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TECHNICAL REPORT ON THE PROJECT "DEVELOPING EXPOSURE CONTROLS BY MATERIAL BALANCE MODELING"

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HARVARD SCHOOL OF PUBLIC HEALTH
665 Huntington Ave
Boston MA 02115

Robert F. Herrick, ScD, CIH   Principal Investigator

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List of Abbreviations

ACGIH TLV - threshold limit value of the American Conference of Governmental Industrial Hygienists
BEI - biological exposure index of the American Conference of Governmental Industrial Hygienists
CO – carbon monoxide
COHb - carboxyhemoglobin
IDLH - immediately dangerous to life and health
NIOSH - National Institute for Occupational Safety and Health
OSHA PEL -permissible exposure limit of the Occupational Safety and Health Administration
$PM_{2.5}$ -particulate mass with an aerodynamic diameter of 2,5 um or less
ppm – parts per million
REL-TWA – recommended exposure limit of the National Institute for Occupational safety and Health
VEM - video exposure monitoring

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Abstract
Emission source characterization and detailed work task – exposure analysis were conducted at a gray iron foundry for the purpose of designing an exposure control system. The source characterization revealed that the emission of carbon monoxide from cooling molds is highly variable from mold to mold, and the quantity of CO emitted does not appear to be directly associated with the size of the casting. The unpredictable nature of the CO emissions made it infeasible to implement a model of ambient CO concentrations based upon the size and number of castings produced, however the detailed work task – exposure monitoring revealed the specific steps in the work process that made the greatest contribution to personal CO exposures. This information provided the basis for a set of recommendations on control options, and the foundry management has taken them under consideration.

Significant Findings
The following have been identified as significant findings of this research:
1. The emissions of CO and other materials from green sand molds are highly variable between molds, and are influenced by a number of factors. Casting size and weight alone is probably not a good predictor of emissions during cooling.
2. Gray iron castings such as those made at the test foundry cool quickly after pouring, and their emissions of CO and PM decay to background levels within one hour after pouring.
3. An effective exposure control strategy is likely to be feasible if the casting can be isolated from the foundry environment during that first hour after pouring. We were unable to verify this experimentally, however.
4. Video exposure monitoring is a very effective tool for identifying the specific steps and activities within a worker's job, and for determining the relative contribution of each step to total exposure. This information can serve as the basis for an intervention strategy.

Usefulness of Findings
The usefulness of these findings to the test foundry has not yet been determined. The possibility exists that they will implement one of the options for control that has been presented to them, however that determination has not been made as of this time. The significant findings mentioned above will be useful to investigators who are seeking to reduce exposures in casting production in foundries.

Scientific report

The study "Developing Exposure Controls by Material Balance Modeling" had seven specific aims:
1. To characterize the emissions, specifically the carbon monoxide (CO) and particulate material (PM) generation rate for pouring, cooling and shakeout of green sand molds, and to develop emission factors for CO and PM;
2. To conduct a detailed work activity exposure analysis of the casting process using video exposure monitoring (VEM);
3. To apply the material balance model to predict CO and PM concentrations in the work area during mold pouring, cooling and shakeout in four foundries, using measurements of emission rates and workplace parameters as terms in the predictive model;

4. To compare the model's predicted CO and PM concentrations with measured CO and PM concentrations in the production area, and to modify the material balance model as needed to optimize its predictive value, using the field study measurement data;
5. To identify the work tasks which make the greatest contribution to total exposure using VEM analysis;
6. To design a control technology system to control casting line emissions based upon the information obtained on the emission characteristics of the exposure sources (step 1) and the work steps that are the most important causes of personal exposures (step 5);
7. After fabricating and installing the control system, to repeat the detailed exposure assessment to evaluate its control performance, and modify the system to optimize its effectiveness

This report summarizes the methods and results of the study, organized by the seven specific aims of the project.

Specific Aim 1: To characterize emissions

The first step in the study was to conduct a detailed characterization of the sources of exposure in the casting production processes. The study focused upon the carbon monoxide (CO) and particulate matter (PM) exposures throughout the foundry. While some information was available from preliminary studies, we conducted detailed exposure assessments to fully evaluate personal exposures to CO and PM throughout the foundry. These findings are shown in Figures 1 and 2, and Table I, which document exposures approaching and in some cases exceeding legal and recommended exposure limits. NIOSH has established a REL-TWA of 35 ppm and a ceiling limit of 200 ppm.(NIOSH, 1973, 1988). In 1988, NIOSH supported the OSHA PEL of 35 ppm with a ceiling of 200 ppm to ensure that exposed workers' COHb levels are maintained at or below 5% in order to protect those workers at greater risk because of cardiovascular or pulmonary impairment. In addition, these limits are intended to protect healthy workers who must work in environments involving exertion, heat stress, or other strenuous conditions (NIOSH, 1988). NIOSH has also established an IDLH value of 1500 ppm for CO. The ACGIH TLV of 25 ppm has been proposed to retain blood COHb levels below 3.5%, to prevent adverse neurobehavioral changes, and to maintain cardiovascular exercise capacity. The present TLV-TWA is intended to keep blood COHb levels below the biological exposure index (BEI) of 3.5% to prevent adverse neurobehavioral changes, and maintain cardiovascular exercise capacity (ACGIH, 1995). The exposure limits that apply to PM in the foundry were generally not approached, therefore we focused on characterization of CO exposure as the critical factor for control in this workplace.

It was apparent from the exposure assessment that the principal source of CO exposure was the cooling molds, which are handled in several different ways after pouring. The largest molds (typically in flasks 52 inches on each side) are poured from a ladle which is moved around the foundry floor. These molds cool in place, and do not move until they are transported for shakeout. There are three other sizes of flasks used for the molding operation: all are square, 42, 38, or 32 inches on a side. In the case of these three smaller sizes, the molds are poured at the cupola (Figure 1), then move on a floor-level roller conveyor around the foundry floor while they cool. These conveyors are shown in Figures 1 and 2.

In the case of the 32 inch molds, these are generally directed to the innermost conveyor line after pouring (Figure 1), and they are removed from the line and stacked for cooling in two rows, each row consisting of up to seven stacks of molds. The stacks are 3 molds high, so at the maximum observed, there can be 42 molds cooling in the area adjacent to the conveyor line. The worker who performs this activity is known as the "Swapper", and he spends the greatest part of his time in an aisle that is formed between the conveyor line and the stacks of molds that he has removed from the line. As is apparent from the data on personal exposures (Table I, Figures 1 and 2), this worker has by far the highest exposures to CO of anyone in the foundry, and it was reported that the swapper is rotated to other jobs (with lower CO exposures) approximately every two hours. Based upon this assessment, we targeted the swapper as the critical worker for control of exposure.

Since the swapper is exposed to the emissions from molds throughout their cooling process, we constructed a sampling hood modeled after that of Toeniskoetter (1977) and Gressel (1988) in order to measure the quantity and temporal pattern of CO emissions throughout the cooling period. This was done because foundry studies using real-time measuring systems have shown that the contaminant generation rate from each mold is highly time dependent throughout the cooling process (Scott, 1976; Gressel, 1988). In general the guidelines applied for general foundry dilution ventilation assume uniform contaminant generation rates. For example, O'Brien and Jensen (1995) cite the recommendation of the AFS Foundry Ventilation Manual that exposure be controlled by general ventilation sized in proportion to the floor area where the pouring is conducted (20 to 50 cfm per square foot of floor area), with a lower value of 10 to 20 cfm per square foot in the cooling area. In addition, the production processes in a modern foundry are typically conducted by pouring a series of molds, with the molds moving through the production area on a conveyor system from pouring, through cooling to shakeout. The overall contaminant generation rate, therefore, is time dependent both on the changing rate of contaminant generation of each individual mold, and the contribution of each mold in the series. As our goal was to design the control system based upon the information obtained on the emissions of the exposure sources (specific aim 1), it was important to fully characterize those emissions.

The sampling hood was constructed of galvanized steel measuring 48 inches on a side. It was open at the bottom, and connected to a straight run of duct at the top. It was designed so it could be positioned directly over the mold after pouring, to contain the emissions released from the mold during the cooling, while exhausting through a blower connected to the exhaust duct. The airflow through the duct was controlled with a blast gate, which allows the exhaust flow to be adjusted. For these measurements, the flow was set to 233cfm, a rate that was selected to keep the concentration of CO and PM in the exhaust stream within the sampling range of the measurement instruments. A gas sampling port, a port for isokinetic PM sampling, and a temperature probe were located in the exhaust stack. CO concentration in the stack was measured continuously throughout the casting process using a Dräger Model PACIII CO monitor equipped with a pump module (for remote sampling) and a data acquisition system. A DustTrak Aerosol Monitor Model 8520 with a $PM_{2.5}$ um size selective impactor precollector was used for PM measurement, and a TSI Q-Trak monitor was used to measure temperature of the exhaust flow inside the duct. The experimental apparatus is depicted in Figures 3 and 4. This continuous monitoring of CO and $PM_{2.5}$ emissions throughout the pouring, and cooling process allowed calculation of the overall (total) generation rate, as well as the time-dependent generation rate for any interval during the total period. These continuous measurements allowed us to observe the temporal pattern of emissions, and to calculate an emission factor for each size of casting. It was also intended to allow comparison of the contaminant generation data obtained in the test foundry with the data obtained in the earlier NIOSH research.

The results of the measurements of CO, $PM_{2.5}$ and exhaust temperature are presented in Figures 5-10. In total six castings were tested using the sampling hood. One casting (Figure 5) was sampled for $PM_{2.5}$ only. This run was conducted for range finding purposes, and while continuous monitoring was conducted for $PM_{2.5}$, Spot measurements were made for CO to determine whether the exhaust rate we had selected (233 cfm) would result in a measurable concentration of CO and $PM_{2.5}$ in the exhaust stream in the sampling duct from the mold. We found that both CO and $PM_{2.5}$ in the duct were within the range for sampling using the direct-reading instruments (0-2000 ppm CO, 0 - 100 mg/m^3 $PM_{2.5}$), however we also found that the measurement of $PM_{2.5}$ from the cooling mold was confounded by other sources of $PM_{2.5}$ in the area, specifically the use of a sand slinger approximately 20 feet from the point at which we were conducting the test pours. As is seen in figure 5, there was a substantial spike in the $PM_{2.5}$ concentration in the sampling duct at 1:07 PM, approximately 80 minutes after the mold was poured. We observed that this corresponded to the time at which a mold maker began using the sand slinger in the area to make a set of specialty molds. We attempted to determine a background level of $PM_{2.5}$ in the area by making a series of measurements throughout the day, but it became apparent that the use of the sand slinger was unpredictable. It was used when castings of a particular shape (cast iron pipe elbows) were being produced, and the level of $PM_{2.5}$ generated at these times was high, and extremely variable (Figure 5). As the area in which we were testing was the only space in the foundry which was accessible to us (the ladle that transported the molten metal from the cupola to our test molds could only reach certain areas), we concluded that it would not be possible to determine a valid $PM_{2.5}$ emission factor for the molds.

We continued the experiment to calculate emission rates for CO, with the goal of determining an emission factor relating the mass of CO emitted to the mass of the casting (Gressel, 1988). Using the sampling hood depicted in Figures 3 and 4, we first measured the CO emissions from a casting in a 38 inch flask. The part being cast was a model LK120 round cover with S612 frame, with a total casting weight of approximately 250 lb. Because of a malfunction in the datalogging of the CO monitor, the CO concentrations in the sampling duct were lost, however, observation of the data display on the CO monitor while the casting cooled showed that the concentration rose to a level of approximately 3000 ppm, and declined to the background in the foundry air after approximately one hour. The sampling hood and ductwork became noticeably warm, and the release of flame and smoke from the mold was apparent during the cooling process.

The second part being cast (Casting A) was a round manhole cover, model L32 C13, with a casting weight of approximately 325 lb. The results of the sampling are depicted in Figure 6. The CO concentration in the sampling duct rose immediately after the mold was poured, reaching a maximum concentration of approximately 250 ppm. The CO concentration decreased over time, with a short spike back to approximately 200 ppm at about 900 sec after pouring, then continued to diminish until at approximately 1 hour after pouring it had settled around the background level of CO in the test area (approximately 25 ppm CO). Approximately one hour after the first mold test was completed, a third mold was tested, using the same experimental conditions as for the first. The third mold (Casting B) was a casting in a 38 inch flask for a round manhole cover and frame (model LK120 cover with S612 frame), with a total casting weight of approximately 250 lb. As can be seen from Figure 7, a very different pattern of CO emission was observed, in comparison to Casting A. The CO concentration in the sampling duct peaked at almost 3000 ppm approximately 3 minutes after the casting was poured, and gradually declined to the background level in the foundry air (approximately 25 ppm) after about one hour. The emissions from this mold were noticeably hotter than for the casting A, and this mold also emitted visible flame and smoke from the seam between the cope and the drag (the top and bottom halves of the flask). These flames and emissions of smoke had not been observed while Casting A was cooling.

