Accident Analysis Simulation in Modular 300MWt Gas Cooled Fast Reactor

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Abstract. Safety analysis of 300MWt helium gas cooled long-life fast reactors has been performed. The analysis of unprotected loss of flow(ULOF) and unprotected rod run-out transient overpower (UTOP) are discussed. Some simulations for 300 MWt He gas cooled fast reactors has been performed and the results show that the reactor can anticipate complete pumping failure inherently by reducing power through reactivity feedback and remove the rest of heat through natural circulations. GCFR relatively has hard spectrum so it has relatively small Doppler coefficient. In the UTOP accident case the analysis has been performed against external reactivity up to 0.002dk/k. In addition the steam generator design has also consider excess power during severe UTOP case..

1. Introduction

In post Fukushima nuclear accidents inherent safety capability is necessary against some hypothetical accidents such as unprotected loss of flow (ULOF), unprotected rod run-out transient over power (UTOP), unprotected loss of heat sink (ULOHS). Gas cooled fast reactors is one of the important candidate of 4th generation nuclear power plant and in this paper the safety analysis related to unprotected loss of flow in small long life gas cooled fast reactors has been performed. Accident analysis of unprotected loss of flow include coupled neutronic and thermal hydraulic analysis. Natural circulation based heat removal system is important to ensure inherent safety capability during unprotected accidents.

Therfore the system similar to RVACS (reactor vessel auxiliary cooling system) is investigated. As the results some simulations for this 300 MWt gas cooled fast reactors has been performed and the results show that the reactor can anticipate complete pumping failure inherently by reducing power through reactivity feedback and remove the rest of heat through natural circulations.

2. Methodology[1,6-14]

The detail model and mathematical formulations for the current safety analysis can be obtained in the following references. Here the algorithm of the simulation will be discussed. After calculating effective macroscopic group constant then steady state multi-group diffusion calculation and steady state thermal hydraulic calculation are performed. The accident simulation begins with the accident initiator such as withdrawal of all control rods in case of UTOP accident and total loss of pumping power in the primary system for the case of ULOF accident. Then the calculation of total coolant flow-rate and flow distribution across the reactor core are performed which followed by the calculation of coolant and fuel temperature distribution, the calculation of energy and mass balance in the steam

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generator. Next, we solve the kinetic equation after calculating current feedback reactivities (Doppler, coolant density, core radial expansion and fuels axial expansion reactivity feedbacks) which then used in the calculation of amplitude and shape functions. The calculation is repeated by going back to the calculation of total coolant flow-rate and flow distribution across the core until reach the end of the simulation time.

3. Results and discussions

Table 1 shows main paramters for sample parameters for the current simulations. The reactor power is 800 MWt and this is a medium sized Modified CANDLE burn-up system.

Table 1 Main paramters used in this simulations

Parameter	Value
Power (MWth)	300
Core Geometry	2-D Cylinder
Refueling Periode(years)	10 years x10 batch
Fuel/cladding/coolant type	UN and PuN/SS316/Pb-208
Active core radius/height	117 cm/237.5cm
Reflector width (Pb-208)	70 cm
Fuel/structure/coolant volume fractions	60/12.5/27.5

The simulation results for Unprotected Loss of Flow (ULOF) accident case are shown in figures 1-4. Figure 1 shows coolant flow-rate in the core during unprotected loss of flow accident. Figure 2 shows power change with time during this accident. Fig. 3 shows The coolant decrease triggers imbalance between produced heat and coolant flow-rate causing temperature increase in coolant and fuel. Figure 3 shows coolant, cladding and fuel temperature change with time during the accident and finally Figure 4 shows reactivity feedback change with time during the accident. Temperature increase in coolant and fuel produces negative reactivity feedback which drive reactor power to decrease. After 100 seconds the coolant flow rate and the reactor power are approaching asymptotic levels and the total reactivity approaching zero. The maximum temperature in fuel and coolant are still far below safety limit.

