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FUEL PERFORMANCE EVALUATION FOR THE CAFE EXPERIMENTAL DEVICE

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ABSTRACT

Fuel rod cladding material is the second barrier to prevent the release of radioactive inventories in a PWR reactor. In this sense, an important safety aspect is to assess the fuel behavior under operational conditions. This can be made by means of fuel performance codes and confirmed by experimental measurements. In order to evaluate the fuel behavior of fuel rods in steady-state conditions, it was designed an experimental irradiation device, the Nuclear Fuel Irradiation Circuit (CAFE-Mod1). This device will allow controlling the surface rod temperature, to measure the power associated to the rod and the evolution of fission gas release for a typical PWR fuel pin. However, to support the experimental irradiation program, it is extremely important to simulate the experimental conditions using a fuel performance code. The aim of this paper is to evaluate some parameters and aspects related to the fuel rod behavior during the irradiation program. This evaluation was carried out by means of an adapted fuel performance code. Obtained results have shown that besides of the variation observed for parameters, such as, fuel temperature and fission gas release as a function of fuel enrichment level, the fuel rod integrity was preserved in all studied conditions.

1. INTRODUCTION

Pressurized water reactors (PWR) commonly use cylindrical uranium dioxide (UO_2) pellets as fuel which are clad in a metal alloy. Consequently, the fuel rod cladding material is, in a PWR reactor, the first barrier to prevent release of radioactive materials to the primary circuit. Therefore, an important safety aspect to license the reactor design is to evaluate the fuel behavior under the reactor normal operational conditions. This evaluation is carried out by means of fuel performance codes and the obtained results have to be checked by experimental measurements.

The Nuclear Power Generation Laboratory (LABGENE) project, developed at the Navy Technological Center in São Paulo (CTMSP), is a test bed for developing the capability to design small and medium power reactors for electricity production, and for nuclear propulsion [1].

As a consequence, theLABGENE project presents specific characteristics regarding to materials and reactor design. Its licensing involves the safety analysis of the fuel rod behavior considering its characteristics. The main difference between LABGENE project and conventional PWR reactors is the cladding material. LABGENE plans to use 348 stainless steel instead of zirconium alloys. 348 stainless steel presents higher corrosion-resistance, but lower permeability to neutrons when compared to zirconium alloys [2].

Fuel performance codes are developed to calculate the long-term burnup response of a single fuel rod. In order to evaluate the fuel behavior in steady-state conditions, there are codes specifically used as analytical tools to estimate fuel rod behavior when power and boundary condition changes are sufficiently slow, what also includes situations involving long time periods at constant power and slow power ramps that are typical of normal power reactor operations [3]. These codes permit to evaluate the variation over the time of all significant fuel rod variables, including fuel and cladding temperatures, cladding oxidation, fuel irradiation swelling, fission gas release and rod internal gas pressure.

Usually, conventional fuel performance codes allow the assessment of fuel rods manufactured using zirconium alloys as cladding material. Therefore, it was necessary to adjust these codes including the mechanical and physics properties of 348 stainless steel to perform calculations considering this material as cladding.

Results obtained by means of fuel performance codes have to be checked by experimental measurements. Then, one of the tools to be used in order to obtain experimental data concerning the LABGENE fuel behavior, under operational conditions, is an experimental irradiation device, the Nuclear Fuel Irradiation Circuit (CAFE-Mod1) [4]. This device will allow to obtain experimental data about the fuel rod behavior under irradiation, which can be used to validate the fuel behavior evaluated by means of the performance code.

The irradiation capsule of CAFE-Mod1 containing test rods will be installed in the IEA-R1 research reactor (IPEN) which will be used as neutron source to perform the irradiation experiments. Due to the neutron flux in the reactor core (10^{13} n/cm^2 s) in the IPEN reactor core, one possibility to be considered to reach the fluence necessary to induce modifications in the fuel rod in a suitable schedule for the LABGENE project is to increase the fuel enrichment degree. However, previously to the setup operation in this particular situation, one must simulate the experimental conditions using a fuel performance code.

The aim of this paper is to evaluate some parameters and specific aspects related to the fuel rod behavior, during the irradiation program applied to CAFE-Mod1 device, using different fuel enrichment degrees.

2. METODOLOGY

2.1. LABGENE Project

The fuel rod in the LABGENE project plans to use 348 stainless steel as cladding material and enriched UO_2 pellets as nuclear fuel. These pellets are fixed by an inconel spring located at the top of the rod. The rod is pressurized with helium gas, like in commercial nuclear fuel elements.

2.2. Fuel Performance Code

The simulations were carried out using an adapted fuel performance code. The subroutines of the code related to the cladding material properties [5] were changed to include the mechanics and physics properties of 348 stainless steel. The obtained results were evaluated considering the 348 stainless steel expected behavior under irradiation [6, 7].