This dramatic difference in emissions between two castings in the same size flask (Figure 8) was unexpected, especially since the casting of the lower weight (casting B) generated a vastly greater amount of CO that did the heavier casting A. The experiment was repeated approximately 3 months later, this time with 32 inch square flasks (the size handled by the swapper). The first casting tested (Casting C) was a round manhole cover model L24C23, weighing approximately 150 lb. The results of the CO sampling and temperature measurement in the exhaust duct are presented in Figure 9. The CO concentration in the sampling duct rose to approximately 2000 ppm immediately after the mold was poured, and the temperature of the air exhausted from the mold exceeded 150F, the maximum reading of the temperature sensor. It remained above 150F for approximately 5 minutes, then the temperature and CO concentration in the duct decayed to background levels in the foundry air after approximately one hour. Approximately 30 minutes later, we sampled casting D, another 32 inch flask that contained a L26 C2 round manhole cover, with a casting weight of approximately 200 lb. The results of CO and temperature measurements in the sampling duct are presented in Figure 10. In contrast to the preceding casting, CO concentration for Casting D did not exceed 185 ppm, and the exhaust temperature peaked at 107F and declined quickly. This casting did not emit the visible flame and smoke that had been observed from Casting C approximately one hour earlier. Foundry personnel verified that the castings in molds C and D were virtually identical in shape, and that casting D was approximately 50 LB heavier than Casting C.

We calculated emission factors for the four castings on which we had complete sampling data. These factors are presented in Table II. The modeling approach we planned to use was predicated on the assumption that for a series of castings, we would be able to experimentally determine an emission factor for each casting, then to calculate the mean CO concentration and cumulative CO on a mass basis emitted for each mold through the casting process. The goal was to develop estimates of the CO emission factors for the pouring and cooling of the castings by dividing the total mass of CO emitted by the mass of the part being produced. We had also considered an alternative of basing the emission factor on the surface area of the castings contained in each mold, if the mass of CO emitted were better associated with the area of metal in contact with the green sand than it is with the mass of metal in each mold. We had not anticipated that there would be such dramatic differences between identical castings, poured under virtually identical conditions within a time period of approximately one hour. Upon consultation with experts at the American Foundrymens's Society, however, we found that this variability is not surprising at all. There are many factors, including the temperature of the metal, the rate and uniformity of energy transfer between the metal and the sand, the distribution of seacoal in the sand, the degree and length of time of lightoff of the decomposition gases, the venting of the mold, and the temperature of the sand prior to pouring that could explain the differences in CO emissions between identical castings (Mosher, 2000). This led us to inquire further about the nature of the mold making process at the LeBaron Foundry. There are four moldmaking operations at the foundry, and the 32 inch molds (which are those handled by the swapper) are all made on the #1 floor mold making machine.

We were, therefore unable to accomplish specific aim 3 and 4, the application of the material balance approach to estimate exposures in the work area. We discussed the situation with the NIOSH Project Officer (Dennis O'Brien) who agreed that while it was disappointing to learn that the material balance approach would not be applied in this research, the project should continue as the detailed work task-exposure analysis promised to yield useful information about the nature of exposure in the foundry, and to help target an exposure control strategy.

Specific Aim 2 - To conduct a detailed work activity exposure analysis

There are approximately 20 workers engaged in the casting process. This includes workers who add metal, and other ingredients to the cupola furnace (two chargers, one fork truck operator); those who tend its operation (one operator, three helpers); those who work with the molds through the pouring and cooling steps (one pourer, one clapper, one swapper, two panel operators); three shakeout operators; and three others (two supervisors, one cold set operator). Previous measurements made in the foundry indicated that approximately half the casting workers have both elevated short-term CO exposures as well as high time-weighted average exposures as a result of their direct contact with the mold emissions, while the others are exposed to CO primarily as an elevated background concentration in the general casting area.

Based upon our survey of CO concentrations in the foundry (Figures 1 and 2), we conducted personal exposure assessments for CO using Dräger Diffusion Tubes on the workers who were in direct contact with the freshly-poured molds, and were therefore at greatest risk of exposure to CO and other mold emissions. These workers held the jobs of pourer, clamper, panel operator and swapper. The pourer worked in an air supplied booth, from which he operated the ladle. He directed the flow of molten metal from the cupola into the molds which moved into the pouring position via the roller conveyor. The clamper worked at a point on the roller conveyor line just before the pourer directed the metal into the molds. The clamper was generally working with molds just before they went to the pouring station, therefore he was a lower risk of exposure to CO and other mold emissions (Table I). The swapper lifted the freshly-poured 32 inch molds from the conveyor line and stacked them approximately 10 ft from the conveyor, forming an aisle between the conveyor and the stack, in which he worked. The panel operator worked at a station approximately 110 ft down the line from the swapper, and he operated a set of switches and gates that directed the poured molds around the foundry on the roller conveyor. The results of the personal air sampling for CO on these workers confirmed the observations of the surveys with the direct reading CO instruments. The swappers are by far the most highly exposed workers, followed by the panel operator, the clamper and the pourer.

We conducted detailed work – exposure analysis of exposure to CO in the foundry using the direct-reading Dräger measurement instrument, with simultaneous videotaping of the work operations. This video exposure monitoring (VEM) system includes four components: the direct reading CO monitor with datalogger, a video camera to record work activities; and a personal computer including a spreadsheet and a program for generating a graphical representation of the exposure profile over time, and a video mixer which allows the graphical overlay of the exposure image on the video of the work process. As the swappers were the most highly exposed workers, we selected them for the detailed exposure analysis. The exposure survey was conducted over a full work day in February, when natural ventilation in the foundry was at a minimum.

The use of the VEM system allowed us to characterize the exposure-time profile over the range of tasks the swapper performed during the time of exposure. Using the measurements of personal CO exposures and simultaneous videotaping of job activities and tasks, we conducted a detailed work analysis for each of the three workers who conducted the swappers job. This method reveals the exposure associated with each step in the work process, and the relative contribution of each step to the total exposure. This approach to work analysis for the purpose of optimizing a control strategy has been described by Andersson and Rosén (1995). By analyzing the videotape of the work process, we identified 14 major work steps performed during the swapper's work cycle. Using this information on the duration of each major work step (t_i), and the proportion of the total exposure accumulated during each work step, we calculated the relative importance of each work step to total exposure by the following expressions:

the proportion p_i of total exposure contributed by each work step i of duration t_i is described by

$$p_i = \sum_{j=1}^{n_i} e_{ij} / \sum_{k=1}^{N} e_k$$

where e_{ij} = momentary exposure measure j associated with work step i

e_k = all momentary measures of exposure

n_i = number of momentary measurements associated with work step i

N = total number of momentary measurements

The exposure $\hat{\varepsilon}_i$ associated with a work step is then

$$\hat{\varepsilon}_i = \sum_{j=1}^{n_i} e_{ij} / n_i$$

and the relative exposure $e_{rel,i}$ for the work step i is

$$e_{rel,i} = \hat{\varepsilon}_i / \hat{\varepsilon}$$

where

$$\hat{C} = \sum_{k=1}^{N} e_k / N$$

This approach to work practice and exposure analysis identifies the contribution of each work task to the overall exposure.

The results of the detailed task-exposure analysis for the swappers are presented in Table III. The overall work activity that comprises the swappers' job was broken down into the 14 subtasks, based upon observation of the video for all 3 workers who performed this job. The average CO exposure for the 5.9 hours that the swappers conducted their activities was 198 ppm. The analysis of the distribution of time reveals that three tasks that involve handling freshly-poured molds: Task A (hook mold and raise mold from conveyor line); Task B (move mold from line to cooling stacks); and Task C (lower mold to cooling stack and unhook mold). These three tasks together accounted for a total of 30.4% of the total time the swappers spent working, while the swappers accumulated 42.6% of their total CO exposures while performing these three steps. Examination of Table IV and Figure 14 shows that the three workers performed their jobs in approximately the same manner, that is the overall distribution of time over the 14 subtasks was approximately the same. The three swappers were exposed to approximately the same average concentrations of CO (175.9 ppm Swapper1; 239.6 ppm Swapper 2, 203.8 ppm swapper 3) for their entire work period. Detailed examination of the distribution of exposure and time across tasks for the 3 workers reveals that while all three workers accrued approximately 40% of their total exposure while performing Tasks A, B, and C which involve handling the freshly-poured molds, worker 2 had substantially higher levels of exposure while performing these three steps, and a higher exposure overall than did the other two swappers. Interviews with the workers and examination of the videotape offer a possible explanation. Worker 2 was very inexperienced at the swapping job, and had only performed it a couple of times before the day we conducted the monitoring. He was clearly less familiar with the work activities than the other workers, and he appears to have worked closer to the molds while manipulating them with the hoist. His proximity to the sources of CO may at least in part explain his higher exposures during the mold-handling steps.

The conclusions based upon the information collected in the characterization of mold emissions (Specific Aim 1) and the detailed work activity exposure analysis (Specific Aims 2 and 5) are as follows:

A. The swappers are the most highly exposed workers in the foundry, and the source of the exposure is the cooling molds.

B. There is great variability in the amount of CO emitted by each mold, and the amount is not explained by the size of the casting. There are apparently a number of factors that determine the quantity of mold emissions during cooling.

C. Despite this substantial variability between molds, they all appear to cool quickly after pouring so that within approximately 1 hour of cooling they have reached room temperature and substantially finished off-gassing CO.

This information was used as the basis for designing the exposure control approach for the foundry. To design a control technology system to control casting line emissions based upon the information obtained on the emission characteristics of the exposure sources (step 1) and the work steps that are the most important causes of personal exposures (step 5), we postulated that if the emissions from the molds were exhausted for approximately the first hour after each was poured, that would dramatically impact the exposures to the swappers, as well as the overall level of CO in the general foundry atmosphere.

Specific Aim 6: To design a control technology system to control casting line emissions

The first design option considered was to improve upon the existing exhaust system in the vicinity of the swappers' work area. In the existing configuration (Appendix, Figure 1), the 52 inch by 10 inch rectangular exhaust ducts now in place are depicted. At this time, the ducts extend to the roof level, but they are not connected to any mechanical exhaust. The foundry management believes that the warmer air from the cooling area rises through these ducts, providing exhaust ventilation to the area. The options for improvement as shown in Figures 2 and 3 of the Appendix were to reconfigure the existing ducts by capping them at the bottom, creating new horizontal slots, and adding a 5000 cfm fan on the roof. Figures 4, 5, and 6 (Appendix) show two options on the same basic design. Option 2 was to partially enclose the area where the swapper works to improve the ventilation of this area. The other (option 3) was to add a separate exhaust hood over the conveyor line, along with the addition of the mechanical ventilation to the existing 52X10 inch ducts.

These options were presented to the foundry management, however, they expressed concern that any of the recommendations were feasible. The primary concern was that the addition of the new roof to partially enclose the area in option 2, and the addition of the overhead duct to ventilate the cooling line in option 3 would interfere with the use of the overhead hoist that the swappers use to lift the molds from the line and move them to the stacks, and back to the line after cooling. The view from the ventilation consultants (DiBerardinis Associates) was that without these features, the quantity of air that would have to be exhausted from the cooling area would be exorbitant.

At this point, another design option was presented by the NIOSH Project Officer, Dennis O'Brien. During his visit to the foundry, he suggested that exposures could be dramatically reduced by isolating the molds from the foundry environment, and the workers, during the time the molds are cooling. Dr. O'Brien described a system he had seen successfully employed, known as a smoke house. This is simply an enclosure isolated from the general foundry structure, through which the molds move on a roller conveyor as they cool. The concept of the smoke house is shown in Figures 7 - 10a, Appendix. The advantages of the system are its simplicity, and the likelihood that exposures not only for the swappers, but for workers throughout the foundry would be dramatically reduced by such a system. Based upon the number of 32 inch molds that are poured on a typical production day (approximately 120), and the need to keep them in the smoke house for at least 1 hour before they returned to the foundry for shakeout, the structure was designed as shown in Figure 9, Appendix. The plan was presented to the foundry management, but it was not deemed feasible. The foundry has very limited space to expand, and the only area suitable for the smoke house partly overlaps the spot where the foundry had plans for a new cupola. Since the time we made these recommendations (Spring 1999), the foundry has in fact installed the new cupola, and the space needed for a smoke house is not available.

The next design option was derived from the concept of the smoke house. The plan for this design is presented in Figure 10b of the Appendix.

The proposal was to isolate the cooling molds from the foundry environment by adding two sections of roller conveyor on the foundry floor. These new lines would be partially enclosed to form a cooling tunnel, which would be ventilated to the roof. The concept was to add two new conveyor lines (A and B in Figure 10b, Appendix) which would be used exclusively for the 32 inch molds - these are the most common size, and are those which are currently handled by the swapper. This plan would add two new conveyor runs, each of approximately 90 feet. They would be partially enclosed by a canopy and baffled on one side - the result is that there is new capacity for storing the 32inch molds as they cool, and the job of the swapper is eliminated.

This proposal was presented to the foundry management, however it too was deemed infeasible as it was in effect a replacement of open floor space with permanent roller conveyor lines A and B. The space that Line A would occupy is now used for stacking the cooling 32 inch molds, and the space intended for Line B is considered flexible space used for a number of purposes, such as pouring large molds from the transfer ladle. The foundry management considers it essential that this floor space be available for quick reconfiguration, depending upon production needs. While there is currently great demand for castings produced in the 32 inch molds that the swapper handles, this could change, and the foundry wants to retain the flexibility to handle other sized castings in these areas.