The flow-rate decrease basically influenced by natural circulation level of the thermal hydraulic system of the NPP. About 100s after the accident begins, the core flow-rate has approached natural circulation levels and around 100 seconds the flow-rate change become relatively slow. In case of the reactor core power level, it also decreases following the decrease of the core flow-rate. However the asymptotic level is still at higher percentage compared to that of flow-rate.

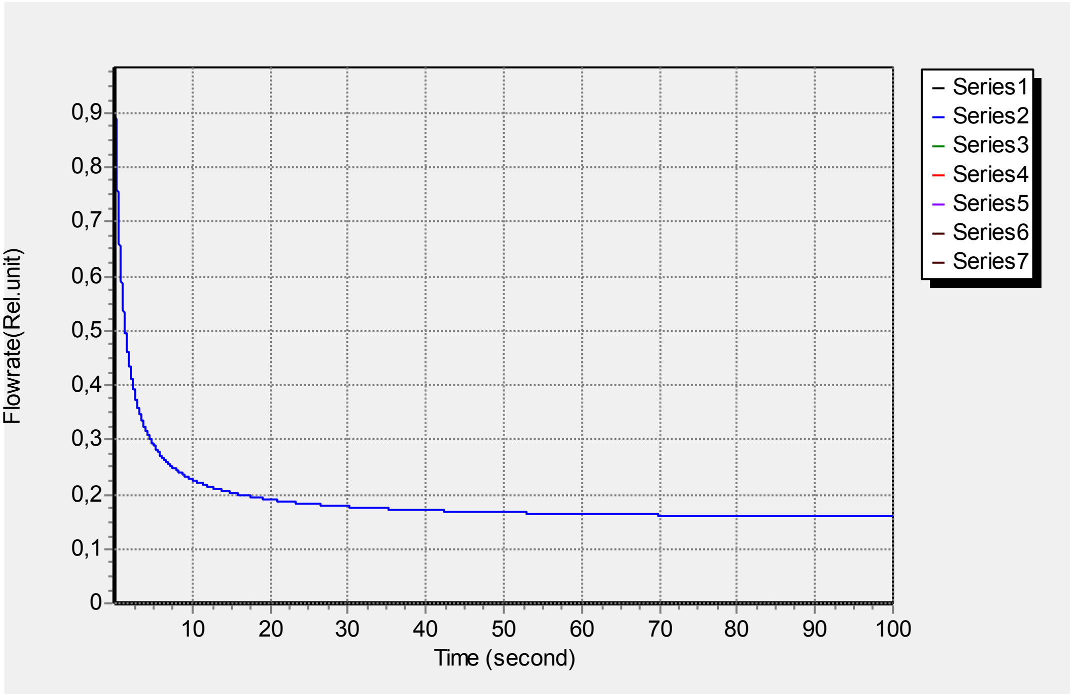


Figure 1 Coolant flow-rate change with time during loss of flow accident

After the decrease of the coolant flowrate, the fuel, cladding and cooolant temperatures initially increase and after reaching the peak then decrease and move toward new equilibrium level. The fuel temperature experience more significant reduction compared to the coolant and cladding temperature. This situation can be explained due to relatively large coolant-center fuel temperature different in the fuel pin. Due to the change of the fuel to coolant temperature difference during the accident the position of maximum fuel, cladding and temperatures are basically changing with the time and may not in the same positions for each coolant maximum temperature, cladding maximum temeprature, and fuel maximum temperature.

The reactivity feedbacks move in more complex situations. The Doppler and fuel axial expansion at the beginning give strong negative feedback, however, after reaching maximum temperature then their absolute values decerase and finally move toward positive direction. On the other hand, the core radial expansion and the coolant density reactivity feedback are definitely negative. However their values also decrease after reaching their maximum peak(absolute).