2.3. CAFE-Mod1 Device

CAFE-Mod1 is a thermohydraulic small loop designed to simulate the operational conditions of a PWR in order to carry out irradiation experiments with fuel rods. This device has been developed by CTMSP with Nuclear and Energy Research Institute (IPEN) and Nuclear Technology Development Center (CDTN) [8].

The irradiation capsule of CAFE-Mod1 will contain three single rods with characteristics similar to the LABGENE fuel rods in a single setup. This capsule will be installed in the IEA-R1 research reactor (IPEN) which will be used as neutron source to perform the irradiation experiments.

2.4 Experimental Parameters

The fuel performance evaluation was focused in the variation of fuel enrichment degree for UO_2 pellets. Two enrichment degrees were evaluated: a typical PWR enrichment and a value about 4 times higher. All the other parameters used as input data in the code were fixed.

3. RESULTS AND DISCUSSION

Considering that the irradiation capsule of CAFE-Mod1 will contain three single rods with characteristics similar to the LABGENE fuel rods in a single setup, the evaluation using the fuel performance code was carried out regarding the length of a single rod.

The power profile was assumed to be practically flat due to the fact that the intermediate single rod in CAFE-Mod1 capsule will be exposed to the higher neutron flux inside the reactor and consequently to more severe irradiation effects.

CAFE-Mod1 presents the following design limits: maximum linear power peak rod: 14.94 kW/ft; maximum internal rod pressure: 1450 psia; and maximum temperature in the cladding surface: 323^{o}C [4]. Thus, the obtained results for these parameters must be lower than the design limits.

First simulation was carried out addressing the design limit condition of CAFE device, i.e, high enrichment and maximum linear power peak condition.

Obtained results have shown that the fuel centerline temperature for the higher studied enrichment degree is about three times higher, as is shown in Figure 1. This can be explained by the higher number of fissions produced in the more enriched fuel. The high number of fissions promotes a higher fuel swelling and consequently the gap is lower for the rod containing a more enriched fuel (Figure 2), conducing to a higher gap conductance.

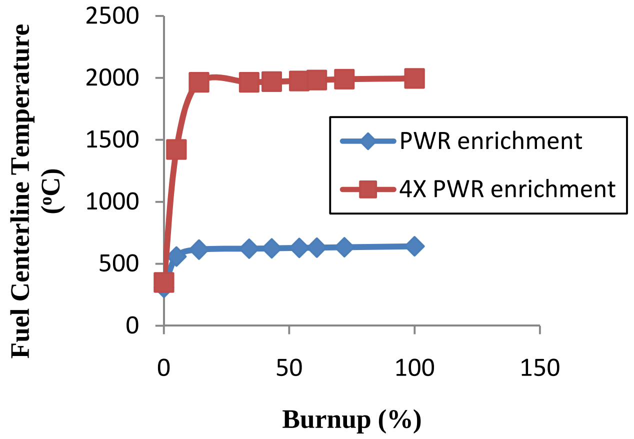

Figure 1. Fuel centerline temperature versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

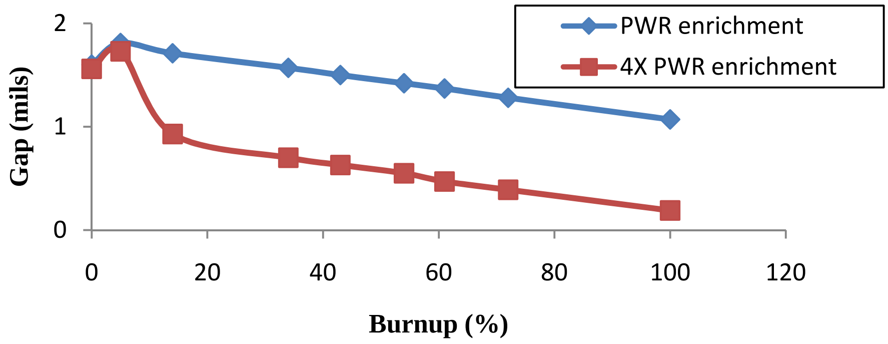

Figure 2. Gap thickness versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

As a consequence of the higher fuel temperatures, the cladding temperatures are also higher for the more enriched fuel, as shown in Figure 3.

