

ANALYSIS OF UO_2 - BeO FUEL UNDER TRANSIENT USING FUEL PERFORMANCE CODE

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ABSTRACT

Recent research has appointed the need to replace the classic fuel concept, used in light water reactors. Uranium dioxide has a weak point due to the low thermal conductivity, that produce high temperatures on the fuel. The ceramic composite fuel formed of uranium dioxide (UO_2), with the addition of beryllium oxide (BeO), presents high thermal conductivity compared with UO_2 . The oxidation of zirconium generates hydrogen gas that can create a detonation condition. One of the preferred options are the ferritic alloys formed of iron-chromium and aluminum ($FeCrAl$), that should avoid the hydrogen release due to oxidation. In general, the $FeCrAl$ alloys containing 10–20Cr, 3–5Al, and 0–0.12Y in weight percent. The $FeCrAl$ alloys should exhibit a slow oxidation kinetics due to chemical composition. Resistance to oxidation in the presence of steam is improved as a function of the content of chromium and aluminum. In this way, the thermal and mechanical properties of the UO_2 - BeO -10%vol, composite fuel were coupled with $FeCrAl$ alloys and added to the fuel codes. In this work, we examine the fuel rod behavior of UO_2 -10%vol- $BeO/FeCrAl$, including a simulated transient of reactivity. The fuels behavior shown reduced temperature with UO_2 - BeO/Zr , UO_2 - $BeO/FeCrAl$ also were compared with UO_2/Zr system. The case reactivity initiated accident analyzed, reproducing the fuel rod called VA-1 using UO_2/Zr alloys and compared with UO_2 - $BeO/FeCrAl$.

1. INTRODUCTION

Nuclear power plants work with fuel systems based on uranium dioxide (UO_2) and zirconium alloys (UO_2/Zr). UO_2 has a lower thermal conductivity, elevated melting point, and excellent stability at high temperatures. Investigated the enhanced thermal conductivity of the composite fuel as UO_2 - BeO , also ferritic alloys as iron-chromium-aluminum ($FeCrAl$) are potentials to replace standard UO_2/Zr alloys. Research from the 1960s tested nuclear fuels that combined UO_2 and beryllium oxide (BeO) [1]. However, advanced fuels such as U_3Si_2 , UN, and UC are used as reliable replacements for UO_2 in nuclear units [2].

In this study, was investigated an enhanced thermal conductivity fuel based on a UO_2 matrix with dissolved BeO as the additive. This ceramic composite has a fraction of 90% by volume of UO_2 , and 10% by volume of BeO , with a high thermal conductivity compared to UO_2 (because of the reduced mass of BeO). One of the objectives was to analyze the behavior of

fuels analyzing the effects of enthalpy pulse of 165 cal/g during 4.4 ms in both fuels UO_2/Zr_4 and $\text{UO}_2\text{-BeO/FeCrAl}$, under reactivity-initiated accidents (RIA). The addition of BeO with high thermal conductivity to UO_2 changes several thermal and mechanical properties in the composite fuel $\text{UO}_2\text{-BeO}$. The melting point has a slight reduction, and the latent heat of fusion increases. Thermal expansion should also increase, and pellet swelling (which depends on fuel temperature) should reduce. In this study, we focused on $\text{UO}_2\text{-BeO}$ during a postulated RIA, with the expectation of a decreased fuel fragmentation and relocation. The inclusion of BeO reduced the inner pellet's thermal gradient, due to high thermal conductivity of BeO 29 W/m-k at 25 °C. A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup code (FRAPCON) was used to calculate the steady state [3], and FRAPTRAN (rod analysis programs transient) was used for the evaluation during a reactivity transient [4]. Modeling measured the performance of the fuel and the review of the physical properties of the BeO additions. A new version of fuel performance code was adapted to UO_2 with BeO to analyze the composite fuel, with the thermic features of $\text{UO}_2\text{-BeO}$ included in the material properties library of the fuel code. In the updated version, thermal conductivity, heat capacity, and enthalpy were revised. In addition, changes to the mechanical behavior of the fuel (due to the elastic and plastic response) were included. Table 1, shows the thermal features and differences of $\text{UO}_2\text{-BeO}$ [5].

