EFFECT OF CONTROL SYSTEMS ON SPACE REACTOR TRANSIENTS

Juan J. Carbajo and Louis Qualls
Nuclear Science and Technology Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6167
carbajojj@ornl.gov, quallsal@ornl.gov

Several transients have been simulated in a space reactor with a power of 180 kW(thermal), 48 kW (electrical), employing eight Stirling Engines (SEs). The purpose of this paper is to investigate the effects of control systems in the outcome of one of the transients.

This space reactor consists of a primary loop and two secondary loops with each secondary loop connected to the primary loop by an intermediate heat exchanger (IHX). Each secondary loop has four SEs. The system coolant in both the primary and the secondary loops is NaK, a eutectic mixture of sodium (22%) and potassium (78%), which has a melting point of 262 K. Coolant mass flow rates are 4.2 kg/s in the primary and 3.2 kg/s in each secondary loop. The system operates at a pressure of 0.3 MPa and at temperatures between 840 and 900 K. This system has been described in detail and results have given in Ref. 1.

The three-dimensional transient analysis computer code RELAP5-3D/ATHENA [Ref. 2] was employed to model and analyze this system. A variety of transients have been simulated, including SE single and multiple failures and trips of primary and/or secondary loop pumps followed by scram of the reactor under different gravity values (Moon or Earth).

The transient analyzed here consists of the simultaneous failure of two SEs in one of the two secondary loops. The failed SEs do not remove power from the system. Thus, the system will have a total of six operating SEs, four in the intact loop and two in the failed loop. In the model, the reactor continues operating at full power (180 kW) which must be removed by the remaining six SEs in operation. Figure 1 shows the calculated power history in the primary and in the secondary loops. The transient is initiated at 200 s, there is a sudden reduction in power that is shortly recovered. The intact secondary loop increases its power from 90 to 114 kW; the failed loop reduces its power from 90 to 66 kW. Every operating SE has to remove now more power than its design value (22.5 kW), thus the SEs are overloaded, up to 33 kW per SE in the secondary loop with the failed SEs and up to 28.5 kW per SE in the intact loop. Table 1 shows powers and loop coolant temperatures before (nominal) and after the transient. There are also significant increases in coolant temperatures, the primary loop increases to 932 K from 903 K, and the secondary loop increases to 913 K from 876 K. There are also increases in the IHX ΔT (Tinlet - Toutlet), up to 65 K from 52 K in the primary and up to 47 K from 34 K in the secondary of the intact loop IHX, the one that takes more power and requires larger ΔTs to remove more heat.

By implementing control systems that reduce the reactor power down to 140 kW (keeping the same coolant flows) after the SE failures, the transient is now significantly milder as shown in Table 1. The power of each operational SE is now 23 or 24 kW (very close to the design value of 22.5 kW), loop temperature and IHX ΔT increases in both the primary and the secondary sides are small, and the transient is much more tolerable with values close to the nominal values. Implementation of more sophisticated controls, including coolant mass flow rate changes in the primary and secondary loops and reactor point kinetics are in progress.

In conclusion, implementation of control systems that reduce the reactor power after two SEs have failed have a significant and beneficial effect on this transient by reducing SE overload and system temperature increases.

References

1.- Juan J. Carbajo and Louis Qualls, "Modeling and Analysis of A Lunar Space Reactor with the Computer Code RELAP5-3D/ATHENA," Paper 8294, *Proceedings of the 208 International Congress on Advances in Nuclear Power Plants (ICAPP '08)*, Anaheim, California, June 8-12, 2008.

2.-INEEL, *RELAP5-3D Code Manual*, INEEL-EXT-98-00834, Rev. 2.4, Idaho National Laboratory (2006).

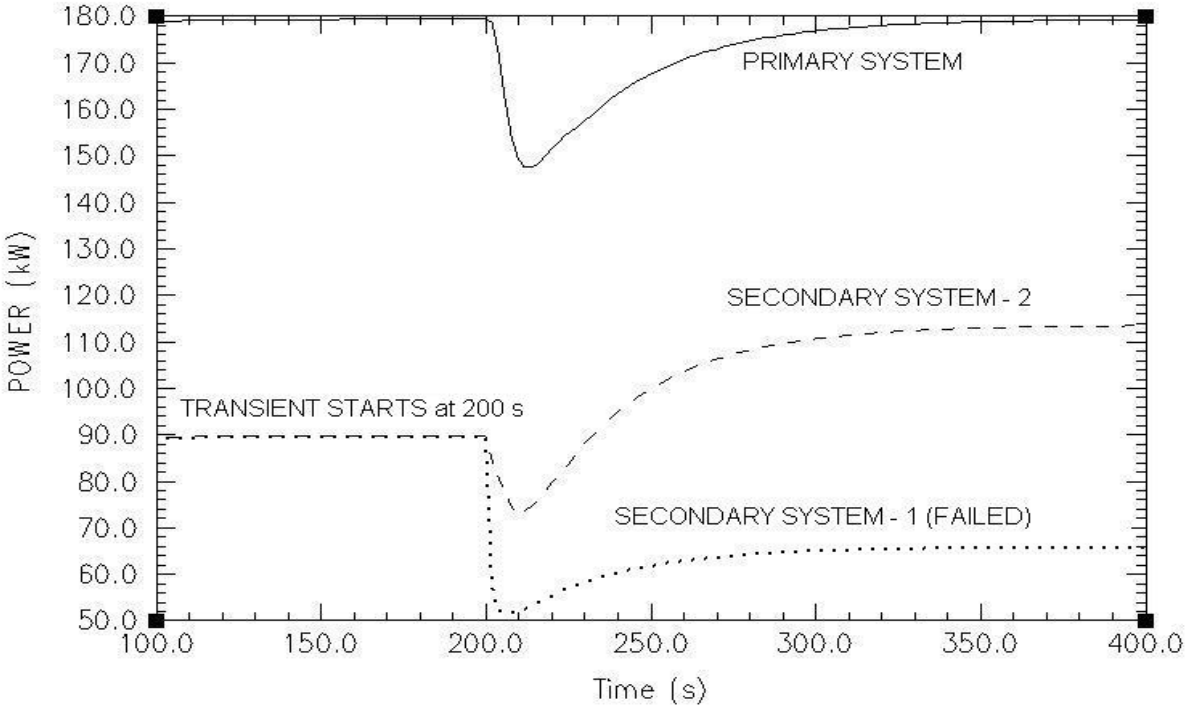

Fig. 1. Calculated powers in the primary and secondary loops without controls

Table 1
Calculated Power and Temperatures before and after the transient

OPERATION MODE	NOMINAL (8 SEs)				6 SEs NO CONTROLS				6 SEs + CONTROLS			
SYSTEM	**POWER** (kW)	**Thot** (K)	**Tcold** (K)	**ΔT** (K)	**POWER** (kW)	**Thot** (K)	**Tcold** (K)	**ΔT** (K)	**POWER** (kW)	**Thot** (K)	**Tcold** (K)	**ΔT** (K)
PRIMARY	180	903 903	851 851	52 52	180	**932** **932**	893 867	39 **65**	**140 ↓**	910 910	882 857	28 53
SECONDARY 1 (FAILED) Stirling Engines	90 4 x 22.5	876	842	34	66 **2 x 33**	**913**	888	25	48 **2 x 24**	895	877	18
SECONDARY 2 (INTACT) Stirling Engines	90 4 x 22.5	876	842	34	114 **4 x 28.5**	900	857	**47**	92 **4 x 23**	885	850	35