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OPERATION AND MAINTENANCE EXPERIENCES WITH RESEARCH REACTORS, JAPAN ATOMIC ENERGY RESEARCH INSTITUTE

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OPERATION AND MAINTENANCE EXPERIENCES WITH RESEARCH REACTORS, JAPAN ATOMIC ENERGY RESEARCH INSTITUTE *

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The four research reactors, JRR-1, JRR-2, JRR-3 and JRR-4, have been provided at Tokai Research Establishment, JAERI. JRR-1 had ceased to operate since October 1968, due to superannuation of the reactor instruments and facilities. JRR-2 have been operated for about 13 years, JRR-3 for 11 years and JRR-4 for 8 years since their first critical tests.

Maintenance works have been performed on the reactors in order to keep them in a good operating condition, including pre-operational check, periodical inspection and maintenance works required by incidents.

Several troubles on reactor instruments and facilities have been experienced, and their repairs and modifications have been performed. This paper describes some principal troubles, repair works and modifications which have occurred and have been performed on JRR-2, JRR-3 and JRR-4.

Two large modification programmes are now going on JRR-2 and JRR-3. It was expected that after completion of these programmes, they should be operated more stably and be used more effectively.

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* Prepared for the South East Asia and Far-East Regional Study Group Meeting on Problems and Experience in the utilization of Research Reactors at Bhabha Atomic Research Centre, Bombay, India, in March 1973.

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日本原子力研究所における研究炉の運転・保守の経験*

日本原子力研究所東海研究所研究炉管理部
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（１９７３年９月１９日受理）

東海研究所には，ＪＲＲ－１，ＪＲＲ－２，ＪＲＲ－３，ＪＲＲ－４と４基の研究用原子炉が設置されている。ＪＲＲ－１は１９５７年以来運転を続けてきたが，原子炉施設の老化のため，１９６８年１０月に運転を中止した。ＪＲＲ－２は臨界以来約１３年，ＪＲＲ－３は約１１年，ＪＲＲ－４は約８年の間運転を行なってきた。

この間，原子炉を良好な状態に保持するため，運転前点検，定期検査，故障した機器の修理等各種の保守作業を実施してきた。

また，原子炉施設に関する各種のトラブルを経験し，修理や施設の改修を実施してきた。本報告は原子炉の運転を通じて経験した，これらのトラブル，修理作業，改修等の主なものについて述べている。さらに現在実施中の改造計画についても述べている。この改造計画が完了すると，ＪＲＲ－２，ＪＲＲ－３はより安定した運転と有効な利用が期待できる。

＊　本報告は１９７３年３月にインド国ボンベイ市のバーバ原子力研究所で開催された，「東南アジアおよび極東における研究炉の利用と経験に関する専門家会議」に提出したものである。

CONTENTS

I. INTRODUCTION

The four research reactors, JRR-1, JRR-2, JRR-3 and JRR-4, have been provided at Tokai Research Establishment, Japan Atomic Energy Research Institute (JAERI). JRR-1 was a homogeneous type reactor of 50 KW in thermal power and its fuel was 20% enriched uranium dissolved in the light water as uranyl sulfate, UO_2SO_4. JRR-2 is a high enriched (90%) uranium heavy water moderated, cooled and reflected tank type reactor with the thermal output of 10 MW and its fuels are MTR type curved plates alloyed with aluminum. JRR-3 is a natural uranium heavy water moderated and cooled tank type reactor with the thermal output of 10 MW and its fuels are natural metalic uranium rods cladded with aluminum. JRR-3 was made by Japanese staffs only in order to get the overall experiences of reactor design, construction and operation. It is so called the first Japan-made reactor. JRR-4 is a forced coolant swimming pool type reactor with movable core tank having two pools. Its thermal power is 2.5 MW with high enriched (90%) uranium ETR type fuels. Table 1 shows the outline of these reactors.

JRR-1 had ceased to operate since October 1968 and the fuel solution was drawn out of the core in December 1969. At the present time, it has been moth-balled as a monument of the first reactor in Japan. The main reasons of the ceasing are as follows;[1)]

1. Many instruments and facilities attached to the reactor became super-annuated and many troubles had occurred at short intervals. Therefore, maintenance works became very hard. Especially, the languishment of the gas recombiner was too serious for repairing.
2. It became difficult to carry out the routine operation of the reactor, because of the superannuation of the instruments and the facilities.
3. It is not so economic to operate JRR-1 in succession. Because the expense for the operation and maintenance of superannuated reactor is very high.
4. All experiments, irradiations and trainings which were carried out on JRR-1 could be transferred to JRR-2, JRR-3 and JRR-4. It was considered

that the ceasing of the operation was reasonable.

II. OPERATION

Nowadays the continuous operations at 10 MW are carried out for JRR-2 and JRR-3. Each operation cycle is 3 weeks, respectively. It is composed of 13 days continuous operation and 8 days shut down. The operation schedules of these reactors are slided each other. Because either of these reactors have to be operated during almost a year. In the shut down periods, we have irradiated sample handling, refuelling and minor repairing for the subjects which have been out of order in the previous operation period. We have periodical inspections twice a year for about 6 weeks. JRR-4 is normally operated at 2.5 MW for about 7 hours on every Tuesday through Friday. On occasion, it is operated for special experiments or irradiations which need special power levels or operation procedures. Two times a year, JRR-4 is operated for 9 weeks to carry out various reactor experiments and to practise reactor operations which are performed by trainees of the Nuclear Engineering School at JAERI. Table 2 shows the operation and the maintenance schedule in 1971.

Tables 3, 4 and 5 show the operation history of these reactors. JRR-2 went critical in October 1960. After that, we performed many kinds of experiments at various powers. And from the end of 1963, the routine operation of this reactor was started at 5 MW and from April 1965, it was operated at 10 MW. A operation time was about 130 hours in the beginning and after that, being increased gradually to 180, 200 and 288 hours.

JRR-3 went critical in September 1962. About one year and a half followed by the critical date was utilized for many kinds of experiments of the reactor characteristics, measurements of the control rod worth, mass reactivity coefficient, temperature coefficient, neutron flux, etc., power up test and functioning tests at full power. In April 1965, the routine operation was started at 10 MW. The operation time was about 88 hours in the beginning and after that, it was increasing gradually to 100, 130, 240 and 288 hours.

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JRR-4 went critical in January 1965. After that, the measurements of the control rod worth, mass reactivity coefficient, void coefficient, temperature coefficient and neutron flux, power up test and functioning tests at 1 MW and 2.5 MW were performed by the end of March 1966. In Octover 1965, the operation for experiments was started and has been continued up to date.

III. MAINTENANCE

The maintenance works on our reactor can be classified as follows;

1. Pre-operational check.
2. Periodical inspection and maintenance.
3. Maintenance works required by incidents.

The pre-operational check is an inspection to make sure all instruments and facilities to be functioning properly in accordance with the pre-operational check list. The check is conducted just before the reactor start up and therefore, it is not a pure maintenance work. However, relatively large number of troubles has been found at the check and most of these troubles were fixed immediately.

The maintenance work called here by "Periodical inspection" is divided into two kinds of inspections. One is named "Over-haul" and the other is named "Govermental inspection". The former is the inspection which is performed twice a year for about 6 weeks by JAERI's responsibility. The latter is the inspection which is performed in the presence of govermental inspectors once a year in accordance with the law.