Table 1: Properties of UO_2 and BeO at 25 °C, room temperature

Thermophysical properties	UO_2	BeO
Molecular mass, (amu)	270.3	250.1
Melting Point (°C)	2850	2550
Density (g/cm^3)	10.96	2.017
Specific Heat (J/kg-K)	235	1229
Linear thermal expansion ($\mu\text{m/K}$)	9.75	7.5
Thermal conductivity (W/m-K)	8.68	29
Heat of fusion (KJ/kg)	215±15	3216

The addition of BeO with high thermal conductivity to UO_2 changes several thermals and mechanical properties in the composite fuel $\text{UO}_2\text{-BeO}$. The differences include a melting point suffer slight changes, an increase of the latent heat of fusion, added variations in the emissivity, an increase in the thermal expansion, and a reduced pellet swelling as a function of temperature. In the 1960s, the General Electric (GE) Corporation proposed the FeCrAl alloys, for nuclear applications. Studies had shown a reducing the oxidation and a better mechanical performance of FeCrAl when compared with zirconium alloys.

1.1 FRAPCON Fuel Code

The Nuclear Regulatory Commission (NRC) defines the fuel performance code FRAPCON, coupled to FRAPTRAN, for licensing process applied to nuclear reactors. The NRC recommends that fuel systems must be accordance with MATPRO (Library of Material Properties for Light-Water-Reactor) [6]. FEMAXI (Thermal and Mechanical Behaviour of LWR Fuel Rods) and FALCON are code systems that utilize MATPRO, based on identical material properties [7], [8]. However, new options are still being researched that not exist in

MATPRO routines. For the composite fuel containing BeO, it can include all properties only for testing. The MATPRO library presents different functions regarding the permanent and transient states. A group of updated MATPRO routines that describe the thermal and mechanical behaviors of nuclear fuels and cladding materials. Therefore, innovative versions created for FRAPCON and FRAPTRAN can work with concept fuel, UO₂-BeO/FeCrAl.

2. COMPOSITE FUEL UO₂-BeO

UO₂ ceramic fuel is an oxide insulator, where conductivity decreases when temperature increases [9]. The low conductivity (2.8 W/m-k at approximately 1000 °C) reached during a loss of coolant is a key factor for improving safety operations. The large thermal gradient of inner fuel may arise from a buildup of fission gas released, which increases fuel swelling [10]. Nuclear units need to produce more power, but UO₂ has constraints due to a density requiring high enrichment [11]. However, UO₂ has the benefits of a higher melting point, and a great corrosion resistance [12]. BeO has been used as a neutron moderator and is utilized as a matrix for dispersed fuels. However, BeO also produces helium at about ten times the rate of tritium, according to the reaction (n, 2n). The preferred composition of UO₂-BeO has 10% by volume of BeO, and has economic benefits for cycles above 60 GWd/MTU. BeO of 10% by volume is the more stable option.

2.1 Fabrication Method of UO₂-BeO

Green granule (GG) and slug bisque (SB) are the two fabrication methods to produce UO₂-BeO pellets with distinct microstructures. The range of volume-fraction-to-composite within the fuel varies from 1 to 13.6% BeO, and the grain size of the beryllium is lower than that of uranium crystal structures. The pellets are sintered using SB granules to create an interface layer between the UO₂ and BeO phases. The pellets fabricated by GG have spherical green granules of UO₂, into which the second phase BeO is introduced. In general, SB-UO₂-BeO 10 v% has an average thermal conductivity of approximately 42% over the GG-UO₂-BeO 10 v% (which is below 500 °C [13].)

2.2 Volume Fractions

Ceramic composites have many factors that determine their physical properties (as defined by the proportions of their matrix). Dual formulations are based on the volume and weight fractions of each oxide in the mixture. In this investigation, the fuel formulation used a 10% by volume BeO to a 90% by volume UO₂ for stability. The BeO has a mass fraction estimated at 3.1% BeO, and 96.9% UO₂ - showing a high confidence with the metallurgical process used [14]. Eqs. (1) and (2) describe the relationship between the weight and volumetric fractions used for UO₂-BeO:

$$W(UO_2) = \frac{V(UO_2)\rho(UO_2)}{V(UO_2)\rho(UO_2) + V(BeO)\rho(BeO)} \quad (1)$$

$$W(BeO) = \frac{V(BeO)\rho(BeO)}{V(UO_2)\rho(UO_2) + V(BeO)\rho(BeO)} \quad (2)$$

where V is volume fraction, W represents the weight fraction of the composite, and ρ represents the fuel density in (Kg/m^3).

