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ABSTRACT

Current federal guidance on occupational radiation protection recognizes the importance of conducting air flow studies to assist in the placement of air sampling and monitoring equipment. In support of this, Pacific Northwest Laboratory has provided technical assistance to Westinghouse Hanford Company for the purpose of evaluating the adequacy of air sampling and monitoring locations at selected Hanford facilities. Qualitative air flow studies were performed using smoke aerosols to visually determine air movement. Three examples are provided of how air flow studies results, along with information on the purpose of the air sample being collected, were used as a guide in placing the air samplers and monitors. Preparatory steps in conducting an air flow study should include 1) identifying type of work performed in the work area including any actual or potential release points, 2) determining the amounts of radioactive material available for release and its chemical and physical form, 3) obtaining accurate work area descriptions and diagrams, 4) identifying the location of existing air samplers and monitors, 5) documenting physical and ventilation configurations, 6) notifying appropriate staff of the test, and 7) obtaining necessary equipment and supplies. The primary steps in conducting an air flow study are measurements of air velocities in the work area, release of the smoke aerosol at selected locations in the work area and the observation of air flow patterns, and finally evaluation and documentation of the results.

INTRODUCTION

Over the past year, Pacific Northwest Laboratory (PNL)[A] has provided technical support to Westinghouse Hanford Company (WHC) for the purpose of evaluating the adequacy of air sampling and monitoring locations at approximately 70 work areas within Hanford facilities. The facilities ranged in size from small crane cabs (<200 ft^2 [18 m^2]) to a quarter-mile-long (400-m) corridor. Qualitative air flow studies, using smoke aerosols to visually determine air movement, and air velocity measurements were performed.

The purpose of this paper is to report the methods used in evaluating air flow patterns and how this information was used as a tool to guide the placement of air samplers and continuous air monitors (CAMs). The following areas are discussed: the regulatory need for air flow studies, the types of air flow studies, qualitative air flow study methods, typical air flow study results, and how these results are used to assist in the placement of samplers and monitors.

REGULATORY REQUIREMENTS

Both the U.S. Department of Energy (DOE), in DOE Order 5480.11,[(1)] and the U.S. Nuclear Regulatory Commission (NRC), in 10 CFR 20,[(2)] have revised requirements for workplace air sampling. Guidance documents being developed

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to support both DOE Order 5480.11 and the revised 10 CFR 20 recommend conducting air flow studies as a basis for assisting in the placement of air samplers and CAMs. Assessors conducting DOE technical safety appraisals and Tiger Team Inspections in recent years have been looking at facilities to determine if they have a documented basis for air sampler placement. Thus, the need for facility health physics staff to conduct air flow studies exists.

TYPES OF AIR FLOW STUDIES

The two types of air flow studies are quantitative and qualitative. Quantitative air flow studies provide measurements of dilution effects in the work area. In a quantitative test, nonradioactive aerosol tracers are released into the workplace air to simulate a radioactive material release. The aerosol concentrations are then measured at selected locations in the work area to provide a quantitative indication of aerosol dispersion.

Qualitative air flow studies (i.e., smoke testing) were chosen for the Hanford work because of the savings in time and cost over quantitative studies. While quantitative studies require the purchase of specialized equipment and the associated training of the staff in using the equipment, the only cost involved with smoke testing is the purchase of smoke tubes, smoke candles, and an air velocity meter. In addition, health physics technicians can be easily trained to conduct air flow studies using smoke aerosols.

QUALITATIVE AIR FLOW STUDY METHODS

The primary steps in conducting a qualitative air flow study are preparation, air velocity measurements, the smoke tests, and documentation of the results.

Preparation for Air Flow Studies

The following preparation activities should be performed to conduct an effective air flow study: 1) identifying type of work performed in the work area, including any actual or potential release points; 2) determining the amounts of radioactive material available for release as well as its chemical and physical form; 3) obtaining accurate work area descriptions and diagrams; 4) identifying the location of existing air samplers and CAMs; 5) documenting physical and ventilation configurations; 6) notifying appropriate staff of the test; and 7) obtaining necessary equipment and supplies.

