Characteristic Measurements of Silicide Fuel Core in JRR-3M

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ABSTRACT

The JRR-3M (Japan Research Reactor No.3), a light water moderated and cooled pool-type research reactor with maximum thermal power of 20MW using low enriched uranium fuels, attained first criticality on March 22, 1990, and has been operated for beam experiments, irradiation test of reactor fuels and materials, production of radioisotopes, and so on.

The fuel conversion of the JRR-3M was projected from the aluminide (UAlx-Al) fuels to the silicide (U_3Si_2-Al) fuels in order to reduce the number of spent fuel generated a year. For the purpose of controlling increased excess reactivity due to an increase of uranium loading, the silicide fuel elements install the cadmium wires covered by the aluminum alloy as the burnable poison.

The characteristic measurements of the silicide fuel core were started on September 6, 1999. The minimum critical core, the excess reactivity, reactivity worth of control rods, moderator temperature coefficient of reactivity, heavy water dump effect, etc. were main measurements of the fuel conversion. As the result, the minimum critical core was achieved with 15 standard fuel elements, the excess reactivity was measured to 14.1%Δk/k , shut down margin was measured to 19.3%Δk/k, heavy water dump effect was measured to 1.55%Δk/k. Beside, the characteristic measurements correspond approximately with results of the neutronics design calculations and the aluminide fuel core.

The obtained data can be utilized for operation and management of the JRR-3M with the silicide fuel core. The silicide fuel core of JRR-3M has resumed the operation for joint utilization on November 15th, 1999.

1.Intoduction

The JRR-3M (Japan Research Reactor No.3 Modified) adopted the batch-refueling method that 26 standard fuel elements were categorized into 5 groups and all fuel elements were changed in 5 cycles while operating at high net working rate as seven or eight operation cycles in a year. A cycle is continuous operation for 26 days. As a result, a lot of spent fuel elements had been generated. The core conversion was carried out in order to reduce the number of spent fuel generated a year. The conversion points are as follows; ① the fuel meat was changed from the uranium-aluminum dispersion alloy (UAlx-Al) to the uranium-silicon dispersion alloy (U_3Si_2-Al) with the high uranium density, ② the burn up–management method was chosen for refueling method, ③ the maximum burn up of fuel element was changed to 60%, ④ the cadmium wires are inserted in the fuel element as the burnable poison. The JRR-3M obtained the national permission for changing in January 1998, and the characteristics measurements of the silicide fuel core were carried out from September 6^{th} to November 14^{th} 1999, so as to confirm validity of results of neutronics design calculations and safe and stable reactor operation while keeping the performance comparable to the aluminide fuel core.

2.JRR-3M

The JRR-3M is a light water moderated and cooled, beryllium and heavy water reflected pool type research reactor with maximum thermal power of 20MW using low enriched uranium (LEU) plate-type fuels. The core of the JRR-3M is composed of 26 standard fuel elements, 6 follower fuel elements with neutron absorber, 12 pieces of beryllium reflector, etc. and installed on the bottom of the reactor pool. A heavy water tank is installed around the core. A schematic diagram of the JRR-3M is shown in Figure 1.