2.3 Density

Fuel composites show a density reflecting the volumetric ratio of each component used. Mechanical properties use the same rule, but other characteristics depend on the density. The composite fuel shows a reduction in the uranium density due to the volume of BeO. Pellets fabricated using BeO should contain a higher enrichment than UO_2 to compensate for the reduction in uranium mass. The composite fuel density depends on the volume fraction rule, multiplied by the single component density for both UO_2 and BeO. Eq. (3) expresses the UO_2 -BeO fuel density:

$$\rho(\text{UO}_2 - \text{BeO}) = V(\text{UO}_2) \times \rho(\text{UO}_2) + V(\text{BeO}) \times \rho(\text{BeO}) \quad (3)$$

The correlation shown is given as a function of the temperature in K, valid from 300 K to the melting point, and a density in g/cm^3 . The following equations display densities (4) for UO_2 , (5) for BeO, and (6) for UO_2 -BeO [8], [14]:

$$\rho(\text{UO}_2) = -2.966 \times 10^{-11} T^3 + 5.04 \times 10^{-8} T^2 - 0.0003495 T + 11.05 \quad (4)$$

$$\rho(\text{BeO}) = 2.049 \times 10^{-11} T^3 - 9.683 \times 10^{-8} T^2 + 3.205 \times 10^{-5} T + 3 \quad (5)$$

$$\rho(\text{UO}_2 - \text{BeO}) = -2.465 \times 10^{-11} T^3 + 3.568 \times 10^{-8} T^2 - 0.0003113 T + 10.25 \quad (6)$$

2.4 Thermal Conductivity

Fuel conductivity is the result of; fission products coupled with porosity, defects created by irradiation, and the fuel density. BeO is a ceramic oxide that presents desirable properties and has much more chemical stability when composited with UO_2 . The advantage of a dual oxide fuel is that the second phase is dispersed in the UO_2 . The composite fuel UO_2 -BeO exhibits thermal conductivity enhanced compared with UO_2 . Thermal conductivity must compute porosity and estimates the theoretical density, 95%. Eq. (7) expresses the thermal conductivity for UO_2 -BeO:

$$k(\text{UO}_2 - \text{BeO}) = k_{95}(\text{UO}_2 - \text{BeO}) \left(\frac{1}{1 - (2.6 - 5 \times 10^{-4} T) \times 0.05} \right) \quad (7)$$

Eq. (4) describes the thermal conductivity of UO_2 , based on temperature in K, valid from 300 to 3120 K. The composite fuel UO_2 -BeO has similar features compared to UN, UC, and U_3Si_2 . The physical properties for BeO are valid at a density of $2.87 \text{ g}/\text{cm}^3$. UO_2 fuel has a conductivity of $7.5 \text{ W}/\text{m}\cdot\text{K}$ at room temperature, whereas BeO exhibits $35.7 \text{ W}/\text{m}\cdot\text{K}$. Eq. (8) shows the theoretical thermal conductivity of UO_2 , and eq. (9) describes the conductivity of BeO valid from 298 K to 2883 K. Eq. (10) describes the conductivity of the composite, valid below the melting point [5].

$$k(UO_2) = \frac{100}{7.5408 + 17.692t + 3.61142t^2} + \frac{6400}{t^{5/2}} \exp\left(\frac{-16.35}{t}\right) \quad (8)$$

$$k(BeO) = -2.706 \times 10^{-8} T^3 + 7.86 \times 10^{-6} T^2 - 0.01653 T + 14.32 \quad (9)$$

$$K(UO_2 - BeO) = -1.293 \times 10^{-9} T^3 + 7.86 \times 10^{-6} T^2 - 0.01653 T + 14.32 \quad (10)$$

where T is temperature in K and k expresses the thermal conductivity in W/m-K.

