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THE IMPACT OF NPP KRŠKO STEAM GENERATOR TUBE PLUGGING ON MINIMUM DNBR AT NOMINAL CONDITIONS

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Abstract

Typically, steam generator tube plugging (SGTP) both decreases the reactor coolant system (RCS) flow rate and the heat transfer surface area of the steam generator. At a constant thermal power and vessel outlet temperature, as tube plugging increases, the vessel average temperature, vessel inlet temperature and steam generator secondary side steam pressure decrease.

This paper presents the analysis of impact of SGTP on Minimum Departure from Nucleate Boiling Ratio (MDNBR) at NPP Krško (NEK), using the Improved Thermal Design Procedure (ITDP), WRB-1 correlation, and COBRA-III-C computer code. No credit was given to high plugging percentage region power reduction resulting from turbine volumetric flow limitations.

MDNBR is found to be decreasing with increasing plugging, but not under the limiting values.

1. Introduction

During the departure from nucleate boiling (DNB), the poor heat transfer on the fuel surface results in high temperatures and subsequent fuel failure. Therefore, one of the main criteria for avoiding the loss of fuel integrity in a pressurized water reactor (PWR) is ensuring that the fuel avoids DNB with 95 % probability at a 95 % confidence level (95/95 criterion) during Condition I and II occurrences.

As a consequence of higher pressure losses, SGTP decreases the RCS flowrate. At a constant thermal power and reactor vessel outlet temperature, as tube plugging increases, the vessel average temperature and vessel inlet temperature decrease.

After reaching 18 % SGTP level, NPP Krško continued to operate with 100 % power and the same vessel outlet temperature. The basis for this was given by Westinghouse's WENX-89-06 - NPP Krško - 18 Percent Steam Generator Tube Plugging Margin Analysis (ref. [3]).

Among others it presented the use of ITDP and the new improved WRB-1 correlation for DNB analysis at 18 % SGTP level. However, since the "Design No Plugging" situation was originally analyzed (FSAR, ref.[1]) only by means of Standard Thermal Design Procedure (STDP) and W-3 correlation, it gives no comparison of different SGTP levels. Here it is given partially, by presenting only the steady state MDNBR calculations for SGTP levels between 0 % and 24 % using the same ITDP and WRB-1 correlation. The computer code used is COBRA-III-C.

2. Improved Thermal Design Procedure (ITDP)

Improved thermal design procedure considers uncertainties in plant operating parameters, nuclear, thermal and fuel fabrication parameters. They are statistically combined to meet the already mentioned 95/95 criterion.

Unlike standard thermal design procedure (STDP), in the ITDP the uncertainties are considered prior to the very MDNBR calculation, since they are incorporated in limiting DNBR, not in the final result. Therefore, ITDP enables the use of nominal values of input parameters at their nominal or best estimate values. The resulting MDNBR is interpreted in terms of limiting DNBR, above which it has to be under any Condition I and II occurrences.

In the scope of this paper is performing only a fraction of ITDP. It does not include the process of developing limit DNBR, nor it's usage for setting reactor protection limits. Limit DNBR from reference [2] is used here as a criterion.

3. Calculation of MDNBR at Nominal Conditions

This section gives the point to which all the different plugging levels MDNBRs will be compared, since it presents the MDNBR calculation at nominal conditions as they appear in table 4.4-1 of the NPP Krško USAR (ref. [2])

Reactor core model described in reference [9] was used to calculate the NPP Krško Minimum DNBR at nominal conditions. To follow the ITDP, nominal values of nine main design parameters presented in Table 1 were used. Conservative, so called "fixed values", were used for the rest of parameters.

DNBR DESIGN PARAMETERS	
PLANT OPERATION PARAMETERS	
Primary coolant flow rate, m^3/s /loop	5.83
Core bypass flow, %	3.0
Core power, MW_t	1876
Inlet temperature, °C	287.1
System pressure, bars	155.13
NUCLEAR & THERMAL DESIGN PARAMETERS	
$F^N_{\Delta H}$ (rod)	1.435
$F^N_{\Delta H}$ (assembly)	1.372
FABRICATION PARAMETERS	
$F^E_{\Delta HI}$	1.0
Fuel rod pitch and bowing, cm	1.91

Table 1 - DNBR Design Parameters
(As per references [2] and [5])

Further, as required by ITDP, this calculation is based on the minimum measured flow, which is verified by measurements to be conservatively less than true nominal flow.

