

ANALYSIS OF WWER-440 FUEL PERFORMANCE WITH FRAPCON-3

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ABSTRACT

Nuclear reactor fuel rods are essential nuclear components from the operational and safety points of view. Recent experience in nuclear industry is to increase fuel discharge burnup as much as possible. This, in turn, raises the question of fuel rod integrity and radioactivity release at extended burnup and especially during operational transients. At this point, cladding may be considered as the most vital and vulnerable component of the fuel rod. Cladding behavior normally is deteriorated as burnup increases and power history dependency is significant.

In this study, steady-state and long term transient behavior of WWER-440 fuel elements is analyzed with FRAPCON-3 computer code. Operational parameters which are related with the overall reactor safety evaluated as a function of fuel burnup. Especially, the effect of power ramp on mechanical parameters and fission gas release analyzed and an assessment is made. Comparison is made for the parameters in cases of relatively fresh fuel and at extended burnup. Hence, the variation of fuel behavior for high burnup fuel is presented.

INTRODUCTION

WWER-440 type nuclear reactors are commonly used in many Eastern European countries and Finland. Such reactors are similar to western type pressurized water reactors in many respects. The main difference is the type of fuel elements. WWER-440 reactors employ hexagonal fuel assemblies rather than square cross sectioned fuel assemblies used in western type PWR's. Operational conditions are similar in WWER and PWR's. Hence, fuel behavior in both reactors are expected to be similar.

FRAPCON is a computer code developed for the analysis of fuel rod behavior under steady-state or long term transients. An earlier version of this code, FRAPCON-2, has been used to analyze WWER-440 fuel rod¹. In this study, the results generated by two mechanical models are compared. In addition to FRAPCON, a number of fuel behavior computer codes have been employed for the analysis of WWER fuel rods. For instance, RAPTA-5², Transuranus³, and PIN-micro⁴ are just few of them.

Currently, there is an ongoing effort to increase discharge burnup of all LWR fuel including WWER's in order to decrease power production cost. Therefore, burnups are expected to be increased to 60 to 70 GWD/MT. This tendency raised a question on the variation of the fuel behavior at extended burnup. Experimental studies have been carried out at different

laboratories. The result of such experiments have been compared with the results of available computer codes. Hence, deficiencies and shortcomings of existing codes were pointed out and necessary modifications have been realized.

In this study, a typical fuel rod of WWER-440 is considered. Model parameters associated with the analysis is given in Table 1. Power history shown in Figure 1 which is similar to the one used in an earlier study¹ is used in order to make an assessment for the code improvements. Fuel rod is divided into 9 axial and 8 radial nodes. For gas release calculations, the fuel rod is separated into twenty equal volume radial rings. Axial power shape is considered to be cosine. Peak-to-average power ratio is taken to be 1.4.

FRAPCON-3 code has certain modifications to improve code results. Fission gas release calculations are carried out with ANS-5.4 model. As opposed to the earlier version of FRAPCON code, this new version only supports ANS-5.4 model due to better agreement of predictions with experimental observations for variety of operational conditions. Highly mechanistic models like PARAGRASS are found to be unsatisfactory especially at high burnup⁵. Thermal conductivity correlations used in the calculations are modified based on the experimental observations. Thus, deviations due to high burnup and low temperature radiation damage are included. The most important modification is made for power and burnup distributions. More realistic burnup calculations are obtained by TUBRNP subcode is included in FRAPCON-3.

In the analysis, three cycle operation is considered. At the end of 920 day operation, the burnup is determined to be nearly 34 MWD/kg U. Linear heat generation rate for this case is 15 kW/m. This is a standard operation for WWER-440 reactors. In order to analyze high burnup behavior, this standard operation period is followed by a subsequent operation period. At this point three different cases with different linear heat generation rates are taken into account; 15, 17.5, 20 kW/m. Operation of the reactor is continued until 55 MWD/kg U burnup is achieved.

