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Safety Analyses of IRT - Sofia LEU Core: Sensitivity Analyses of Loss of Flow Accident

S.I. Belousov
Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Science
Tsarigradsko 72, 1784 Sofia - Bulgaria

ABSTRACT

Sensitivity analyses (by the PARET/ANL code) of the loss of forced flow accident because of pump stop as a result of loss of the offsite electricity supply for the IRT - Sofia are presented in this paper. These analyses are carried out because the used hydro dynamic calculation evaluation for a period of the downward coolant flow coast down has very wide tolerance (from 2 to 25 sec) and gives right to doubt in its accuracy calculation. The transient results sensitivity to duration of reactor operation before the accident was also analyzed. According to the obtained results the relation between evaluated and allowed conditions of the fuel operation does not vary significantly in the analyzed limits. Moreover for all analyzed conditions the peak cladding temperature reached in this transient is below the temperature for onset of nucleate boiling (117°C) and far below the safety limit of 425°C for the fuel cladding temperature that is fully consistent with the conclusion from the IRT - Sofia SAR for this accident.

1. Introduction

The HEU to LEU conversion of the new IRT - Sofia research reactor of the Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Science, Sofia, Bulgaria was jointly studied with the RERTR Program at Argonne National Laboratory (ANL) during 2003 - 2010. The main purpose of the collaboration consisted in accomplishment of safety analyses and preparation of documents used for regulatory approval tasks solution was finalized at the end of 2010. The new revision of the IRT - Sofia Safety Analyses Report (SAR) was submitted to Bulgarian Nuclear Regulatory Agency (NRA) in December 2010. There were no comments or remarks connected with Neutronics, Thermal Hydraulics and Accident analyses from the NRA. The only remark was connected with the annual limit of 0.1 mSv dose value required by the NRA for normal reactor operation (instead of used in the SAR 1 mSv). However the annual population doses (evaluated in the SAR) are still far below this limit too.

Sensitivity analyses (by the PARET/ANL (v 7.3) code [1]) of the loss of forced flow (LOF) accident because of pump stop as a result of loss of the offsite electricity supply for the IRT - Sofia [2] are presented in this paper. These analyses are carried out because the used hydro dynamic calculation evaluation for a period of the downward coolant flow coast down has very wide tolerance (from 2 to 25 sec [3 – 5]). It is difficult to make experimental validation of the hydro dynamic calculation because of significant modification of the previous core design (IRT – 2000 [6]) and lack of available appropriate measurement data. The transient results sensitivity to duration of previous operation time of reactor is also analyzed.

2. Sensitivity calculation

The sensitivity calculations were carried out on the base of the calculation model elaborated and calculated previously [2, 7] in joint study with the RERTR Program at Argonne National Laboratory (ANL) for this accident description. According to this model the reactor is operating at 1000 kW with one pump in the primary coolant circuit. When electric power is lost the reactor control system is activated with delay less than 200 ms and the control rods drop to the core after 800 ms. In this previous calculation the forced downward coolant flow coasts down was over a period of 6 sec according to calculated data from [3]. This transient calculation results showed that the maximum temperature on the clad surface during this transient was 86°C; reached at about 0.5 sec after the transient initiation. This temperature is below the temperature for onset of nucleate boiling (117°C) and well below the clad softening temperature limit of 425°C. The repeated temperature increasing at about 8 sec after the coolant flow reverses to the natural convection mode because of decay heat does not reach this maximum level.

The PARET code input was modified for the sensitivity calculation by varying of the coolant forced flow coast down period t_0, (from 2 to 25 sec). A linear flow coast down time dependence (Table 17 [1]) and previous operation time of reactor value of 30 days (OPT variable from the 1113 input card) are used in the calculation. The PARET results for the coast down period of 6 sec are compared with previously obtained [7] for calculated (non-linear) coolant flow coast down time dependence [3] during the same period.

The transient results sensitivity to the duration of the reactor operation before the accident is analyzed by varying of the OPT value in the range 0.01 - 100 days for calculated (non-linear) downward coolant coast down period t_0 = 6 sec.

