Thermal Analysis of the Neutral Particle Spectrometer

Pablo Campero, Mary Ann Antonioli, Peter Bonneau, Aaron Brown, Brian Eng, George Jacobs, Mindy Leffel, Tyler Lemon, Marc McMullen, and Amrit Yegneswaran
Physics Division, Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
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This note presents the results of the computational fluid dynamics (CFD) thermal analysis using Ansys Fluent for the temperature field in the crystal array and the enclosure of the Neutral Particle Spectrometer (NPS).

The simplified NPS model for CFD thermal analysis with Ansys Fluent is shown in Fig. 1.

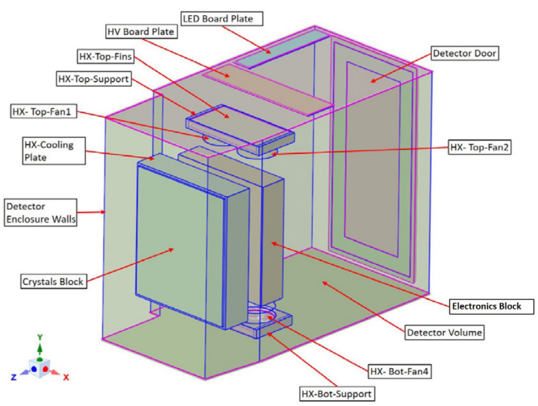

FIG. 1. Simplified model of the NPS enclosure used for Ansys Fluent simulations. Model shows the heat exchanger (HX) components, the HV and LED board plates, and the crystal and electronics blocks in the detector volume.

The cooling system consists of a copper cooling plate that goes around the crystal array block and two heat exchangers located at the top and bottom of the electronics block, Fig. 2 [1]. Each heat exchanger set at 10°C [2, 3] has two fans that circulate the cooled air.

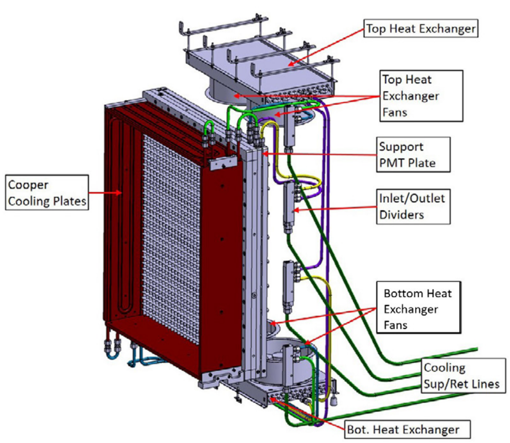

FIG. 2. Cooling system components.

The Fluent model, generated with SpaceClaim software, was based on the original NX-12 model. Tools in SpaceClaim were used to combine parts of the detector with the detector volume and to ensure thermal interaction. For example, Check Geometry and Interference, to ensure that the model had no overlapping parts, and Shared Topology for contact between surfaces, were used.

The model's mesh was generated using Fluent meshing options. The crystal array block was set to be a fluid domain so that the porosity feature could be used to allow airflow through the crystal volume. Parameters for the setup of the thermal simulation were calculated, some of which are shown in Table I.

Power per crystal block	0.326 W
Total power dissipated in crystal block	341.65 W
Heat generation rate	3426.76 W/m3
HX liquid inlet T	10°C
HX max T air inlet	25°C
HX liquid flow	1 gal/min
HX air pressure drop	24.9 Pascals
HX fan flow rate	500 CFM
HX fan angular velocity	1650 RPM
HX airflow inertial resistance	386 [m^{-1}]
Inlet temp difference (ITD)	15°C
Performance capability (Q/ITD)	117 W/°C

TABLE. I. Calculated values for thermal simulation, cell zones, and boundary conditions; HX is used for heat exchanger.

To simulate the heat exchanger performance capability, polynomial coefficients based on provided Q/ITD vs flow rate curves from specifications were calculated, as well as airflow inertial resistance for each heat exchanger fin area, based on its dimensions, air density, pressure drop, and loss factor; the calculated values were implemented in Fluent.

For the simulation, cell zone conditions—which assign the magnitude of the heat exchanger fans' angular velocity vector, the heat source, the heat exchanger plates' and fin areas' fixed temperatures, the porous volumes to allow airflow through fins and the crystal array block, airflow direction, inertial resistance, and fluid porosity values—were defined; as were boundary conditions, which define the stationary and moving walls, the shrouds for each fan set as a moving wall but with 0 RPM and rotational movement adjacent to the inner volume of the fan, the convection heat transfer applied to the detector enclosure walls, and the heat transfer coefficient and temperature for the air of 5 W/m^{2}K and 20°C respectively.

Fluent solver configurations and model are shown in Table II.

Solver	Fluid Flow Fluent, pressure-based
Velocity formulation	absolute
Solver time method	steady
Model	k-omega, shear stress transport
Gravity	-9.8 m/s
Heat transfer	convection
Precision	double
Processors	6

TABLE II. Solver and model configurations.

The pre-simulation configurations determine the solution method, solution controls, report definitions, initialization methods' initial variables, number of iterations for calculation, time scales, and reporting intervals. Some of the selected configurations are shown in Table III.

Solution method	coupled, pseudo time, global time step
Spatial discretization	second order
Solution controls	default values
Report definitions variables	T, flow, velocity, fans performance
Solution initialization method	standard
Simulation iterations	2500
Initial ambient air temp	20°C
Reporting interval	5
Time scale factor	1
Processors	6

TABLE III. Fluent pre-simulation configurations.