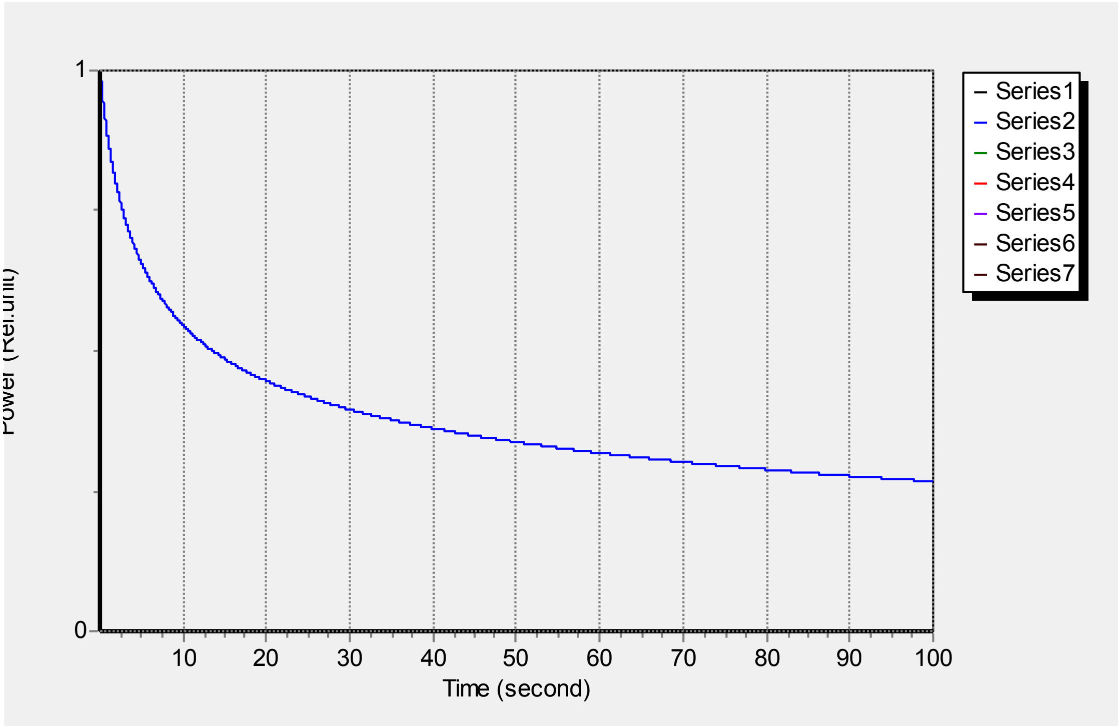


Figure 2 Power change with time during loss of flow accident