3. Calculation results

The PARET calculation results show that for all analyzed coolant flow slowing down periods the maximum clad surface temperature transient time dependence has two maximums (Figure 1).

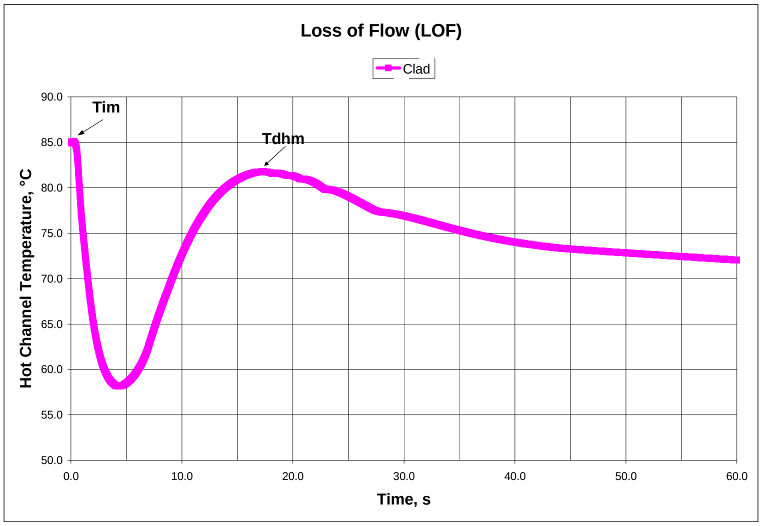

Fig 1. Maximum clad surface temperature for the LOF accident (t_0 = 6 sec, linear, OPT = 30 days)

The first short temperature peak - T_{im}, is reached soon (0.2 - 0.5 sec) after transient initiation because the reactor' control system activation delay of 0.2 sec and the coolant downward flow slowing down. The repeated temperature broad peak - T_{dhm}, because of decay heat is reached at 8 - 13 sec after the coolant flow reverses to the natural convection mode. The T_{im} and T_{dhm} values are decreasing when t_0 value is increasing as it could be expected because of the better clad cooling. The corresponding PARET results are illustrated in Figure 2.

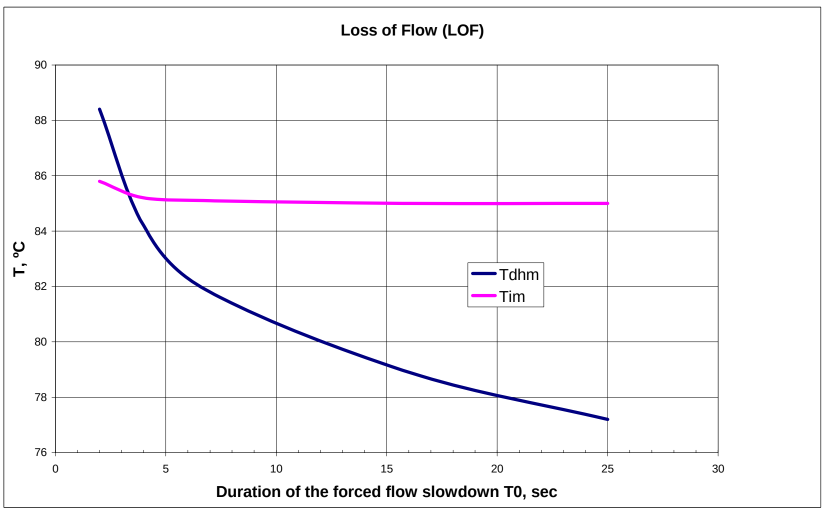

Fig 2. Clad surface temperatures T_{im} and T_{mdh} dependences on t_0 (OPT = 30 days)

The T_{im} is higher than the T_{dhm} and the peaks' values difference increases along with t_0 (up to 8°C at t_0 = 25 sec) for t_0 greater than 3 sec. The T_{dhm} becomes higher than the T_{im} (Figure 3) by a few degrees (°C) just for a rather short coolant slowing down period (t_0 less than 3 sec).

