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Operational Indices of VVER-1000 Fuel Assemblies and Their Improvements

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1 Introduction

This paper deals with the most general design features of VVER-1000 fuel assembly as compared with the other prototypes. The advantages of design are stated as well as their operational confirmation and the main operational occurrences. The essence of anomalies occurred in 1993-1994 concerning the time of emergency protection (EP) actuation. Measures to eliminate these occurrences are described. The main activity to enhance the design and to provide high economic indices of VVER-1000 fuel cycle are outlined.

2 Design Features

As it is known, the VVER-1000 fuel assembly design differs greatly from the western ones. It is predetermined by the original solutions including the peculiarities of materials, technologies, reactor design whose development was performed under the conditions of information isolation from the Western countries as well as by the continuity of VVER-based developments. Objective comparison indicates a number of significant advantages in the VVER-1000 fuel assembly designs:

a) "packing" density (tight-lattice) of fuel rods within the fuel assemblies and the latter within the core;
b) simple handling with the fuel assemblies, its small vulnerability during fuel handling procedures;
c) good conditions for coolant mixing;
d) protection of the absorber rods against coolant effect;
e) adaptability to manufacture that provides stable quality.

3 Main Operational Indices

During 10 years (from 1982 till 1992 including the period of transition for 3-year cycle) the fuel assembly structure operated successfully at 17 units with VVER-1000. The results of it were as follows:

- average burnup was reached to be about 45 *MWd/kgU*;
- out of 8500 fuel assemblies being examined only 193 ones were recognized to be leaky (it is 0.0072%), 8 fuel assemblies were unloaded ahead of time;
- about 170 fuel assemblies were in successful operation for 4 years;
- average activity of coolant was decreasing as shown in Fig.1.

Application of 18 guide channels of stainless steel have provided no radiation growth of the fuel assembly as a whole and cancelled the question on preserving the channel geometry during LOCA.

Minimum corrosion of all the fuel assembly components has been provided.

Radiation growth of the fuel assemblies is stable and is provided by the fuel assembly design.

Behaviour of the fuel rods, spacer grids, fuel as-

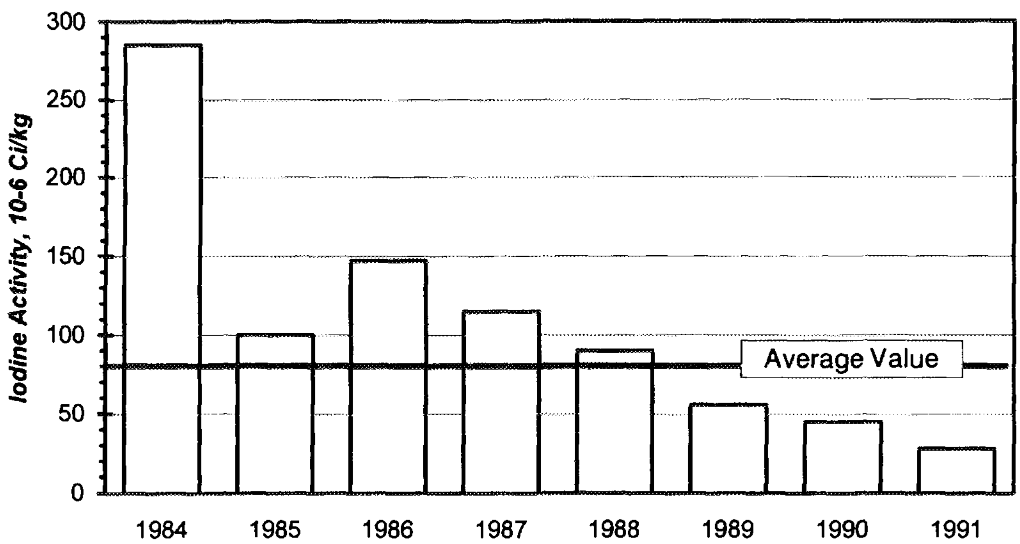

Figure 1 Total average activity of iodine isotops for all units at the moment of unloading

sembly cap springs have been studied and found to be, mainly, in conformity with the design prerequisites.

Worth and burnup rate of the absorbing elements and burnable poison rods have been revised.

For this period some operational occurrences were observed, among those we should highlight the following:

- Till 1986 delay in emergency protection actuation was practically at all units. In 1986-1987 it was eliminated by replacing the CRDM screw-type detectors by the linear ones.
- In 1983 the South Ukraine NPP experienced failure of the reactor coolant pump (RCP) bearings that resulted in carbon-containing deposits on the fuel rods and caused increased depressurization of the fuel assemblies
- In 1991 Zaporozhye NPP experienced partial degradation of the RCP thermal shield, ingress of metal chip into the core, increased depressurization of the fuel assemblies
- In 1991 Kalinin NPP after the preventive maintenance experienced ingress of organic materials.
- In 1987 undetected failure of the fuel assembly by the mast of fuel handling machine was observed at Kozloduy NPP during fuel assembly loading into the core. This and further deviation from the technological schedule during circulation loop connection resulted in increased depressurization of the fuel assemblies in 1988. A value of fuel assembly depressurization exceeded the normal operational indices (10^{-5} - 10^{-6} *Ci/l*) but did not exceed the allowable ones.

4 Provision for Emergency Protection Reliability

Since 1993, with other indices of VVER-1000 NPPs being favorable, the time delays in EP actuation (> 4 *sec*) have been observed. In June 1994 this question was reviewed at IAEA experts' meeting.