As for the inspection, detailed inspections, tests on functions and characteristics of almost all instruments and of mechanical facilities of a reactor are conducted in accordance with manuals of the inspection. Instruments and facilities for the inspection include those on the control console, rod drive mechanism, cooling system, utilization facilities and so on. Tables 7 and 8 show the main items of maintenance works in the periodical inspection.

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When relatively minor troubles happened during a operation period, they were repaired while the reactor being operated or in a shut down period of the next operation cycle. Major troubles which happen accidentally during a operation period are not so many experienced and therefore, the maintenance works for this kind of troubles are relatively less.

It is an important problem that who will be responsible for maintenance and who will maintain the reactor actually. In the case of our reactors, operators are also responsible for maintenance and all maintenance works are conducted by the operators.

In Table 9, the number of troubles on JRR-3 is tabulated.

IV. TROUBLES EXPERIENCED

We have experienced with many troubles on our reactors which occurred accidentally and gradually in a long time. We describe briefly outlines, causes and countermeasures of some principal troubles in JRR-2, JRR-3 and JRR-4 as follows;[2)]

1. Troubles on JRR-2

1.1 Repairing of piping

In July 1964, the piping of exhaust air system in the core cracked because of poor welding. Consequently helium gas leaked into the air system. The reactor was shut down for about 3 months for its repair.

1.2. Repairing of support-ring (I)

The heavy water leakage occurred in July 1965 because of the mechanical damage of the aluminum packing which is used for sealing between the core tank and its support-ring. The reactor was shut down for about 6 months (from July to December 1965). Adhesive resin was used temporarily to prevent leakage of heavy water into the thermal shield tank.

1.3. Breakage of U-tubes in main heat exchangers

We had two main heat exchangers in the heavy water cooling system and their U-tubes were made of aluminum. In July 1967, the two U-tubes in the heat exchanger were damaged due to fretting corrosion. The faulty U-tubes were temporarily stopped up with aluminum plugs and adhesive resin. The reactor was shut operation cycle. Major troubles which happen accidentally during a operation period are not so many experienced and therefore, the maintenance works for this kind of troubles are relatively less.

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1.4. Repairing of support-ring (II)

Heavy water began to leak again into the thermal shield tank in March 1966. At this time, heavy water leaked from the inner side of the core tank's support-ring. Then, as a temporary repair, the bolts on the inner side were fastened with and adhesive resin was packed. Furthermore, a seal-plate was additionally welded between the outer side of the core tank's support-ring and the reactor containment to stop completely the heavy water leakage, because the adhesive resin which was packed on the outer side of the support-ring in 1965 found to be damaged with radiation. A seal-plate was not able to be welded between the inner side of the support-ring and the core tank, because of high radiation dose rate on the welding position. The repair work was performed between July 1968 and January 1969.

1.5. Repair works of lower plug

Two plugs (lower and upper) are used on the core tank as the upper shielding. Rectangular aluminum tubes which were used for fuel handling through the lower plug were warped inward, so that they interfered with movement of the fuel plugs. All the 24 tubes were replaced with new ones between July 1968 and January 1969. The cause of this deformation was considered to be due to corrosion of aluminum tubes. Two years after the repair, corrosion pores on the inside surface of some rectangular tubes were found out. These corrosion pores were packed with adhesive resin as a temporary repair in January 1972. This lower plug will be replace by new one in near future.

2. Troubles on JRR-3

2.1. Fuel failures

From April 1968 to January 1969, fuel failures had occurred at seven times at burn up of about 300 MWD/T. Two of them had significant failed portions and some amount of corroded uranium oxide was released into the heavy water cooling system. Therefore, it became difficult to detect a fuel failure because of increasing of back ground levels on the Failed Fuel Detector system (FFD). It took about one year to purify the heavy water and to make the FFD system work normally. The uranium oxide which was released into the heavy water system was able to be eliminated by using of earthenware filters.

The mechanism of the failure seems that wrinkling grown by irradiation pushed up and splitted the aluminum cladding from inside and heavy water permeated through small cracks and corroded gradually the uranium metal rod.

2.2. Rupture of canned motor's can (DP-1)

We have two main pumps canned motor type in the heavy water cooling system. In August 1970, one of them (DP-1) had been stopped by the action of no fuse circuit breaker and thermal relay. The insulation between the stator coils and pump body was deteriorated. It seemed that heavy water leaked into the stator can.

As the result of disassembling it, the stator can was scratched with the rotor can. The cause, we believed, is abrasion of radial bearings of the canned motor pump and vibrations during its rotation. As it would take about a half year to remanufacture a motor part of the pump, we had to operate the reactor at 7 MW till we had finished to replace it. It was replaced in June 1971.

2.3. Leakage of carbon dioxide gas into heavy water and helium gas system

In January 1971, we noticed that the carbon dioxide gas which was used as coolant in the radio-isotope production system leaked into the heavy water and helium gas system. The electrical conductivity of heavy water was increasing little by little from 0.6 μmho/cm to 2 μmho/cm and its pH was reducing from 7 to 5.5. As the result of inquiry of the cause, a sheet packing (made of neoprene rubber) of vertical irradiation hole was weakened. It took about two months to find out the cause and repair it.

2.4. Heavy water leakage

Treatment of heavy water is very important for a heavy water reactor because of heavy water cost, tritium hazard and the reactivity decrease. The electrical conductivity of heavy water is measured continuously and its pH and concentration are measured once a day during operation periods. We have about 100 heavy water leakage detectors on the heavy water cooling system.

Many troubles of heavy water leakage have been experienced with our reactors. Some of these troubles are tabulated in Table 6. We should pay attention not to leak heavy water while maintaining instruments or facilities of the heavy water cooling system. Because most of all troubles of large heavy water leakage have been experienced while maintaining instruments or facilities of the cooling system.

2.5. Increasing the radiation dose rate in the pump room

Recently the radiation dose rate in the pump room has been gradually increasing. The level came up to 1 R/hr or more on the surface of heavy water coolant pipes. The cause seems due to ^{60}Co which is heaped up on the inside surface of coolant pipes. Because some parts of the heavy water pumps are made of cobalt alloy (e.g. impeller rings, bearings, etc.). Any materials with some elements which have long half lives like cobalt should not be used in the primary cooling system. We intend to change the materials of these parts to the other ones which do not include such elements. At the present time, we are planning to remove ^{60}Co from the coolant pipes. But it is very difficult. Because the pipes on which ^{60}Co heaped up are too intricate to remove them.

3. Troubles on JRR-4

3.1. Contamination of reactor water

The reactor water on JRR-4 is purified by demineralizer and the limitted values of the conductivity and pH are fixed at 10 μmho/cm and from 5.5 to 7.0 respectively. However, the actual value of the conductivity is about 0.5 μmho/cm. In the early few years, main radio-active nuclides detected in the reactor water were ^{24}Na, ^{27}Mg, ^{18}F and ^{41}Ar, and their concentrations were less than 10^{-3} μCi/ml. The reactor water are frequently drained and supplied about half amount of total volume in order to set or remove experimental facilities or materials. Usually, the reactor water will be drained about two days after the reactor is shut down. Because two days are so enough that ^{24}Na and other radio-active nuclides in the water decrease to the level of permissible concentration.