The final set of options, therefore, have been presented in Figures 11 and 12 of the Appendix. The option in Figure 11 is an exhaust system similar in concept to that presented in Option 1, however it has been scaled down in size and will exhaust only the single existing 52x10 inch exhaust duct located at the end of the cooling area closest to the cupola. This is the spot at which the swapper spends the greatest amount of his time, and the goal is to install this limited system in hope that the reduction in exposure it causes will persuade the foundry management to install similar exhaust along the entire mold cooling area.

The second of the final options is to supply tempered outside air overhead the swapper. This is depicted in Figures 12 and 13, Appendix. This option is the least desirable of those considered, as it does not remove CO from the foundry environment. It does, however offer the promise of reducing the swapper's exposure by providing a shower of outside air from overhead. This is the same type of system that is currently in use for the pourer, who works in an air-supplied booth. The effectiveness of the approach is apparent from the data in Table I and Figure2, as it is clear that the pourer has substantially lower exposures to CO than does the swapper, even though they both are in contact with freshly-poured molds.

The foundry management has not yet determined whether they consider either of these final two options feasible.

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NIOSH Recommendation for Occupational Health Standards, 1988. Morbidity and Mortality Weekly Report Supplement S-7 37:1-29, 1988.

O'Brien, D.M., and Jensen, P.A.: Evaluation of Dilution Ventilation Criteria for the Open Floor Pouring of Metal Castings, February 21, 1995 (unpublished)

Toeniskoetter, R.H., and Schafer, R.J.: Industrial Hygiene Aspects of the Use of Sand Binders and Additives. Presented at the BCIRA International Conference "The Working Environment in Iron Foundries", University of Warwick, England, March 22-24, 1977.

U.S. Department of Labor, Occupational Safety and Health Administration: 29 CFR Part 1910, Air Contaminants; Final Rule. Fed. Reg. 54(12):2651-2652 (January 19, 1989).

Figure 1 – Carbon monoxide and particulate <2.5 μm exposures
January 14, 1999

PC: Particle Concentration, mg/m^3
CO: Carbon Monoxide Concentration,ppm
TP: Total Particulate, mg/m^3
PEM: Particles<2.5μm, mg/m^3

Station # in ()
Square: Monitoring Station
Shaded Oval: Worker
Shaded Octagon: Area Air

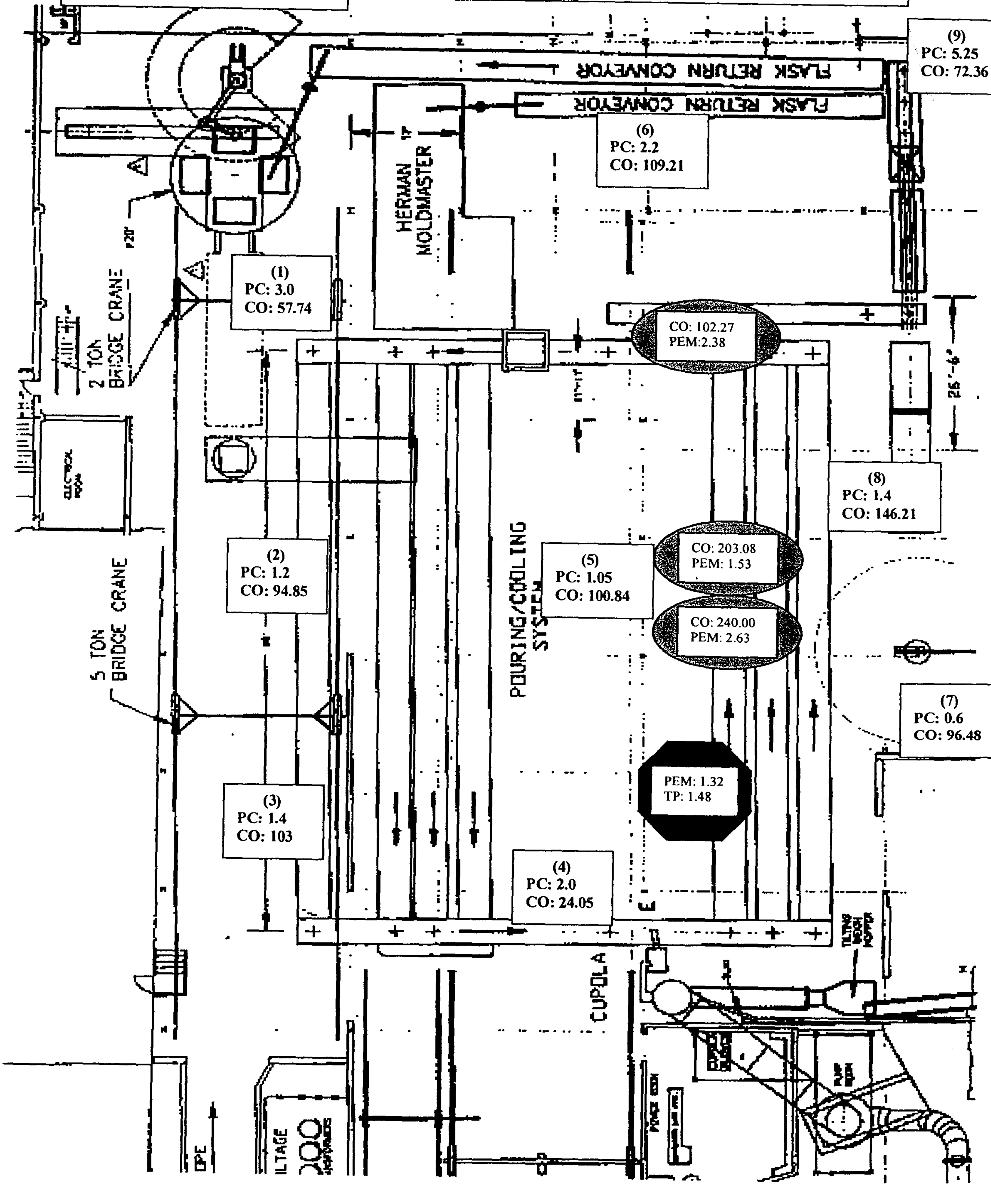


Figure 2 - LeBaron Foundry
January 14,1999 and October 21, 1999

Square: Monitoring Station with Station # in ()
Shaded Oval: Worker
CO: Carbon Monoxide Concentration on 10/21/99, ppm
[CO]: Carbon Monoxide Concentration on 1/14/99, ppm

The CO concentration listed for each worker on 10/21/99 is an average of two readings taken in the morning and afternoon (except swapper #1).

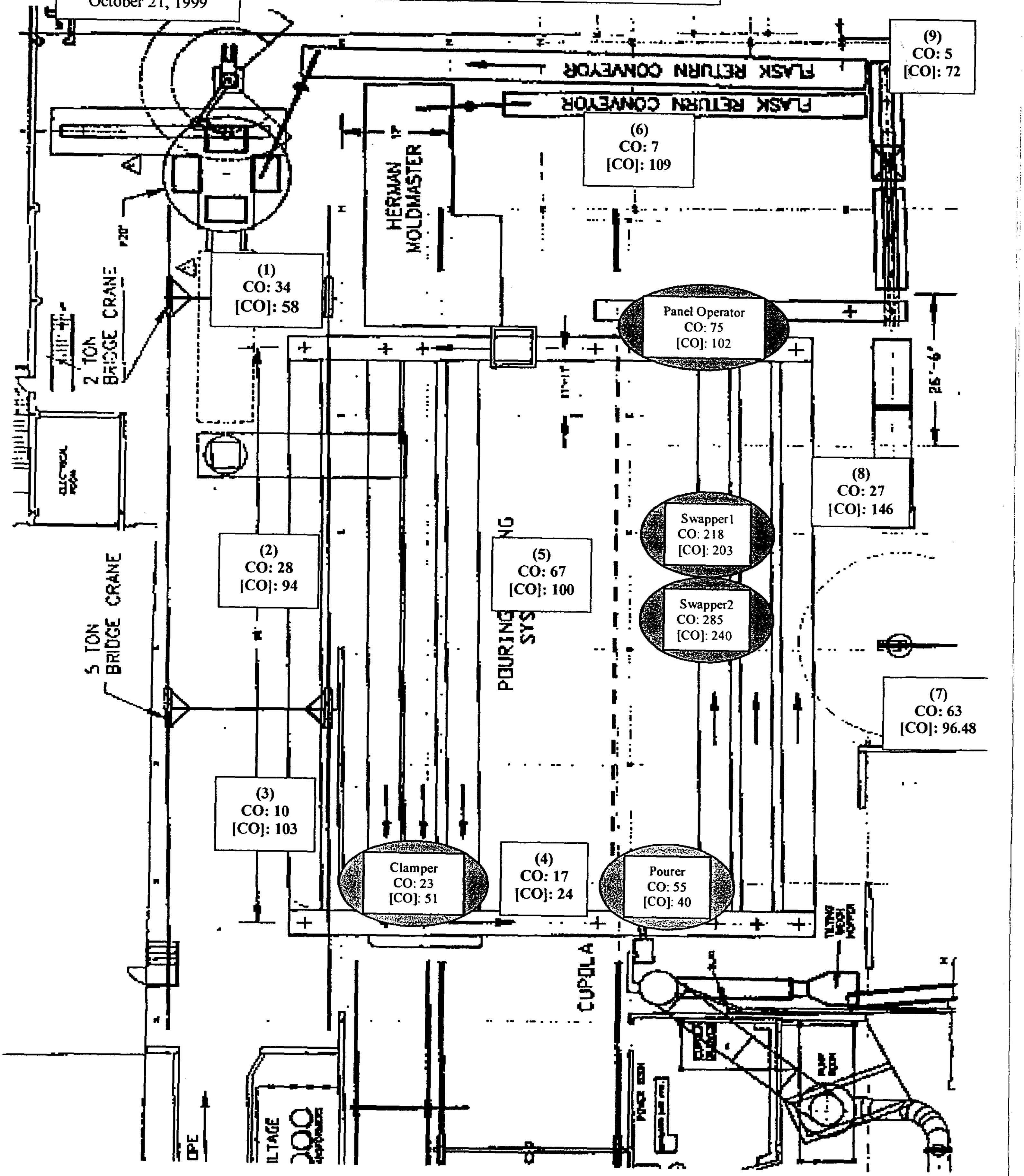
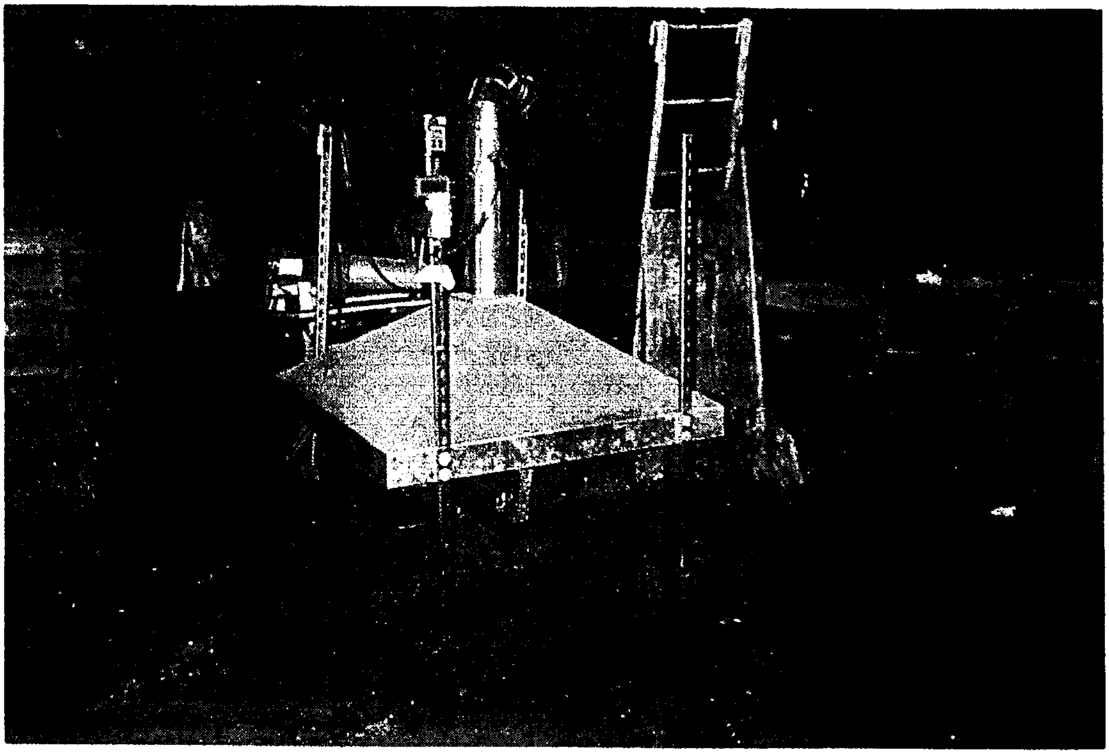
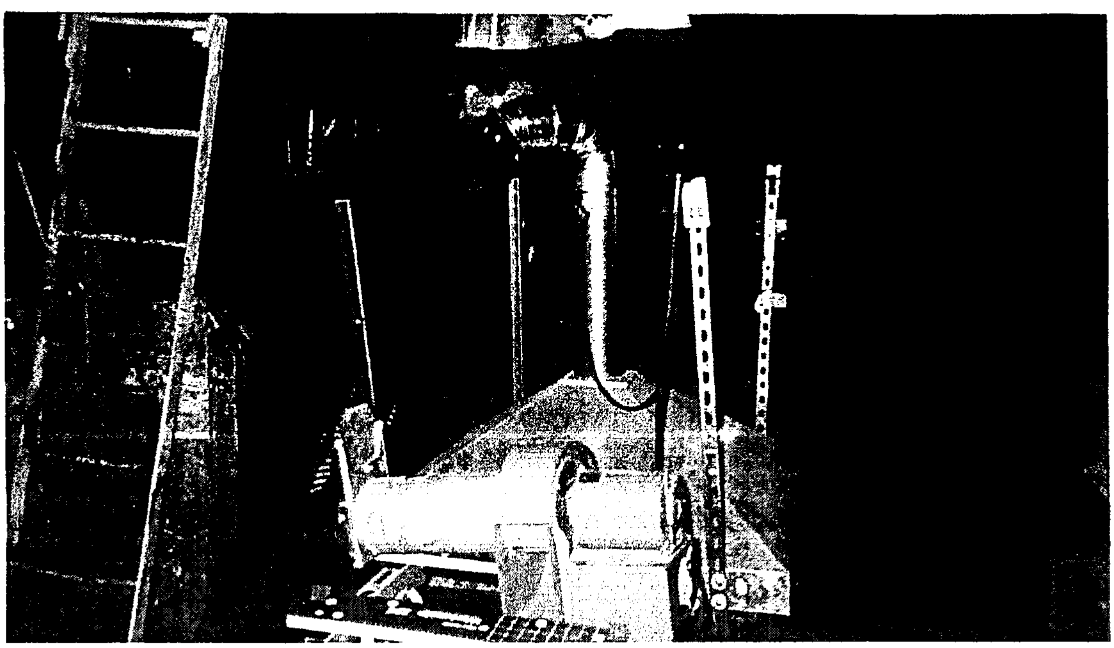