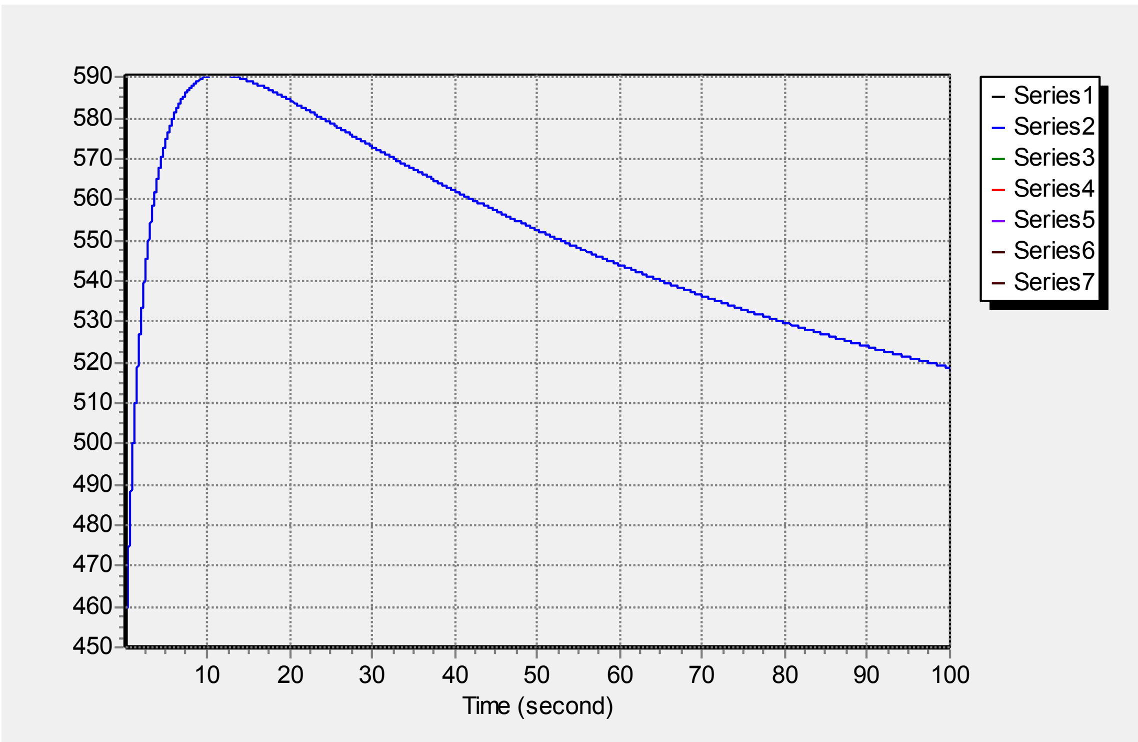
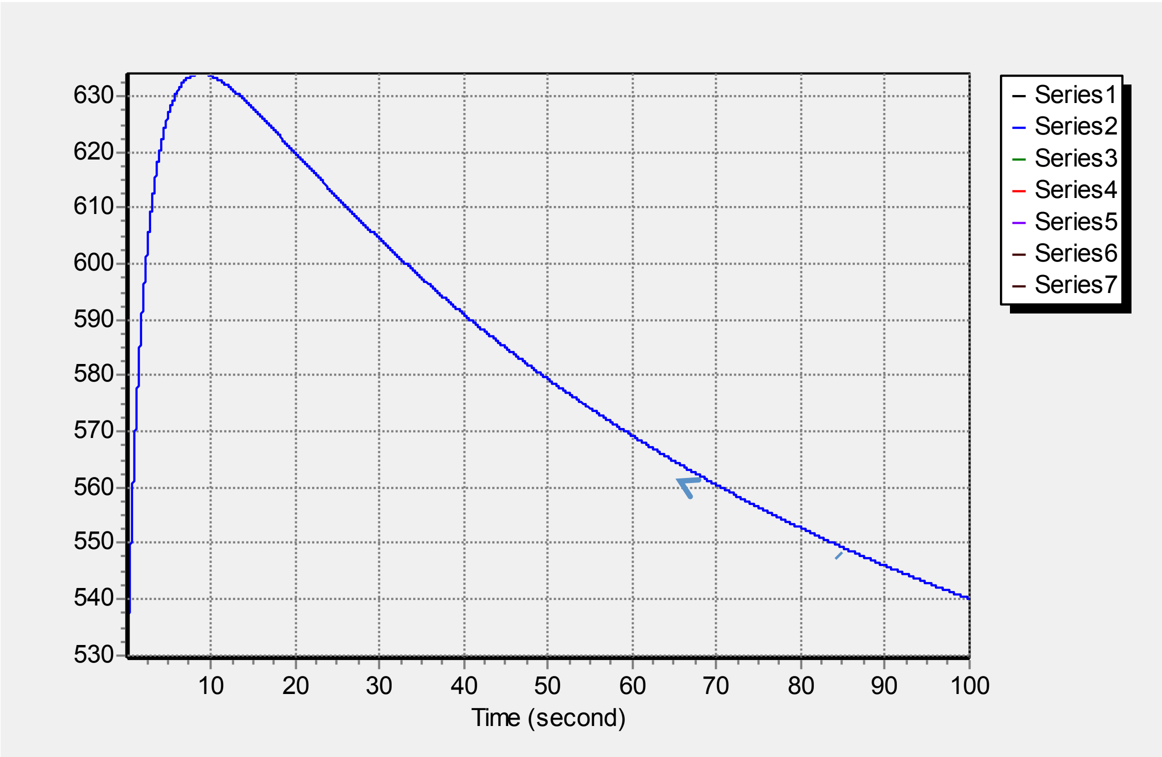