RESULTS

Results of this study may be represented in two parts; normal operations, i.e., low burnup, and follow-up operation, i.e., high burnup. During the normal operation period, there is no significant variation in code results compared to the earlier study¹. Figure 1 represents the power history in term of linear power and fuel rod average burnup. Mechanical integrity of the fuel rod may be justified by mechanical parameters such as hoop and axial stress as well as strain. Figure 2 shows the variation of these parameters during the operation. Hoop and axial stresses are negative throughout the operation and follow the power history. As power is increased, both stresses become more and more negative. Strain curve also follows the shape of power history. Due to significant contribution of thermal strains there are observed spikes at power ramps. At the end of normal operation the magnitude of strain is about -0.25% which is

well below the operational limits. Other indicators of fuel performance is maximum fuel and cladding temperatures. Figure 3 shows these parameters for the fuel node with the highest heat generation as a function of time. Another operational parameter is fission gas release. The increase in the release of fission gas is stepwise. During shutdown and following startup periods, there is a step increase in gas release. However, fission gas release at the end of normal operation period is still about 0.2%. This is relatively low gas release due to low fuel temperatures. In order to observe significant gas releases, fuel temperatures should exceed 1800 K.

As mentioned earlier, the second stage of this study deals with a follow-up operation with 15, 17.5 and 20 kW/m of linear heat generation rates. Calculations are performed until the burnup reaches 55 MWD/kg U. During this operation, power is kept constant and the mass flow rates are not changed from one case to another. Results are shown in Figures 4 and 5 and Table 2. Observations show that there is no significant deviation in operational parameters with compared to the parameters obtained for the normal operational period. There is a decrease in the gap conductance with increasing burnup. Slight increase in the fuel centerline temperature is due to this effect. Table 2 shows that cladding hoop stress does not vary significantly as a function of burnup. In case of the intermediate power operation, the decrease of gap conductance is more pronounced. Therefore, fuel centerline temperature increase is more significant but still at an acceptable level. If high power operation is performed, observations show significant variations. When the burnup exceeds 40 MWD/kg U, gap conductance starts decreasing from 3522 W/m²-K to 784 W/m²-K at 40 MWD/kg. Fuel temperature rise within this period is from 1336 to 2271 K. During this period cladding hoop stress changes from -71 MPa to 141.2 MPa. At the end of operation at 55 MWD/kg U, it increases to 197.5 MPa.. Fission gas release increases to about 70% and cladding strain is 1.21%.

CONCLUSIONS

FRAPCON-3 code does not show any operational problems at low burnup for WWER-440 fuel. However, there are significant variations in operational parameters at high burnup. Results suggest that fuel rod designed for low burnup operation in WWER-440 is under severe conditions. This may be due to either design deficiencies of the rod or misprediction and stability problems experienced in the code. Another reason may be the insufficient cooling condition since it is kept constant for all cases. In order to justify the results a more detailed analysis should be performed.

REFERENCES

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Table 1. Some Parameters used in the WWER-440 fuel rod behavior

Cladding Outer Diameter	9.1mm
Cladding Thichkness	0.65 mm
As Fabricated Gap Thickness	0.125 mm
Pellet Height	1.24 cm
Initial Porosity	5.2%
Total Fuel Column Length	2.42 cm
Cold Plenum Height	7.6 cm
U-235 Enrichment	3.6%
Initial Fill Gas Pressure	0.5 MPa
Peak-to-average Power Ratio	1.4
Number of Axial Regions	9
Number of Radial Regions	8
Number of Radial Regions for Gas Release Calculations	20

Table 2. Cladding hoop stress at high burnup for different linear power levels

Burnup	Linear Power (kW/m)		
	15	17.5	20
35	-73.34	-72.88	-72.33
40	-73.05	-72.48	-70.99
45	-72.43	-71.83	141.20
50	-71.48	-70.77	169.30
55	-70.23	-67.19	197.48

