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# Accident tolerant fuels to replace uranium dioxide

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**Abstract**. The thermal conductivities for the traditional fuel $UO_2$ and for the Accident Tolerant Fuel (uranium Molybdenum alloy, U-10Mo and uranium silicide, $U_3Si_2$) are calculated and compared. Then the temperature distributions on these core reactor, namely on the surface of the rod and in the center line of the rod were determined. The calculation is carried out using MATHCAD program. The calculations showed enhancement of thermal conductivity of the Accident Tolerant Fuel as they increased linearly with increasing temperature, and reduction of their center line temperatures of the rods. Beside, their steep thermal gradient, which may reduce the induced heat stresses in the core of the reactor.

## 1. Introduction

Since the Fukushima accident in Japan in 2011, a lot of research has been carried out, aiming to replace the traditional fuel system in the reactors, namely the uranium dioxide as a fuel and zirconium alloys as a cladding materials [1-4]. However, the fuel itself may be more challenging problem than oxidation resistant cladding material [5] in the light water reactors (LWRs). This suggests the development of Accident Tolerant Fuel (ATF) to replace the $UO_2$ fuel.

The ATF materials could overcome the limitations of UO2, through their higher thermal conductivities than that of uranium dioxide. The poor thermal conductivity of UO2 could result in high center line temperature of the core reactors and steep temperature gradient during power reactor operation with undesirable results [7,8]. The non-uniform redistribution of pores, grains or fission products could result in thermal stresses which may leads to cracking in the fuel pellet or fission gas release [7].

Thus, if accident occurs, it is expected that ATF fuels can withstand for a longer time (for loss of cooling) by faster dissipation of heat [9]. Thus, it is intended in this work to replace the uranium dioxide with uranium molybdenum alloy U-10Mo and with uranium silicide $U_3Si_2$.

The temperature distribution in the core of the reactor will be compared for the three types of fuels $UO_2$, U-10Mo and $U_3Si_2$ in the center line of the rod and on the surface of rod.

## 2. Theoretical

The thermal conductivity of $UO_2$ is obtained from previous work of Alekseev, et.al.,[11], whereas the thermal conductivity of $U_3Si_2$ is obtained from the approach of White, et.al.,[12], using the equation:

$$K_{U3Si2} = 0.0107T + 3.99 \qquad (1)$$

Where $T$ is the temperature in $K$.

On the other hand the theoretical approach of Rest, et.al., [10], is followed to obtain the thermal conductivity of U-10Mo fuel at different temperatures. The thermal conductivity of metallic uranium takes the form:

$$K_U = 21.73 + 1.591 \times 10^{-2}\, T + 5.907 \times 10^{-6}\, T^2 \tag{2}$$

Where $Ku$ is the thermal conductivity in $W/m.K$ and $T$ is the temperature in $K$, for temperature interval, $255 \leq T \leq 1173K$.

Thermal conductivity of metal Mo is:

$$K_{Mo} = 150 - 4 \times 10^{-2}\, T \tag{3}$$

Thermal conductivity of alloy U-10Mo is:

$$K_{UMo} = \left(1 - \sqrt{1 - X_{Mo}}\right) K_{Mo} + \sqrt{1 - X_{Mo}} \left\{(1 - X_{Mo}) K_U + X_{Mo} K_{C,Mo}\right\} \tag{4}$$

Where $K_{UMo}$ is the thermal conductivity for U-10Mo in W/m· $K$, $X_{Mo}$ is the Mo content in weight fraction. $K_U$ is given by equation (2), and $K_{Mo}$ is given by equation (3).