2.5 Thermal expansion

The elastic properties of composite fuel are resulting from the application of volumetric rates, utilizing fractions of 10 %v for BeO and 90 %v for UO₂. Under normal conditions, UO₂ works in temperatures around 1273 K, showing a coefficient of 11.4 μm/K. BeO exhibits reduced coefficients when compared to UO₂ (8.2 μm/K.) Eq. (11) describes the thermal expansion coefficient for UO₂-BeO fuel using the rule of mixtures relationships [15], [16], [17]:

$$\frac{\Delta L}{L}(UO_2 - BeO) = V(UO_2) \times \frac{\Delta L}{L}(UO_2) + V(BeO) \times \frac{\Delta L}{L}(BeO) \quad (11)$$

Fuel using BeO will work with lower thermic gradients than UO₂, producing an reduced thermal expansion to composite fuel. Eq. (4) expresses the linear expansion of UO₂, integrated into both FRAPCON and FRAPTRAN codes. A small reduction in the volumetric expansion delays the gap closures that are an active feature of composite UO₂-BeO. The FETHEXP routine is a function of temperature and irradiation, calculated using the weight fraction of BeO in a UO₂ matrix. Eq. (12) represents the classical thermal expansion of UO₂ [18], [19], while eqs. (13), (14), and (15) describe the coefficients of linear thermal expansion for UO₂, BeO, and UO₂-BeO, respectively [20].

$$\frac{\Delta L}{L_0}(UO_2) = 9.8 \times 10^{-6} T - 2.61 \times 10^{-3} + 0.316 \exp\left(-\frac{E_D}{kT}\right) \quad (12)$$

where T is temperature in K, E_D is the energy of formation defect in Joules, and k is Boltzmann's constant (1.38×10^{-23} J/K).

$$\alpha(UO_2) = 1.873 \times 10^{-10} T^3 + 2.29 \times 10^{-6} T^2 - 0.002343 T + 10.38 \quad (13)$$

$$\alpha(BeO) = -3.644 \times 10^{-10} T^3 + 1.49 \times 10^{-7} T^2 + 0.004648 T + 3.86 \quad (14)$$

$$\alpha(UO_2 - BeO) = 1.321 \times 10^{-10} T^3 + 2.076 \times 10^{-6} T^2 - 0.001644 T + 9.78 \quad (15)$$

where T is temperature in K and α is the linear thermal expansion in μm/K.

An active feature of UO₂-BeO is the small reduction in the volumetric expansion that delays gap closures. The FTHEXP routine is a function of temperature and irradiation, calculated using the weight fraction of BeO in UO₂ matrix [21].

2.6 Heat Capacity

Both codes (FRAPCON and FRAPTRAN) obtain identical calculations for heat capacity and the enthalpy of fuel. In MATPRO, the routines proposed for UO₂ were “*fcp*” for specific heat, and “*fenth*” for fuel enthalpy. Calculations for ceramic composites may apply mass portions. The heat capacity of UO₂-BeO fuel results from the weight fractions applied to both oxides, and the proportionality of mass must be considered in order to calculate heat capacities:

$$C_p(UO_2 - BeO) = W(UO_2) \times C_p(UO_2) + W(BeO) \times C_p(BeO) \quad (16)$$

Eq. (11) is a theoretical function for the heat capacity of UO₂. Eqs. (12) and (13) describe the heat capacities of UO₂ and BeO, respectively. Eq. (14) describes the heat capacity of UO₂-BeO. The formulation used to compute heat capacity is valid from 298 K to melting point, and is the result of numeric fitting [21]:

$$C_p(UO_2) = \frac{K_1 \theta^2 \exp(\theta/T)}{T^2 [\exp(\theta/T) - 1]^2} + K_2 T + \frac{Y K_3 E_D}{2RT^2} \exp\left(-\frac{E_D}{RT}\right) \quad (17)$$

where T is temperature given in K, the constants are $K_1 = 296.7$ J/kg-K, $K_2 = 0.0243$ J/kg, $K_3 = 8.75 \times 10^7$ J/kg, Y is the oxygen to metal ratio (O/M), θ is the Einstein temperature ($\theta = 535.285$ K), R is the universal gas constant ($R = 8.315$ J/mole-K), and E_D is the activation energy for Frenkel defects of UO₂ ($E_D = 1.577 \times 10^5$ J/mole.)

