



Radiative heat transfer effects on EBC/TBC: Extended capabilities of OpenNCC's radiation solver

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Introduction



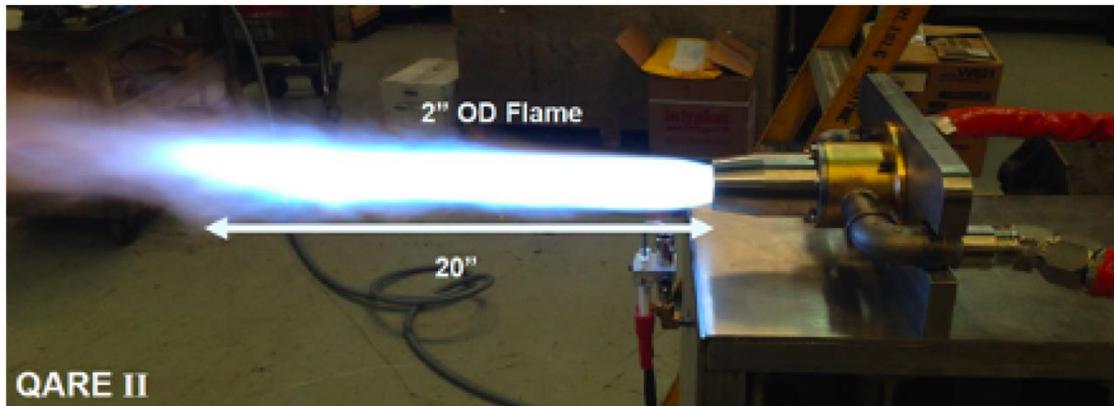
- OpenNCC is the opensource version of National Combustion Code actively being developed at NASA Glenn Research Center. It has been successfully utilized in combustor related simulations for multiple objectives (CHT, LBO, etc.).
- In the recent years, capability to solve thermal radiation has been incorporated (See TFAWS2023 presentation/papers [1]).
- In this work, we will utilize the standalone version of OpenNCC's radiation solver to numerically resolve the radiation field. This version of the code was recently developed with the intension of providing access to the radiation solver without background knowledge of OpenNCC.



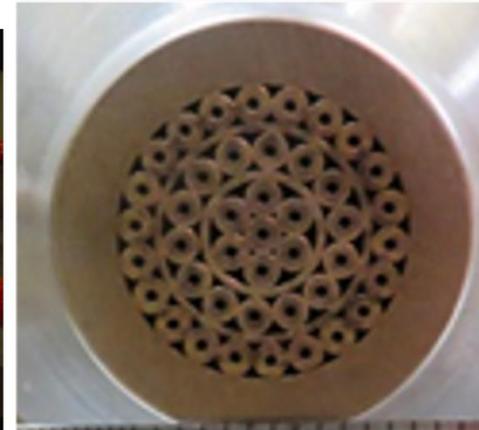
Quick Access Rocket Exposure (QARE) Rig



- Environmental/thermal barrier coatings (EBC/TBC) are enabling gas turbine engines to operate at more severe conditions than ever before. Testing various failure modes is a critical process for material selection of such coatings. The Quick Access Rocket Exposure (QARE) Rig is a natural gas/oxygen fueled combustion rig located at the NASA Glenn Research Center that is used to evaluate the failure modes of recession, oxidation, thermo, mechanical, Erosion/Foreign Object Damage and Calcium-Magnesium-Aluminosilicate[2].



(a) Nozzle assembly



(b) Nozzle exit configuration

- QARE-II is a surface mixing nozzle where the fuel and oxidizer mix at the nozzle exit. Natural gas flows through the inner tubes and the Oxidizer comes out between the tubes.

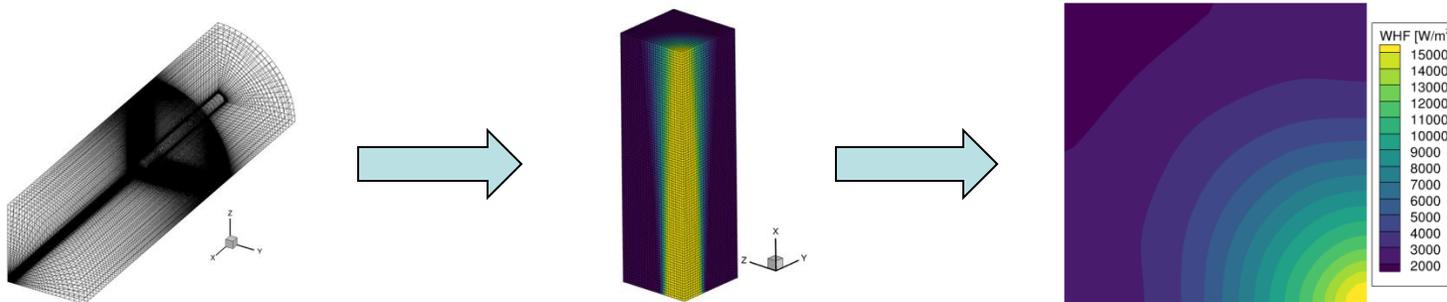
Flame impinging on the material coupons are at high temperature with large concentrations of CO_2 and H_2O . Therefore, thermal radiation is likely to have meaningful effect.



