FEASIBILITY OF USING PYREX DISCRETE BURNABLE ABSORBER IN HIGH PERFORMANCE NUCLEAR FUEL ASSEMBLIES

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ABSTRACT

Discrete burnable absorber rods consisting of PYREX material (borosilicate) have been used in power reactors, as for example in ANGRA1 NPP, to decrease the initial reactivity of fuel assemblies operating at first cycle. These rods consist of an internal PYREX cylinder, which is the neutron absorber, surrounded by two steel cylinders containing a vacuum gap among them. This design shows a low thermal conductivity which results in high temperatures at the rod center. The transition to employing high performance fuel assemblies, that operate with higher power generation, has increased this issue, and even structural damages can occur if a defined temperature threshold is surpassed at rod center. The feasibility of using PYREX absorber at high performance fuel assemblies, namely the 16NGF that is going to be used after ANGRA1 replacement of steam generators, is investigated for two cases:

- Using a full region reload with nominal power;
- Using a full region reload with power uprate (6.3%).

Calculations were performed with existing and licensed thermal-hydraulic methodology and codes for Angra 1. The results have shown that for both cases the maximum temperature criteria at rod center is not fulfilled, that means PYREX absorber rods are not appropriated to be employed in such power levels. It has also been determined the maximum power (in terms of $F_{\Delta H}$) that still fulfill the temperature criteria.

1. INTRODUCTION

The burnable absorber (BA) rods are used for the partial control of excess reactivity available in fresh fuel cores and to achieve a negative moderator temperature coefficient at BOL. In addition, BA rods are located in the core to give favorable radial power distributions. During operation, the absorber content is depleted to add positive reactivity to compensate for some of the negative effects of fuel depletion and fission product buildup. Normally, the depleted BAs are removed from the core during refueling and fresh BAs are installed with the feed fuel assemblies.

The borosilicate (pyrex) BA design material is currently 12.5 w/o B2O3 borosilicate glass tubing. Some plants in the past used 18 w/o B$_2$O$_3$. The absorber is clad with type 304 stainless steel tubing, which is plugged and seal-welded at the ends. The BA rod is inserted into a zircaloy-4 guide thimble and is attached to the plugging device baseplate in the upper
nozzle assembly. The dashpot end plug hole and four thimble cooling holes just above the dashpot region provide the flow required for BA cooling. These discrete burnable absorber rods have been used historically in many nuclear power reactors, as for example in ANGRA1, to decrease the initial reactivity of fuel assemblies operating at first cycle. These rods consist of an internal PYREX cylinder, which is the neutron absorber, surrounded by two steel cylinders containing a vacuum gap among them and are used specially in the initial first cycle.

This design however shows a low thermal conductivity which results in high temperatures at the rod center. High temperatures can lead to structural failures in the materials these rods are built and in fact, this characteristic is the main reason why this burnable absorber has not been used for high performance applications. Currently PYREX is a burnable absorber with a lot of restrictions and not used commonly in the Nuclear Stations worldwide.

Figure 1 presents a sketch of the Borosilicate Glass Burnable Absorber Geometry (PYREX) currently in use in Angra 1 NPP.

Figure 1 - Borosilicate Glass Burnable Absorber Geometry
Due to the change of the Nuclear Fuel used in Angra 1 NPP, from the 16STD to the 16NGF, the analysis was performed in order to verify the PYREX limits based on the current plans to use the 16NGF in Angra 1. It consists in calculate the heat flux towards the PYREX rods and based on that evaluate the maximum temperatures reached during operational and transient conditions.

2. PYREX ROD THERMAL ANALYSIS

2.1 Model description

The numerical model basically consists in a series of one dimensional heat conduction equations in cylindrical coordinates in order to calculate surface and temperature distribution along the burnable poison Rod design. The current licensed code for Angra 1 analysis is called POISON.

The initial temperature boundary equation for each increment along the poison length is input using the surface temperature calculated by another code in a non-isothermal run (BYPASS).

POISON considers internal heat generation, the temperature dependant values of thermal conductivity and coefficients of thermal expansion for each of the rodlet materials.

