

# WIND-TUNNEL MODELING OF STACK DISPERSION IN COMPLEX TERRAIN<sup>1</sup>

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## ABSTRACT

A wind-tunnel study was conducted to simulate stack releases of tritiated water vapor (HTO) from its National Tritium Labeling Facility (NTLF). Physical modeling simulations were performed in the Atmospheric Boundary Layer Wind Tunnel (ABLWT) at University of California, Davis. A circular-based scaled-model (1:800) of the site represented a full-scale area of 3,000 feet (914 meters) in diameter, including all buildings, topography, and the relative tree cover. The model was also turntable mounted so that it could be rotated to any desired wind direction. Two stacks of different design and location were individually tested: i) an existing stack located in the same location as air sampling station ENV-75EG; and ii) a proposed stack to be built on the rooftop of Building 75. Stack effluent was modeled by releasing a neutrally buoyant tracer gas (ethane) from the scaled model exhaust system. Simultaneously, concentration (or dilution) levels of the dispersed emissions at specified downwind ground-level receptor sites were measured using a hydrocarbon gas analyzer. The wind tunnel simulated near-neutral atmospheric conditions (between stability category B and C of the Pasquill-Gifford categories). Tests were conducted over a wide range of wind regimes that dynamically matched full-scale speeds ranging from a few mph to speeds in excess of 25 mph.

## INTRODUCTION

This report documents a wind-tunnel study of the release of tritiated water vapor (HTO) from existing and proposed exhaust stacks located at the National Tritium Labeling Facility (NTLF) of the Ernest Orlando Lawrence Berkeley National Laboratory. The study was primarily driven by the

interest of where to appropriately locate proposed air monitoring stations. Results from this study would provide physical modeling information for positioning proposed tritium monitoring stations. The existing stack is 9.14 m (30 ft) tall and 1 m (3.28 ft) in diameter (see Figure 1). It is solely situated on the hillside slope of the Eucalyptus Grove above and to the west of NTLF Building 75 and is surrounded by numerous tall Eucalyptus trees. The proposed stack is to be constructed on the rooftop of Building 75 with a height of 4.57 m (15 ft) and a square exit cross-section of 20 by 20 inches. Both stacks are also bordered by steep topographic inclines spanning from west to east. A photo consisting of the existing stack and the location of the proposed stack is presented in Figure 2. The main objectives of the current investigation is to assess the nature of the local flow effects due to the complex terrain features of the Berkeley hills and to estimate the magnitude of concentrations dispersed from the source stacks.



Figure 1: Site Photo of Existing Stack Located Inside Eucalyptus Grove Hillside.

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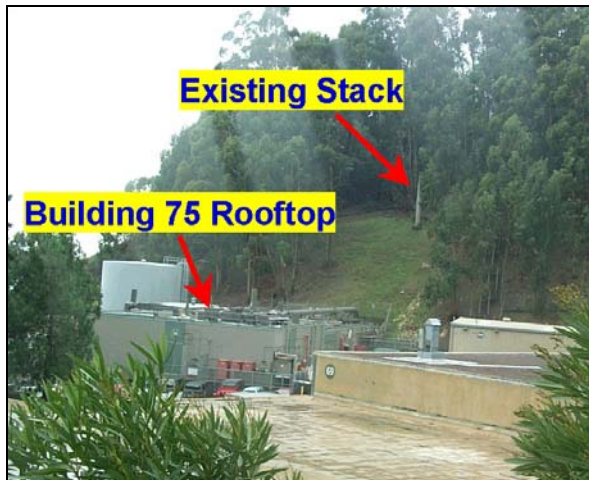


Figure 2: Site Photo of Existing Stack and Proposed Location of Building 75 Stack.

### **SIMILITUDE ANALYSIS**

#### **Comparison of Atmospheric Modeling Techniques**

Dispersion of potentially hazardous stack exhausts is of great concern when addressing the possible consequences of such releases on human health and safety and on the environment near the stack. Many variables affect the dispersion of exhausts from a stack such as wind speed and direction; stability of the atmosphere; stack height; surrounding buildings, trees, and topography; stack exhaust velocity; and initial pollutant concentrations.

Environmental assessment of an exhaust stack can be approached in three different techniques: numerical modeling, full-scale tests, or wind-tunnel simulation. Numerical models, dispersion models in particular, incorporate semi-empirical theory that generally leads to reasonable predictions of concentration levels around and even beyond the vicinity of the source emission. Many numerical models are also limited by failing to account for the local effects of nearby obstacles and of complex topography or by requiring locally measured turbulence data. Full-scale dispersion tests provide useful data for determining true concentration levels. However, conducting full-scale tests for numerous wind directions and wind speeds is relatively impractical.

Physical modeling in a wind tunnel has great potential for the simulation of atmospheric boundary

layers. A model of the site of interest is placed in a wind tunnel where wind-speed and dispersion measurements can be taken. This modeling technique can be an efficient means of obtaining reasonable estimates of a desired data while properly accounting for local flow around obstacles and turbulence characteristics of the full-scale flows.

Wind tunnel testing could also be utilized for physically simulating the flow field over highly complicated terrain conditions such as the hills around the Lawrence Berkeley National Laboratory. For terrain with complex topography, where the height changes in the order of the height of the release stack, both physical and/or numerical simulation techniques required the input of additional field measurements, especially meteorological measurements on the site. On-site wind speed, wind frequency, and atmospheric stability measurements are very important for the accurate simulation whether it is numerical or physical in nature. However, the ability of physical modeling to simulate the turbulence characteristics of the flow over small-scale terrain features in nearly neutral flow is still considered superior to available numerical models. Therefore, physical modeling can be helpful in the process of evaluating the dispersion process from a source stack. The only drawback is that the wind tunnel used in the current investigation did not simulate non-neutral atmospheric conditions that can add substantial effects on the nature of the dispersion process.

#### **Wind-Tunnel Atmospheric Modeling Parameters Emphasizing Complex Terrain**

The present wind-tunnel investigation was performed in the Atmospheric Boundary Layer Wind Tunnel (ABLWT) located at University of California, Davis (UCD). A detailed description of the facility is given in White et al.<sup>1</sup> Testing was conducted using a 1:800-inch scaled-model built on a 1.15-m diameter turntable base and centered on the site of the existing exhaust stack. Figure 3 presents a photo of the model installed inside the wind tunnel test section. In full scale, the model would encompass an area with a diameter of 3,000, which includes not only buildings of the national laboratory but also the Lawrence Hall of Science, the Math Sciences Research Institute, and the Space Science facilities, as well as all tree groves contained within the area. A small model scale was chosen due to the complexity of the terrain.