The results of NPP Krško MDNBR calculation are presented in Table 2.

NPP KRŠKO MDNBR CALCULATION RESULTS	
DNBR for thimble channel at nominal conditions	2.70
DNBR for typical channel at nominal conditions	2.76

Table 2 - NPP Krško MDNBR Calculation Results

4. Steady State DNB Calculations for NEK SGTP Levels Between 0 and 24%

As previously mentioned, the original DNB analysis for 0 % plugging (FSAR, ref. [1]) was done using the old STDP. The switch to the new ITDP performed for 18 % plugging (ref. [3]) left no means of comparison, since the design thermal-hydraulic parameters used for MDNBR calculation (Table 4.4-1, both in FSAR and USAR) changed not only due to plugging, but also due to the changed methodology. This is observable in the case of the vessel/core input temperature and especially primary coolant flow rate. Most of the main design parameters are input into ITDP analysis with their nominal or best estimate values. Only for the flow its conservative, "minimum measured" value is entered.

What's more, reference [4] excepts the same minimum measured flow value for 24 % plugging. Figure 2.1 from the same reference presents both calculated best estimate flow curve and expected (extrapolated) measured flow curve, which is, for the conservativity reasons, some 2.5 % below. It also suggests the same minimum measured flow over the full plugging range from 0 % to 24 %. This is doubtful, since it would mean 8 % of conservatism at 0 % plugging. If the ITDP was used in the moment when FSAR analyses was conducted, the minimum measured flow would probably be on the mentioned expected measured flow curve. Another confirmation for this thesis is the fact that this curve at the 24 % plugging point has almost exactly the value of nominal minimum measured flow.

As a consequence, this calculation was performed with the assumption that the minimum measured flow, as input parameter to ITDP follows the expected (extrapolated) measured flow curve from Figure 2.1 in reference [4].

Comparison of references [1] and [2] shows that core inlet temperature decreased from 288.6°C at 0 % plugging, to 287.1°C at 24 % plugging and nominal minimum measured flow. It is assumed that the decrease rate follows the decrease of flow rate, so the individual values for different plugging percentages could be calculated by the following formula:

$$T_{inX} = T_{in24.3} + \frac{Q_x - Q_{24.3}}{Q_0 - Q_{24.3}} \times \left(T_{in0} - T_{in24.3}\right)$$

It should be noted that this formula, based on Figure 2.1 from reference [4], matches 24.3 % plugging (and not 24.0 %) to nominal minimum measured flow ($Q_{24.3}$).

Based on this, Figures 1 and 2 graphically presents the change of primary coolant flow rate and inlet temperature with plugging level used in steady state MDNBR calculations for NPP Krško SGTP levels between 0 and 24%.

