CERMET FUEL ELEMENT (FE) ON THE BASIS OF MICROFUEL – FE PROTOTYPE FOR FUTURE POWER ENGINEERING

I.I.Fedik, V.P.Deniskin, V.I.Nalivaev S.S.Gavrilin

FSUE "SRI SIA "Luch"

The FE with ceramic fuel and cladding of E110 alloy under average impletion depth of 43-45MW day/kg U with providing of 3 and 4 year operation periods are used successfully in VVER. The program had been developed for improving of the fuel cycles economical indexes and for further increasing the VVER operational characteristics. In this program the reactor safety increasing has been foreseen and also the coefficient of capacity using (KIUM) has at the expense of the average implement of 55-60 MW day/kg U achieving. The program foresees also the integration of 5-6 year fuel cycle and other developments [1,2]. It is planning to solve the pointed problems with help of traditional technical solution, directed to the improving of FE with ceramic fuel.

In the present paper the design-engineering and experimental development results have been presented for creation of cermet FE on the basis of micro-fuel with matrix structure (in the further -the cermet FE) for VVER. The works have been carried out over period of the last 10 years in SRI SIA "Luch" jointly with"
OKB "Gidropress", VSRINM Bochvar name, RNTs "Kurchatovsky institute," FEI and other.

The construction description. Cermet FE is differed from FE with ceramic fuel and from known dispersion type FE by following (Fig. [3,4]):

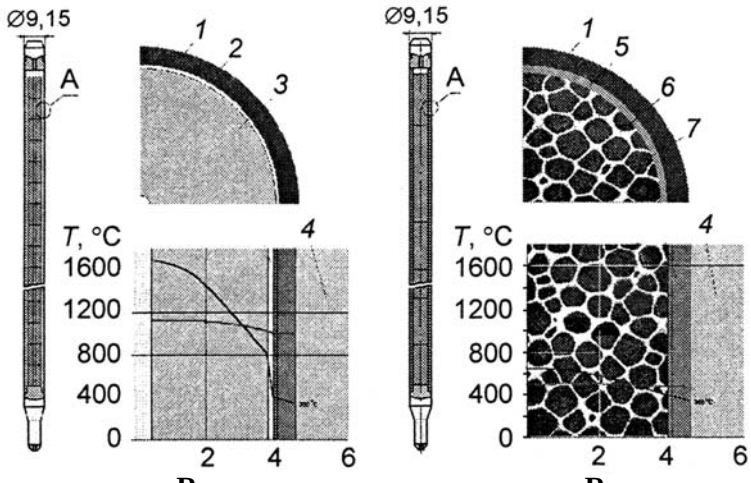

Fig. 1. Base differed signs of ceramic and cermet FE:
1.-cladding (zirconium alloy), 2.-gap (the thickness of 100 micron), 3.-fuel-uranium dioxide, 4.-heat transfer agent-water, 5.-percoat-alloy on the basis of aluminum, the thickness of 100 micron, 6-matrix-alloy on the basis of zirconium, 7-microfuel (micro-particles of UO_2,thickness of 500 micron).

cermet fuel core has matrix structure, excluding the contacts between fuel particles of 500 micron size at the nuclear fuel volume part in the composition of 79%;

in the capacity of matrix material the alloy on the basis of Zr is used;

between the cladding and the core the precoat of type silumin material is placed, providing the metallurgy adhesion and high heat conductivity.

Development of such FE in the capacity of alternative version will allow to increase the NPP safety cardinally, to increase operational and economical reactor , characteristics, to decrease capital and operating expenditures components in electrical capacity cost structure. Accordingly to geometrical and cladding material sizes (diameter of 9.15mm, Zr alloy EP110 or E635), the both FE type are like. The cermet FE integration will allow to release in great volume the base VVER virtues.