^{140}Ba - ^{140}La, ^{95}Zr - ^{95}Nb and ^{137}Cs had been detected in the water in 1969 when a failed fuel element was found out in the core. The pool wall and the core tank were contaminated up to about 3×10^{-5} μCi/cm^2, and main nuclides were ^{95}Zr - ^{95}Nb, ^{51}Cr and ^{60}Co. They had adhered to the walls with a slight amount of machine oil. For keeping the reactor less contaminated, whole of the reactor water drained and then the reactor water was purified by demineralizer and the wall and bottom of the pool were cleaned by brushing with "Synthetic Detergent" dissolved in pure water mainly included "Sodium-Dodecyl Benzen Sulfonate". After that, those surface were washed with pure water. However, the core tank was not able to be cleaned because of its high activity.

Recently, the core tank, pool wall and bottom were contaminated again. In this case, the active nuclides were ^{51}Cr and ^{60}Co only. It seems to be quite sure to consider that these nuclides are recoiled atoms from stainless steel in the core and stellite particles which are desolved from pumps, valves, etc. in the primary coolant system to the water. We are planning the countermeasures to exclude these nuclides.

As other troubles of water contamination, we have a trouble of transparency of the water. In JRR-4, only demineralyzer is used for the purification of supplied water. Micro-organisms in the supplied water are able to pass through the demineralyzer. They make the transparency of the water decrease. However the no other bad effects to the reactor is recognized. It seems that this trouble occurs especially in the summer season because of suitably high temperature of the water. So we have to take care of the water condition and discontinue the reactor water during summer. Now we have some plans to modify the supply water line for avoiding this trouble as follows;

1) Change the supply water to the sterilized water.

2) Add some mechanical filters after the demineralyzer line in order to take off micro-organisms.

3.2. Shim (control) plate vibration

Before the power up test, we had experienced a fluctuation of nuclear instruments when the reactor was critical at low power with normal flow in the primary coolant. Linear power meter fluctuated in $\pm$ 8 % of the indicated power, and period meter reached to 7 sec. As the result of investigating the cause, the following facts became clear;

1) Shim plates were vibrated by primary coolant flow. Because they were 5 mm in thickness and were moving in 11 mm gaps in the core in order not to make them stick.

2) Mechanical vibration of the shim plates made the reactor power fluctuate. So, the fluctuation of the nuclear instruments occurred as the result of the fluctuation of the reactor power.

Then we added stainless steel rollers with 10 mm diameter to the shim plates for decreasing mechanical vibration as well as avoiding rod stick and added stainless steel support plates for decreasing of their bending. As the result of this modification, movable gaps of shim plates decreased to 1 mm, the period meter noise became longer than 100 sec and the fluctuation of the linear power meter also became less than $\pm$ 3 %.

3.3. Surveying of fuel cladding corrosion

ETR type fuel elements are used in JRR-4. Over half amount of fuel elements has been located in the core for about eight years, because of their low burn-up (about 2 % burn-up per year). A fewer information is obtained that how many years the fuel element can be located in the core against the corrosion of aluminum cladding. In 1969, we found out a ruptured fuel element and performed destructive inspections of this element. As the result of this investigation, the following facts were recognized;

1) Over half alodized cover as a protection against corrosion on the fuel plate surface had lost.

2) Thickness of cladding was in permissible dimension.

From the fact described above, we might conclude that the fuels would be able to be used more several years. And no fuel failure has been found out after that time. However, we will carry out the destructive inspection of the fuel again in near future in order to get some information about lifetime of the fuels in core.

V. IMPROVEMENTS AND MODIFICATIONS

It is one of the purposes for us to construct our reactors in order to get the over-all experiences in reactor design, fabrication and installation. Therefore, we have performed many improvements and modifications of instruments and facilities on our reactor to operate more stably, continuously and effectively as well as to get these experiences. As examples of these improvements and modifications, we describe the modification programme on JRR-2 and the programme to change natural metalic uranium fuels to natural and slightly enriched uranium oxide fuels on JRR-3.

1. Modification programme on JRR-2 [3)]

1.1. General

JRR-2 has been in operation continuously for eight years for utilization service, as described in preceding section. Some of modifications for the reactor facility including control system modularization, main pumps, main heat exchangers, fuel elements, cooling tower and the other necessary repairments were already carried out in consequence of the operation experiences.

However, heavy water leakage, lower plug corrosion and control rod trouble were remained. Now a modification programme for these problems is planning at JAERI.

When forming the plan, it is regarded that both the experience in the past and the utilization in the future must be incorporated with.

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When forming the plan, it is regarded that both the experience in the past and the utilization in the future must be incorporated with.

JRR-2 had many difficulties to be improved or modified. When several corrosion pores were found on the surface of the lower shield plug in February 1972 and when complete repairment for those were found impossible, a modification programme was planned. A study group was set up for the modification plan studying the shielding structure and the control rod mechanism. Among discussions at the group, attentions were paid (1) to stop the heavy water leakage (2) to keep away the shield plug from corrosion (3) to improve the control rod drive mechanism (4) to provide room for in core facilities enough.

A draft of the modification of the top shield was designed according to a report submitted by the group and it was accomplished up to December 1972. JRR-2 will be modified as shown in Fig. 1. Main subjects of the modification are as follows;

1) The lower shield plug will be divided into an annulus plug and a central plug.
2) Rotary type plug in the upper shield plug will be changed to fixed one.
3) Circular fuel guide tubes will be adopted instead of rectangular ones.
4) Two seal plates will be welded each on the heavy water tank flange and reactor containment.
5) Control rods will be driven with ball-nut instead of rack-pinion and their drive shafts will be removed to the reactor top.
6) Top shield disk will be installed newly.

1.2. The upper shield plug modification

Shielding effect on several kinds of shielding materials, such as surpentine and barite rock, iron, lead and combination of these are surveyed for the shielding plugs. After preliminary study, it is concluded that the shielding plug should be made with barite concrete similar to the existing shield plug.

Circular guide tubes instead of rectangular ones will be adopted to avoid deformation accompanied with corrosion products. It is expected also that circular tubes can be welded better. These tubes will have inner diameter of 110 mmϕ to insert the existing B type fuels and new ones.

An annulus plug will be placed on the support ring. This plug have functions to reduce the radiation emitted from the core. The lower shielding plug will be inserted into the lower annulus plug on the support ring, providing 24 fuel element access holes, 7 vertical thimbles, 6 control rod access holes and 3 new vertical thimble holes. Shielding materials used in the plug are dense concrete, lead and boral plate.

The standing seal, closely inserted between these plugs, will be welded at the lower edge to the heavy water tank flange and at the upper to the inner flange of the lower annulus. As the outer flange of this plug will be welded to the reactor containment with thin aluminum plate, the support ring will be isolated from helium gas and heavy water.

Both a top shielding disk and a rotary shutter will be set on the existing reactor top. The control rod horizontal drive shaft and its drive mechanism will be set in that disk. The rotary shutter has 4 fuel handling holes and one control rod hole like the existing rotary plug to reduce radiation emitted from the gap between each fuel plug and its thimble. The existing rotary plug will be replaced to fixed one, that provides 24 fuel holes, 6 control rod holes and 3 new vertical thimbles. The shutter, about 200 cm in diameter, will be rotated by electrical motor adjusting the position to each fuel and control rod hole.