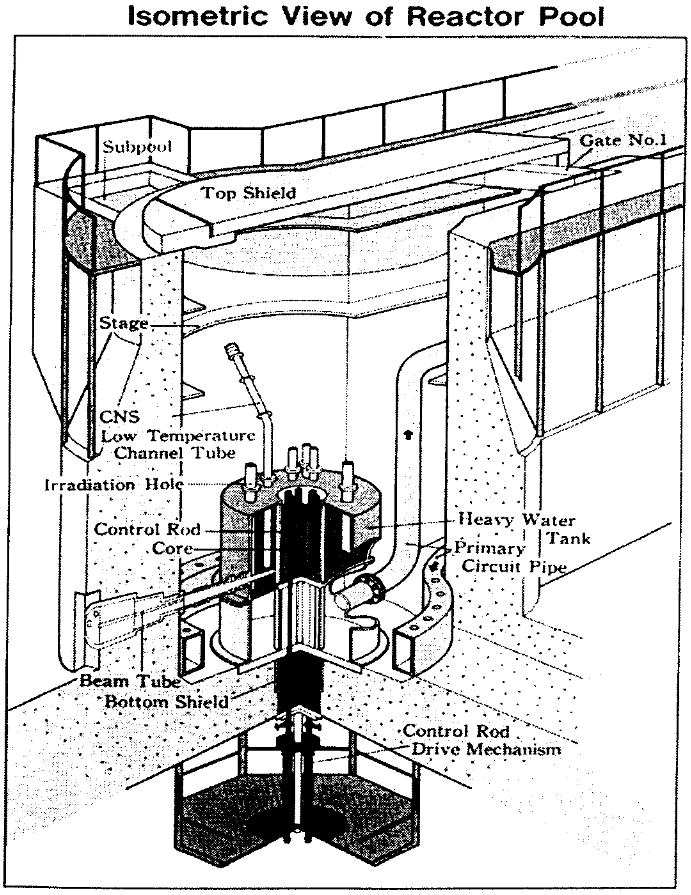

Figure 1 Bird's-eye View of the reactor

3.Silicide Fuel Element

The comparison between the silicide fuel element and the aluminide fuel element is shown in Table 1. A schematic diagram of the silicide fuel elements is shown in Figure 2. The silicide standard fuel element is composed of 21 fuel plates, side plates, nozzle, 42 cadmium wires and so on. The Cd wires are inserted between the side plate and the fuel plate in order to repress the initial excess reactivity, which was caused by increase of uranium loading amount.

Table 1 Specification of standard fuel element

Items	Silicide fuel	Aluminide fuel
Size of element ($\times 10^{-3}$m)	76×76×1,150	
Enrich of U-235(wt%)	20	
Density of uranium($\times 10^{3}$kg/m^{3})	4.8	2.2
Mass of U-235($\times 10^{-3}$kg)	472	300
Size of plate($\times 10^{-3}$m)	1.27×71×770	1.52×71×770
Number of plates (number/element)	21	20
Coolant channel($\times 10^{-3}$m)	2.35	2.28
Cladding	Aluminum alloy	
Maximum Burn-up (%)	60	50
Burnable poison	Cadmium wire	-

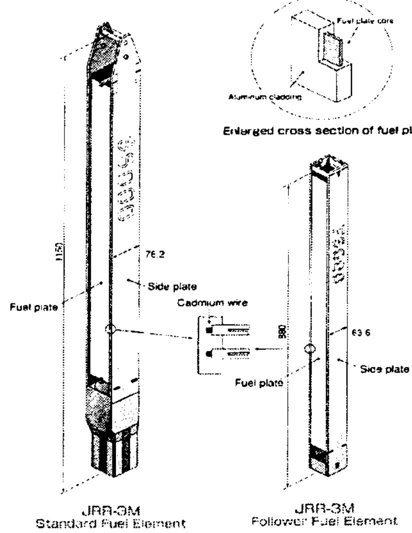

Figure 2 Silicide fuel element

4. Results of characteristic measurements

4.1 Temporary Neutron Instruments system and Neutron Source

For the characteristic measurements, 6 temporary neutron detection systems were installed. Four BF_3 detectors were placed in the irradiation holes and two Compensated Ionization Chambers (CIC) were placed in the heavy water tank. The neutron source, irradiated antimony, was placed in beryllium reflector. Positions of the detectors are shown in Figure 3.

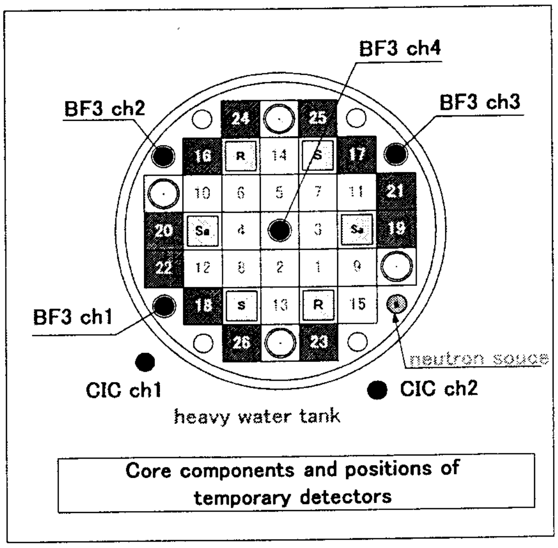

Figure 3 horizontal cross section of reactor core

4.2 Criticality approach test

Loading of standard fuel element was started on September 13th. Figure 3 shows the order of fuel element loading. Inverse multiplication factor was measured at every fuel-loading step.

Inverse multiplication factor of loading fuel element is shown in Figure 4. The minimum critical core consisted of 15 standard fuel elements with 6 follower fuel elements.