The correlations to find the heat capacity of composite fuel depend on the heat capacities for UO₂ and BeO. Eqs. (18), (19), and (20) are a result of the weight fraction rules:

$$C_p(UO_2) = -1.363 \times 10^{-11} T^4 + 1.5 \times 10^{-7} T^3 - 0.0004136 \times T^2 + 0.4547 T + 136.5 \quad (18)$$

$$C_p(BeO) = 9.117 \times 10^{-8} T^3 - 5398 \times 10^{-7} T^2 + 1.25 T + 1148 \quad (19)$$

$$C_p(UO_2 - BeO) = 6.571 \times 10^{-8} T^3 - 0.0002423 T^2 + 0.334 T + 204.1 \quad (20)$$

2.7 Fuel Enthalpy

The heat capacity of BeO is five times that of UO₂ at room temperature. As a consequence, there is a small reduction in the value of UO₂-BeO fuel. Fuel enthalpy is the numeric integration of the heat capacity curves from room temperature (25 °C) to the desired temperature. During the postulated RIA, fuel pellet temperature quickly grows, showing fuel fragmentation and relocation. The increase in fuel pellet heat is measured as an enthalpy increase of fuel. Stored energy is a parameter calculated from enthalpy, resulting in lower energy. All advanced fuels have a reduction of enthalpy as U₃Si₂ increases security. The heat capacity of UO₂. Eq. (21) is

adopted for fuel codes. The polynomial fitting for fuel enthalpy is applied to simulations, using the temperature in K. Enthalpy is given as a temperature function in eq. (22) for BeO, and eq. (23) for UO₂-BeO ceramic-ceramic composites. They are valid for temperature ranges from 298 K to their melting points:

$$H(UO_2) = \frac{K_1\theta}{\exp(\theta/T)-1} + \frac{K_2T}{2} + \frac{Y}{2} \left[K_3 \exp\left(-\frac{E_D}{RT}\right) \right] \quad (21)$$

$$H(BeO) = 2.2793 \times 10^{-8}T^4 - 1.7993 \times 10^{-4}T^3 + 0.625T^2 + 1148T - 393246 \quad (22)$$

$$H(UO_2 - BeO) = 1.6427 \times 10^{-8}T^4 - 8.0767 \times 10^{-5}T^3 + 0.167T^2 + 204.1T - 73687 \quad (23)$$

2.8 Melting Point and Heat Fusion

The melting point of ceramic-ceramic fuels should be approximately 10 K for UO₂, however this is irrelevant for safety limits. The routine PHYRRP defines the heat of fusion for a pellet. The inclusion of BeO makes the heat of fusion 2.74×10^5 J/Kg.

2.9 Mechanical Properties

Elastic properties use the volume fraction rules, based on their compositions. Composites use a portion of the volume to analyze all elasticity parameters via Young's modulus and Poisson's coefficient [22]. Eqs. (24) and (25) describe the volume fraction used to calculate mechanical properties:

$$E(UO_2 - BeO) = V(UO_2) \times E(UO_2) + V(BeO) \times E(BeO) \quad (24)$$

$$\nu(UO_2 - BeO) = V(UO_2) \times \nu(UO_2) + V(BeO) \times \nu(BeO) \quad (25)$$

The mechanical response of the composite fuel depends on the metallurgical processes used to fabricate UO₂-BeO, but exist as slight variations. Theoretically, a composite will increase the elastic modulus and decrease the Poisson ratio. Table 2, compares mechanical properties of UO₂ and BeO at room temperature:

Table 2: Mechanical properties of UO₂ and UO₂-BeO at room temperature

Mechanical properties	UO ₂	BeO
Crystal structure	Face centered cubic	Hexagonal
Lattice Constants Å	5.474	4.398
Elastic modulus (GPa)	270.3	345
Poisson ratio	0.28	0.23

Eq. (26) defines the elastic modulus correlation for UO₂ in Pa, given as a function of temperature in K and a stoichiometric ratio (O/M) varying from 0.0 to 0.01:

$$E(UO_2) = (2.334 \times 10^{11}) \times (1 - (1.0915 \times 10^{-4}) \times T \times \exp(-1.34 \times (O/M))) \quad (26)$$

Generally, mechanical properties decrease with an increasing temperature, due to the melting point. The elastic modulus of ceramic–ceramic fuels experiences a slight increase. Eq. (2) shows a linear approximation of Young’s modulus for UO_2 in GPa, using a metal ratio of 0.01. The resulting composite is shown in eq. (28). Slight changes have an effect that should reduce the fuel fragmentation and cracking:

$$E(UO_2) = -0.02514 \times T + 233.4 \quad (27)$$

$$E(UO_2 - BeO) = -0.02263 \times T + 245.1 \quad (28)$$

3. FUEL ROD SIMULATION

Test rod used for simulation using UO_2 /Zirlo, irradiated at 71 GWd/MTU. The cladding showed oxide thickness of 73 μm , and hydrogen content of 660 ppm. The VA-1 fuel rod utilized The Nuclear Safety Research Reactor (NSRR), supported by the Japan Atomic Energy Agency (JAEA). Table 3, shown the main characteristics of experiment. In Fig. 1, exhibits fuel centerline temperature of VA-1 simulation and Fig. 2, shown average cladding temperature.