Expression Report Definitions and Report Definitions were generated to monitor the velocity pathlines, the maximum temperature in the crystal block, and the top and bottom heat exchangers' performance capability.

The pathline plot, Fig. 3, shows the airflow through the crystal block to the top and bottom heat exchanger fans.

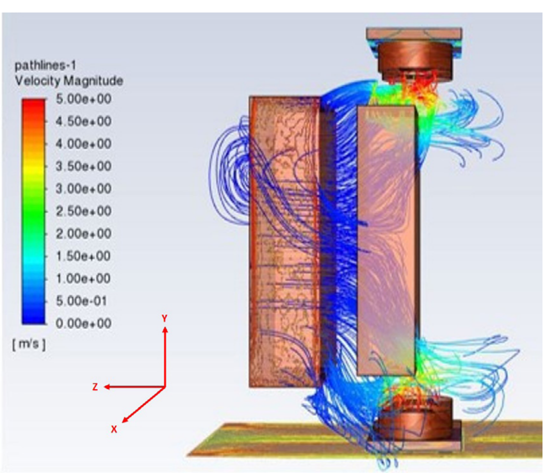

FIG. 3. Velocity pathlines in the *yz* plane and temperature contour plot in the *xz* plane.

Figure 4 shows the contour lines of the air velocity of each fan through the heat exchanger cooling plate, after which the cooled air hits the detector enclosure's ceiling and floor.

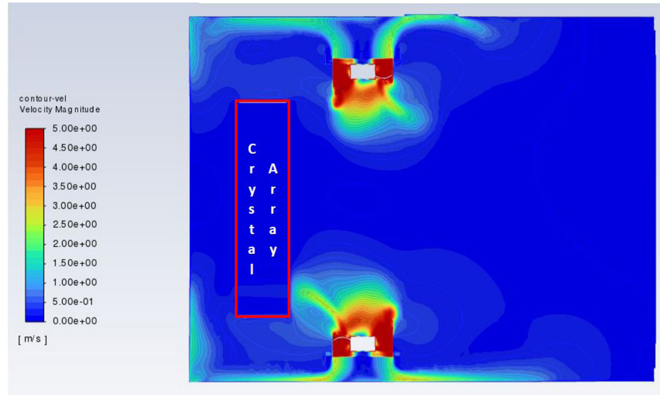

FIG. 4. *yz* plane contour plot of velocity magnitude, maximum velocity (red color) generated in the fan inlet sections.

Figure 5 shows the contour lines of the temperature distribution in the detector volume. The temperature in the crystal array block is about 23°C.

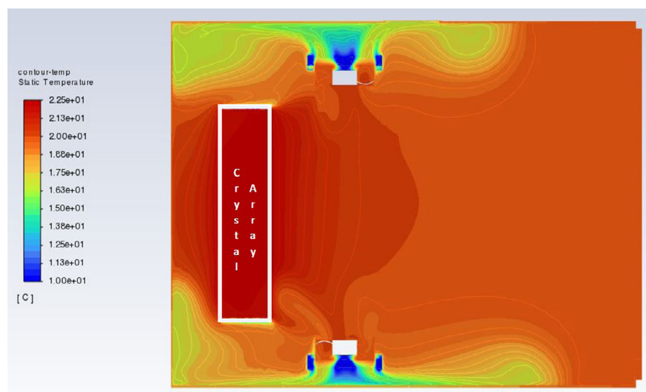

FIG. 5. *yz* plane contour plot of temperature magnitude. Blue sections indicate the top and bottom heat exchanger plates set at 10°C, red indicates the temperature in the crystal block array is ~23°C.

Figure 6 shows the performance capability of the top heat exchanger; the simulated value, ~105 W/°C, is close to the calculated value, 117 W/°C.

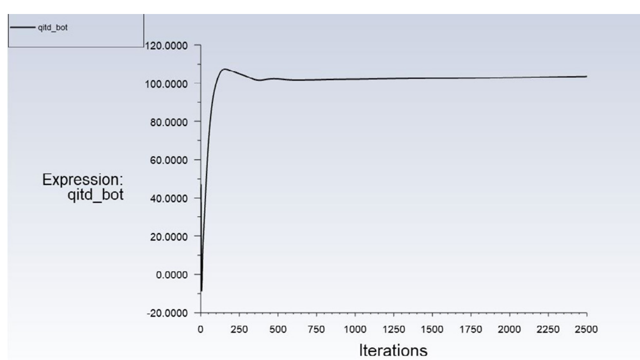

FIG. 6. Performance capability plot for the top heat exchanger.

In conclusion, the results of the CFD thermal analysis using Ansys Fluent simulation showed the temperature for the crystal block array, ~23°C, to be close to the result of the Ansys steady state thermal analysis.

[1] E. Rindel, *NPS Cooling System*, Unite Mixte de Recherche, Universite of Paris-Sud 11, January 2021.
[2] A. Brown, et al. *Ansys Steady-State Thermal Analysis of the Engineered Cooling Design for the Hall C*, DSG Note 2022-02, 2022.
[3] A. Brown, et al. *Ansys Steady-State Analysis of the Hall C Lead Tungstate Crystals of the Neutral Particle Spectrometer*, DSG Note 2022-11, 2022.