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NGNP Conceptual Design Study: Reactor Parametric Study

Revision 0

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Section	Title	Description
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LIST OF TABLES

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ACRONYMS

Acronym	Definition
BEA	Battelle Energy Alliance
CB	Core Barrel
CFD	Computational Fluid Dynamic
DLOFC	Depressurised Loss of Forced Coolant
DPP	Demonstration Power Plant
INL	Idaho National Laboratory
NGNP	Next Generation Nuclear Plant
PBMR	Pebble Bed Modular Reactor
PCDR	Preconceptual Design Report
RIT	Reactor Inlet Temperature
ROT	Reactor Outlet Temperature
RPV	Reactor Pressure Vessel

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SUMMARY AND CONCLUSIONS

The objective of this study is to evaluate the impact on reactor component temperatures when varying the reactor outlet temperatures and reactor power levels for a fixed reactor design. The entire study is performed on the existing Demonstration Power Plant (DPP) reactor design. The only modifications made to the DPP reactor model were the inlet flow configuration, as defined in the Westinghouse PCDR, as well as reactor boundary conditions. The base case defined for this study was the reactor boundary conditions proposed for the Westinghouse PCDR, which was a 500MWt reactor with a reactor outlet temperature of 950 ºC and a reactor inlet temperature of 350 ºC.

This reactor parametric study presents the temperatures to be expected in the fuel, core barrel (CB) and reactor pressure vessel (RPV) during normal operation and a Depressurized Loss of Forced Coolant (DLOFC) event. The effect of power level and reactor outlet temperature on these reactor component temperatures was evaluated.

The base case defined for this study was the reactor boundary conditions proposed for the Westinghouse PCDR, which was a 500MWt reactor with a reactor outlet temperature of 950 ºC and a reactor inlet temperature of 350 ºC. The base case has sufficient margin during normal operation and during a DLOFC event for the fuel and reactor metallics. None of the cases that were analyzed decreased the margin during normal operation and during a DLOFC event and all trends were as expected. The reduction of the ROT generally has the greatest impact in increasing these margins during normal operation for the fuel. The reduction of the power level generally has the greatest impact in increasing these margins during the DLOFC.

Lowering of the reactor outlet temperature from 950ºC to 700ºC, reduces the maximum fuel temperature during normal operation from 1235ºC to 932ºC. During normal operation the CB and RPV will be closely linked to the reactor inlet temperature and are not significantly affected by the reactor outlet temperature. During a DLOFC event the maximum fuel temperature will reduce from 1703ºC to 1622ºC if the reactor outlet temperature is reduced from 950º to 700º. During a DLOFC event the difference in maximum core barrel temperature is expected to be approximately 20ºC and approximately 15ºC for the maximum reactor pressure vessel temperature.

Lowering of the reactor power level from 500MWt to 250MWt, reduces the maximum fuel temperature during normal operation from 1235ºC to 1025ºC. During normal operation the CB and RPV will be closely linked to the reactor inlet temperature due to the inherent flow path. During a DLOFC event the maximum fuel temperature will reduce from 1703ºC to 1174ºC if the power is reduced from 500MWt to 250MWt. During a DLOFC event the difference between the maximum temperatures for the CB and RPV is expected to be approximately 170ºC and 125ºC respectively. The base case maximum CB temperature of 634ºC is below the 750ºC limit and the maximum RPV temperature of 452ºC is below the 538ºC limit.

Although a DLOFC event can be initiated quickly, the reactor temperatures respond very slowly due to the immediate reactivity shut-down (negative temperature coefficient of reactivity) while the resultant temperatures are driven by decay heat generation. The maximum temperatures can be expected to be reached after hours and not within minutes (between 40-60 hours for all cases).

In determining the expected fission product releases from the fuel, it is important to consider the actual time the fuel will be exposed to the very high temperatures (time at temperature). Only a small portion of the fuel will be exposed to these high temperatures for a relatively short period of time, which imply reduced overall releases. For a 500MWt PBMR reactor operating at 950ºC, only 5-7% of the fuel is expected to be exposed to temperatures above 1600ºC during a typical DLOFC transient.

References

1. *NGNP and Hydrogen Production Preconceptual Design Report, NGNP-ESR-RPT-001, Revision 1, Westinghouse Electric Company LLC, June 2007.*

INTRODUCTION

This report documents the results of the reactor parametric study. The objectives of the study and the organization of this report are summarized below.

Objectives and Scope

The overall objective of the study is to evaluate the impact of various reactor operating conditions on the fuel, core barrel (CB) and reactor pressure vessel (RPV) temperatures during normal operation as well as during a Depressurized Loss of Forced Coolant event (DLOFC) for a base case design of 500MWt with an ROT of 950C.

The parametric study can be divided into two sets of analyses. Firstly, the reactor outlet temperature (ROT) is considered in increments of 50ºC for a fixed reactor power level of 500MWt. Secondly, the reactor power level is varied in increments of 50MWt with a fixed ROT of 950ºC.

The above objectives were achieved in the course of the study and the results are documented in this report.

1 ANALYSIS DESCRIPTION

The parametric study can be divided into two sets of analyses.

- Variation of reactor outlet temperature in increments of 50ºC for a fixed reactor power level of 500MWt.
- Variation of reactor power level in increments of 50MWt for a fixed ROT of 950ºC.

The various cases analyzed are described in Table 1-1.

Analyses Description	Reactor Power [MWt]	ROT [ºC]	RIT [ºC]	Mass flow rate [kg/s]	Constraints
Base Case	500	950	350	160.4	Limited by ΔT (=ROT-RIT) across reactor core structures
Case 1	500	900	300	160.4	Limited by ΔT across reactor core structures
Case 2	500	850	280	168.9	Limited by minimum RIT
Case 3	500	800	280	185.1	Limited by minimum RIT
Case 4	500	750	280	204.8	Limited by minimum RIT
Case 5	500	700	280	229.2	Limited by minimum RIT & velocities in reactor outlet slots
Case 6	250	950	350	80.2	Limited by ΔT across reactor core structures
Case 7	300	950	350	96.3	Limited by ΔT across reactor core structures
Case 8	350	950	350	112.3	Limited by ΔT across reactor core structures
Case 9	400	950	350	128.3	Limited by ΔT across reactor core structures
Case 10	450	950	350	144.4	Limited by ΔT across reactor core structures

Table 1-1: Case Definitions

The minimum RIT (presently set at 280°C to have margin with respect to the actual RPV metal temperature) is determined by ductility limits of the low-alloy steel (SA508 / SA533) of the RPV, which should ideally be kept above a temperature of 260°C (current irradiation database justifies a range of 260°C–300°C). The RIT is limited to a minimum of 280°C (20°C margin) to avoid further qualification of the irradiation effects of the RPV at lower temperatures (<260°C).

The temperature difference across the reactor core for the DPP reactor design is limited to a nominal value of 550°C and a maximum value of 600°C for normal operation. This constraint is related to limits on thermally induced stresses in the non-replaceable core graphite blocks.

The volumetric flow in the reactor is constrained by limitations on forces, vibration and erosion. For the current DPP volumetric flow rate (~54 m^3/s) the design is within German erosion and vibration data, though it remains to be assessed whether it is the case for increased flow rates. The reactor velocity results in a resultant force on the bottom of the reactor. Again, the reactor design is within German design data limits. If the flow velocity is increased, a detailed calculation (taking up to 6 months) will be required to confirm whether the reactor can withstand the increased forces due to higher velocities. It is suspected, pending calculation confirmation, that it will not be possible to increase the flow above 20% of the current value. However, since the detailed calculations have not been performed, it has conservatively been assumed to fix the limit at the current volumetric limit of 54 m^3/s.

2 CALCULATION DESCRIPTION

2.1 Software Utilized

TINTE (Time dependent Neutronics and Temperatures) is a reactor dynamics program for computing the nuclear and thermal transient behaviour of the primary circuit of an HTGR, taking into account mutual feedback effects in two-dimensional R-Z geometry. Examples of the topics of TINTE application in design and safety analyses of general HTGRs are:

- Time dependent heat transport with and without natural convection.
- Time dependent heat conduction with/without cooling gas.
- Neutron diffusion.
- Critical conditions (steady state).
- Reactivity transient with/without gas flow.
- Xenon transient (long-term behaviour).
- Xenon oscillation behaviour of pebble bed reactors.
- Treatment of graphite oxidation in mixed and pure coolant gases.
- Water/air ingress and its reactivity and chemical attack behaviour.

TINTE Version 3.07 was used for this study.

The combined temperature and fluid-dynamic functions of TINTE provide the capability to solve problems such as:

- Heat production in a pebble bed in different gas media.
- Natural convection modeling.

