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SOME APPROACHES TO SOLVING THE PROBLEM OF DIMINISHING THE INTERACTION BETWEEN U-M? FUEL PARTICLES - Al MATRIX

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INTRODUCTION

- **The post-reactor examinations of irradiated fuel elements with U-Mo fuel composition in aluminium matrix has shown:**

- **during the irradiation owing to the reaction between the fuel particles and the Al matrix the interaction zone consisting of uranium aluminides, UAl_3 ? UAl_4, is forming;**
- **a layer formed due to the implantation of fission fragments into the matrix can be observed around every fuel particle;**
- **in some cross-sections of the fuel elements these layers merge together and form continuous frameworks;**
- **inside the zone of the maximal energy release, along the contact lines of the zones of interaction with matrix, gas-filled voids are being formed around the fuel particles, and in some cases they make up gaseous bubbles;**
- **in cases of high fuel burnups the clusters of gas-filled voids cause the breakings inside the fuel kernel and form the bulges of cladding under the action of the internal gas pressure.**

THE MECHANISM OF VOID FORMATION AT AN "INTERACTION ZONE-MATRIX" BOUNDARY

- **Interaction within the "fuel particle - matrix" couple occurs owing to the mutual interdiffusion of atoms according to the vacancy mechanism.**

- **In the course of the operation the fission fragments are flying out into the matrix. With it, the vacancy concentration within the zone of the fragment flight (a narrow layer of the matrix whose thickness is no more than ~ 14 μm – the average free path of fission fragments in aluminium) increases by several orders of magnitude (up to several thousands of vacancies per fission fragment).**

- **It is obvious that in the case of so high vacancy concentration the diffusive processes can proceed at very high rates.**

- In accordance with the U-Al phase diagram, three intermediate phases are observed: UAl_4, UAl_3, UAl_2 (Figure 1).

- The available experimental data show that the neutron irradiation of the UAl_X-Al system results in the growth of fuel particles and of their volume fraction in the composition, and in the reduction of the volume fraction of the matrix. The mechanism of this process is based on the interdiffusion of U atoms from the UAl_x particles into the matrix and, vice versa, of Al atoms from the matrix into the particles with the formation of an Al-supersaturated solid solution in the intermetallic compound.