After reactor's investigations of the base characteristics of FE with ceramic fuel, determining the operating life-time. Base results are came down to the following:

1) Diameter gap between uranium dioxide pellets and FE cladding in some of its cross sections disappears at the impletion achieving of about 60MW day/kg U. It is caused by the diameter decreasing at the expense of cladding creep under the heat transfer agent pressure action and uranium dioxide pellets swelling [5].During disappearing of diameter gap in the pellet butt parts field under operation nonstationary regimes additional deformation may arise. It have been discovered by investigations [6], that the cladding diameter in pellets butt field exceeds the diameter of 20-50 microns over the rest of its part ("bamboo" effect).

2) The stresses in FE cladding in the stationary operation regimes under impletion to 45-50MW day/kg U are stayed as the compressing ones. With impletion depth increasing as result of uranium dioxide pellets interaction with cladding, due to gas fusion product (GFP) outlet [7], in the cladding the tensile stresses arise. These stresses provoke the processes, reducing to the damages accumulation in cladding (such as corrosion, hydrogenation, plastic deformation accumulation etc.) In this case these processes are running more intensive.

3) The FE length is increasing as a result of its cladding radiation growth under radiation exposure [8].

The comparison of cermet and ceramic FE characteristics, increasing the operating life-time. One of the base cermet FE advantage is core heat release low temperature (see Fig. 1). Hence, the smaller

(about 1.5-2 times) level of stored heat energy is carried out in the reactor active zone. At the operation under nominal using regimes, the core maximum temperature do not increase 600^0C against 1700^0C in the FE with ceramic fuel. Such condition is provided at the expense of high contact material heat conductivity coefficient (about 150W m/ ^{0}C) at its thickness of 100 micron and cermet core high heat conductivity coefficient (about 9-10W m/^{0}C) The heat conducting core low temperature allows to increase the principal reactor installation operational characteristics (safety, impletion, mobility, etc.).

The cermet FE using provides the high rate of the first contours heat transfer agent purity in the operating normal conditions at the expense of:

the exit from non hermetic cermet fuel of many times smaller of the radioactive fission products quantity, than from non hermetic ceramic fuel [9];

the smaller possibility of the cermet FE claddings loss of sealing;

sufficiently smaller pollution of the first contours (FE, HRA elements construction) by uranium, which may be washed out from the cracks of non hermetic cermet FE.

The pointed above increase reactor installation radiation safety at the heat transfer agent ejection from the first contour, the leakages into second contour, lower the dose expenses, lower schedule preventive maintenance time, and, as consequence, reduce the price of operation.

The cermet FE fulfillment in form of monolithic FE, using of matrix material of needed strength properties and fuel core low temperature, all of this increase the rigidity and FE geometrical stability. The diameter increasing at the reach of 140MW day/kg U impletion will not exceed of 0.5%.The last is reached at the expense of the uranium dioxide "solid" swelling compensation by its porosity (Fig.2). The ceramic FE diameter is decreasing about of 80 micron before contact with uranium dioxide pellets, at the impletion increasing – it is raised too.

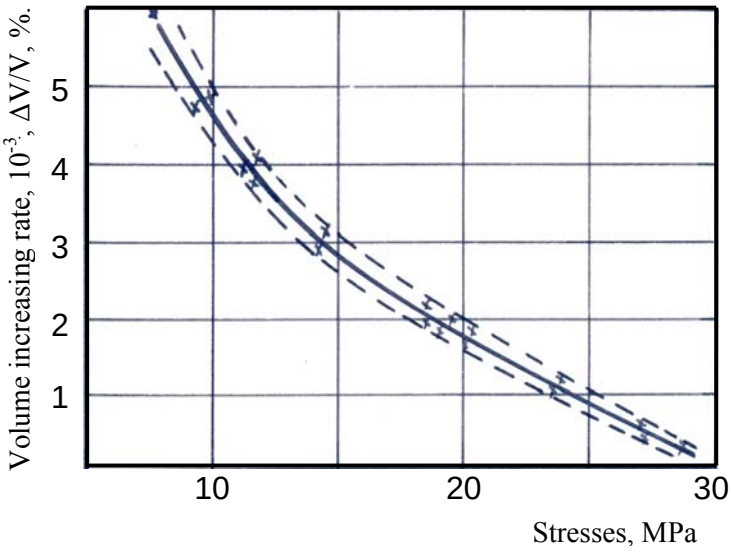

Fig. 2. The porous UO_2 swelling dependence on tensile stresses.