Figure 3 Hot spot temperatures change with time during loss of flow accident



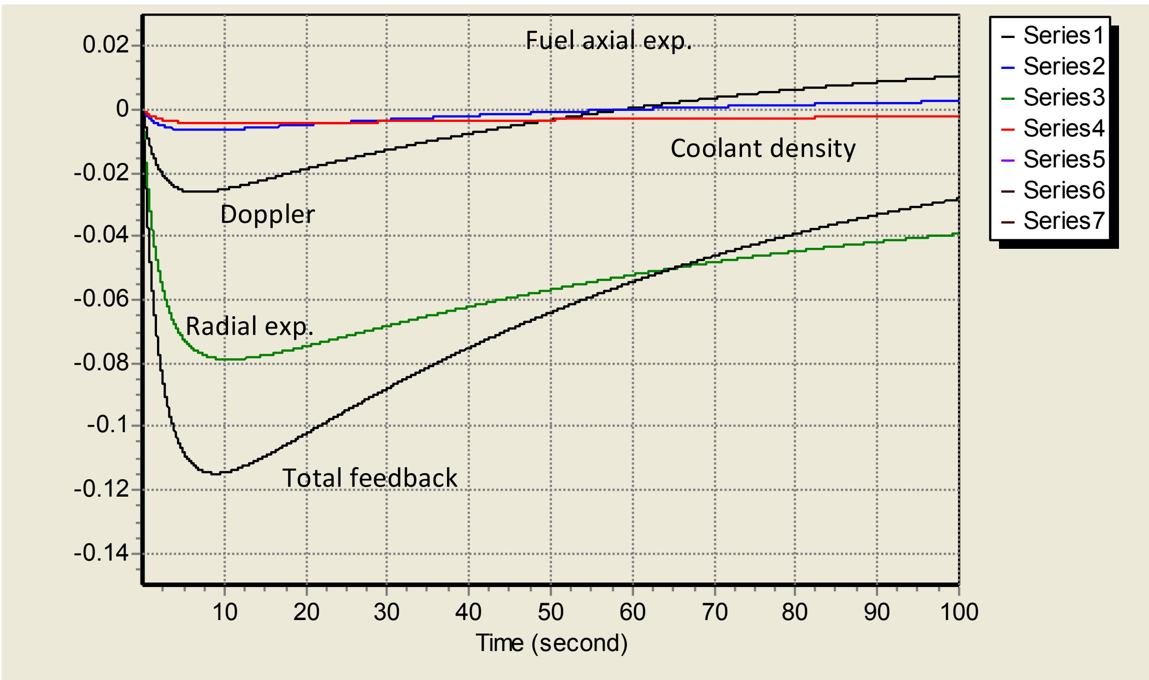


Figure 4 Reactivity feedback change with time during loss of flow accident

The accident analysis simulation results for Unprotected rod run-out Transient Over Power (UTOP) accident are shown in figures 5-8. As the accident intitator, the positive external reactivity triggers power increase which then causes temperature increase in coolant, cladding and fuel. Temperature increase in coolant, cladding and fuel produces negative reactivity feedback which is used to gradually compensate external positive reactivity. After 100 seconds the power level approaching asymptotic levels and the total reactivity approaching zero. Doppler and Core radial expansion feedback play dominant role in UTOP accident. The temperature increase in fuel and coolant is still far below safety limit.

There are overshoot pattern of power following fast withdrawal of the control rod. Therefore this pattern influence the pattern of hotspot fuel, cladding and coolant temperature change with time and also the feedback. The most important difference between ULOF and UTOP cases are the fact that in the UTOP accident the fuel, cladding and coolant temperatures are continuously increase till approaching the asymptotic new power levels while in the ULOF case there are peak values of fuel coolant and cladding temperature as shown in Figures. 3 and 7. In the UTOP case the power is also increases till reaching asymptotic level while in the ULOF case decreases and then approaching asymptotic new power level as shown in Figs.3 and 6. In case of the UTOP accident the position change of maximum temperature for coolant, cladding and coolant are not significant.