Calculation Procedure



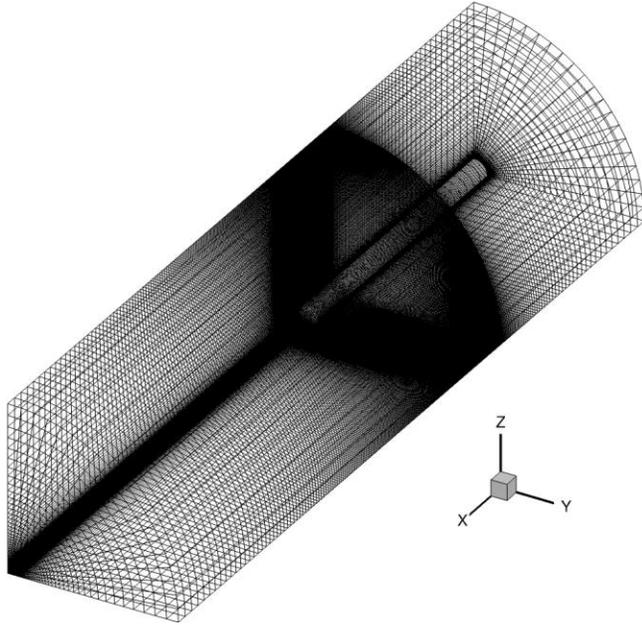
1. Calculate the temperature and the species concentrations (FUN3D).
2. Interpolate the CFD results to the radiation mesh (Tecplot).
3. Run the OpenNCC's standalone radiation solver and evaluate the radiative heat flux at different location and operating conditions.



- I. Standalone radiation solver of OpenNCC is not limited to the above combination of CFD solver and interpolation procedure (just need volumetric temperature and species information).
- II. Interpolation will not only reduce the domain of interest but also avoid the use of elongated mesh for the radiation calculation.



CFD Simulation

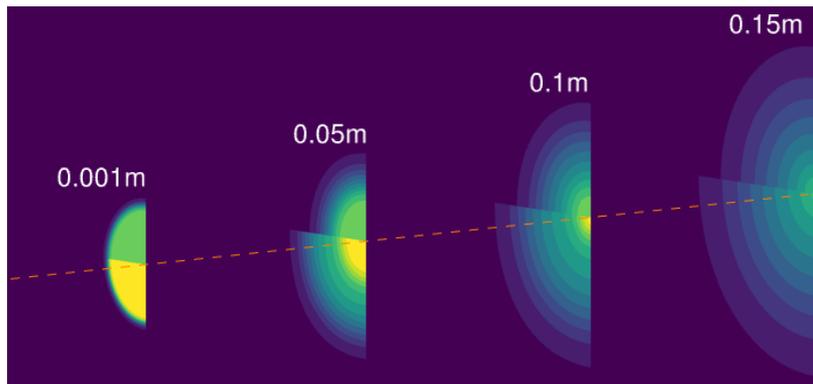
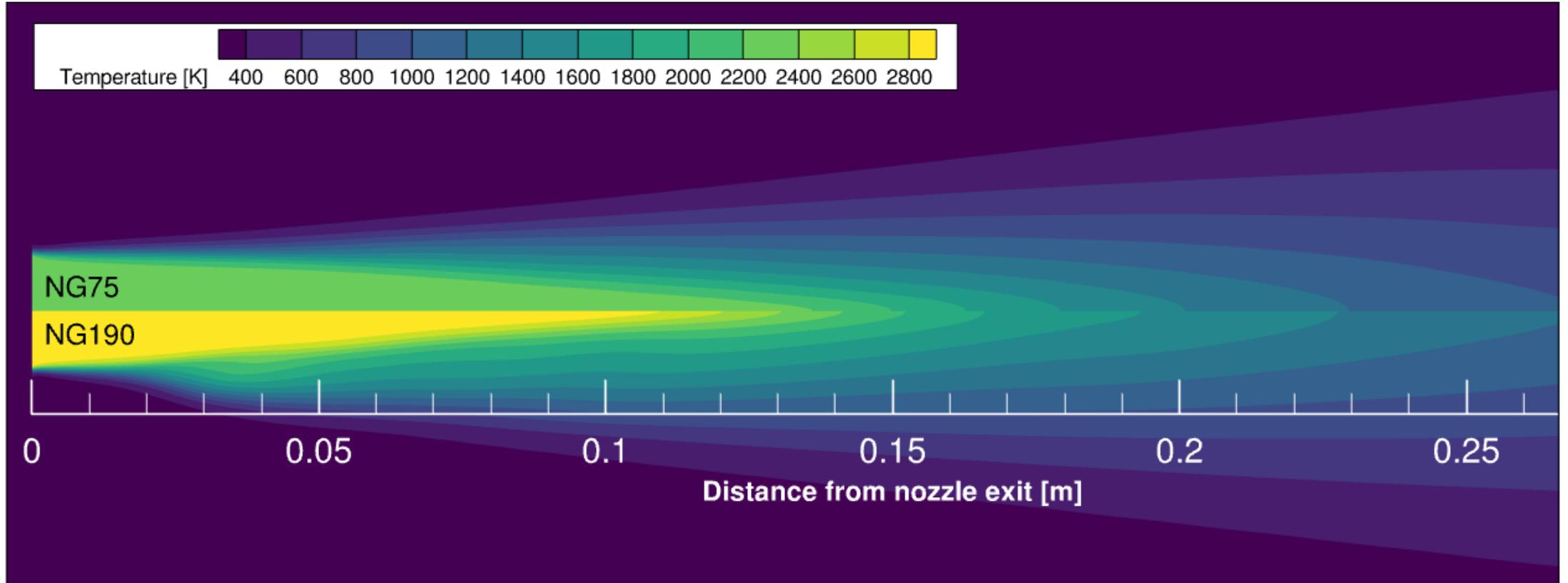


