THE TEST METHOD AND SOME RESULTS FOR WWR-M FUEL.

G.A. Kirsanov, K.A. Konoplev, Yu.P. Saikov, A.S. Zakharov.

Petersburg Nuclear Physics Institute, Russia

Presented at:
The 1998 International
Reduced Enrichment for Test Reactor Conference
Sao Paulo, Brazil
October 18-23, 1998

THE TEST METHOD AND SOME RESULTS FOR WWR-M FUEL.

G.A. Kirsanov, K.A. Konoplev, Yu.P. Saikov, A.S. Zakharov.

Petersburg Nuclear Physics Institute, Russia

1. Definition of Non-Integrity of Fuel Elements

In WWR-M reactors, the parameter used as the operational indicator of fuel elements non-integrity is the criterion (β), defined as the ratio of the number of fission fragments leaking out in the coolant to the number of fission fragments generated in the fuel [1, 2]. For stable equilibrium conditions:

$$\beta = \frac{V}{q}, \text{ where}$$

V - is the leakage out rate of nuclide from the fuel element into the coolant, and

q - is the rate of nuclide generation in the fuel.

The notion of non-integrity may be applied to an individual assembly, the entire core, or an individual fuel element.

Admissible β values for a reactor core is limited on the radiation created by fission products within the reactor premises and environment.

The average non-integrity of each fuel assembly determines the β value for the entire core. β values within an individual fuel assembly change in the course of the burn-up process. Each individual fuel element within the core operates in different modes, is subjected to reloading, and has its specific variations in plating thickness, fuel concentration, etc. These factors turn the functional dependence of the β parameter to the burn-up process into a purely statistical indicator. The relation of β to specific heat energy generation may vary considerably (3 times or more) between individual fuel assemblies. However, the general variation pattern has been identified sufficiently well to enable us to form an opinion on the operational characteristics of an individual fuel element as early as after its initial operating cycles.

Fuel elements are usually tested in the reactor's core. However, to be measured for non-integrity they have to be reloaded to the loop channel (Fig. 1) [3]. During measurement, the reactor operates at its full capacity. A fuel element releases approximately 50 percent less heat in the loop channel compared to its average heat release in the core.

Table 1 below compares the operating parameters of regular WWR-M5 fuel elements in the core and in the loop with the reactor operating at a capacity of 18 MW.

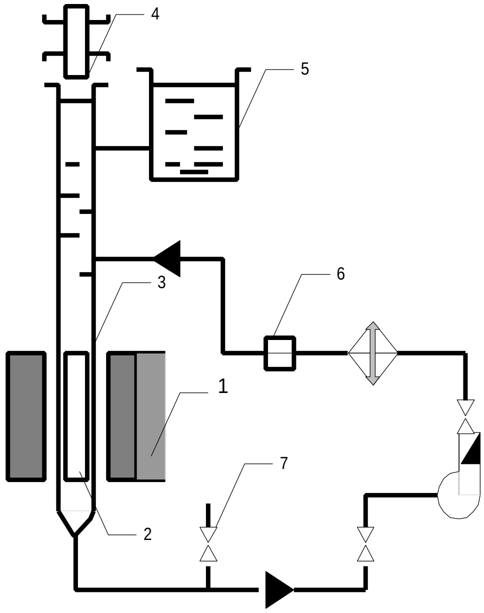

Figure 1. Loop Chart for Fuel Element Testing
1 - the core, 2 - fuel element tested, 3 - loop channel, 4 - gas collector and gas sampler, 5 - water feeder, 6 - delayed neutron detector, 7 - water sampler

Table 1. Operating parameters of regular WWR-M5 fuel elements in the core and in the loop with the reactor operating at a capacity of 18 MW.

Parameter	Core	Loop Channel
Maximum heat release for different loading, KW/l MW/m^2	450 ÷ 750 0.7÷ 1.2	≤150 ≤ 0.3
Coolant velocity, m/s	4	≤ 4
Fuel element wall temperature, °C	≤ 95	≤ 95
Mean thermal neutron flux , $n/cm^2.c$	8.10^{13}	6.10^{13}

2. Choice of Nuclides for b Measurement

In principle, the β value will depend on the nuclide chosen for the measurement.
We conducted our measurement using the sum total of fission radionuclides I+Br, Sr, Ba; individual nuclides Kr-85m, Kr-87, Kr-88, Xe-135 and Xe-138. Relative measurements were done using the Te-132 radionuclide on a shut down reactor. In the loop channel, the delayed neutron count method also was used. The resultant spread in readings, depending on the choice of detectable radionuclide, did not exceed the spread of β values for several individual fuel elements of the same type. According to the accepted practice for WWR-M reactors, measurements are conducted using the following five radionuclides: Kr-85m, Kr-87, Kr-88 , Xe-135 and Xe-138.