Health physics and operations staff responsible for the work area should be consulted to obtain information on the type of work performed and any actual and potential airborne release points in the work area. Information on the type and amounts of radioactive materials present, chemical and physical forms of the materials, and the type of containment and confinement present should also be requested. Observation of air flow patterns around actual or potential release points will be of primary importance during the smoke testing.

Building drawings should be obtained that show major physical structures (e.g., equipment, doors, windows) and ventilation structures (i.e., location

of supply air vents and exhaust vents). The location of existing air samplers and air monitors should be identified on the building drawing. In addition, the building configuration during normal working conditions should be documented. This includes the status of doors and windows to the outside and within the work area, as well as the status of the ventilation system (i.e., operability of supply air and exhaust ducts, supply and exhaust flow rates, and differential pressure readings between work areas). Building personnel such as the building manager should be consulted when trying to document the normal configuration for the building. This configuration should be maintained throughout the air flow study or any differences in parameters should be noted.

Personnel performing the air flow study should notify the building manager so the timing of the test can be arranged to minimize the effect on operations. Arrangements need to be made to evacuate facility staff from the work area during the smoke testing. The fire department also needs to be notified to deactivate any smoke detectors in the building and work areas.

Equipment and supplies needed to perform the test include smoke tubes, smoke candles, air velocity meters, full-face respirators, and other miscellaneous supplies. Smoke tubes produce a small amount of smoke (i.e., about that of a burning cigarette). The tubes produce a cold (chemical) smoke and consist of either ethylenediamine/acetic acid or stannous chloride. Smoke is released when air is forced through the tube using an aspirator bulb. Smoke candles typically consist of zinc chloride and are available in several sizes (e.g., candles which produce 4000 ft^3 [113 m^3] of aerosol in 30 seconds and candles which produce 8000 ft^3 [227 m^3] of aerosol in 60 seconds). Air-

purifying respirators should be provided with cartridges to filter out both particulates and gas vapors.

Air Velocity Measurements

Air velocity measurements are taken with an air velocity meter, typically a hot-wire anemometer. The air velocity measurements provide a means of quantifying the air flow movements throughout the work area. Air velocity readings should be taken at supply air and exhaust vents that are accessible, entrances and exits to the work areas, and near actual and potential airborne release points. Areas of rapid air movement and stagnant air flow will be identified. Correlation of air flow study results and velocity measurements showed that air velocities less than about 30 linear feet per minute (lfm) (0.15 m/s) represent slow air flow. Air velocities between 30 and 100 lfm (0.15-0.51 m/s) are considered moderate and velocities above 100 lfm (0.51 m/s) are considered rapid. Air velocities into exhaust ducts and out of supply air vents are generally greater than 100 lfm (0.51 m/s). Air flows less than 100 lfm (0.51 m/s) at the duct opening generally indicate that the ventilation unit is not operating.

Smoke Testing

Smoke testing should immediately follow the air velocity measurements to ensure that these measurements are consistent with the smoke test results. Two reasons for this are that 1) the building configuration will be the same, eliminating the need to reverify, as would be necessary if the smoke test was

performed at a different time, and 2) building and outside environmental conditions will be the same. This becomes particularly important for the situation where the normal building configuration consists of large openings to the outside. If there are significant delays, there could be a major wind direction or velocity change that could alter the air flow patterns in the building.

The size of the work area is the dominant factor in determining the type of smoke aerosol to use, whether smoke tubes or smoke candles. If the room is small (<500 ft^2 [46 m^2]), and particularly if it has little air flow as determined by air velocity measurements, then the use of the smoke tubes is recommended. Another reason for using only smoke tubes would be the presence of sensitive analytical equipment or computers in the work area, which could be affected by the particulate material released from smoke candles.