- FUN3D ver.14.2 [3].
- 496,720 cells (small for parametric study).
- 37 species diffusion are considered[4].
- Gas exits the nozzle as pre-burned based on CEA.
- Nozzle diameter is approximated to 19.81 mm.
- Nozzle walls are adiabatic and no-slip near the exit.
- Turbulence model is "sst-v2003m"[5].
- Unsteady calculation was performed and the result presented are time-averaged.
- Calculation performed for two conditions:

Name	Natural Gas (CH4) Flowrate [SCFH]	Oxidizer Flowrate [SCFH]	Equivalence Ratio, ϕ	Temperature [K]
NG75	75	650	0.248	2302.13
NG190	190	650	0.628	2915.79

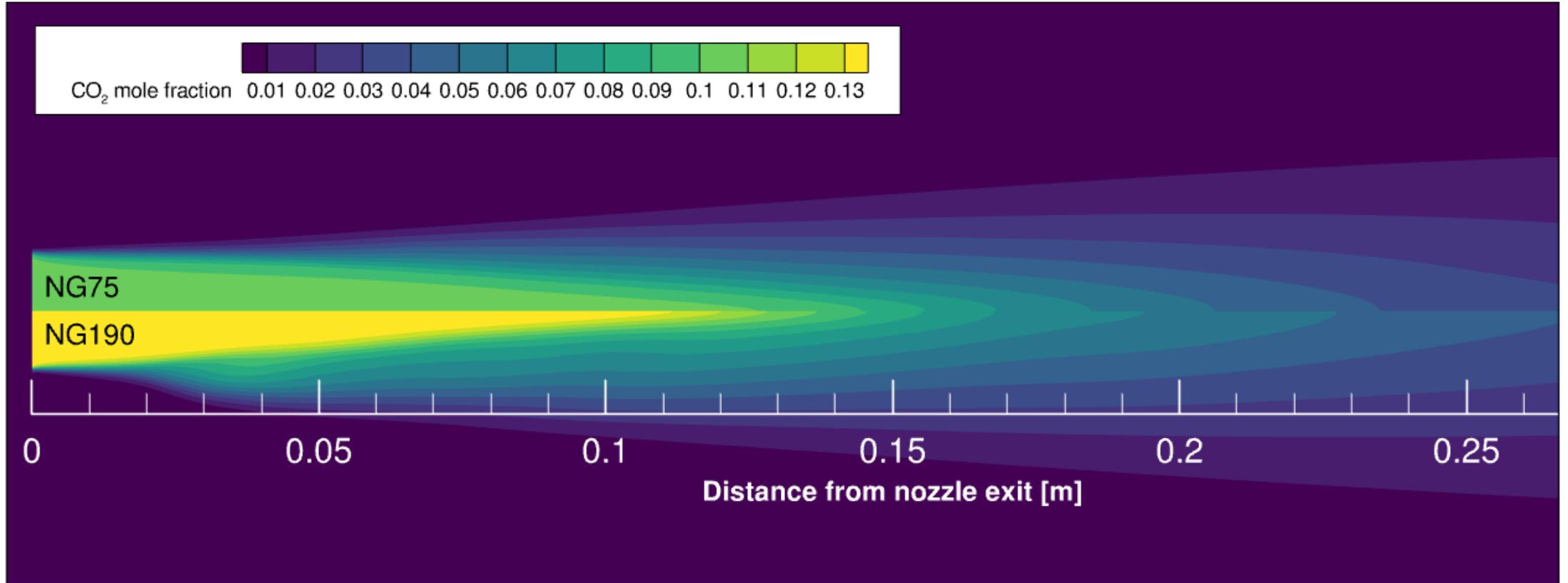


Temperature Comparison



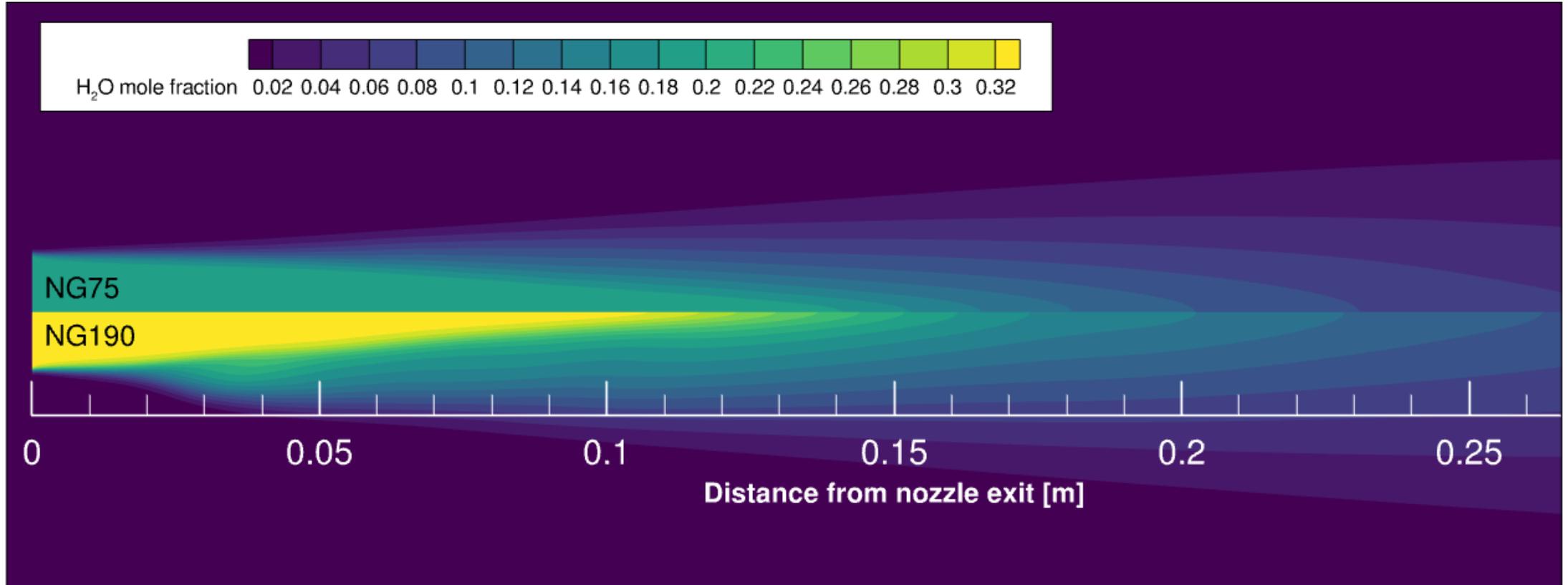


CO₂ Mole Fraction Comparison





H₂O Mole Fraction Comparison

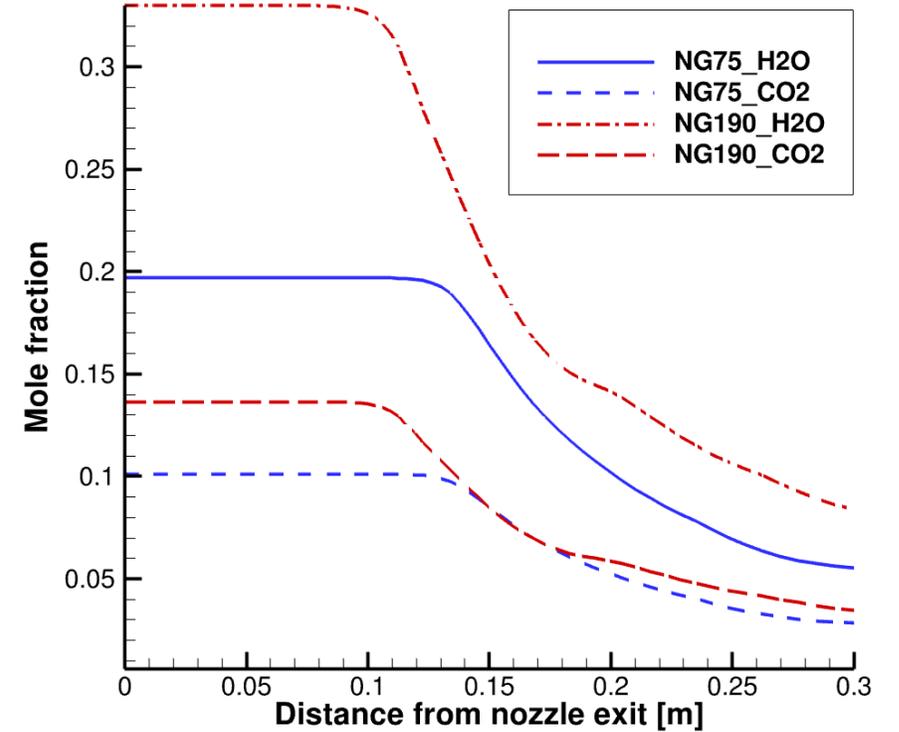
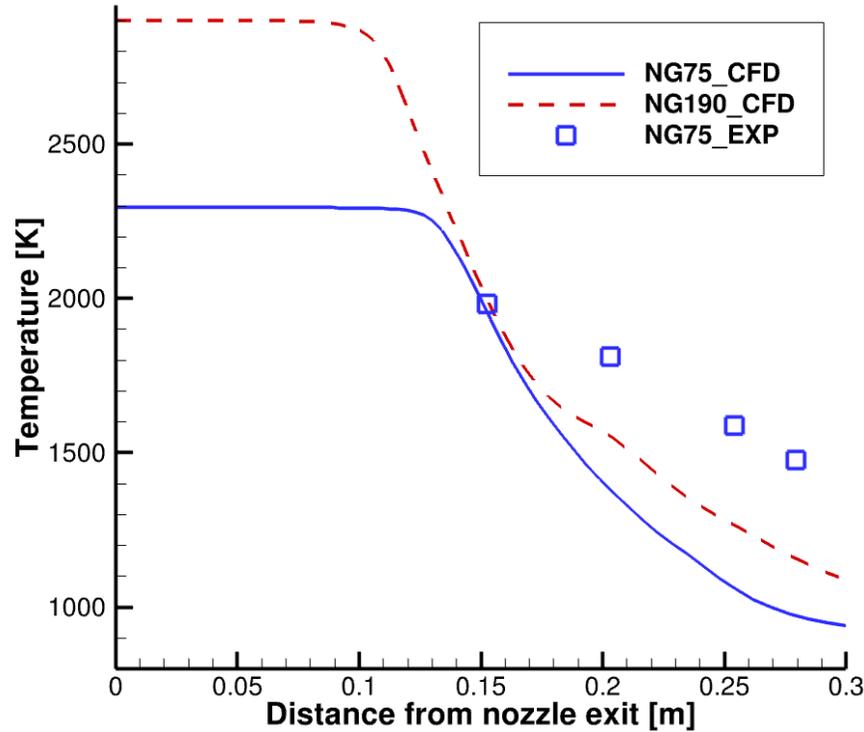




