ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB371

# NUMERICAL ANALYSIS ON NITROGEN INJECTION FIRE EXTINGUISHING SYSTEM IN THE LINAC AREA AT TPS

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*Abstract*

The Linear accelerator (LINAC) of Taiwan Photon Source (TPS) could generate electrons to 150 MeV. The main subsystems including an electron gun, buncher, accelerating sections, vacuum system, and focusing and steering magnets are located in the LINAC area of 223.5 $m^2$ and 3 m in height. We designed a nitrogen injection fire extinguishing system for the LINAC area and performed Computational Fluid Dynamic (CFD) simulation to analyse the fire extinguishing performance with and without fresh air supplied from the air conditioning system.

## INTRODUCTION

The LINAC of TPS has been applied to provide required specifications since 2014. Electrons are extracted from electron gun (e-gun), then accelerated from 90 keV to 150 MeV through three linear accelerating sections [1].

In the LINAC area, there are equipped installed the accelerating section, quadrupole, waveguide, buncher, e-gun, and cable trays. There are also equipped with various high voltage power supplies, such as PFN kicker, half-sine kicker and half-sine septum with different peak current and pule power passing through. Figure 1 shows the various PS in the storage ring and the LINAC area of TPS.

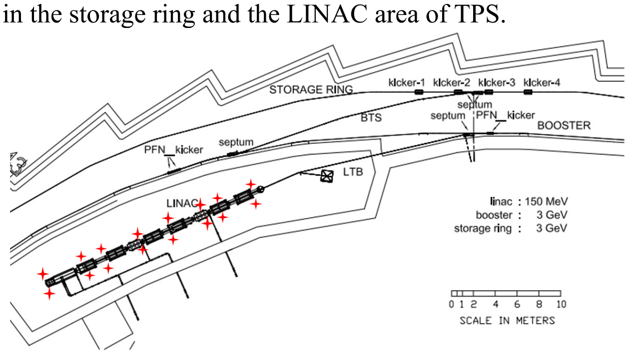


Figure 1: PS in the storage ring and the LINAC area of TPS.

Therefore, safety is another critical issue in this area. To keep from induced fire hazard, we plan to install a nitrogen injection fire extinguishing system for the LINAC area. The nitrogen is supplied from the floor through a 4” pipe, then distributed to 16 nitrogen injection exits above the three linear accelerating sections and the buncher at the height of 2.3 m above the floor, as marked in red in Fig. 1.

To predict the effect of the nitrogen injection fire extinguishing system, we performed CFD simulation to analyse effect of nitrogen discharge in the area. We simulated two cases of nitrogen discharge flow rates of 1.02 kg/s and 1.55 kg/s with and without fresh air supplied from the air conditioning system.

## NUMERICAL SIMULATION

CFD began from the early 30s of the 20th century to solve the linearized potential equations with 2D methods (1972). As rapid development of numerical analysis and computer science, CFD has more advantage of well adaptation than traditional theoretical analysis and experimental measurements. Nowadays, CFD has been widely applied in many fields. Detailed 3D numerical simulation was performed using a commercial general purpose CFD code ANASYS Fluent. We also had applied 3D numerical simulation on the safety issue at TPS [2].

### *Governing Equation*

We set our simulated model as a 3D turbulent flow in this study. The basic governing equations include the continuity equation, the momentum equation and the energy equation.

We apply the k-ε turbulence model and SIMPLEC to solve the velocity and pressure problem.

Mass conservation equation (continuity equation)

$$\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho\mathbf{u})=0 \tag{1}$$

where $\rho$ is density of fluid, $t$ is time and $\mathbf{u}$ refers to fluid velocity vector.

Momentum conservation equation

$$\frac{\partial(\rho\mathbf{u})}{\partial t}+\nabla\cdot(\rho\mathbf{uu})=-\nabla p+\rho\mathbf{g}+\nabla\cdot(\mu\nabla\mathbf{u})-\nabla\cdot\tau_t \tag{2}$$

where $p$ is pressure, $\mathbf{g}$ is vector of gravitational acceleration, $\mu$ is dynamic viscosity of fluid, and $\tau_t$ is divergence of the turbulent stresses which accounts for auxiliary stress due to velocity fluctuations.