The indicated qualities increase the HRA vibration strength and improve distance grids work conditions at the expense of without gap contact between FE and distance grid during operation process.

The placing of uranium dioxide micro-spheres of about 500 micron size in matrix, low temperature provide the localization of 95% fission products in nuclear fuel. In this condition GFP act as solid fission products. It allows to exclude compensation volume for its gathering and also to exclude the cladding contact with chemically aggressive environment, containing fission products (I, Cd, Cs, etc.).

Using the cermet FE allows to increase the impletion depth to 140MW day/kg U. Such conclusion has been based on the design-experimental investigations results, which have been shown, that the cermet core will have minimum swelling under condition, if:

matrix material strength characteristics (tensile strength, creep characteristics) and its quantity in composition will be enough for creation in the fuel micro particles the tensile stresses not less, then 30MPa. Such conditions may be realized in the case of Zr doping by several percent Nb.

The fuel micro spheres porosity will be enough for compensation of uranium dioxide solid swelling.

Afterreator investigations of the cermet FE on the basis of micro fuel, development for differed reactors, have shown, that they have the resource store and capable to provide more deep impletion, then it had been foreseen by technical task for development (about 120MW day/kg U). The structure of fuel composition, radiated to the impletion of 110MW day/kg U, differs from the initial by bigger fuel elements density (Fig.3).

In the basis of radiation stability in the reactor MIR (NIIAR) experimental FE with cermet fuel (UO_2-Zr alloy) are radiated. In radiated FE heat realized cores have been gathered from cermet rods of 50%. Uranium dioxide volume part in composition consists 75%. During the time from November of 1997 to 2003 year the impletion of 62MW day/kg U had been achieved. All of the radiated FE kept hermetic.

The impletion depth increasing will lower used nuclear fuel mass at the unit of worked out electric power. This will lower the expense of storage, carriage, and FE processing. The VVER work in the maneuver regime is

limited, in the first turn, by the FE capacity for work in the operation transient conditions, which for ceramic FE is determined by [10]:

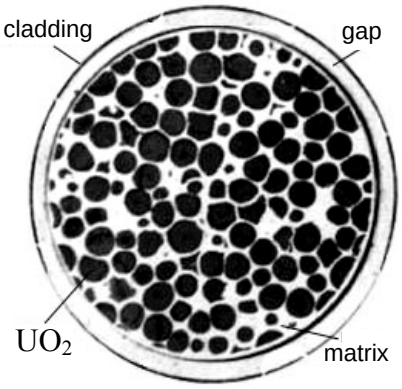

Fig.3. The structure of fuel composition, radiated to the impletion of 110MW day/kg U.

stresses, arising under mechanical interaction of cracked uranium dioxide pellets fragments with cladding;

arising and micro-cracks development on a cladding inner surface with fission products participation.

The thermal stresses, arising in the cermet fuel core, are not enough for its destruction, the thermal stresses, arising in the cladding do not exceed tensile strength. The moving of fission products to a cladding do not take place because of the low temperature and its localization in uranium dioxide pellets.

All of the considered allow to give to the NPP with VVER more maneuver. This fact will make its work more accessible in controlling regimes without limiting concerning cycles and controlling depth.

Metallurgy adhesion between cladding and heat realize core at the expense of the contact precoat creation, matrix material with enough strength properties, excluding nuclear fuel swelling result in FE cladding minimum stresses. This allows to decrease requirements to the base cladding material characteristics Accordingly to the calculated estimates, the alloys E110 and E635 may provide the cermet FE work to impletion not less of 140MW day/kg U.