Centerline Property Comparison



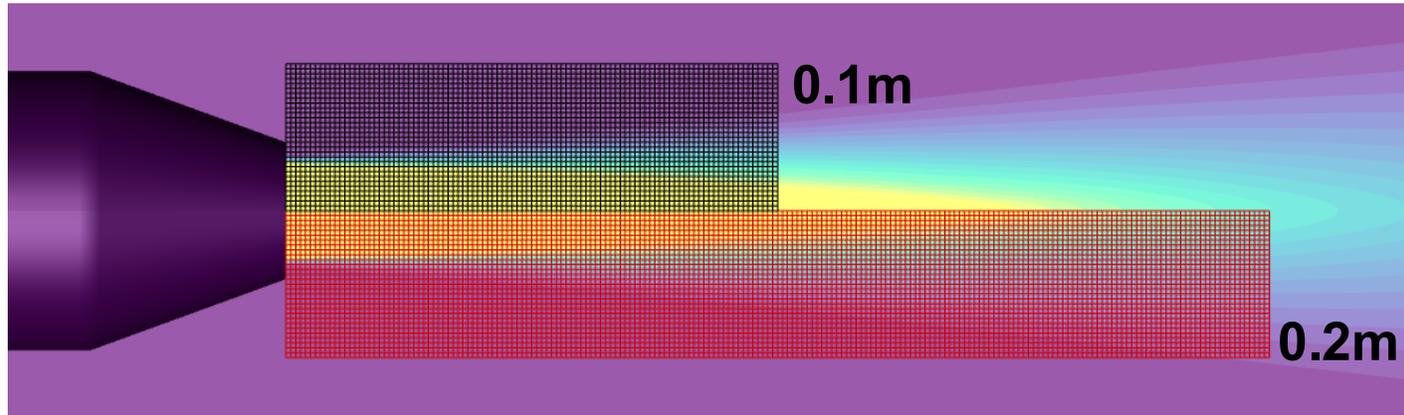
200NG experiment image*



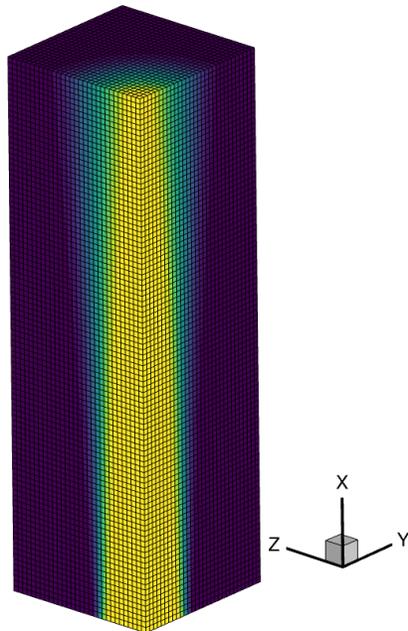
Centerline temperature shows difference between CFD and experimentally measured thermocouple data. Nozzle exit condition is probably over simplified.



Radiation Simulation



- Rectangular mesh with equal spacing of 1mm.
- Domain size is 3cm x 3cm x Length.
- The distances from nozzle exit are 0.1m and 0.2m.
- 90,000 cells and 180,000 cells.
- Two symmetric BC and four cold&black BC.



