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MODIFICATION OF JRR-2

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This report gives an outline of some of the main modifications carried out around the Reactor Core on the Research Reactor JRR-2, at the Tokai Research Establishment of JAERI.

The JRR-2 was shut down in December 1973, to improve it in heavy water leakage from the metal packing between core tank and support ring, corrosion of the lower shielding plug, and fault in the control-rod mechanism.

Main modifications were a standing seal weld at the support ring to stop heavy water leakage, replacement of the reactor top shield and improvement of the helium system. The control-rod assemblies and the refueling devices were replaced by the newly designed ones also. In addition to the modification plan, the irradiated air exhaust system was improved to reduce radioactive argon gas release through the stack.

Works were completed successfully in September 1975. But a light water leakage occurred at the stand pipe below the light water tank on November 11, 1975, which was repaired in about 4 months.

When considering the operation of above 5,000 hours after the modification, however, the quality of the modification work may be said to be quite satisfactory. The present report in which works to the completion are described may be valuable as a record of reactor modification which is a new experience at JAERI.

Keywords: Research Reactor JRR-2, Modification, Heavy Water Leakage, Corrosion, Standing Seal Weld, Reactor Top Shield, Helium System, Control-Rod Mechanism, Refueling Cask, Irradiated Air System, Radioactive Argon, Light Water Leakage, Repair Works

JRR－2の改修

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この資料は，東海研究所にある研究用原子炉JRR－2の改修についてまとめたものである。

JRR－2は，サポートリングと重水タンク間の金属パッキン不良による重水漏洩，下段遮蔽プラグの腐食及び制御棒の故障を改善するため1973年12月炉を停止した。

主要改修内容は，サポートリング部での重水漏洩を止める立上りシール溶接，炉心上部遮蔽体の交換及びヘリウム系の改良である。また，制御棒装置及び燃料交換キャスクは改良型の新しいものと交換した。被照射空気系の改良工事は改修計画の途中で，アルゴン41放出低減対策として追加された。

以上の作業は順調に1975年9月までに完了したが，軽水タンクの下につながるスタンドパイプのところで軽水漏洩れが，1975年11月11日に起り，その補修のために約4ケ月を要した。

しかし，改修後の5,000時間以上の運転実績からみて，改修の質としては十分満足すべきものであり，その過程をまとめた本報告は，原研における新しい経験であり，炉の改修技術として十分な意味をもつものと考える。

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1. Introduction

The JRR-2 was shut down in December 1973, for some major modifications.

The main modifications were a standing seal weld to stop heavy water leakage at support ring, replacement of the reactor top shield, and improvement of the helium system. The control rod assemblies and the refueling devices were replaced by the newly designed ones also. In addition, the irradiated air system was also improved to reduce radioactive argon gas released through the stack.

These works were completed in September 1975 as shown in Table 1. But, during low power characteristic measurements after the modification, a thermal shield light water leakage occurred on November 11, 1975, which delayed reactor operation for about six months.

During the modification works on the reactor, radiation exposures were strictly controlled to ensure the safety of the JRR-2 personnel working around the reactor. The risks of internal body radiation exposure due to the presence of tritium in the heavy water vapor were considerably reduced by use of local air exhaust system and protectors such as air-line suit, masks, etc. Consequently, the whole-body radiation exposures of JRR-2 members were kept below 240 mrem/man and average 40 mrem/man.

2. Repair of the Heavy Water Leaks

The JRR-2 has been repaired three times for stopping the heavy water leakage since 1965, as follow.

Repair Works in 1965

The first heavy water leakage occurred in July 1965, because of the mechanical damage to the aluminum packing which is used as a sealing between the thermal shield light water tank and support-ring. Adhesive resin (Epikoto 828) was used to prevent leakage of heavy water into the thermal shield light water system.

Repair Works in 1968

Heavy water began to leak again in March 1966. At this time, heavy water leaked from the inner side of the core tank's support-ring. As a temporary measure, the bolts on inner side were fastened and some adhesive resin was packed. Furthermore a seal-plate was additionally welded between the outside of the core tank's support-ring and the reactor containment, because of the radiation damage to the adhesive resin This repair work was carried out in autumn 1968.

Repair Works from 1974 to 1975 (Standing seal weld)

The heavy water concentration in the thermal shield light water increased gradually since the summer of 1971. Total amount of heavy water leakage into the thermal shield light water system since September 1971 till December 1973 was estimated to be about 520 kg. The repair works were planned to eliminate heavy water leakage trouble and to improve design of the reactor top shield at the same time. The "standing seal weld" for stopping heavy water leakage was carried out in June 1975 after the full size mock-up tests. The standing seal inserted between the lower annulus plug and the lower central plug was welded at the heavy water tank flange as shown in Fig. 1 and Fig. 2.

The three-pass welding at the heavy water tank flange (position No.1) under high radiation level were performed by automatic MIG arc. The other four positions were welded in two passes by semiautomatic MIG arc. Inspection after the welding showed good results, including visual inspection, penetration test and helium leak test. Refer to photo No.1 and 2.

During the repair works the dose rate in the working area was successfully reduced to about 10 mrem/hr by means of about 15 cm thick P_b-Fe shields set up on the support ring and the core tank. Also, before the welding work, the bolts on the heavy water tank flange were replaced with new one's to decrease the dose rate in the working area. Each activated bolt had dose rate of 15 R/h at the surface. Consequently, the whole-body radiation exposure of welders were kept below 30 mrem.

3. Modification of Reactor Top Shield

Before the modification, the reactor top shield consisted of the lower plug, the upper plug and the rotary plug. These plugs were replaced, because some troubles were observed in the fuel holes of the lower plug etc. The lower plug troubles were caused due to deformation of the rectangular aluminum tubes by corrosion products ($Al_2O_3 \cdot 3D_2O$).

Fig. 1 shows the cross section of JRR-2 reactor top shield after the modification. The modified lower plug consists of the annular shield plug and the central lower shield plug. The shapes of fuel hole in the lower plug and the upper plug are changed from rectangular to circular considering good welding conditions and larger cylindrical fuel elements. The rotary shield shutter is installed recently to utilize reactor top face sufficiently and to reduce the radiation level caused by streaming through small ducts and annular narrow gaps. The reactor containment annular gap between the annular shield plug and the reactor containment was plugged with about 10 cm wide, 40 cm high stainless steel plates in the circumference.

The lower and upper shield plugs were welded carefully to avoid heavy water vapor penetration inward through liners. The liner surface in contact with the concrete were painted to prevent corrosion. For resistance against radiation, heat and alkali reaction, the following paints were used inside the reactor top shield containment,

(1) Polyamide imide (Polyamide resin) - on outside surface of the fuel holes and vertical experimental hole tubes.

(2) Amercoat (Epoxy Resin) - on inside surface of the sheilding vessel.

Assembling of the reactor top shield plug was carried out successfully after the welding work. It was most important technically to aline the nozzle positions on the grid plate and the fuel multiple-holes in the lower central shield plug in high accuracy under high gamma-ray radiation and tritium vapor field. This was solved by providing a special gauge and tools. Whole-body radiation exposure of the assembling workers were kept below 30 mrem/man by radiation control. Tests on the outpile stand were repeated to confirm the assembling work including pre-installation test and pre-checks.