2.2 Calculation Model

The updated TINTE model, developed for the forthcoming 2008 DPP SAR analyses, was used as the basis for this study. Several major changes were performed on the previous TINTE model. In summary, the major changes from the previous TINTE model are the following:

- Introduction of enhanced reflector cooling and leak flows. Several additional horizontal leak flows from the reactivity control system and reserve shutdown system channels added a significant amount of reflector and core cooling. Lower fuel temperatures up to 200ºC (local) and 80ºC (global) have been observed in preliminary steady-state and DLOFC testing of the 400 MW DPP model.
- The NBG-18 graphite replaced the NBG-10 graphite previously used as reflector material. The effect on fuel temperature of the higher density and lower conductivity values in this specification have not yet been isolated, but is estimated in the order of 20 ºC on a typical 400 MW DPP DLOFC.
- The mass of the bottom reflector has decreased significantly, but since heat removal through this structure was of lesser importance during the typical DLOFC transient

compared to the central and side reflector, this change is not viewed to be significant.

In summary, both the steady-state (SS) and DLOFC fuel temperatures are lower than previous PBMR TINTE results, due to: increased cooling along the axial height of the core decreased the very hot regions of fuel next to the central reflector during SS, and drastically cooler central and side reflectors changed the overall heat removal pattern in the core structures significantly. (For example, the central reflector went from being a major heat source in the prior model to an effective heat sink in the new model during the early stages of the DLOFC). This accounts for the lower fuel and component temperatures reported in this study, compared to earlier 2007 data.

The TINTE Model is currently undergoing independent review, but a preliminary version was used for the analyses in this study. The following modifications were made to the DPP TINTE reactor model:

- Reactor inlet flow configuration
- Control rod inserted positions were adjusted to obtain comparable levels of excess reactivity to the base case during normal operation

The TINTE code has been developed for accident analysis, and is not commonly used for best estimate design studies at PBMR. This is mainly due to the nature of the software and model assumptions that are made in the code. In particular it should be noted that the fuel, CB and RPV temperatures are determined within bandwidths of approximately 15% uncertainty. The assumptions made on the modeling of thermal radiation and convective heat transfer, especially between the CB and RPV, result in lower than expected temperatures for the RPV. PBMR utilizes computational fluid dynamic (CFD) software to calculate CB and RPV temperatures accurately. No CFD calculations were performed for this study. It is cautioned that the TINTE analysis results should not be used to determine absolute RPV and CB temperatures. They should only be used to indicate relative temperature deltas and trends.

3 REACTOR STEADY STATE RESULTS DURING NORMAL OPERATION

This section summarizes the fuel, core barrel and reactor pressure vessel steady state temperatures during normal operation.

Analyses Description	**Max. Fuel temp. (ºC)**	**Ave. Fuel temp. (ºC)**	**Max. CB temp. (ºC)[1]**	**Ave. CB temp. (ºC)[1]**	**Max. RPV temp. (ºC)[1]**	**Ave. RPV temp. (ºC)[1]**
Base case (500MW, 950ROT, 350RIT)	1235	920	350	350	308	305
Case 1 (500MW, 900ROT, 300RIT)	1183	868	301	301	266	263
Case 2 (500MW, 850ROT, 280RIT)	1127	819	281	281	249	247
Case 3 (500MW, 800ROT, 280RIT)	1065	771	281	281	250	247
Case 4 (500MW, 750ROT, 280RIT)	1002	721	281	281	251	247
Case 5 (500MW, 700ROT, 280RIT)	932	650	280	280	251	249

Table 3-1: Reactor steady state temperature results for normal operation at a fixed reactor power level of 500 MWt

Analyses Description	**Max. Fuel Temp. (ºC)**	**Ave. Fuel Temp. (ºC)**	**Max. CB Temp. (ºC)[1]**	**Ave. CB Temp. (ºC)[1]**	**Max. RPV Temp. (ºC)[1]**	**Ave. RPV Temp. (ºC)[1]**
Base Case (500MW, 950ROT, 350RIT)	1235	920	350	350	308	305
Case 6 (250MW, 950ROT, 350RIT)	1025	817	349	349	302	299
Case 7 (300MW, 950ROT, 350RIT)	1045	827	349	349	304	301
Case 8 (350MW, 950ROT, 350RIT)	1072	834	350	350	306	305
Case 9 (400MW, 950ROT, 350RIT)	1095	838	350	350	307	304
Case 10 (450MW, 950ROT, 350RIT)	1127	849	350	350	308	305

Table 3-2: Reactor steady state temperature results for normal operation at a fixed reactor outlet temperature of 950 ºC

[1] Core barrel and reactor pressure vessel temperatures are only indicative and should not be used as absolute temperatures

4 REACTOR TRANSIENT ANALYSIS RESULTS DURING DLOFC

This section contains the analysis results for the fuel, core barrel and reactor pressure vessel temperatures during a Depressurized Loss of Forced Cooling (DLOFC) event. A DLOFC event is where the pressure is lost within the reactor and no forced helium flow occurs. During this event the active reactor cavity cooling system is not available. The following actions are taken in the calculation model:

- Total removal of all convective heat transfer at t=0.1 s (i.e., zero mass flow rate, zero pressure)
- Reactor scram at t=60 s

Figure 4-1 plots the maximum anticipated fuel temperatures during a DLOFC event for a fixed reactor power of 500MWt (a single 250MWt case is included), whereas Figure 4-2 plots the maximum fuel temperatures if the reactor outlet temperature is kept at 950ºC. The TINTE code scans the core model mesh and extracts the maximum temperature anywhere in the core at that time point and defines it as the maximum fuel temperature.

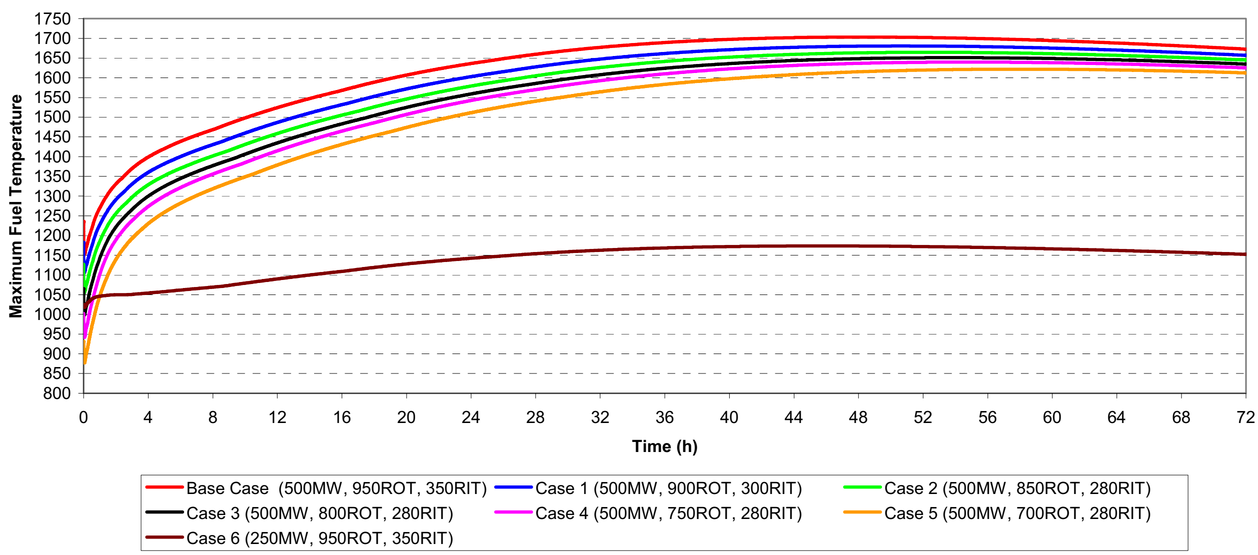


Figure 4-1 Maximum fuel temperature results during DLOFC for a fixed power level of 500 MWt

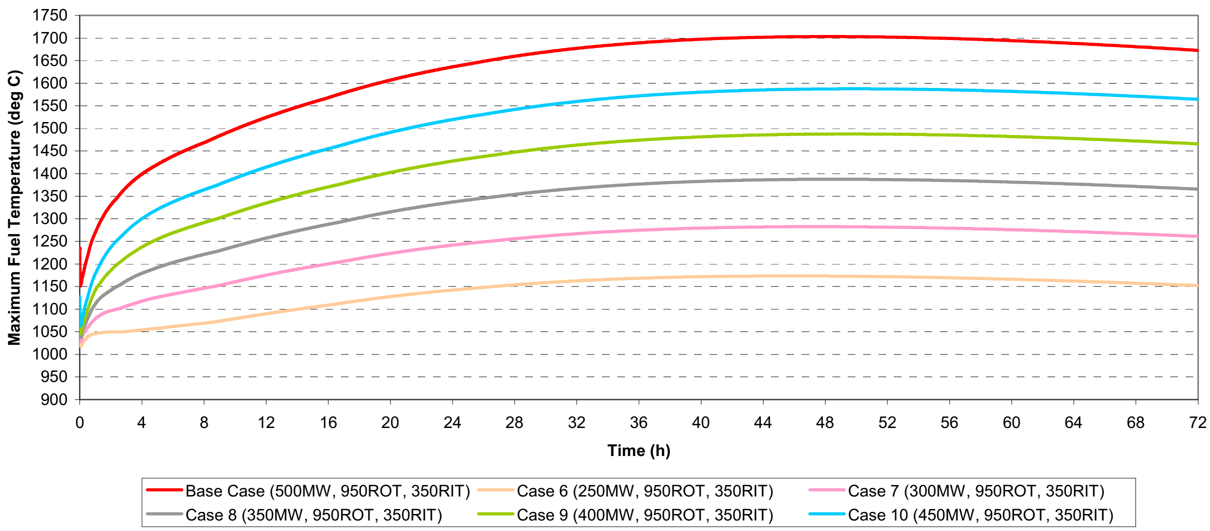


Figure 4-2 Maximum fuel temperature results during DLOFC for a fixed reactor outlet temperature of 950 ºC

Figure 4-3 plots the core average fuel temperatures to be expected during a DLOFC event for fixed reactor power of 500MWt, whereas Figure 4-4 plots the core average fuel temperatures if the reactor outlet temperature is kept at 950ºC.

