SIMULATION OF A CONTROL ROD EJECTION IN A VVER-1000 REACTOR WITH THE PROGRAM RELAP5-3D*

Juan J. Carbajo, Jess C. Gehin, Graydon L. Yoder
Oak Ridge National Laboratory**
Oak Ridge, Tennessee, 37831

and

Victor Ivanov
Kurchatov Institute
Moscow, Russia

SUMMARY

This summary presents a simulation with the RELAP5-3D code[1] of a control rod ejection at the Balakovo-4 plant, a VVER-1000 V320 plant located in Russia. Results from point and three-dimensional (3-D) kinetics models are presented and compared. The detailed RELAP5 model was initially prepared by the Kurchatov Institute of Moscow, Russia, and modified at Oak Ridge National Laboratory. The VVER-1000 core model contains one Lead Test Assembly (LTA) with mixed oxide (MOX) fuel with the remaining of the core being UO_2 fuel. The purpose of this work is to support licensing of this plant to burn MOX fuel.

The RELAP5-3D[1] code is a 3-D version of the RELAP5 mod 3.2 code[2]. RELAP5-3D can model in three dimensions thermal-hydraulic control volumes and core neutronics. The control volumes can be modeled in Cartesian or cylindrical geometry. The multi-dimensional neutron kinetics model is based on the NESTLE code[2]. Cartesian (rectangular) or hexagonal geometry can be employed in the neutronics model. For the VVER-1000 core, hexagonal geometry was utilized.

---

* Sponsored by the U.S. Department of Energy, Fissile Materials Disposition Office.
** Managed by UT-Batelle, LLC for the U.S. Department of Energy under contract DE-AC05-00OR22725

The detailed RELAP5 model comprises 718 hydrodynamic control volumes, 808 junctions, 623 heat structures, 95 control functions, and 254 trips. Both the primary and the secondary systems of the plant are modeled. The core 163 assemblies are modeled thermal-hydraulically employing 9 different control volumes and 11 heat structures, each one divided into 10 different horizontal levels. These control volumes and structures model the average core (with one control volume and three structures), the UO_2 hot assembly, the MOX assembly, and the hottest rods for UO_2 or MOX fuel. The reactor point-kinetics model employs only one node for the core. The 3-D kinetics model employs hexagonal geometry with 12 horizontal levels and 8 rings, totaling 2170 nodes, of which 1630 nodes model the 163 assemblies (with 7 rings and 10 different horizontal levels). The remaining nodes model the core reflector at the top (one horizontal level), bottom (one horizontal level), and sides (one ring). Cross sections and feedback coefficients for the different assemblies of the code were calculated with the code HELIOS[4] and input into RELAP5-3D. The different burnups of the assemblies are modeled with different cross sections and with different thermal properties.

Before the control rod ejection accident was initiated, the reactor was assumed to be operating at 3120 MWt, or 104% of full power (3,000 MWt). It was assumed that the control rod drive cover fails, thus ejecting the control rod. Consequently, a small primary coolant break (with an opening 82 mm in diameter) also occurs when the control rod is ejected.

Graphical results are presented in Figs. 1 and 2. Point kinetics results obtained with the codes RELAP5-3D[1] and the US Nuclear Regulatory Commission version of RELAP5 (RELAP5 mod 3.2[2]) were totally identical. After steady state conditions are obtained, the accident is initiated at 2 s by rapidly ejecting a control rod. The control rod ejection is modeled in the point kinetics calculation by inserting a positive reactivity of \$0.40. The reactor power increases, and a scram signal is activated when the power reaches 107% of the initial power. The shutdown control rods are inserted into the reactor with a time delay of 0.3 s after the reactor scram signal is activated. The control rods take 4 s to be fully inserted.

Before the control rods shutdown the reactor, the power has increased to 162% of the initial value. The shutdown control rods inject a negative reactivity of ~$12. Fig. 1 shows the calculated relative power as a function of time.

The 3-D kinetics calculation modeled the ejection of one of the control rods located near the center of the core, a location with a very effective control rod. Control rod ejections at different locations of the core can be modeled with the 3-D model, a feature not available with the point kinetics model. The peak power calculated by the 3-D model was about 150% of the initial power, lower than the peak power calculated by the point kinetics model. The shutdown control rods appear to be more effective in the 3-D model, as they reduced the reactor power more rapidly.

Fig. 2 shows calculated cladding temperatures for the hottest rods of the hot assembly. Critical heat fluxes were calculated to occur by both models at some elevations, with sharp temperature increases. Results from both models agree reasonably well. The peak temperatures are calculated to occur 2 s earlier in the 3-D kinetics model. Fuel melting or cladding failures were not predicted to occur by either model.