Figure 3 – Sampling apparatus for mold emissions
Figure 4 – CO and PM instruments and sampling apparatus





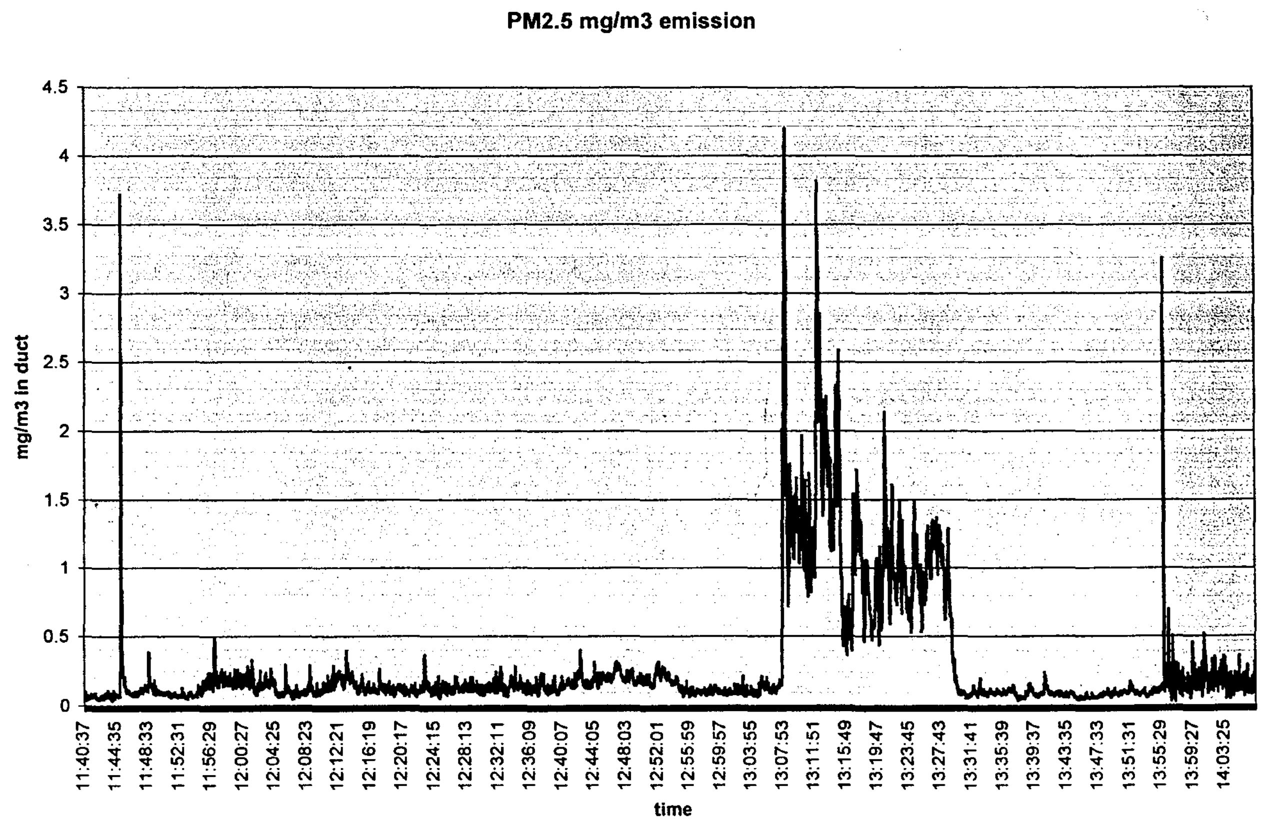
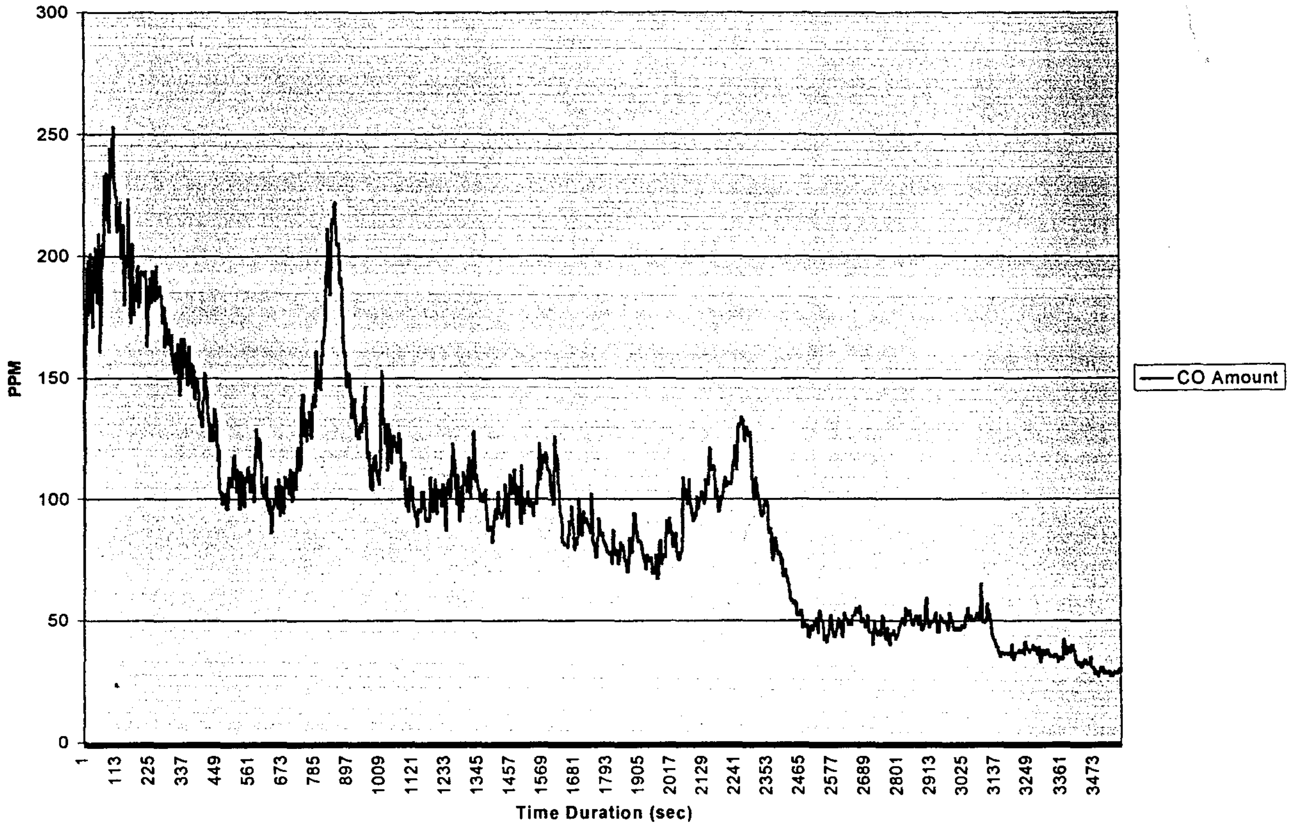