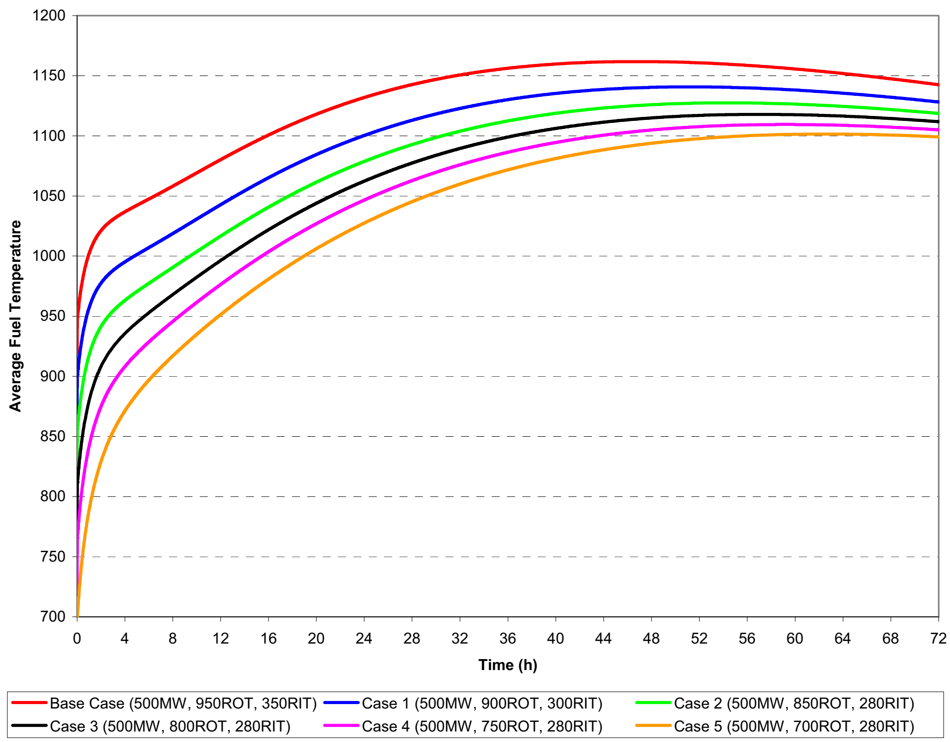


Figure 4-3 Core average fuel temperature results during DLOFC for a fixed reactor power level of 500 MWt

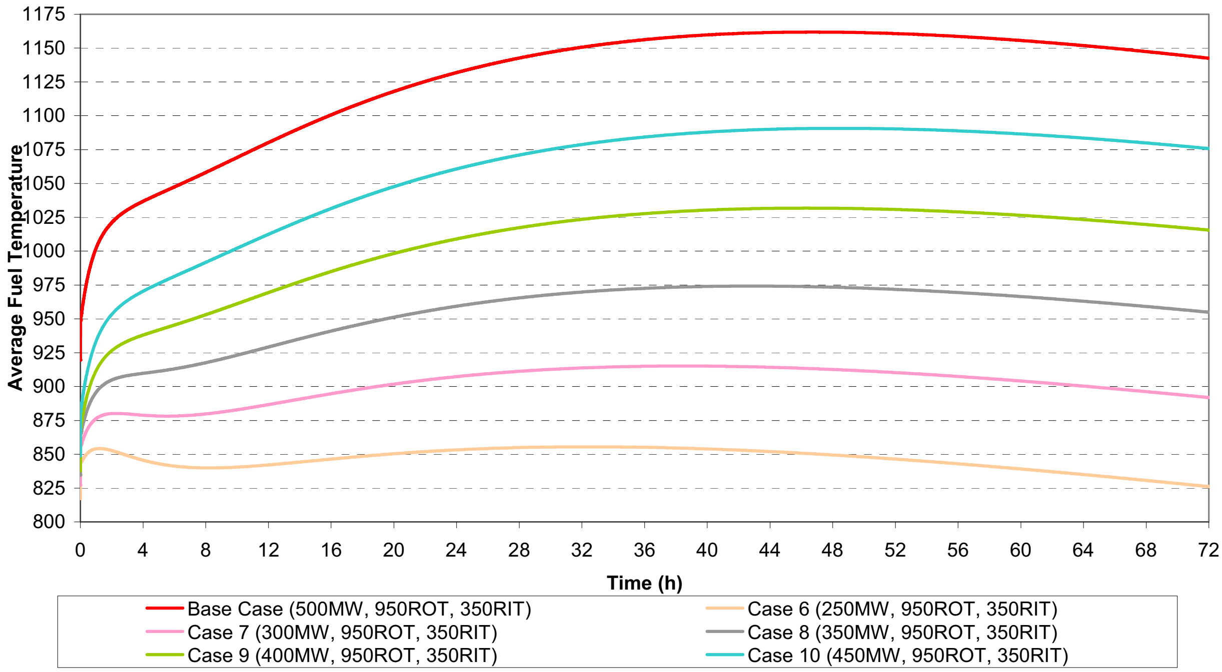


Figure 4-4 Core average fuel temperature results during DLOFC for a fixed reactor outlet temperature of 950 ºC

The fractions of the core (fuel) volume within certain temperature intervals are presented in Figure 4-5 to Figure 4-15. The temperature histogram data shown here are the fuel surface temperatures for the hottest fuel. From Figure 4-5 it can be seen that only a very small fraction (~7%) of the core volume experiences surface temperatures higher than 1600ºC during the DLOFC event.

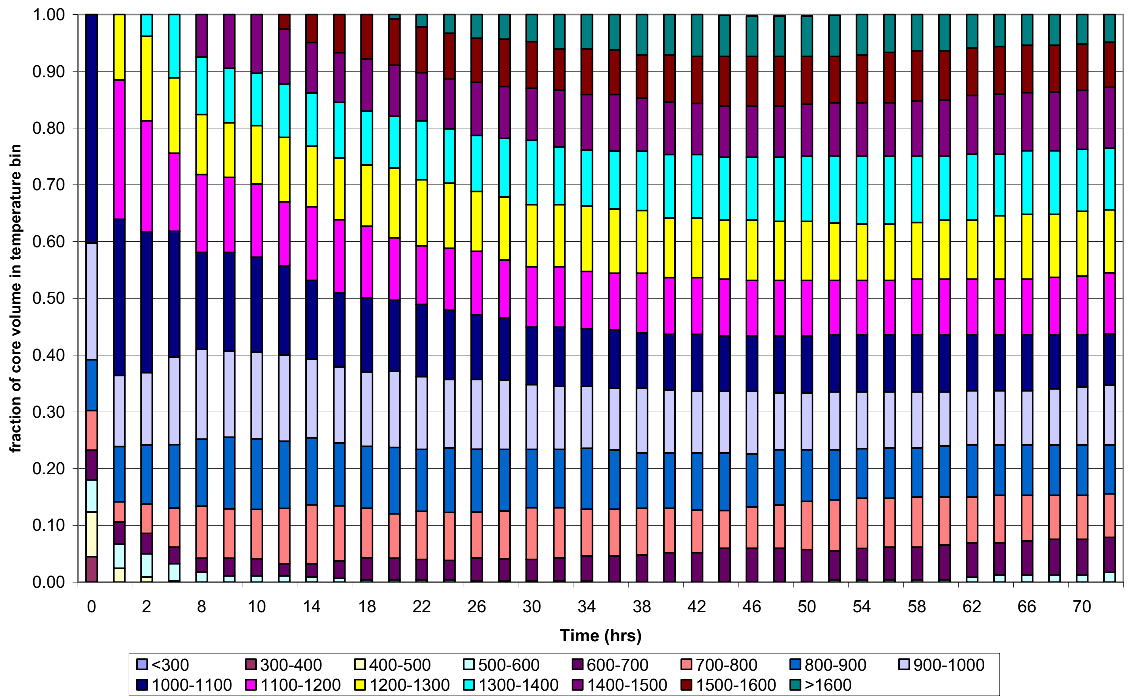


Figure 4-5 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Base case - 500MW, 950ROT, 350RIT)