Figure 3: Wind Tunnel Scaled Model of the Berkeley Hills with the Lawrence Berkeley National Laboratory.

Since models used in a wind-tunnel simulation are typically orders of magnitude smaller than the full-scale object, it is not obvious that the results obtained will be corresponding to nature. However, results from wind-tunnel tests can be representative to full-scale conditions, as long as critical simulation of flow parameters between the model and full-scale are satisfied. For exact modeling, all flow parameters should be matched, which is impracticable, if not impossible. Thus, similitude parameters, critical to the modeling of the present wind-tunnel simulation, must be selected.

By normalizing the time-averaged equations of fluid motion, similitude parameters are given by the Rossby number, the Densimetric Froude number, the Prandtl number, the Eckert number, and the Reynolds number. Application of these non-dimensional quantities along with their host equations of motion can describe atmospheric flows over all types of terrain conditions, including those that are complex in nature. Based on an analysis of the similitude parameters presented in White et al.<sup>1</sup>, only the critical Reynolds numbers related to boundary-layer dynamic similarity are important for the current wind tunnel modeling (given that the targeted simulated flow is neutrally stable and corresponds only to the lowest hundred meters of the atmosphere). Thus, for the current investigation, the Rossby number similarity is neglected since effects of upper atmospheric motion, driven by the earth's rotation, become insignificant for length scales less than five miles. Froude number matching is ignored for neutrally stable conditions. The Prandtl number already matches since the fluid media is identically air. The Eckert number is excluded since the modeled and full-scale flows are incompressible.

### Wind-Tunnel Atmospheric Boundary Layer Similarity For Complex Terrain

Physical modeling of the complex terrain was additionally limited by the required atmospheric boundary-layer similarities and by the physical size constraints of the wind-tunnel test section. Analysis of such modeling conditions is presented in White et al.<sup>1</sup> A circular turntable model can easily encompass the entire 1.18-m width of the test section. However, geometric scaling was restricted given two critical conditions: i) the highest point on the model is maintained within the wind tunnel boundary layer region that meets full-scale similarity; and ii) the model cross-sectional area facing the incoming flow does not cover more than 15% of the test section cross-section so as to prevent pressure-gradient driven flow.

Boundary-layer similarities were satisfied by the long flow development design of the Atmospheric Boundary Layer Wind Tunnel. With the use of triangular spires and the distribution of roughness elements, a fully developed aerodynamically rough boundary layer is generated at the test section. For a free stream wind tunnel speed of 3.8 to 4.0 m/s, the boundary layer grows to a height of about one meter at the test section, in which the logarithmic wind profile region is in the lowest 20%. Since this region is the only portion of the wind-tunnel boundary layer that is dynamic similar to the surface region of the atmosphere, the first requirement suggested that the model be scaled so that the highest peak of the terrain is no higher than 0.2 m. If the model diameter was equivalent to the test section width, a 0.2-m height limitation provides a model cross-sectional area much less than 15% of the test section cross-section.

Since the main objective of the wind-tunnel study was to trace the resulting concentration distribution due to the effects of complex topography, a model representing the largest full-scale area that essentially includes the most dominant terrain features was initially considered. Thus, the turntable model was constructed on a 1.15-m diameter base, spanning the test-section width. Considering the size and similarity constraints, the wind tunnel model was geometrically sized using a 1:800 reduction. Centering on the UC grid coordinates, 3500E and 500N, which is near the location of the existing stack, the wind tunnel model depicted a circular full-scale area 3000 ft. in diameter. Although, the wind tunnel

model can represent only a few kilometers of the regional topography, it still captures the most distinct land features that could contribute significant local dispersion process of stack emissions. Wind-tunnel simulation can be a useful tool in the analysis of the dispersion process within a complex terrain region such as the hills around the Lawrence Berkeley National Laboratory.

### **Wind-Tunnel Stack Emission Dispersion Modeling**

Stack emissions were modeled using a neutrally buoyant, hydrocarbon tracer gas. By monitoring hydrocarbon concentration levels with an ion flame detection system, the dilution of the stack emissions was determined at a measured receptor location. The scaling was accomplished by maintaining the momentum ratio of the vertical exhaust effluent to the horizontal wind speed, at the stack height and location, constant between full scale and the wind-tunnel simulation. To insure a fully turbulent discharge, a tripping device was incorporated in to the model exhaust stack.

The full-scale meteorological data, acquired on 20-meter tower near Building 44, used in the following manner to determine the wind speed at which the model test was to be conducted. The wind speed and direction, in the tunnel, was set to model the full-scale conditions at the meteorological tower, the wind speed then was measured in the wind tunnel at the model stack location and height. Note, this value could be substantially different from the speed observed at the meteorological tower due to the affect on the complex terrain on the wind flow patterns. Thus, it was essential to correlate the relationship between the meteorological tower speed and direction to that of the speed and direction the wind at the top of the stack being measured. This correlation data was measured for all 16 major wind sectors used in the annual average analysis and the wind-tunnel settings made according to the results of the correlation.

For each of the 16 wind directions that were measured at the Lawrence Berkeley National Laboratory in full scale, a separate wind-tunnel simulation test was conducted for each of the 16 wind directions. These tests were conducted to correlate the change in wind speed and directions between the meteorological station and the wind and direction that would be experienced at the stack locations.

## **WIND TUNNEL RESULTS AND ANALYSIS**

Wind-tunnel simulations were divided into three test phases. An initial test was performed to examine the horizontal dispersion of the exhaust plume downwind of the source stack. In the second phase, concentrations were collected over a grid network of 49 points around the emission source, representing a 600-ft by 600-ft square area. For the third phase, measurements over a larger grid system that encompassed the entire wind-tunnel turntable model were conducted for estimation of annual average exposure levels.