Figure 5 - PM 2.5 emissions during cooling of a 38 inch mold

Figure 6 - CO emissions from Casting A



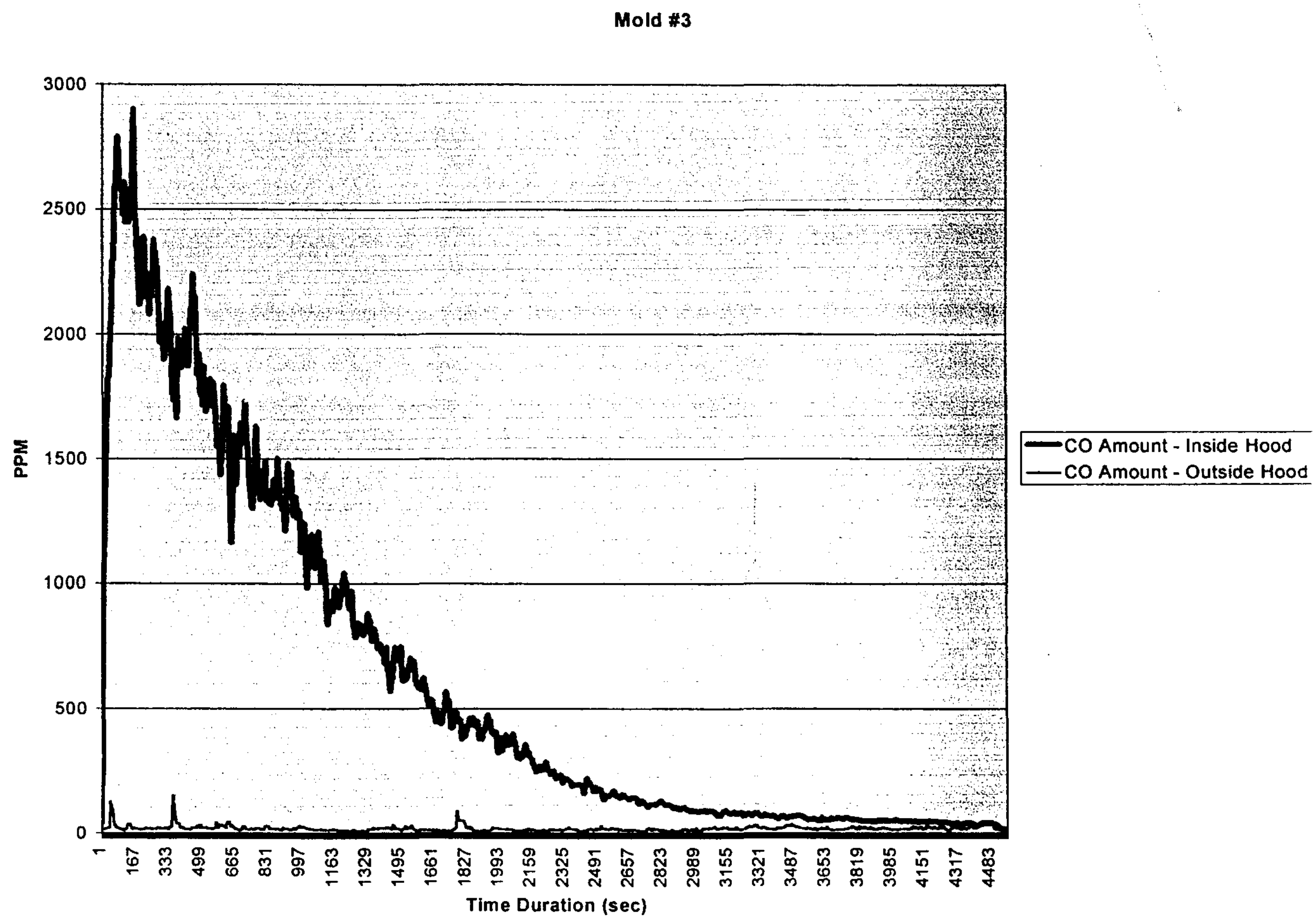


Figure 7 – CO emissions Casting B

Figure 8 - Comparison of CO emissions Molds A and B

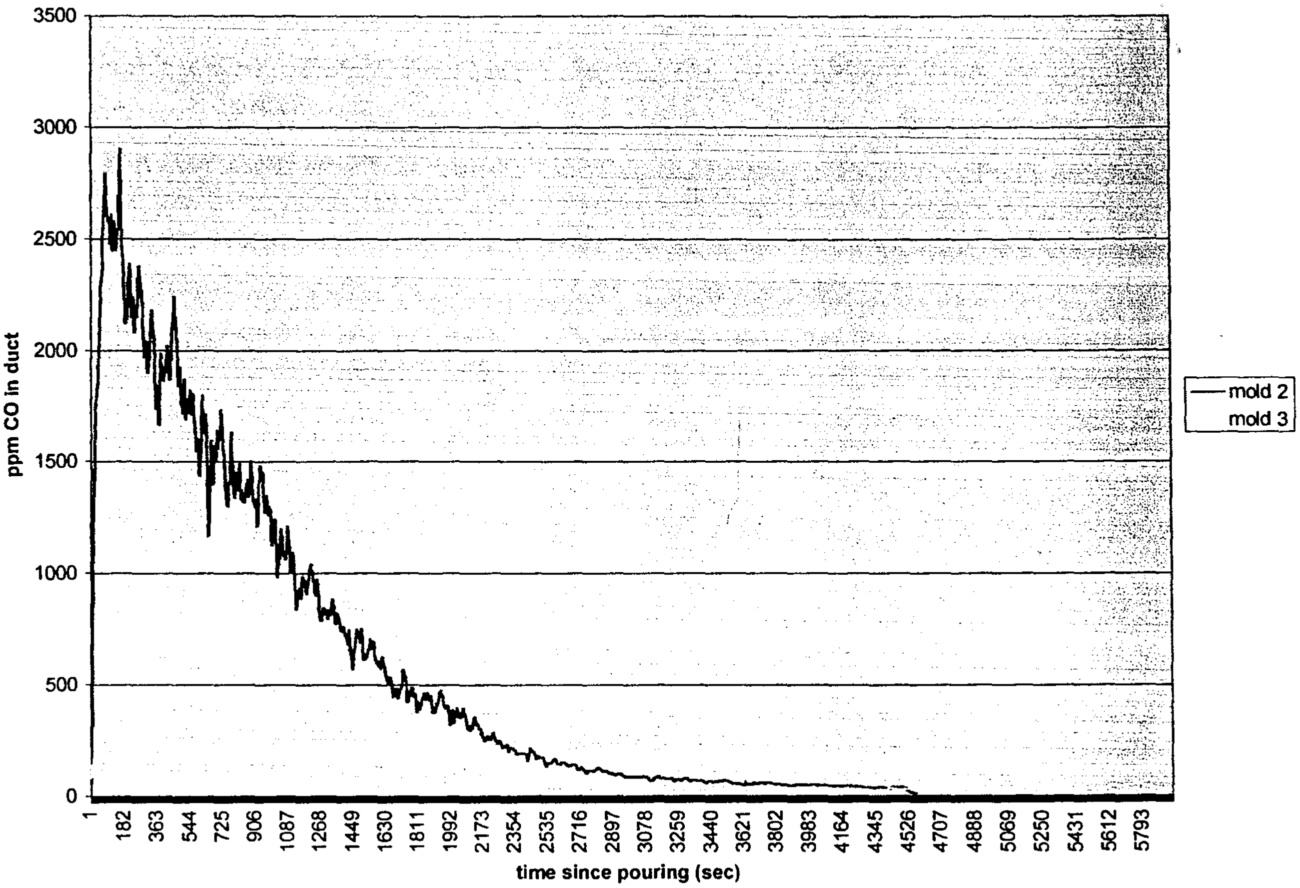


Figure 9 - Casting C, CO emissions and temperature during cooling

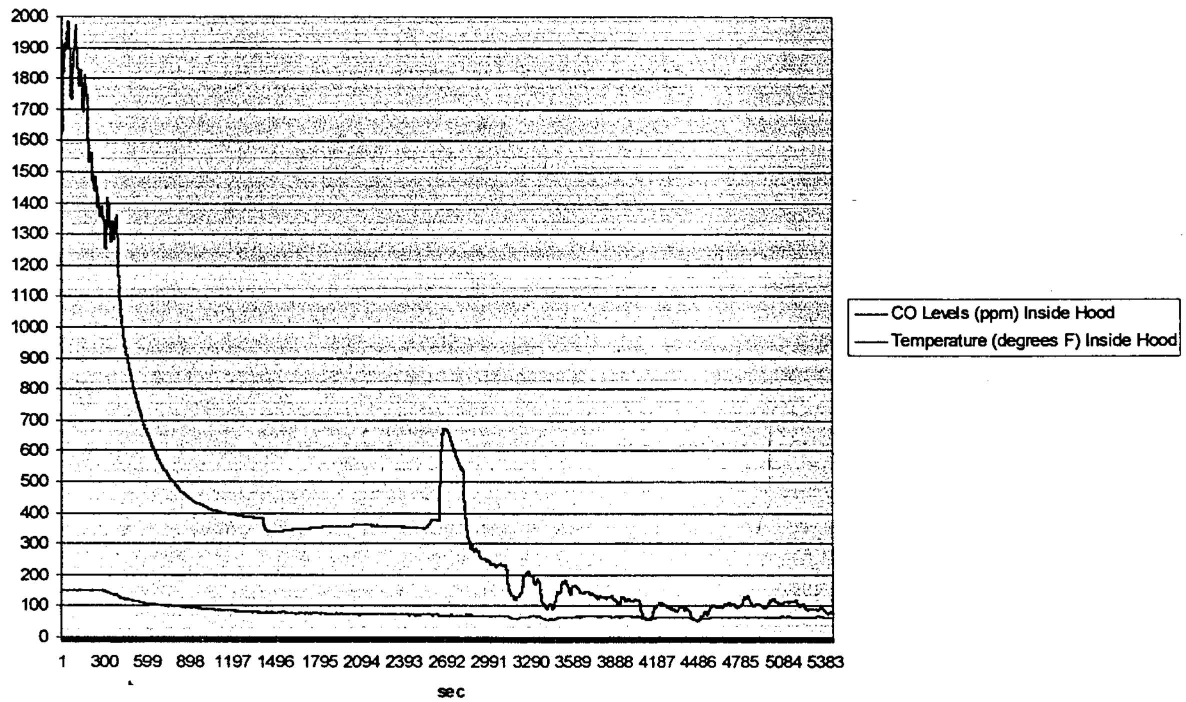


Figure 10 - Casting D, CO emissions and temperature during cooling

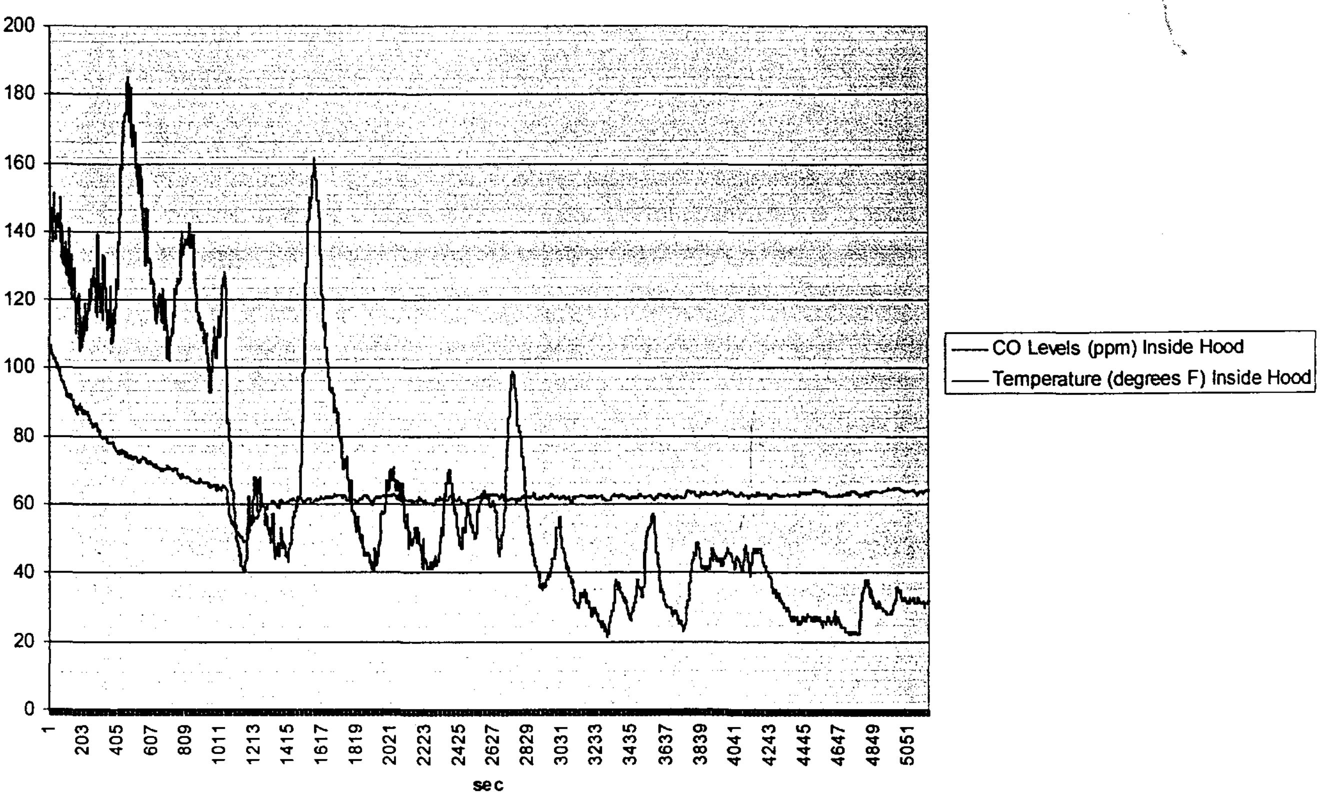


Figure 11 - CO Levels for Mold #1 and Mold #2 Versus Time

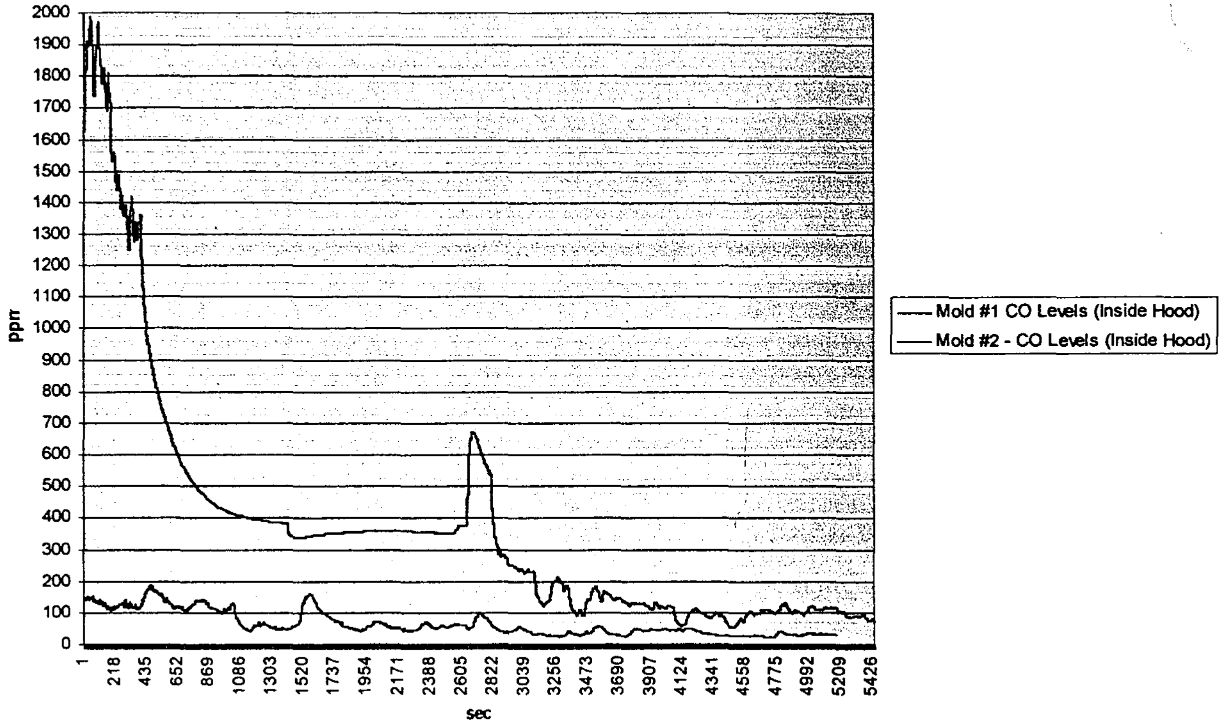


Figure 12 - Average CO exposure by task

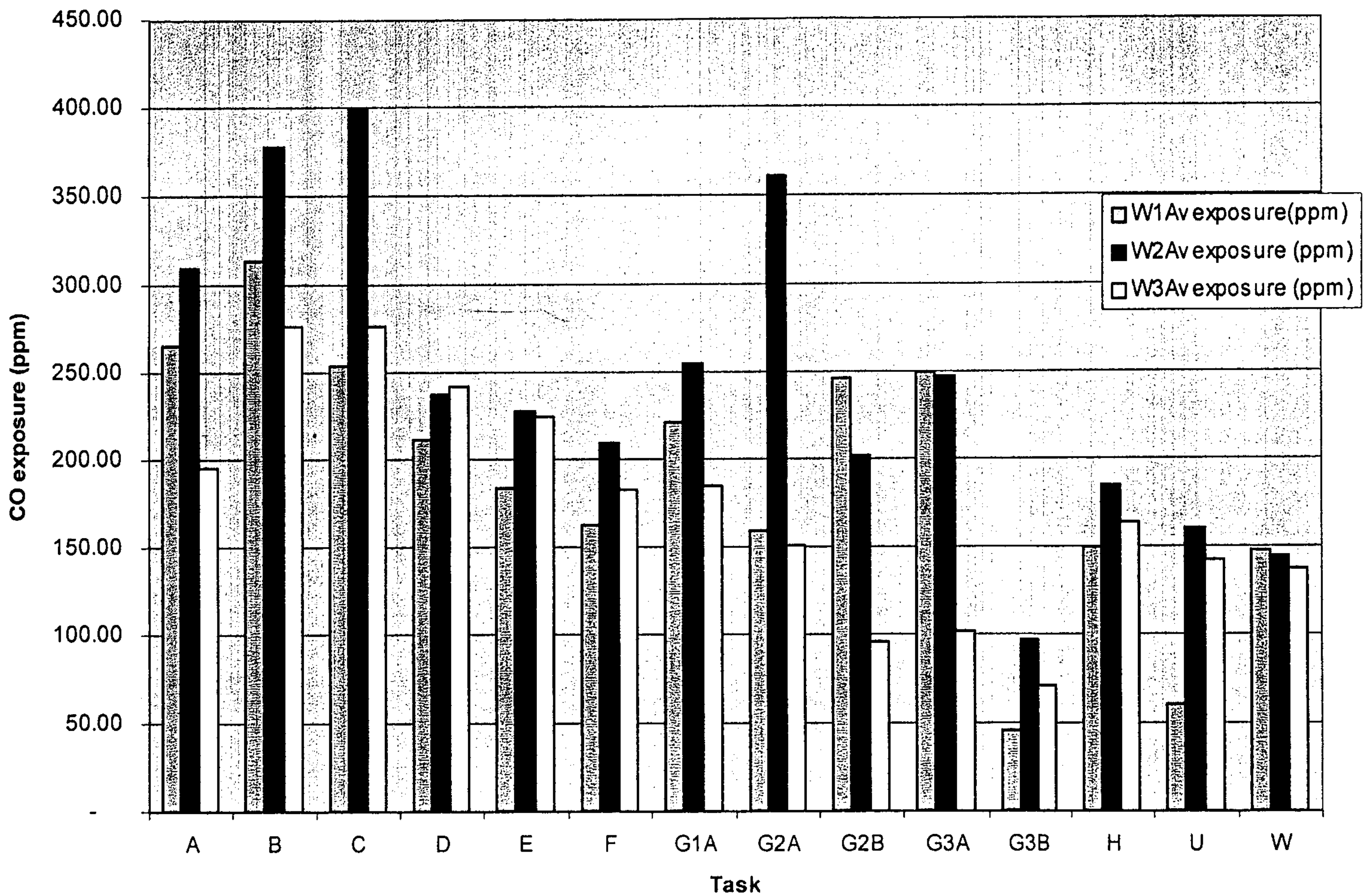
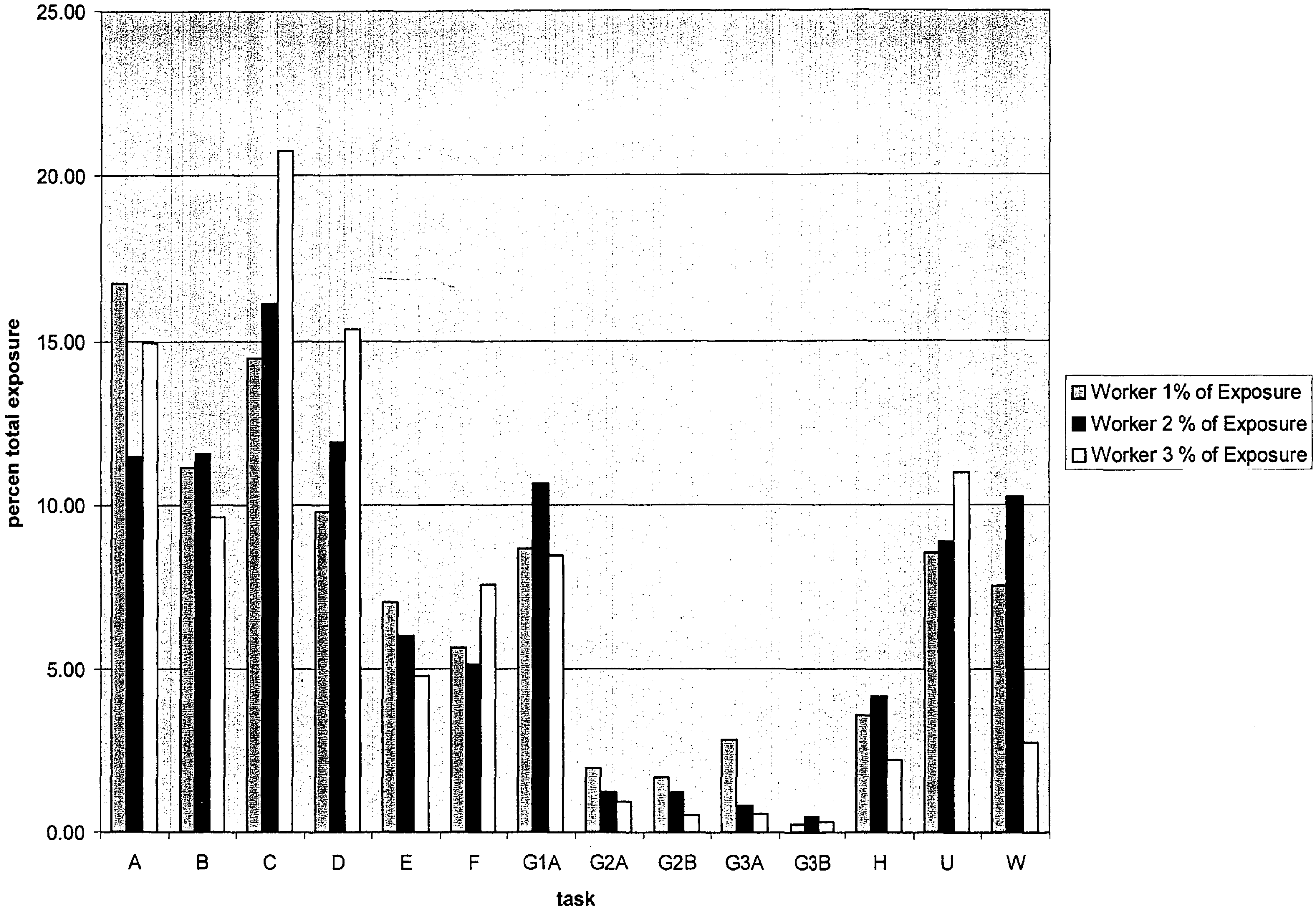


Figure 13 - Distribution of total exposure by task



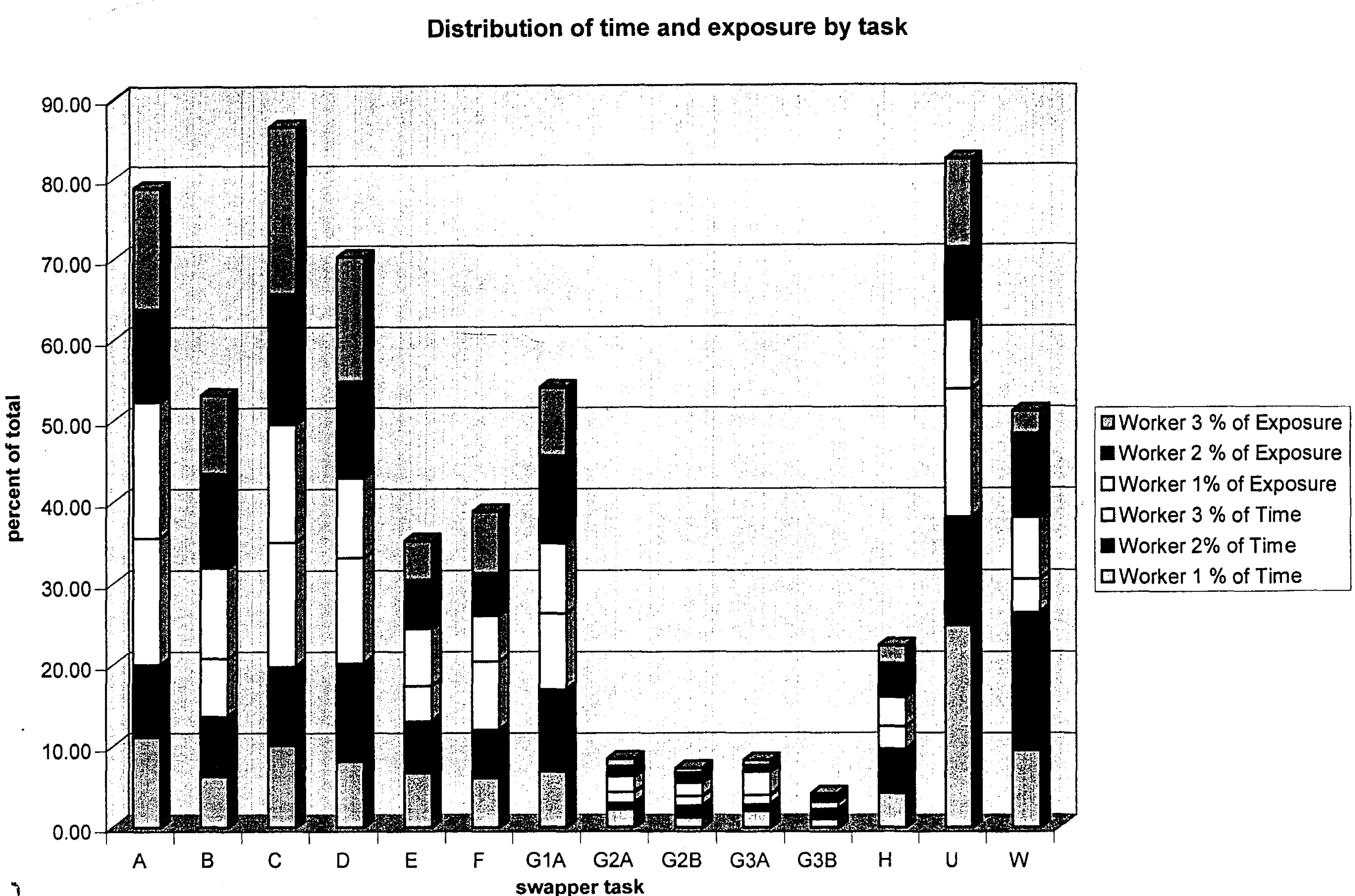


Figure 14 – Distribution of time and exposure by task for each swapper

Table I - Personal exposure to CO

21 October 1999

Name	Job Title	CO tube		Total time	Total time	CO tube indication	CO exposure
		ON	OFF	(min)	(hours)	(ppm)	(ppm)
Pedro	Pourer	8:39	11:50	191	3.18	190	59.69
Marvin	Clamper	8:41	11:52	191	3.18	75	23.56
Bert	Swapper	8:45	10:02	77	1.28	280	218.18