When using smoke tubes to determine the air flow patterns in a work area, the smoke aerosol should be released at actual and potential release points. Each aerosol puff should be tracked until it is too dispersed to observe, then another puff should be released. This method is continued until the entire work area has been evaluated. One person can perform an evaluation of air flows using smoke tubes; however, an additional person can be valuable in documenting the air flow results.

Smoke candles are generally preferred for work areas >500 ft^2 (46 m^2). The size of the smoke candle (i.e., 4000 or 8000 ft^3) used can be tailored to the situation. When in doubt, the smaller size candle should be tried first to avoid inundating the area with smoke.

Generally, smoke candles should be positioned near each release point or potential release point. The smoke aerosol should be tracked as it passes

worker locations and exhausts from the work area. In most cases, this will allow determination of air flow patterns in the entire work area. Positioning candles near supply air locations (e.g., supply air vents) is also a good method of tracking the smoke aerosol through the work area.

The number of smoke candles needed for a given area will be highly dependent on the air flow patterns observed. For example, if an area shows a strong directional flow, few candles would be needed when compared to the situation where complex air flow patterns are present.

At least two observers are needed to conduct smoke tests. One observer should be located at the expected downstream location relative to the aerosol release, to observe the leading edge of the plume and the plume width. The other observer (who lights the candle) should watch the trailing edge of the plume and also note the plume width. The observers should concentrate their observations on the air flow from potential release points. They should also observe whether the smoke aerosol exits through established exhausts. Both observers should try to limit movements as much as possible, as this can affect the flow (particularly during the first minute when the candle is still releasing smoke). The initial buoyant force of the smoke aerosol affects the initial dispersion and needs to be considered by the observers. The smoke aerosol should be observed until the smoke is dispersed into a thin haze. Generally, from the time a candle is lit until it is dispersed is less than 10 minutes. The amount of time required should be noted as a visual indication of the air change rate in the area.

Documentation of Results

In the field, as observers watch the smoke aerosol disperse, they should sketch the flow patterns on their work area diagram and also write a brief description of the flow. Before the next candle is lit, the observers should confer and discuss air flow movements observed for the previous candle. They should come to a general agreement on the flow pattern. If there are major differences of opinion, consideration should be given to repeating the test.

As the day's testing is completed, one of the observers should be given the responsibility for consolidating the input of all observers for a given area. This would include air velocity measurements and smoke testing results information which will form the basis of the report. The product of this consolidation process would be a work area diagram with the air velocity readings on it and a diagram of air flow patterns observed. In addition, there should be a short (i.e., several sentence) description of the air flow for each smoke candle. It is important that this information be consolidated within a day or two of the testing so details are not forgotten. Experience has shown diagrams to be the best form of documenting air flow patterns; however, videotapes and photographs may be valuable for special situations such as training aids.

After completion of testing in a building, observers should meet to review this consolidated information and develop recommendations for air sampler placement. The report for each building or work area should address the following areas: potential release points, building configuration, velocity measurement results, smoke test results, and recommendations for air sampler placement based on air flow patterns observed.

PLACEMENT OF AIR SAMPLERS AND MONITORS IN THREE SAMPLE WORK AREAS

An airborne radioactive material release in the workplace will disperse as it flows away from the release point and eventually find its way to an exhaust point. The purpose of air flow pattern studies is to define the path from the release point to the exhaust and determine where a sampler can be best positioned to intercept the major portion of such a release. However, the purpose of the sample being collected must be known when positioning an air sampler. If the sample is being used to provide an indication of confinement control for an operation (i.e., general air sampler), then the sampler should be positioned near the release point or potential release point in a downwind direction. If the sample is being used to estimate a worker's intake for purposes of calculating internal dose (i.e., breathing zone sampler), then the sampler should be positioned near the worker's mouth and nose. Continuous air monitors are typically used to provide workers an early warning of an airborne release. They are usually positioned between the release points and the workers in the predominant air flow direction.

As discussed earlier, over 70 work areas were evaluated as part of this study. Air flow study results are presented below for three work areas. An abbreviated discussion of how three tests were conducted and used in guiding the placement of air samplers and monitors is also presented.

