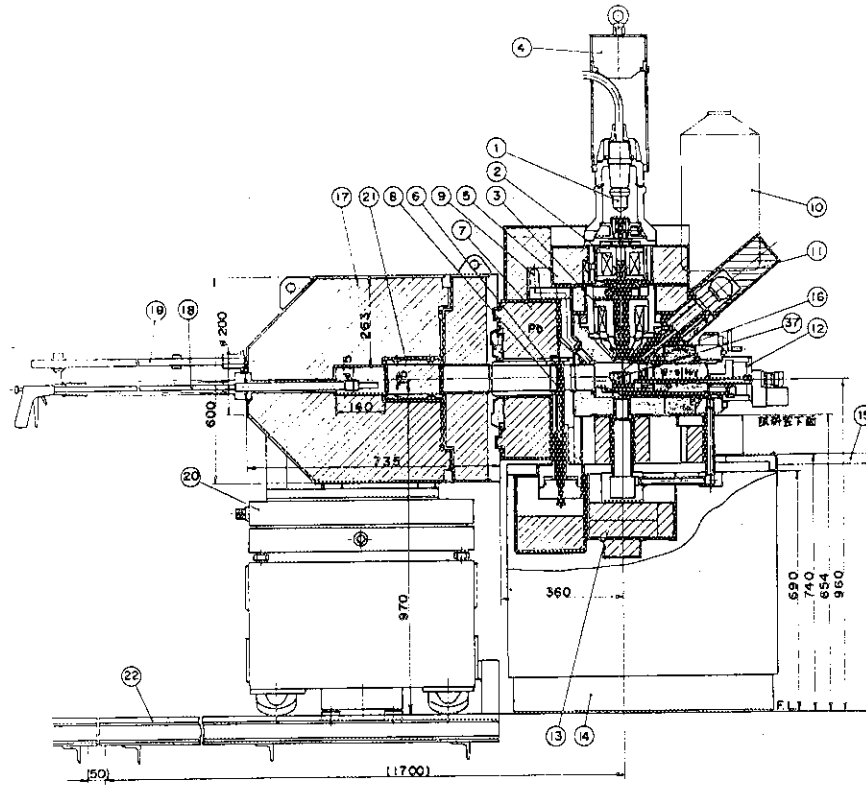


Fig. 9.30 Shielded X-ray Micro-Analyzer

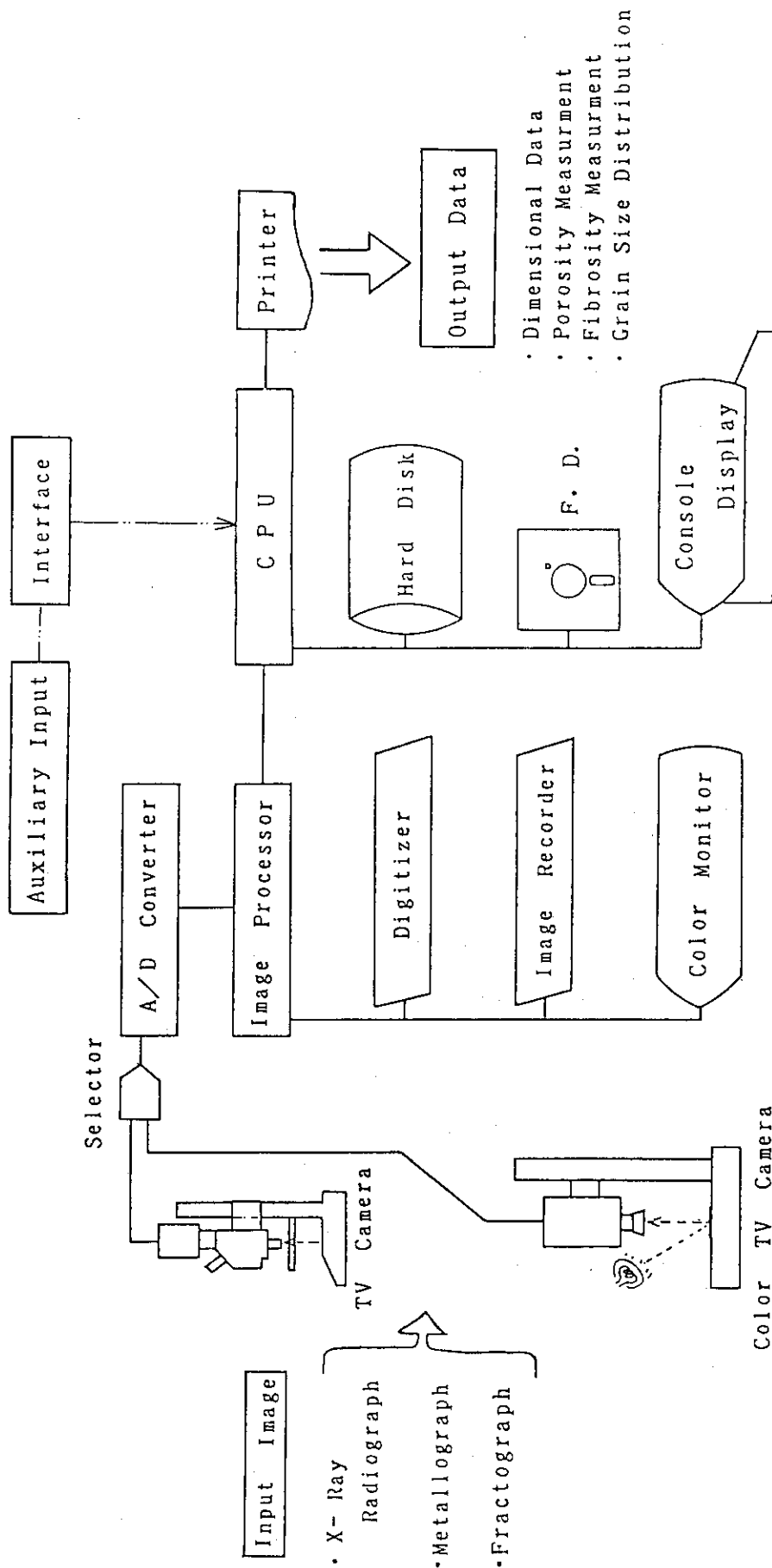