The measurements of shielding effect at 10 MW operation showed good results of the modification. Radiation level at the reactor top was reduced to 1/10 $\sim$ 1/100 after the modification. Radiation total dose rate is less than 1 mrem/hr on the rotary shutter surface and radiation caused by streaming through reactor containment annular gap is kept 1 $\sim$ 10 mrem/hr.

4. Improvement of Helium System

Helium gas is used to maintain an inert atmosphere in the space above the liquid level in the heavy water tank and in the heavy water storage tank. The gas is pressurized slightly (2.5 inches of water) to prevent in-leakage of air, which would become radioactive if exposed to the core tank neutron flux.

The helium also serves as a means of sweeping dissociated D_2O from the core tank atmosphere to the recombiner where the D_2 and O_2 are recombined catalytically.

The helium system flow diagram of JRR-2 after the modification is shown in Fig. 3. Helium gas above the liquid level in the heavy water tank is separated by the skirts of the guide tube array, so that the helium release in refueling is reduced to only about 500 ℓ (the volume inside the skirts). The total leak rate of the helium system at 10 MW was improved to about 2 ℓ/h after the modification. Heavy water dissociation rate was decreased to about (2 g D_2O/Mwh) 1/6 of the value before the modification. Fig. 4 shows the D_2 and O_2 gas concentration in the helium circulating lines.

5. Modification of Control Rods Drive System

Six vertical control rods are located symmetrically within the core volume for reactivity control of the reactor as shown in Fig. 5. They are positioned by individual control rod drive assemblies which provide controlled vertical movement of the rods, from above the core, in response to control signals from the automatic control channel or the manual control circuit. Although, the six control rods are identical in design, one is controlled separately as a regulating rod while the remaining five are gang controlled as shim rods. Reactivity worth of each control rod is about 6%Δk/k and the combined worth of six rods is about 35%Δk/k.

In the past the control rod drive system had been experienced various mechanical and electrical troubles. Moreover the maintenance was extremely difficult due to inaccessibility of the vertical assembly due to the presense of high activity at the place of mounting.

All the six control rod drive systems were replaced by the modified ones, in order to solve the problem mentioned above. Figs. 6 and 7 show comparatively the new system and the old control rod system. Major differences between are drive mechanism and location of the drive package. The drive mechanism consists of magnet and ball-nut screw instead of rack-pinion. The location of drive package is in the duct of the reactor top instead of the reactor wall.

The new assembly cousists of a control element and its actuating ball-nut screw, an electromagnet, an armature and an outer aluminum tube housing the shielded plug etc. The magnet attaches to an armature which is connected to the control element through a stainless steel extension pipe. Lifting is made by a screw assembly with the ball-nut mounted on top of the magnet.

An electromagnet consists of 690 turns of AIW coil (Polyimido Amide insulated copper wire). This sub-assembly is potted in Epoxy resin which is canned in Ni-Fe alloy with hard chromecoating. The yoke of magnet and armature consist ot Ni (50%)-Fe alloy instead of Mo (4%)-Ni (79%) alloy (permally).

On-magnet switch uses the non-contact switch instead of the lead switch, of which principle is to detect the difference of the inductance of sub-coil in the magnet can between ON and OFF contact.

The neutron absorber is made of cadmium and stainless steel as before. The cadmium is completely sealed from the reactor atmosphere by stainless steel. The outside diameter of the element is 76 mm and sandwiched in between the stainless steel cylinder and the cadmium is 1.5 mm thick.

The control rods drive mechanisms are designed to work in D_2O vapor atmosphere at temperatures of more than 50°C. A "V" ring seal is used at the rotary boundary at the drive mechanism to keep helium leak rate below 10^{-5} atm·cc/sec.

Four-wire curl cord is used to supply electric power to the magnet. The insulator of curl cord is made of ethylene propylene, rubber which has a resistance of about 10^9 rads against gamma rays.

The drive package contains a motor, gear reduction unit, UP-DN limit switches, position transmitter overload detector, etc. The replacement of control rod systems were completed in September 1975.

Functional tests and reactivity worth measurements showed good results of the new system. Refer to Table 2.

6. Modification of Refueling Cask

Refueling System Outline

Two kind of devices are required for refueling works: the first is "refueling cask" for with drawing spent fuel element from the reactor core and for transporting to the spent fuel storage pond; and the second is "spacer plug and new fuel element charge handler". This handler is installed on the rails at reactor top.

Refueling Cask

The refueling cask which is used to transfer spent fuel from the core to the spent fuel storage pond, is designed to give sufficient shielding in refueling 2.5 hours after reactor shutdown.

This cask was replaced with a modified one in the summer of 1975 to avoid some troubles concerning the old fuel cask such as shield gripper dropping or the rack disconnection by failure of stopper bolts etc.

Major differences between the new cask and the old are chain hoist device instead of the rack assembly, rotary shield door instead of slide-door, and electric motor drive instead of manual drive.

A cross-section is shown in Fig. 8. A stainless steel tube of 117 mm inner diameter and about 2.3 m high is surrounded by an annular lead shield of 330 mm thickness. The weight is approximately 13 tons.

The chain hoist device is shown in Fig. 9, which is equipped with a chain slide cam to actuate the gripper fingers. The shield gripper consists of a gripper finger assembly and a shield plug assembly. The gripper finger assembly provides a set of fingers that can grasp the fuel.

The operating mechanisms are inter locked by the situation of over and off load of the load cell, opening and closing of the door and actuating of the gripper fingers. Also, this cask is equipped with a position indicator of the gripper.

While the irradiated fuel element is in the cask, cooling air is delivered at rate about 2 m^3/h in the fuel element to prevent fuel failure by gamma-decay heating. The air is drawn to the irradiated air system through the flexible duct.

Functional tests and spent fuel handling works showed good results of the new cask.

7. Improvement of Irradiated Air System

The irradiation air system exhausts air from the experimental tubes, through sub-micron filters to the outside stack. This system was improved to reduce radioactive argon (^{41}Ar) gas release from the stack in autumn 1975. The block diagram after the improvements is shown in Fig. 10.

Main improvements are as followings: first, all experimental tubes which are sealed on the reactor wall, are maintained to keep good air tightness not to allow leakage of irradiated air into the reactor room more than 10 mm Aq pressure difference. Second, ^{41}Ar decay ducts were provided in the horizontal beam tube air line. The duct is in 24 units and has total volume 2.4 m^3. Each unit 200 × 300 mm rectangular, 200 mm long, 3 mm wall thickness aluminum alloy. Third, two ^{41}Ar decay tanks are installed in the pneumatic tube system. The volume of each tank is about 80 ℓ.

After the improvements, operation showed good results as follow: ^{41}Ar gas release rate from the JRR-2 stack reduced to 0.22 Ci/h from 3.2 Ci/h per day on the average as shown in Table 3. Also, ^{41}Ar gas release rate is kept below 0.3 Ci/h by adjusting below 7 ℓ/min the flow rate through the horizontal beam tube air line such as in Fig. 11. These values are less than 1/2 the managing mark level of 0.8 Ci/h.

8. Repair of Light Water Leakage from Stand Pipe below Light Water Tank

An Outline of the Thermal Shield Light Water System

The thermal shield system removes heat generated in the reactor shield and transfers this heat to the secondary cooling system for ultimate disposal to the atmosphere.

The stainless steel thermal shield plates, which surround the reactor core tank and protect the biological shield from overheating, represent the principal source of gamma heating to be removed by the thermal shield system. These shield plates are located in the water filled annular space outside the heavy water tank and in the space below the core tank.

