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EVALUATION OF FUEL PERFORMANCE WITH DIFFERENT ENRICHMENT DEGREES FOR AN EXPERIMENTAL DEVICE

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ABSTRACT

Evaluation of fuel performance is conventionally carried out using specific codes developed to this aim. The obtained data are confirmed by experimental measurements performed using devices, which are located inside research reactors, projected to simulate reactor conditions under normal operation. Due to the limitations of the available reactor core length for irradiation in research reactors core, fuel rods used to obtain experimental data must present the same characteristics of the real fuel rod, but with a shorter length. Then, in order to compare the obtained results to the expected behavior of the real fuel rod, the experimental fuel rod should be designed with a free volume to fuel volume ratio very closed to the one of the full scale fuel rod. The aim of this paper is to evaluate some parameters and aspects related to the fuel rod behavior in a rod applied to the experimental irradiation device called Nuclear Fuel Irradiation Circuit (CAFE-Mod1) considering two fuel enrichment degrees: a typical commercial PWR enrichment and a value about 4 times higher. This evaluation is carried out by means of an adapted fuel performance code. Some of the parameter evaluated were fuel temperature and fission gas release as function of the fuel enrichment level. The results obtained in this paper were very similar to the ones previously obtained without consider similar free volume between the experimental and the full length fuel rod, regardless of low increases observed for the internal rod pressure and the amount of fission gas released.

1. INTRODUCTION

The fuel pellets in pressurized water reactors (PWR) are considered 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 assuring that temperatures are kept under the fuel melting temperature during the irradiation. 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, the LABGENE 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-based alloys. 348 stainless steel presents higher corrosion-resistance, but lower permeability to neutrons when compared to zirconium alloys [2].

Fuel performance codes [3] are developed to calculate the long-term burnup response of a fuel rod. 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, fuel performance codes allow the assessment of fuel rods manufactured using zirconium-based alloys as cladding material, since this is the material used for PWR applications from the years 1960 until today. Therefore, it is necessary to adjust these codes, including the thermo-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 containing test rods, the Nuclear Fuel Irradiation Circuit (CAFE-Mod1) [4]. This device will allow obtaining experimental data about the fuel rod behavior under irradiation, which can be used to validate the fuel behavior evaluated by means of the fuel performance code.

In order to perform the CAFE-Mod 1 experiment, considering that it will be used as neutron source the IEA-R1 research reactor (IPEN), one possibility to be considered to achieve 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. Then, previously to the setup operation in this particular situation, it is necessary to simulate the experimental conditions using a fuel performance code.

The aim of this paper is to predict some parameters and specific aspects related to the fuel rod behavior, during the irradiation program applied to CAFE-Mod1 device, using two different fuel enrichment degrees and considering that the free volume to fuel volume ratio is very closed to the one of the full scale fuel rod.

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 thermo-mechanical 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 experimental fuel rod considered for simulations was designed in order to maintain a free volume to fuel volume ratio very closed to the one of the full scale fuel rod [9] (LABGENE fuel rod). In this sense, plenum height and plenum spring characteristics were modified, maintaining the same geometry of the fuel rod.

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

The simulations were carried out considering a single fuel rod submitted to a practically flat power profile, which can be considered the most severe irradiation conditions.

The design limits for CAFE-Mod1 are: 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.

From the simulations carried out considering the design parameters and two enrichment degrees (conventional PWR enrichment and four times higher) were obtained the data of fuel centerline temperature, gap thickness, cladding outer surface temperature, fission gas release and internal rod gas pressure as function of burnup percentage, which are presented in the Figures 1 to 5.

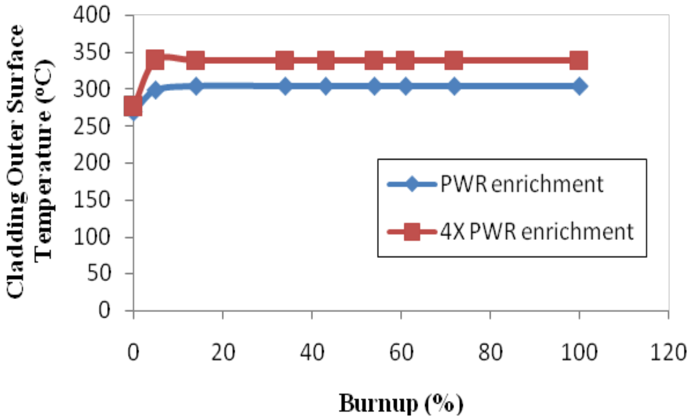

Figure 1. Cladding outer surface temperature versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

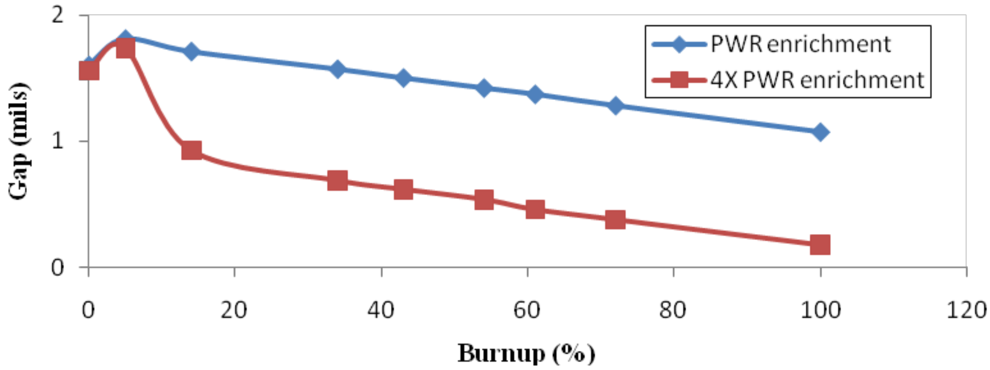

Figure 2. Gap thickness versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

