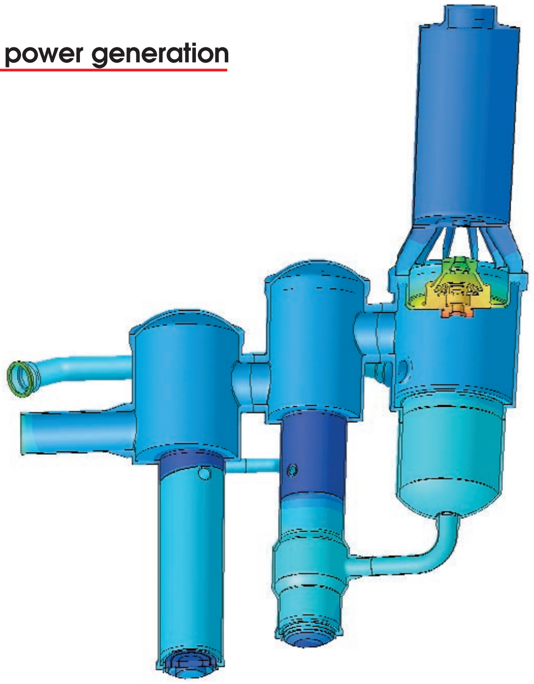
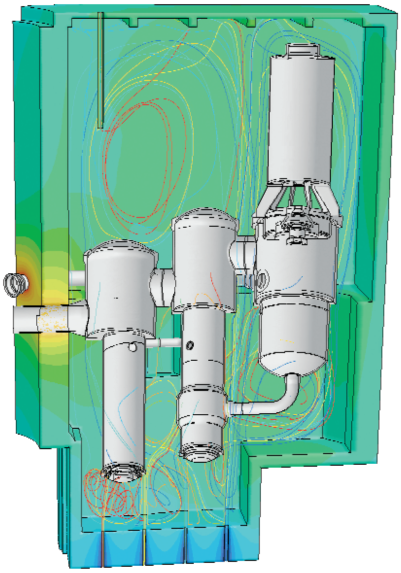
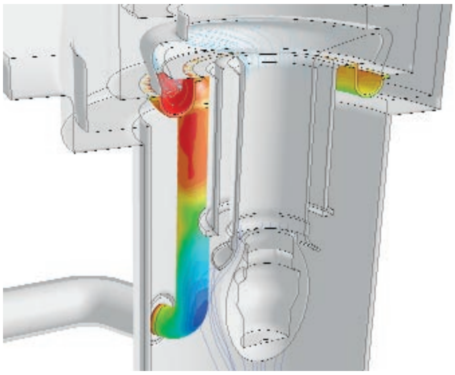


Temperature distribution in the pressure vessel, serving as input to an FEM analysis



The PCU pressure vessel within the concrete enclosure, colored by temperature, showing airflow pathlines surrounding it



Temperature profile on the outlet of the low-pressure compressor and pathlines indicating the duct's cooling flow

Pebble Bed Modular Reactor

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The Pebble Bed Modular Reactor (PBMR) is a small, inherently safe and adaptable nuclear power plant. It is a helium-cooled, graphite-moderated high-temperature reactor that uses a three-shaft recuperative Brayton cycle for power conversion. The main power system consists of two primary parts: the reactor, where thermal energy is generated by nuclear fission, and the power conversion unit (PCU), where thermal energy is converted to mechanical work and then electrical energy by means of a thermodynamic cycle and a generator. The reactor uses 60 mm diameter fuel spheres consisting of coated uranium-dioxide particles encased in graphite.

The PCU consists of three turbomachines: the high- and low-pressure turbo units, and the power turbine (including the generator). Supporting components include inlet volutes and outlet diffusers to the turbomachines as well as various piping and interfaces. The high-efficiency recuperator situated downstream of the power turbine uses high temperature helium exiting from the power turbine to recover thermal energy. Lower energy helium passes through pre- and inter-coolers and low- and high-pressure compressors before it is returned to the reactor core through the recuperator.

The high pressure and temperature of the helium provides for the PBMR's comparatively high thermal efficiency. By comparison, the steam turbines for Light Water Reactors (LWRs) operate at such low temperatures and pressures that they are more costly to build and less efficient than the turbines for a fossil-fuel-fired plant, where temperatures and pressures may be several times higher. While a typical LWR has a thermal efficiency of 33%, an efficiency of about 40% is anticipated in the basic PBMR design. Increases in fuel performance for higher temperature operation offer the prospect of increasing the efficiency to almost 50%.

During the design of the PBMR, the determination of thermal loads on various structures, systems, and components (SSC) is very important, and FLUENT has been used extensively to study this in the PCU. A CFD analysis of the PCU and its main components was recently conducted to verify design parameters. The temperature distribution through the walls of the PCU container (the pressure vessel) will be input to an FEM analysis to predict stresses and displacements within the pressure vessel in order to verify its structural design. The CFD model included most of the major components within the PCU, the air cavity around it, as well as the concrete walls surrounding it. The turbomachinery itself was excluded from the simulations, with inlet and outlet boundaries in the appropriate locations accounting for the flow into and out of the turbomachines. Inlet volutes and outlet diffusers to the turbomachines were included, however. This resulted in a model of approximately 3.8 million cells and 97 cell zones including 11 separate fluid flow paths, connected through fluid conduction, convection, and conjugate heat transfer.

The CFD results have been used mainly for design verification and design input, but also to understand the complex 3D flow fields within the various components. CFD is recognized as an invaluable part of the design of the PBMR. ■