In full power operation, the heat generated in the shield (about 300 kW) is removed with flow rate about 25 m^3/h of water.

The Water Leakage Trouble

Water leakage occurred in November 1975, in pitting corrosion of the aluminum pipe. The location was about 180 mm below the light water tank, along the heavy water dump line. Detailed examination was made with fibre scope and ^{192}Ir radiograpy.

The cause of the water leakage was presumed to be acidic pitting corrosion by analysis of corrosion products. Corrosion products were mainly chloride, aluminum hydroxide and Bayerite ($Al_2O_3 \cdot 3D_2O$). About 800 μg/g of chlorine was also detected in the waste materials. The chlotine was supposed to be released by radiation damage of polyvinyl chloride sheets wrapping the aluminum pipe in inferior JRR-2 construction.

Repair Works

The repair works are outlined in Fig. 12. To stop the leakage, resin (Epikote 828) was packed into the gap between the light water pipe and the cover pipe about 350 mm long. The resin is estimated to have a life of about 10 years.

Special tool "heavy concrete cutter" shown in Fig. 13 was used to eliminate surrounding concrete of the light water pipe at the leakage location. Repair works were completed in March 1976 after various examinations and mock-up tests.

9. Conclusion

The JRR-2 is being operated in good condition since the modifications. Heavy water leakage into the thermal shield water system is stopped completely by the standing seal weld. The amount of heavy water loss is also reduced to about 30 kg/year by improvement of the helium system etc.

Operation efficiency after the modification is nearly 100 % operating plan. The modified control-rod assemblies, replacement of nuclear instruments such as CIC, UIC, noiseless cables, and other various maintenance techniques contribute to it very much.

In full power operation, radioactive argon gas release from the stack is reduced to about 1/10 due to improvement of the irradiated air system. ^{41}Ar release rate is kept below 0.3 Ci/h for managing mark level of 0.8 Ci/h.

To be interesting technically, heavy water dissociation rate is reduced to about 1/6 of the value before the modification. Perhaps, it comes from the fact that heavy water is maintained usually below 0.2 μU/cm of conductivity since the modification. Consequently, D_2O filter and resin life will be more than 2 years.

Refueling works are carried out smoothly by new refueling devices and modified reactor top shield. And, this work increased safety.

Whole-body radiation dose rate during the JRR-2 modification was less than in routin operation and maintenance. The trainings at out pile and various of radiation control experiences contributed to reduce the radiation dose rate.

Now, we are considering JRR-3 and JRR-4 grade up plans. The valuable experience gained during the modification of JRR-2 systems will effectively contribute in the planning and execution of work, under high radiation level.

Table 1 Progress of the JRR-2 modification

Sep., 1972	JRR-2 modification plan start
Jan. 1973	JRR-2 modification design Full size mock up tests of "standing seal weld", mock up tests of shield plug, Control rod drive system out pile tests, Chain drive mechanism mock up tests of refueling cask, Selection tests of paints, etc.
Nov., 1973	Final design check for safety
Dec., 1974	JRR-2 shut down
May, 1974 June, 1974	Withdrawing of old control rod drive systems, vertical experiment tubes, etc.
Dec., 1974	Withdrawing of reactor top shield plug
Jan., 1975 Feb., 1975	Improvement of helium system, reactor top modification and measurements of size in the reactor containment
Mar., 1975	Seal welding of D_2O tank drain holes
June, 1975	Standing seal welding
July, 1975	Assembling tests of reactor top shield plug at out-pile-stand
Aug., 1975 Sep., 1975	Assembling of reactor top shield plug. Fitting of control rod drive system. Fitting of refueling devices. Improvement of irradiated air system
Oct., 1975	Final functional tests
Nov., 1975	Critical tests and low power operation tests
Nov., 1975 Mar., 1976	Thermal shield water leakage trouble (Nov. 11, 1975). Repairing for water leakage, reactor low power operation tests
May, 1976	Power up tests
July, 1976 Dec., 1977	Full power long time operation test Full power operation for utilization services (21 cycles)

Table 2 Final functional tests of control rod devices and rod reactivity worth

Control rod device		Insulation test		Drive stroke	Spead	pick up current	Total scram time *3	Brake away time *3	Rod reactivity woth *4
In-Core Position	Fabrication	Insulation resistance	Withstand Voltage test	711.5 mm	70 mm/min	mA	600 msec	50 msec	%ΔK/K
CR-1	BC-5	150 MΩ	good	710	67.3	155	520	24	6.27
CR-2	BC-2	140	"	709	66.5	155	530	23	5.70
CR-3	BC-3	130	"	711	67.4	140	530	34	5.45
CR-4	BC-6	65	"	710	66.8	170	520	20	5.54
CR-5	BC-8	15	"	711	67.7	120	525	26	5.65
CR-6	BC-7	250	"	711	66.3	150	530	25	6.14
Spacer	BC-4	20	"	711	67.8		(514)	(27)	

*1 Passing criterion : >10 MΩ (500 DC)

*2 Test condition : 500 V AC 1 minute

*3 Setting point of magnet current 400 mA DC

*4 Positive period method (at core cold clean)

Table 3 ^{41}Ar gas release rate before and after improvement of the irradiated air system

Irradiated air system		^{41}Ar gas release rate (Ci/h) Measurement date 1973	12~22 Dec.,1976	Design point (Ci/h)
Horizontal beam tube air system		2.6 ~ 2.9	0.03	0.5
Pneumatic tube system		0.3 ~ 0.6	0.02	0.1
Other	Vertical thimble	—	0.06	—
	Thermal shield light water system	0.02	0.11	—
Stack		3.2	0.22	0.6

