Thermal Performance Prediction of UO2 Pellet Partly Containing 9% wTungsten Network

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Abstract

Sintered UO2 exhibits very stable in reactor core compared to UC, UN, U metal and its alloys. However, its thermal conductivity is very low (about 2.5 W/m K), that limits its performance. UO2 pellet containing Tungsten network invented by Song improves considerably its conductivity. The paper reports an analysis of thermal performance for UO2 pellet that containing partly or holy with 9% b. of Tungsten. The tungsten network having a high melting point and excellent thermal conductivity is continuously formed around UO2 grains. Since the presence of network decreases the amount of fissile material and the burn up of fissile material is higher in the near surface zone of pellet but high temperature zone that releases low conductivity fission gas to the gap located in inner part of pellet, the analysis has been done for different outer radial-portion of tungsten-free pellet. The analysis takes into account the correction factor for pellet conductivity related to both pore and temperature distribution and high burn up effect. The gap conductance has been considered invariable since decrease caused by wider gap size related to lower pellet expansion is compensated by increase caused by fewer of refractory fission gas released. The results (47 kw/m, 40% burnup) show temperature decrease in all of pellet position containing W network. Pellet containing 9% b. tungsten network lower consecutively its center line temperature from 1578 to 1406, 1292, 1231, 1192, 1111, and 1038 C for 0, 50, 67, 75, 80, 90, and 100 % portion of network. An 80 to 90 % portion of inner pellet containing tungsten network can be considered a best fuel design. This preliminary analysis is prospective and more realistic analysis is recommended.

Keywords: UO2 containing W network, thermal performance, prediction.
INTRODUCTION

The economic improvements achieved by burnup extension through increasing the U235 enrichment have been supplemented with a whole range of measures geared towards improving the fuel utilization by enhancement of the neutron economy. These measures comprise the introduction of part low leakage, the consequent use of low neutron absorbing rate materials in the fuel assembly structure, transition to Gd2O3 designs so as to realize full low leakage core loadings and, as more recently, implementation of super low leakage and transition to the low gadolinium concept where technically feasible. In total, these development measures resulted in a saving in U235 enrichment In the case where the improvement of the fuel utilization by enhancement of the neutron economy is transferred into an increase of the discharge burnup – which is being done wherever possible – the resulting economic effects can be considerably higher. This fact will be of increased interest when the 5% enrichment limit is reached, i.e. under this border condition, improvement of neutron economy will gain substantially in economic importance[1].

Fuel cycle cost as function of burnup reduces greatly with discharge burnup when back-end cost independent of spent fuel mass. It reduces more when the back-end cost depends on mass of spent fuel. The potential economic of high burn-up fuel rises interest of development project for high burnup fuel.

Historically, uranium dioxide has been used almost exclusively in all light water reactor applications. Other forms of uranium fuel include: uranium metal, uranium carbide, uranium nitride, uranium phosphide and uranium sulfide. The main advantages in the use of uranium dioxide are its high melting point, dimensional and radiation stability and its chemical compatibility with other reactor components. The main disadvantages are its low thermal conductivity and low fuel density which leads to high centerline temperatures and large volume cores. All factors considered, oxide fuels have been the fuel of choice in light water reactor applications.

The stable form of stoichiometric uranium dioxide, for all temperatures up to its melting point (2865°C), is the Fluorite structure. This structure may be considered as a 3 x 3 cube of simple cubic anion sublattices with an interpenetrating FCC cation sublattice. The unoccupied central positions of the simple cubic structures provide locations for the buildup of fission products or sites for interstitial oxygen. Oxide fuels may also form hyperstoichiometric and hypostoichiometric compounds depending upon the ratio of oxygen to uranium atoms (O/M) such that stoichiometric compounds have an O/M ratio of 2.00, hyperstoichiometric compounds have an O/M ratio greater than 2.00 and hypostoichiometric compounds have an O/M ratio less than 2.00. [1]

The relatively low thermal conductivity of UO2 requires that large temperature gradients be established to drive the heat from the fuel. This results in a high centerline temperature which, during extreme transient conditions, can rapidly approach the melting point of the fuel.

