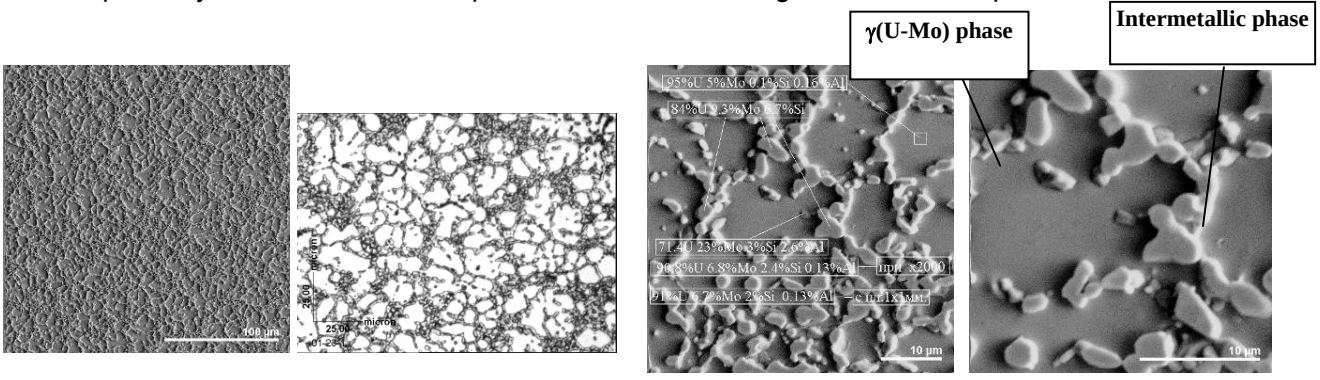
Conceptual study of multiphase structure of high uranium density alloys to reduce chemical interaction

A. Savchenko

A.A. Bochvar Institute of Inorganic Materials (VNIINM), P.O.Box 369, Rogova Street 5A, 123060, Moscow, Russia
e-mail : sav-alex111@mail.ru

The basic factor that limits the serviceability of fuel elements developing in the framework of RERTR Program (transition from HEU to LEU fuel of research reactors) is interaction between U10Mo fuel and aluminium matrix [1]. Interaction results in extra swelling of fuels, disappearance of a heat conducting matrix, a temperature rise in the fuel centre, penetration porosity, etc. Several methods exist to prevent fuel-matrix interaction. In terms of simplifying fuel element fabrication technology and reducing interaction, doping of fuel is the most optimal version.

We developed a concept of U-Mo fuel alloying that consists in producing an alloy of the two or multiphase structure, viz., basic γ(U-Mo) and intermetallic phases [2]. The alloys should be of eutectic type for strengthening interatomic bonds and stabilization of γ(U-Mo) phase. The intermetallic phase shall have the maximal density of uranium, low molybdenum content, be well compatible with aluminium, highly irradiation resistant and precipitate along grain boundaries. The latter condition allows fuel particle production via grinding. After grinding the weakly interacting with Al intermetallic phase is primarily available at the fuel particle surfaces, forming some kind of a protection barrier.



a) **b)**

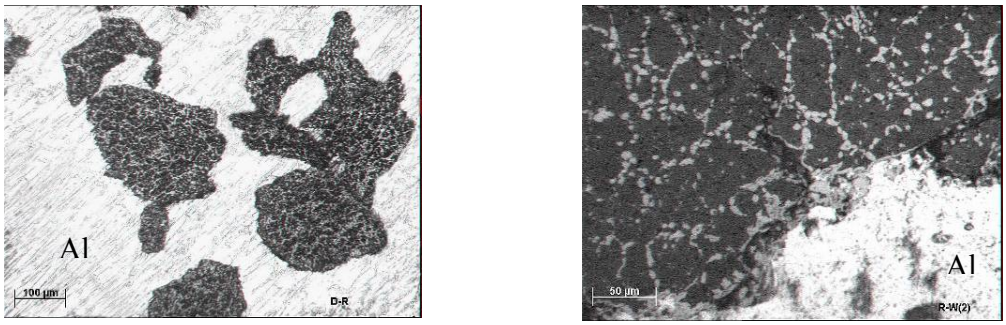
Fig.1. Structures of alloyed UMo two-phase alloy; a – U + 5.7Mo + 0.9Si; b – U + 6.3Mo + 0.9Si + 0.15Al.

Using casting and powder metallurgy methods a group of alloys were fabricated with additives of Si (0.8-1.5%) as well as Si plus Al (1.2% in total) and various Mo content within 5 to 9%.

After casting some alloys were annealed at 500^0C for 4 hours to study stability of γ(U-Mo) phase. Microstructures of two alloys (U+5.7%Mo+1.04%Si – weight percent) as well as (U+6.3%Mo+0.9%Si+0.15%Al) are shown in the figure 1. It consist of mainly of 2 phases: γ(U-Mo) phase containing 5% of Mo and 0.1% of Si and intermetallic ternary phase U-9.3Mo-6.7Si, probably $(UMo)_3Si_2$. It should be mentioned that gamma phase did not decompose after annealing in spite of low Molybdenum content.