$K_{C,Mo}$ is a result of the regression analysis of the data to equation (4) and takes the form :

$$\begin{aligned} K_{C,Mo} = {} & -274.4 + 985.2 X_{Mo} - 1.941 \times 10^{-3} X_{Mo^2} + 3.640 \times \\ & \times 10^{-2} T + 7.365 \times 10^{-5} T^2 + 5.793 \times 10^{-2} X_{Mo} T \end{aligned} \tag{5}$$

The MATHCAD program is used to model and calculate the thermal-hydraulic parameters in nuclear power plant system. The program is used in this work to obtain the thermal conductivities and temperature distributions of the three fuels considered in the LWRs, type VVER, as can be seen in next figures. It should be noted that the MATHCAD is one of popular computer algebra system (math software) in the world. Like other CAS's, it has the capabilities to perform algebraic operations, calculus operations and draw graph of 2 or 3 dimensions. We can use it to get numerical, symbolic and graphic solution of math problem [12].

## 3. Results and discussion

The following table shows the values of thermal conductivities for the three fuels considered in this work, these values are potted versus temperature in figure 1.

**Table 1.** Thermal conductivities of the three fuels considered.

| Temperature, K | Thermal conductivity of U-10Mo, W/m.K | Thermal conductivity of $UO_2$, W/m.K | Thermal conductivity of $U_3Si_2$, W/m.K |
|---|---|---|---|
| 293 | 6.09 | 7.80 | 4.20 |
| 373 | 10.60 | 6.83 | 5.06 |
| 473 | 14.30 | 6.00 | 6.13 |
| 573 | 17.50 | 5.30 | 7.20 |
| 673 | 20.10 | 4.73 | 8.27 |
| 773 | 23.00 | 4.30 | 9.34 |
| 873 | 26.50 | 3.88 | 10.41 |
| 973 | 30.00 | 3.55 | 11.40 |
| 1073 | 32.50 | 3.26 | 12.55 |
| 1173 | 35.50 | 3.01 | 13.62 |
| 1273 | 37.20 | 2.79 | 14.69 |

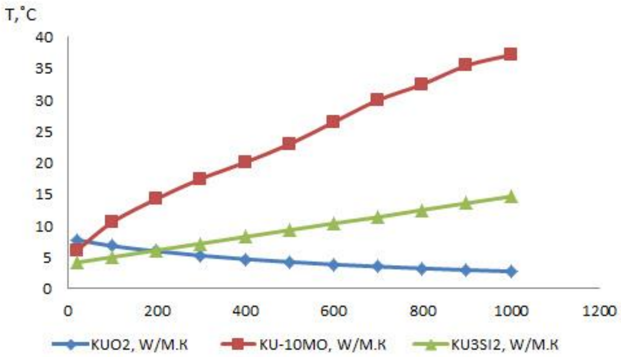

**Figure 1.** Thermal conductivities for the fuels considered, $UO_2$, U-10Mo and $U_3Si_2$ versus temperature.

It is visible from table 1 and figure 1, that for both ATF fuels, the thermal conductivity increases linearly with temperature, namely, from ~ 6 to ~ 37 W/m·K for U-10Mo and from ~ 4 to ~ 14 W/m·K for $U_3Si_2$, compared with thermal conductivity of $UO_2$ which decreased from ~ 8 to ~ 2.8 W/m·K for the same temperature interval. However, the linear increase for U-10Mo is more markable.

The temperature distributions for the three fuels considered are shown in figures (2-4).

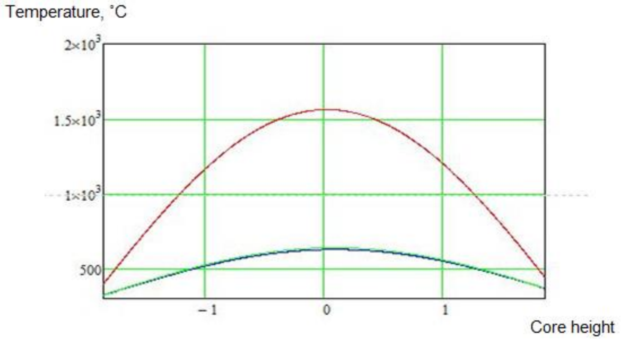

**Figure 2.** Temperature distribution in the center and on the surface of the fuel, $UO_2$, over the height of the core.