The minimum critical mass was estimated at 8.82kg U^{235}. Effective multiplication factor (keff) was calculated 1.00671 with Monte Carlo MVP code under the condition that 15 standard fuel elements are loaded in the reactor core. The measurement of minimum critical core corresponds approximately with the results of neutronics design calculations.

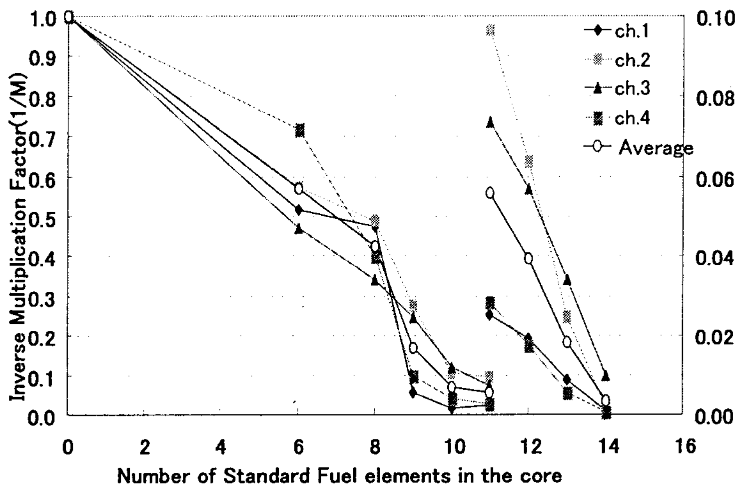

Figure 4 Inverse multiplication factor of loading fuel element

4.3 Excess reactivity

After the criticality approach test, fuel element loading was continued one by one up to the full core configuration. The reactivity added by loading a fuel element was measured by the inverse kinetic method. The excess reactivity was given by adding up the reactivity of loading fuel element as shown in Figure 5. The excess reactivity was measured to 14.1%Δk/k at 20℃, and estimated at 14.9%Δk/k with SRAC code system that is a general purpose neutronics code system applicable to core analyses of various types of reactors. The excess reactivity corresponds approximately with results of neutronics design calculations and was confirmed within 18.1%Δk/k that was permitted in the safety review.

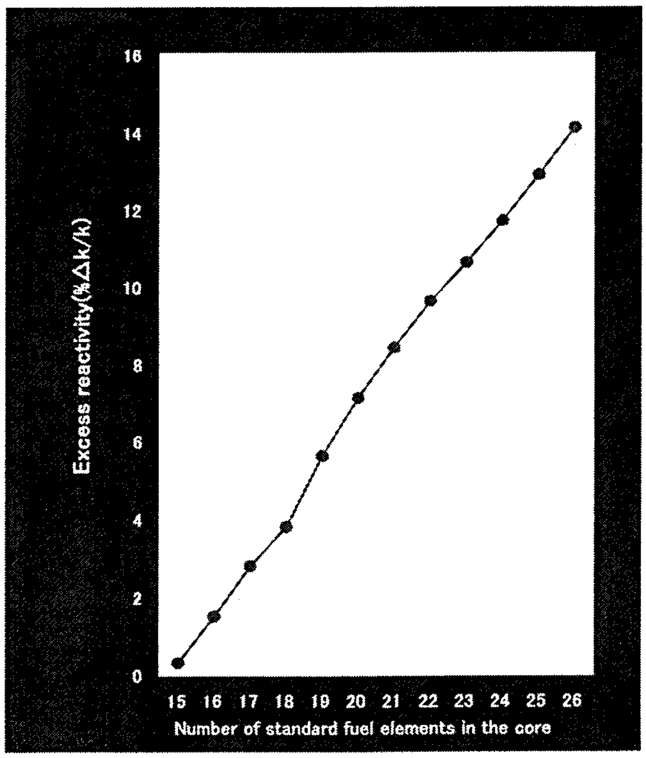

Figure 5 Excess reactivity of every loading element

4.4 Control rod worth

Table 2 Control rod worth

Control rod	Reactivity (%Δk/k)
Sa-1	4.3
Sa-2	4.6
S-1	4.0
S-2	3.9
R-1	3.5
R-2	3.7
Total	24.0

The control rod worth was measured by the inverse kinetic method. The result is shown in Table 2. Control rod worth of the shim rod was 3.9～4.6%Δk/k and the regulating rod was 3.5/3.7% Δ k/k. The reactivity control ability, the total control worth without adding the maximum control rod worth, was measured 19.4%Δk/k and confirmed over 19.1%Δk/k that was permitted in the safety review.