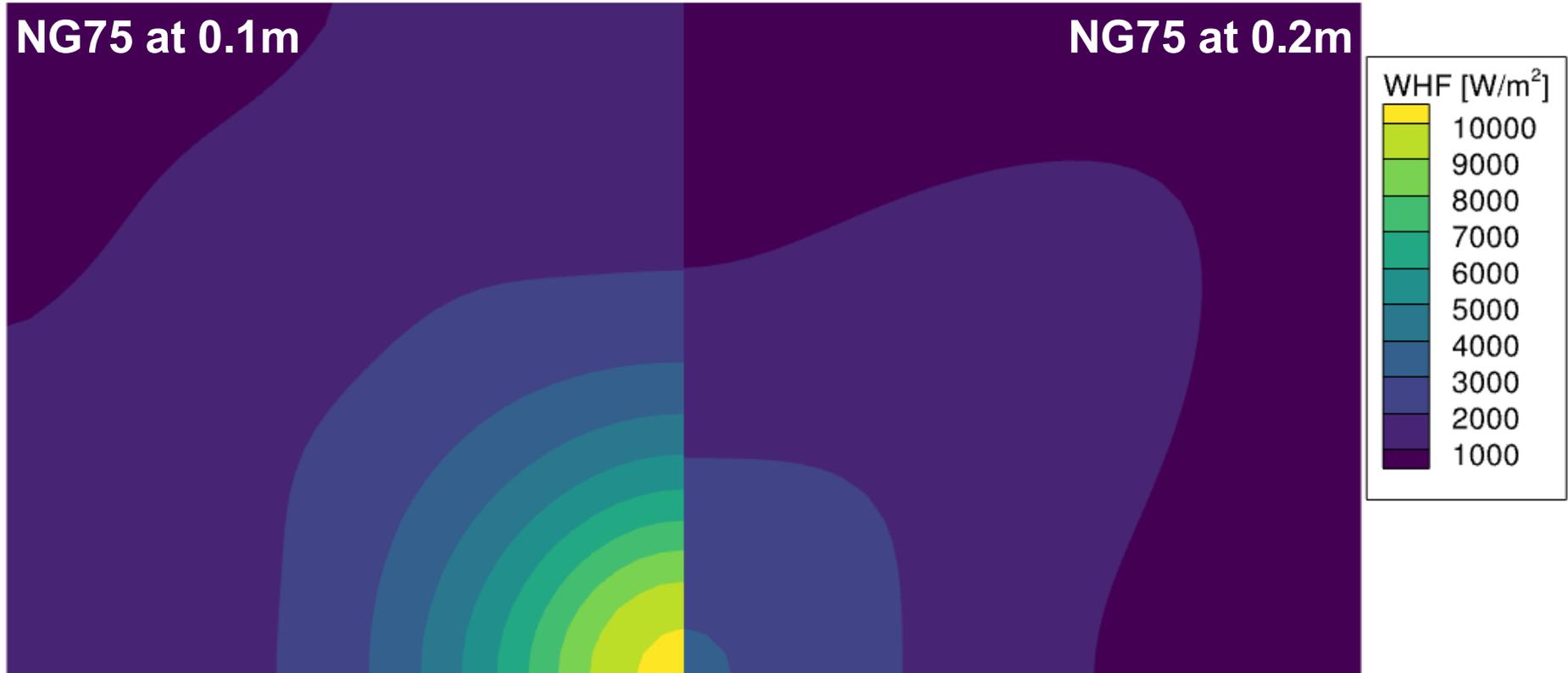
Solver Settings:

- Discrete ordinate method with T4 quadrature set [6] (128 direction in 3D).
- CO₂ and H₂O are the participating species.
- Weighted Sum of Gray Gas model by Bordbar et al.[7] is used (*5bands*).

The objective is to compare the radiative heat flux at 0.1m and 0.2m for the two different conditions (NG75 and NG190).

