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Improvements to the INTERPIN Code for High Burnup and MOX Fuel

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INTRODUCTION

INTERPIN has been derived from the full-scope fuel performance code INTERPIN-FRPS [1]. The primary purpose of the simplified version of INTERPIN (known as INTERPIN-3 (IP3) [2]) is to provide data for average fuel pin temperatures as a function of burnup and linear heat generation rate for the Studsvik CMS codes - CASMO [3] and SIMULATE-3 (S3) [4].

In recent years, some S3 comparisons with plant data indicate that IP3 calculated fuel temperatures may be too low [5]. Consequently, numerous INTERPIN models have been recently reviewed, improved, and summarized in this paper. These improvements result in an average fuel temperature increase of 50K - 60K for LWR fuel rods at nominal conditions.

INTERPIN-4 IMPROVEMENTS

The following models have been reviewed:

- fuel thermal conductivity
- intra-pellet radial power distributions
- waterside corrosion
- gaseous gap conductance

Fuel Thermal Conductivity

The Wiesenack fuel thermal conductivity correlations present in IP3 [6-7] have been replaced by the Nuclear Fuel Industries UO₂ and MOX thermal conductivity correlations, as described in reference 8.

Intra-Pellet Power Distribution

Intra-pellet radial power profiles as a function of rod burnup have been computed with CASMO-4 for typical UO₂ pins with 4.5% enrichment and for reactor-grade MOX pins. This data has been tabulated within INTERPIN-4 (IP4) for ten equal volume radial rings over the burnup range from 0 to 70 GWd/T.

Waterside Corrosion

The IP3 waterside corrosion models tend to under-predict recent experimental oxide layer growth data, leading to an underprediction of the temperature drop in the oxide layer. The IP3 corrosion model has been updated using the work of Jernkvist and Massih [9],

taking into account new experimental data for Zircaloy-4, ZIRLO and M5 cladding materials.

Pellet/Clad Gap Conductance

The benchmark parameter in the Kjaerheim-Roldstad gaseous gap conductance sub-model [10] that accounts for the effect of fuel pellet surface and clad inner surface roughness has been calibrated to match measured centerline temperatures from in the Halden Reactor Project [11-12].

RESULTS

S3 predictive calculations have been performed for the Ringhals-2 and Ringhal-4 PWRs, over a wide range of operating conditions - including both load follow operation and EOC coast-downs. The use of IP4 fuel temperatures has resulted in significant improvement in S3 predictions, as compared to plant data [13].

These improvements are well illustrated by the Ringhals-4, cycle 18 EOC coast-down from 100% to 55% of rated power. Figure 1 compares the measured (red line) and S3 predicted critical powers using the IP3 fuel temperature predictions (yellow line) and the IP4 fuel temperature predictions (blue line). The predictions using IP4 fuel temperatures are in excellent agreement with measured data.

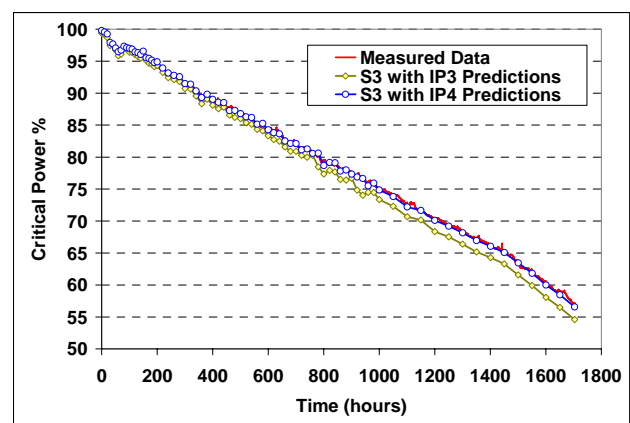


Fig. 1: Ringhals-4 C18 Coast-down Power

An even more sensitive reactor parameter to fuel temperature is the axial power shape which results from the ensuing Xenon transient during the coastdown. Figure 2 compares S3 delta-flux predicted using IP3

(yellow line) and IP4 fuel temperature predictions (blue line) with the plant data (red line).

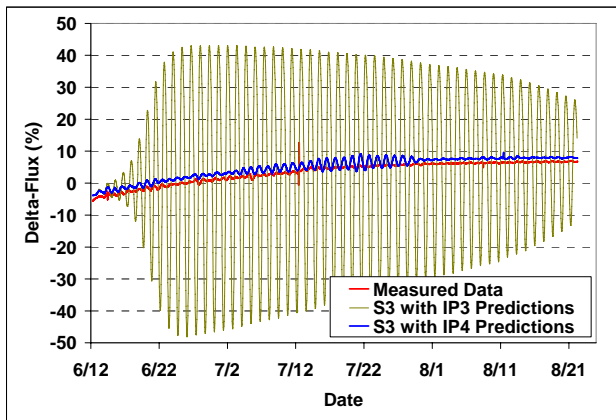


Fig. 2: Ringhals-4 C18 coast down. Delta-flux

Note that while the measured plant data is smooth, the S3 calculation using IP3 fuel temperatures shows large axial power swings, which is symptomatic of an under-damped Xenon transient. The S3 calculation using IP4 predictions is in very good agreement with measurement.

SUMMARY

The INTERPIN changes presented here are part of the ongoing development of Studsvik fuel pin model. IP4 fuel temperatures are higher than those predicted by IP3, resulting in significant improvements in predictions of PWR transients.

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