Figure 1

Primary coolant flow rate as function of plugging

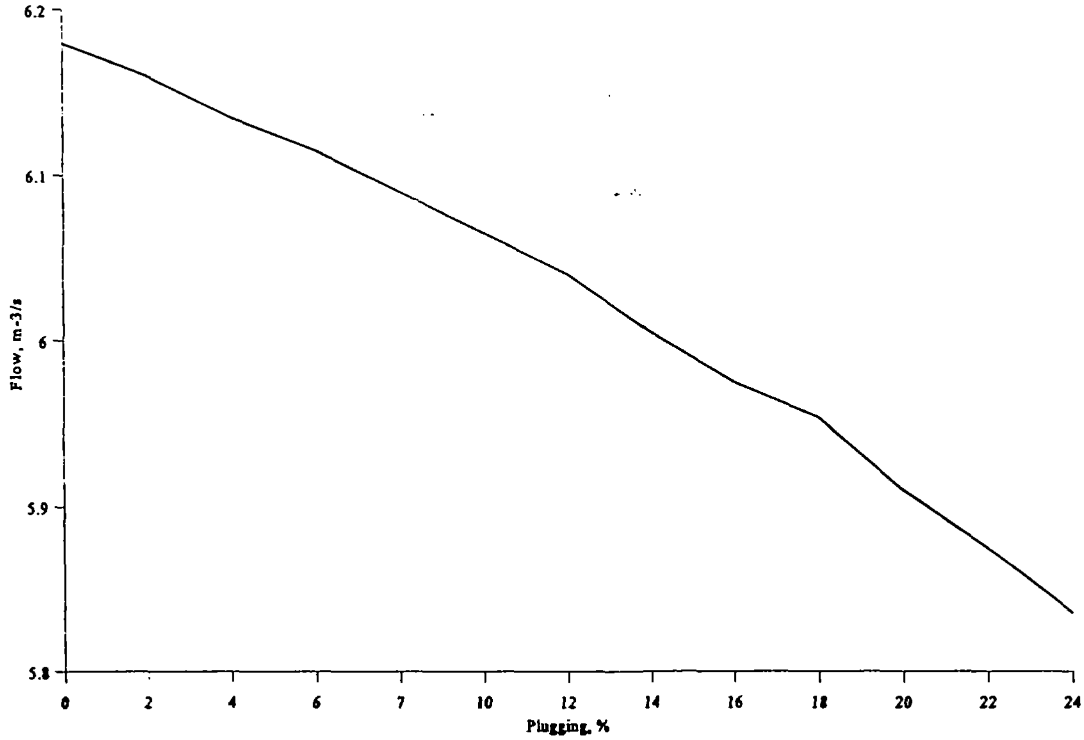
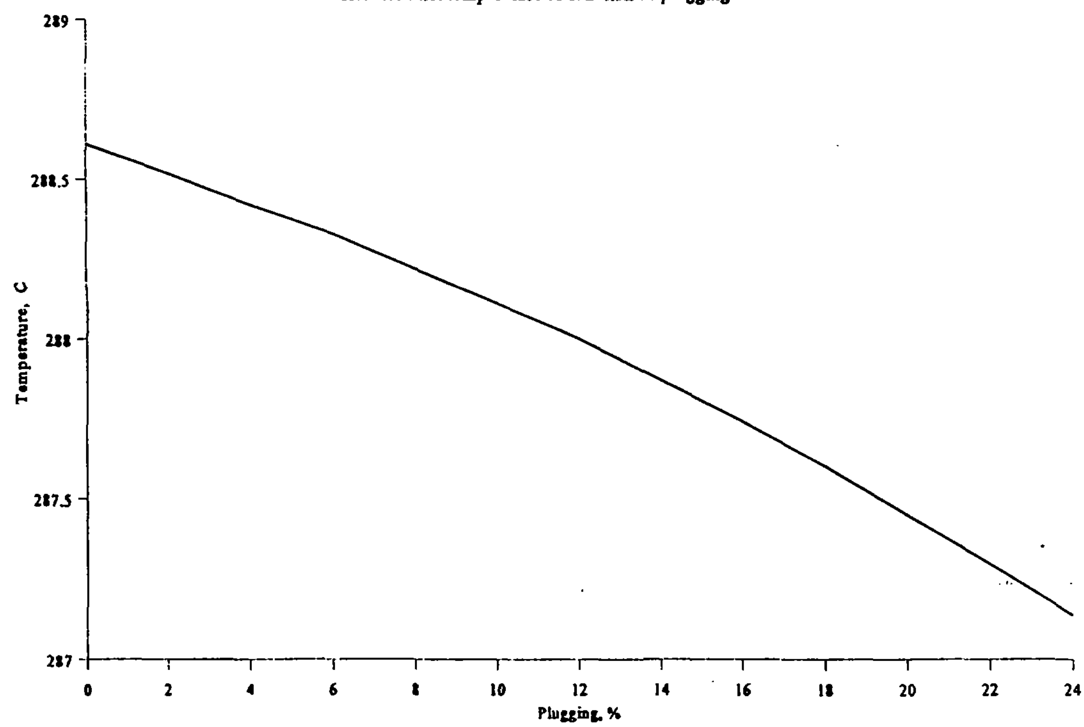


Figure 2

Reactor inlet temperature as function of plugging



In reference [4], due to NPP Krško turbine volumetric flow limitations, a reduction of power for higher plugging levels is involved. Since the processes outside the reactor core are out of this paper scope, it is neglected, and full power reactor operation for all SGTP levels is assumed.

5. Calculation Results and Conclusions

Figure 3 presents the results of the MDNBR calculation for NPP Krško SGTP level between 0 and 24 % using ITDP, WRB-1 correlation and COBRA-III-C computer code.