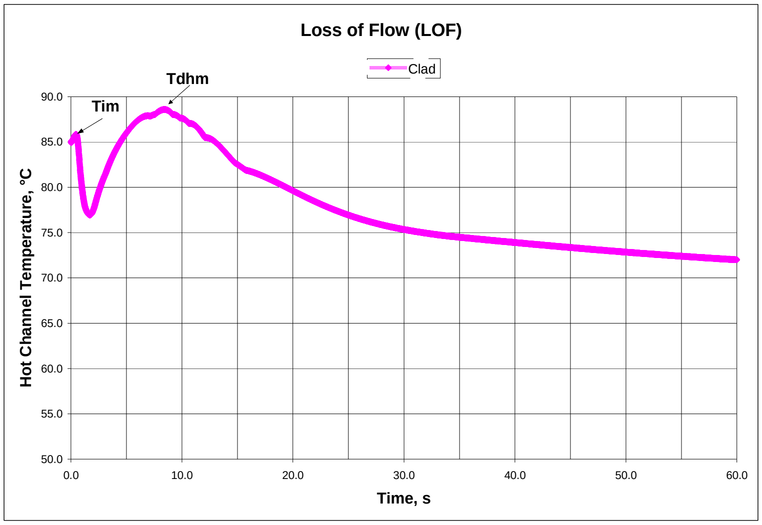

Fig 3. Maximum clad surface temperature for the LOF accident (t_0 = 2 sec, OPT = 30 days)

The difference in the clad temperature for linear and calculated (non-linear) [3] downward flow coast down time dependences is illustrated in Figure 4.

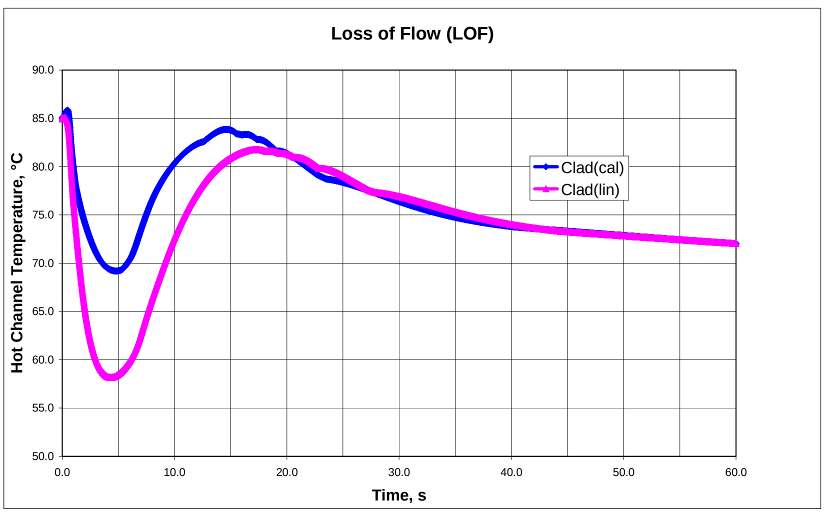

Fig 4. Clad surface temperature for linear and calculated (non-linear) downward flow slowdown (t_0 = 6 sec, OPT = 30 days)

The clad surface temperature relation for linear (lin) and calculated (cal) [3] downward flow coast down is consistent with the clad surface cooling provided in both cases - a better cooling gives a lower clad surface temperature. That is demonstrated in the Figure 5 (the downward flow rate is signed as negative) by the coolant flow rate calculated by the PARET code for both cases.