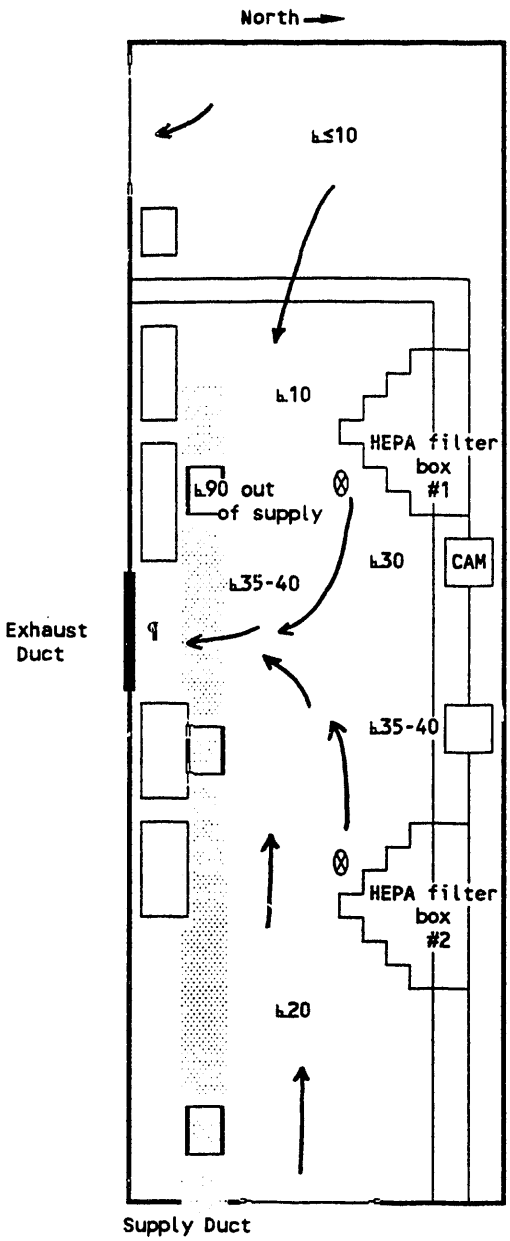
Work Area 1

Work area 1 is a filter changeout area and access corridor. An air flow study was conducted to determine whether the air monitor was in an adequate

location to provide workers an early warning of an airborne release. The potential release points in the work area are the high-efficiency particulate air (HEPA) filter boxes as shown in Figure 1. All doors into the work area were closed during the testing to simulate normal work conditions. The general air flow was downward from the supply ducts to floor level and across the work area from each end toward the center. The candle was lit in front of and beneath the east filter box (HEPA filter box 2). A portion of the aerosol was allowed to disperse. The aerosol was then suppressed and the container was reopened to allow the remaining aerosol to disperse at the west filter box (HEPA filter box 1). The aerosol flowed to the exhaust duct, with a very small portion dispersing beyond the middle of the corridor, prior to eventual dilution and removal through the exhaust. Almost all the aerosol was drawn into the exhaust duct without passing the existing CAM located along the north wall just east of HEPA filter box #1. It was recommended that the CAM be relocated near the exhaust duct.

Work Area 2

Work area 2 is a decontamination area for a reactor facility, as shown in Figure 2. An air flow study was conducted to determine whether the air monitor was in an adequate location to provide workers an early warning of an airborne release. Decontamination activities take place in the decontamination hood located along the east wall, the work table located in the center of the room adjacent to the decontamination hood, and the ultrasonic cleaner located along the north wall. A waste compactor is also