Figure 3
MDNBRs as function of plugging

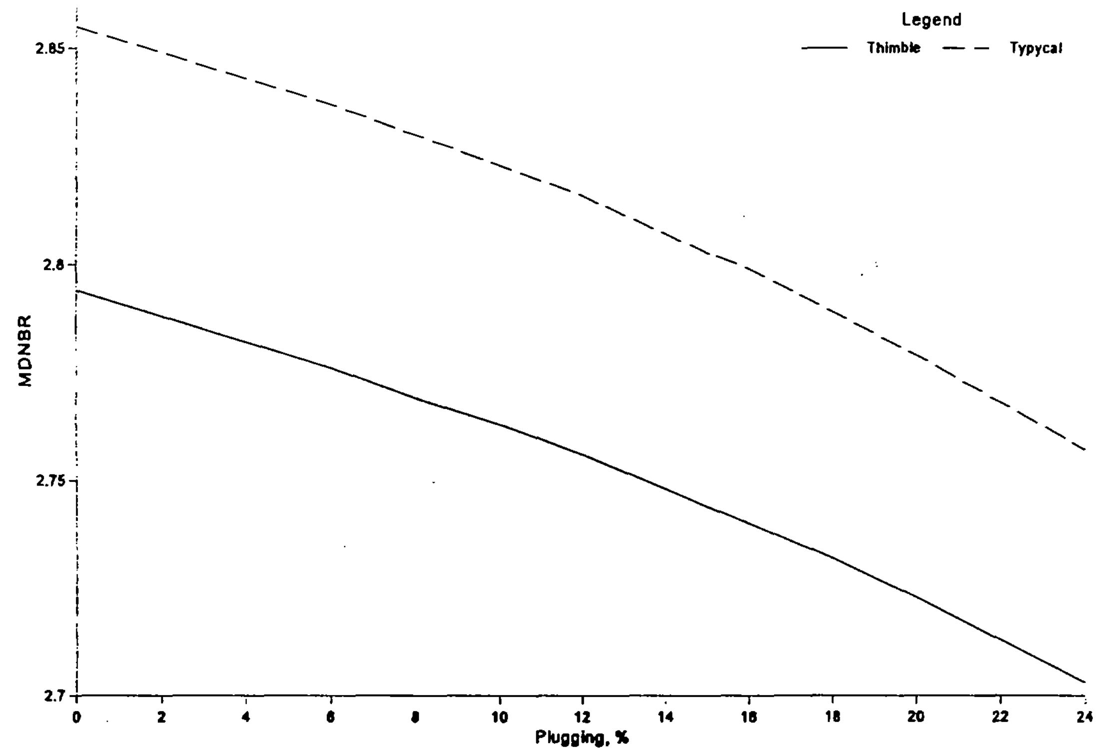


Table 3 presents the same results for three most significant points (0 %, 18 % and 24 % plugging).

MDNBRs FOR 0 %, 18 % & 24 % PLUGGING						
PLUGGING [%]	MDNBR		limit MDNBR		change to 0 % [%]	
	thimble ch.	typical ch.	thimble ch.	typical ch.	thimble ch.	typical ch.
0	2.794	2.855	1.52	1.54	-	-
18	2.732	2.789			-2.22	-2.31
24	2.703	2.757			-3.26	-3.43

Table 3 - MDNBRs for NPP Krško SGTP levels of 0 %, 18 % and 24 % plugging

The results indicate a decrease of MDNBR of -2.22 % for thimble channel and -2.31 % for typical channel at 18 %, and -3.26 % for thimble channel and -3.43 % for typical channel at 24 %. But, even for the worst plugging conditions of 24 %, the values are above the values from the section 3. of this paper, calculated for the present USAR (ref. [2]) input parameters values. This is consequence of USAR DNBR analysis usage of the inlet temperature and coolant flow values that are slightly more conservative than the ones used here. The plugging up to 24 % would only "spend" the whole overconservative part of margin hidden in present nominal "minimum measured flow".

Also, for the full plugging range from 0 % to 24 % the results are above the limit DNBR values, which are 1.52 for thimble channel, and 1.54 for typical channel.

Of course, full picture would be available only after the full ITDP analysis, including determination of new limit DNBRs, transient analysis and analysis of reactor protection limits over the SGTP range between 0 % and 24 %.

6. References

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