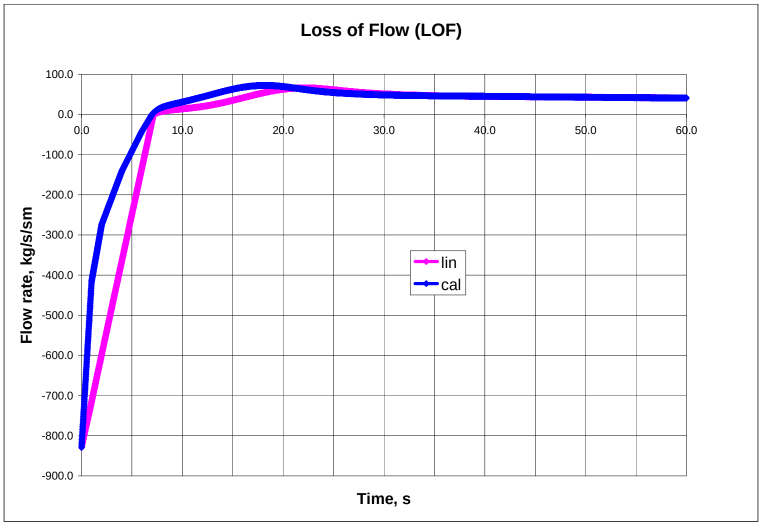

Fig 5. Coolant flow rate for linear and calculated (non-linear) downward flow slowdown (t_0 = 6 sec, OPT = 30 days)

The clad surface temperature depends on the duration of the previous reactor operation before the accident (OPT) because the decay heat is the OPT dependent. Consequently only the second maximum clad temperature peak T_{dhm} depends on the previous operation time of reactor. The T_{dhm} dependence on the previous operation time of reactor (OPT) for the calculated downward flow coast down dependence (non-linear, t_0 = 6 sec [3]) is depicted in the Figure 6.

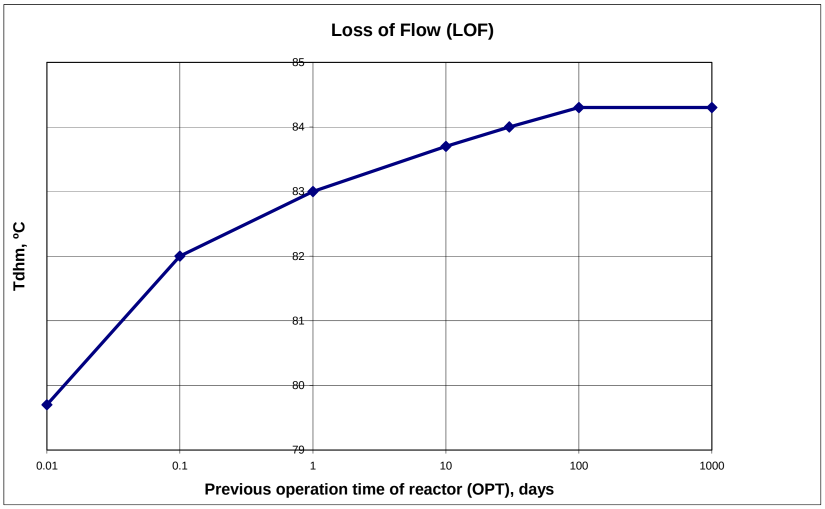

Fig 6. T_{dhm} dependence on OPT (t_0 = 6 sec, non-linear)

The similar T_{dhm} dependence on OPT will take place for other values of t_0 and linear/non-linear downward flow coast down dependence. The T_{dhm} value decreases just with about one degree (ºC) when OPT value decreases from 1000 to 1 days. The time dependence becomes more significant in the frames of one day operation but again the difference is just a few degrees (ºC) when OPT value decreases from 1 day to 0.01 day (14 minutes).

4. Conclusion

The sensitivity analysis of the LOF accident is performed. The maximum clad surface temperature dependence on the downward coolant flow coast down period t_0, the coast down time dependence shape and the previous operation time of reactor value (OPT) is obtained. The obtained results show that in the analyzed limits: of the t_0, coolant flow coast down time dependence shape (linear/non-linear), and the OPT value, the relation between evaluated and allowed conditions of the fuel operation during the LOF accident does not vary significantly. Moreover for all analyzed conditions the highest cladding temperature reached in this transient is below the temperature for onset of nucleate boiling (117°C) and far below the safety limit of 425°C for the fuel cladding temperature [7]. It is fully consistent with the conclusion presented in the revised SAR version [6] submitted to the NRA (December 2010). In other words the SAR conclusion about the IRT – Sofia Safety System capability to work properly providing safe operation during the analyzed accident remains valid independently on the uncertainty of the hydro dynamics downward flow coast dawn data used for evaluations [3 – 5].

The obtained results for the maximum clad temperature OPT' dependence should be also useful for reactor safety substantiation in the case of possible the IRT – Sofia duty schedule modification.

4. Acknowledgement

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5. References

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