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Gas Dispersion Analysis for Glovebox Accident in a Ventilated Process Room

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INTRODUCTION

Glovebox facilities at the Savannah River Site are monitored for radioactive hydrogen isotope gas released into the process room. At selected threshold values, typically 4 x 10^{-5} µCi/cc, a visual and audible alarm sounds to alert workers to leave the room. The configuration of the process rooms varies significantly (room height, room width, number of sample points, response times of alarms, etc.). The purpose of this study is to demonstrate that under conservative accident scenarios with conservative initial conditions, a single sample point will result in an alarm of the radioactive gas monitoring system.

For bounding room geometry as shown in Fig. 1, high ceilings will be used as sample points are located at approximately 80 inches from the floor. The radioactive hydrogen gas source term modeled will be in the middle of the room as this is representative of most glovebox and process hood configurations. The sample point location will be 80 inches from the floor at the maximum distance from the source term. This paper is focused on the cases with a ventilated room since the modeling analysis for an unventilated room was made in a previous study [1].

In this study, a release case will be evaluated to address tritium migration for a room fire resulting in a release of a small quantity of tritium due to a loss of confinement from a hypothetical tank breach, which results in a hot gas plume release. The air circulation effect caused by the room ventilation system was considered to quantify the tritium migration into a ventilated room during the accidents. The case represents a baseline case for fire in a room leading to the breach of a glovebox and its associated process tanks in a standard process room of 500 m^3 containing a single glovebox system and releasing about 0.867 gm of tritium in oxide form to the process room. Figure 1 shows the standard process room, 30ft long (L), 30ft wide (W) and 20ft high (H), with a single glovebox as modeled for the analysis. The room is ventilated with 1800 cfm in total via four square-type air registers as shown in Fig. 2.

Based on these postulated accident scenarios in a large and ventilated process room, the modeling calculations of the tritium migration are performed to estimate local gas concentrations due to the sudden leakage and release from a glovebox system associated with the process tank. The transient calculations were performed to evaluate local concentrations of tritium gas in the process room resulting from the sudden release of radioactive gas such as tritium during the hypothetical accident scenarios. The geometrical configurations for the air space with internal gas release from the process tank in a large process room are shown in Fig. 1.

The primary objective of the present work is to perform a modeling analysis for radioactive gas release and dispersion under the postulated accident scenarios with room ventilation. The modeling work was performed by taking a computational fluid dynamics (CFD) approach. A CFD model was developed to evaluate gas circulation patterns following the gas release under postulated scenario of tritium leakage accidents and to estimate local concentration of tritium inside a process room with 500 m^3 capacity.

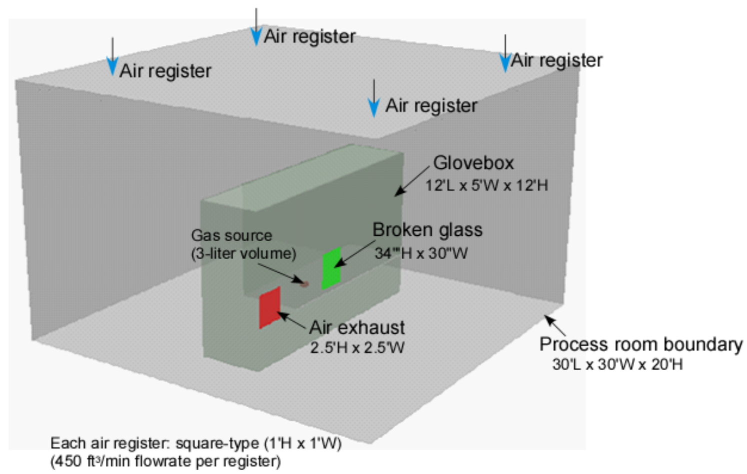


Fig. 1. Modeling domain used for the modeling study

DISCRIPTION OF THE WORK

A three-dimensional CFD approach was used to calculate flow patterns and gas release rate for the baseline case during the accident scenario in terms of gas concentration. A finite volume CFD approach was used here to perform the gas modeling and analysis under three-dimensional prototypic domain. A prototypic geometry was modeled with a non-uniform, non-orthogonal, hybrid mesh by using FLUENT [2].