It is a goal of fuel development to increase the rod power and the burn up with a view to optimizing the economics of fuel assemblies. Overpower Margin Increase, Fuel Reliability Enhancement, Operation Flexibility. However, this causes increased amounts of fission gases to be released, which can have the effect of restricting the burn up. Basically the increase of burnup of the fuel has some influence on the safety of reactor operation and on fuel cycle facilities. The most relevant effect of increased
burnup on reactor operation is related to the integrity of the cladding material of the fuel rods. In addition, shutdown margin, reactivity behavior and increased heat are relevant.

Some solution of increase of internal temperature affecting burn up increase by pellet modification are reducing of elements diameter [3] pellets with central hole [4] duplex pellets [5] graphite discs between pellets [6-7]. The two first solutions minimize the fuel, so they are not favorable.

Other pellet having high thermal conductivity has been invented by Song [xx]. It is an oxidic fuel containing tungsten. The tungsten metal having high melting temperature and better dissipate thermal energy than the fuel (UO2, PuO2, ThO2). Particularly, the nuclear fuel body comprises tungsten network that is continuously formed between fuel grains and thus envelops fuel grains (see Fig. 1).

As shown in Fig.1.b, tungsten network is continuous between fuel grains throughout the entire uranium oxide sintered body and acts as a heat-conducting channel. The lines metal network--shown in two-dimensional photograph mean the planes in three-dimensions, and the polygon fuel grains in two-dimensional photograph are the polyhedrons in three-dimensions. Thus, the metal tungsten has a shape which envelopes the polyhedral grains. As tungsten network is completely formed, nuclear fuel materials are in polyhedral tungsten and such tungsten polyhedrons are continuously gathered together to constitute a sintered body. The sizes of the tungsten polyhedrons are corresponding to those of fuel grains.

The fuel grain size depends on the conditions of its preparation method. The fuel grains become larger as additives are added to nuclear fuel materials. As an additive, Nb, Ti, Al, Si or Mg oxide can be used. The grain size of nuclear fuel sintered body provided by the present invention is between 5 and 500 μm in diameter in two-dimensional photograph. Thus, the size of one unit of tungsten network is also between 5 and 500 μm in diameter and the tungsten channel between two neighboring fuel grains has thickness ranging from 0.1 to 20 μm.

The amount of tungsten in the fuel body increases with increasing the thickness of tungsten channel and with decreasing the size of fuel grain. On the contrary, the amount of nuclear fuel material in sintered body decreases with increasing the amount of tungsten therein and so does the fission energy produced in fuel body, causing a drop in economical efficiency. Therefore, it is desirable to enhance the thermal conductivity of fuel body by a small amount of tungsten. The nuclear fuel sintered body provided by this invention has the amount of tungsten ranging from 0.2 to 50% by weight of fuel.

Figure 1. Microstructure of UO2 pellet containing Tungsten (a) dispersed within UO2 and (b) Tungsten phase precipitated on UO2 grains boundary, acting as matrix / network [8]
The melting point of tungsten is 3400 degree C. and the melting point of uranium oxide is 2800 degree C. That is the reason why tungsten is chosen as a network material. Tungsten alloys containing other metals up to about 10% by weight can be used as network materials unless they do not significantly decrease the melting point of tungsten alloys.

The nuclear fuel body of the present invention is characterized by being composed of nuclear fuel materials and tungsten network. Uranium oxide or uranium oxide mixture, prepared by mixing one selected from a group consisting of gadolinium oxide, plutonium oxide and thorium oxide with uranium oxide, can be used for the nuclear fuel material. If tungsten is dispersed in a form of isolated particles with no tungsten network, tungsten cannot act as a heat-conducting channel. The nuclear fuel body of the present invention is characterized by having tungsten network, not by tungsten dispersed in a form of isolated particles.

There are two steps of transferring the heat generated from nuclear fuel materials in the nuclear fuel body of the present invention. The heat generated in the nuclear fuel grains by nuclear fission of uranium is conducted to the neighboring tungsten network through uranium oxide (step 1), and the heat is further conducted through the tungsten network having relatively high thermal conductivity and being continuous throughout the entire sintered body, and thereby the heat generated in the center of the body can be conducted to the surface of the body (step 2). The thermal conductivity of tungsten is higher by 25 times than that of uranium oxide. Thus, the nuclear fuel body of the present invention has enhanced thermal conductivity.