Under compatibility testing after anneal at 600^0C for 6 hours the intermetallic phase weakly interacting with aluminium strongly reduced interaction. The interaction was small in comparison with standard fuel – granules of U-10Mo alloy, and of a nodular mode. The acquired results indicate the feasibility of diminishing the interaction through this method.

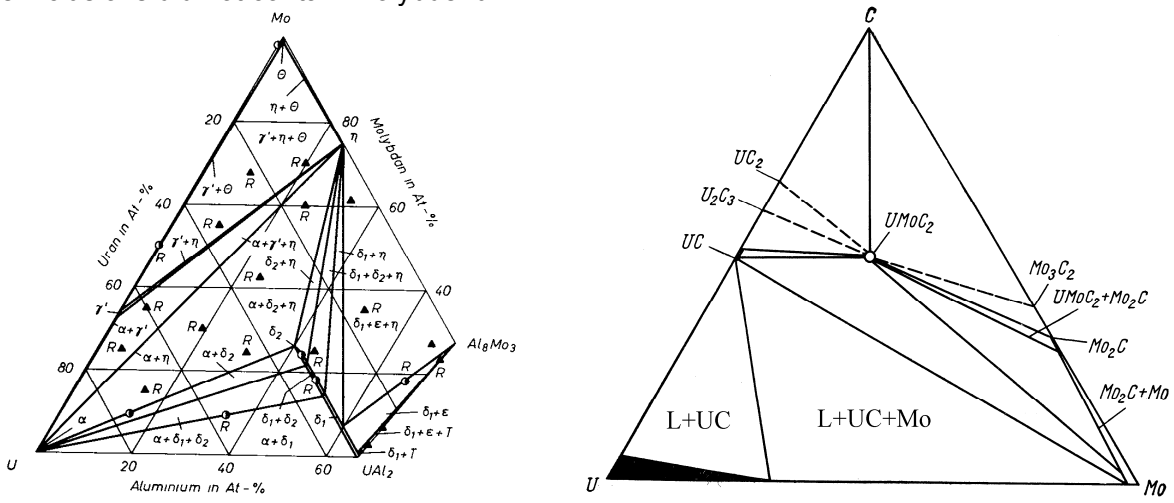
Principally novel results were received for stabilizing γ-(U-Mo) phase with low uranium content in eutectic type alloys by the third neutral stabilizing element. It can be explained by additional stabilizing impact of Mo located not only in γ-(U-Mo) phase, but also in intermetallic phase.



a) **b)**

Fig.2. Microstructure of fabricated fuel composition with UMo alloy, a – (U+5.7Mo+1.04Si) + Al as fabricated; b – (U+6.3Mo+0.9Si+0.15Al) + Al - 6 hours annealed at 600 °C.

To eliminate the molybdenum leaving from the γ-U phase for the intermetallic phase, depleting in this way the γ phase solid solution in Mo, a thermodynamic analysis using phase diagrams was implemented. As a rule, the alloying of UMo alloy with elements that form intermetallic compounds with uranium leads to the undesired type of the phase diagram with ternary intermetallic phases that comprise molybdenum, e.g., U-Mo-Al, U-Mo-Si, U-Mo-Sn etc systems (Fig. 3a). For molybdenum not to enter an intermetallic phase but to remain in a solid solution with uranium, the type of the phase diagram (Fig. 3b) has to be realized, where the phase triangle is restricted by U-U_2Mo-UX phases, where UX is a binary intermetallic compound of uranium and an alloying element. This version is feasible in the U-Mo-C system (Fig. 3b) in which theoretically ternary compounds must not form close to the uranium angle of the phase diagram. This can be confirmed by forming carbide phase inclusions along the grain boundaries of the γ-solid solution in U-10Mo alloy with carbon impurities. These carbon phase inclusions did not contain molybdenum.



a) **b)**

Fig. 3. Types of phase diagrams of UMo alloy with elements that form intermetallic compounds with uranium, a – system with ternary compounds (U-Mo-Al) [3], b – isothermal section of U-Mo-C phase diagram at 1500 °C.

References

[1] G.L. Hofman, M.R. Finlay, Y.S. Kim, H.J. Rue and J. Rest "Observations of the Nucleation and Evolution of Porosity in U-Mo Fuels", Proc. 2005 International Meeting on Reduced Enrichment for Research and Test Reactor, Nov. 6-11, 2005, Boston, USA.

[2] A. Savchenko, E. Malamanova, I. Konovalov, Y. Petrov. Novel Trends in Fuel and Matrix Alloying to Reduce Interaction, Proceedings of the Research Reactor Fuel Management (RRFM-2007) Conference, Lion, France, 11.03-14.03.2007, available through the European Nuclear Society (ENS) website.