A guide tube array will be welded to the bottom of the lower shielding plug, in order to keep helium gas in the core on refuelling. Therefore, fuel handling works will be done without the helium gas purge and it will be useful to decrease heavy water loss and to keep the heavy water concentration high.

1.3. Control rod modification

For years, the control rod drive system used in JRR-2 has been experienced various mechanical and electrical troubles. Even if control rod assemblies were required repairments, it would be inaccessible to approach vertical assembly because of the high activity. The modified control rod drive system will have two features which help to solve the problem mentioned above. First, the new system will incorporate electrical wire without using naked connector to leadout. Second, the system will incorporate the ball-nut mechanical parts and provisions for its removal without withdrawing the control element from the core.

The control rod assembly will be housed in an outer aluminum tube with a shield block penetrated by ball screw and with a support flange at the middle. The modified drive package, drive shaft and electrical cable will be placed in the top shielding disk. The control element, the neutron absorber, made of cadmium and stainless steel, will be identical as before.

Major differences between two system are drive section consisting of magnet and ball-nut screw instead of rack-pinion, and the location of drive motor on the reactor face instead of the reactor wall. Lifting will be done by a screw assembly with the ball-nut mounted on the top of magnet. The motor drive package consists of limit switches, position readout and rod seat switch.

1.4. Scope

As mentioned above, JRR-2 modification will be carried out during 6 months in 1973 including also the period to cool down radio-activity from the core and the test operation period to check off the reactor for resumption of normal operation.

2. UO_2 fuel programme on JRR-3

The main purposes of this programme are as follows;

1) To secure the more stable operation by using UO_2 fuels which have no chemical reaction with heavy water.
2) To increase neutron flux.
3) To increase the burn-up of fuels and the operation efficiency by using slightly enriched uranium.

We began to change our fuels to UO_2 fuels from January 1972. We will need about two years from beginning to finishing. The outline of this programme is to change out fuels to UO_2 fuels and to add three safety rods. Table 10 shows the nuclear data in each step which is performed on JRR-3. The programme for measurements of the characteristics in each step is shown in Table 11. The outline of UO_2 fuel assembly is shown as follows;

Enrichment : 1.5%(184*), Natural (59*)

Fuel type : Cluster with aluminum shroud tube, 4 segments

(10.83 mmϕ x 2100 mmL)

UO_2 pellet (10.71 mmϕ x 15.0 mmL)

Cladding with Zry-2

see Figure 2

* : The numbers enclosed by parentheses represent the numbers of fuel assemblied in the core

If we will finish this programme, the neutron flux will increase approximately double and the reactor will be used more effectively.

VI CONCLUSION

Our research reactors have been operated in a long time since their first critical.

Many kinds of troubles on reactor instruments and facilities have been experienced. However, no major troubles which proved fatal to the reactor operation have happily occurred.

The philosophy of a reactor's maintenance may be different from one reactor to the other, depending upon the purpose of construction. For example, the philosophy for a test reactor which can be considered to be a facility to develop a new type of a reactor or to test the reactor itself may be much different from that for a research reactor which is a neutron source for various experiments so that fairly steady operation is required. However, improvements of reactor instruments and facilities are useful for getting experiences to design and construct a new research reactor as well as for more stable operation and more eff-outline of UO_2 fuel assembly is shown as follows;

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Any way, the philosophy of maintenance must be established at first. Forcusing the discussion to a research reactor, the philosophy must be established considering the following things.

1. Required condition of operation.

First of all, a standard condition of the reactor must be selected. Then, in practical maintenance works, efforts must be made to keep the standard condition as steady as possible. On our research reactors, the standard conditions were selected to be those at high power test operation after the functional test and low power experiments. Of course, these standard conditions may be revised with operational experiences.

2. Future plans on the use of the reactor.

According to the future plans on the use of the reactor, rough period through which the reactor must be maintained in a standard condition must be evaluated and at the same time, a certain limit on the improvement of the reactor must be set up, because improvements usually require more money than maintenance and the effect of improvement must be always evaluated in comparison with the money spent for. Thus, all maintenance works should be conducted considering these future plans. Our reactors plan to be operated for more than 20 years. Then, as mentioned above, many kinds of minor improvements and modifications of reactor instruments and facilities have been performed as far as they proved desirable and useful.

3. People to maintain the reactor

As mentioned above, it must be examined sufficiently that who will be responsible for maintenance and who will maintain the reactor actually. In the case of our reactors, operators are responsible for maintenance and all maintenance works are conducted by the operators.

As mentioned above, two major modification programmes are being performed. One is the top shield modification programme on JRR-2 and the other is the programme to change the fuels to UO_2 fuels on JRR-3. After performing these programmes, these reactors will be operated and used more stablly and effectively.

VII ACKNOWLEDGMENT

The authors are pleased to acknowledge the considerable assistance of Dr. Hiroshi Amano, Dr. Mitsuho Hirata and Mr. Eiji Shirai.

REFERENCE

1) Division of Research Reactor Operation : JAERI-M 4699 "Mothball of JRR-1" (1972)

2) I. Miyanaga et al. : JAERI-memo 4303 (published) "Operational Experiences of Heavy Water Reactor : JRR-2 and JRR-3" (1971)

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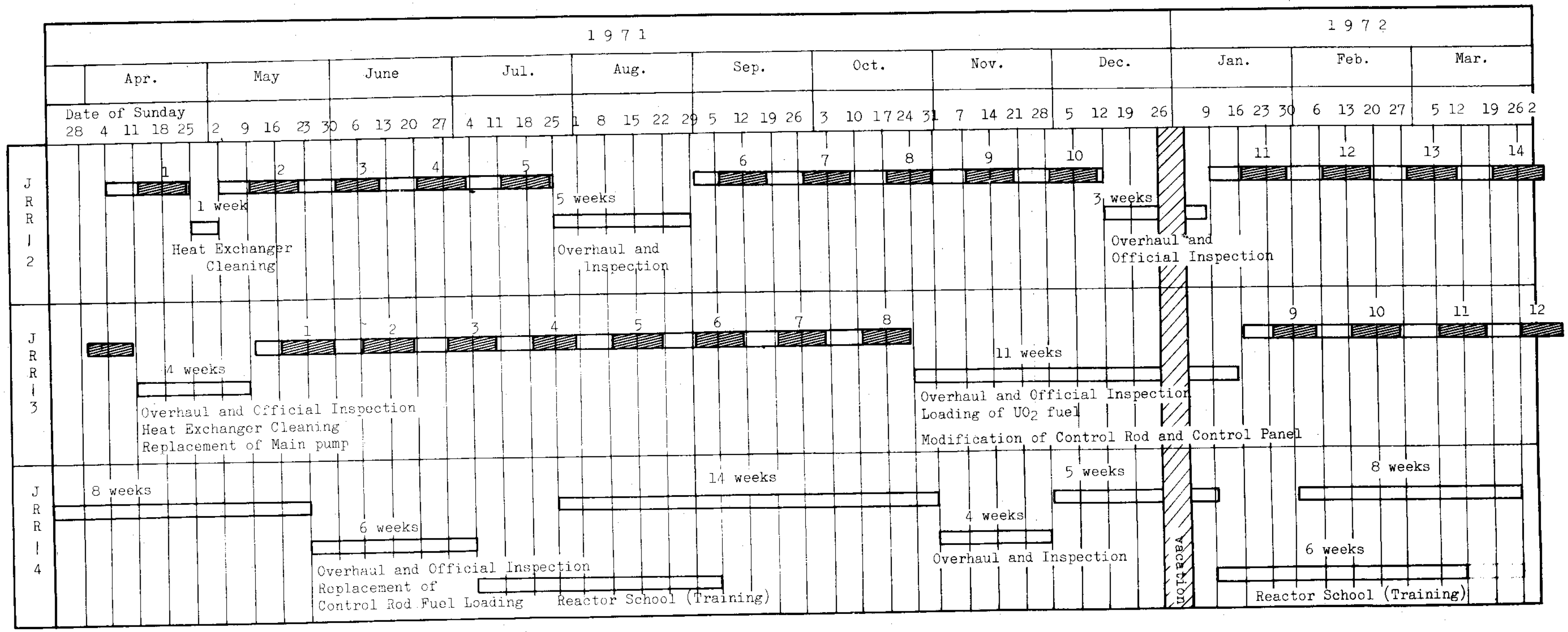
Table 1 OUTLINE OF JRR-1, JRR-2, JRR-3 AND JRR-4