Tungsten network channel is not a line but a plane in three-dimensions, so point damage of a plane does not much degrade the heat conduction through the tungsten channel. The nuclear fuel body of the present invention includes the tungsten network throughout the entire fuel body. Some variations are possible in the spirit of this invention. The tungsten network can be formed in local regions of the fuel body. Especially, it is possible to prepare a cylindrical fuel body in which an inner cylinder has tungsten network but the outside ring does not. Conversely, it is also possible to prepare a fuel body in which tungsten network is formed only in the outside ring. In order to supplement the low thermal conductivity of conventional nuclear fuel bodies, every possible factor that might decrease the thermal conductivity have been restricted. Since the nuclear fuel body of the present invention comprises tungsten network, which means heat is conducted through the tungsten network, thermal conductivity does not much affected by the change in the oxygen/uranium ratio and the density of the fuel body. That is, the nuclear fuel body of the present invention can be

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Thermal diffusivity of nuclear fuel body comprising tungsten network (A)</th>
<th>Pure uranium oxide body (B)</th>
<th>Ratio of A to B (A/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>5.271</td>
<td>3.617</td>
<td>1.46</td>
</tr>
<tr>
<td>400</td>
<td>4.456</td>
<td>2.772</td>
<td>1.61</td>
</tr>
<tr>
<td>600</td>
<td>3.287</td>
<td>1.945</td>
<td>1.69</td>
</tr>
<tr>
<td>800</td>
<td>2.629</td>
<td>1.487</td>
<td>1.77</td>
</tr>
<tr>
<td>1000</td>
<td>2.239</td>
<td>1.238</td>
<td>1.81</td>
</tr>
<tr>
<td>1200</td>
<td>1.978</td>
<td>1.085</td>
<td>1.82</td>
</tr>
<tr>
<td>1400</td>
<td>1.619</td>
<td>0.926</td>
<td>1.86</td>
</tr>
</tbody>
</table>
used in the wide range of oxygen/uranium ratio and density

The objective of the study is steady-state thermal analysis of the rod using novel pellet – containing tungsten network of 9% w. Since the presence of network decreases the amount of fissile material and the burn up of fissile material is higher in the near surface zone of pellet but high temperature zone that releases low conductivity fission gas to the gap located in inner part of pellet, the analysis has been done for different outer radial-portion of tungsten-free pellet: a control is conventional pellet, cylindrical form, pellet wholly containing metal matrix, and pellet which only inner part (50, 33, 25, 20, 10)% radial containing tungsten network.

METHOD

The analysis takes into account the correction factor for pellet conductivity related to both pore and temperature distribution and high burn up effect. The gap conductance has been considered invariable since decrease caused by wider gap size related to lower pellet expansion is compensated by increase caused by fewer of refractory fission gas released. The results (47 kw/m, 40% burnup) show temperature decrease in all of pellet position containing W network. The thermal conductivity changes of irradiated UO2 pellets may be related to different phenomena such irradiation-induced point defects, fission products and irradiation-induced micro bubbles. The degradation of thermal conductivity related to high burnup has long been studied, but still all be fully understood. The formation of HBS (rim structure at high burnup) that contains more pore has been studied for long time.

The temperature distribution has been obtained by applying a simple model of steady-state heat transfer of fuel rod at particular level of high burn-up. Calculation has been done by typical models of pore distribution and gap conductance at high burn-up. The model takes into account thermal properties dependent of pellet to temperature, pore, and burn-up. The procedure evolves the following steps.

Choice pore distribution at high burn-up, model pore and temperature dependent of pellet conductivity, and temperature on cladding thermal conductivity. Pore contribution is modeled as factor to pellet thermal conductivity, computes coolant water temperature along rod side related to the model of axial power distribution that is considered as cosines type. The cladding surface to water coolant heat transfer is calculated according to simplified model of Dittus-Boelter. The temperature of cladding surface is determined without taken into account thermal conductivity of CRUD. The radial power distribution is modeled as a linear combination function, fitted from typical density from experimental data. Rod heat transfer in the axial direction is omitted. Heat transfer equation in the fuel pellet is approached by a combination of finite element and finite differences Saturn-FS1 [2].