A standard two-equation, k-ε model [3], was used to estimate the gas turbulence. The two-equation model was benchmarked against the literature results [4]. The tritium source in the process room was modeled by using a species balance equation. Thus, the governing equations to be solved are composed of one mass balance, three momentum equations for the three-dimensional space, two turbulence equations, and one species transport equation for tritium gas. Gas migration inside the process room was modeled as species mixture in the governing equations. The computational domain boundary used for the present calculations is shown in Fig 1.

Modeling assumptions for the calculations are as follows:

- There are no flow obstructions except for gas source region and basic glovebox in a process room.
- Air and gas species are assumed to follow the ideal gas behavior.
- Radioactive hydrogen gas evolution rate from the release spot is constant and uniform.
- Process room is ventilated with air flowrate of 1800 cfm (ft^3/min) via four registers located at the room ceiling.
- Room wall temperature is constant, so cooling effect through the room boundary can be ignored because of a large room.
- No chemical reactions during the gas transport and mixing process.
- Hydrogen gas is a dilute mixture component, so the mass diffusion coefficient is independent of gas composition.

Hydrogen gas mass fractions for the modeling case are computed under transient conditions. The analysis used a second order differencing scheme in order to minimize the numerical diffusion caused by the discretization. The flow conditions for the vapor space are assumed to be fully turbulent since Reynolds numbers for the nominal conditions are in the range of 10,000 based on the inlet conditions of the release spot. A standard two-equation turbulence model, the $k-\varepsilon$ model [3], was used since the benchmarking results showed that the two-equation model predicts the flow evolution of turbulent flow in a large stagnant fluid domain with reasonable accuracy. A full three-dimensional representation of the entire room space was used to capture significant circulation phenomena related to the turbulent behavior of the gas flow. Air was used to simulate the initially ventilated and 25°C gas in a process room.

Table 1. Baseline modeling conditions used for the calculations

Parameters		Modeling input
Process room dimension	Height	20 ft
	Wide x Length	30 ft x 30 ft
Process room volume		About 500 m^3
Room ventilation condition		Ventilation (1800cfm)
Hydrogen gas source		Center of glovebox floor
Sampling location of radioactive hydrogen concentration in room		80-in elevation at the corner of room
Wall boundary conditions for room		25°C

The study case simulates total release of 0.867 gm tritium as result of the fire incident in a room leading to the breaches of a glovebox. The case models the accidental tritium release due to the release of flammable mixture from the process tank following the release duration of 25 seconds from the process tank of the glovebox. For the simulation, surface heat flux of 50 kW/m^2 is applied to the hemispherical source surface.

From the mesh sensitivity studies, about 200,000 meshes for the modeling domain were established for the calculation. The major material and physical properties used for the calculations are listed in Table 2.

RESULTS

The present models for the gas concentration calculations employed a three-dimensional CFD transient approach with two-equation turbulence model described in terms of turbulent dissipation and eddy diffusivity, referred to as k-ε model in the literature. It assumed ideal gas behavior for the gas species in the modeling domain so that natural convection was included. The models actually compute tritium mass concentrations. The gas radioactivity concentration was obtained by applying the conversion factor of 9690 Ci for 1 gm tritium.

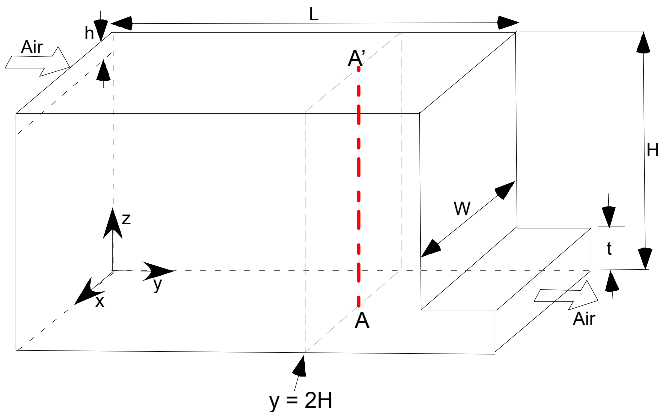
Table 2. Material and physical properties used for the calculations