Fig. 9.31 Image Analysis System

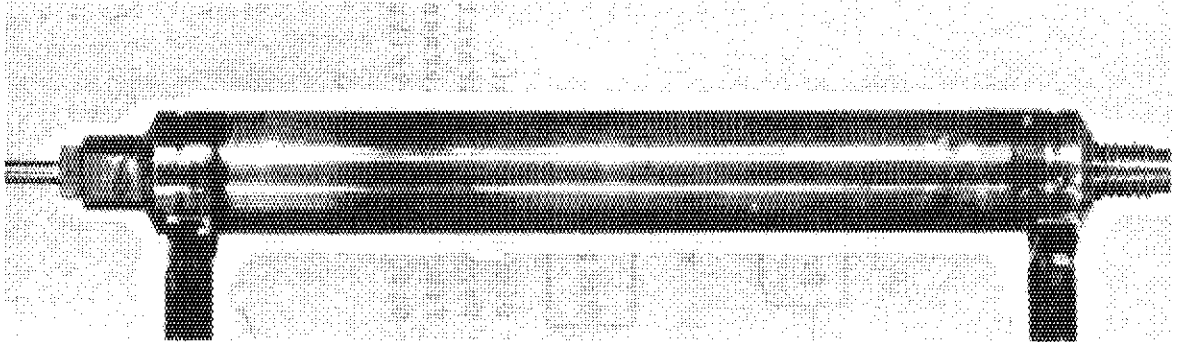


Fig. 9.32 Photograph by View Camera