The shut down margin is one of the most important parameter on the reactor core. It was evaluated from the measured value of the excess reactivity and the control rod worth using the following equation.

$$\rho_s = \rho_T - \rho_{ex} - \rho_{max}$$

Where,

ρ_s : shut down margin

ρ_T : total control rod worth (=24.0%Δk/k)

ρ_{ex} : excess reactivity (=14.1%Δk/k)

ρ_{max} : maximum control rod worth (=4.6%Δk/k)

Therefore, shut down margin was estimated 5.3%Δk/k. And besides shut down margin was confirmed over 1%Δk/k that is permitted in the safety review.

4.5 Heavy water dump effect

The reflector of JRR-3M is beryllium and heavy water. As the backup shutdown system, the heavy water dump effect is expected to give negative reactivity enough to shut down the reactor when the control rod is stuck. The schematic diagram of heavy water dumping system is shown in Figure 6. Heavy water in the heavy water tank was drained through the dump valves. And then the reactivity of heavy water dump was measured to -1.55%Δk/k. According to the analysis, the reactivity of heavy water dump was estimated -1.64%Δk/k.

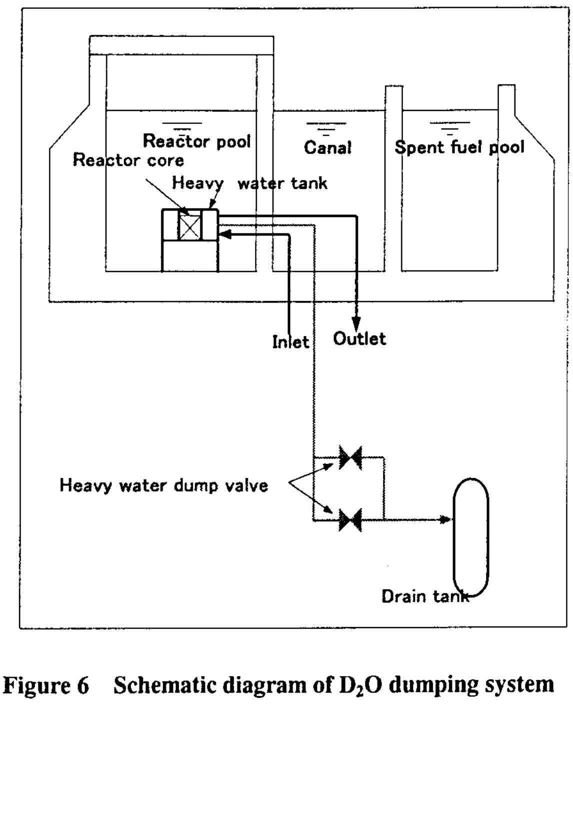

Figure 6 Schematic diagram of D_2O dumping system

As for the aluminide fuel core, the reactivity of heavy water dump was estimated -1.60%△k/k. Therefore, the measurement of heavy water dump effect corresponds approximately with results of neutronics design calculations and the aluminide fuel core.

4.6 Moderator temperature coefficient of reactivity

The moderator temperature coefficient of reactivity, which is one of the feedback effects, was measured without secondary cooling system operation while the primary water temperature was more and more increased using primary pump joule's heat. The moderator temperature coefficient of reactivity was measured to –0.013%△k/k/℃. As for the aluminide fuel core, the moderator temperature coefficient of reactivity was measured to –0.010%△k/k/℃. Therefore, the measurement of the moderator temperature coefficient of reactivity corresponds approximately with results of the aluminide fuel core.

5. Conclusion

The core conversion from the aluminide fuel to the silicide fuel was carried out in order to reduce the number of spent fuel generated a year. The main nuclear reactor physics parameters were measured. And the results of measurements are as follows:

(1) The minimum critical core was achieved with 15 standard fuel elements with 6 follower fuel elements on September 17^{th}, 1999.

(2) The excess reactivity was measured to 14.1%△k/k.

(3) The reactivity control ability was measured to 19.4%△k/k.

(4) The shut down margin was estimated 5.3%△k/k.

(5) Heavy water dump effect is -1.55%△k/k of negative reactivity.

(6) The moderator temperature coefficient of reactivity was measured to –0.013%△k/k/℃.

The characteristic measurements correspond approximately with results of neutronics desigh calculations and the aluminide fuel core. The obtained data can be utilized for operation and management of the JRR-3M with the silicide fuel core. The silicide fuel core of JRR-3M has resumed the operation for joint utilization on November 15^{th}, 1999.