Pore distribution is obtained by linear combination fitting an experimental data, and modification for this parametric study.

\[
\text{por}(y) := \begin{cases} 
0.05 \frac{\text{Power}(y)}{0.375} & \text{if } y < 0.8 \\
0.05 \frac{\text{Power}(y)}{0.375} + (y - 0.8) \cdot 1.6 & \text{if } 0.8 \leq y \leq 0.9 \\
0.05 \frac{\text{Power}(y)}{0.375} + 0.16 & \text{if } 0.9 < y 
\end{cases}
\]  

(1)
Pore and thermal conductivity.

Two models of thermal conductivity of irradiated fuel is applied:

a. Correction factor for fuel pore that is modeled as pure pore variable of

\[ F_p := \frac{1.1316(1 - \text{por})}{1 + (\text{por} + 10\text{por}^2)} \]  

(2)

b. Correction factor of pore that depends on pore and a coefficient depending on temperature. The measured thermal conductivities were normalized to the values of 96.5%TD (TD: theoretical density) by using the Loeb’s equation:

\[ \lambda_n = \lambda_m (1 - 0.035\varepsilon) / (1 - \varepsilon P), \]  

(3)

where: \( \lambda_n \) is the thermal conductivity normalized to that of 96.5%TD; \( \lambda_m \) the measured thermal conductivity; \( \varepsilon \), the parameter which express the effect of pore shape on the thermal conductivity of pellets; is \( P \), the porosity evaluated from the sample density. The parameter expressed as follows [3]:

\[ \varepsilon = 2.6 - 5 \times 10^{-4} (T(K) - 273.15), \]  

(4)

Washington [4.1], F, pore factor

\[ F = 1.0 - 2.5 \cdot P; \quad P = 1 - TD \]  

(5)

The last two models may be unified as correction factor of Waisenak

\[ F_p = (1 - \beta \cdot P) / (1 - 0.05 \cdot \beta) \]  

(6)

\[ \beta = 2.58 - 0.58 \times 10^{-3} \cdot T \quad T = T_c \]  

(7)

\[ K = K_{95\%TD} \cdot (1 - \beta \cdot P) / (1 - 0.05 \cdot \beta) \]  

(8)

MatPro v 9.0 model of temperature dependent of thermal conductivity of fresh/un-irradiated UO2 fuel has been chosen.

For: \( 0 < T < 1650 \) °C

\[ \frac{K_{mp - l}(\beta, D, T)}{1 - \beta(1 - D)} = \frac{40.4}{464 + T} \cdot 1.216 \times 10^{-4} \exp\left(1.867 \times 10^{-3} T \right) \]  

(9)

and for: \( 1659 < T < 2840 \) °C

\[ \frac{K_{mp - h}(\beta, D, T)}{1 - \beta(1 - D)} = \frac{0.0191 + 1.216 \times 10^{-4} \exp\left(1.867 \times 10^{-3} T \right)}{1 - 0.05 \beta} \]  

(10)
Coolant temperature along the channel

The surface temperature $T_s$ at each axial location of the fuel rod is the starting point for calculation of the radial temperature distribution of related $z$ position. The flowing coolant temperature is calculated from the energy balance of fuel and coolant system, local and total along the fuel rod.

\[
T_{cool(z)} = \frac{1}{Q_{mw} c_{pw}} \int_{T_{in}}^{T_{sat}} q_{r}(z) dz \quad \text{if } \eta = 1
\]

\[
T_{cool(z)} = \frac{1}{Q_{mw} c_{pw}} \int_{T_{in}}^{T_{sat}} q_{r}(z) dz \quad \text{if } \eta = 2
\]

$Q_{mw}$ is mass flow rate of coolant, $c_{pw}$ is the heat capacity of the coolant - temperature dependent, $T_{cool}$ is coolant temperature and $T_{in}$ is inlet coolant temperature. The parameter $\eta$ represents reactor type, 1 for LWR and 2 for PWR. The linear power, $q_{r}(z)$, is position dependent as follow [2]:

\[
q_{r}(z) = \cos \left[ \pi \left( \frac{z}{3L} - 0.25 \right) \right] - \sin \left[ \pi \left( \frac{z}{3L} - 0.3 \right) \right] - 1.0 q_{0}
\]

Where $q_{0}$ is Linear Heat Generation Rate and $L$ is fuel rod length.

