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Performance Evaluation of Annular Fuel in OPR-1000 Plant During a Main Steam Line Break Accident

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1. Introduction

The performance of the solid fuel and the externally and internally cooled annular fuel [1] loaded into the existing two-loop PWR of OPR-1000 (Optimized Power Reactor-1000) during a main steam line break accident (MSLB) is assessed using the best-estimate T-H system code, MARS [2]. The steady-state and transient calculations for the solid fuel and the annular fuel both at a 100% power and the annular fuel at a 120% power are performed by employing conservative initial/boundary conditions and assumptions.

2. MSLB Analysis

2.1 Analysis Model

Figure 1 shows the MARS system nodalization used for this analysis. Two hot legs, one pressurizer (PZR), two SGs, four RCPs, four cold legs, and four safety injection lines are modeled separately as designed. The downcomer is modeled by two split channels having cross-flow junctions.

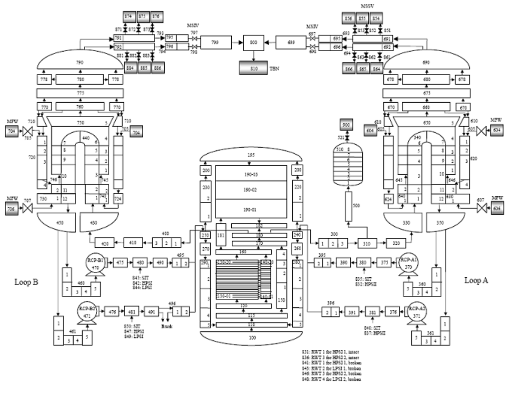

Fig. 1. MARS system nodalization for the OPR-1000.

For both fuel types: a) the core is modeled as an average fuel assembly channel (176 FAs), a hot fuel assembly channel (1 FA), and a core bypass region. b) the heat structure of the average fuel rods are embodied in the average fuel assembly channel. c) the heat structures of the hottest fuel rod and other remaining hot fuel rods are embodied in the hot fuel assembly channel. For the solid fuel, two fuel channels are connected by cross-flow junctions for a lateral flow between the channels. However, for the annular fuel, the core hydraulic node is divided into the inner and outer flow channels for each fuel assembly channel. The outer flow channels of the average and hot fuel assembly channels are connected by cross-flow junctions for a lateral flow between the channels, while the inner flow channels of the fuel assembly channels are not connected laterally.

Table 1 shows the main parameters used for the core modeling.

Table 1: Main Parameters used for Core Modeling

Parameter	Models		
	solid	annular	
Core thermal power	2871 MW	3378 MW	
No. of Fuel Channels	Average(176 FA) & Hot (1 FA)		
Fuel Rod Array	16 × 16	12 × 12	
No. of Axial Nodes	20		
No. of Radial Cells	8	11	
Axial Power Shape	1.58 Top Skewed		
Radial Power Peaking	1.62		
Average Linear Power	18.04 kW/m	34.34 kW/m	
Direct Heating	2.5%		
Gap Conductivity (W/K-m)	0.7567	inner	outer
		0.2711	0.2179

2.2 Initial and Boundary Conditions and Assumptions

For the conservative results by MSLB analysis, the moderator density and doppler reactivity values are selected as the most negative ones. The minimum shutdown rod worth with the most reactive rod stuck out is credited. A conservative ANS-73 decay heat curve is used with a 1.2 multiplication factor.

For the annular fuel with the 120% power case, the initial pressure of the SG secondary side is lowered to 6.54 MPa to maintain approximately the same core exit temperature as the 102% power case.

The high power trip setpoint of 103.5% is applied to the MSLB accident inside of the containment.

3. Analysis Results

3.1 Steady-state Results

The steady-state calculations for the solid fuel at a 102% power (considering the uncertainty of the nominal power) and the annular fuel at a 120% power were performed to obtain the stable conditions as shown in Table 2. The calculated values of the major parameters are in good agreement with the desired values.