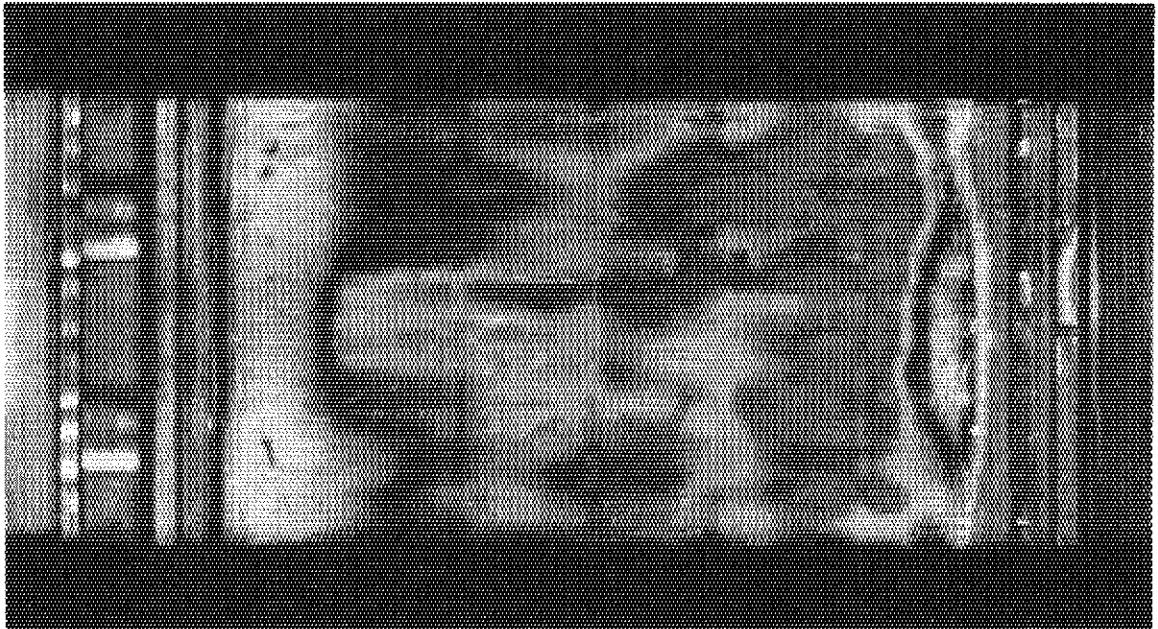


Fig. 9.33 Photograph by Panorama Camera

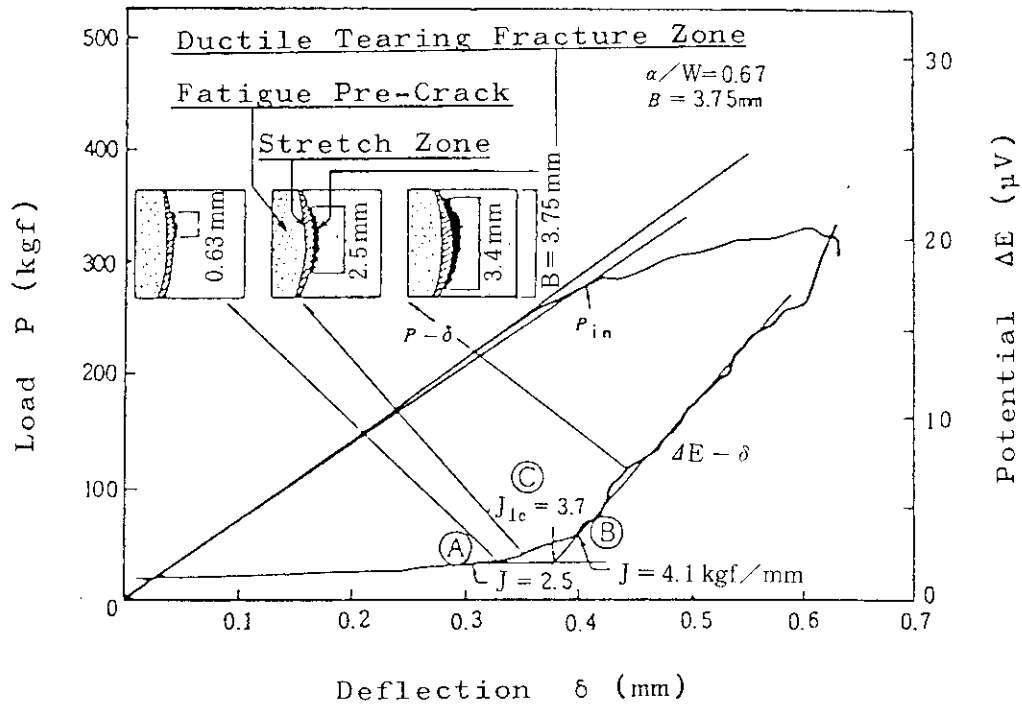