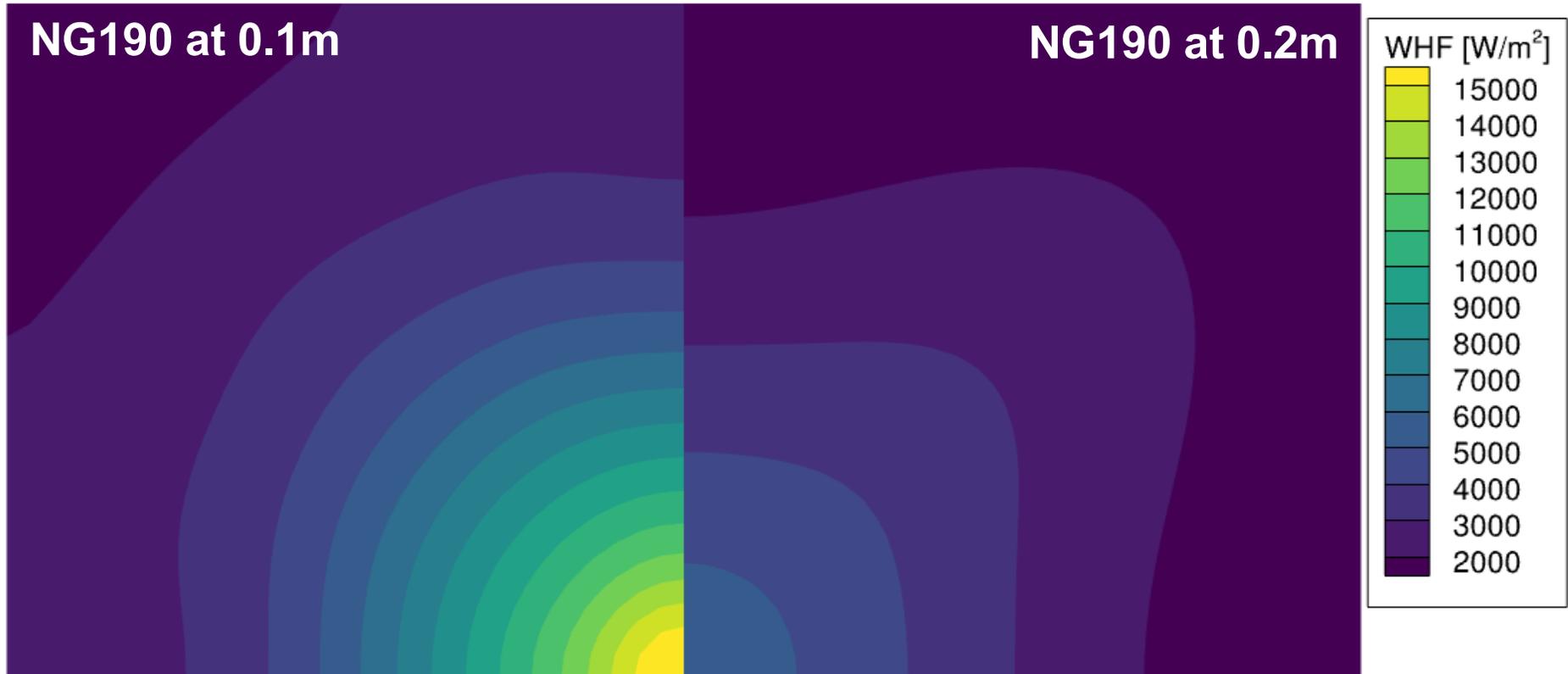


Radiative Heat Flux at Different Distance NG75 ($\phi=0.25$)



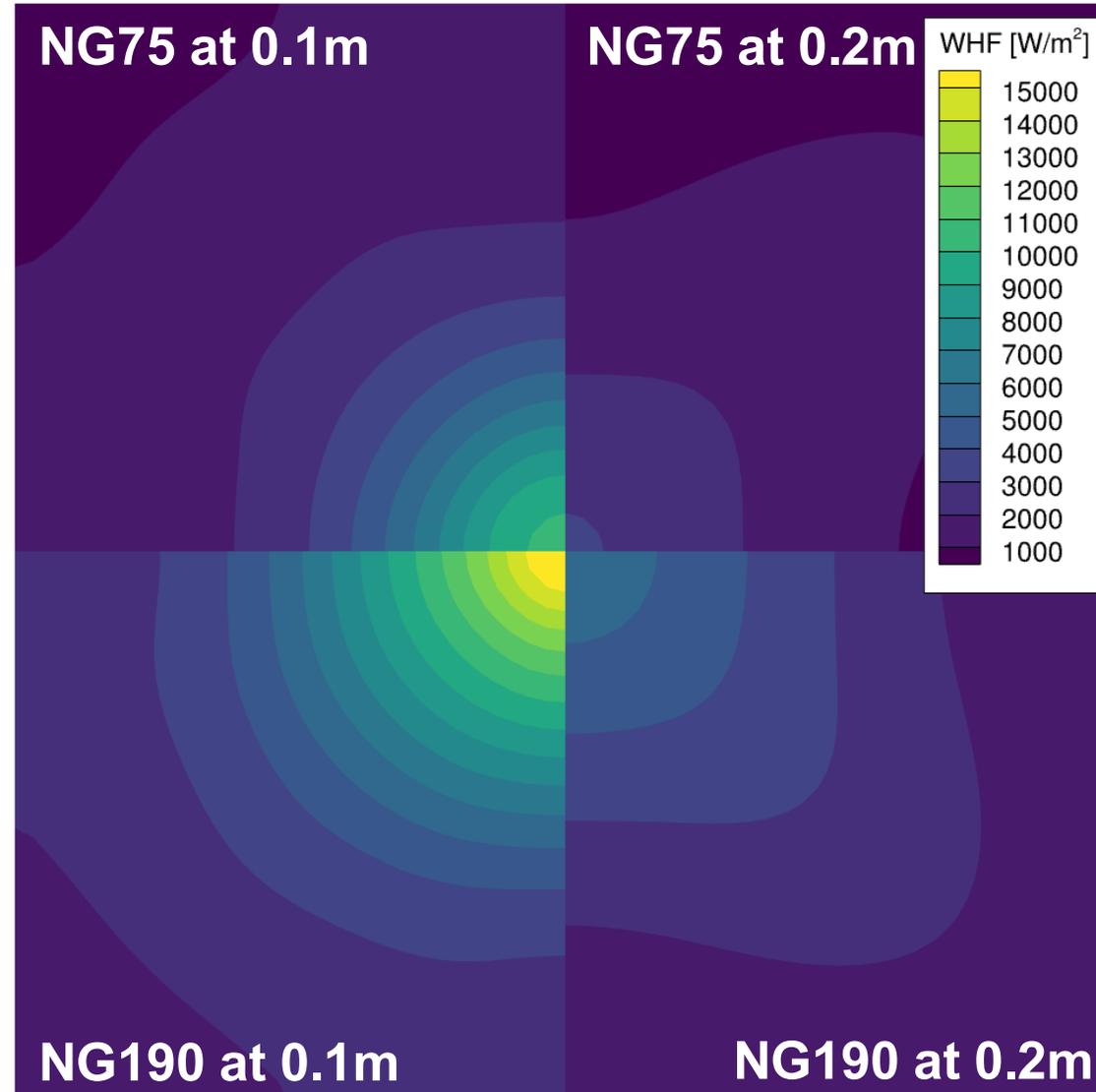


Radiative Heat Flux at Different Distance NG190 ($\phi=0.63$)