Name of Reactor	JRR-1 (Water-Boiler Type)	JRR-2 (CP-5 Type)	JRR-3 (First Japan-made Reactor)	JRR-4 Swimming-Pool Type)
A. TYPE				
Power	50 KW	10 MW	10 MW	2.5 MW
Flux (n/cm^2 sec)	ϕ_{th} max $1.2x10^{12}$ ϕ_f max $1.5x10^{12}$	ϕ_{th} max $1.8x10^{14}$ ϕ_f max $3.8x10^{13}$	ϕ_{th} max $2x10^{13}$ ϕ_f max $9x10^{12}$	ϕ_{th} max $5.2x10^{13}$ ϕ_f max $1.1x10^{14}$
Fuel	UO_2SO_4 solution, 20 % enriched uranium (1.3 kg of U-235)	Curved plate type, 90% enriched, uranium aluminum alloy, aluminum clad; 22 MTR type fuels, U-235 contents 195 g per element, 2 cylindrical type fuels, 120 g per element. (4 kg of U-235)	Natural metalic uranium, cyrindrical rods, cladding with aluminum. (6 tons of natural uranium)	Plate type; 90% enriched, uranium aluminum alloy, aluminum clad. (3.3 kg of U-235)
Moderator	Light water	Heavy water (9 tons)	Heavy water (28 tons)	Light water
Reflector	Graphite (9.5 tons)		Graphite (80 tons)	
Coolant	Light water		Heavy water	
Core	Sphere: 20 cm dia	Cylinder: 84.5 cm dia x 60 cm h, 24 fuel assemblies loaded.	Cylinder: 260 cm dia x 275 cm h, 246 fuel assemblies loaded.	Rectangular: 26.3 cm x 40 cm x 60 cm h, 20 fuel assemblies loaded
Control rod	4 cylindrical type stainless steel clad Boron-carbide tube.	6 cylindrical type stainless steel clad cadmium tube.	12 shim rods, 2 regulating rods, 3 safety rods(added in Nov. 1971), cylindrical type aluminum clad cadmium tube.	4 plate type, stainless including B-10
Shielding	Dense concrete (1.8 m thick)	Stainless steel(6 sheets), Lead and dense concrete.	Dense concrete (2 m thick)	Light water and concrete
B. HISTORY				
Begin to construct	Aug. 1956	Apr. 1958	Jan. 1959	Jan. 1962
Critical, Full power Ope	Aug. 1957, Nov. 1957	Oct. 1960. Oct. 1962	Sep. 1962. Mar. 1964	Jan. 1965, Mar. 1966
Total operation time	8043 hr	23562 hr (Apr. 1972)	18881 hr (Apr. 1972)	5455 hr (Apr. 1972)
Accumulated power	182 MWH	185373 MWH	152811 MWH	5983 MWH
C. PURPOSE	Fundamental research Personnel training	Fundamental research, isotope production, material irradiation test	Experience in design, construction and operation, development and testing, isotope production	Shielding study for nuclear power ship, general experiment, personnel training
D. Experimental facility	Horizontal holes (9), Vertical holes (4), Thermal columns (2), Pneumatic tube (2)	· Crystalmonochrometer, Crystal type neutronspectrometer, Pulsed type neutronspectrometer, Neutron diffractometer, Thermal-column · Water loop, Gas loop, Sodium loop · In-core irradiation hole (2), Vertical thimble (9), Pneumatic irradiation tube (1), Isotope train(2)	· Neutron diffractometer(4), Neutron spectrometer(1), Compton spectrometer(1), Neutron radiography(1) · Gas loop(2), Fission gas release loop(1) · Pneumatic tube(3), Vertical irradiation facility in core(3), in reflector(27), Horizontal irradiation facility(2), Isotope train (2), Thermal column(1)	· Pool · Lid tank including thermal-column and fast neutron converter (uranium) · Dry shielding test facility including helium and lead filter · Irradiation pipe (reflector area)
E. REMARK	Cease to operate the JRR-1 in October 1968. Draw fuel slution out of the core in December 1969. It has been mothballed as a monument of the first reactor in Japan		Programme to change the metalic fuel to the ceramic fuel Enrichment : 1.5%(184), Natural(59) Fuel type : Cluster with aluminum shroud tube, 4 segment (10.83 mm0 x 2100 mmL) UO_2 pellet (10.71 mm0 x 15.0 mmL) Cladding with Zry-2 Control rod : Adding to 3 safety rods Date : From Jan. 1972 to Apr. 1974.	

Table 2. TIME SCHEDULE OF RESEARCH REACTOR (1971/72)



Cycle Operation ; JRR-2 and JRR-3

1 st week	Sun. Man. Tue. Wed. Thu. Fri. Sat.	Core-cooling Handling of Radio-isotope Refueling Insertion of Irradiation Material Reactivity Measurements Purification of Helium Gas System
2 nd and 3 rd week	Sun. Man. ⟆ Sat.	 Start of Operation (9:00) ----- 13 days operation ----- Shut-down (15:00)

Operation Schedule ; JRR-4

Sun.	
Man.	Preparation of Experiments
Tue.	Operation, Every day (10:00 ~ 17:00)
Wed.	
Thu.	
Fri.	
Sat.	Preparation of Experiments

Note :

Maintenance works are done during one week shut down period for each operation cycle, and during 5 ~ 10 weeks overhaul and inspection period twice a year.