In conclusion, results of a control rod ejection at the Balakovo-4 plant modeled with the point and 3-D kinetics models of RELAP5-3D have been presented and compared. Both calculations agree reasonably well. The 3-D model is capable of performing localized kinetics calculations.

REFERENCES

1. RELAP5-3D Code Development Team, "RELAP5-3D Code Manual," Idaho National Engineering and Environmental Laboratory, INEEL-EXT-98-00834 (5 volumes), February 1999.

2. C. Allison et al, "RELAP5/MOD3 Code Manual," Idaho National Engineering and Environmental Laboratory, NUREG/CR-5535, 1995.

3. Al-Chalabi, R. M., et al, "NESTLE, A Nodal Kinetics Code," Transactions of the American Nuclear Society, 68, 1993.

4. J. J. Casal, et al, “HELIOS: Geometric Capabilities of a New Fuel-Assembly Program,” Proc. International Topical Meeting on Advances in Mathematics, Computations, and Reactor Physics, Pittsburgh, Pa, 1991.

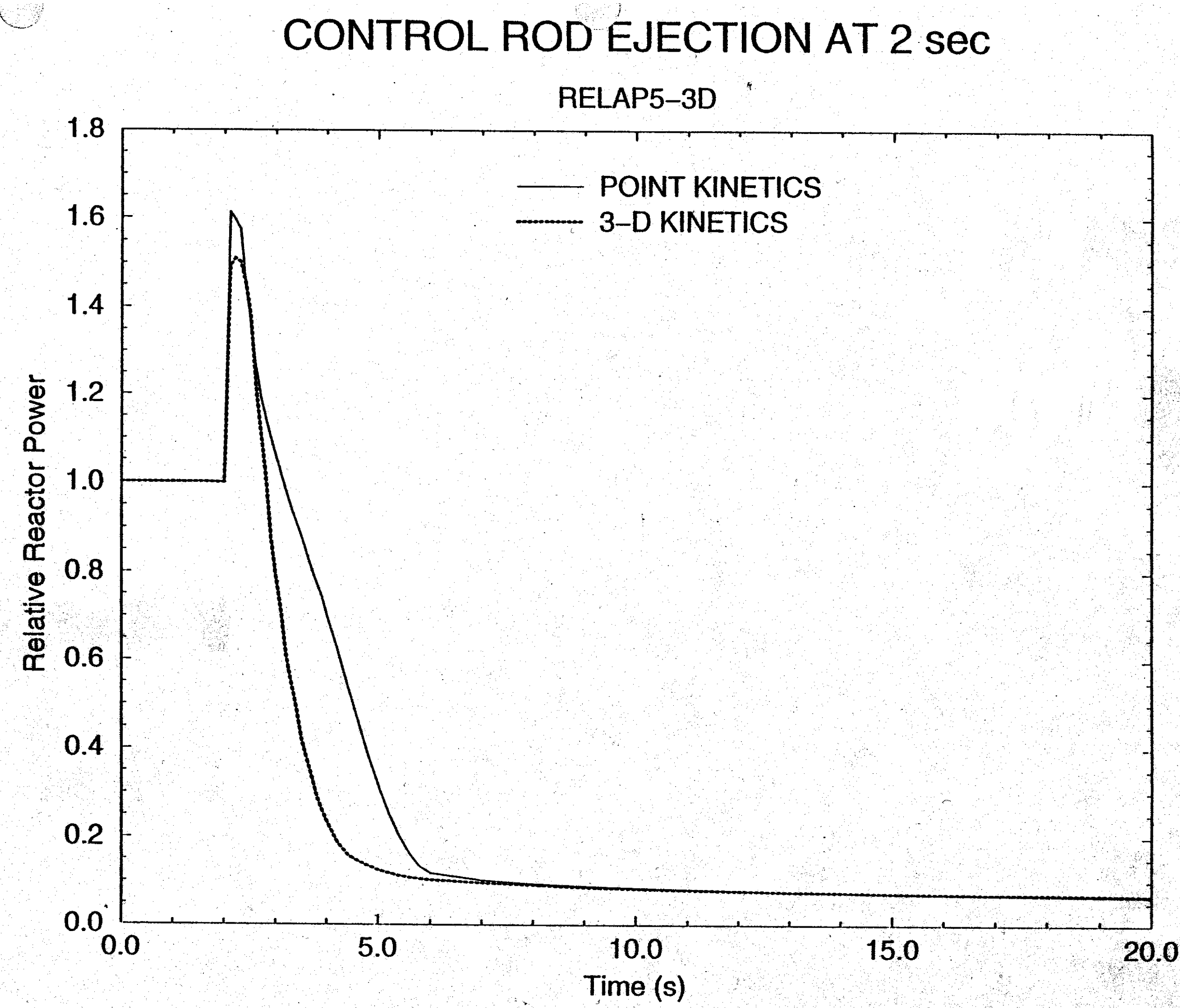

Fig. 1 Relative reactor power versus time for the control rod ejection accident

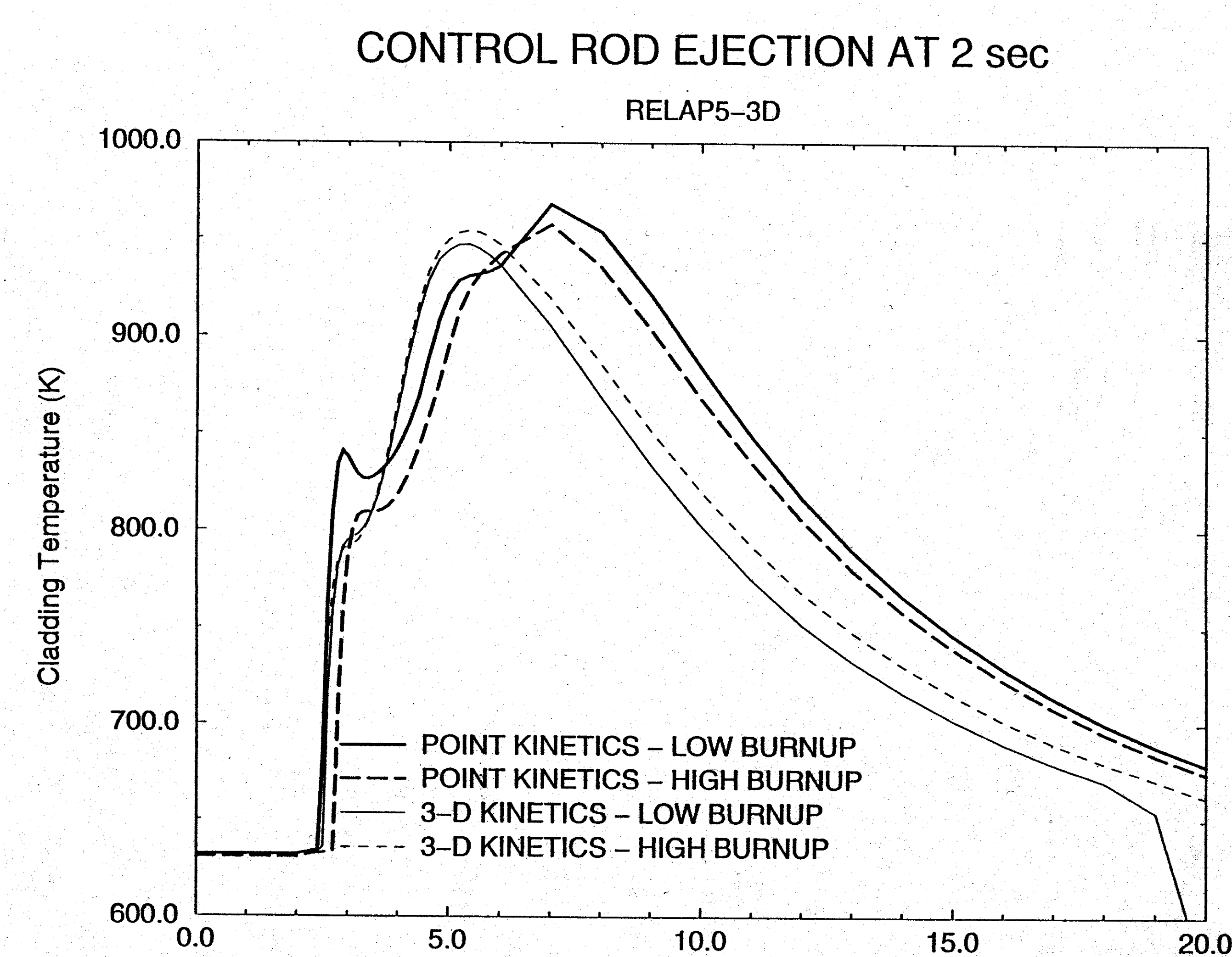

Fig. 2 Calculated cladding temperature for the hottest fuel rods