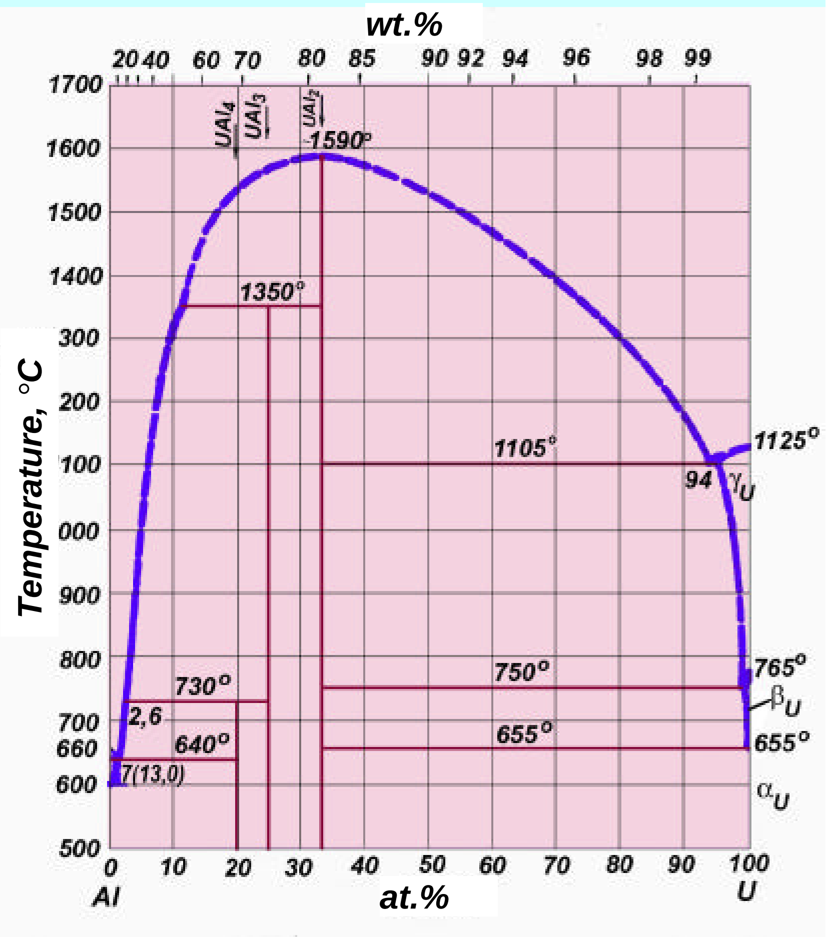


Figure 1 – Phase diagram Al-U

- **The atoms of uranium have a lower diffusion mobility than the aluminium ones. As a result of this, pores must appear in the aluminium matrix (in accordance with the Kirkendall effect), and they can serve as traps for the fission-fragment gas.**
- **In the course of the irradiation of a nuclear fuel the formation of gas-vacancy complexes is observed. They consist of inert fission fragment gas atoms and are gradually growing, forming the gaseous bubbles.**
- **As a result of the bubble coalescence the volume of a newly-formed pore turns out to be greater than the volumes of the initial bubbles. It is easy to calculate that the volume of the newly-formed gas-filled pore will then be ~ 2,75 times higher than the sum of the volumes of the two initial bubbles.**
- **Thus, the formation of a "framework" from the merged interaction layers assists formation of larger voids and the free migration of gaseous fragments, which results eventually in the local deformation of a fuel element cladding.**
- **In this connection it is necessary to diminish the interaction between the fuel particles and the matrix.**

THE WAYS OF DIMINISHING THE RATE OF INTERACTION BETWEEN FUEL PARTICLES AND MATRIX

- **Two ways of the solving of this problem are considered:**

- **the diminishing of the rate of interaction between the (U-Mo) fuel particles and the aluminium matrix in the course of the neutron irradiation;**
- **the increasing of the specific surface energy at the "(U-Mo) fuel – aluminium matrix" boundary in order to reduce the possibility of pore formation at this boundary.**

- **The first way is realized by means of covering the (U-Mo) fuel particles by suitable protective coatings.**

- **The second one – by means of adding into the matrix an element capable to increase the specific surface energy at the "(U-Mo) fuel – aluminium matrix" boundary.**

❑ **The realization of these two ways has been begun:**

♦ **spherical particles of the (U-9%Mo) fuel alloy have been coated with: niobium, (Zr+1%Nb) alloy, and uranium dioxide, (UO_2). The fuel particles with each kind of coating are placed into the fuel mini-elements with cladding of the SAV-1 aluminium-based alloy and with the fuel matrix of (PA-4n) aluminium alloy, see Figures 2, 3.**

