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High-performance computations for convective flow analysis in the TPC drift volume of MPD/NICA

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The Multi-Purpose Detector (MPD) being developed for the NICA project comprises a Time-Projection Chamber (TPC) whose performance is highly sensitive to temperature non-uniformities in the drift volume. Small temperature fluctuations change working gas density and hence electron drift velocity, degrading detector' s spatial and temporal resolution. Acceptable temperature inhomogeneities are estimated at ±0.25 ℃ and ±0.1 ℃ for Ar/CH_4 (90:10) and Ar/CO_2 (80:20) gas mixtures, respectively. We report HPC-driven Large-Eddy Simulation (LES) of steady free convection in the TPC drift volume for specified gas mixtures, explicitly accounting for heat release from the Time-of-Flight (ToF) system and the geometry of the outer thermal screen. The study produced high-resolution 3D temperature and velocity fields. Mean flow diagnostics and applied hydrodynamic analyses including turbulence spectra and identification of coherent flow structures were performed to characterize the nature of convective transport and its spatial scales. Results demonstrate that convective patterns and associated thermal gradients depend strongly on heat-load distribution and screening configuration, and can generate local deviations that may approach the stated stability limits.

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