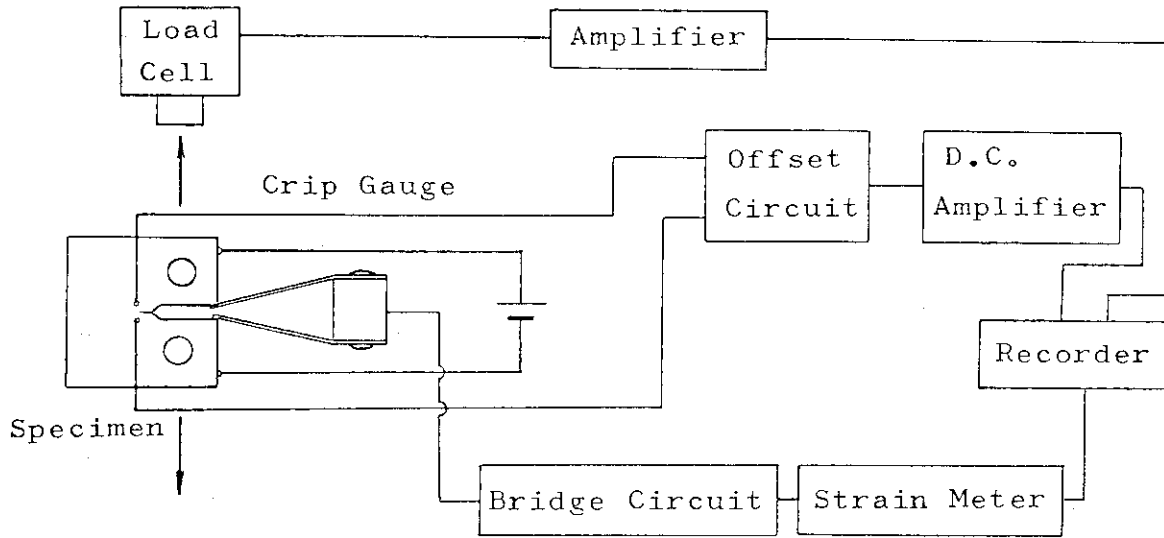


Fig. 9.34 Measuring System of Fracture Toughness
(D.C. Electrical Potential Method)