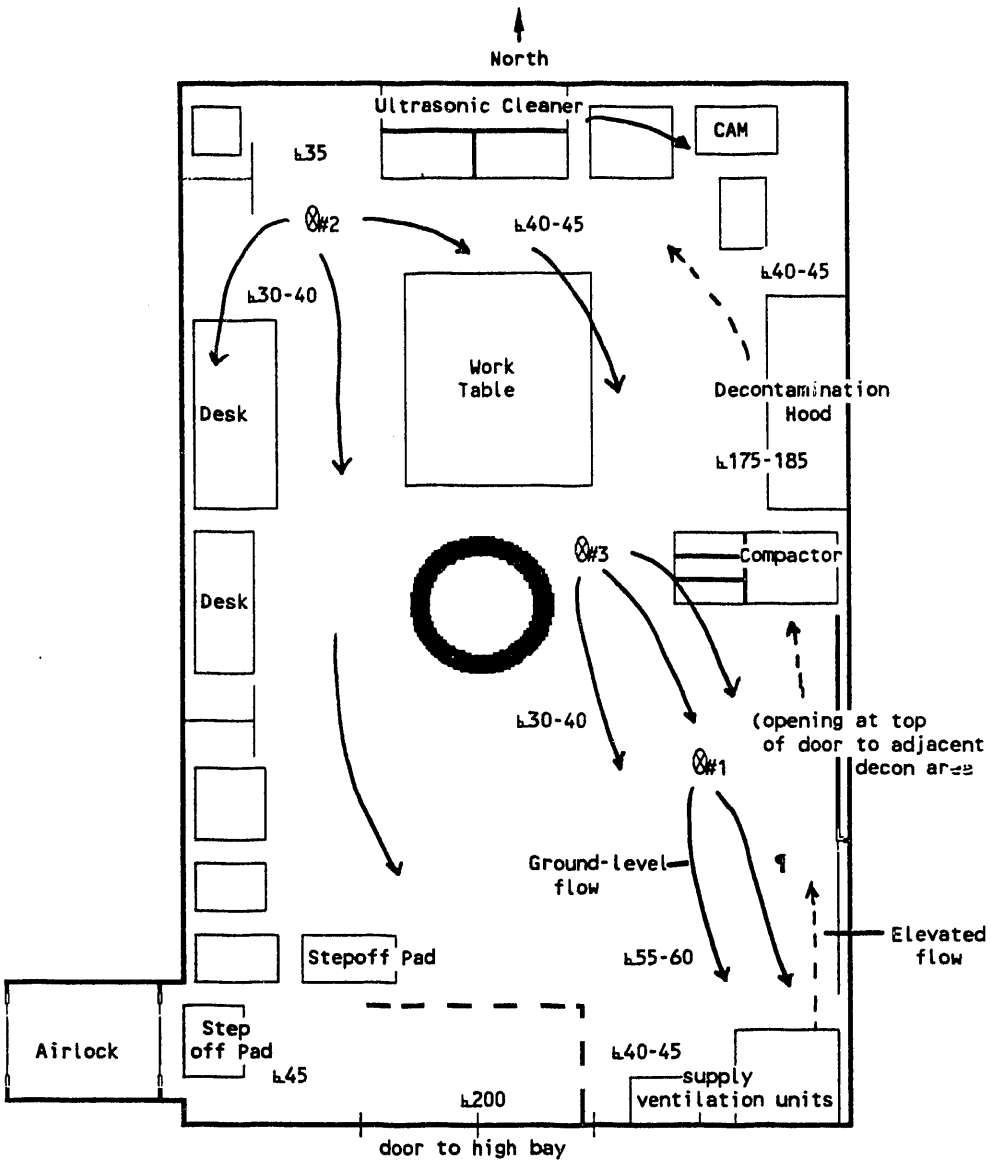


L = Air velocity in linear feet per minute (lfm)

⊗ = Smoke candle locations

¶ = Recommended location for CAM

Figure 1. Work Area 1



¶ = Recommended location for CAM

= Air flow velocity in linear feet per minute (lfm)

⊗ = Smoke candle, # [all candles were 4000 cubic feet of aerosol]

Figure 2. Work Area 2

located along the east wall. Work is frequently done at all locations simultaneously.