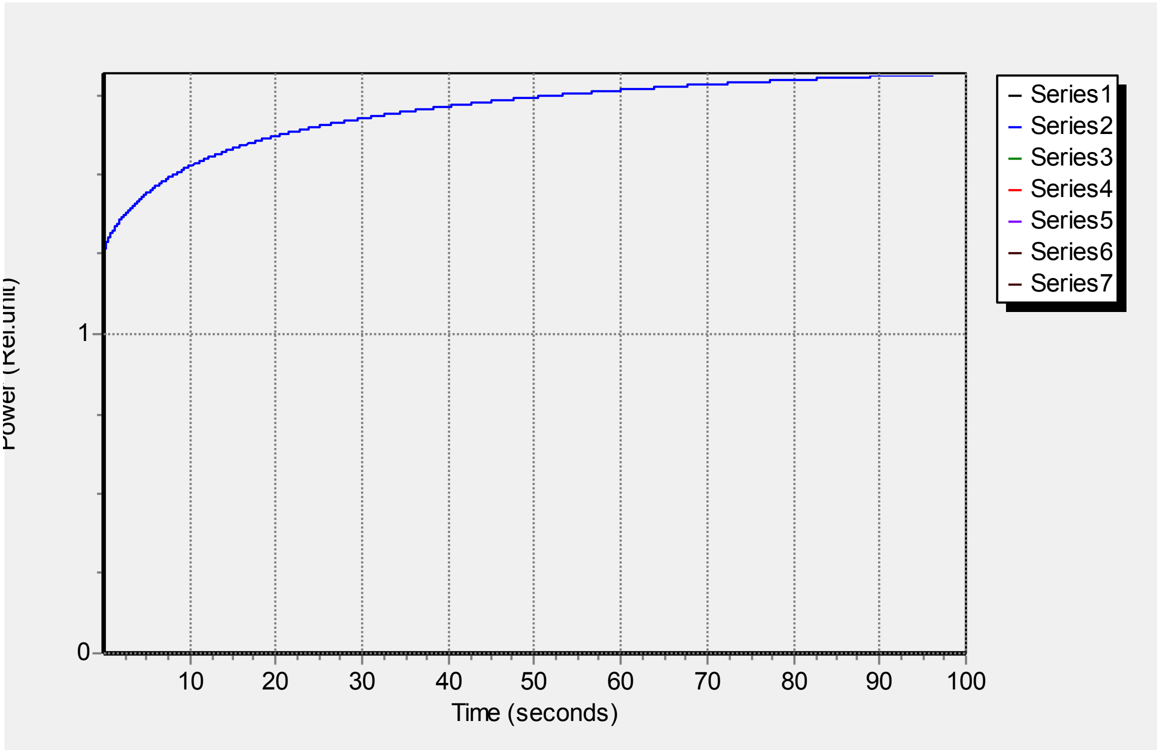


Figure 5 Power change with time during UTOP accident

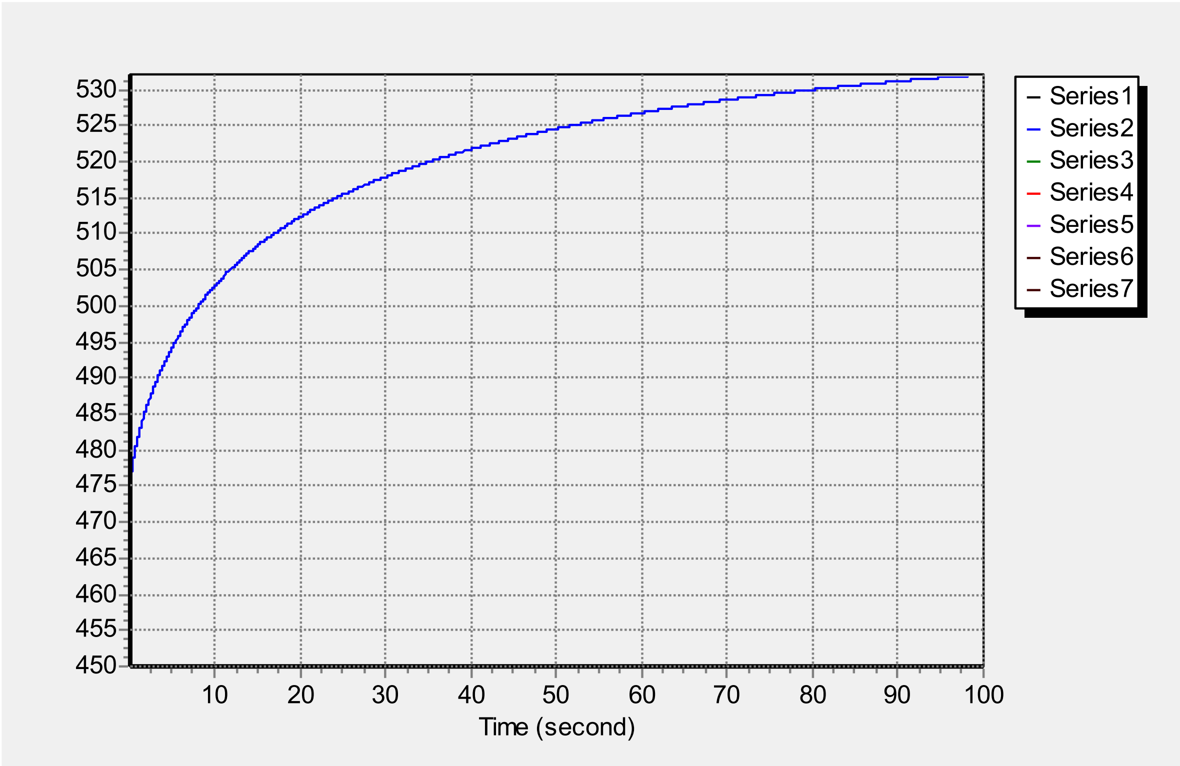


Figure 6 External and total reactivity feedback change with time during UTOP accident