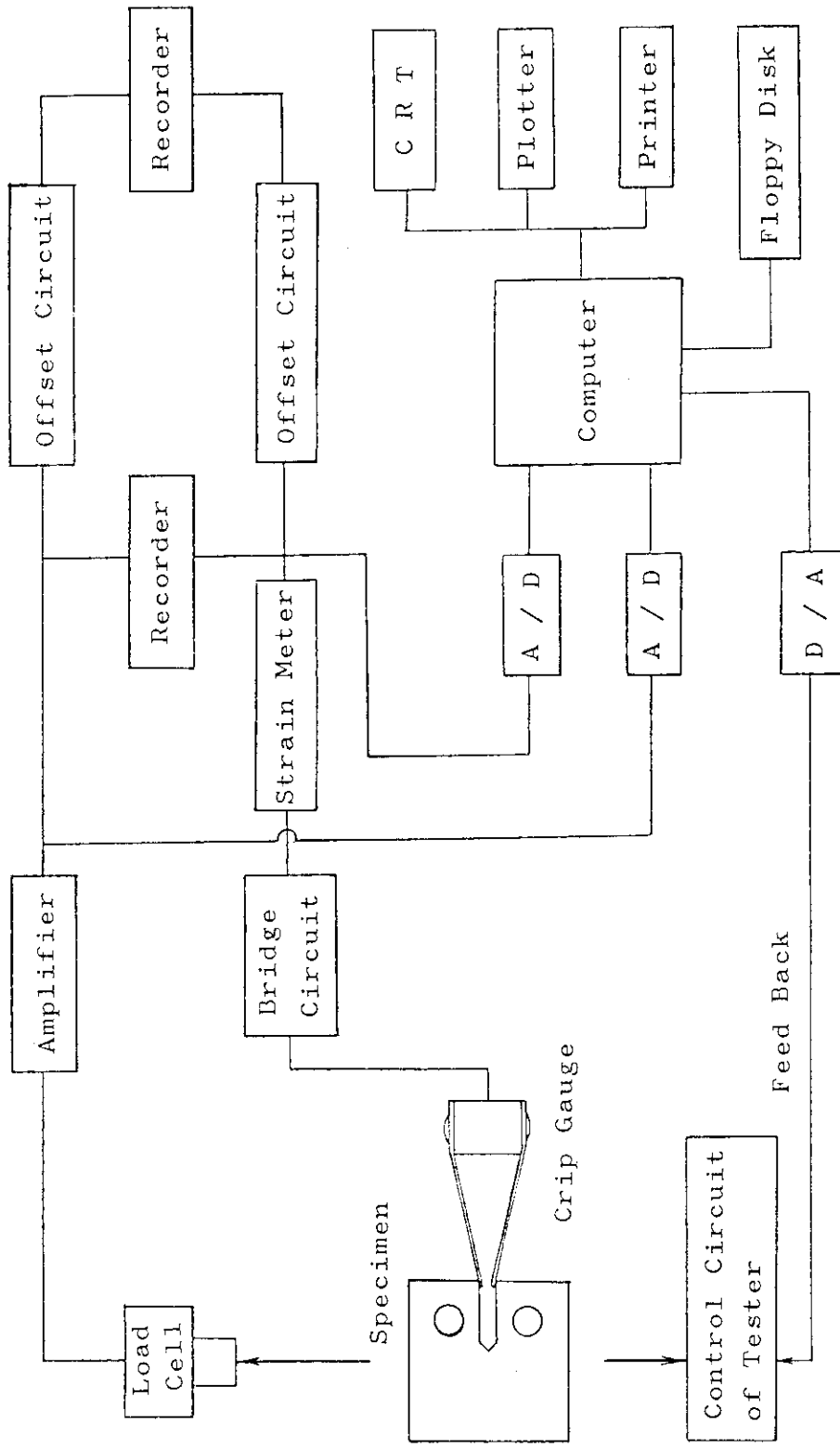
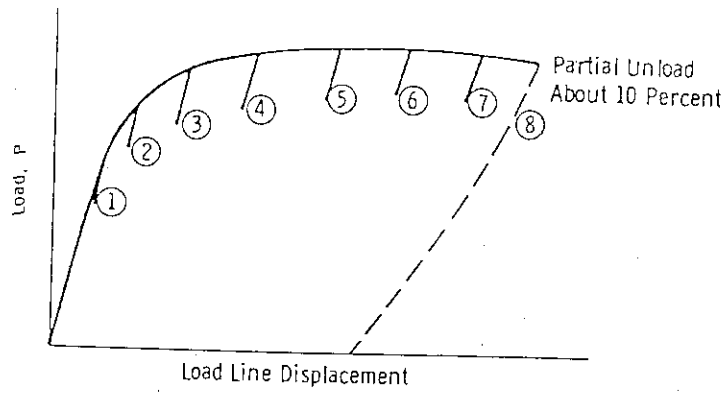
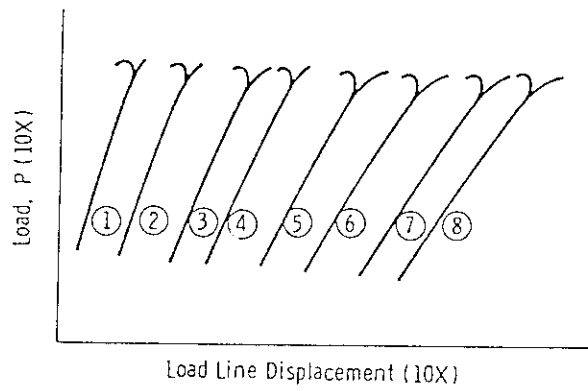