Comparison of radiation conditions in accident situations under using of the cermet and ceramic FE. In all of variety of NPP accident regimes with VVER the most unfavorable conditions concerning FE thermo mechanical and thermo-physical state have the accidents with heat realize agent loss, especially connected with rupture of the base circulation pipeline (the project accident). FE with ceramic fuel behaviour investigation are carried out at the electro-heating stands in differ organization. Experimental investigations, carried out in SRI SIA "Luch" on the stand "PARAMETER-M" and in VSRIINM on the stand "TEFSAI-19" [11, 12, 13] with FA on the basis of FE with ceramic fuel and calculated estimates of cermet FE behaviour in accident running analogous, show the following:

1). At the first stage of project accident (the fist 8-10 sec.) ceramic FE cladding material experiences the physical and mechanical changing, which may results in loss of sealing. Increasing of the cladding temperature at this stage is determined , first of all, accumulated heat energy in active zone. It, in its turne, is determined by temperature difference on the fuel pellet, which in nominal regime for ceramic fuel consist of 1100^0C at the same time the temperature in inner pellet hole=1700^0C, and on external surface is of 600^0C.

The results of design investigations, got in OKB "Gidropress," show, that maximum cermet FE cladding temperature in the analog accident situation do not exceed 500^0C and the FE at these conditions remain serviceability.

2). At the second stage of project accident, at the temperature increasing from 400 to 1100^0C at the expense of the rest energy realize the maximum deformation is resulted in fuel pellets and also the loss of sealing of the cermet FE cladding (Fig.4, a, b).

a b

Fig. 4. The deformation of ceramic FE with cladding of zirconium alloy at the accident modeling with heat transfer loss in the assembly of 37 FE.

The loss of sealing is observed in the temperature interval of 800-900^0C. As a result of deformation and the cladding loss of sealing the blocking of FE bunch flow section comes (Fig. 4, b). In the deformation field and the loss of sealing the more intensive oxidation of external and inner cladding surfaces comes in the atmosphere of superheated vapour.

The investigations of the experimental cermet FE behaviour under isothermal stand during 1.5-6 h confirmed its geometrical stability. The contact material transfer into liquid state is not resulted in the loss of sealing. The contact material interaction with the cladding stimulate the interaction layer formation, consisting of different intermetallics of binary system of Al-Zr. After escaping all of contact material, the thickness of contact material of interacting zone do not exceed 100 micron.

In the after project accidents the heat, released in the cermet FE, consists of two components: the residual heat and the heat, released under running of couple-zirconium reaction (CZR). The last component is the determining component under developing of accident with following possible melting of active zone constructive elements. The self-sustaining CZR may arise under defined parameter combination, which are formed at the first and at the second project accident stages.

In the after project accidents the FE are destroyed under acting of stresses, arising at the expense of the gas pressure inside and outside. In the cermet FE there is no such load. The measurements of cermet FE on the basis of micro fuel are not changed in the after project accidents conditions in comparison with the base FE. Diameter increasing is typically for ceramic FE. This fact has been resulted in the blocking of flow sections for flowing heat-transfer agent (see Fig. 4,b), in FE cladding destroying (see Fig. 4,a), that has been resulted in grows of zirconium alloy surface, contacting with water vapour, in destroying of sheer oxide film on the FE surface. Under using of cermet FE on the basis of micro fuel it is more easily to escape this reaction arising.

In the active zone with cermet FE on the basis of micro fuel the possibility of getting into heavy operating regime with fuel melting is incomparably lower.

The works, carrying out with purpose of increasing of uranium dioxide quantity in cermet FE. During the cermet FE development it has been foreseen nuclear fuel maximum load at the minimum of fission products enrichment This is realized at the expense of:

carry to completion of the uranium dioxide volume part to 70%. Such composition is radiated in the reactor MIR;

decreasing of cladding thickness from 0.72 to 0.4 mm;

increasing of reactor active zone height at the expense of excluding of butt compensation volume.

Cermet FE manufacture technology development works state. In SRI SIA "Luch" the cermet FE laboratory manufacture technology had been developed on the basis of micro fuel and on its base, with CSRIL JSC "MSZ participation" the work directions have been selected concerning of base operation improving, applying to this cermet fuel production.