An ad-hoc interbranch commission of Russian and Ukraine specialists have been formed to study and to eliminate the reasons for such occurrences. Under review were the following versions:

a) influence of water chemistry including formation of deposits during boiling;

b) fuel assembly and guide channel distortion as a result of radiation and thermomechanical effects;

c) fuel assembly and guide channel distortion as a result of axial loads upon the fuel assemblies.

Apart from it the influence of observed disturbances upon safety was under investigation. In accordance with these versions the investigations have been performed in the cooling pond and reactor at Unit 2 of Balakovo NPP and in NIIAR hot cell.

The main works performed at Balakovo NPP are as follows:

- visual examination by means of TV-camera;
- corrosion products sampling in the guide channel;
- measuring the guide channel diameter;
- measuring the guide channel curvature in the separate fuel assemblies and in the core;
- measuring the spring performances;
- measuring the fuel assembly cap elevation and the forces of their preliminary compression;
- measuring over the reactor components.

A set of special equipment have been designed and fabricated to perform these works.

Two faulty fuel assemblies from Zaporozhye NPP were disassembled in NIIAR hot cell and subject to the detailed examination. Among other results it was confirmed that no deposits and foulings were available on the channel walls and inlet holes as well as no radiation growth of the guide channel and uniform radiation growth of the fuel rod.

As a result of all activities performed it was set up that the main reason for delay in EP actuation was increase of friction between the guide channel and the absorber element due to fuel assembly distortion caused by the axial loads exceeding the design value.

To provide power unit startup the reactor internals modification have been performed as well as the calculation analysis of safety. This calculation includes the analysis of accident progression with EP actuation time delay up to 10 *sec* as well as the thermohydraulic analysis of fuel rod heat engineering reliability within the fuel assembly with the measured curvature and respectively increased water gaps between the fuel assemblies.

To cope with operational occurrences the standard set of measures have been elaborated to retrofit the units to the design state. These measures have been already implemented at 5 units.

The number of occurrences prior to modification amounted to the following: 36 for Balakovo - 2 NPP, 29 for Balakovo - 3 NPP, 3 for South Ukraine - 2 NPP and 5 for Kalinin NPP.

After modification no disturbances were observed.

Such experience proves the absolute necessity for these measures to be implemented. However, some NPPs when linking the quantity of disturbances with duration of fuel assembly irradiation make decision on usage of the shortened fuel cycle. Nowadays, it is possible to say that economical losses from it can't be compared with losses for unit modification.

The basic conclusion is that references for the negative influence of the fuel assembly inherent properties, incapability thereof to operate adequately during all the design life are not correct.

At the same time the experience gained gives a lot of information for further improvement of the fuel assembly design. And one of the main conditions to be accounted for should be the detailed study of reactor properties, its geometry and heat engineering conditions.

The said disturbances and methods of their elimination have no influence on the program of fuel improvement as planned by Russian Minatom. Moreover, its implementation will increase the operational inventories of fuel. The main arrangements of this program are published in the proceedings of IAEA experts' meeting in April 1994. Some easily implemented solutions will be realized in 1995 fuel delivery without changes made in the terms and conditions of delivery.

Other solutions, in particular, replacement of the guide channel and spacer grid materials will be implemented since 1997. For this period of time the thermomechanical properties of fuel rod bundle will be investigated and the operating experience will be gained at NPP.

5 Direction and Status of Improvements

5.1 Improvements to Increase the Fuel Economy

Certain improvements aim to incease the efficiency of fuel utilisation:

1. Replacement of the guide channel and spacer grid materials by the zirconium alloy. It has 5-year operating experience with VVER-440. Pilot operation with VVER-1000 is going on since 1993.
2. Provision for maintainability of the fuel assemblies. It is reached owing to the cap being remotely detached and the fuel rods being remotely withdrawn without any mechanical failure. Pilot operation is under way since 1993.
3. Application of Gadolinium burnable absorber incorporated into the fuel instead of boron burnable poison rods. Pilot operation is going on since 1993.
4. Application of the new materials $Dy_2O_3TiO_2$ and Hf for absorbers in the region of intensive neutron flux. There is a positive operating experience of $Dy_2O_3TiO_2$ in VVER-1000 during 4 years in the automatic control group. At stage 1 the extended service life is achieved as well as the gravitational weight. At stage 2 the service life is above 10 years, physical and gravitational weights are increased. Materials testing has been completed whereas mechanical life tests together with control rod drive mechanism are coming to the end.
5. Fuel cycle optimization (implementation of 4-year cycle, application of "in-out" refuelling schemes.
6. Implementation of pitch-by-pitch detectors (pitch is 20 *mm*) to monitor the control rod movement.

5.2 Modifications to Improve Control Rod Operability

Some modifications aim to improve dimensional stability and to enhance reliability of control rod insertion into the core:

1. Optimization of the fuel assembly axial loads in VVER-1000.
2. Core layout with low non-uniformity of power distribution due to better profiling over the core and fuel assemblies.
3. Implementation of the more strict control for water chemistry.
4. More rigid fuel assembly structure.
5. Application of fuel cladding and guide channel materials providing the better dimensional stability under irradiation.
6. Increase in the control rod gravitational weight.
7. Implementation of the regulatory restrictions for heatup conditions.