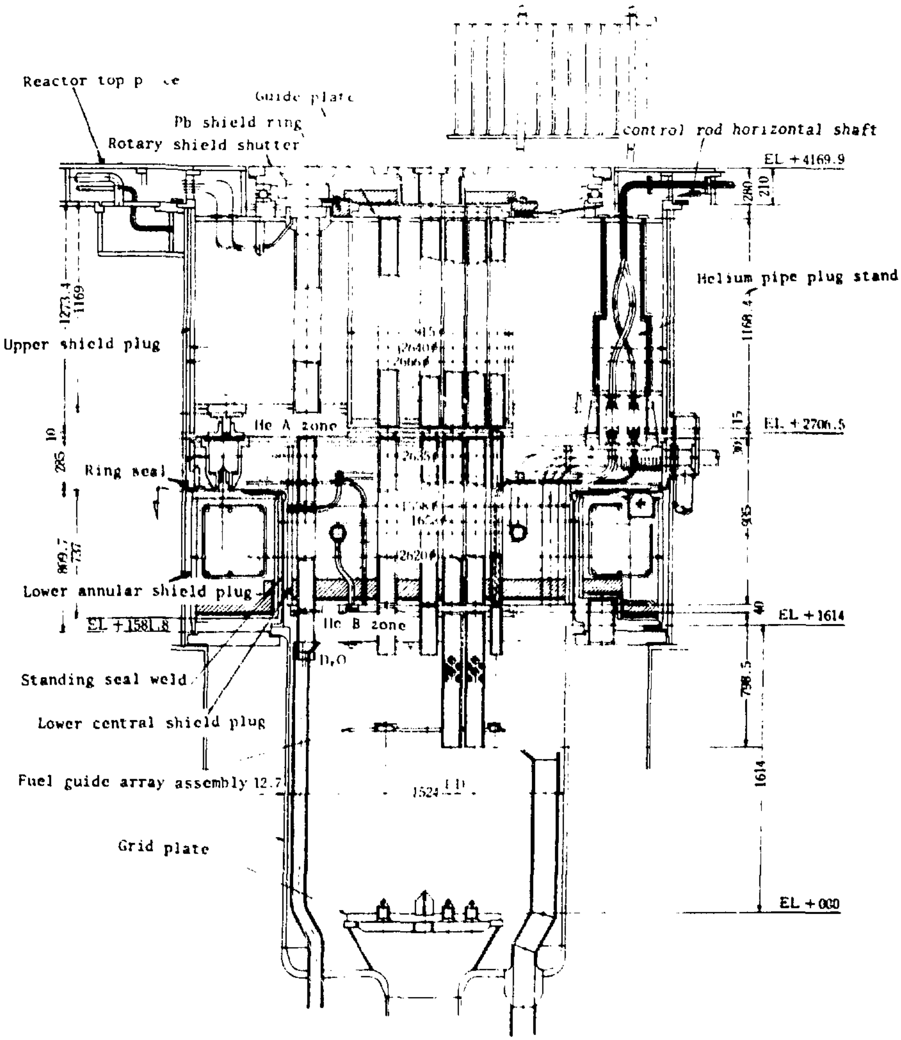

Fig. 1 JRR-2 cross section after modification

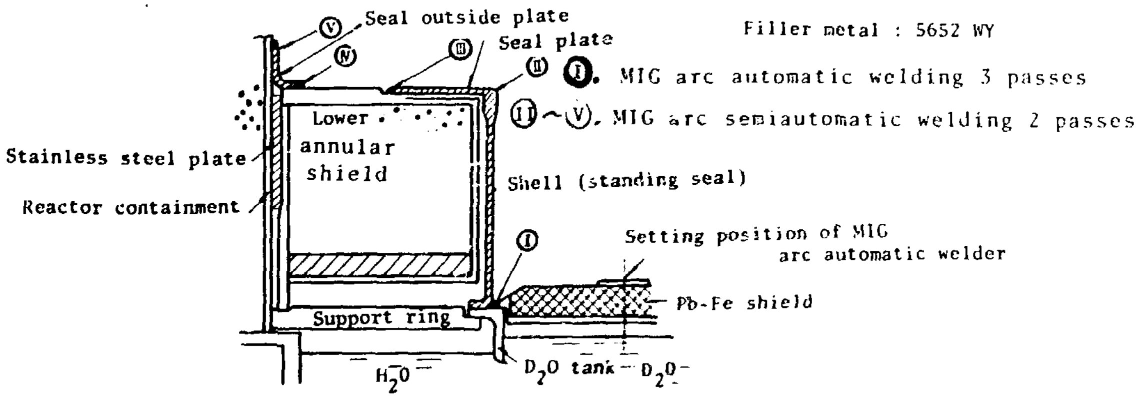

Fig. 2 Standing seal weld.

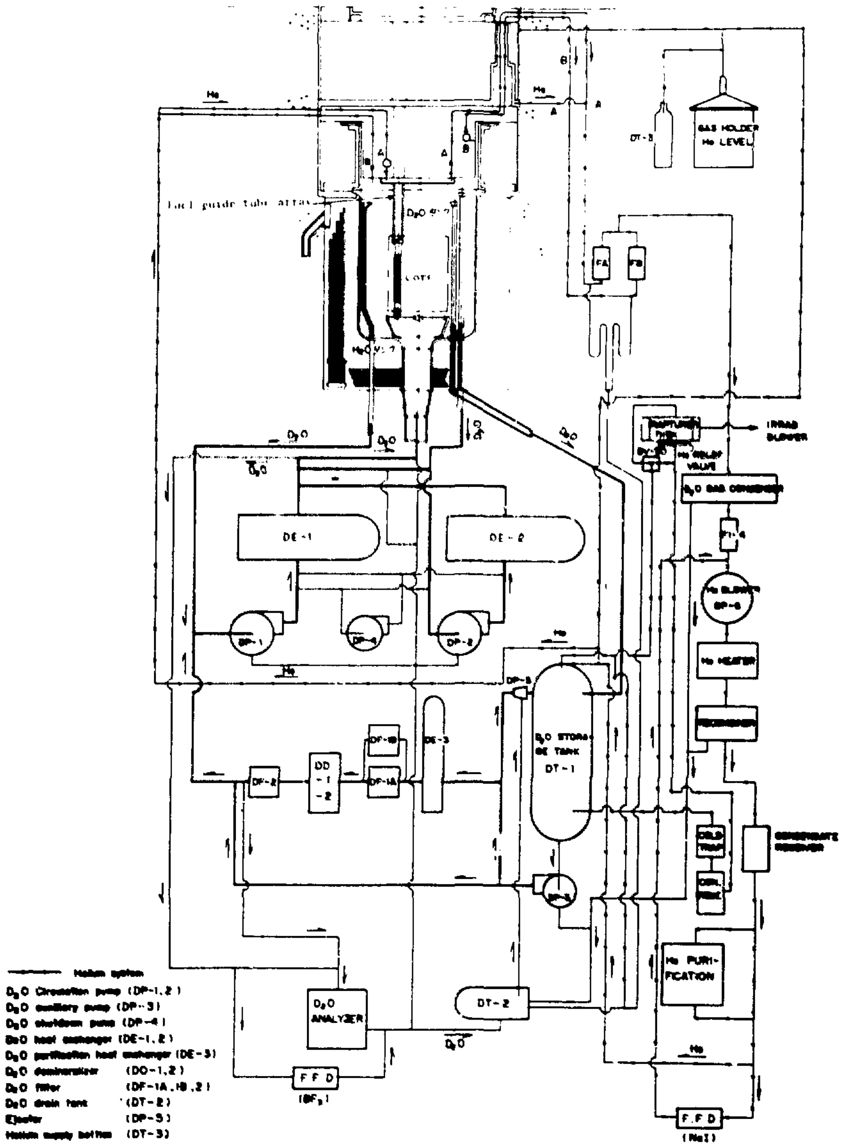

Fig. 3 JRR-2 heavy water cooling and helium system flow diagram after modification