Table 3: Main features of VA-1 test performed at NSRR, included on RIA benchmark

Name	Reactor	Fuel	Burnup	Cladding	Enthalpy	Pulse
VA-1	PWR 17x17	UO_2	71 GWd/MTU	Zirlo	165 cal/g	4.4 ms

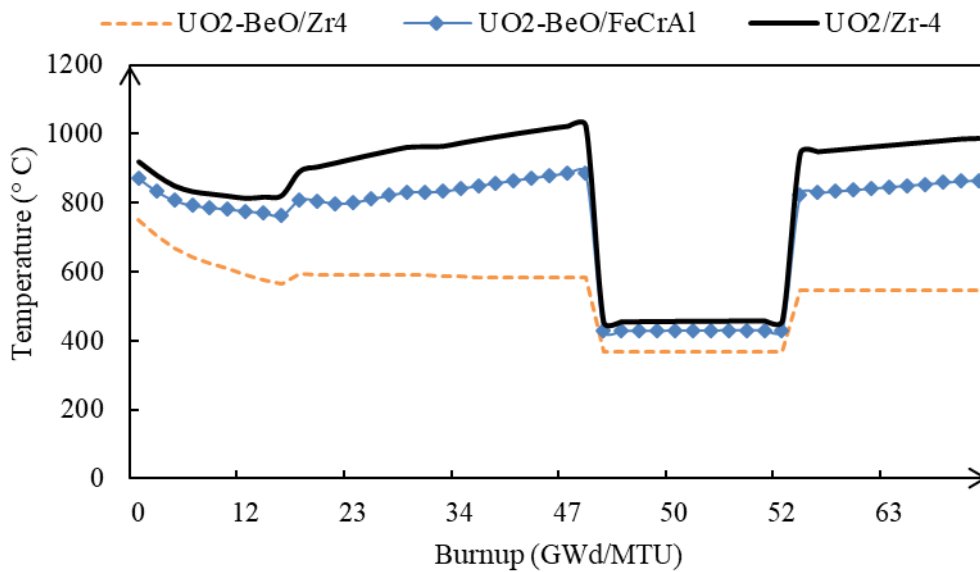


Figure 1: Fuel temperature during steady state for different fuel concepts

The fuel rod was refabricated and was applied an enthalpy pulse width of 4.4 ms. The enthalpy pulses have a narrow width, because of enormous energy inserted on the fuel rod. The rod failure at enthalpy of 64 cal/g considered lower energy inserted due to extended burn cycle. The same condition were applied for $\text{UO}_2\text{-BeO}$ 10% v using FeCrAl as cladding. The basic idea was verified the fuel behavior of UO_2/Zr system compared with $\text{UO}_2\text{-BeO}/\text{FeCrAl}$.