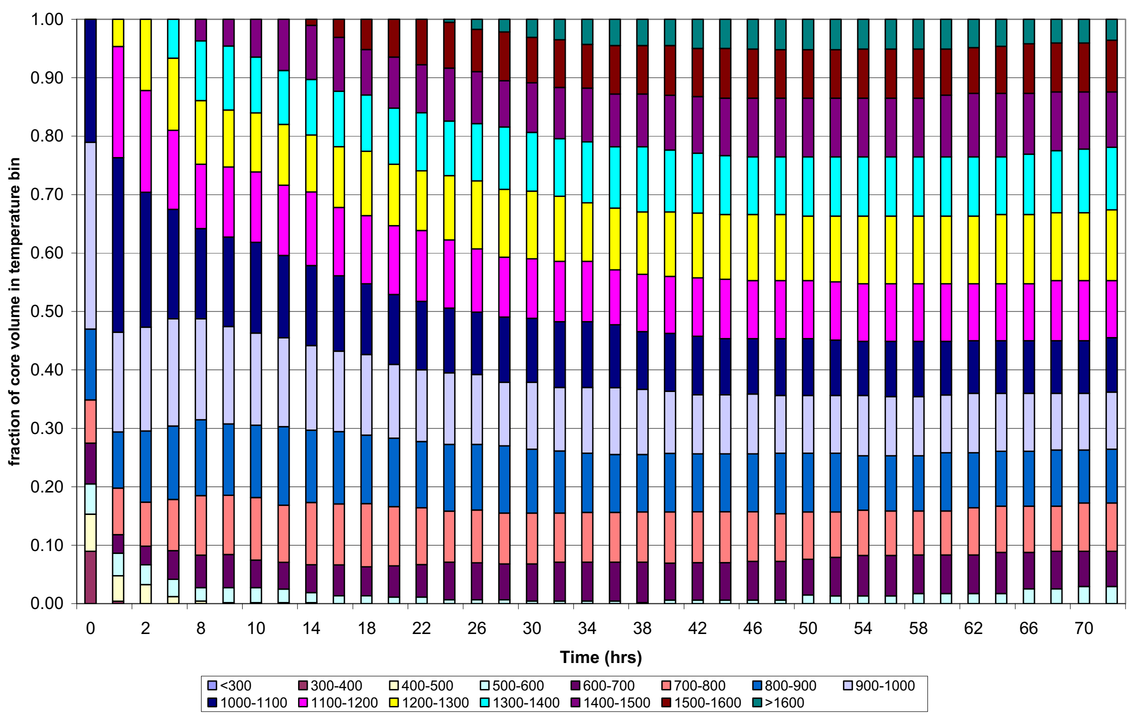


Figure 4-6 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 1 -500MW, 900ROT, 300RIT)

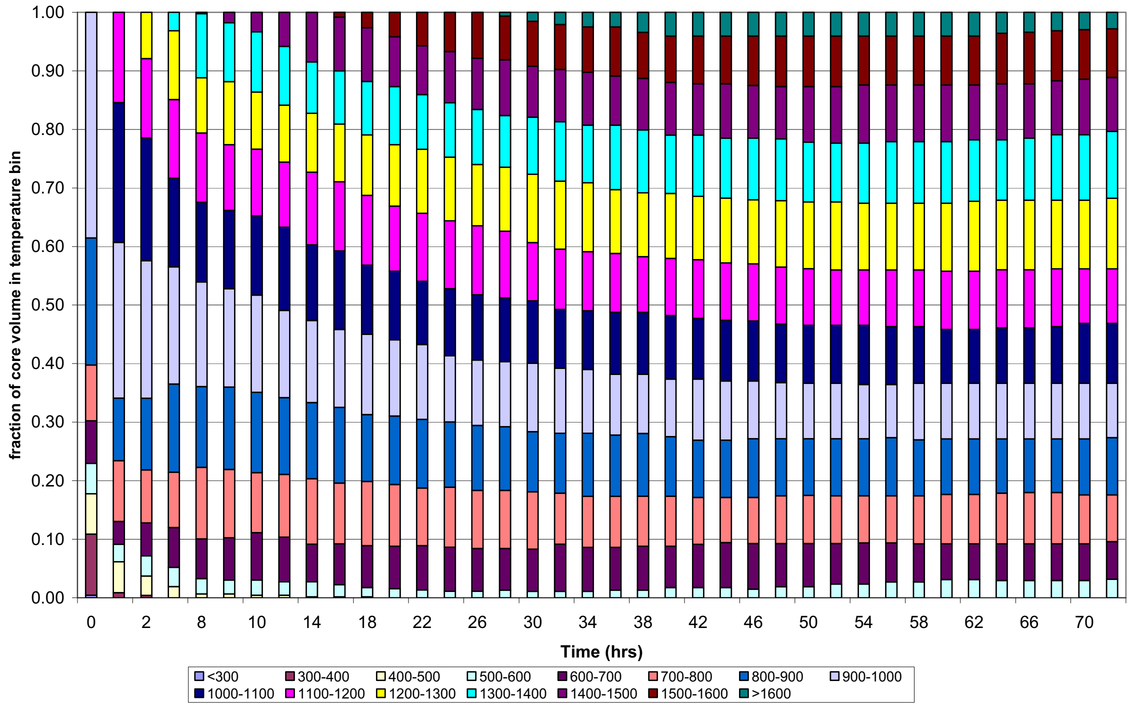


Figure 4-7 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 2 -500MW, 850ROT, 280RIT)

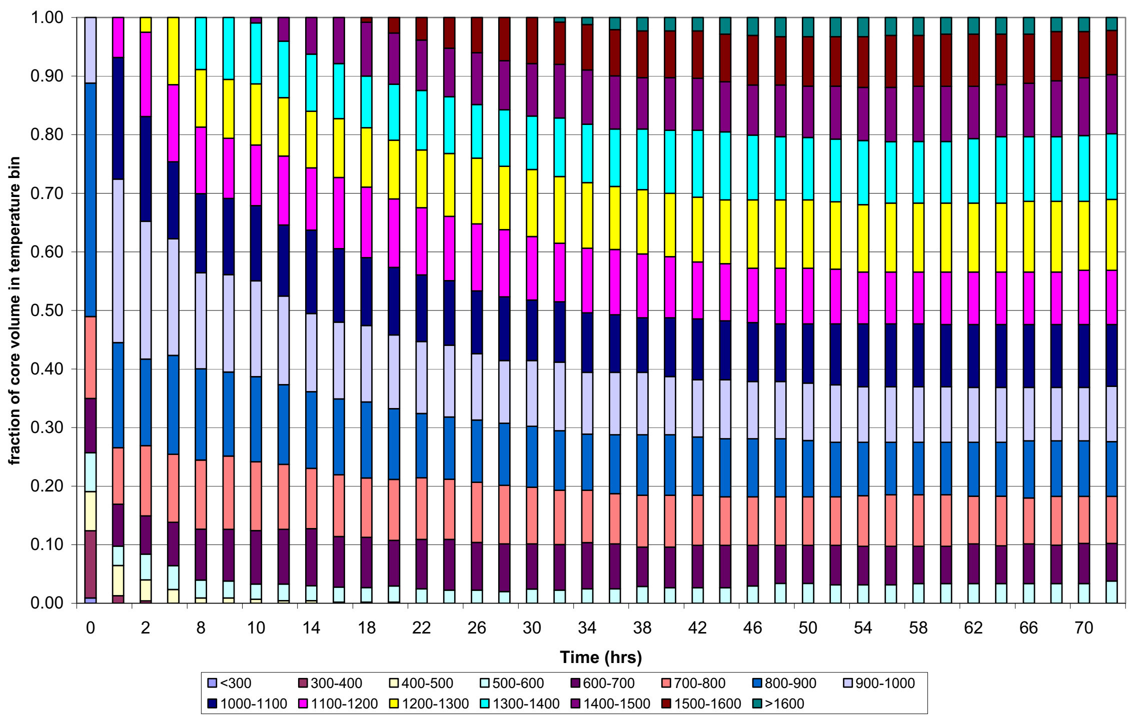


Figure 4-8 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 3 -500MW, 800ROT, 280RIT)