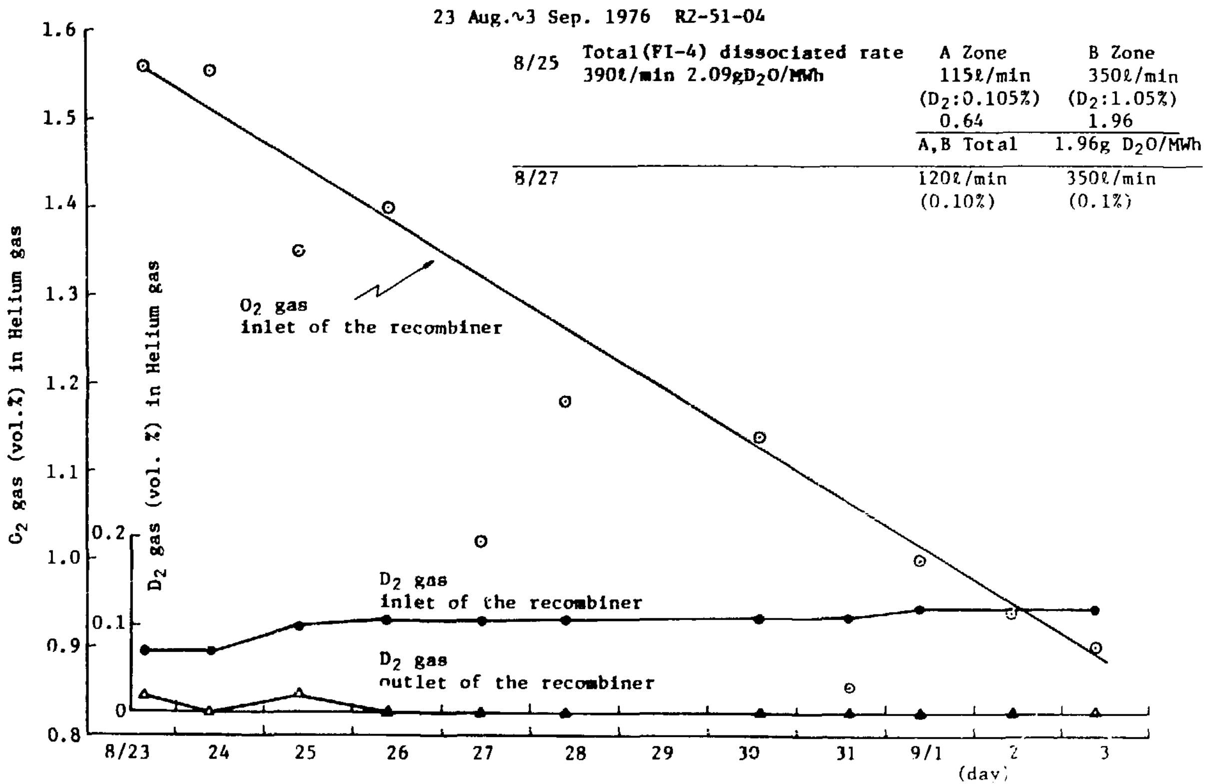

Fig. 4 D_2 and O_2 gas in the Helium circulating line (R2-51-04 cycle)