The main supply air unit was located in the southeast corner of the room and was elevated about 10 ft (3 m) above floor level. Supply air was directed at a high velocity to the north through four vents on the front face (see Figure 2). The only exhausts in the room were through the decontamination hood located along the east wall and the ultrasonic cleaner located along the north wall. Air flow velocity into the hood was 170 to 185 lfm. Air flow into the exhaust of the ultrasonic cleaner was approximately 1800 lfm.

Three smoke candles were lit in the room. Smoke candle #1 was positioned about 10 ft (3 m) to the north of the supply air vent near the east wall. The air flowed initially in a southerly direction at ground level. As it rose it was influenced by the supply air vent and directed to the north, mixing throughout the room. Smoke candle #2 was located in the northwest corner of the room. It flowed in an easterly and southerly direction at ground level and once elevated it dispersed evenly throughout the room. Smoke candle #3, positioned in the center of the room, flowed initially to the south. It then rose and was influenced by the supply air, which rapidly dispersed the smoke aerosol throughout the room.

The beta CAM at its current location on the north wall would only be adequate to evaluate releases from the ultrasonic cleaner. For other release points, the flow would be away from the CAM initially until it was diluted with supply air and mixed throughout the room. Therefore, either a quantitative study needs to be performed or additional air monitoring is needed in the work area. Since the ground-level flow (below about 7 to 8 ft [2.1 to 2.4 m]) was towards the southeast, placement of an additional beta CAM

along the east wall just south of the doorway into an adjacent decontamination area (see Figure 2) should detect any releases from the center work area, the decontamination hood, and the compactor before they are dispersed by the supply air.

Work Area 3

Similar to the other two work areas, an air flow study was conducted to determine whether the air monitor was in an adequate location to provide workers an early warning of an airborne release. Work area 3 is a storage pool containing cesium and strontium doubly encapsulated as solids in stainless steel capsules. The pool contains 11 individual cells; each is covered with two concrete cover blocks. A transfer aisle to allow movement of the capsules between pools runs the length of the east wall. Potential release points would be from leakage and evaporation of contaminated water in the pipe trench along the west wall or the evaporation of contaminated water from any pool cell, should a capsule breach occur.

Supply air was from four circular vents located in the center of the room with the flow directed downward. The exhaust was located in the southwest corner of the room at about floor level, with a total surface area of about 12 ft^2 (1.1 m^2). A beta CAM monitored the exhaust via a short sample transport line running to the face of the exhaust. The sample line had three inlets on the surface of the exhaust, which were positioned horizontally across the top third of the exhaust as shown in Figure 3. Air velocity readings taken on the surface of the exhaust were highly variable.