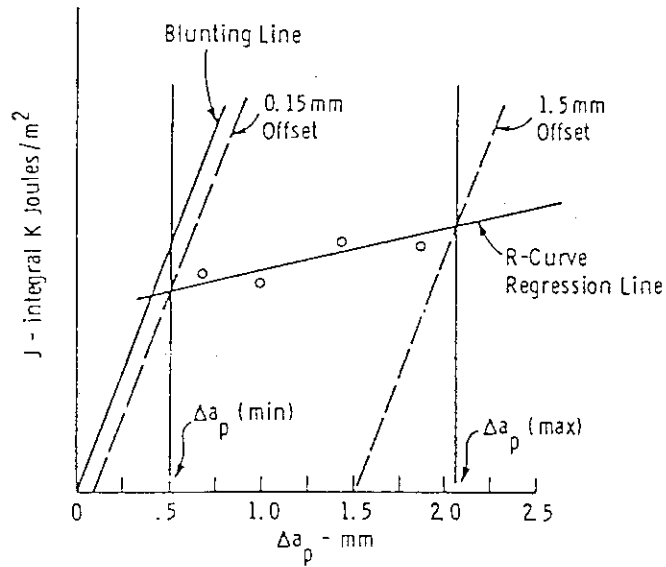
Fig. 9.35 Measuring System of Fracture Toughness (Unloading Compliance Method)



Schematic Test Record with Partial Unloading Slopes



Schematic of Amplified Unloading Slopes



Linear Regression Fit to R-Curve Data

Fig. 9.36 J_{IC} Measurement of Fracture Toughness (Unloading Compliance Method)