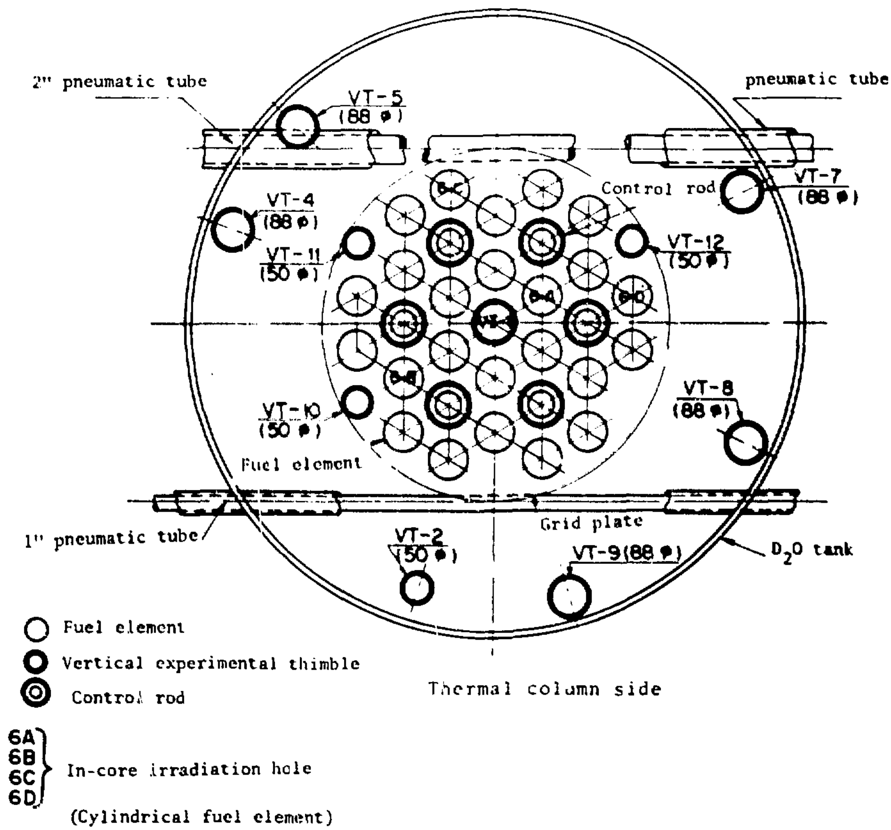

Fig. 5 JRR-2 core configuration radial pattern after modification

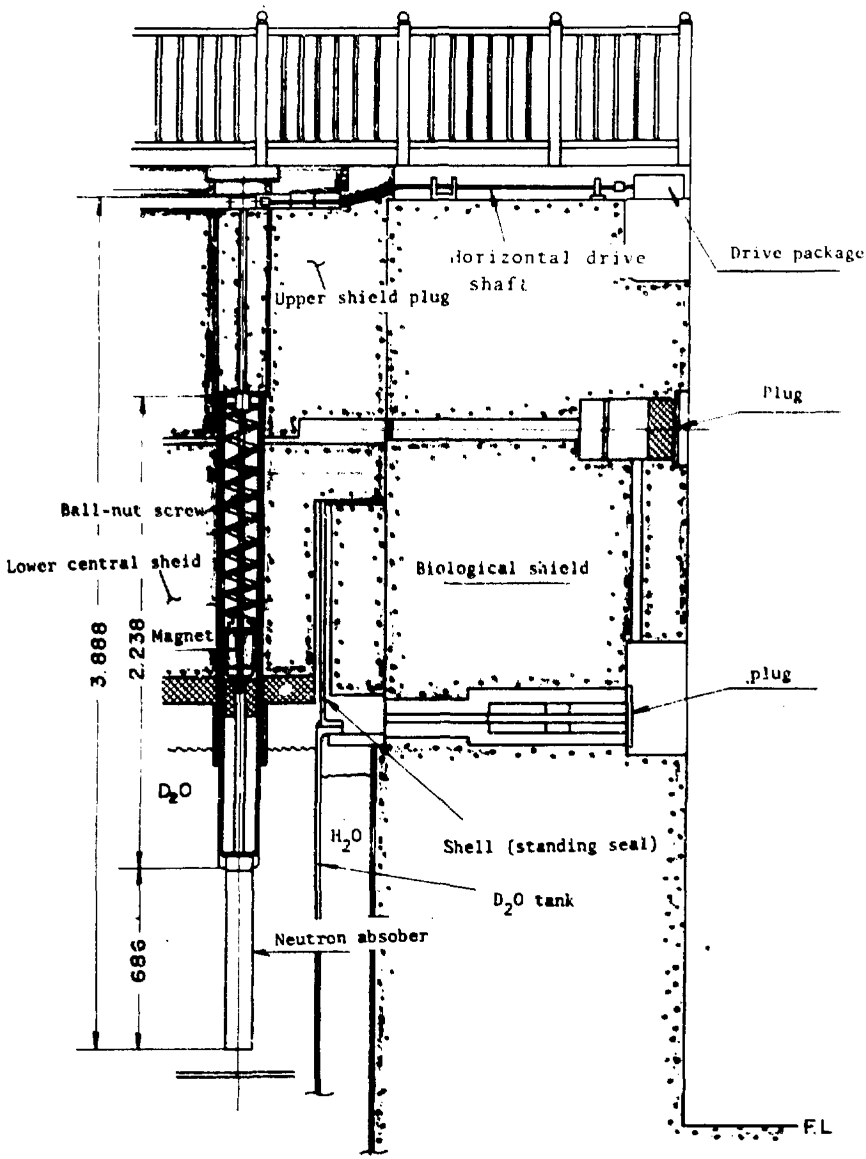

Fig. 6 Control rod drive system after modification

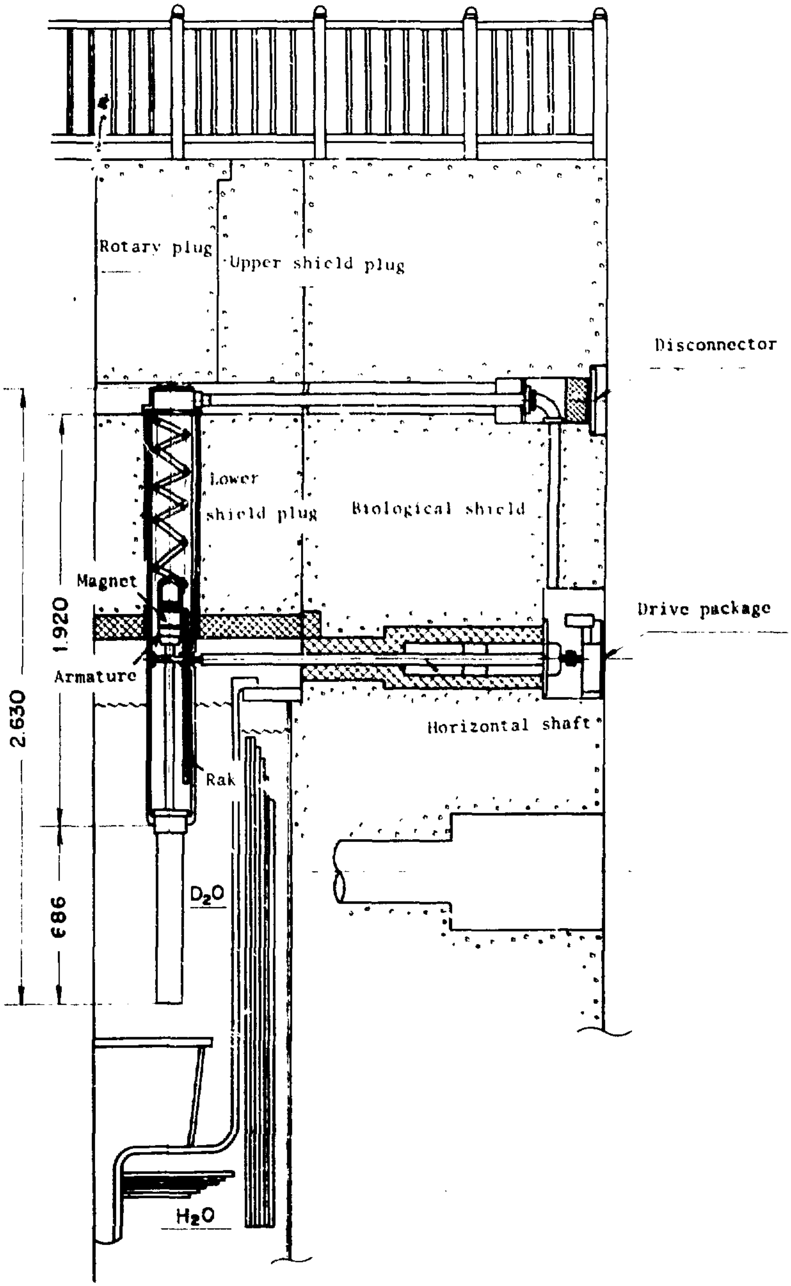

Fig. 7 Old control rod drive system

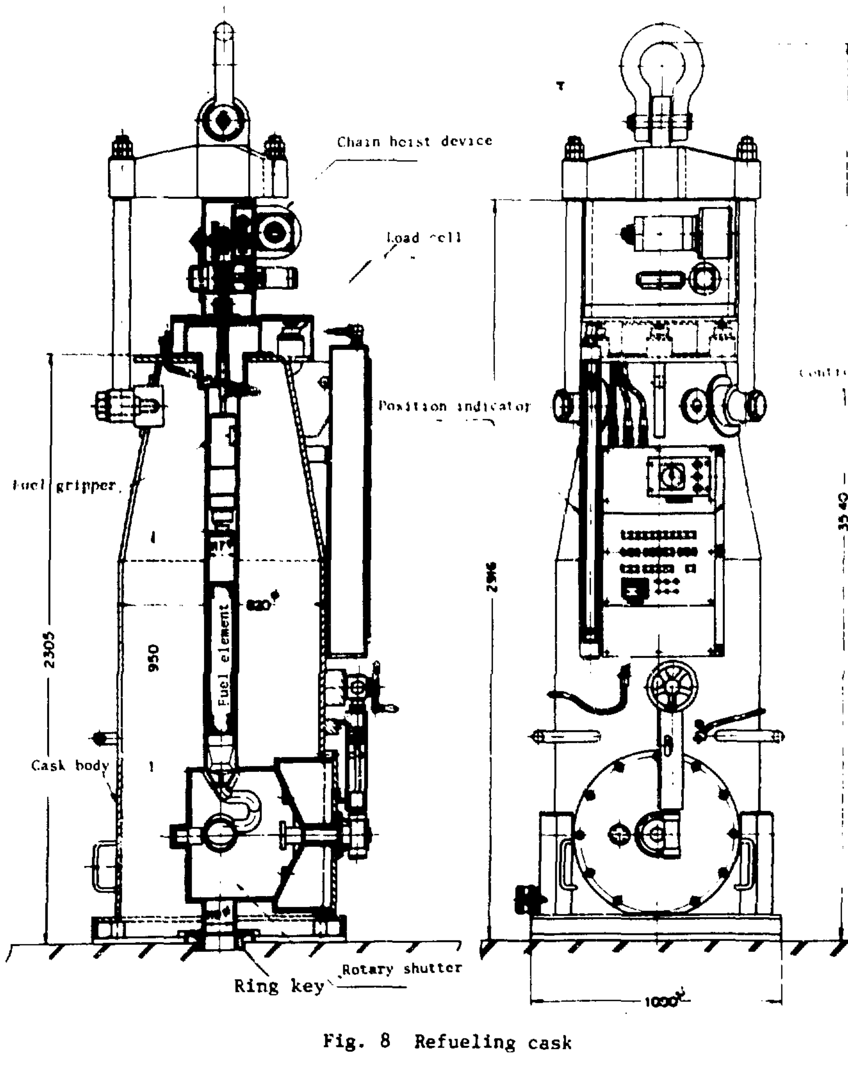