3. Uranium Content on Fuel Element Surfaces

For fresh fuel elements, uranium content on the fuel element's surfaces is assessed using the non-integrity parameter. Usually, a fresh fuel element will have a non-integrity value of around $\beta=0.2.10^{-7}$, which indicates a surface content of uranium 235 of about 5.10^{-10} g/cm^2. One of the assumptions underlying this method of surface uranium content measurement is that no fission fragments leakage occurs from the nuclear fuel layer.

We conducted direct measurement of uranium content using the track detection method. The average uranium 235 surface contamination value was $(3\pm1).10^{-10}$ g/cm^2 [4], i.e. a very close approximation to the value derived from the β parameter. The distribution of surface contamination is shown in Figure 2.

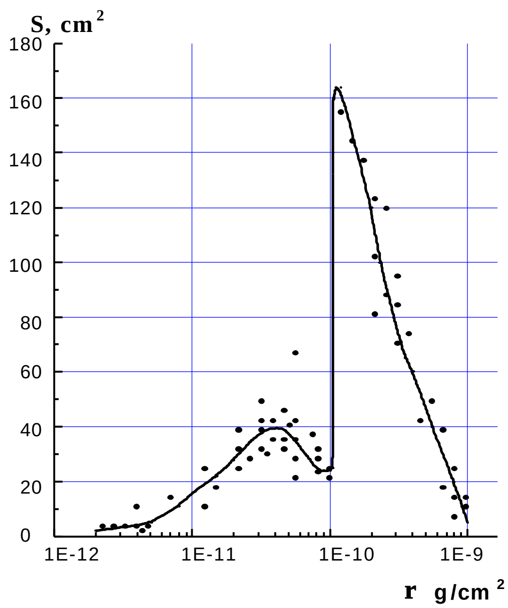

Figure 2. Uranium 235 Density Distribution Across Fuel Element Surface

4. <u>Alteration in Non-Intagtity During the Burn-Up Process</u>

The β values for fresh fuel were well below the core value of $\beta=(20\div40)10^{-7}$, and the contribution of the initial (i.e. the manufacturer's) surface contamination to the coolant's fission fragment activity was negligible. Just after the fuel elements are placed inside the core, when the burn-up level does not yet exceed 1÷2%, β values sharply increase (by a factor of 3 or more) and remain steady until the burn-up level reaches 10%. This behavior may be accounted for by the uranium sorption on the fuel element's surface. The uranium traces usually exists in the cooling system. This explanation is partially corroborated by our tests whereby we first cleaned the fuel element's surface, and then re-measured the β parameter.

The non-integrity value variation over the course of the nuclear fuel burn-up process in fuel elements used in the reactor is shown in Figure 3 [5].

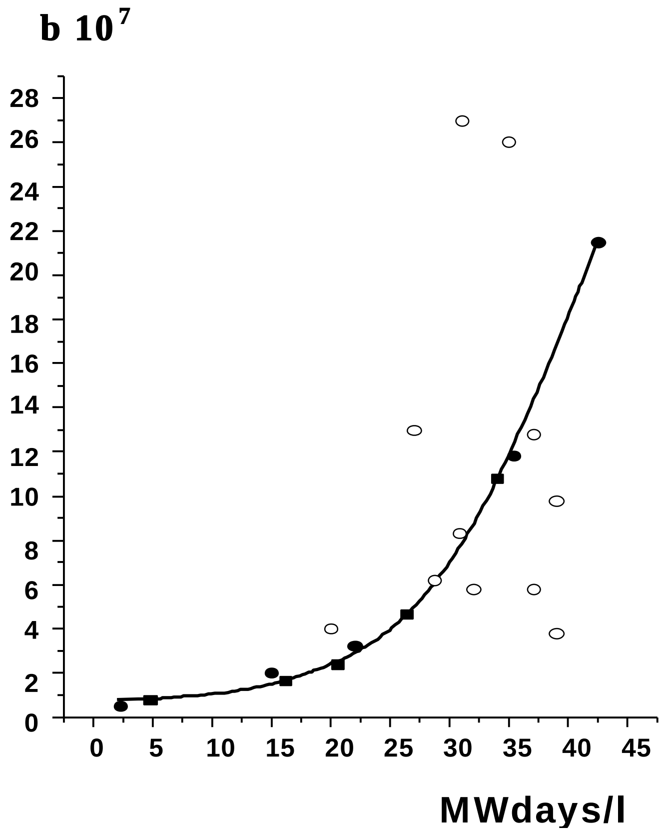

Figure 3. Relation of mean non-integrity β to specific energy release for two types of fuel elements: ■ -WWR-M2 and ● -WWR-M5 and O - β values for individual fuel elements.