Energy conservation equation

$$\frac{\partial(\rho e)}{\partial t}+\nabla\cdot((\rho e+p)\mathbf{u})=\nabla\cdot\left(k\nabla T-\sum_j h_j\mathbf{j}_j\right) \tag{3}$$

where e is the specific internal energy, T is fluid temperature, k is heat conductivity, h is the specific enthalpy of fluid, jj is the mass flux. In this study, RNG (Re-Normalisation Group) $\kappa$ - $\varepsilon$ turbulent model was used.

### *Geometry and Grid Generation*

A detailed 3D model of the LINAC area of the TPS was built for the numerical simulation. The space of the simulation zone is about 682.7 $m^3$. The accelerating section, quadrupole, waveguide, buncher, e-gun, wind duct, cable trays and nitrogen piping system are modelled. The geometry was built according to the actual dimensions of this

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area, as shown in Fig. 2. We also take the effects of the air conditioning system into consideration. One supplied air exit and one air exhausts are distributed on overhead of the inner wall.

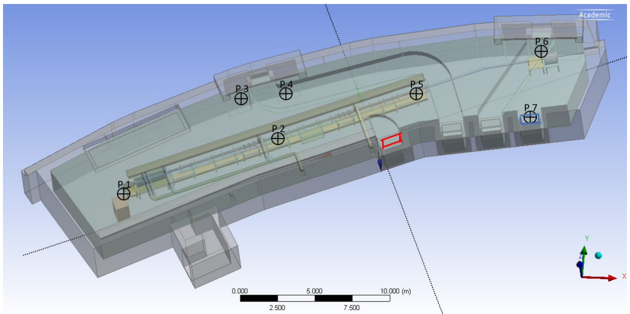


Figure 2: Numerical model of LINAC area of TPS.

According to the geometry of the model, we applied hybrid grid to discretize the model. The total number of the grid elements was about 2.81 million. To more accurately analyse the flow fields and greater control over sizing function, we applied the Advanced Size Function. The size of relevance center was fine. The minimum grid element size is 0.00572 m near the nitrogen discharge exit. Figure 3 shows the generated grids of the numerical simulation.

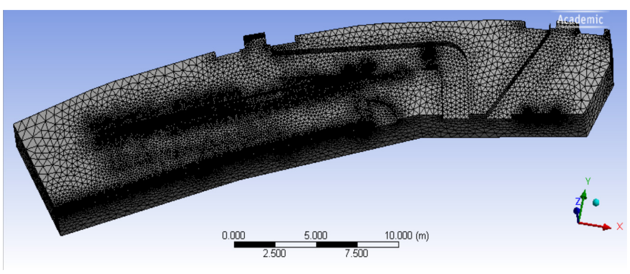


Figure 3: Generated grids of the numerical model.

### *Initial and Boundary Conditions of Three Cases*

In this study, we simulate three cases as follow: A. The flowrate of nitrogen discharge was given the case of 1.02 kg/s without fresh air supplied. B. The flowrate of nitrogen discharge was given the case of 1.55 kg/s without fresh air supplied. C. The flowrate of nitrogen discharge was given the case of 1.55 kg/s with fresh air supplied Vair = 2 m/s. There is only one air supplied exit and one air exhaust, respectively marked in red and blue color in Fig. 2. All three cases are transient and total time are 300s. Other initial and boundary conditions are list as follow.

1. Oxygen mole fraction in the air is 21% at t = 0s.
2. Wall and floor are adiabatic.
3. Back pressure of the air exhaust is 1000 Pa.

## ANALYTICAL SIMULATION

We also calculate the analytical solution of the bulk nitrogen concentration in this area to compare the results between the numerical and the analytical simulation. We assume the air and nitrogen concentrations are uniformly distributed in this area.

According to the law of mass conservation, the nitrogen concentration may be written as

$$V\frac{dC_{N2}}{dt} = C_0Q_{air} + Q_{N2} - C_{N2}(Q_{air} + Q_{N2}) \quad (4)$$

where: V is volume of the room, Q is the air flow through the room, $C_{N2}$ is internal concentration of nitrogen, $C_0$ is concentration of the nitrogen in the surrounding, $Q_{air}$ and $Q_{N2}$ are flow rates of air and nitrogen, respectively, and t is time.