### **Phase 1: Effect of Complex Terrain on the Dispersion of Stack Emissions**

In the first phase of wind tunnel simulations, the downwind dispersion of emissions from the existing stack model was traced to determine the combined effects of angular wind offset and of the surrounding complex terrain. Wind speeds at the stack height were simulated based on equivalent full-scale magnitudes of 2.5, 5, and 20 mph. According to atmospheric field data recorded from a nearby 20-m meteorological (MET) tower located at LBNL Building 44. Local wind speeds routinely range from 0.5 to 20 mph.

Single-source emission dispersion over flat terrain is Gaussian in nature where the highest downwind concentrations are expected to fall at locations directly centerline from the stack. Due to the complex terrain in which the national laboratory is situated, exhaust dispersions may not always be Gaussian where the downwind peak concentrations could be off centerline from the direction of the incoming wind angle. Located on the map in Figure 4 are four test point locations found to be useful for examining concentration measurement sensitivity.

It was expected that the typical Gaussian distribution of normal dispersion of stack effluent would not be observed due to the complex nature of the surrounding terrain of the Berkeley hills. Consequently, it was necessary to determine the ranges of variations that might be expected to be observed in the wind-tunnel testing of the various combination of stack release-receptors that would be needed to be tested. The Gaussian distribution of the effluent was not observed and the following describes the approach taken to determine the variation of the effluent.

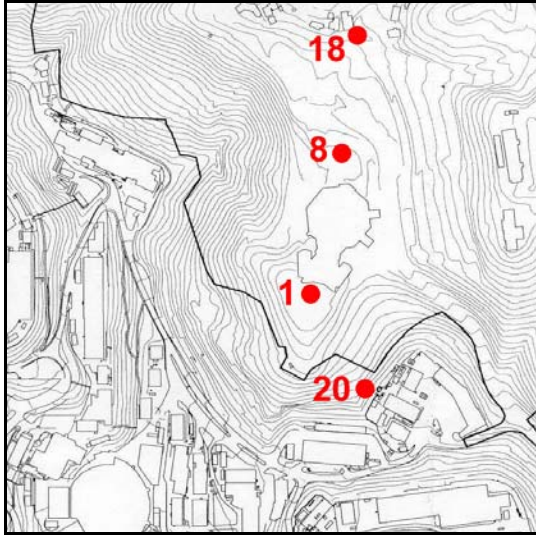


Figure 4: Map Locations of Phase 1 Test Points.

Downwind concentration measurements for each wind-speed model were first attempted for a setting where the test points were at a straight-line distance directly downwind from the source stack. Such a baseline setting was referred to as the “zero-angle”. Using the same wind speed range, measurements were then made at the same test point location for a range of angle rotations clockwise and counter-clockwise about the source stack (as viewed from above) deviating the test location away from the “zero angle” setting. The angular offset was continually increased in both rotational directions about the “zero angle” until the concentration measurements were no longer sensitive to angular variation or negligible in magnitude.

Resulting graphs of full-scale concentrations and dilution factors measured at each of the Phase 1 test point locations are presented in Figures 5 to 8 and Figures 9 to 12, respectively, for a range of simulated wind speeds at the height of the stack. Accordingly, an observed trend was that the highest concentrations were measured for settings where the test point location was directly downwind from the stack (i.e., zero angle) and also for stack wind-speeds corresponding to 2.5 mph or less in full-scale. The exception was Point #20, located at the UC grid system coordinates, 3527 E and 566 N, the immediate vicinity of the Eucalyptus Grove air-monitoring station location (ENV-75EG). For a simulated 2.5 mph full-scale wind, a maximum concentration of 12,063 PPM was predicted when Point #20 was rotated from the “zero angle” setting at an angle of  $-20^\circ$ .

This initial test simulation produced concentration measurements within the same major wind sector (i.e. south, southwest, etc.). Thus, the data would not appropriate for calculation of annual average concentrations, which incorporate MET tower data for all wind directions impinging upon any given point. However, a particularly important deduction from this phase showed that the nature of the complex terrain would contain the downwind exhaust plumes within a maximum  $\pm 22.5^\circ$  angular dispersion.

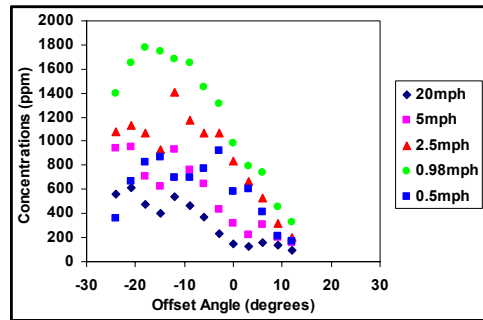


Figure 5: Full-scale Concentrations at Point #1 at Each Rotation from the Dispersion Centerline.

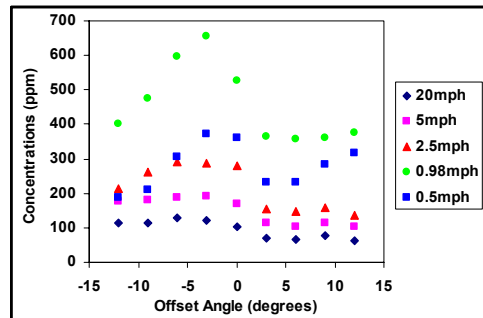


Figure 6: Full-scale Concentrations at Point #8 at Each Rotation from the Dispersion Centerline.

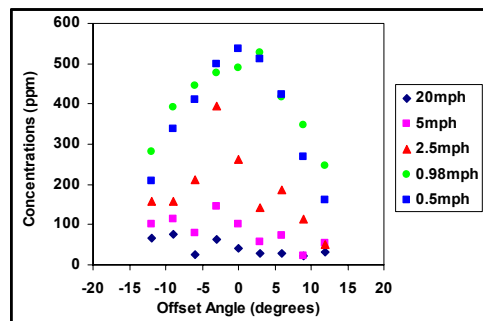


Figure 7: Full-scale Concentrations at Point #18 at Each Rotation from the Dispersion Centerline.

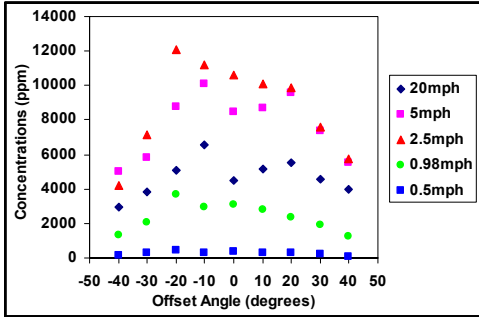


Figure 8: Full-scale Concentrations at Point #20 at Each Rotation from the Dispersion Centerline.