Fig. 8 Refueling cask

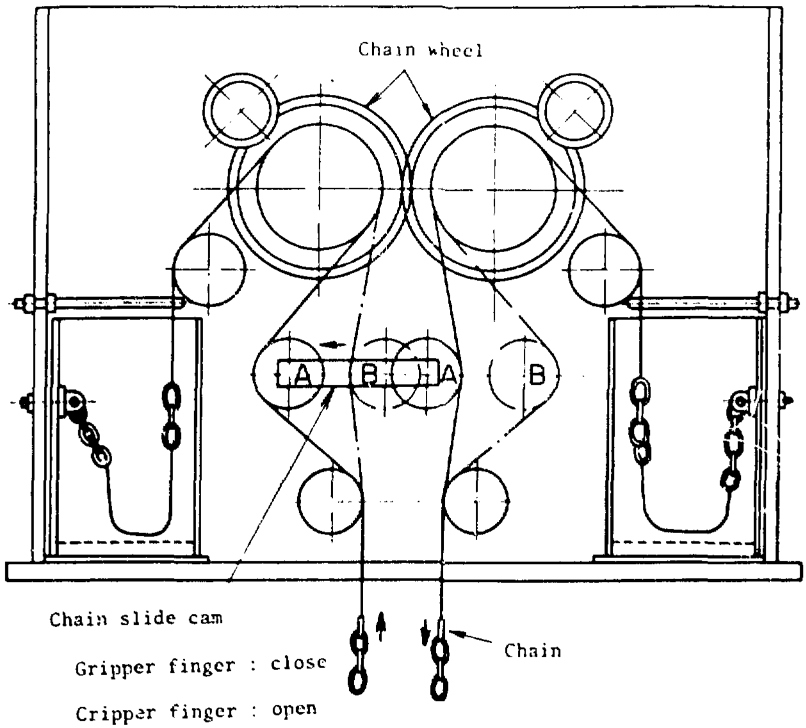

Fig. 9 Chain hoist for refueling cask

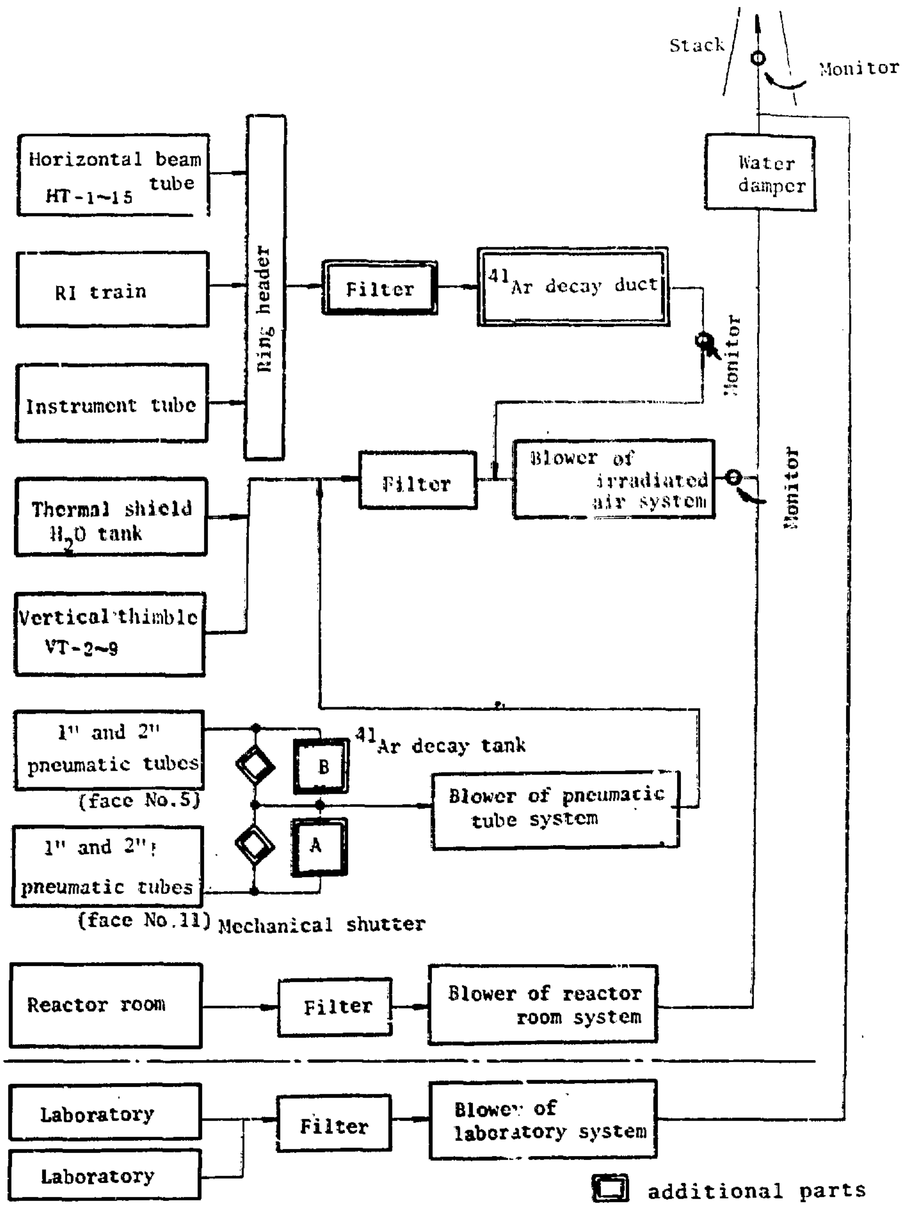

Fig. 10 Flow diagram of ventilation system

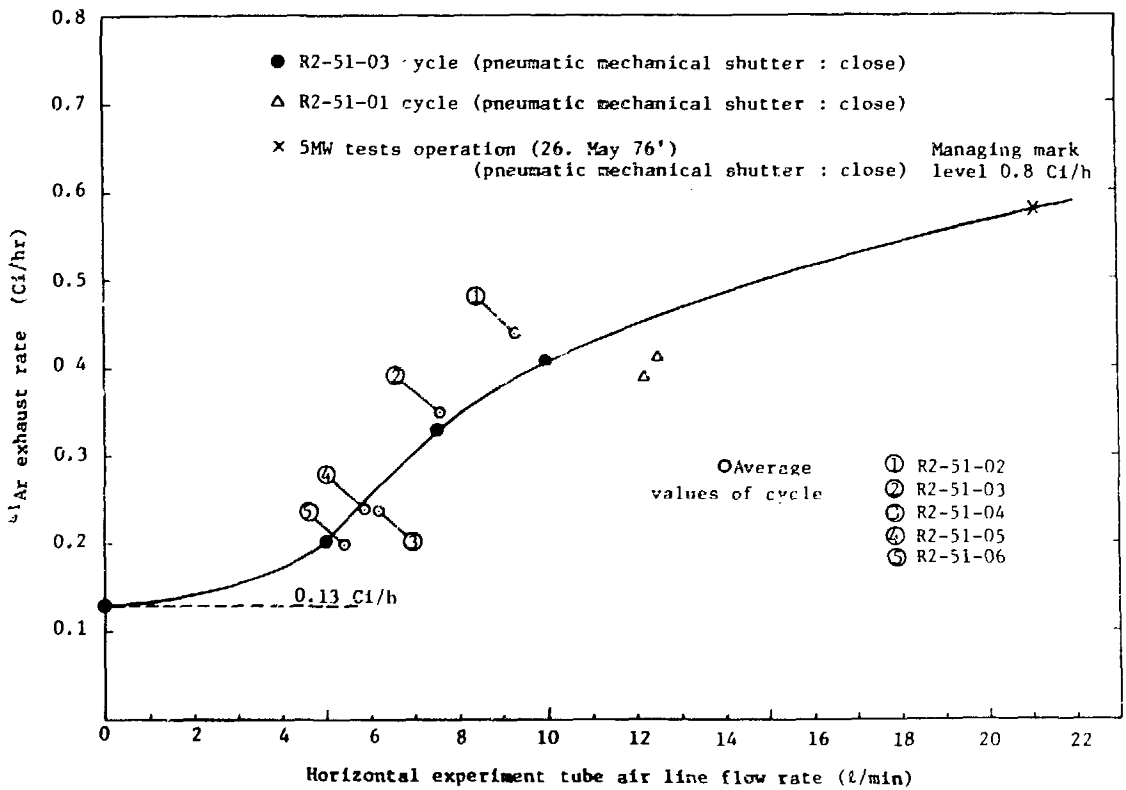

Fig. 11 Radioactive argon (^{41}Ar) gas from the JRR-2 stack

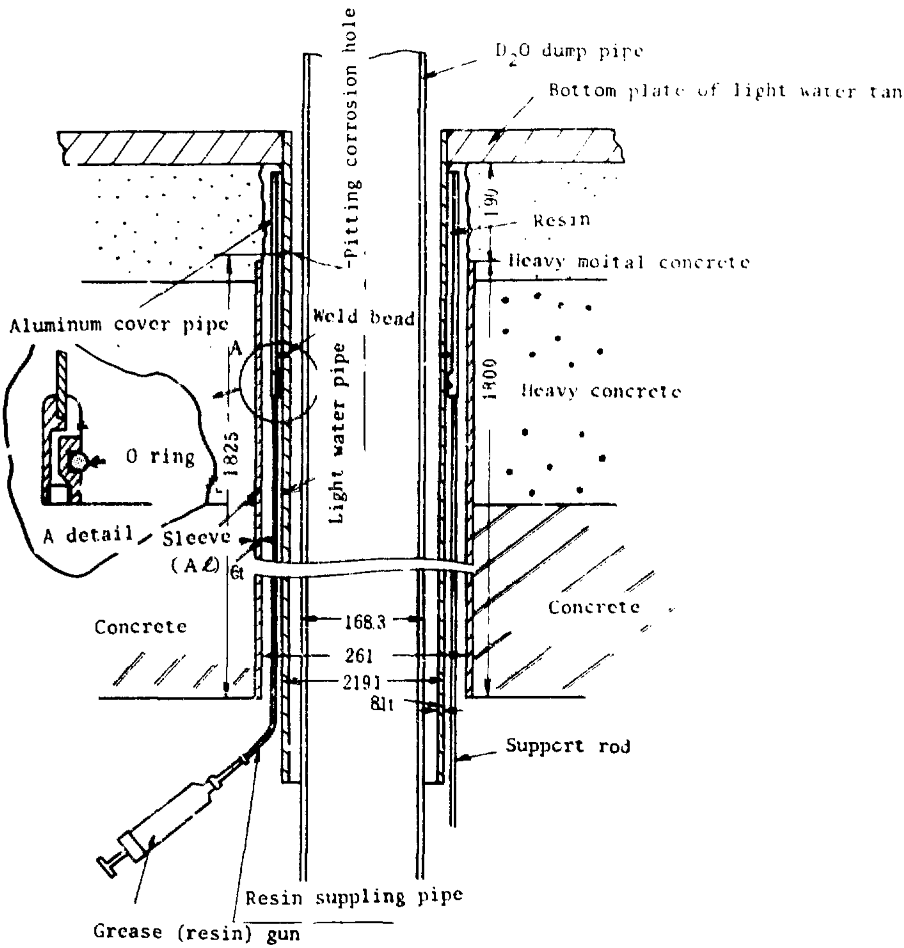