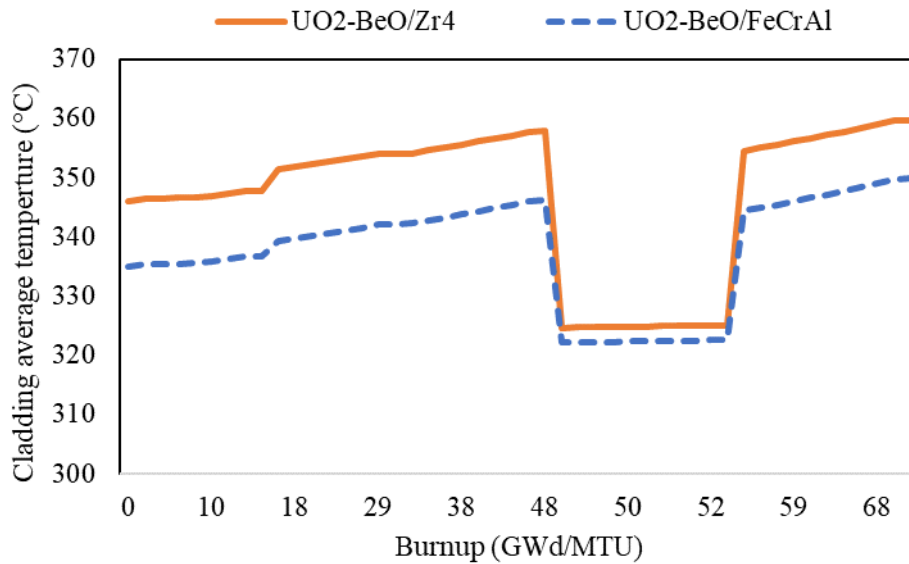


Figure 2: Cladding temperatures for different claddings

The fuel rod simulation maintains typical operation under extended burn cycle, working under normal operation. The FRAPCON and FRAPTRAN code were adapted to system $\text{UO}_2\text{-BeO}/\text{FeCrAl}$, $\text{UO}_2\text{-BeO}/\text{Zr}$ was compared with fuel system UO_2/Zr . Reactivity initiated accident VA-1 simulation show small differences, the fuel failure occurs practically at same time due to degradation of material produced by irradiation. Fig. 3, show that result of simulation of $\text{UO}_2\text{-BeO}/\text{FeCrAl}$ system.

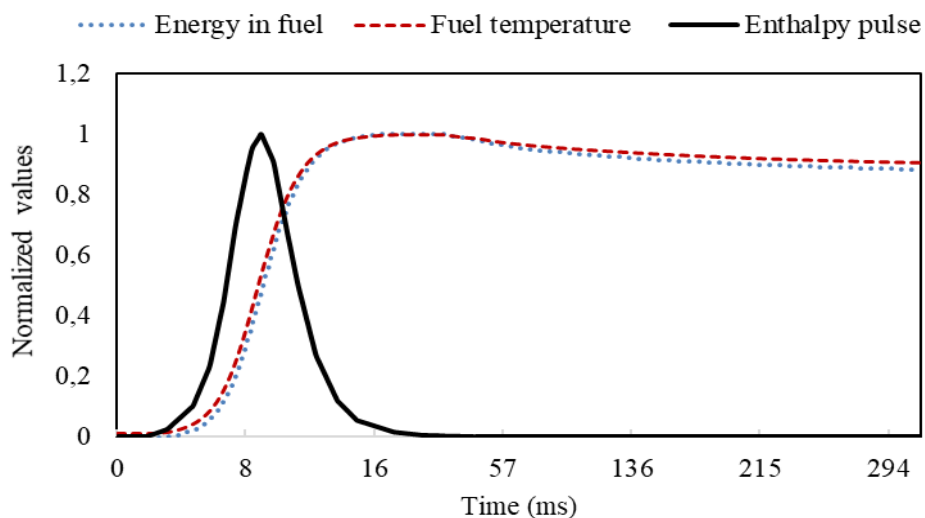


Figure 3: Enthalpy pulse, fuel temperature and stored energy

Also, we developed other simulation using both fuel systems $\text{UO}_2\text{-BeO/FeCrAl}$ and UO_2/Zr . The test was based on PWR 17x17 using two linear average power profiles 16 KW/m and 65 KW/m during 300 effective power days. Fig. 4, shows fuel centerline temperature. In Fig. 5, describe average power distribution given as function of radius.