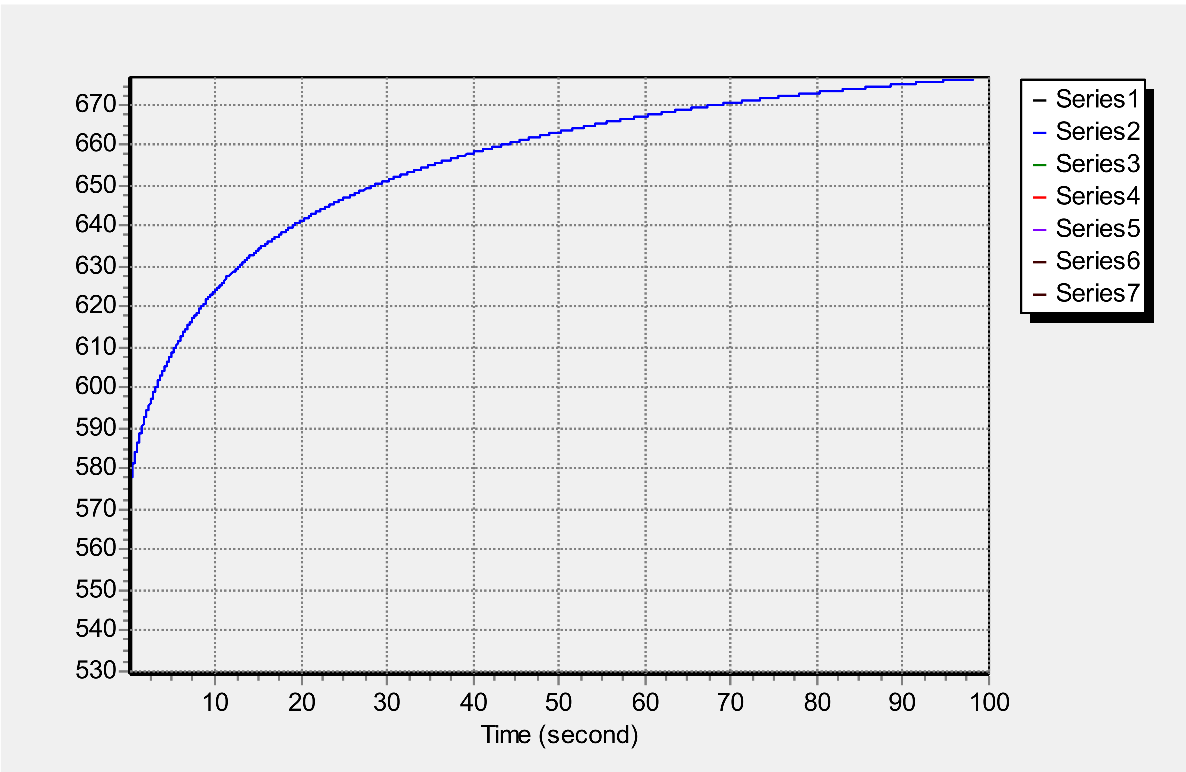


Figure 7 Hot spot temperatures chhange with time during UTOP accident

Figure 8 shows teh change of external and feedback reactivities during UTOP accident simulations. As shown in this figure, the new equilibrium conditions can be reached after total feedback reactivity can completely compensate external reactivity. From figure 8 it is shown that after 100 seconds from the accident begin the asymptotic level have been approached.

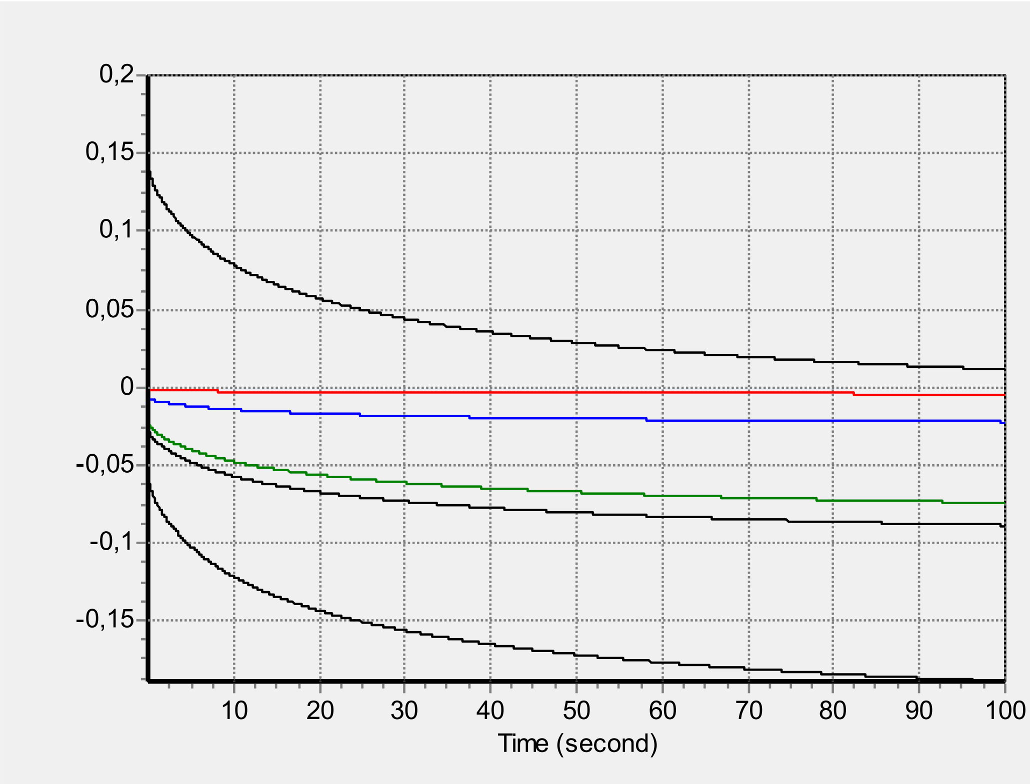


Figure 8 Reactivity change with time during UTOP accident

4. Conclusion

Safety analysis simulations have been performed for helium cooled 300MWt gas cooled fast reactors especially against unprotected loss of flow (ULOF) and unprotected rod-run out transient overpower (UTOP). Helium Cooled Small Modified CANDLE Reactors can survive ULOF and UTOP inherently. Natural circulation plays important role in the ULOF accident. Core radial expansion and Doppler reactivity feedback plays important role in the ULOF and UTOP accident.

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