Table 3 HISTORY OF OPERATION AND MAINTENANCE ON JRR-2

Date	Reactor operation	Repair, Modification, etc.
1960		Apr. 1958-Dec. 1959 Reactor construction -Sep. 1960 Performance tests Oct. Critical experiments (20% enriched uranium fuel)
1961	3 MW Many kinds of	
1962	10 MW reactor experiments and Test operation	Apr. Modification of fuel element (20% enriched uranium fuel → 90%)
1963		May. Replacement of pumps (Spare)
1964	5 MW, 130 Hr (16 cycles)	Jul. Piping failure of irradiated air exhaust system in core
1965	8 MW, 130 Hr (2 cycles)	Jul. Support-ring packing damage Sep. Replacement of pumps (Spare)
1966	10 MW, 130 Hr (30 cycles)	Dec. Damage of fuel handling-plug
1967	10 MW, 180 Hr (13 cycles)	Apr. Replacement of main pumps (Spare) Jul. U-tube failure of heat exchanger
1968	10 MW, 200 Hr (8 cycles)	Jul. 1) Repair of lower plug 2) Weldment of support-ring
1969	10 MW, 288 Hr (7 cycles)	3) Modification of control panel board 4) Replacement of main pumps (Spare) Jul. Replacement of main pumps (Spare)
1970	10 MW, 288 Hr (13 cycles)	Jan. Modification of fuel element (175 g U-235 — 195 g) Jul. Replacement of heat exchangers and pumps (Spare)
1971	10 MW, 288 Hr (13 cycles)	Jul. 1) Replacement of main pumps (Spare) 2) Changing of auxiliary pump (mechanical seal — canned motor)
1972	10 MW, 288 Hr (12 cycles)	Mar. Repair of lower plug Aug. Changing of main pumps (mechanical seal — canned motor)

Table 4 HISTORY OF OPERATION AND MAINTENANCE ON JRR-3

Date	Reactor operation	Repair, Modification, etc.
	Jan. 1959 1962 Sep. 1962 1963 - 1964	Comencement of reactor construction Pre-critical tests Critical experiments Performance tests
1965	10 MW, 68 Hr 10 MW, 88 Hr 10 MW, 88 Hr (6 cycles) 10 MW, 100 Hr (5 cycles)	Jan. Government's licence for performance examination of 10 MW operation.
1966	10 MW, 130 Hr (5 cycles) 10 MW, 130 Hr (15 cycles)	Feb. Modification of ion exchange column.
1967	10 MW, 240 Hr (13 cycles)	Jan. Installation of heavy water condencer in helium gas system. Aug. Modification of ion exchange column.
1968	10 MW, 240 Hr (7 cycles) 10 MW, 288 Hr (5 cycles)	Jan. Breakage of secondary coolant pipe. Apr. Fuel failure (No. 1) Oct. Fuel failure (No. 2 - No. 5) Nov. Fuel failure (No. 6)
1969	Halt of reactor operation	Jan. Fuel failure (No. 7) Apr. - Mar. '70 Purification of heavy water system and maintenance of F.F.D. system. Nov. Trouble on the auxiliary pump(DP-3)
1970	10 MW, 240 Hr (1 cycle) 10 MW, 288 Hr (6 cycles) 7 MW, 288 Hr (7 cycles)	Aug. Rapture of canned motor's(DP-1) can
1971	7 MW, 80 Hr (1 cycle) 7 MW, 140 Hr (1 cycle) 10 MW, 288 Hr (9 cycles)	Jan. CO_2 gas leakage into He gas system May. Replacement of canned motor pump, DP-1.
1972		Jan. Change 61 metalic fuels to UO_2 fuels (STEP I) Jun. Change 57 metalic fuels to UO_2 fuels (STEP II) Aug.- Nov. Putting out a testing fuel which was dropped into the core while refueling

Table 5 HISTORY OF OPERATION AND MAINTENANCE ON JRR-4

Date	Reactor operation	Repair, Modification, etc.
		Apr. 1962-Dec. 1964 : Reactor construction
1965	Sum power : 10MWD	Feb.-Mar. : Critical experiment and zero-power experiments (standard core : 16 fuels) Apr.,May. : Shim control plate modification
1966	Operation : 127 days Sum power : 30 MWD	Aug. : Repair core tank leg and He-filter
1967	Operation : 137 days Sum power : 41 MWD	
1968	Operation : 123 days Sum power : 30 MWD	Jan.: Add reflector elements to thermal-column site in core Jun.: Replacement of Shim-plates. Add two fuel element (18 fuels standard core) Stand two irradiation pipes in core Modification of thermal-column and Lid-tank
1969	Operation : 157 days Sum power : 35 MWD	Jan.: Modification of control desk for reactor school Modification of core tank for transfer activated materials from core to pool Jun.: Findout a failed fuel element Modification of LogN-Period detector case Nov.: Cleaning of pool
1970	Operation : 171 days Sum power : 45 MWD	Feb.: Mount a filter in primary collant line
1971	Operation : 167 days Sum power : 59 MWD	Apr. and Jul.: Shim-plate stick by swelling of reflector cladding Jun.: Add two fuel elements (20 fuels standard core) Modification of other core elements
1972		Jun.: Fire of under roof in reactor room Aug.: Decrease of pool water transparency

Table 6 OUTLINE OF HEAVY WATER LEAKAGE TROUBLES IN JRR-3

I. Troubles of heavy water leakage while maintaining instruments of cooling system

CONTENTS OF TROUBLES	DATE	LEAKED VOLUME	RECOLLECTED VOLUME	CAUSE AND COUNTERMEASURE
1. Leakage from a flange of D_2O filter	17/ 1/63	850 l	740 l	Poor fitting of the flange on D_2O filter body
2. Leakage from a drain valve of flow meter on purified D_2O monitor	1/ 7/65	75 l	15 l	Poor closing of a drain valve
3. Leakage from drain pipe of main D_2O pipe's expansion joint at the time of modification work	17/ 4/68	65 l	60 l	Caused by some mistake of modification work
4. Leakage from temporary piping of delayed neutron tank in F.F.D. system	20/ 2/70	86 l	81 l	Caused by some mistake of maintenance work
5. Leakage from sampling tubes which were connected between fuel assembly and pipe of F.F.D. system	7/ 7/70	175 l	97 l	Breakage of neoprene rubber sampling tubes Thickness of tubes was increased

II. Troubles of heavy water leakage during the reactor operation

CONTENTS OF TROUBLES	LEAKED VOLUME or LEAK RATE	CAUSE AND COUNTERMEASURE
1. Leakage from valve sheets of diaphragm type valves	10 cc	Neoprene rubber sheets became weak with the lapse of time
2. Leakage from mechanical seal of overflow pumps (DP-4, 5)	60 cc/hr	Caused by wearing of mechanical seal They were changed with new ones in Nov. 1968
3. Leakage from O-ring seal of flow meters in F.F.D. system	10 cc	Caused by wearing of O-ring seal They were changed with new ones at that time

Table 7 MAIN ITEMS OF PERIODICAL INSPECTION. (Governmental inspection)

This inspection is performed in the presence of the government's inspector.

Measurement of many kinds of saturation values during the reactor operation at nominal power (10 MW).

a. Temperature of heavy water, light water, secondary coolant, carbon dioxide gas, etc.

b. Radiation dose rate in reactor room.

c. Activity monitor of dust and air at the stack.

Functional tests of heavy water dump, emergency instruments and safety valves.

Functional test of control rod drive mechanism.

Functional tests of interlock, scram, reverse and alarm.

Calibration of control rod reactivity worth.

Measurement of excess reactivity.

Check of fresh and spent fuel storage and waste disposal facilities.