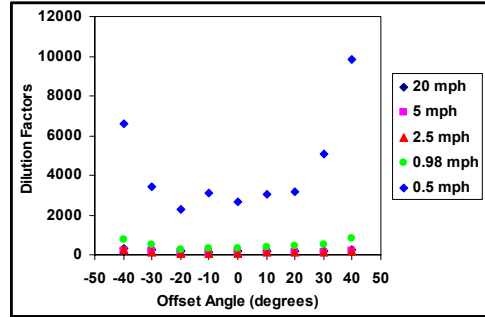


Figure 12: Dilution Factors at Point #20 at Each Rotation from the Dispersion Centerline.

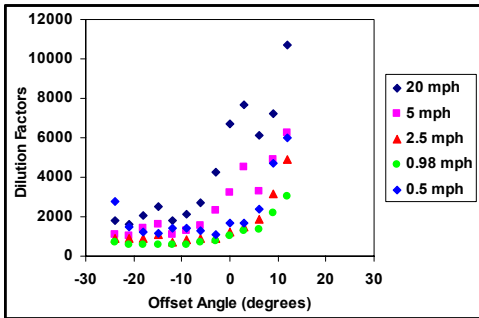


Figure 9: Dilution Factors at Point #1 at Each Rotation from the Dispersion Centerline.

### Phase 2: Contours for Two Predominant Wind Directions

The objective of second phase of wind-tunnel simulations was to collect concentration samples over a grid network of 49 points around the emission source, representing a 600-ft by 600-ft square area, for releases dispersed from the existing stack and from the proposed stack on the roof of Building 75.

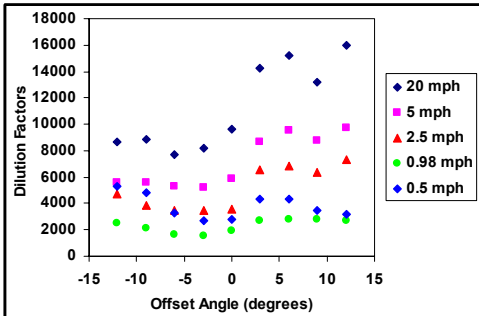


Figure 10: Dilution Factors at Point #8 at Each Rotation from the Dispersion Centerline.

Each grid network was sampled for the three wind speeds and two directions with its upwind edge centered on the original stack location at UC grid coordinates, 3550 E and 520 N. The grid was later shifted to center the upwind edge on the proposed Building 75 stack location at UC grid coordinates, 3622 E and 449 N. Figures 13 and 14 show the grid for wind from West and Southeast, respectively. The grid sampled is for the wind from the southeast.

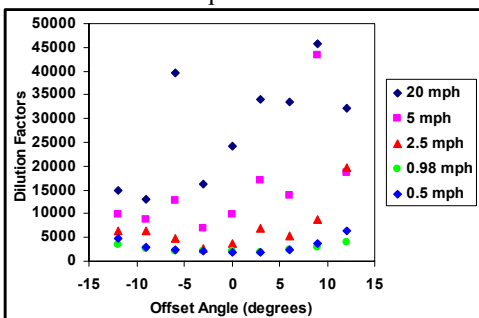


Figure 11: Dilution Factors at Point #18 at Each Rotation from the Dispersion Centerline.



Figure 13: Phase 2 Grid Network of Test Locations for West Wind Setting.

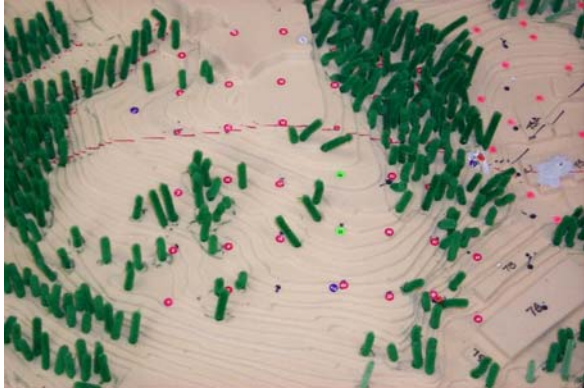


Figure 14: Phase 2 Grid Network of Test Locations for Southeast Wind Setting.

In all, twelve contour plots were produced and are presented in Figure 15 thru Figure 26. Figure 15 to Figure 17 present concentration contours for the original stack with winds originating from the West, blowing directly toward Building 69. Examination of these contours will show the 20-mph wind from the West to have a highest peak concentration of 11,000 ppm located near the stack. This trend was a common observation for higher wind speeds simulated over the stack. It is a result of the effluent being pulled into the stack wake. This is commonly referred to as a downwash effect, prevalent at high wind speeds. Another observation is the second peak seen in each of these plots. This peak occurs near the vicinity of Building 69 and is evidently caused by the plume trajectory impacting onto the hill located directly to the East (relative to grid North) as the plume impinges on this elevated terrain. The values of this second peak were as low as 120 ppm for the more dispersive 20-mph wind and as high as 480 ppm for the lower wind case of 2.5 mph.

Figure 18 to Figure 20 present concentration contours generated by a west wind for the proposed 15-ft stack at Building 75. This stack has a cross-sectional area of 400 in<sup>2</sup> and a volumetric flow rate of 6500 cfm. Thus, the exit velocity is 39 ft/s compared to 14.7 ft/s for the original stack. This higher exit velocity explains the absence of a peak concentration value near the base of the stack for the 2.5 and 5.0 mph wind speed cases since the effluent has more momentum to escape the downwind stack wake. The peak concentrations range from 490 ppm in the 5-mph case to 770 ppm in the 2.5-mph case and occur near the vicinity of Building 69. The 20-mph case exhibits a high wind behavior similar to the downwash flow observed from the existing stack simulation where the effluent is pulled into the wake

of the stack. This wind condition resulted to a 1500-ppm peak concentration near the base. A second peak concentration as high as 200 ppm was also observed again at the site of Building 69. The irregular contour shape is due to the large-scale circulation of the flow field and the mixing associated with this occurrence because of the higher wind speeds and complex terrain.