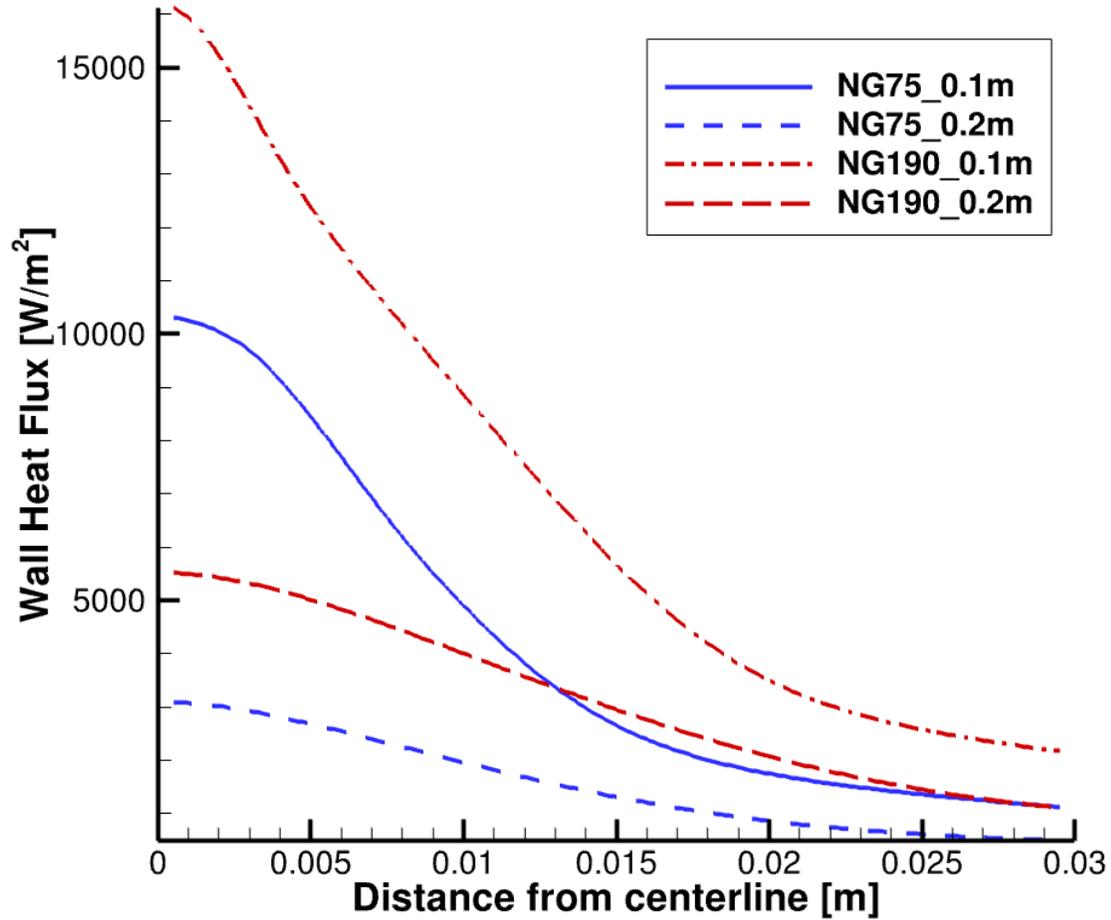


Radiative Heat Flux Comparison (Distance & Condition)





Radiative Heat Flux Comparison (Distance & Condition)



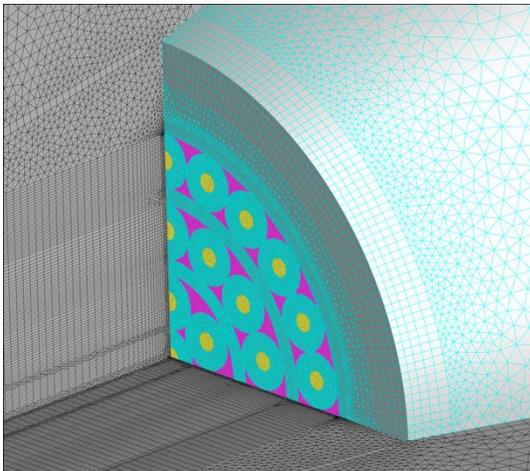
- Peak heat flux is about 16 kW/m² for the case of NG190 at 0.1m.
- Considering the difference in the temperature measurement between CFD and experiment, this value should be treated with caution.



Summary



- Through the calculation of QARE-rig at different operating conditions, the procedure to run the OpenNCC's standalone radiation solver has been demonstrated.
- Peak radiative heat flux of approximately 16 kW/m^2 was found for the case of 190SCFH of natural gas and 650SCFH of oxidizer.
- Some differences were found between the simulated temperature field and the experimentally measured value. Likely to be caused by the simplified approximation at the nozzle exit.



Plan to revisit the cases with simulating the combustion.



Acknowledgments

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