## RESULTS AND DISCUSSION

We select seven monitor points P1 to P7, respectively shown in Fig. 2, where P1, P2 and P5 near accelerating sections, P3, P4 and P6 near cable trays on the outer wall, and P7 located at the air exhaust. Those points are selected because we concern those equipment and cable trays once fire accident occurs.

We also select three monitor planes PA and PB, respectively at z = 1.6 m and 2.2 m. In this study, we analysed the oxygen mole fraction. According to NFPA, our goal is to reduce the oxygen mole fraction less than 16%.

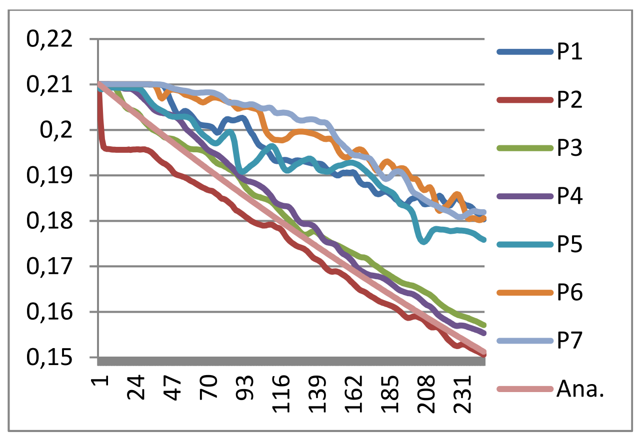


Figure 4: Simulation results of oxygen mole fraction of case A of P1 to P7 and analytical solution.

Figure 4 shows the simulation results of oxygen mole fraction of cases A of P1 to P7 and analytical solution.

The simulated oxygen mole fractions range from 21% to 15%. It can be observed that oxygen mole fractions at P2, P3, P4 and analytical solution are close and lower than those at other points. Because P2 is located at the middle of the accelerating sections and the nitrogen injection exits, the oxygen mole fraction at P2 drops quickly at the beginning. On the other hand, the oxygen mole fraction at P7 reduces slowly because P7 is located at the air exhaust and thus has slowest response to the nitrogen injection.

Figure 5 shows the simulation results of oxygen mole fraction of case B of P1 to P7 and analytical solution.

Due to more nitrogen discharged in case B, the oxygen mole fractions would be reduced lower and simulated oxygen mole fraction range from 21% to 11% in Fig. 5. Although oxygen mole fractions at P2, P3, P4 and analytical solution are close and still lower than those at other

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points, the difference become smaller. Like simulation results of case A, the oxygen mole fraction at P2 drops quickly at the beginning and the oxygen mole fraction at P7 reduces slowly. The analytical solution results close to a linear line without fluctuation.

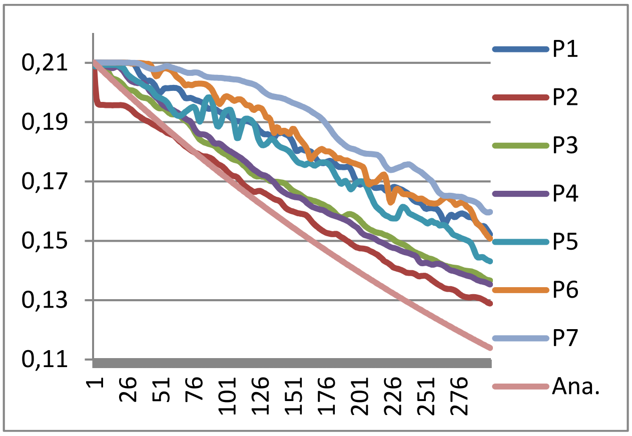


Figure 5: Simulation results of oxygen mole fraction of case B of P1 to P7 and analytical solution.

Figure 6 shows the simulation results of oxygen mole fraction of case C of P1 to P7 and analytical solution.

Because supplied fresh air would reduce the effect of discharged nitrogen in case C, the oxygen mole fractions would be higher than those of case B and simulated oxygen mole fraction range from 21% to 16% in Fig. 6.