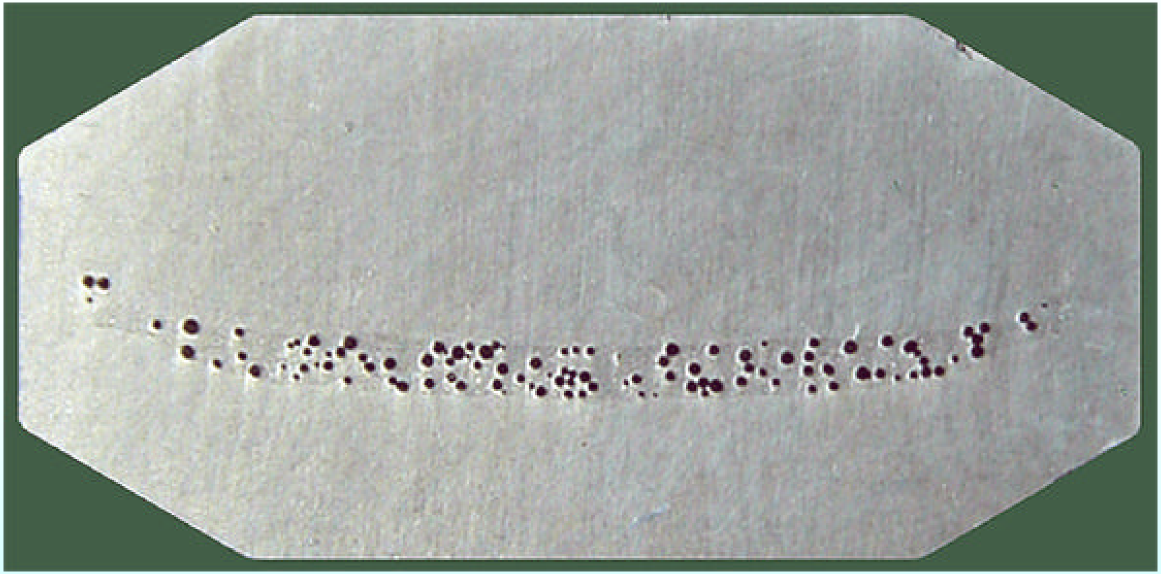
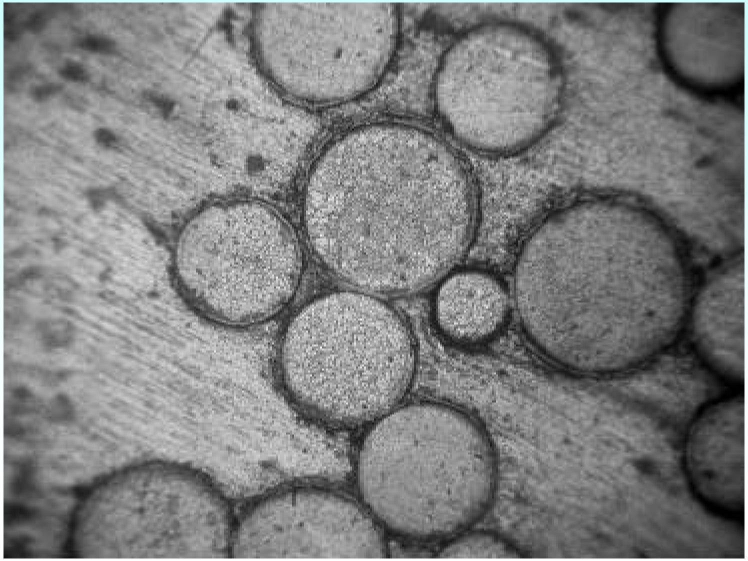
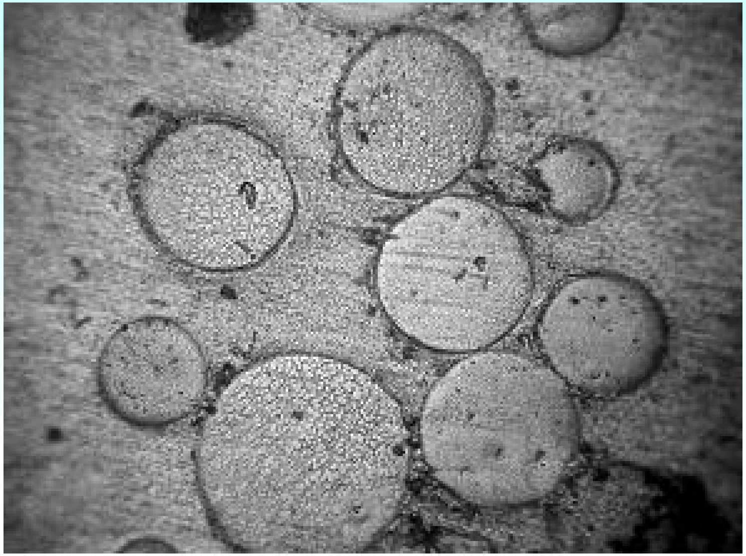


Figure 2 – A macrophotograph of the longitudinal section of a fuel mini-element



Sample No. 41
U–9%Mo + Nb +PA-4n alloy, ×200



Sample No. 34
U-9%Mo oxidized+PA-4n alloy, ×200

Figure 3 – The microstructures of the samples of the fuel mini-elements

- ♦ **spherical particles of the (U-9%Mo) alloy without any coating were dispersed throughout the matrix of the aluminium - 12 % silicon alloy, and the resulted fuel was placed inside the fuel mini-elements with claddings of the aluminium-based alloy of SAV-1 grade.**

CONCLUSIONS

- **In order to reduce the rate of forming the layers of interaction between the (U-Mo) fuel particles and aluminium matrix, the fuel particles have been covered with the protective coatings of Nb, the (Zr+1%Nb) alloy, and UO_2;**

- **In order to increase the specific surface energy at the (U-Mo)-Al boundary and to diminish the possibility of the pore formation at this boundary, the aluminium matrix with an addition of silicon has been used;**

- **Fuel mini-elements have been made in order to realize the engineering solutions considered above. The test fuel assemblies with those fuel mini-elements elements are being irradiated now in the IVV-2M reactor (Zarechniy).**