Table 8 MAIN ITEMS OF PERIODICAL INSPECTION. (Over-haul)

This inspection is performed by our responsibility.

I. Instruments and facilities of cooling systems
(Heavy water system, Helium gas system, Thermal shield cooling system, Carbon dioxide gas in reflector system, Radio-isotope production facility cooling system, Emergency cooling system, Secondary cooling system, Waste water system, etc.)

1. Inspection on electrical facilities.
   a. Insulation check of electrical facilities.
   b. Measurement of motor wire's resistance.
   c. Check and cleaning of contact points of operating switches on pumps, blowers, etc.
   d. Check of announciator lamps.
   e. Calibration of volt-meter, ampere-meter, etc.
   f. Working test of inter-lock and alarms.
2. Inspection on mechanics.
   a. Measurement of pumps' and blowers' characteristics.
   b. Overhaul of pumps, blowers and other facilities.
   c. Functional test of emergency system and safety valves,
3. Others.
   a. Cleaning of heat exchangers.
   b. Oil and grease supply on pumps, blowers, valves and other facilities
   c. Vibration measurement of instruments and facilities on cooling systems.

II. Measuring instruments in cooling systems.
   a. Calibration of thermometer, flow-meter, pressure-meter, level-meter, etc.
   b. Overhaul of recorders.
   c. Functional test of alarm, reverse and scram of these instruments.

III. Neutron flux measurement and control system.
   a. Calibration of Log N and period channel, power channel, safety channel, automatic control channel and galvanometer channel.
   b. Functional test of interlock, alarm, reverse and scram on these instruments
   c. Overhaul and functional test of control rod drive mechanism.
   d. Insulation check of these instruments.

IV. Other instruments.
(Electronic instruments of F.F.D. system. Activity monitor in heavy water, carbon dioxide gas, helium gas, light water and secondary coolant, Measuring instrument of differential temperature between inlet and outlet coolant of a fuel assembly. Other instruments.)
   a. Insulation check of these instruments.
   b. Calibration of these instruments.
   c. Functional test of alarms.

Table 9 NUMBER OF TROUBLES IN JRR-3

		1968	1969	1970	1971
Cooling system	A	1	0	5	2
	B	3	0	0	2
	C	23	12	16	4
	T	27	12	21	8
Instruments of water-gas measurement	A	1	0	1	0
	B	0	0	2	0
	C	30	19	24	13
	T	31	19	27	13
Instruments of neutron flux measurement and control	A	6	0	1	2
	B	5	4	2	2
	C	29	6	24	21
	T	40	10	27	25
* F.T. and ** F.F.D.	A	4	0	0	0
	B	2	0	2	0
	C	31	9	21	16
	T	37	9	23	16
Others	A	12	1	8	8
	B	4	0	0	2
	C	19	6	23	0
	T	35	7	31	11
Total	A	24	1	15	12
	B	14	4	6	6
	C	132	52	108	54
	T	170	57	129	72

* F.T. : Measuring instrument of differential temperature between inlet and outlet coolant of a fuel assembly

** F.F.D. : Failed fuel detector system

A : Number of troubles during nominal oper on with unscheduled shut down

B : Number of troubles at starting up with unscheduled shut down

C : Number of minor troubles without shut down

T : Number of all troubles experienced (T = A + B + C)

Table 10 NUCLEAR DATA OF JRR-3

		STEP 0	STEP 1	STEP 2	STEP 3	STEP 4
Number of fuel assemblies in the core	MNU	246	185	125	66	0
	NUO_2	0	0	0	59	59
	EUO_2	0	61	118	118	184
Date		—	Jan. '72	Jun. '72	July '73	Apr. '74
Weight of loading U (T)		6	5	3.9	2.9	1.7
Weight of loading U-235 (Kg)		45	38	34	27	22
Neutron flux in the core (mean)	ϕ_f (n/cm^2sec)		$2.0x10^{12}$	$2.0x10^{12}$	$2.2x10^{12}$	$2.3x10^{12}$
	ϕ_{ep} (n/cm^2sec)		$2.4x10^{12}$	$2.5x10^{12}$	$2.7x10^{12}$	$2.8x10^{12}$
	ϕ_{th} (n/cm^2sec)	$9.0x10^{12}$	$1.2x10^{13}$	$1.3x10^{13}$	$1.6x10^{13}$	$1.6x10^{13}$
K_{eff}		1.05	1.069	1.112	1.107	1.149
Excess reactivity ($\%\Delta k/k$)	*Cal.		6.1	9.9	9.0	12.3
	*Meas.	4.2	6.7	10.6	6.6	—
Poison (Xe, Sm)		2.1	2.6	2.9	3.2	3.3
Temperature effect		0.8	0.8	0.8	0.8	0.8
Burn up			0.5	3.5	2.3	5.0
Experiment, Irradiation		1.3	1.5	2.0	2.0	2.5
Operation			0.7	0.7	0.7	0.7
Number of control rods	Regulating rod	2	2	2	2	2
	Shim rod	12	12	12	12	12
	Safety rod (added)	0	3	3	3	3
K_{eff} (all rods in)			0.879	0.912	0.887	0.933
Shut down margin ($\%\Delta k/k$)	*Cal.		-13.8	-9.6	-12.8	-7.2
	*Meas.		-8.0	-4.9	-9.0	—
Total worth of control rods ($\%\Delta k/k$)	*Cal.		19.9	19.5	21.8	19.5
	*Meas.	11	14.7	15.5	15.6	—

Note
- *Cal. : Calculated value
- *Meas. : Measured value
- MNU : Natural uranium metallic fuel assembly
- NUO_2 : Natural uranium ceramic fuel assembly
- EUO_2 : 1.5% enriched uranium ceramic fuel assembly

Table 11. ITEMS OF REACTOR CHARACTERISTICS EXPERIMENTS

Date of experiments	STEP 1	STEP 2	STEP 3	STEP 4
	Jan. '72	Jun. '72	Jun. '73	Apr. '74
1. Critical experiment	O	O	O	O
2. Control rod calibration	O	O	O	O
3. Measurements of reactivity coefficient				
a. Temperature coefficient		O		O
b. Fuel coefficient		O		O
c. Reactivity effect with D_2O dump		O		O
d. Reactivity effect of experimental holes		O		O
4. Neutron flux measurement and power calibration	O	O	O	O
5. Neutron flux measurement in experimental holes and irradiation holes				O
6. Radiation survey in the reactor room	O	O	O	O
7. Activity monitoring with stack gas and dust	O	O	O	O
8. Analyses of coolant water and gas				
9. Reactivity effect of Xenon poisoning				O
10. Power up test	O	O	O	O

Note O : Items of experiment to be performed in each step.