Figure 21 to Figure 23 display concentration contours for the existing stack for winds blowing from the Southeast, generally towards the Lawrence Hall of Science. These plots show similar concentration contours with maximum concentrations of approximately 5000 ppm occurring within a 140-ft radius of UC grid coordinates 3400 E and 600 N.

The concentration values decline rapidly in the Northeast and Southwest directions. The 20-mph wind speed case in Figure 23 shows the peak concentration of 7200 ppm localized in the immediate vicinity of the stack. The concentration falls to 1000 ppm within 300 feet of the stack in the downwind direction.

Figure 24 to Figure 26 present concentration contours for the Building 75 stack for the Southeast wind direction. These concentrations are generally lower than those measured for the existing stack location due to a relatively lower volumetric flow rate of 6500 cfm coupled with its 39 ft/s exit velocity. The combined effects of these two factors facilitate faster mixing rates and dilution of the plume.

Figure 24 shows the effect of decreased plume mixing due to the relatively lower 2.5-mph wind. The contours show a plume with a concentration of 1400 ppm extending approximately 560 feet in the downwind direction. The 5 and 20 mph wind cases, shown by Figures 14 and 15, respectively, demonstrate that the Building 75 stack would have relatively lower concentration values than the original stack location for this same direction.

The twelve contour plots from this test phase illustrate results that would lend well to the study of a worst case, accidental release scenario. These results are for constant wind directions and are only appropriate for the examination of events occurring on a time scale less than, approximately, one hour. The following example illustrates a means for calculating exposures in the scenario mentioned above.

Dimensionally, the formula is the following:

$$[pCi/m^3] = (X[Ci]) * \left( \frac{10^{12}[pCi]}{1[Ci]} \right) * \left( \frac{C[ppm]}{10^6} \right) * \left( \frac{1[hr]}{1[m^3]} \right)$$

Here, 'X' is the total amount of concentration in Ci released in one hour, 'C' is the concentration from the desired location on the contour plots, and m<sup>3</sup> is the total volumetric flow rate of the mixture released in the units of cubic meters per hour. Entering the following example values for an accidental release scenario:

X = 1 Ci  
 C = 100 ppm (at a fictitious point location selected from a contour plot)

Flow rate = (6500 CFM)(0.3048 m/ft)<sup>3</sup>(60 min/hr) = 11,044 m<sup>3</sup>/hr

The resulting exposure is calculated to be:

Exposure = (1 x 10<sup>12</sup> pCi)(100 ppm/10<sup>6</sup>)(1 hr/11,044 m<sup>3</sup>) = 9054.7 pCi/m<sup>3</sup>.

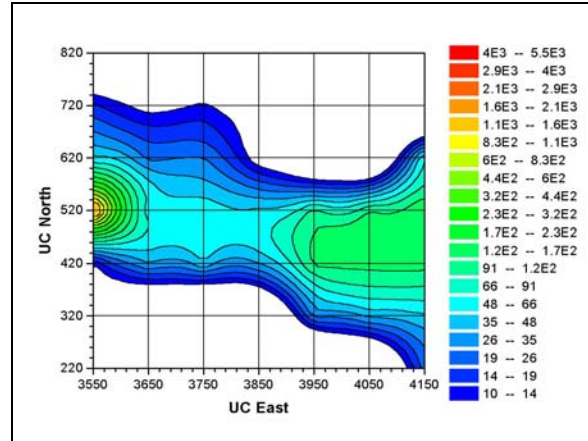


Figure 16: Concentration Isolines (PPM) Measured from the Existing Stack for 5 mph Westerly Wind.

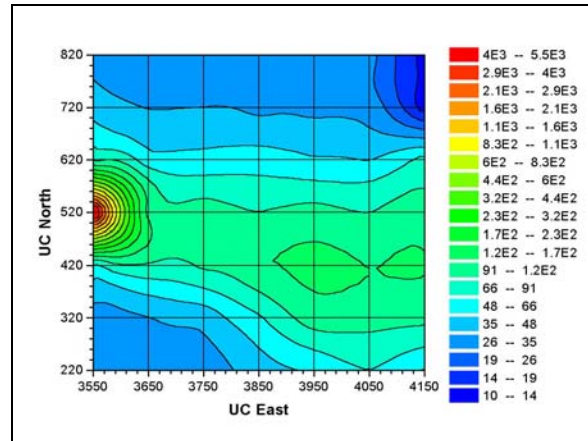


Figure 17: Concentration Isolines (PPM) Measured from the Existing Stack for a 20 mph Westerly Wind.

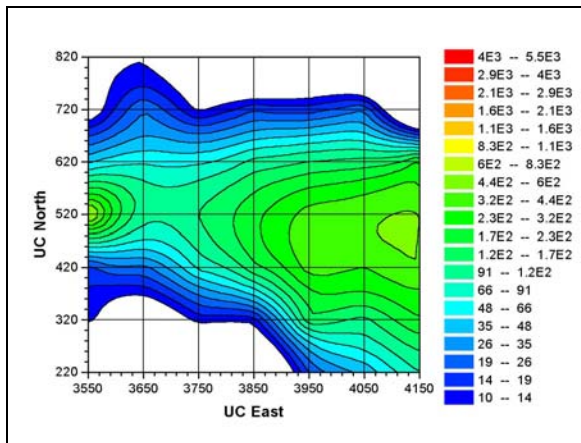


Figure 15: Concentration Isolines (PPM) Measured from the Existing Stack for a 2.5 mph Westerly Wind.

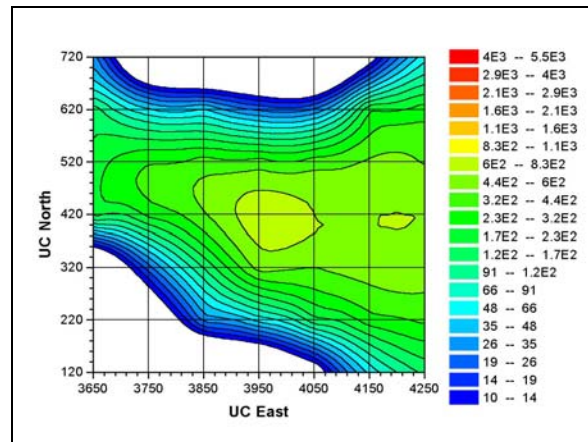


Figure 18: Concentration Isolines (PPM) Measured from the Proposed Building 75 Stack for a 2.5 mph Westerly Wind.