Fig. 12 Repair of light water leakage in stand pipe below the light water tank

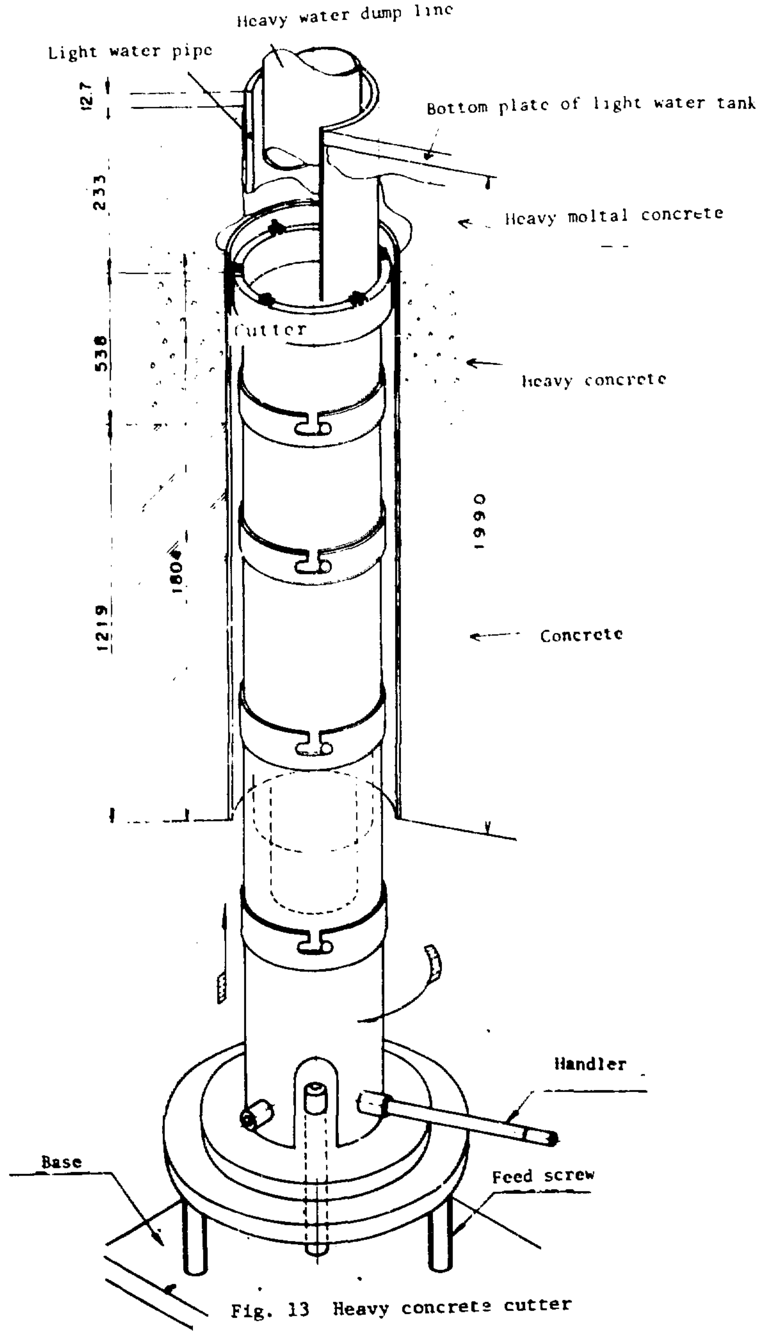

Fig. 13 Heavy concrete cutter

Photo 1. MIG Arc Automatic Welding at Position No. 1

Photo 2. Standing Seal after Welding
(view of D_2O tank, horizontal beam tube and grid plate)