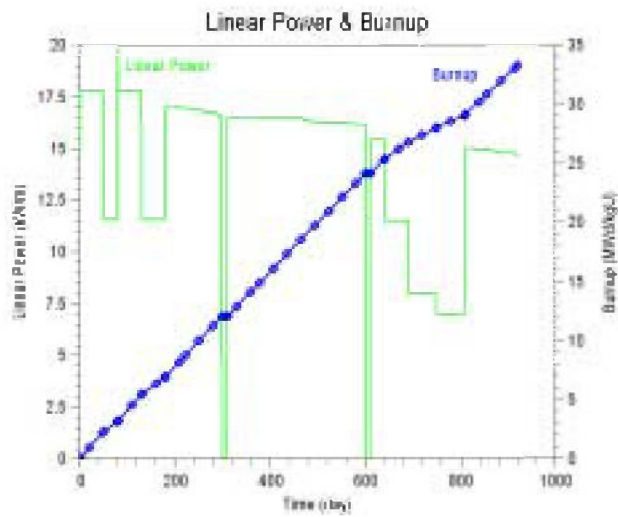


Figure 1. Power history and fuel burnup

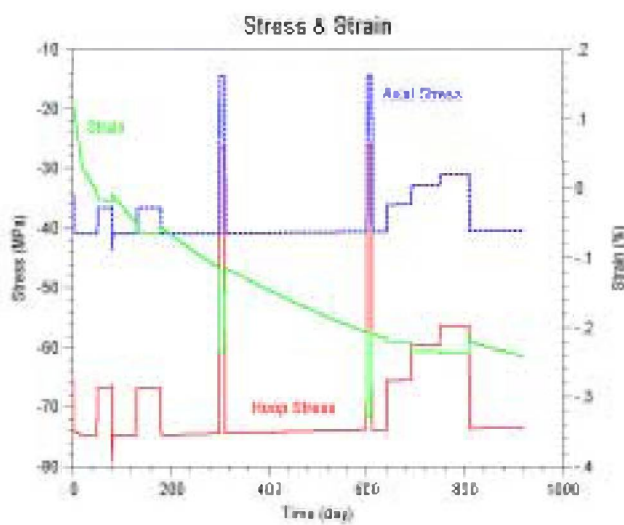


Figure 2. Variation of stress and strain

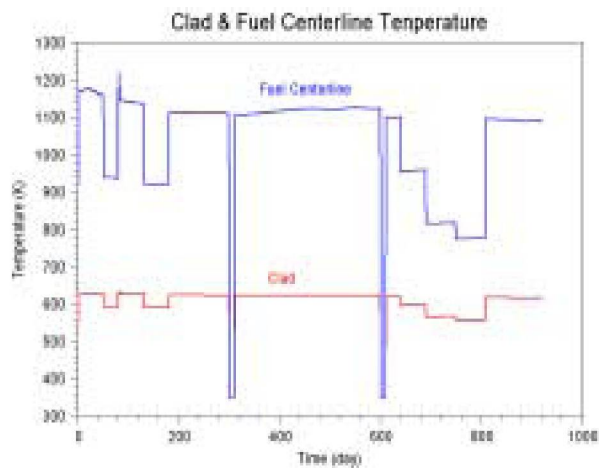


Figure 3. Clad and fuel centerline temperatures

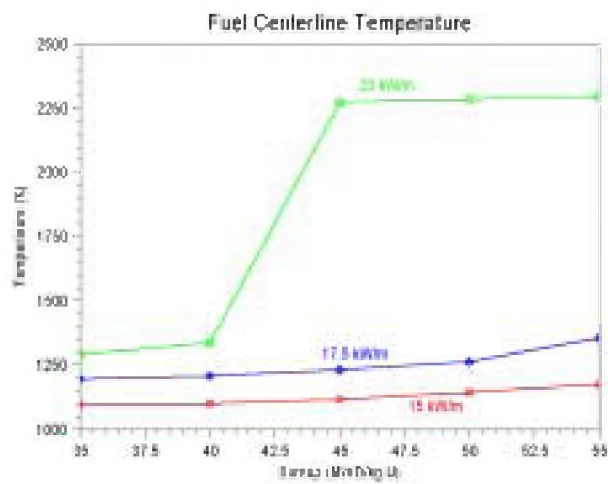


Figure 4. Fuel centerline temperatures at high burnup

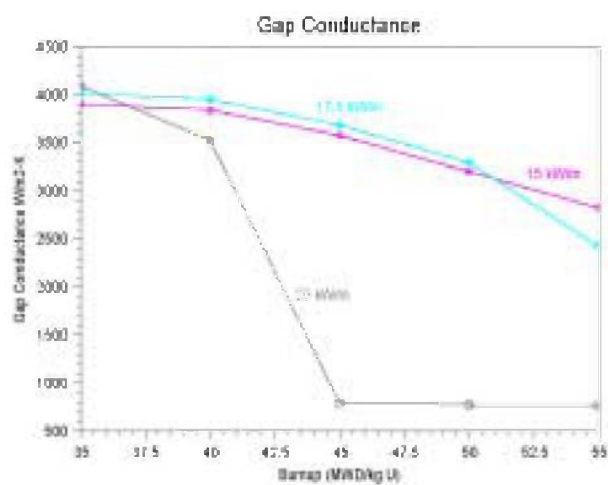


Figure 5. Gap conductance at high burnup