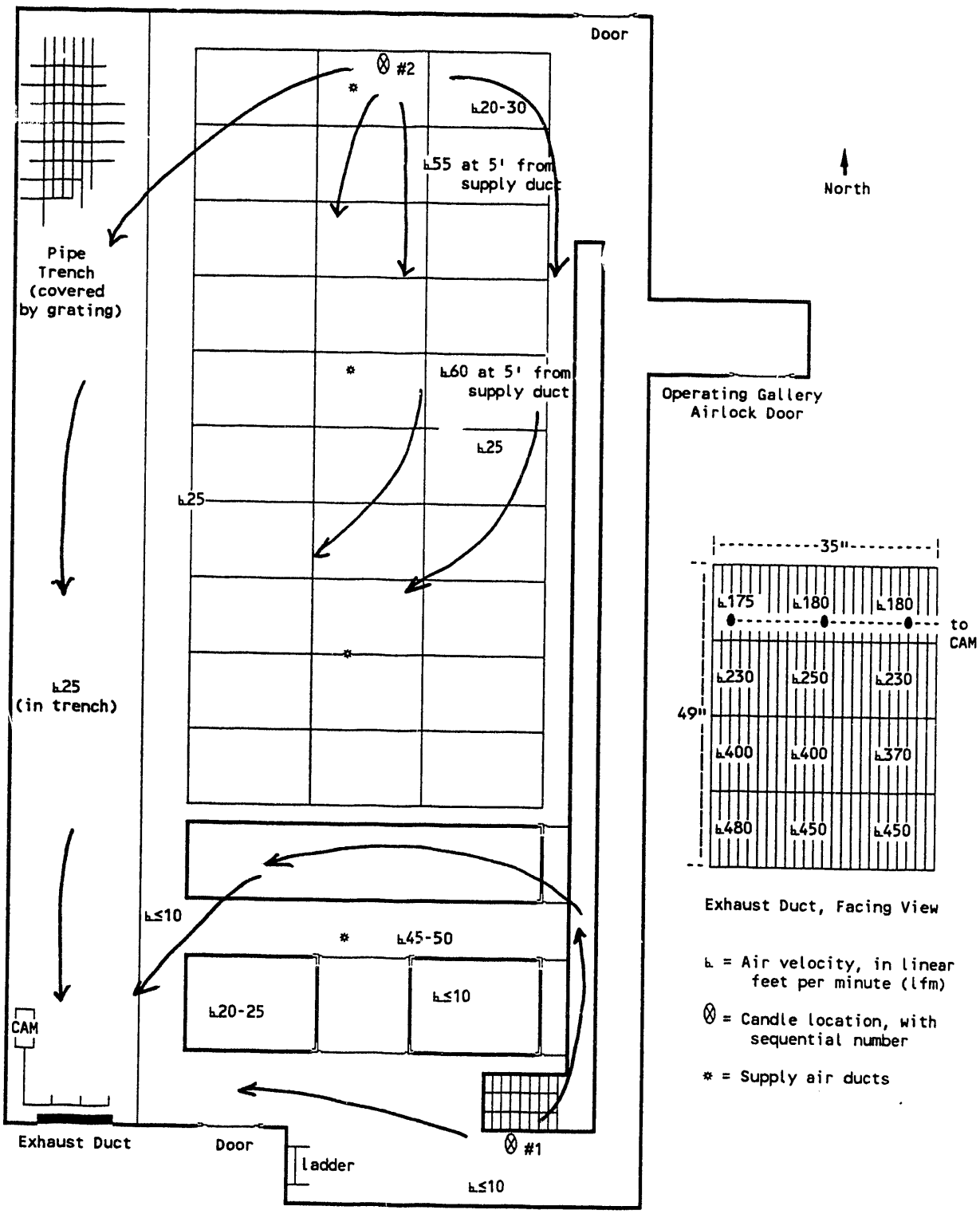


Figure 3. Work Area 3

Smoke candle #1 was lit in the southeast corner of the room. The aerosol drifted very slowly to the north where it was dispersed by supply air from the southernmost supply air vent. After about 3 minutes, some of the aerosol was observed flowing into the exhaust. More aerosol was observed flowing into the top portion of the exhaust. No aerosol was observed to travel further north than the second supply air vent.

Smoke candle #2 was lit under the northernmost supply air vent. Most of the aerosol traveled southerly down the east wall to about the second supply air vent from the south end, where the flow was directed toward the west wall and out the exhaust. A portion of the aerosol flowed into the pipe trench and then moved southerly toward the exhaust. The aerosol from the pipe trench was observed flowing into the bottom third of the exhaust.

The flow into the exhaust was dependent on the approach direction of the aerosol (i.e., flows into the top portion of the exhaust when approaching from the southeast and flows into the bottom portion of the exhaust when approaching from the pipe trench). The current sample line arrangement (i.e., sample line inlets running horizontally across the top third of the exhaust surface) is not adequate because a release from the pipe trench may go unmonitored. It is recommended that the sample transport line be reoriented vertically which should allow detection from any location in the room.

REFERENCES

1. U.S. Department of Energy (DOE): Radiation Protection for Occupational Workers. DOE Order 5480.11 (1988).

2. Code of Federal Regulations: Standards for Protection Against Radiation; Final Rule. U.S. Nuclear Regulatory Commission. 10 CFR Part 20.

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