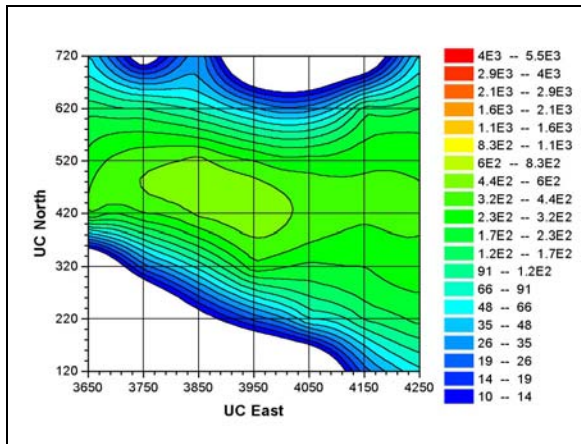


Figure 19: Concentration Isolines (PPM) Measured from the Proposed Building 75 Stack for a 5 mph Westerly Wind.

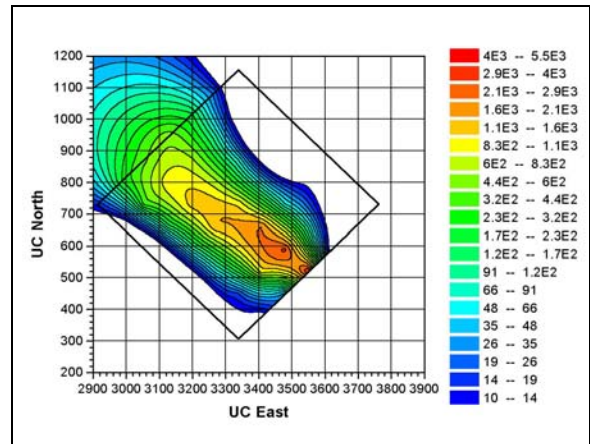


Figure 22: Concentration Isolines (PPM) Measured from the Existing Stack for a 5 mph Southwesterly Wind.

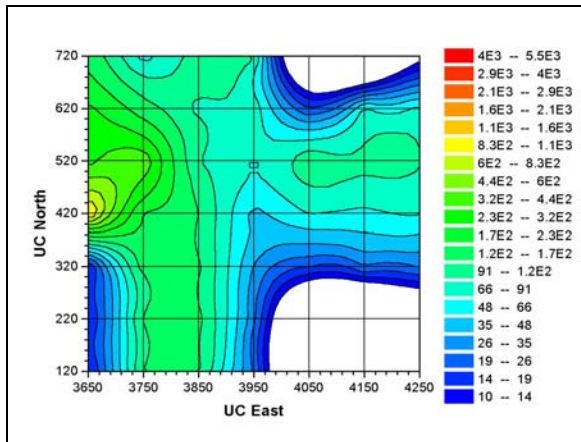


Figure 20: Concentration Isolines (PPM) Measured for Proposed Bldg. 75 Stack for a 20 mph Westerly Wind.

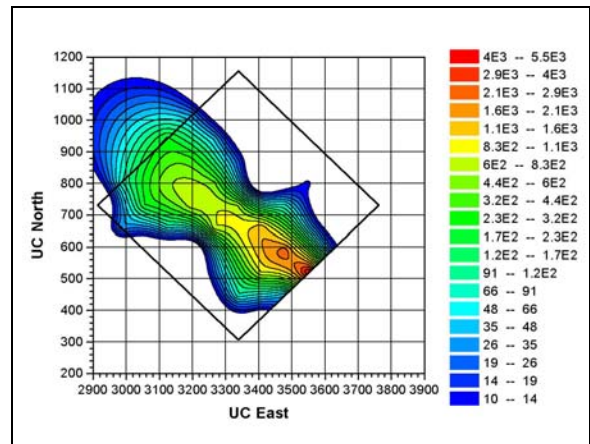


Figure 23: Concentration Isolines (PPM) Measured for Existing Stack for a 20 mph Southwesterly Wind.

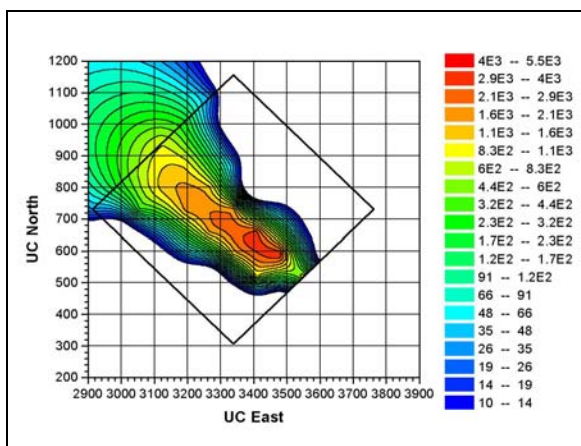


Figure 21: Concentration Isolines (PPM) Measured from the Existing Stack for a 2.5 mph Southwesterly Wind.

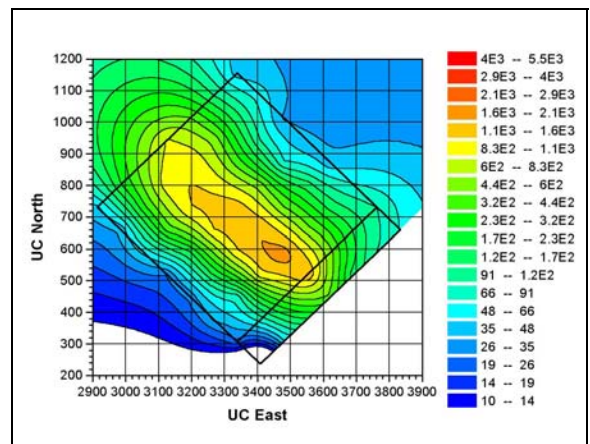


Figure 24: Concentration Isolines (PPM) Measured from the Proposed Building 75 Stack for a 2.5 mph Southwesterly Wind.