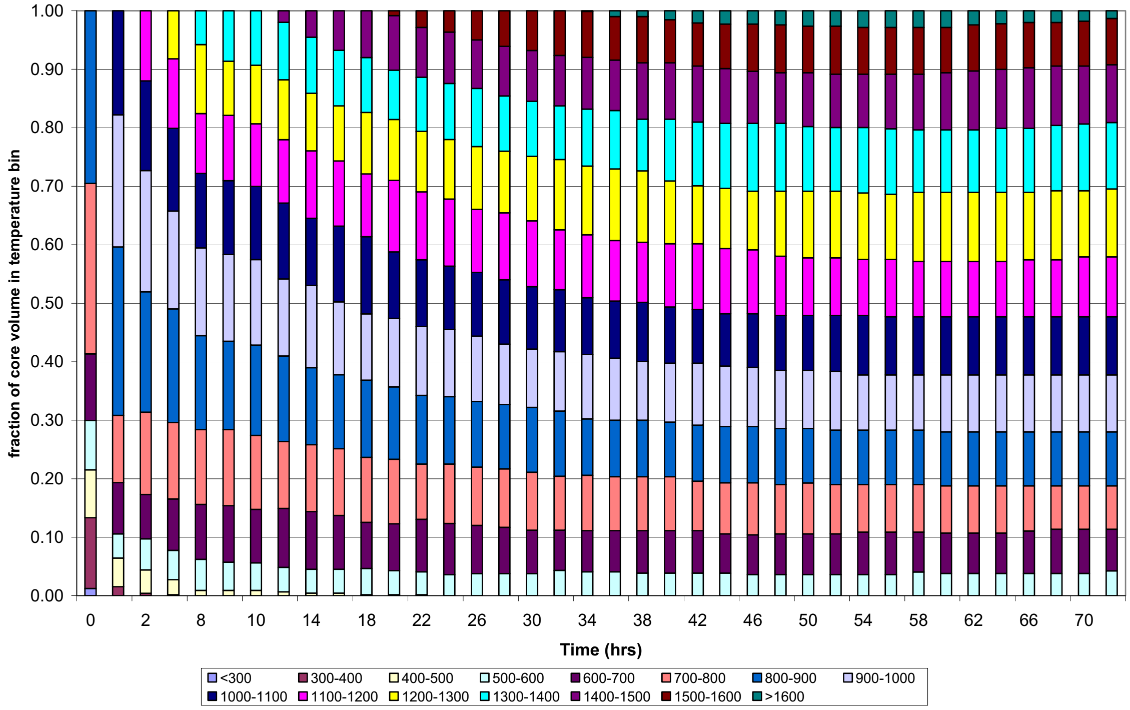


Figure 4-9 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 4 -500MW, 750ROT, 280RIT)

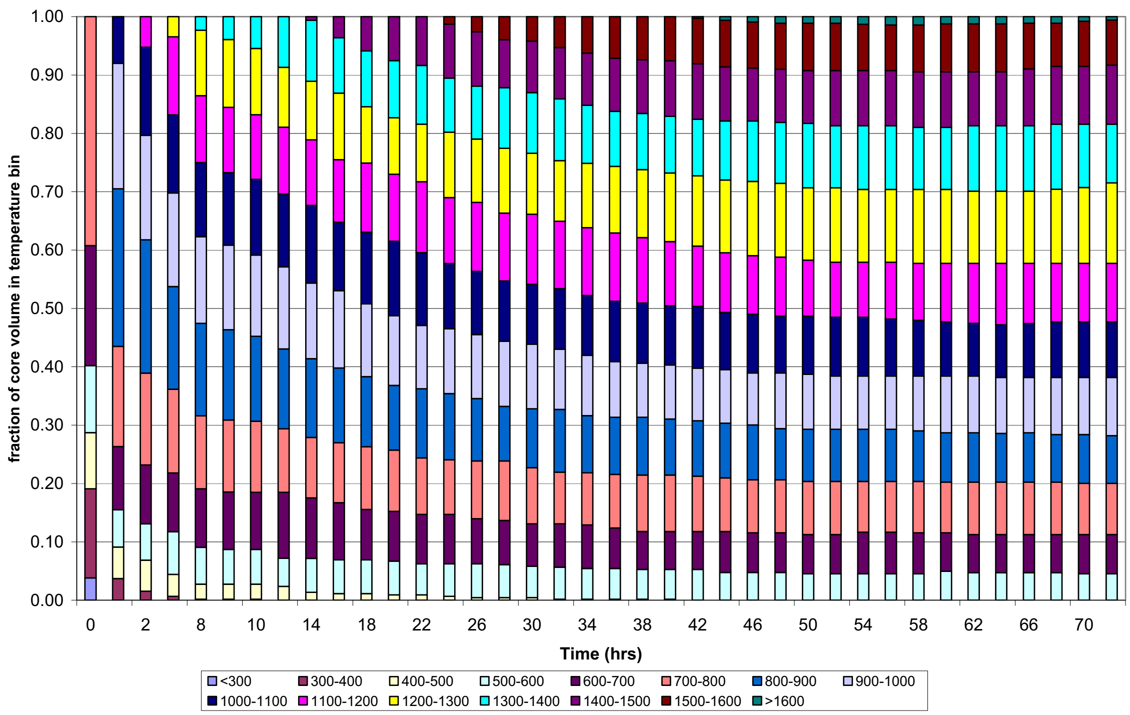


Figure 4-10 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 5 -500MW, 700ROT, 280RIT)

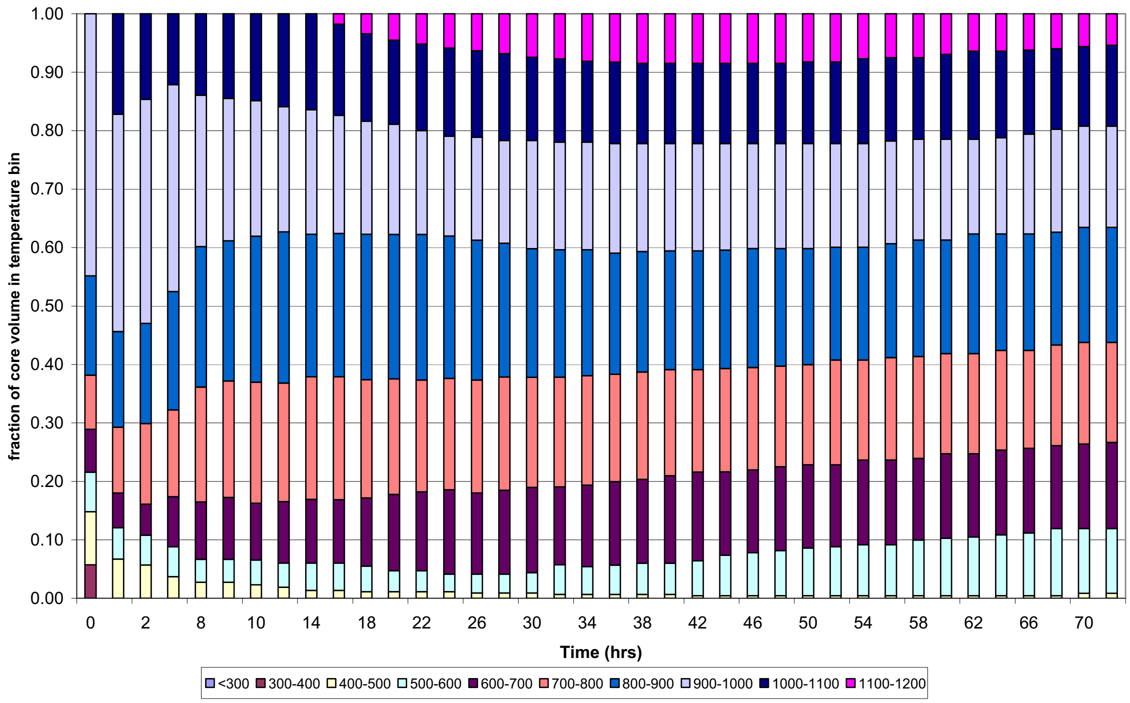


Figure 4-11 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 6 -250MW, 950ROT, 350RIT)