Mike	Panel Operator	8:44	11:55	191	3.18	250	78.53
Malcolm	Swapper	9:59	11:50	111	1.85	550	297.30
Name	**Job Title**	**CO tube**		**Total time**	**Total time**	**CO tube indication**	**CO exposure**
		ON	OFF	(min)	(hours)	(ppm)	(ppm)
Pedro	Pourer	13:31	15:36	125	2.08	110	52.80
Marvin	Clamper	13:29	15:19	110	1.83	40	21.82
Muyemo	Swapper	13:34	15:24	110	1.83	500	272.73
Rich	Panel Operator	13:36	15:21	105	1.75	125	71.43
		14-Jan	**1999**				
Name	**Job Title**	**CO tube**		**Total time**	**Total time**	**CO tube indication**	**CO exposure**
		ON	OFF	(min)	(hours)	(ppm)	(ppm)
Pedro	Pourer	8:49	11:49	180	3.00	120	40.00
John	Clamper	8:53	11:48	175	2.92	150	51.43
Kevin	Swapper	8:58	10:03	65	1.08	220	203.08
Mike	Panel Operator	9:01	11:57	176	2.93	300	102.27
Mike R.	Swapper	10:15	11:55	100	1.67	400	240.00

Table II – CO emission factors

Casting	Sampling time (sec)	Total CO emission (g)	Average CO emission rate (g CO/min)
Casting A:L32 C13 round cover, approx 325 lb	5960	53.5	0.54
Casting B:LK120 cover with S612 frame, approx 250 lb	4568	350.0	4.60
Casting C: L24C23, round cover, approx 150 lb	5448	258.0	2.84
Casting D: L26 C2 round cover, approx 200 lb.	5176	41.7	0.48