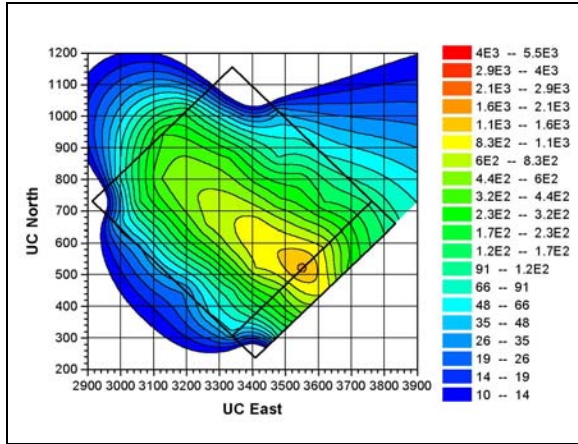


Figure 25: Concentration Isolines (PPM) Measured from the Proposed Building 75 Stack for a 5 mph Southwesterly Wind.

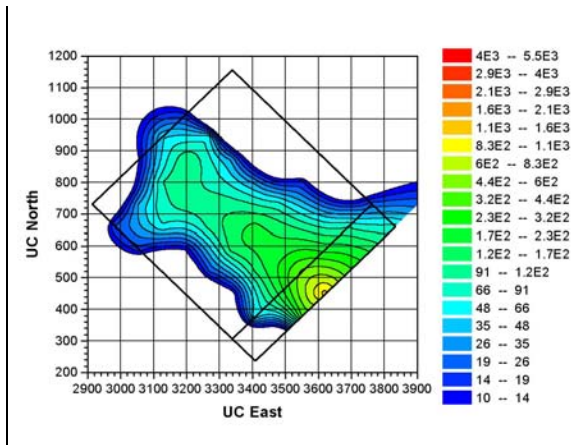


Figure 26: Concentration Isolines (PPM) Measured from the Proposed Building 75 Stack for a 20 mph Southwesterly Wind.

**Phase 3: Concentration Distributions For a Given Annual Release**

A final phase of the wind-tunnel study investigated the amount of annual concentrations dispersed from the proposed stack on Building 75 given the annual release rates of 30 and 100 Ci of tritiated water vapor (HTO). Results from this simulation were compared to predictions generated by SENES Oak Ridge Inc.<sup>2</sup> using the numerical dispersion code, CALPUFF. To accurately predict annual-average concentrations, both wind tunnel and numerical calculations incorporated wind data collected at the Lawrence Berkeley National Laboratory 20-meter meteorological tower located at

Building 44. Stack releases also were assumed to occur continuously during a day for an entire year.

CALPUFF generated predictions for an area of several kilometers extending from the site of the national laboratory. In order to produce results that are more comparable to that of CALPUFF, the wind-tunnel simulation involved concentration measurements on a grid system of 29 test points, which encompassed the entire area of the turntable model. The model area represented a full-scale diameter of 3000 ft. centered on the laboratory stack sites. Using the UC grid system, each of the 29 test points was located at each 500-ft node within a 3000 ft diameter.

Wind-tunnel simulations at each test point were conducted in correspondence to the full-scale wind speeds of 4, 10, 16, and 24 mph. According to the wind data, a 4-mph wind was used to represent the combined wind bins with a range of 1 to 3 knots and 4 to 6 knots. The 10-mph and 16-mph winds covered the 7 to 10 knots and 11 to 16 knots, respectively, while the 24-mph wind corresponded to both the 17 to 21 knots and greater than 21 knots range. For the combined wind bins, the hours of occurrences for each wind direction were also combined. Measurements also were performed for 16 primary wind direction rotations. For each direction, concentrations were collected not only for test points that fall within a 22.5° sector downwind from the source stack but also for a few points off the sector still indicating high enough concentrations that could be significant to the annual average. Upon completion of the wind-tunnel test, all measured concentrations for each wind direction and speed settings were then converted to full-scale dilutions.

Assuming the stack releases are continuous day and night for one year and given the full-scale stack release rate of 6500 CFM, the presumed annual-average releases of 30 and 100 Ci of HTO correspond to concentrations of  $3.10 \times 10^5$  and  $1.03 \times 10^6$  pCi/m<sup>3</sup>, respectively, initially emitted from the source stack. Dividing these source concentrations by the full-scale dilutions calculated at each test point and then multiplying by the corresponding wind bin frequency for a particular direction, the fraction of HTO concentration that has reached each test location was then determined for each wind speed and direction setting. Summing these fractions from each wind speed setting resulted to an annual concentration value accumulated at each test location for a particular wind direction. The total annual concentrations generated at each test point location were then found by adding the annual concentrations contributed by each wind direction. With a grid

system of calculated total annual concentrations, concentration isolines were constructed by using a linear interpolation scheme to estimate values for locations between known test locations.

Predicted concentration isolines from the wind-tunnel simulation show a slight variation to those predicted by CALPUFF. From an annual release of 30 Ci, the numerical code calculated a highest concentration of 20 pCi/m<sup>3</sup> would appear a few feet passed the southeast end of Building 69. The wind-tunnel method, on the other hand, predicted that the 20-pCi/m<sup>3</sup> ranges would occur in two areas, over the slopes of the Eucalyptus Grove and at the center of Building 69. One other significant difference shows in the trace of the 5 pCi/m<sup>3</sup> isoline. CALPUFF predicted that the Lawrence Hall of Science would be excluded from this concentration range, whereas, the wind-tunnel approach showed that the southern half of the complex would be exposed.

### CONCLUSION

A wind-tunnel study was conducted for the Environmental, Health, and Safety Division of the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) to simulate stack releases of tritiated water vapor (HTO) from its National Tritium Labeling Facility (NTLF). Physical modeling simulations were performed in the Atmospheric Boundary Layer Wind Tunnel (ABLWT) at University of California, Davis. A circular-based scaled-model (1:800) of the site represented a full-scale area of 3,000 feet (914 meters) in diameter, including all buildings, topography, and the relative tree cover. The model was also turntable mounted so that it could be rotated to any desired wind direction. Two stacks of different design and location were individually tested: i) an existing stack located in the same location as air sampling station ENV-75EG; and ii) a proposed stack to be built on the rooftop of Building 75. Stack effluent was modeled by releasing a neutrally buoyant tracer gas (ethane) from the scaled model exhaust system. Simultaneously, concentration (or dilution) levels of the dispersed emissions at specified downwind ground-level receptor sites were measured using a hydrocarbon gas analyzer. The wind tunnel simulated near-neutral atmospheric conditions (between stability category B and C of the Pasquill-Gifford categories). Tests were conducted over a wide range of wind regimes that dynamically matched full-scale speeds ranging from a few mph to speeds in excess of 25 mph.