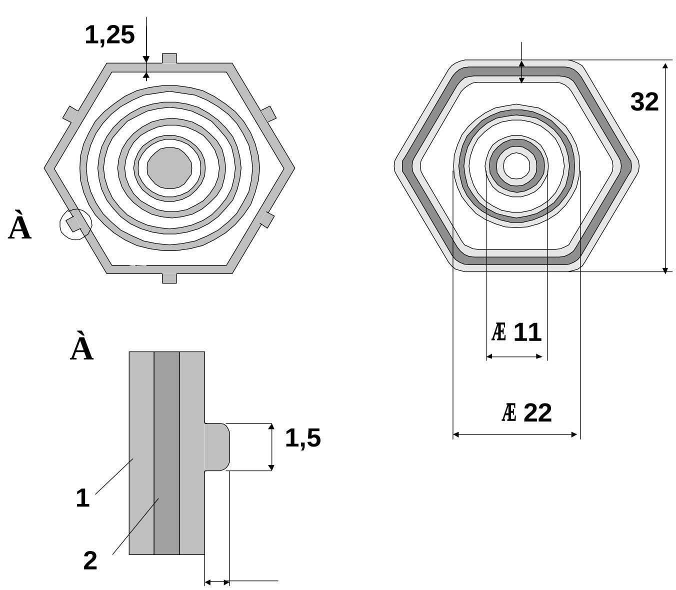

Figure 4. Cross-Sections o f Fuel Assemblies of the WWR-M2 type (right) and WWR-M5 type (left). 1 – plating. 2 - nuclear fuel layer

Figure 3 compares readings for two types of fuel elements used in WWR-M type reactors, namely, WWR-M2 type thick-wall fuel elements, and WWR-M5 type thin-wall fuel elements (Fig. 4). These fuel element types are described in Table 2 below.

Table 2. WWR-M Fuel Elements

Fuel Element Type	**Enrichment: ^{235}U %**	**Wall thickness (nuclear fuel layer) mm**	**Specific heat release surface, cm^2/cm^3**	**Fuel composition**	**Uranium density in the fuel, g/cm^3**	**^{235}U concentration in the core, g/l**
WWR-M2 (WWR-SM)	36	2.5(0.7)	3.67	U+A1	1.33	61.2
WWR-M5	90	1.25(0.53) 1.25(0.39)	6.6	U+A1	0.77	125
	90		6.6	UO_2+A1	1.2	125
WWR-2E*)	36	2.5(0.9)	3.67	UO_2+A1	2	122
	19.75	2.5(0.78)	3.67	UO_2+A1	2.5	77
WWR-5E*)	36	1.25(0.43)	6.6	UO_2+A1	2	102
	21	1.25(0.43)	6.6	UO_2+A1	3	83

*) indicates the number of test assemblies
WWR-M2E (36%) up to burn-up 43% - 9 assemblies
WWR-M2E (19.75%) up to burn-up 13%-27% - 5 assemblies
WWR-M5E (36%) up to burn-up 44% - 3 assemblies
WWR-M5E (21%) up to burn-up 57% - 9 assemblies.

On the basis of the methodology described above, we tested WWR-M5 fuel elements, which have been approved for mass manufacture, and are currently in operation.
In the Petersburg Nuclear Physics Institute WWR-M reactor, WWR-M5 type fuel elements are in uses, which have a well-developed heat release surface and a high multiplication coefficient of k_∞ = 1.78 [5]. WWR-M2 fuel elements are used in similar reactors in Kiev, Budapest and Dalaht (Vietnam). WWR-M2 and WWR-M5 fuel elements are interchangeable, as their preset dimensions are identical. WWR-M2 fuel elements with k_∞ = 1.65 can transition to low-enriched fuel without losing their k_∞ through higher uranium concentration. It appears even more worthwhile to refit these reactors with low-enriched WWR-M5 fuel elements, which would also permit to increase core power.
As part of the current phase of Russia's LEU program for exported fuel elements for research reactors, testing is in progress of WWR-M2 type fuel elements with uranium dioxide composition and enrichment below 20%. The parameters of fuel elements currently being tested are shown in Table 2.
So far, a burn-up level of 27% has been achieved. We have not been able to take non-integrity readings at this burn-up level, but we hope that such measurement will be possible later.