Besides, supplied air also make the oxygen mole fractions in this area more uniform. Therefore, the oxygen mole fractions of P1 to P7 are closer, as shown in Fig. 6.

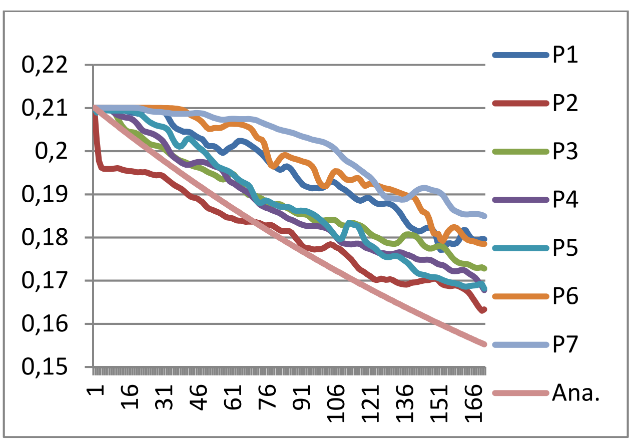


Figure 6: Simulation results of oxygen mole fraction of case C of P1 to P7 and analytical solution.

Figure 7 shows the simulation results of oxygen mole fraction of case B on PA (z = 1.6 m) at t = 60s. It can be observed 16 nitrogen injection exits distributed in the middle of the LINAC area in green color. The oxygen mole fraction near the middle area is thus lower, especially near the outer wall area, where little equipment would block injected nitrogen.

On the other hand, the oxygen mole fraction near the LTB area, right side in Fig. 7 is higher, especially near the air exhaust. Besides, the oxygen mole fraction near the buncher area is also higher. This area is near point P1, and Fig. 4-6 shows the same simulation results. The simulation results provide us valuable information once fire accident occurs.

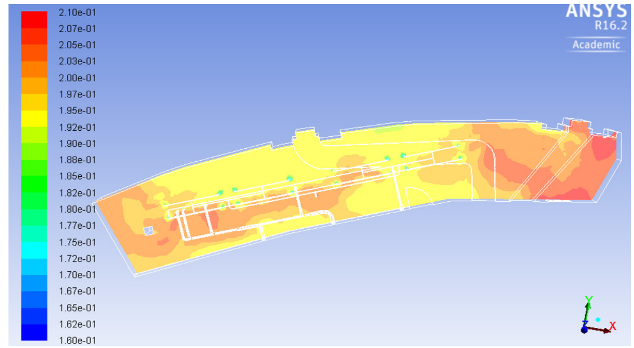


Figure 7: Simulation results of oxygen mole fraction of case B on PA (z = 1.6 m) at t = 60s.

Figure 8 shows simulation results of oxygen mole fraction of case B on PB (z = 2.2 m) at t = 60s.

The simulation results are close to those shown in Fig. 7. Because plane PB is close to the nitrogen injection exits, injected nitrogen is not fully expanded, 16 nitrogen injection spots in green color are smaller those shown in Fig. 7.

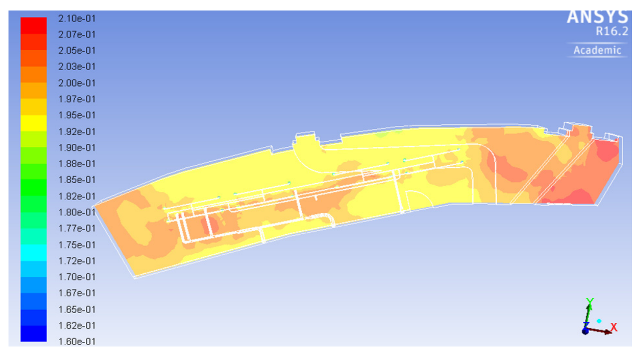


Figure 8: Simulation results of oxygen mole fraction of case B on PB (z = 2.2 m) at t = 60s.

## CONCLUSION

We performed CFD simulation to analyse three cases of nitrogen injection in the LINAC area. It shows the oxygen mole fractions near the buncher and LTB areas is higher than others.

## ACKNOWLEDGEMENT

Authors would like to thank colleagues in the LINAC group of NSRRC for their assistance.

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