Cladding Surface Temperature

In the analysis a single-phase heat transfer model simplifies the heat transfer coefficient of cladding surface. The Dittus-Boelter equation for heat transfer coefficient

\[
h_{w} = 0.023 \left( \frac{k}{D_{e}} \right) \left( \frac{D_{e} \nu \rho}{\mu} \right)^{0.2} Pr^{0.4}
\]

is reduced by choosing the right hand side with the mean value, except the coolant thermal conductivity. The surface temperature of cladding in $z$ position ($T_{cl}(z)$) is then calculated, knowing the linear power $q_{r}(z)$ and the convective heat transfer coefficient ($h_{w}$)

\[
T_{cl}(z) = T_{cool(z)} + \frac{q(z)}{2\pi h_{w}}
\]

Radial Distribution of Cladding Temperature

Discretion of cladding, using the term of cladding radius ($r_{c}$), $n_{c}$ = number of cladding segment, $R_{ci}$, inner cladding radius and $R_{co}$ for outer cladding radius.

The range of cladding radius $r_{c}$ is:

\[
r_{c} = \left( R_{ci}, R_{ci} + \frac{R_{co} - R_{ci}}{n_{c} - 1}, \ldots, R_{co} \right)
\]

The cladding temperature is calculated from the energy balance around the cladding. The balance around a slice of cladding ring, omitting the cladding water side corrosion, can be arranged as:

\[
T_{c}(r_{c}) = T_{c0} + \frac{q_{0}}{2 \pi \lambda_{cl} (T_{c})} \ln \left( \frac{R_{co}}{R_{c}} \right)
\]

$T_{c}(r_{c})$ is temperature of cladding at $r_{c}$. $T_{c}(R_{co})$ is the temperature of outer cladding. $\lambda_{cl}$ stands for thermal conductivity of cladding. Iteration is needed since the equation contains an implicit variable.

The difference between inner and outer cladding surfaces is:
\[ T_c(Rci) - T_c(Rco) = \frac{qz_0}{2\pi h c l(T_c)} \ln\left(\frac{Rco}{Rci}\right) \]  

(17)

At this point the temperature of flowing coolant to the inner surface of cladding is known.

The outer surface of fuel pellet than is calculated using a simplified input of gap conductance. It is assumed that the gap distance is not change by difference temperature distribution caused be non-heterogeneity of power:

\[ \Delta T_{\text{gap}} = \frac{qz_0}{2\pi Rf \lambda_{\text{gap}}(T)} \]  

(18)

Radial Distribution of Fuel Temperature and Porosity

The heat transfer from pellet surface to the inner surface of cladding is calculated using a simplified correlation of gap conductance as a temperature function.

The radial temperature gradient is assumed higher than it’s axial; the axial heat transfer is neglected. The energy balance in the fuel contains a power density term that depend on the corresponding radius,

\[ -\lambda(T(r), \text{por}(r)) \frac{dT(r)}{dr} = \frac{1}{2\pi} q_r(r) \]  

(19)

The \((q_v(r))\) is volumetric power density profile according to radial coordinate, be modeled as polynomial eq.10 that is fit of typical power distribution.

\[ q_v(r) = p \cdot v(r) \]  

(20)

For high burn-up the polynomial is expressed by eq.-11.,

\[
\begin{bmatrix}
0.373 \\
0.22 \\
0.410
\end{bmatrix}
\text{and } v(x) = \begin{bmatrix}
1 \\
x^{12} \\
x^{24}
\end{bmatrix}
\]  

(21)

The correlation between linear power density / LHGR \(q_r(r)\) and volumetric power density \(q_v(r)\) is:

\[ q_r(r) = 2\pi \int r q_v(r) dr \]  

(22)

A finite element approach is applied for the radial distribution of fuel temperature.