5. New Fuel Element Testing Resources in WWR-M Reactors

The WWR-M research reactor owned by the Petersburg Nuclear Physics Institute of the Russian Academy of Sciences has the capability of testing pilot fuel elements for research reactors. Testing may be conducted either directly in the core or in a special water loop with its channel placed inside a beryllium reflector. It is envisaged that fuel elements to be tested will be placed inside a special tube. The outside dimensions of this tube will be identical to those of a fuel assembly of a WWR-M reactor (a hexahedron with an outside «turnkey» size of 33.5 mm and a height of 0.5 m). Specifically, plate fuel elements may be placed diagonally in the tube; in this case, their sizes may not exceed 0.035 m x 0.5 m. Technologically, testing options will depend on fuel element type. It is definitely possible to test plate fuel elements without a wall side boiling effect at heat pressures up to 1.5 MW/m^2 in the core, and up to 1.0 MW/m^2 in the loop channel. In order to create a higher heat release, a fuel element testing tube may be placed in the center of a neutron water trap specially set up inside the reactor's core. The size of the trap will depend on the testing conditions. Possible parameters are given in Table 3.

Table 3. Plate Fuel Element Testing Parameters in the Core and in the Loop at Reactor Power of 18 MW

Parameter	**Core Channel**	**Loop Channel**
Maximum Heat Flux, MW/m^2	1.5	1.0
Coolant velocity, m/s	≤ 5.5	≤ 4
Wall temperature, °C	≤ 110	≤ 110

During loop testing, it is possible to monitor non-integrity of fuel elements on a steady basis. The level of non-integrity of fuel elements is determined by the ratio between the measured influx of the fission radionuclides Kr-85m, Kr-88 Xe-135 and Xe-138 into the coolant (**V**), and of their rated generation in the fuel element being tested (**q**):

$$\beta = \frac{V}{q}$$

and of their rated generation in the fuel element being tested. Sensitivity of this method and testing equipment is 1.10^{-7} at a heat release level of 10 kW. During core testing, non-integrity is monitored periodically as the nuclear fuel burns up.

The WWR-M reactor is equipped with a reloading hot cell with a protected see-through window and M-22 manipulator, as well as a number of hot cells where the surfaces of the fuel assembly being tested can be inspected visually. This equipment may also be used to test and measure some other parameters.

We welcome orders for testing mini-fuel elements and new fuel elements for research reactors.

Contact:
K.A. Konoplev,
Petersburg Nuclear Physics Institute,
Gatchina, Leningrad District,
188350, Russia
Telephone: (+007) (812) 714-6735
Fax: (+007) (812) 713-1282
E-mail: kir@1npi.spb.su

Acknowledgments:
Thanks to all WWR-M reactor personnel. Special thanks to chief reactor engineer R.G. Pikulik for his unrelenting attention and help in our work. Our discussions of testing conditions with NIKIET researchers V.G. Aden, E.F. Kartashov and V.A. Lukichev proved crucial for our work. Thanks to N.V. Arkhangelsky for his support. The authors thank all those mentioned above very much.

References:

1. N.G. Badanina, Y.P. Saikov
Condition Comparison Criteria of Reactor Core Fuel Elements
Atomnaya Energia 24, (5), 429-432, 1968. (In Russian).

2. N.G. Badanina, K.A. Konoplev, R.G. Pikulik, Yu.P. Saikov
Hermetic Sealing of WWR-M2 Fuel Elements During Operation
Leningrad Institute of Nuclear Physics preprint, No. 265, 1976 (In Russian).
N.G. Badanina, K.A. Konoplev, R.G. Pikulik, Yu. P. Saikov
A Study of Fission Product Release From WWR-M Reactor Fuel Elements as a Function of Burn-Up
Reactortagung, Duesseldorf , March 30 - April 2, 1976, Deutsches Atomforum E.V., p. 446, 1976.

3. B.S. Razov, Yu. P. Saikov, V.M. Sokolov
Water Loop in WWR-M Reactors
LINP Methodologies and Application Works, Leningrad, p. 143, 1988. (In Russian).

4. K.A. Konoplev, R.G. Pikulik, Yu. P. Saikov
Fuel Assembly Sealing Monitoring in the WWR-M Reactor Belonging to LNPI of the Academy of Sciences of the USSR
LINP Methodologies and Application Works, Leningrad, p. 129,1988. (In Russian).

5. A.A. Enin, A.N. Erykalov, G.A. Kirsanov, K.A. Konoplev, V.S. Lvov, Yu. V. Petrov, Yu. P. Saikov, A.S. Zakharov, V.S. Zvezdkin
Design and experience of HEU and LEU fuel for WWR-M reactors
Nuclear Engineering and Design, 182, 233-240, 1998.