CFX for Complex Nuclear Safety Analysis

A pioneering study uses CFX to evaluate reactor cooling

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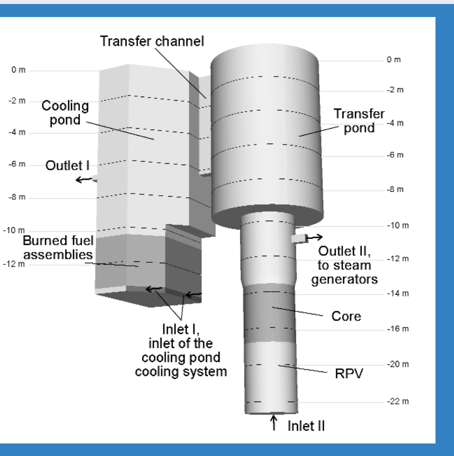
Three-dimensional CFD codes are expected to play an essential role in the safety analysis of nuclear reactors, similar to the role of one-dimensional system codes currently used. In the Institute of Nuclear Techniques of the Budapest University of Technology and Economics, our CFX team has examined many of the components of the VVER-440 type nuclear reactors, including the fuel assembly, the fuel assembly head, and the reactor pressure vessel itself.

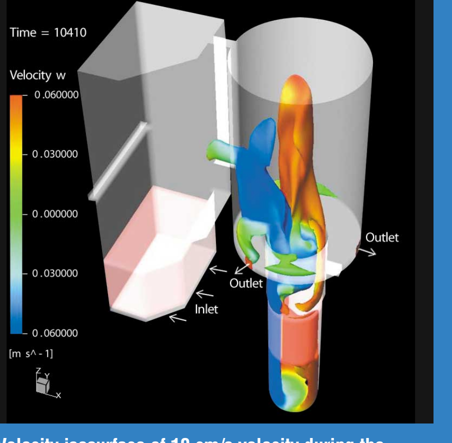
A pioneering CFD study recently addressed a comprehensive safety analysis of a complete nuclear system. In this study, CFX was used to examine the natural circulation processes between the reactor pressure vessel (RPV) and the cooling pond of VVER-440 type reactors under the special circumstances that arise during maintenance. During annual maintenance, the RPV and the cooling pond form a connected flow domain, and some of the fuel assemblies are transported underwater from the reactor to the cooling pond. Because of radioactive decay, a significant amount of heat is generated by the fuel assemblies located in the reactor and the cooling pond. The reactor is cooled by natural circulation through one or two steam generator heat exchangers. The cooling pond has its own cooling loops. The study was performed to determine whether it would be possible to cool the reactor if the steam generators failed and other emergency systems were not available.

In large water tanks, intensive circulation can be caused by even very small temperature differences. The main goal was to investigate whether this natural circulation would be sufficiently strong to allow the cooling system of the pond to cool the entire system. The transient calculation that was performed showed that the cooling pond system as currently designed would not be capable of removing the heat produced in the RPV. Modifications were also studied and proposed to ensure that the cooling pond system would be capable of removing the heat generated in the reactor under these circumstances.

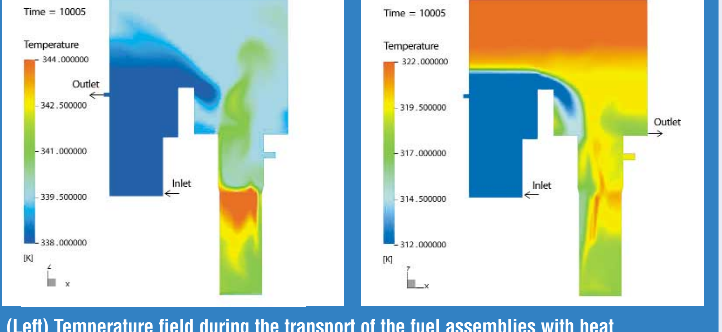
Using CFX, natural circulation was investigated in an extremely large domain and complex geometry. Typically, the calculations covered more than 10,000-second-long transients. This study has shown clearly that CFX is a very effective tool for performing safety analyses of complex nuclear systems. ■



The modeled geometry. After a calculation for the normal operational state, the Inlet II and Outlet II boundaries were closed.

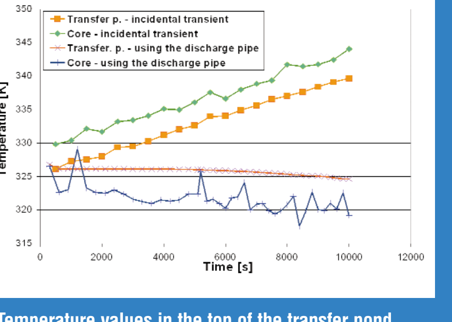


Velocity isosurface of 10 cm/s velocity during the transport of the fuel assemblies using the discharge pipe chunks as outlet. The isosurface is colored by the axial velocity components, so the red shows up-flow, the blue down-flow.



(Left) Temperature field during the transport of the fuel assemblies with heat exchanger failure.

(Right) Temperature field during the same event using the "discharge pipe chunks" as outlet.



Temperature values in the top of the transfer pond and the reactor core during the transport, and the transient calculated by the assumption that the coolant outlet was replaced by the discharge pipe chunks at the bottom of the transfer pond.