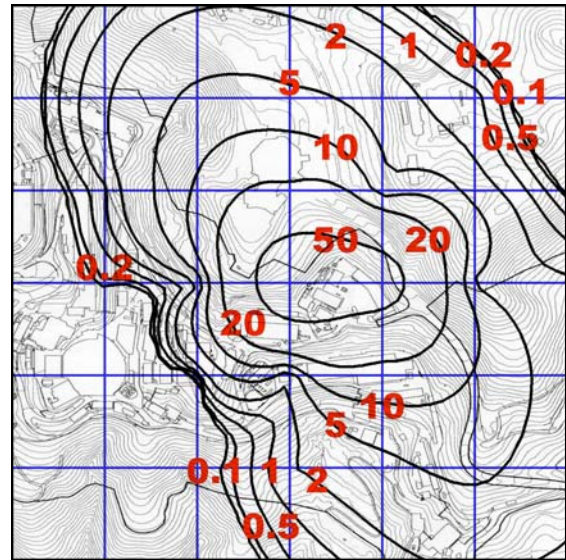


Figure 27: UC Davis Wind Tunnel Predictions of Annual Averaged Tritium Concentration (pCi/m<sup>3</sup>) Isolines Based on a Yearly Release of 100 Ci HTO.

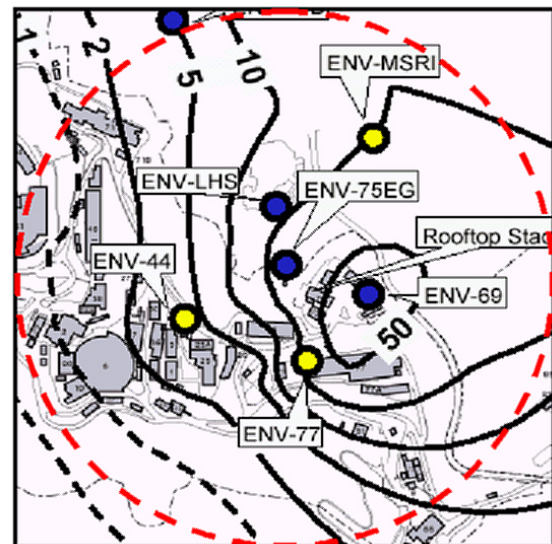


Figure 28: CALPUFF Predictions of Annual Averaged Tritium Concentration (pCi/m<sup>3</sup>) Isolines Based on a Yearly Release of 100 Ci HTO. Ref. 2.

Due to the complexity of the terrain, this wind-tunnel study was coordinated into three phases. An initial test was performed to determine the effects of the Berkeley site topography on the dispersion of the stack release. In order to design a complete test matrix for the site, a general understanding of the complex terrain's diversion of regions of highest concentrations must be first established. This preliminary examination was accomplished by measuring and comparing the concentration levels accumulated at a specific test point for various wind-vector rotations about the effluent source. Over relatively flat or leveled terrains under neutral atmospheric stability, emission dispersion from a single point-source emission inherently develops a statistically Gaussian distribution of lateral concentrations with peak levels at the centerline for any distance downwind. This initial simulation showed that the downwind dispersion angle from both the existing and proposed test stacks were limited to a maximum spread of  $\pm 22.5^\circ$  from its source.

The second phase of the current study assessed the concentrations and dilution factors over a uniform grid of 49 downwind test receptors for the two most frequent wind directions blowing from the west and southeast and for three common full-scale wind speeds: 2.5, 5, and 20 mph. Both the existing stack and the proposed stack on top of Building 75 were simulated. The downwind measurement area for both stack settings was approximately 600 by 600 feet in full scale, with the test stack situated at the center of the upwind edge of the grid. Based on the measured downwind dilutions from the west wind direction setting, the existing stack's performance proved slightly better than that of the proposed stack on Building 75. For the southeasterly wind direction, the result is opposite in which the proposed stack on top of Building 75 would provide better dilution in the comparable downwind areas than the existing stack. Plots of concentration isolines would simulate routine exhaust releases for the common wind directions. The results also could be used to simulate an accidental release of non-elevated temperature effluent resulting from non-scheduled event such as a large-magnitude earthquake, human error, major equipment failure, etc. An exposure estimate could be made by knowing (or assuming) the total amount of radiation release over a specified time and then by applying the dilution factors as a function of location. For example, if 10 Ci were released continuously for one hour and a downwind area measured a full-scale concentration of 100 ppm, which corresponds to a

dilution factor of 10,000, the tritium radiation concentration would be  $(10 \times 10^{12} \text{ pCi})(100 \text{ PPM}/10^6)(1 \text{ hr}/11,044 \text{ m}^3) = 90,547 \text{ pCi}/\text{m}^3$ .

The third phase of wind-tunnel tests were conducted to determine the annual averaged tritium concentration in  $\text{pCi}/\text{m}^3$  for yearly releases of 30 and 100 Ci HTO respectively. It was assumed that the release process was occurred 24 hours per day and seven days per week during an entire year. The contour isolines shown were generated from 29 individual receptors located on the intersection of the 500 feet node lines of the UC grid map in the figure. The red circular dotted line represents the physical size of the area simulated on the turntables during the testing. Figures 21 and 22 display the SENES Oak Ridge Inc. CALPUFF predictions of tritium concentration ( $\text{pCi}/\text{m}^3$ ) for the same set of isoline contours based on the identical yearly releases of 30 and 100 Ci HTO, respectively. Patterns of dispersion predicted by the two approaches (CALPUFF and wind tunnel) differ slightly; however, the magnitudes of concentrations estimated by each approach are similar.

## REFERENCES

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- [2] Thomas, B.A., 2001, "A Safety Study of Exhaust Stack Emissions from the National Tritium Labeling Facility (NTLF) Located at Lawrence Berkeley National Laboratory, Berkeley, CA," SENES Oak Ridge Inc. Oak Ridge, Tennessee.