Parameters	Input data
Air density at initial room temperature	1.177 kg/m^3
Tritium molecular weight	6 kg/kg mol
Air molecular weight	29 kg/kg mol
Tritium oxide molecular weight	20 kg/kg mol
Hydrogen molecular diffusion coefficient in air	4.10 x 10^{-5} m^2/sec [6]
Turbulent Schmidt number*	0.7

Note:*: Ratio of turbulent viscosity to mass diffusion

The benchmarking tests for the model representing the natural convection cooling behavior, gas species mixing, radiative heat transport, and air turbulence were made prior to the performance calculations since these phenomena are closely related to the gas driving mechanisms within a large air space of the tritium process room. Fig. 2 shows the benchmarking results for the two-equation turbulence model against the literature data [4].

The benchmarked model was applied to the tritium process system for a transient dispersion assessment of the gas flow patterns inside the process room using the boundary conditions and material properties as provided in Table 1 and Table 2.



(L/H = 3.1, W/H = 4.7, h/H = 0.056, t/H = 0.16, H = 0.0893 m)

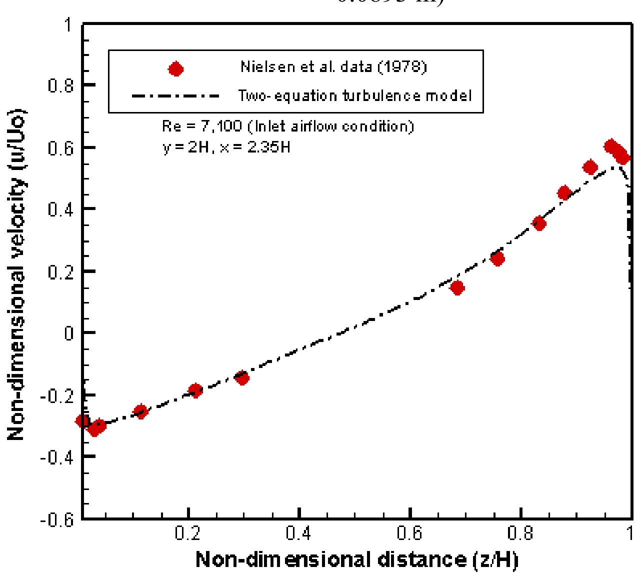
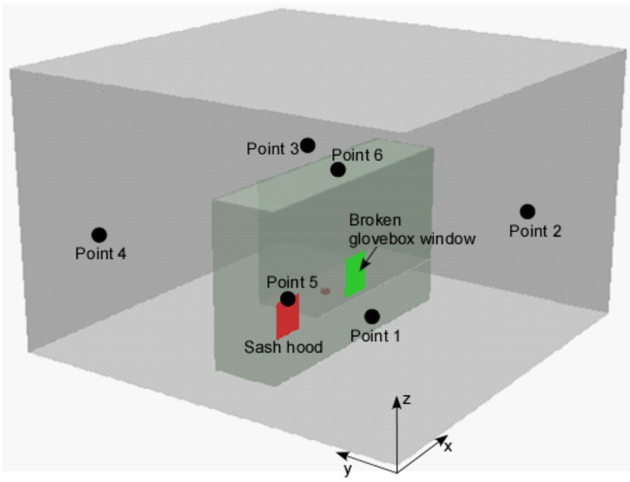


Fig. 2. Benchmarking results of non-dimensional horizontal air velocity along the line A-A' on the plane of y=2H distance from the air inlet plane at Re = 7,100 inlet flow (inlet air velocity, U_o = 10.371 m/sec).

The benchmarking test for the computational model was made as a typical case representing the air turbulence in a ventilated process room because the test case is closely related to the turbulent air circulation in a room. Based on the solution methodology and the modeling assumptions as discussed earlier, three-dimensional transient CFD approaches were taken to compute forced flow distributions for the discretized computational domain of the tritium process room containing a glovebox. In this work, the boundary conditions provided in the previous section were imposed on the modeling domain for the calculations.