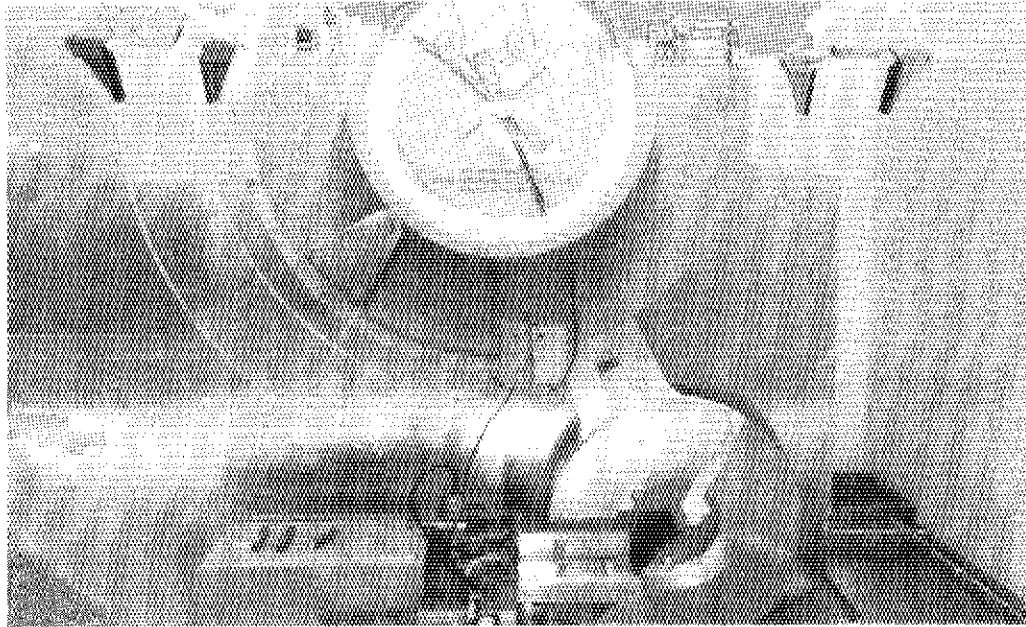


Fig. 9.37 Charpy Impact Tester

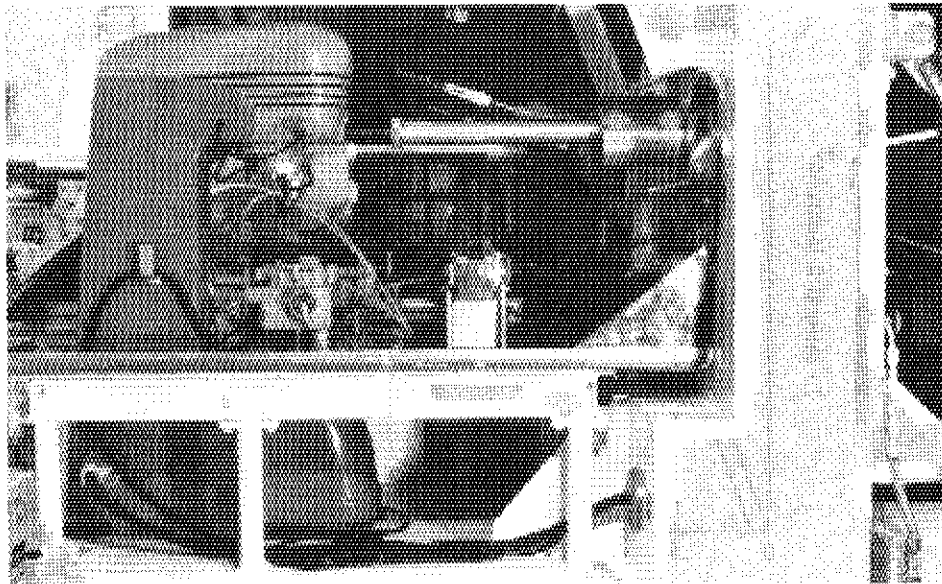


Fig. 9.38 Vickers Hardness Tester

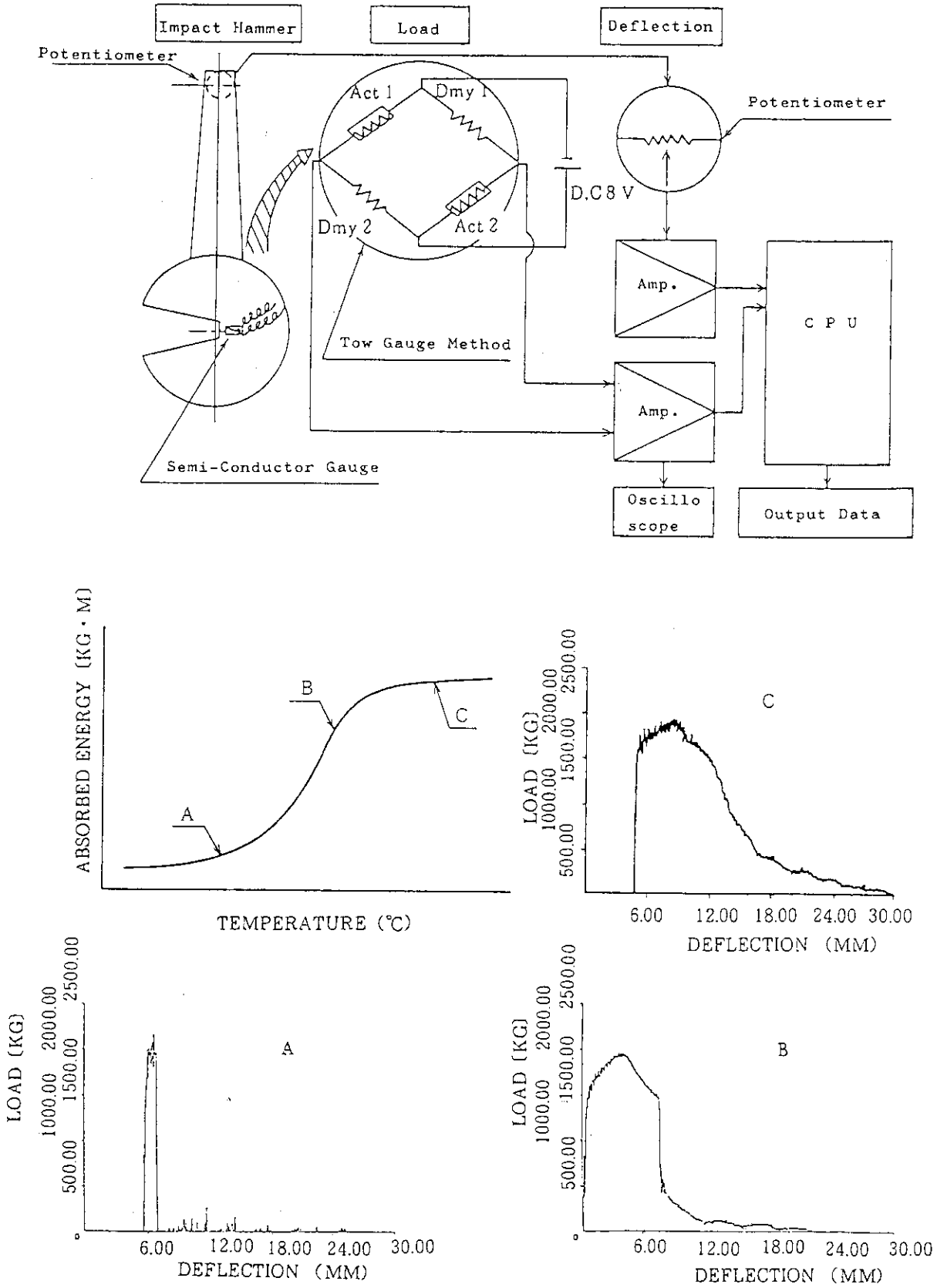


Fig. 9.39 Diagram and Data of Instrumented Charpy Impact Test

10. Conclusions

Various irradiation experiments on development of the fuel and material have been carried out in the JMTR reactor. General description are given on the various kinds of irradiation facilities in the JMTR. Experimenter is able to choose a suitable facility for his irradiation experiments.

The JMTR wishes to play an important role on not only development of power reactor and VHTR reactor but also other field of peaceful use of atomic energy through a wide variety of irradiation experiments.

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A. JAERI or JAERI-M Reports

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10. Conclusions

Various irradiation experiments on development of the fuel and material have been carried out in the JMTR reactor. General description are given on the various kinds of irradiation facilities in the JMTR. Experimenter is able to choose a suitable facility for his irradiation experiments.

The JMTR wishes to play an important role on not only development of power reactor and VHTR reactor but also other field of peaceful use of atomic energy through a wide variety of irradiation experiments.

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