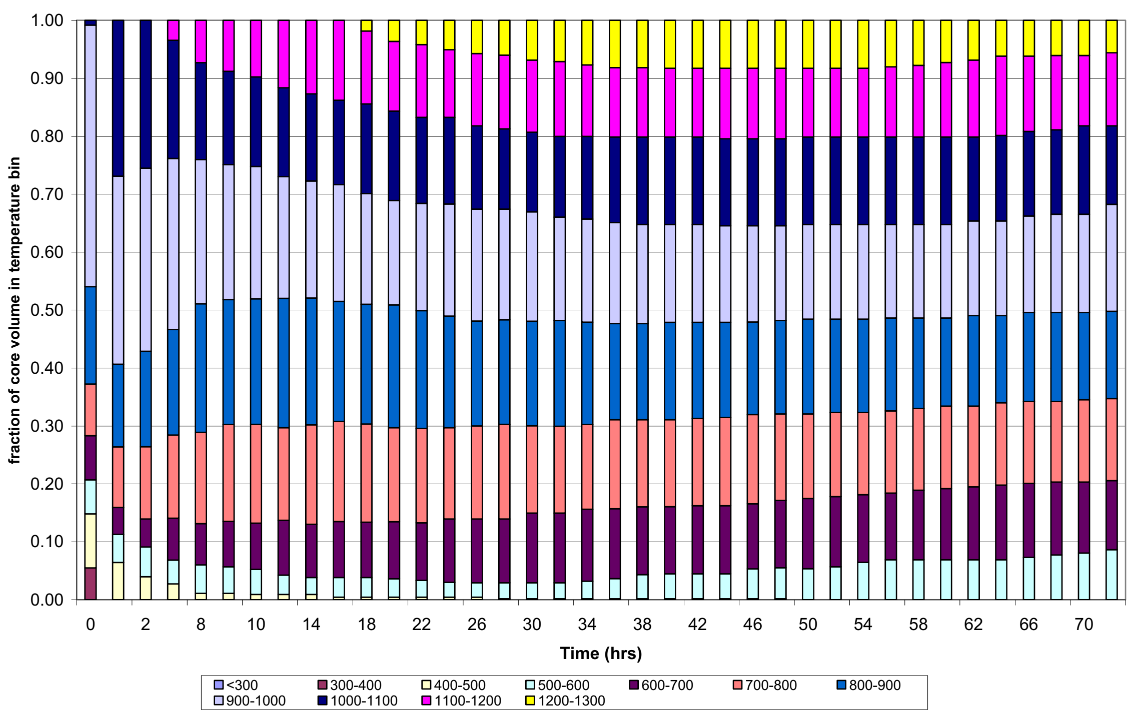


Figure 4-12 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 7 -300MW, 950ROT, 350RIT)

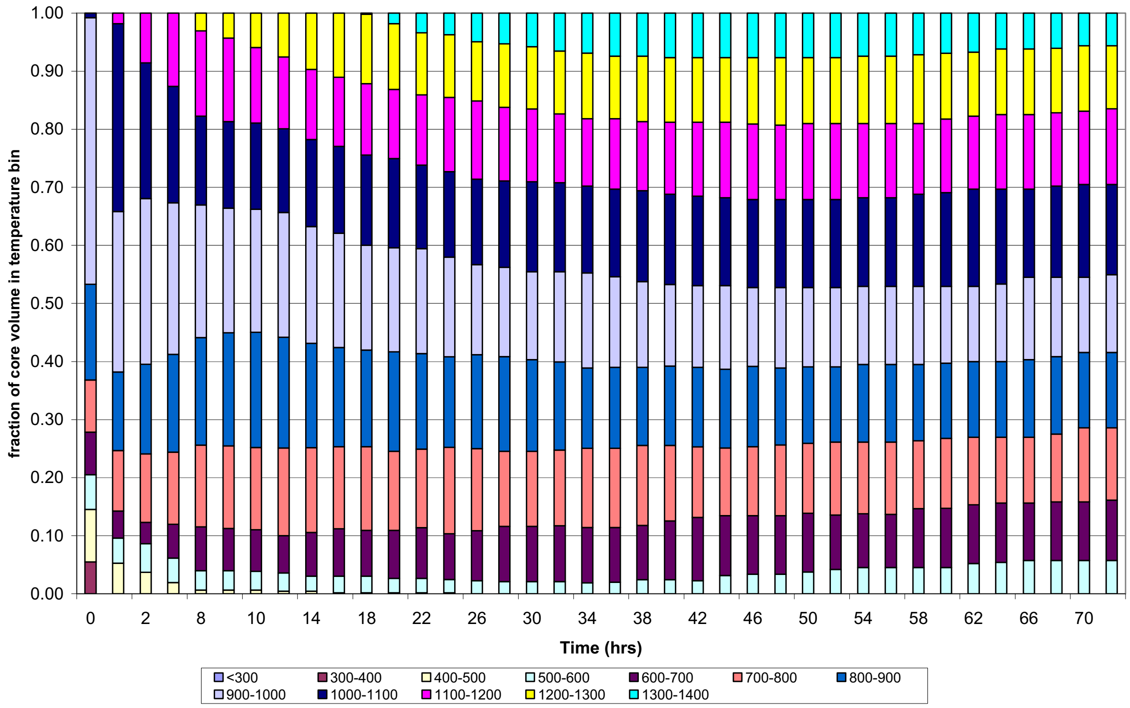


Figure 4-13 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 8 -350MW, 950ROT, 350RIT)

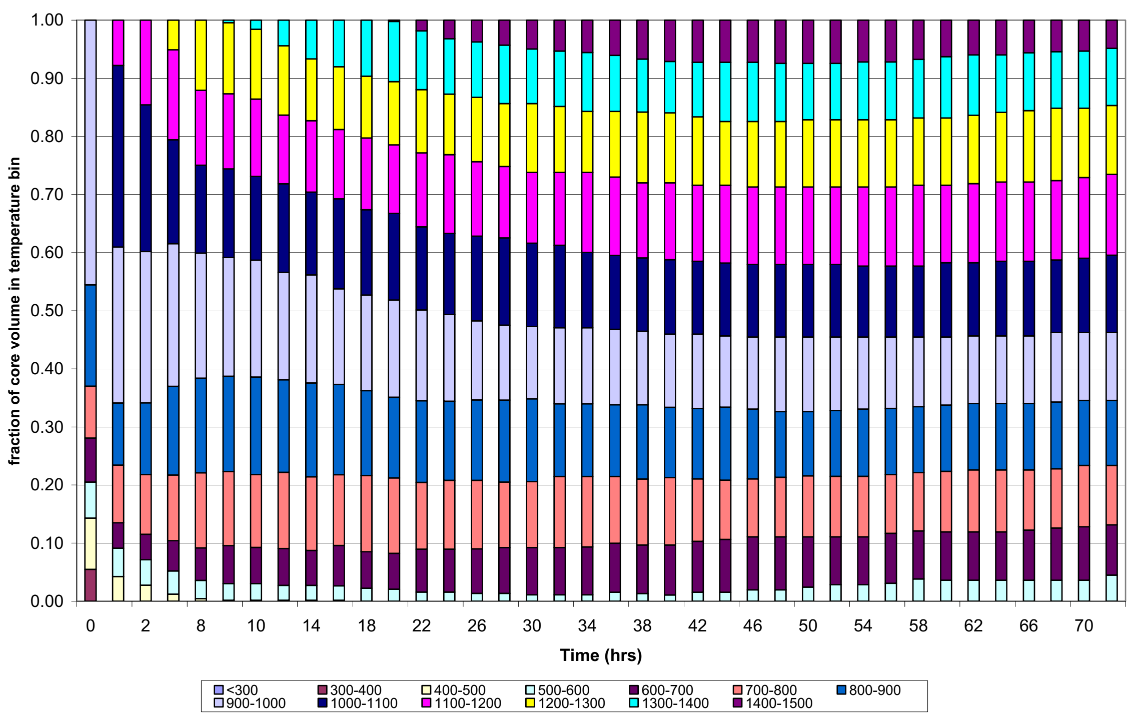


Figure 4-14 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 9 -400MW, 950ROT, 350RIT)