For the analysis, the baseline case for a standard process room was selected for the modeling calculations. As shown in Fig. 1, the species release region due to the panel breach caused by the hypothetical glovebox fire was simulated using the layout of the interior of the process room and location of the exhaust sash hood. The monitoring probes inside the standard process room are shown in Fig. 3. In the calculations, it is assumed that the initial glovebox pressure prior to transient simulations is about 0.2-inch Water Column (WC) lower than one atmospheric pressure corresponding to -49.8 N/m^2 gauge pressure. During the transient calculations, the process room maintains 1800 cfm airflow via four corner square-type air registers. The room wall in each case is kept constant at 25°C, and it is assumed to be airtight.

When the 2nd window panel near the exhaust sash hood is completely broken under Case 1 Scenario 1, the results indicate that the entire glovebox region has tritium species concentrations higher than a threshold value of 4.0 x 10^{-5} µCi/cc to trigger the tritium alarm within about 30 seconds after the initiation of the breach accident. When the accident takes place, the results show that the ventilated airflow of 1800 cfm via four ceiling registers requires average room pressure of -36Pa (-0.15-inch WC). The incoming ventilation air moves downward along the side wall of the process room, and then it moves upward along the wall boundary of the glovebox system toward the room ceiling combined with tritium leak out flow through the broken panel. The four corner sampling points are located six feet away from the side wall of the process room and 80 inches above the room floor. When 5.8 gm tritium oxide, corresponding to 0.875 gm of tritium element, is released into the process room 25 seconds since the initiation of the accident as defined by Table 3, Fig. 4 compares transient species concentrations among all the monitoring points inside the process room under the modeling scenario. As compared in the figure, the results demonstrate that when 5.8 gm of tritium oxide is released in a standard process room for a fire accident, the response time to trigger a threshold concentration of 4 x 10^{-5} µCi/cc for all of the monitoring points ranges from 25 to 140 seconds, and the best location to detect the species migration is Point 6, which is located above the top of glovebox in the middle of the room. it is noted that the species concentration for the monitoring point near the breaching point reaches the threshold value of 4 x 10^{-5} μCi/cc in about 25 seconds, and the remote one reaches it in about 140 seconds.



Point 1 (6', 6', 80") Point 2 (24', 6', 80") Point 3 (24', 24', 80") Point 4 (6', 24', 80")
Point 5 (6.5', 12.5', 5.75') - Top of sash hood
Point 6 (17.5', 15', 12.2') - External top of glovebox center

Fig. 3. Six monitoring points for standard process room

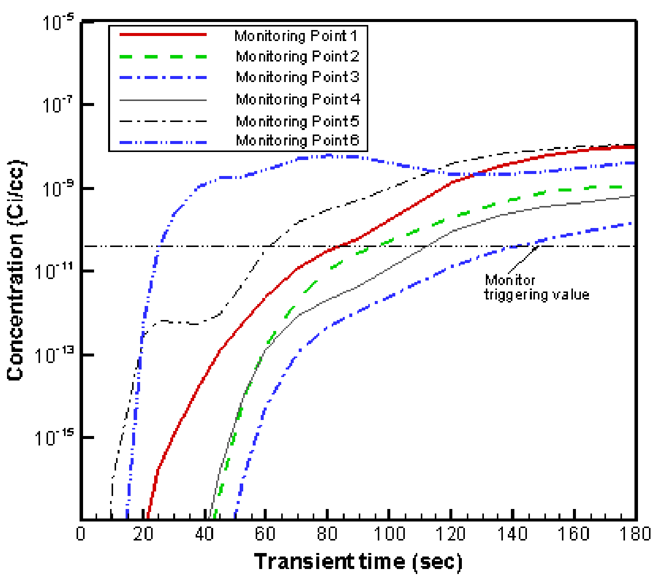


Fig. 4. Transient species concentrations for various monitoring points inside the process room under the accident scenario.

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