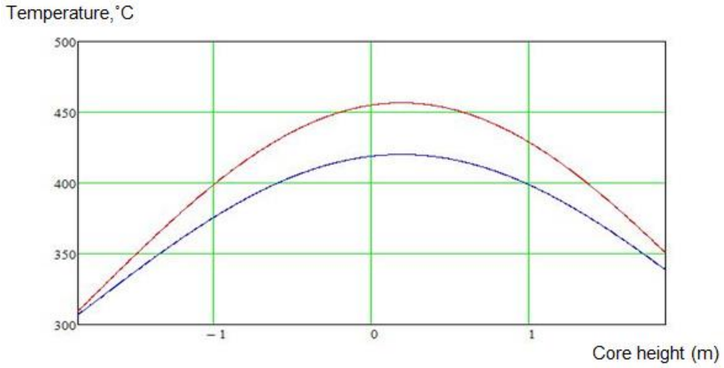

**Figure 3.** Temperature distribution in the center and on the surface of the fuel, U-10Mo, over the height of the core.

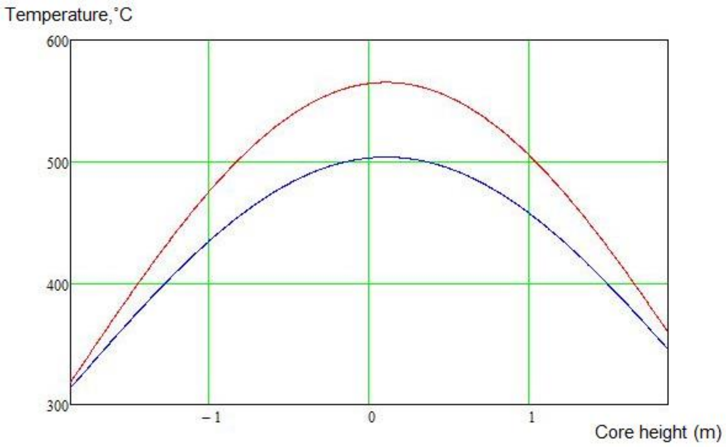

**Figure 4.** Temperature distribution in the center and on the surface of the fuel, $U_3Si_2$, over the height of the core.

It is evident from figure 2 that temperatures, were 678 ˚C and 1570 ˚C at the surface and in the center of the $UO_2$ fuel, respectively. Whereas, this high temperature range dropped markedly, for U-10Mo fuel, being 420 ˚C on the surface and 457 ˚C in the center line. The $U_3Si_2$ fuel showed similar drop in temperature, being 502 ˚C on the surface and 571 ˚C in the center of fuel.

This is due to marked increase in thermal conductivities of ATF materials, which resulted in the reduction of the center line temperature of the core reactor and in lower thermal gradient of temperature distribution curves. Both reductions are beneficial to the LWRs plant, through increasing margin to melt and decreasing hoop stresses induced in the fuel during startup and power maneuvering [5, 13 and 14].

However, the performance of fuel depends on cladding materials as well and this need to be investigated, further. The finding may be helpful in development of ATF materials as the poor thermal conductivity of $UO_2$ may deteriorates further during burn up, and replacement of such fuel is necessary for more safety of the reactors.

## 4. Conclusion

ATF fuels could be a proper tool to overcome the most commonly cited limitations of $UO_2$, namely the poor thermal conductivity.

The lower temperature distribution of the U-10Mo and $U_3Si_2$ fuels in the reactor core compared with that $UO_2$ distribution may increase the margin to melt, by lowering the heat stored in the fuel system.

The lower thermal gradient of ATF curves may decrease the hoop stresses in the fuel reactor, which could affect the steady state performance and the accident behavior in the plant.

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