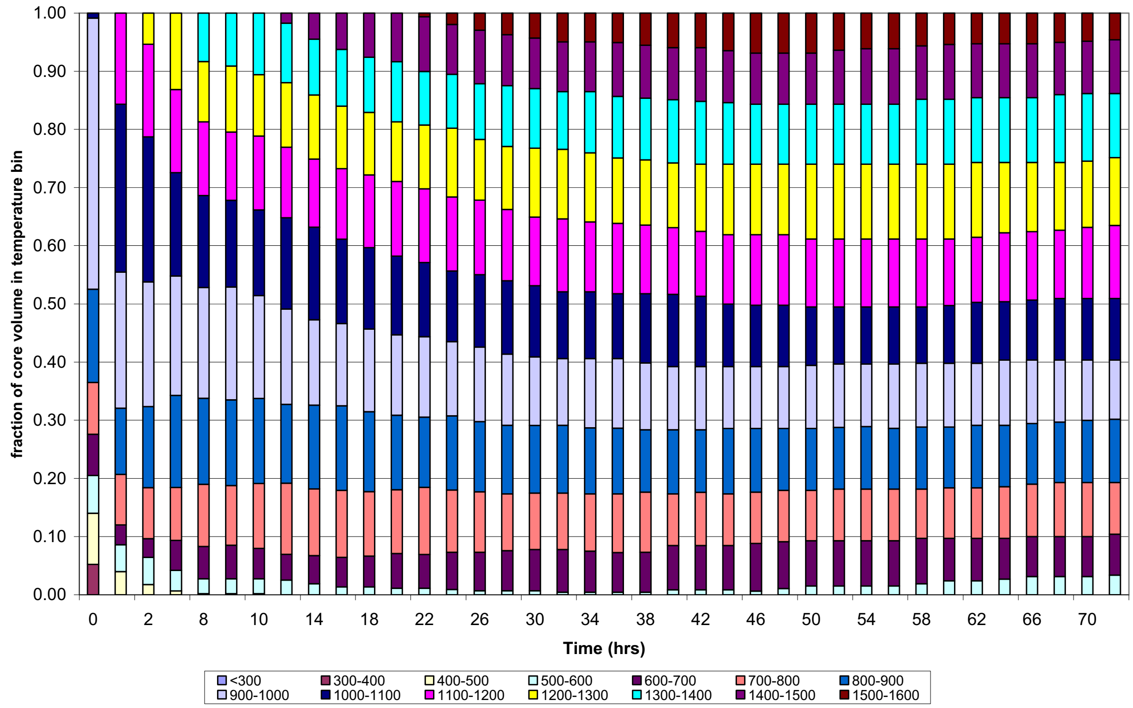


Figure 4-15 Fraction of fuel spheres in temperature ranges during entire DLOFC event (Case 10 -450MW, 950ROT, 350RIT)

The maximum temperatures to be expected during a DLOFC event are tabulated in Table 4-1 and Table 4-2.

Parameter	Base Case 500MW, 950ROT, 350RIT	Case 1 500 MW, 900 ROT, 300 RIT	Case 2 500MW, 850ROT, 280RIT	Case 3 500MW, 800ROT, 280RIT	Case 4 500MW, 750ROT, 280RIT	Case 5 500MW, 700ROT, 280RIT
Maximum fuel temperature (°C)	1703	1681	1665	1651	1640	1622
Core average fuel temperature (°C)	1162	1141	1127	1118	1109	1101
Estimate time max. fuel temperature is reached (h)	45	49	51	52	53	56
Maximum core barrel temperature (°C)	634	626	621	617	613	613
Maximum average core barrel temperature (°C)	437	423	415	410	404	399
Maximum reactor pressure vessel (°C)	452	446	442	439	437	437
Maximum Average Reactor Pressure Vessel (°C)	305	293	287	283	279	275

Table 4-1: Reactor temperature parameters during a DLOFC event for a fixed power level of 500MWt

Parameter	Case 6 250MW, 950ROT, 350RIT	Case 7 300MW, 950ROT, 350RIT	Case 8 350MW, 950ROT, 350RI	Case 9 400MW, 950ROT, 350RIT	Case 10 450MW, 950ROT, 350RIT	Base Case 500MW, 950ROT, 350RIT
Maximum fuel temperature (°C)	1174	1282	1387	1488	1588	1703
Core average fuel temperature (°C)	856	915	974	1032	1091	1162
Estimate time max. fuel temperature is reached (h)	44	42	45	48	49	45
Maximum core barrel temperature (°C)	466	502	536	567	598	634
Maximum average core barrel temperature (°C)	366	378	391	403	417	437
Maximum reactor pressure vessel (°C)	328	355	380	403	426	452
Maximum Average Reactor Pressure Vessel (°C)	299	301	302	304	305	305

Table 4-2: Reactor temperature parameters during a DLOFC event for an initial reactor outlet temperature of 950ºC

5 CONCLUSIONS

The reactor parametric study presents the temperatures to be expected in the fuel, core barrel (CB) and reactor pressure vessel (RPV) during normal operation and a Depressurized Loss of Forced Coolant (DLOFC) event. The effect of power level and reactor outlet temperature on these reactor component temperatures was evaluated.

The base case defined for this study was the reactor boundary conditions proposed for the Westinghouse PCDR, which was a 500MWt reactor with a reactor outlet temperature of 950 ºC and a reactor inlet temperature of 350 ºC. The base case has sufficient margin during normal operation and during a DLOFC event for the fuel and reactor metallics. None of the cases that were analyzed decreased the margin during normal operation and during a DLOFC event and all trends were as expected. The reduction of the ROT generally has the greatest impact in increasing these margins during normal operation for the fuel. The reduction of the power level generally has the greatest impact in increasing these margins during the DLOFC.

Lowering of the reactor outlet temperature from 950ºC to 700ºC, reduces the maximum fuel temperature during normal operation from 1235ºC to 932ºC. During normal operation the CB and RPV will be closely linked to the reactor inlet temperature and are not significantly affected by the reactor outlet temperature. During a DLOFC event the maximum fuel temperature will reduce from 1703ºC to 1622ºC if the reactor outlet temperature is reduced from 950º to 700º. During a DLOFC event the difference in maximum core barrel temperature is expected to be approximately 20ºC and approximately 15ºC for the maximum reactor pressure vessel temperature.

Lowering of the reactor power level from 500MWt to 250MWt, reduces the maximum fuel temperature during normal operation from 1235ºC to 1025ºC. During normal operation the CB and RPV will be closely linked to the reactor inlet temperature due to the inherent flow path. During a DLOFC event the maximum fuel temperature will reduce from 1703ºC to 1174ºC if the power is reduced from 500MWt to 250MWt. During a DLOFC event the difference between the maximum temperatures for the CB and RPV is expected to be approximately 170ºC and 125ºC respectively. The base case maximum CB temperature of 634ºC is below the 750ºC limit and the maximum RPV temperature of 452ºC is below the 538ºC limit.

Although a DLOFC event can be initiated quickly, the reactor temperatures respond very slowly due to the immediate reactivity shut-down (negative temperature coefficient of reactivity) while the resultant temperatures are driven by decay heat generation. The maximum temperatures can be expected to be reached after hours and not within minutes (between 40-60 hours for all cases).

In determining the expected fission product releases from the fuel, it is important to consider the actual time the fuel will be exposed to the very high temperatures (time at temperature). Only a small portion of the fuel will be exposed to these high temperatures for a relatively short period of time, which imply reduced overall releases. For a 500MWt PBMR reactor operating at 950ºC, only 5-7% of the fuel is expected to be exposed to temperatures above 1600ºC during a typical DLOFC transient.

5.1 References

1-1 *NGNP and Hydrogen Production Preconceptual Design Report*, NGNP-ESR-RPT-001, Revision 1, Westinghouse Electric Company LLC, June 2007.

BIBLIOGRAPHY

None.

DEFINITIONS

Depressurized Loss of Forced Coolant (DLOFC): A DLOFC event is where the pressure is lost within the reactor and no forced helium flow occurs in the reactor. During this event the active Reactor Cavity Cooling System is not available.

LIST OF ASSUMPTIONS

The following assumptions served as a basis for this report:

1.

APPENDIX A: 90% REVIEW VIEWGRAPHS

Reactor Parametric Study

Conceptual Design Studies FY 08-2
Next Generation Nuclear Plant

90% Review Meeting with BEA

WBS Element Code Level: NHS.000.S11

Cambridge, MA
23 July 2008

Objective

- The objective of this study is to evaluate the impact of various Reactor operation conditions on the Reactor Fuel, Core Barrel and Reactor Pressure Vessel Temperatures during normal operation as well as during a Depressurized Loss of Forced Cooling event (DLOFC)

Analyses Definition

- The following limited cases were evaluated:

Analyses	Reactor Power [MW]	ROT [ºC]	RIT [ºC]	Mass flow rate [kg/s]	Constraints
Base Case	500	950	350	160.41	Limited by ΔT across Reactor
Case 1	500	900	300	160.41	Limited by ΔT across Reactor
Case 2	500	850	280	168.85	Limited by RIT
Case 3	500	800	280	185.09	Limited by RIT
Case 4	500	750	280	204.78	Limited by RIT
Case 5	500	700	280	229.16	Limited by RIT & Velocities in Reactor outlet slots
Case 6	250	950	350	80.21	Limited by ΔT across Reactor

Software Tools

- **Software used: TINTE Version 3.07**
- **Software Model: 2008 PBMR 400 MW DPP (Prelim)**

Modifications made to the DPP reactor model:

- Reactor inlet flow configuration
- Control Rods inserted positions were adjusted to obtain comparable levels of excess reactivity to the Base Case during normal operation

TINTE Model currently undergoing independent review, but preliminary version used for these analyses

TINTE does not calculate Core Barrel and Reactor Pressure Vessel Temperatures very accurate due to modeling assumptions made on thermal radiation and convective heat transfer between across large gaps (~10% Uncertainty)