The cores (UO_2-alloy on the base of zirconium) regeneration works have carried out in VSRINM and in RNC "Kurchatovsky institut". Accordingly to the results of this investigations the possibility of cermet FE processing along technology chain of RT-1 plant after carrying out of thermo-gas chemical processing at the air under 1000-1100^{0}C during several hours. After such processing the deep fuel destruction has been achieved, providing the accept of reagents for fuel component into solution and extraction the components from it. The estimation of using having equipment and RT-1 plant technology chain need reconstruction possibility has been done for creation of the modulus of thermo-gas-chemical process of depleted FA with cermet fuel preparation.

Conclusion. During introduction cermet FE on the basis micro fuel at the acting NPP, external FE construction constant is kept. That allows to install the new active zones without any sufficient changing of reactor installations constructions. Using of cermet FE in a new generation of VVER will allow to realize its quality in large volume, in particular, to create the first hermetic contour, to simplify and to reduce of the price of safety systems, automatic adjustment, radiation protection, heat transfer purity, etc. The using of cermet FE, for example, in VVER may attach to the installation the exceeded operational properties of safety in different operation conditions, manoeuvrability, vibration strength, FA life time and FE geometrical stability.

References.

1. Lavrenyuk P.I., Vasiljev B.A., Lunin G.L., etc. Fuel for NPP. The State and Perspectives. In: The Third Science conf. Minatom of Russia "Atomic Energetics." The State and Perspectives, M., 2002, p. 160-177.
2. Nigmatulin B.I., Severinov V.V. The Role, Potential and Conditions of NPP dynamical Development–There p.5-14.
3. Chernikov A.S., Permyakov L.N., Gavrilin S.S. Fuel Element with Cermet Fuel of Matrix Type for VVERs of Enhanced Safety. – In: The Seventh Intern. Conf. on Emerging Nuclear Energy System. Sept. 20-24, 1993, Nakuhari, Japan.
4. Chernikov A.S., Permjakov L.N., Fedik I.I., etc. Fuel Elements on the basis of sphere Particles with protection Coating for enhanced Safety Reactors.-Atomic Energy, 1999, v. 87, issue 6, p. 451-462.
5. Ivanov V.B. Science-technical Problems of Nuclear Fuel Cycle – In: Science conf. Minatom of Russia "Nuclear Fuel Cycle." M., June 2000, p. 3-16.

6. Tsikanov V.A., Vasiljev V.Ya., Gadzhiev G.I., etc. The Review of the Base Investigate Works, carried out in NIIAR, 1994. Dimitrovograd, 1995, p.52-58.
7. Solonin M.I., Reshetnikov F.G. Ioltukhobskiy A.G., Nikulina A.V. New Construction Materials of NPP Active Zones.-In: Selected Proceedings VNIINM, M., 2002, v. 1, p. 84-101.
8. Solonin M.I., Bibilashvili Yu.K., Nikulina A.V., etc. Zirconium –Niobium Alloys for FE and FA claddings for Energetic Reactors of NPP type VVER and RBMK.-In: Selected Proceedings VNIINM, M., 2002, v. 1, p. 65-83.
9. Chernikov A.S., Permyakov L.N., Gavrilin S.S. Cermet Fuel Elements for VVERs. – In: Proc. of ARS"94 Intern. Topical Meeting on Advanced Reactor Safety, 1994, V.2, p. 1097-1101, Pittsburgh, USA.
10. The Creation Problems of VVER-1000 FE for Operation in the Condition of manoeuvre NPP and Enhanced Impletion. – Atomic Energy, 1988, v. 64, issue 4, p. 258-267.
11. The Experimental Investigation of FE Simulators Behaviour in of the Model FA type VVER at the Stand "Parameter-M" in Conditions, modeling different Accident Stages with large leakage. –In: Proc. of SRI SIA "Luch.", 2000-2002, p. 69-80.
12. Modeling at the Stand "Parameter" the FE of VVER Behaviour at the First stage of MPA.-Reports theses on the Third Science conf. "NPP with VVER Providing Safety", may 26-30, 2003, Podolsk, p. 52-53.
13. Thermo mechanical Properties of Oxidated Cladding of Zr alloys in Conditions of Accidents with loss of Heat Transfer. – In: Selected Proceedings VNIINM, M., 2002, v. 1, p. 221-239.