Task	Task Description	*Total Time (seconds)*	*% of Time*	*Total Exposure (ppm-sec)*	*% of Exposure*
A	**Hook mold, raise mold from line**	2,557	12.05	623,734	14.84
B	**Move mold from line to cooling stacks**	1,435	6.76	452,570	10.77
C	**Lower mold to cooling stacks, unhook mold**	2,469	11.64	712,388	16.95
D	**Hook and raise cooled mold from cooling stacks**	2,222	10.47	510,813	12.15
E	**Move cooled mold from cooling stacks to line 1A**	1,246	5.87	254,164	6.05
F	**Lower cooled mold onto line 1A, unhook mold**	1,439	6.78	258,842	6.16
G1A	**Hammer off clamps from molds on line 1 ("near side")**	1,765	8.32	382,934	9.11
G2A	**Hammer off clamps from molds on line 2 ("near side")**	342	1.61	61,075	1.45
G2B	**Hammer off clamps from molds on line 2 ("far side")**	262	1.23	50,222	1.19
G3A	**Hammer off clamps from molds on line 3 ("near side")**	315	1.48	67,087	1.60
G3B	**Hammer off clamps from molds on line 3 ("far side")**	213	1.00	14,013	0.33
H	**Walk to and over lines**	846	3.99	138,273	3.29
U	**Unknown**	4,134	19.48	397,108	9.45
W	**Waiting for next mold**	1,974	9.30	280,068	6.66
	Total	21,219		4,203,291	

Table III – Distribution of time and exposure by task – all swappers combined

Task	Worker 1% of Exposure	W1Avexposure (ppm)	Worker 2 % of Exposure	W2Av exposure (ppm)	Worker 3 % of Exposure	W3Av exposure (ppm)
A	16.76	265.10	11.49	309.22	14.96	196.56
B	11.15	312.99	11.58	377.65	9.64	276.15
C	14.49	253.42	16.13	399.80	20.75	276.65
D	9.78	212.28	11.93	237.42	15.38	241.72
E	7.04	184.74	6.00	227.93	4.80	225.44
F	5.65	163.43	5.16	210.33	7.59	183.58
G1A	8.67	221.53	10.65	255.02	8.48	185.06
G2A	1.98	159.74	1.22	359.94	0.96	150.97
G2B	1.67	247	1.24	203.08	0.54	96.35
G3A	2.85	249.71	0.81	247.17	0.58	102.49
G3B	0.26	45.59	0.49	97.04	0.31	71.00
H	3.60	150.58	4.15	185.18	2.23	164.21
U	8.56	60.75	8.91	160.50	11.02	143.40
W	7.54	148.74	10.24	145.08	2.77	137.09
Overall Average		175.94		239.61		203.80

Table IV – Distribution of CO exposure by task and average CO exposure for 3 swappers

APPENDIX

Final Report to NIOSH

Ventilation Upgrade
LeBaron Foundry
Brockton, MA

By

DiBerardinis Associates Inc.
24 Twitchell Street
Wellesley, MA 02482

February 12, 2001

Phase I

Introduction

The foundry area is presently exhausted by a passive exhaust system. Several 10 in x 52 in ducts provide a pathway from the mold storage area to the roof. The pathway is shown in Figures 1 and 2.

Several exhaust options were explored. These options are shown diagrammatically in Figures3-10. Table 1 shows the overall exhaust quantity required for various exhaust options. The required exhaust volumes varied from 143,150 CFM to 81,300 CFM.

Two pilot studies are proposed to evaluate effectiveness and feasibility of control.

Phase II

Background

After 5 recommendations for exhausting the mold line were explored and not deemed feasible by the client, LeBaron Foundry, further brainstorming was conducted to determine any other solution which would not hamper the foundry activity while at the same time would improve the emission exposure of the workers handling molds.

The first pilot study would be just to exhaust one selected bay to demonstrate the efficacy of the exhaust approach. This option is indicated in Fig. 11. No make up air would be provided. The cost of the system is described in Table 2.

The second solution proposed is illustrated in Figure 12; the concept is to supply ventilation (and cooling) air over the worker with the mold. The supply air outlet was to move along with the crane carrying the mold. The air was provided through a "zippered" connection. Though extremely ingenious the option had to be set aside as it was a very expensive and had operating difficulties.

Another option was the possibility to provide supply air to the worker. Several configurations were reviewed. In place of a "zippered" supply air connection it was felt that multiple air supply outlets located over the length of the mold line might approximate the continuos air supply concept of the "zippered" connection. Obviously this supply air needed to be conditioned. Instead of heating the supply air using additional energy it is recommended that the supply air be heated by recovering some heat from the foundry area. The foundry area is always warm and recovering heat energy to preheat the make up air is very cost efficient.
Various heat recovery options were considered. These included 1) runaround loop, 2)-plate heat exchanger, 3) heat pipe and heat recovery wheels. All of the options were rejected due to high first cost.

DBA charge was to propose a modular solution, which could be attempted at LeBaron foundry with minimum of disruption and cost. The following option was selected.

Description of System

Regent ECO Heat Recover System is a proprietary product of BKM Energy and Environmental Products of East Hartford, CT. The concept is both simple and effective. The system (Figure 13) consists of two banks of aluminum plate cassettes whose surface area has been maximized to absorb energy from the exhaust stream. Exhaust air from a process heats one cassette while the outside air is drawn through newly energized cassette bank where the captured energy is released. A two position motorized damper, as it changes position, switches exhaust air and the supply air stream from cassette to cassette. A schematic layout of the arrangement is shown in Fig. 13.

The system also has capability of some latent heat recovery. In colder months, heated exhaust air passes over previously cooled plates, condensation occurs due to temperature differences. When the reverse flow occurs, this moisture is captured and returned to the space.

The system is available in a 625 CFM cassette module.

Application of System

On a pilot basis it is proposed that LeBaron Foundry install one 625 CFM module in its plant. The layout is shown in Fig. 13. No attempt is being made to exhaust the mold area. Rather the exhaust air stream is taken high from the ceiling where it is anticipated that due to stratification air would be at a high temperature. The supply air would be brought down to the worker level. The cost of such a system is shown in Table 3.

Table 2
Cost of Pilot System

(1) 5000 CFM Exhaust Fan	$ 1,500
Roofwork	$ 500
Ductwork	$ 5,500
Electrical	$ 500
Air Balancing	$ 500
Sub Total	$ 8,500
Contingency (10%)	$ 850
Total	**$ 9,350**

Table 3
Cost of ECO Heat Recovery System

(1) 625 CFM Cassette Module	$ 3000
Roofwork	$ 500
Ductwork	$ 1500
Electrical	$ 500
Air Balancing	$ 500
Sub Total	$ 5,000
Contingency (10%)	$ 500
Total	**$ 5,500**