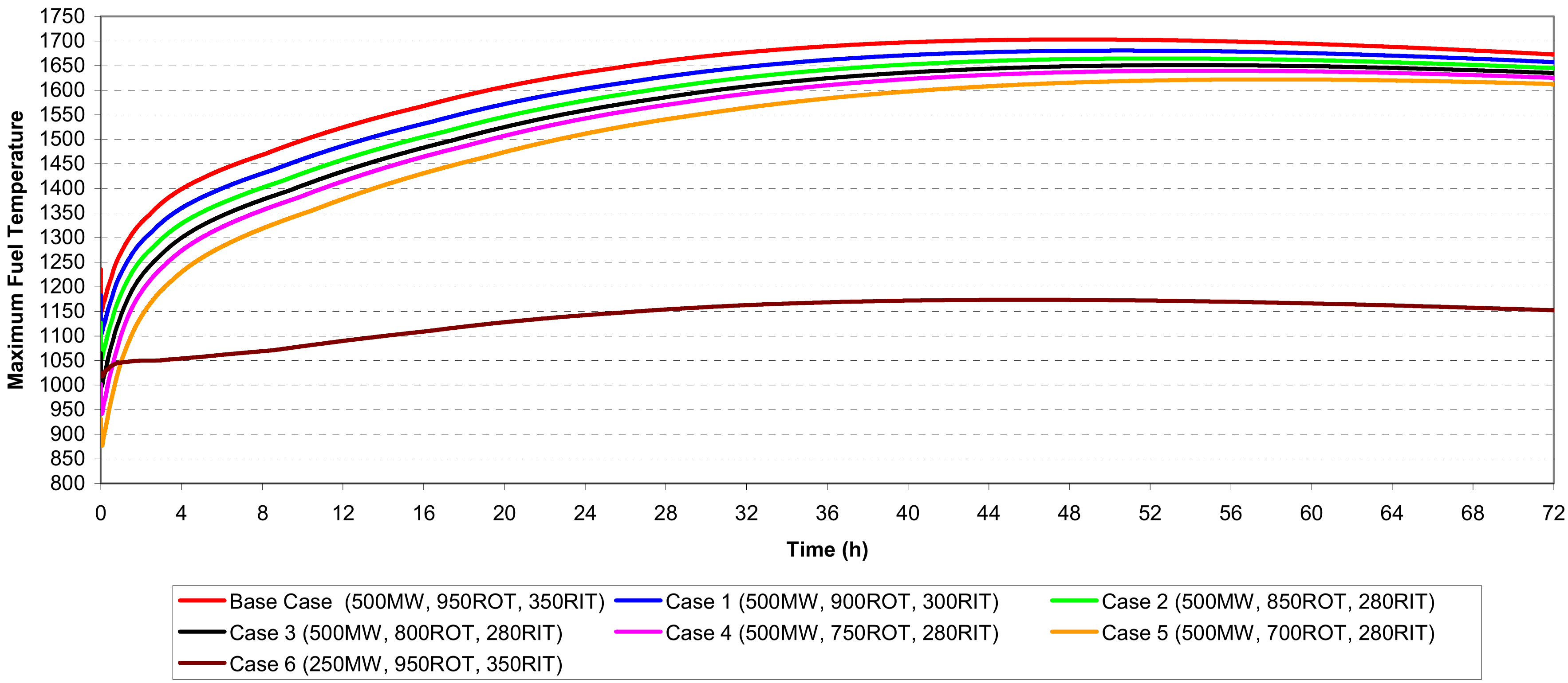
TINTE analysis will however indicate relative and trend CB and RPV Temperature variations between the various cases

Analyses Results – Steady State during Normal Operation

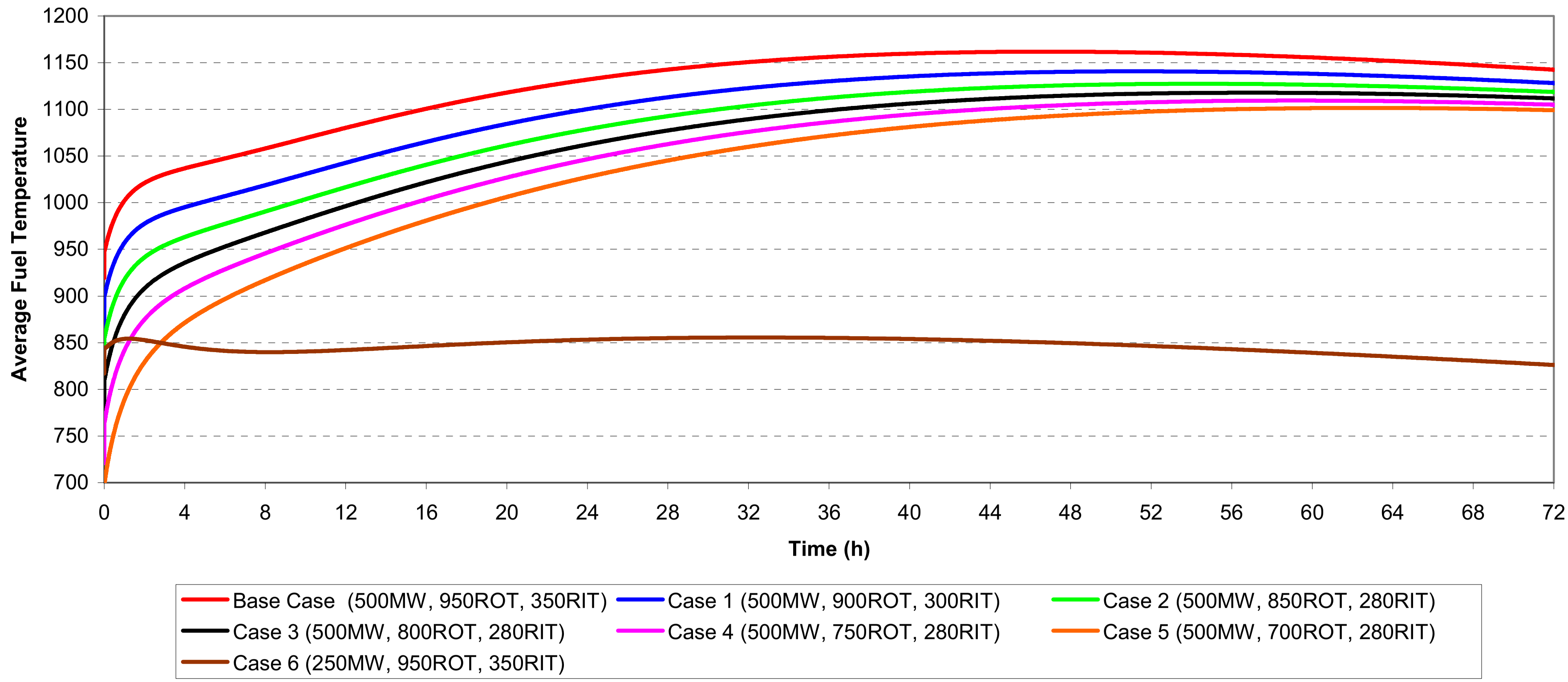
Analyses	Max. Fuel Temp. (ºC)	Ave. Fuel Temp. (ºC)	Max. CB Temp. (ºC)	Ave. CB Temp. (ºC)	Max. RPV Temp. (ºC)	Average RPV Temp. (ºC)
Base Case	1235	920	350	350	308	305
Case 1	1183	868	301	301	266	263
Case 2	1127	819	281	281	249	247
Case 3	1065	771	281	281	250	247
Case 4	1002	721	281	281	251	247
Case 5	932	650	280	280	251	249
Case 6	1025	817	349	349	302	299

*Core Barrel and Reactor Pressure Vessel Temperatures are only indicative

Analyses Results – Max. Fuel Temperature during DLOFC



Analyses Results – Ave. Fuel Temperature during DLOFC



Analyses Results Summary Table

Parameter	Base Case (500MW, 950ROT, 350RIT	Case 1 (500MW, 900ROT, 300RIT)	Case 2 (500MW, 850ROT, 280RIT)	Case 3 (500MW, 800ROT, 280RIT)	Case 4 (500MW, 750ROT, 280RIT)	Case 5 (500MW, 700ROT, 280RIT)	Case 6 (250MW, 950ROT, 350RIT)
Max. Fuel Temperature (°C)	1703	1681	1665	1651	1640	1622	1174
Ave. Fuel Temeprature (°C)	1162	1141	1127	1118	1109	1101	856
Estimate time Max. Fuel Temperature is reached (h)	45	49	51	52	53	56	44
Max. Core Barrel Temperature (°C)	634	626	621	617	613	613	466
Ave. Core Barrel Temperature (°C)	437	423	415	410	404	399	366
Max. Reactor Pressure Vessel (°C)	452	446	442	439	437	437	328
Ave. Reactor Pressure Vessel (°C)	305	293	287	283	279	275	299

***Core Barrel and Reactor Pressure Vessel Temperatures are only indicative**

Summary and Conclusions

- Temperatures decrease as ROT decreases for the same power level during normal steady state conditions and DLOFC

- Operation at lower power levels decreases temperatures during normal steady state conditions and DLOFC