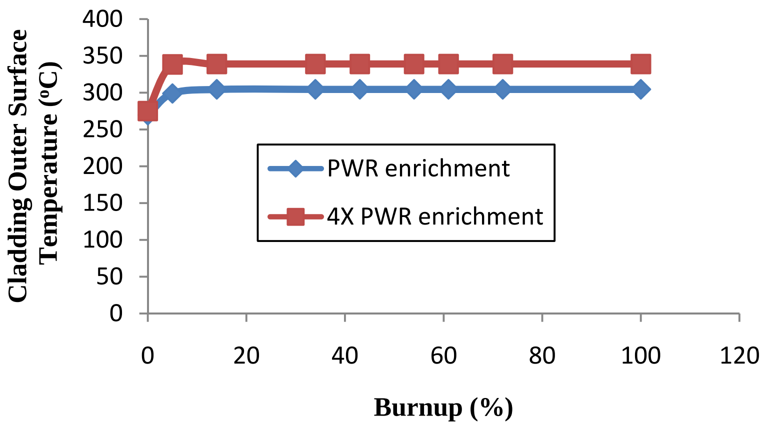

Figure 3. Cladding outer surface temperature versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

The higher number of fissions in the more enriched fuel releases about 30 times higher amount of fission gases, as shown in Figure 4. Consequently, the gas pressure obtained in the simulations with the more enriched fuel is also higher, as shown in Figure 5.

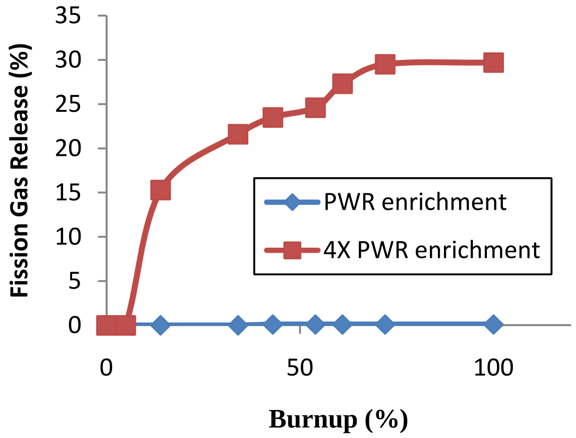

Figure 4. Fission gas release versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

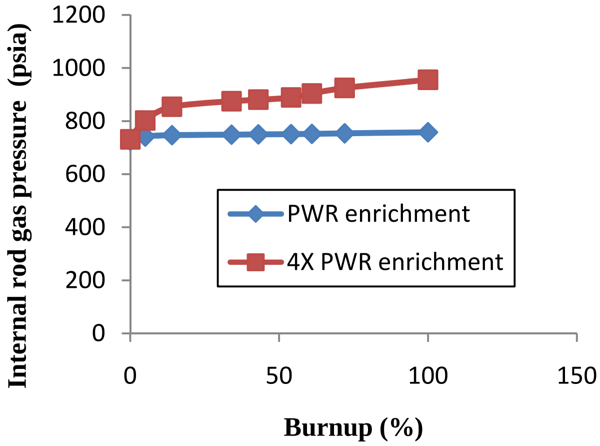

Figure 5. Internal rod gas pressure versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

Results obtained by means of simulations performed with the two fuel enrichment studied degrees have shown that the gap thickness remains open during all the rod life time due to the thermal expansion of 348 stainless steel under irradiation, consequently there is no pellet-cladding interaction phenomenon. The maximum strain increment (elastic + plastic), in both studied cases, is lower than 1 %, assuring the integrity of the rod under the evaluated irradiation conditions [9].

The results also have shown that using a fuel pellet with 4X a typical PWR enrichment the estimated LABGENE maximum burnup level is reached in 220 irradiation days, considering the maximum linear power peak rod for CAFE. On the other hand, using a typical PWR enrichment, it will be necessary 900 irradiation days to reach the same burnup level.

The gas pressures obtained for the two studied fuel enrichment degrees were lower than the CAFE maximum internal rod pressure (1450 psia), assuring also the rod integrity in the studied conditions.

The cladding outside temperature for the enrichment four times higher than a typical PWR reaches the maximum value of 339^{o}C, which exceeds the CAFE maximum temperature in the cladding surface of 323^{o}C [4]. Then, this parameter must be taking into account to assure the rod cooling during the CAFE circuit operation, considering the use of UO_2 pellets with 4X a typical PWR enrichment.

4. CONCLUSIONS

The obtained results have shown that the fuel rod integrity, in the studied simulated conditions, is preserved in the CAFE experimental device, using a typical fuel PWR enrichment degree as well as when it is about four times higher.

The main reason to use a higher fuel enrichment degree is to spend a less irradiation time to reach the estimated LABGENE maximum burnup level compared to a typical fuel PWR enrichment degree. The results confirmed this fact, indicating that it will be necessary about a quarter of the irradiation time, when the UO_2 pellets have enrichment degree four times higher than in a typical PWR.

For the cladding outer surface temperatures estimated in the simulations, it will be necessary to carry out new experiments with the CAFE device, in order to evaluate that the cooling system will be able to dissipate the generated heat produced by UO_2 pellets, using an enrichment degree four times higher than in a typical PWR.

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