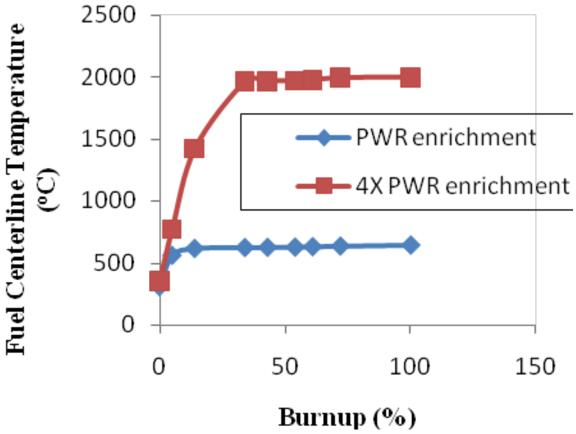

Figure 3. Fuel centerline temperature versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

The values obtained showed that as consequence of the higher number of fissions in the more enriched fuel, the fuel centerline temperatures registered during all the irradiation time were about three times higher than the ones observed for the fuel manufactured with a conventional enrichment degree. However, the fuel melting temperature was not reached, assuring the fuel integrity under the studied conditions.

Due to the higher fuel swelling observed for the more enriched fuel, the gap between the pellet and the cladding is lower in this case, and consequently, the cladding temperature are also higher. Despite of this, it was not observed the gap closure during the irradiation time, which was expected due to the thermal expansion of the 348 stainless steel under irradiation.

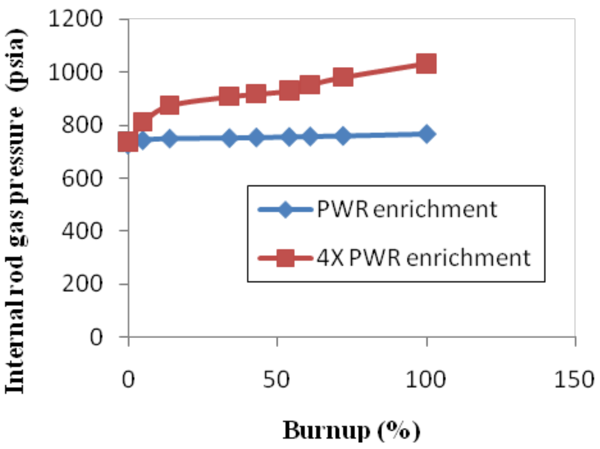

Figure 4. Internal rod gas pressure versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

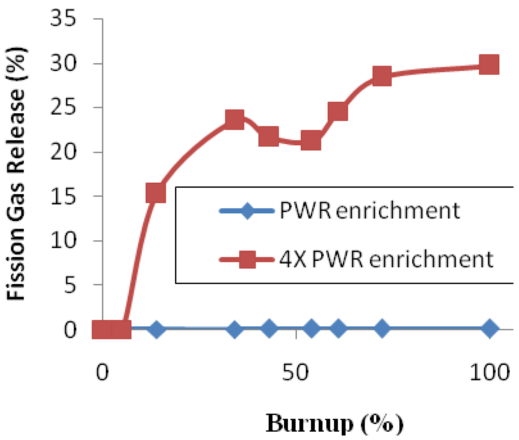

Figure 5. Fission gas release versus burnup percentage obtained by simulations considering a typical PWR enrichment and 4X a typical PWR enrichment.

Considerable differences were observed for internal gas pressure and fission gas release as function of the enrichment degree. The higher number of fissions of the more enriched fuel promotes the release of about 30 times higher amount of fission gases.

The obtained results did not present significant differences to the ones previously obtained [10] without consider the free volume to fuel volume ratio very closed to the one of the full scale fuel rod. The internal gas pressure presented a value about 5% higher when the free volume in the experimental fuel rod is closer to the one of the full length fuel rod.

The LABGENE maximum burnup level is reached in 220 irradiation days using the fuel with the higher enrichment degree, 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 results showed that the fuel rod integrity was maintained under all studied conditions, also considering the different enrichment degrees.

The results obtained in this paper were very similar to the ones previously obtained [10] without consider similar free volume between the experimental and the full length fuel rod, regardless of low increases observed for the internal rod pressure and the amount of fission gas released. However, this is very important in order to permit the extrapolation of the results obtained from a short length experimental fuel rod to that expected to the full length fuel rod. In order to satisfy this condition, the design of the experimental fuel rod to be applied for the CAFE-Mod1 device shall consider the free volume to fuel volume ratio and, consequently, the obtained results will be more representative of the behavior of the LABGENE fuel rod.

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