The radial space is discretized into \(nr\) element of linear LaGrange type. Fuel temperature in each element is defined as according to SATURN-FS1 algorithm, that give a solution of pellet temperature as eq.23

\[
T_k = T_{i+1} + D_k \cdot \frac{Q_v}{\lambda(T(r), \text{por}(r))} [Q_v R_i D_{nr-1} (AA_i + A_{nr-1} pm) + BB)]
\]  

(23)

Where Q, R, A, B, AA, BB, F and G are numerical variable mentioned some where [9,10]
The two constants pp and pm in AA and BB are correction factors. For this analysis are 1.0. Now the radial temperature distribution of z position is established. For other z coordinate the different in qr and Tcool. Tcool(z) has been calculated in eq-1. Linear heat generation (qr at radial position R) for different Z is LHGR multiplied by the axial power-factor. Repeating the radial distribution for all axial position using corresponding coolant temperature in eq-1, and volumetric heat generation eq-10 the temperature distribution in 2-dimensional space is calculated.

Comparing the temperature distribution does the analysis and the corresponding thermal property calculated by different heterogeneity of power density in radial or in axial direction.

RESULTS AND DISCUSSION

Fig.2 shows plot of thermal conductivity data from Tab.1 from room temperature to 1500 oC for UO2 pellet (noted UO2 square – red) and for UO2 pellet containing tungsten network (noted UO2W diamond-blue). The data of Tab.1 has been obtained by using the same measurement method [8]. It appears that the thermal conductivity of fuel without metal network is lower than usual about 2 absis scale of Fig 2.a. Nevertheless, the ratio is very close and comparable to one invented by Dorr et. al in Fig. 2.b[11] with a note that Fig.2b is thermal conductivity in radial direction. Dorr et all have made differences metal network contained UO2 pellets, and shows different thermal conductivities.

The ratio between the two conductivities pellet with to without tungsten network, has been fitted to a square fitting the ratio resulted equation for the conductivity ratio to temperature as : kTh(T,oC) = -3.E-07.T^3 + 0.000.T + 1.4646, with a good correlation coefficient of 0.9872. The diffusivity ratio increases with increasing temperature. This property is beneficial since by implementing this network the hot zone will be better lowering than in the colder zone. The ratio of thermal conductivity of fuel invented by Dorr also have same tendency, i.e., increase with temperature.

The thermal analysis of fuel comprising 9%w of tungsten network has been carried out by using typical data of UO2 pellet and the thermal conductivity has been calculated by applying thermal conductivity ratio to correct the new fuel conductivity. Pellets partially containing tungsten network also have been analyzed. The results is presented in Fig.3.
Figure 3. Different radial temperature distributions of six UO₂ pellets partly (0, 50, 67, 75, 80, 100 %) containing 9% w tungsten network at high burnup.

The upper curve noted TW₀₀ in Fig.4 shows the radial distributions of pellet temperature for in UO₂ pellet without tungsten network. The lower curve noted TW₁₀₀ is for pellet fully, all radius, contained 9% w tungsten. In this case the temperature is lower and maximum lowering temperature at the fuel center is about 440 K.

Since the tungsten reduces U contain and U contain in the rim zone of pellet will be burn much more than other zone, it is interesting to apply W network in the outside of rim zone. UO₂ pellets contained only partially (in radial fraction) as one is illustrated by inset of Fig.3 contained are noted as TW₉₀, TW₈₀, TW₇₅, TW₆₇, and TW₅₀. The effect of the tungsten network on maximum temperature is nearly 440 K when the fuel contain 9% w tungsten distributed equally to the whole pellet as network that function as good thermal conductor. The analysis did not taken into account the power reduction for the reduction 9% w of fuel that occupied by tungsten metal. When the application of tungsten network only 0.9 part of radial while 0.1 of exterior or rim zone is still pure UO₂, the lowering temperature of center pellet will be 346 K. Accordingly, for other portion of network application.

Table 2. Maximum lowering temperature for different portion of pellet containing 9%w tungsten network.