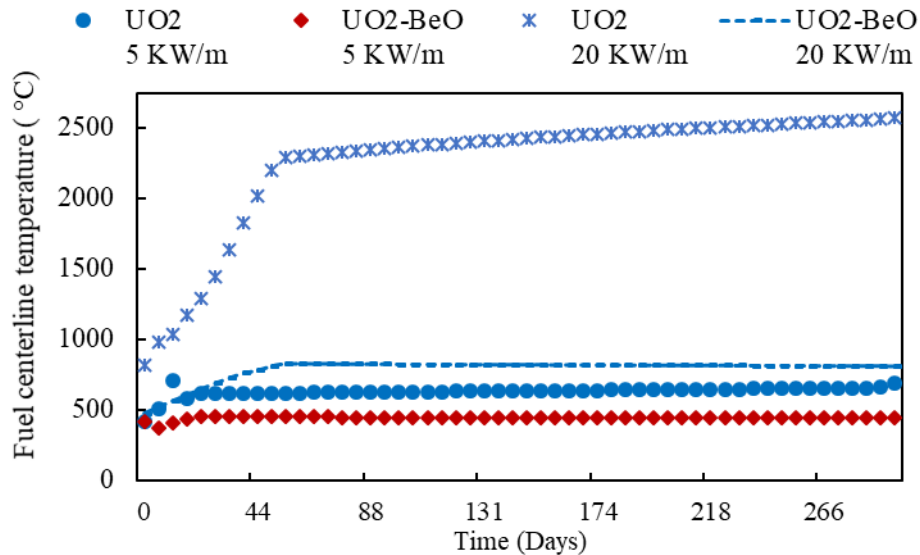


Figure 4: Fuel centerline temperature to 5 KW/m and 20 KW/m (Zr-alloys)

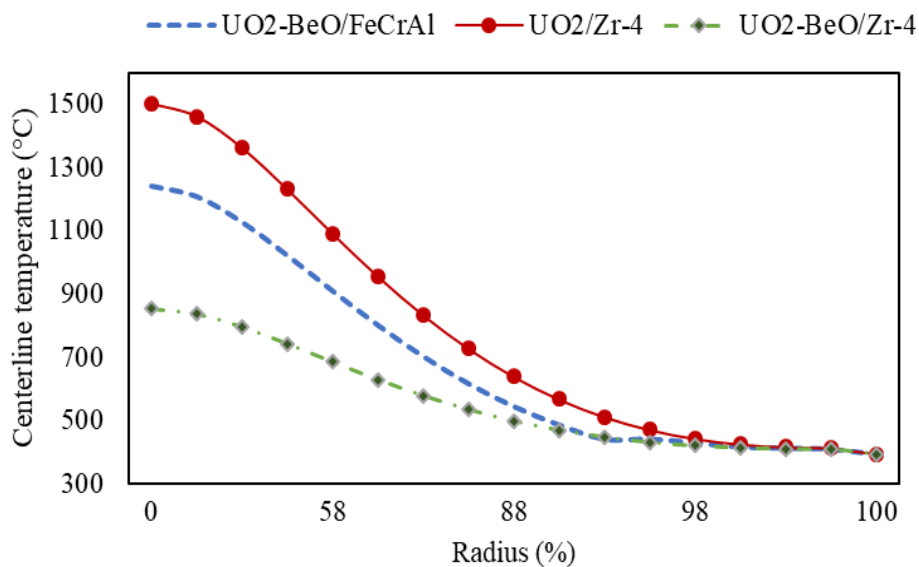


Figure 4: Fuel centerline temperature to average power of 20 KW/m

4. CONCLUSIONS

The $\text{UO}_2\text{-BeO}$ fuel system was analyzed using fuel codes adapted to the innovative fuel concept showing safety conditions improved. The composite fuel $\text{UO}_2\text{-BeO}$ 10% volume, has been modeled a light water reactor and used to simulate RIA test, VA-1, showing a better response

than UO₂/Zr system. Thermal and mechanical fuel response are analyzed the changes are based from constitutive laws implemented include UO₂-BeO, that also are burnup dependent. The modelling applied should express slight variability due to metallurgical process used to fabricate composite fuel. BeO oxide is chemically compatible with UO₂, also has high melting point, low thermal expansion coefficient, acceptable neutron absorption. The models implemented in FRAPCON and FRAPTRAN can reproduce fuel swelling, fuel densification, fuel thermal and irradiation creep. In RIA test was maintained the fuel enthalpy failure of 165 cal/g, but UO₂-BeO show higher enthalpy than UO₂, where stored energy in the fuel can accelerate the failure process. The ferritic iron-chromium-aluminium alloy represents the cladding concept that works with 73% of zirconium alloys thickness and maintaining radial gap. FeCrAl alloys have a better mechanical response than zirconium alloys, showing a lower creep rate, and improved mechanical performance. The UO₂-BeO/FeCrAl expressed the capability of decreasing the pellet temperatures, improving the safety operations, decreasing the fission gas released, reducing the gap pressure, also the plenum pressure due to temperature. The UO₂-BeO/FeCrAl system showed advantages relative to that of the UO₂/Zr alloy system. UO₂-BeO has low thermal gradients under normal operations. FeCrAl has a better response under steady state and transient conditions and should avoid undesirable hydrogen accumulation.

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