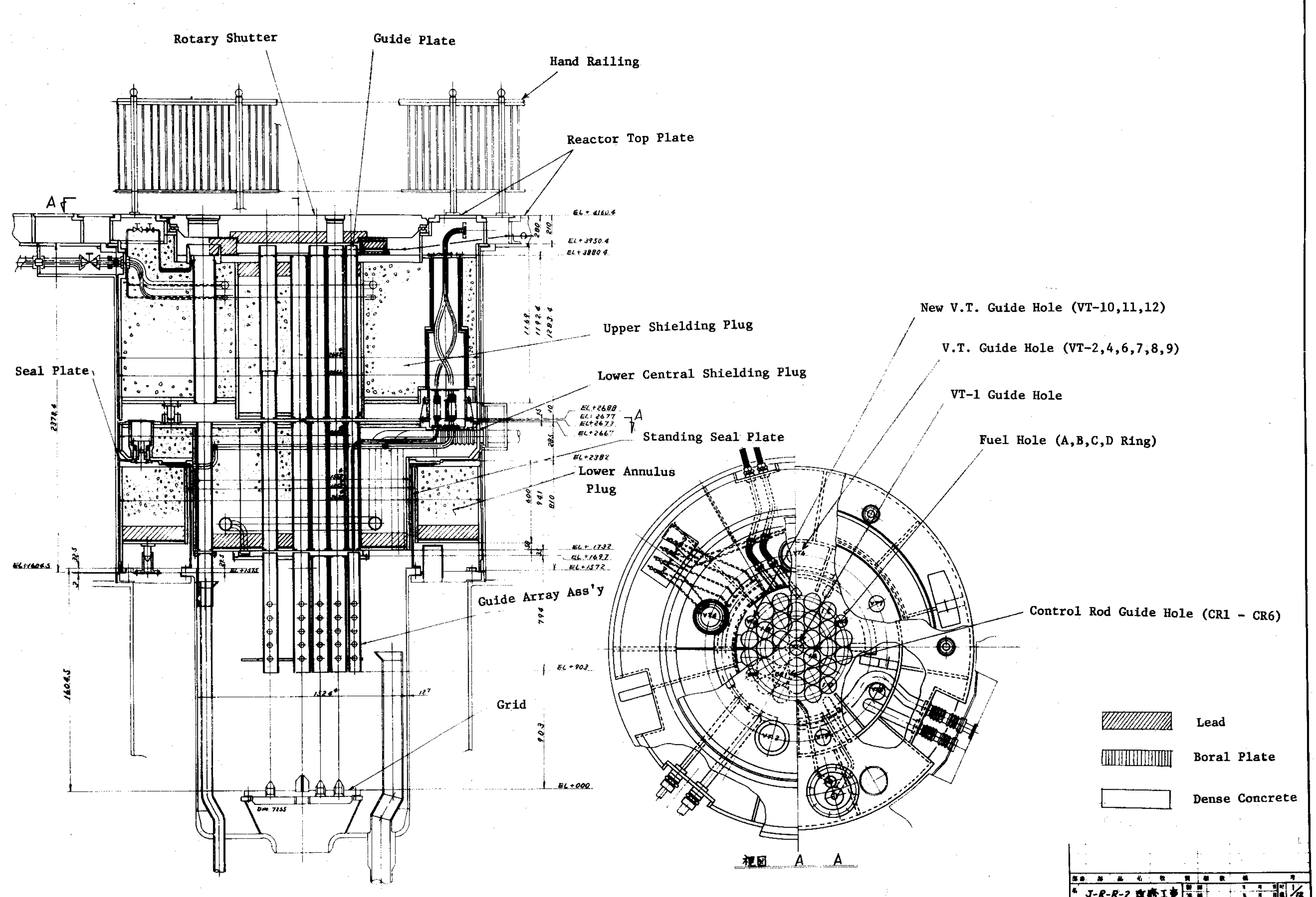


Fig. 1 Upper and Lower Shield Cross Section in JRR-2 (Modification)

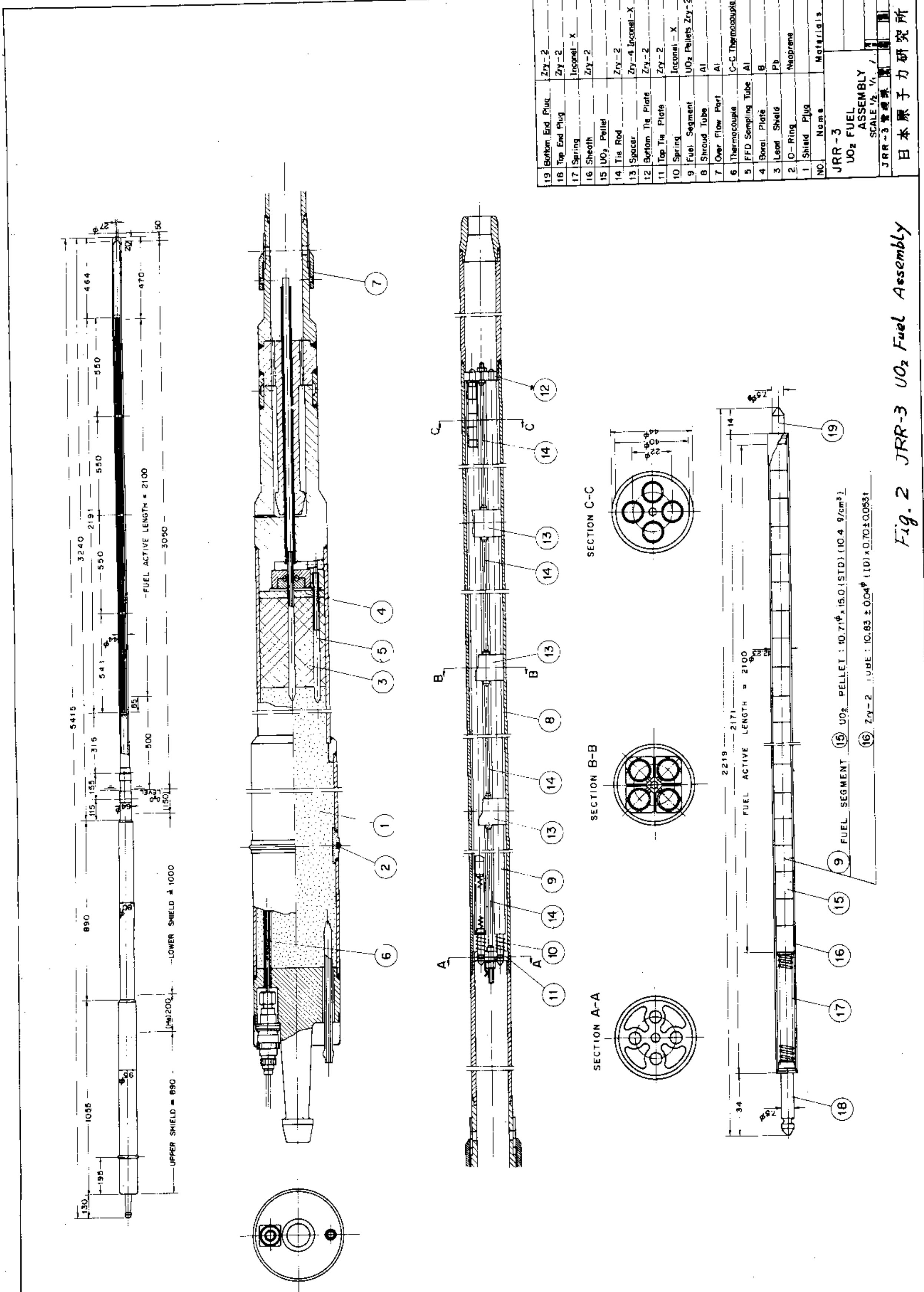


Fig. 2 JRR-3 UO_2 Fuel Assembly