In addition to temperature calculations, the model provide hot dimensions of the burnable poison rod, cold and hot volumes of the backfill gases, moldes fractions of air and helium and the rod internal gas pressure. For thermal-hydraulics purposes, the model assumes a 100% B10 burnup and release. The temperatures in the rod are calculated at the beginning of life, before any helium is released. This approach is used because the assumption of 100% release is conservative for stress considerations, while the assumption of 0% helium is conservative for thermal considerations.

The numerical model examines the temperature profile along the entire burnable poison length. This capability enables enter the axial flux shape calculated by the BYPASS code (set as boundary conditions). At the end, a plot of the surface temperature (TSURF) of any of the six material surfaces is shown or a composite plot of all surfaces.

The input is defined by a number of parameters, such as Cold plenum Length, Cold fill gas pressure at beginning of life, length of glass pellets, time increment and others.
2.2 Mathematical Modeling

Figure 2 illustrates schematically how the PYREX rod heat transfer is modeled in POISON. The equation basically is based on direct application of the Fourier’s law (uniaxial direction in cylindrical coordinates).

\[ Q = \frac{2\pi l(T_1 - T_4)}{\ln \left( \frac{r_2}{r_1} \right) / k_A + \ln \left( \frac{r_3}{r_2} \right) / k_B + \ln \left( \frac{r_4}{r_3} \right) / k_C} \]

Figure 2 – Heat Flux transfer in uniaxial direction in cylindrical coordinates

2.3 16NGF Model description

4 16NGF LTA’s are planned to be inserted in Angra 1 next cycle (Cycle 17). During this cycle a low FΔH is planned (around 1,55). It implies that the PYREX is still possible to be used. However during 16NGF full reload (starting on cycle 20), this poison burnable absorber would not withstand the planned conditions (6,3% power uprate and FΔH = 1,70).
Based on this scenario, the following options were analyzed and presented in this paper:

- Use of PYREX in Angra 1, with $F_{\Delta H} = 1.70$ but no uprate of 6.3% and;
- In case the current limits are not met, what would be the maximum $F_{\Delta H}$ to allow the PYREX to be used in the 16NGF fuel.

Conservative axial power shapes, core inlet temperatures and others parameters were used in this calculation. The maximum heat generated in the glass (defined as being POWP) and the maximum heat towards the steel rodlet (defined as being POWS).

### 2.4 Results

The parameters POWP and POWS for the 16NGF fuel in Angra 1, considering $F_{\Delta H} = 1.70$ would be defined as being:

POWP = $28.8 \, (w/cm^3) \times 96645 \, (BTU/h\cdot ft^3) / (w/cm^3) \times 1.70 \, (F_{\Delta H}) = 4731739 \, BTU/h\cdot ft^3$

POWS = $14.1 \, (w/cm^3) \times 96645 \, (BTU/h\cdot ft^3) / (w/cm^3) \times 1.70 \, (F_{\Delta H}) = 2316581 \, BTU/h\cdot ft^3$

Based on these maximum heat flux the reached temperature at the PYREX rodlet is 1259 °F, at an axial elevation of 64. This value is above the maximum design criteria limit of 1220° F. Thus, a $F_{\Delta H}$ of 1.70 is not acceptable.

Varying the $F_{\Delta H}$ values, in order to decrease the POWP and POWS values, the maximum hot channel factor that does not exceed the current criteria limit is 1.58, as follows:

POWP = $28.8 \, (w/cm^3) \times 96645 \, (BTU/h\cdot ft^3) / (w/cm^3) \times 1.58 \, (F_{\Delta H}) = 4397734 \, BTU/h\cdot ft^3$

POWS = $14.1 \, (w/cm^3) \times 96645 \, (BTU/h\cdot ft^3) / (w/cm^3) \times 1.58 \, (F_{\Delta H}) = 2153057 \, BTU/h\cdot ft^3$

The maximum temperature on the PYREX rodlet was 1217 °F, at the same axial elevation of 64. This value is acceptable based on the maximum design criteria limit of 1220° F in the PYREX rodlet.

### 3. CONCLUSIONS

The analysis with the BYPASS and POISON codes confirm that PYREX poison burnable absorber will limit the 16NGF fuel with a low $F_{\Delta H} (~ 1.58)$, even with no uprate conditions. It is recommended a use of another type of burnable absorber.
4. REFERENCES


4. ANG-05-31 Angra1 Unit 1 RSG/NGF/Uprating Program Final PCWG Parameters, Westinghouse Electric Company, March 31, 2005