<table>
<thead>
<tr>
<th>Fraction of pellet contains 9%w W network, Radial Volume</th>
<th>Notation in Fig.4</th>
<th>Maximum temperature</th>
<th>Average weight percent of W to pellet</th>
<th>Maximum lowering temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 1.00</td>
<td>TW₁₀₀</td>
<td>1038</td>
<td>9</td>
<td>440</td>
</tr>
<tr>
<td>0.90 0.81</td>
<td>TW₉₀</td>
<td>1111</td>
<td>7.29</td>
<td>368</td>
</tr>
<tr>
<td>0.80 0.64</td>
<td>TW₈₀</td>
<td>1192</td>
<td>5.76</td>
<td>254</td>
</tr>
<tr>
<td>0.75 0.5625</td>
<td>TW₇₅</td>
<td>1231</td>
<td>5.0625</td>
<td>193</td>
</tr>
<tr>
<td>0.67 0.4489</td>
<td>TW₆₇</td>
<td>1292</td>
<td>4.0401</td>
<td>154</td>
</tr>
<tr>
<td>0.50 0.25</td>
<td>TW₅₀</td>
<td>1406</td>
<td>2.25</td>
<td>73</td>
</tr>
<tr>
<td>0 0</td>
<td>TW₀₀</td>
<td>1578</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2 resumes the pertinent results from Fig.4 and calculated average weight fraction of tungsten in the different pellets. In case only 0.5 radial fraction containing
W network, the related volume fraction is 0.25 and the average weight of tungsten is only 2.25%. It should be noted that since the network is only in the inner part where the burnup is concentrated on the rim zone of pellet especially at high burnup, so the simplification of not taken into account decrease in power density related to average weight of tungsten may be justified for rim zone is tungsten-free.

If the application of tungsten network only in the three-quarter of inner pellet, than the lowering maximum temperature will be about 250 K, and again the simplification of the analysis will less significant. Figure 4 shows the relation between the radial fraction of pellet comprising W network and typical center pellet temperature. Of course it must be considered how technically the fabrication can be carried out when only little part of inner pellet will be added a tungsten network. The results may be used as guidance for early step of fabrication development, pre-irradiation testing and for more detailed analysis that take into consideration of pellet heterogeneity, microstructure related properties and neutronic of containing tungsten etc.

![Max Temperature vs Radial Fraction W-Network](image)

Figure 4. Different radial temperature distributions of six UO2 pellets partly (0, 50, 67, 75, 80, 100 %) containing 9%w tungsten network at high burnup.

In addition of temperature limit of fuel in fuel safety criteria, a lower pellet temperature reduces the mobility of the fission gases in the fuel and thereby lowers the rate at which fission gases are released. The lower overall heat content of pellets with an increased thermal conductivity improves the fuel assembly performance under accident conditions (LOCA=Loss of coolant accident; RIA=reactivity initiated accident) by lengthening the time before the fuel assembly is destroyed. A lower central temperature with otherwise identical fuel properties also reduces what is known as the hour-glass effect, which has an adverse effect on the pellet cladding interaction (PCI) properties of a pellet. It seem the potential use of the new pellet that may change fuel performance.

Result obtained by Tulenko et al. for improving thermal performance of fuel rod by applying metal liquid bond between pellet and cladding for 6 kW/ft ~ 2 kW/m power rating is showed A lowering temperature around 350 K [12]. It is roughly comparable to application of tungsten network about half portion of inner pellet.

**CONCLUSION**

Thermal performance of new fuel UO2 containing tungsten network invented by Song et al. has been carried out for steady state at high burnup. The thermal conductivity of
the fuel is based by thermal conductivity ratio of new to typical UO2 for different temperature which tends increasing with temperature. Beside local composition and temperature, the analyses take into account the influent of porosity and burnup to conductivity. Since important part of burned fuel located in pellet rim zone, it has been also analyzed new fuel with ‘rim’ free-tungsten of different thickness from 0.1 to 0.5 radial fraction, that related to 7.29 to 2.25 %average weight of tungsten. All pellet containing tungsten network permit lowering 440 K center temperature, while the different partial network lower from 368 to 73 K. The analyses shows the potential use of new fuel and may be used as guidance for early step of fabrication development and for more detailed analysis.

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