Table 2: Comparison of steady-state results with design values

	Plant Parameter	Design 100%	Solid 102%	Annular 102%	Annular 120%
Reactor Vessel	Core Power [MWt]	2815	2871.3	2871.3	3378.0
	Reactor pressure drop [bar]	3.77	4.42	4.44	4.69
	Core shroud flow [kg/s]	146.2	317.2	315.6	309.8
	Core flow [kg/s]	14,855	14,880	14,846	14,859
	Bypass flow fraction (%)	3.0	3.0	3.0	3.0
Primary Side	Total loop flow [kg/s]	15,308	15,341	15,305	15,319
	Hot leg temperature [K]	601.0	601.0	601.1	601.0
	Cold leg temperature [K]	569.0	569.4	569.3	563.0
	Pressurizer water level [%]	52.6	51.6	51.7	43.9
	Pressurizer pressure [MPa]	15.82	15.50	15.50	15.50
	Pump head [m]	102.7	110.2	110.3	111.2
	Pump speed [rpm]	1,190	1,190	1,190	1,190
Secondary Side	Downcomer FW flow [kg/s]	80.3	81.7	81.7	98.1
	Economizer FW flow [kg/s]	721.0	735.6	735.6	882.7
	Steam flow rate/SG [kg/s]	801.3	813.3	815.2	947.5
	Steam pressure [MPa]	7.56	7.31	7.32	6.54
	SG DC collapsed level [m]		11.96	11.96	12.30
	SG recirculation ratio	3.7	3.91	3.93	3.24

3.2 Transient Results

The sequence of events for MSLB is shown for the solid and the annular fuels in Table 3.

Table 3: Sequence of events for MSLB

Event	Solid 102%	Annular 102%	Annular 120%
Break at the main steam line	0.0	0.0	0.0
Reactor trip signal on 103.5% overpower	4.96	5.07	7.56
Reactor trip with delay of 0.55 seconds	5.51	5.62	8.11
Turbine trip	5.77	5.88	8.37
Start of CEA insertion	6.01	6.12	8.61
Initiation of auxiliary feedwater supply	10.51	10.62	13.11
MSIV isolation signal on low steam line pressure	20.95	20.31	19.12
Start of isolation of MSIV and feedwater	22.30	21.66	20.47
ECC injection signal on low PRZ pressure	36.09	35.49	42.31
Start of ECC injection (30 s delay)	66.09	65.49	72.31
Maximum of reactivity (%Δ ρ)	162.5 (-0.121%)	185.0 (-0.550%)	196.5 (-0.732%)
Depletion of PRZ inventory	244.0	250.5	244.0

The thermally-hydraulic behavior during the transient is shown in Fig. 2. The break of a main steam line causes an uncontrolled steam blowdown and excessive heat removal from the broken steam generator, which results in a rapid cooldown of the primary system. The core inlet coolant temperature decrease combined with the large negative MTC causes a core power increase, which results in a reactor trip on a high power signal.

For this accident, the minimum DNBR (MDNBR) is a major parameter of concern. Figure 3 shows the hot channel MDNBR behavior during the initial period of the transient. For the annular fuels the MDNBR of 120% power case is lower than that of 102% power case. Furthermore, this MDNBR of the annular fuel with 120% power is higher than that of the solid fuel.

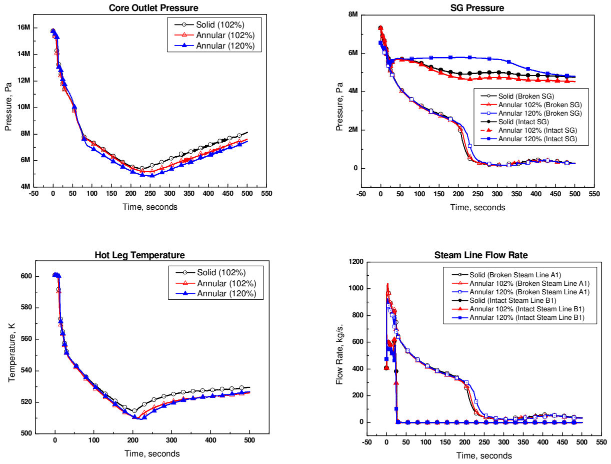

Fig. 2. System thermal-hydraulic behavior during the transient.

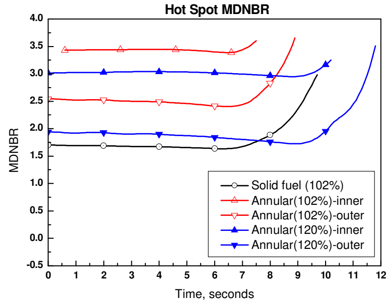

Fig. 3. Comparison of minimum DNBRs for the solid and annular fuels.

4. Conclusions

The feasibility of power uprating by 20% for the annular fuel is assessed for the MSLB accident.

From the present study it is shown that the annular fuel has a higher safety margin compared with the solid fuel, and a core replacement by the annular fuel with the same plant configuration can be a very promising measure to increase the reactor power up to 20% for the reference plant.

REFERENCES

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