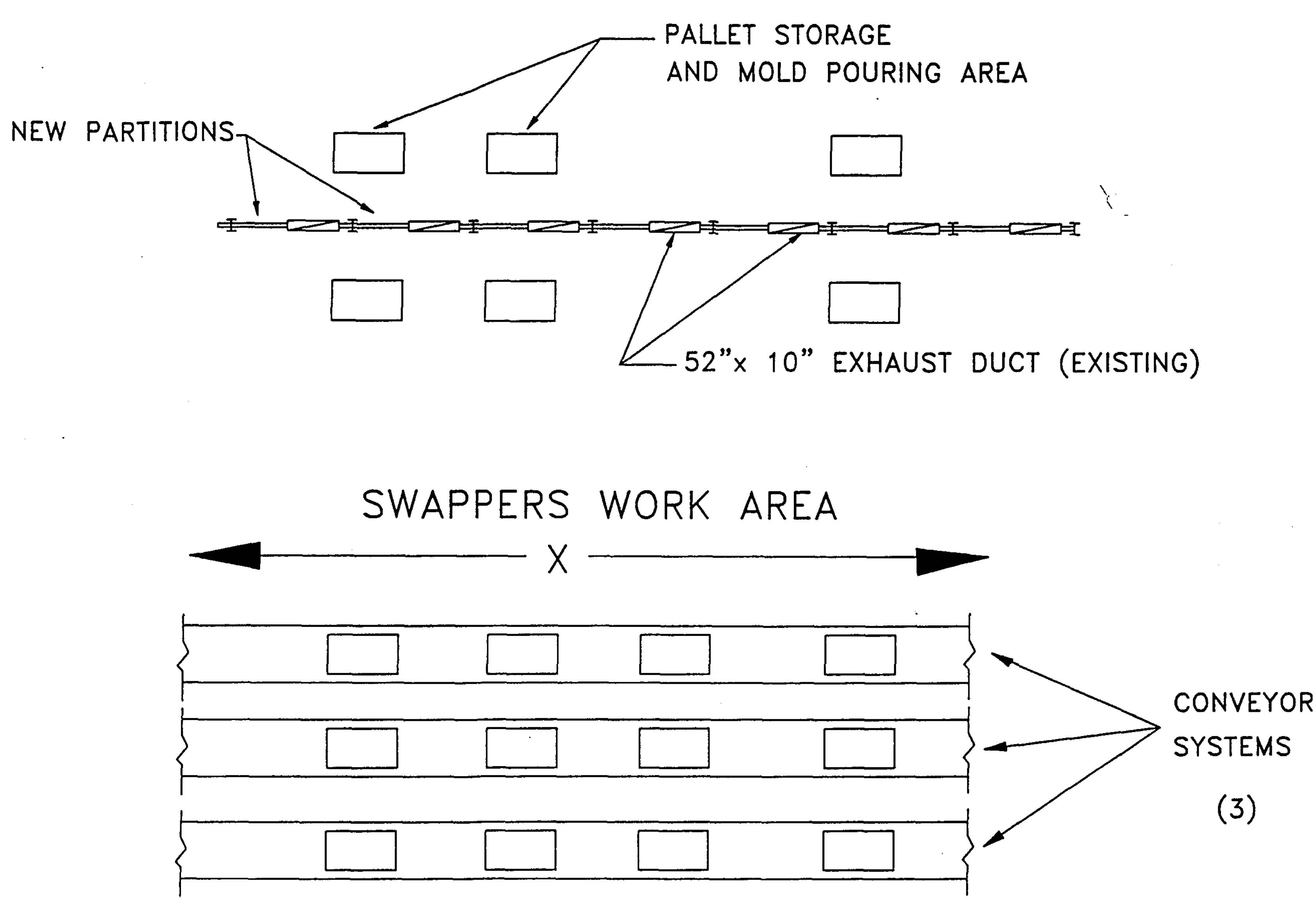


FIG.–1

EXISTING CONDITIONS

LEBARON FOUNDRY N.T.S. DATE: 01–30–01

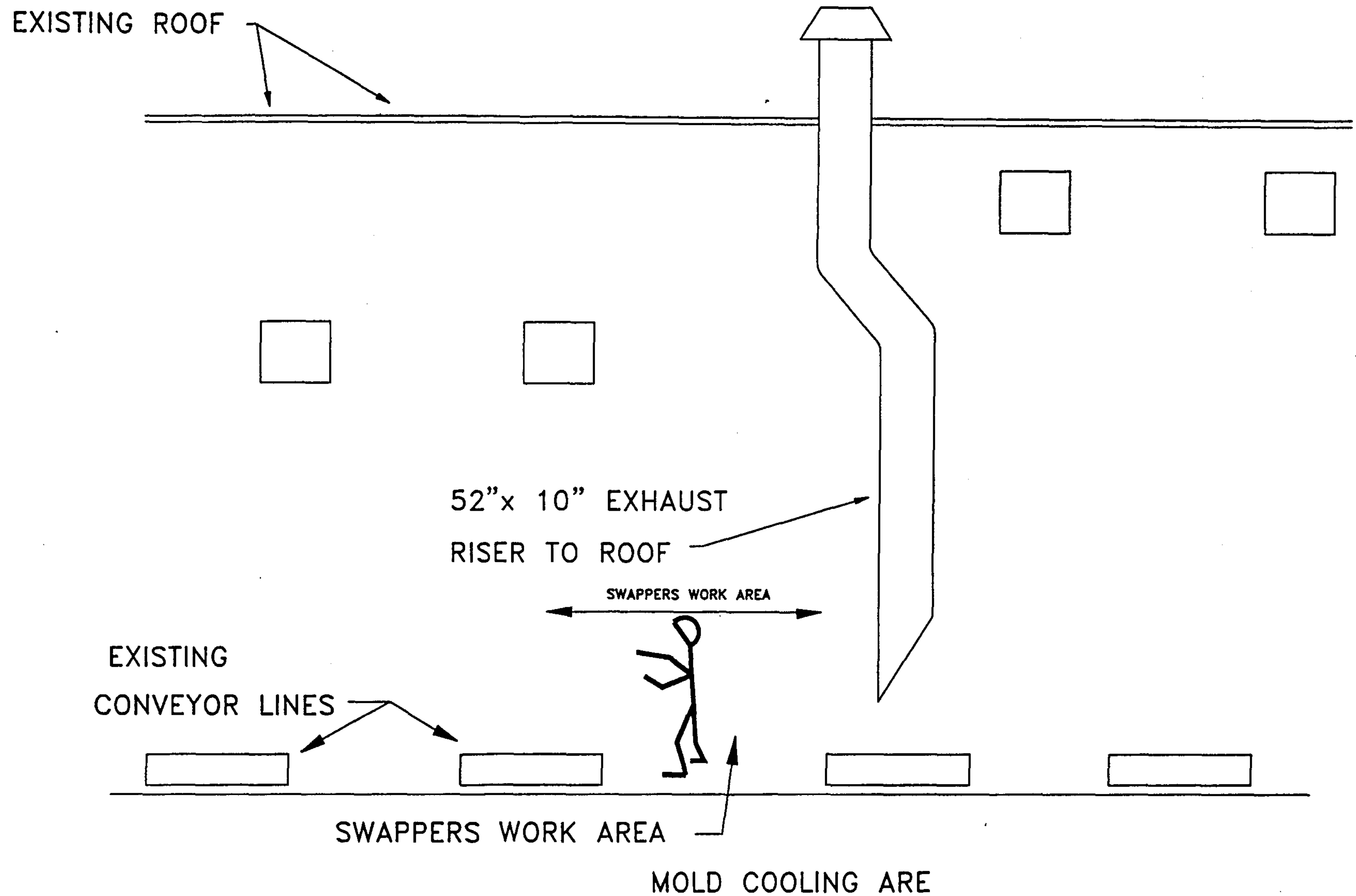


FIG.-2

EXISTING CONDITIONS

LEBARON FOUNDRY N.T.S. DATE: 01-30-01

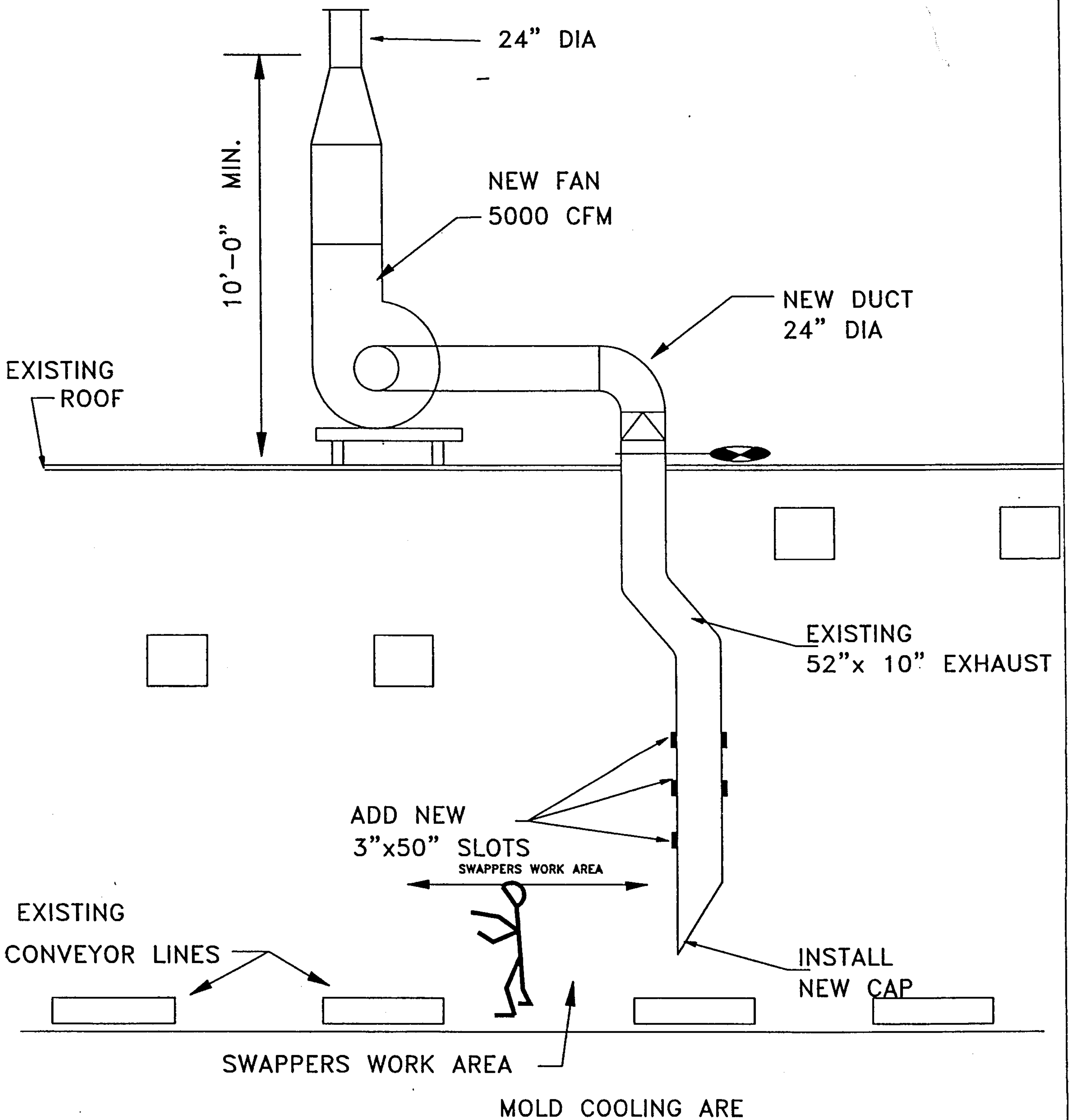


FIG.-3

LEBARON FOUNDRY N.T.S. DATE: 01-30-01

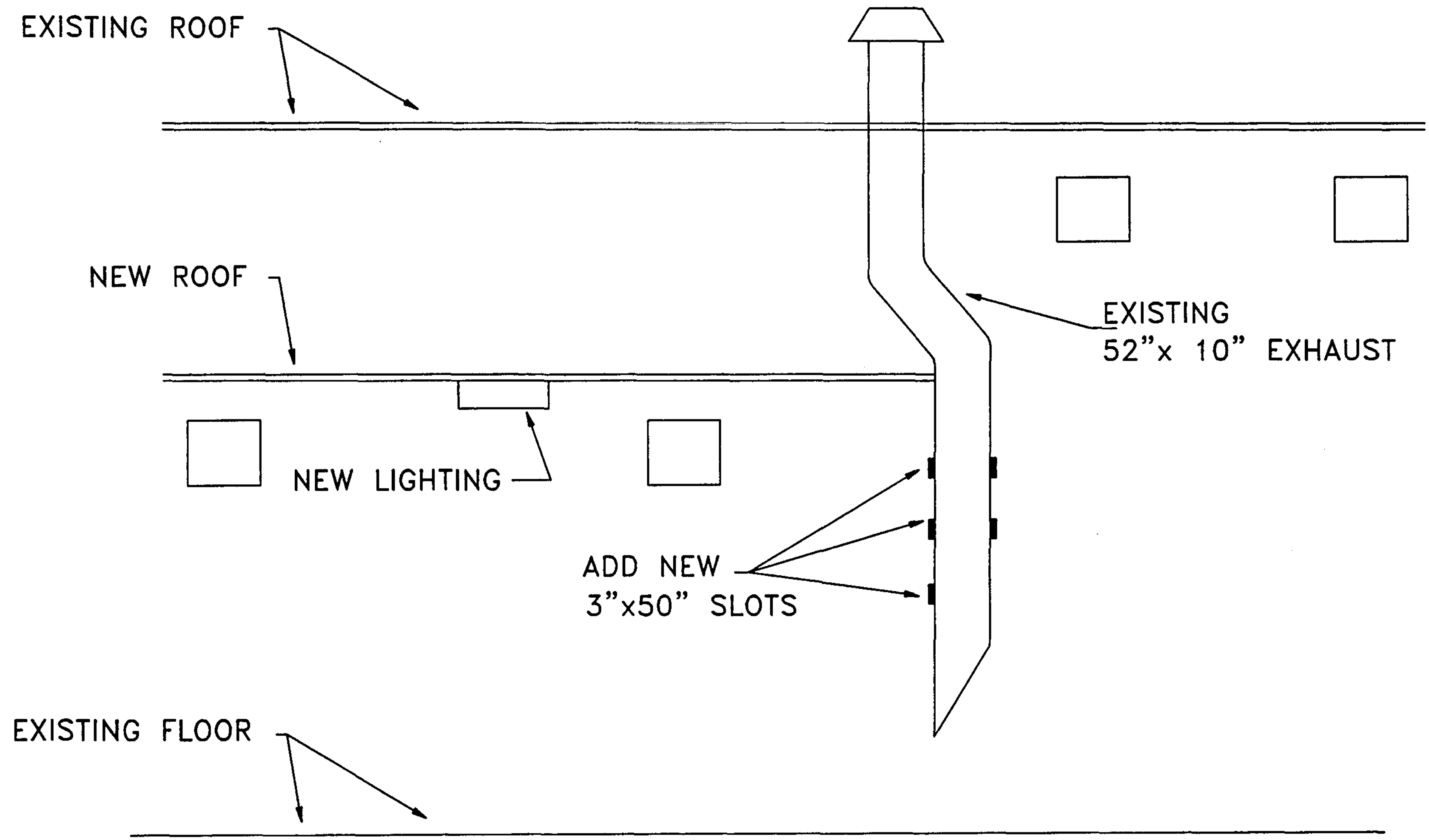


FIG.-4

OPTION # 2

LEBARON FOUNDRY

N.T.S.

DATE: 01-30-01

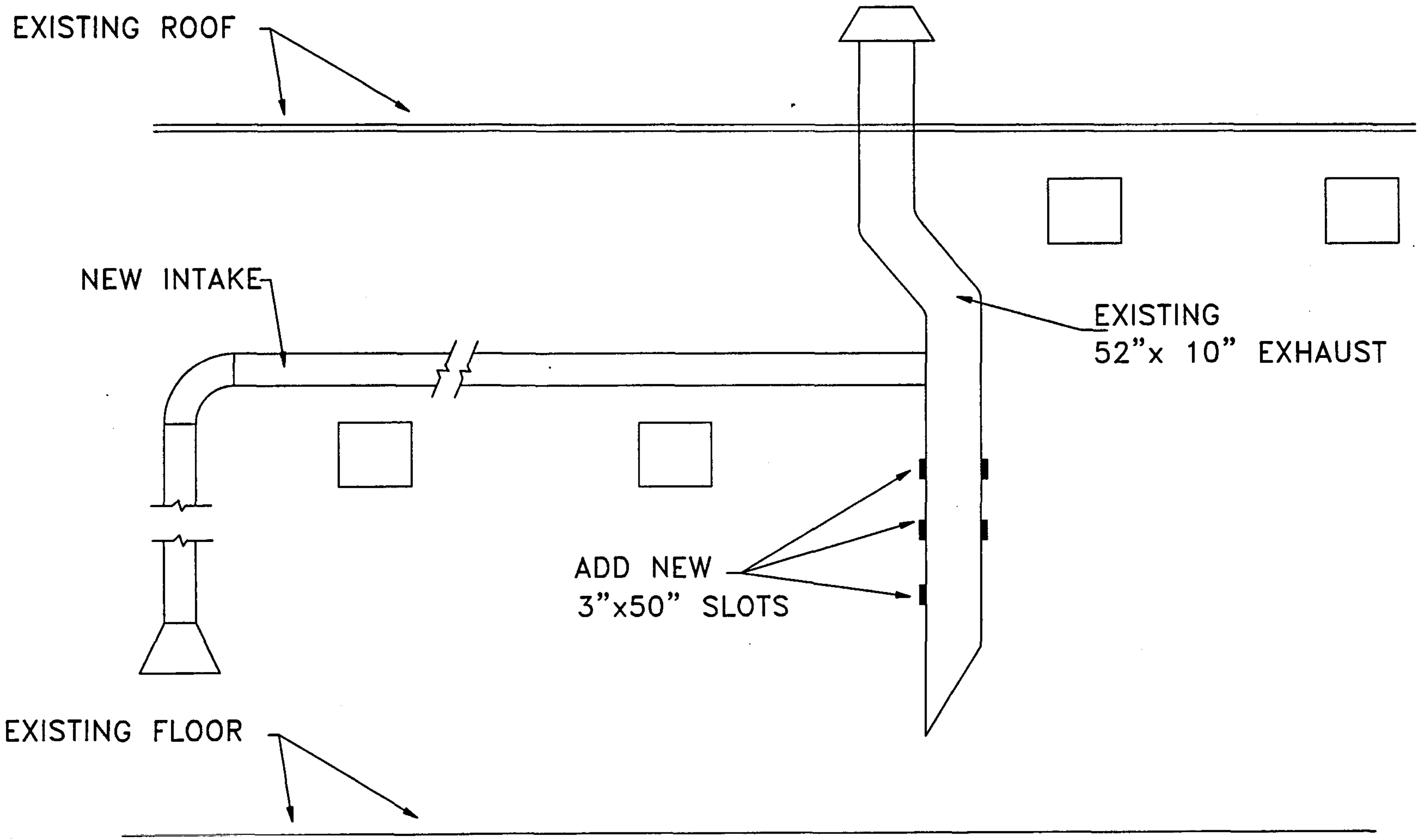


FIG.–5

OPTION # 3

LEBARON FOUNDRY N.T.S. DATE: 01–30–01

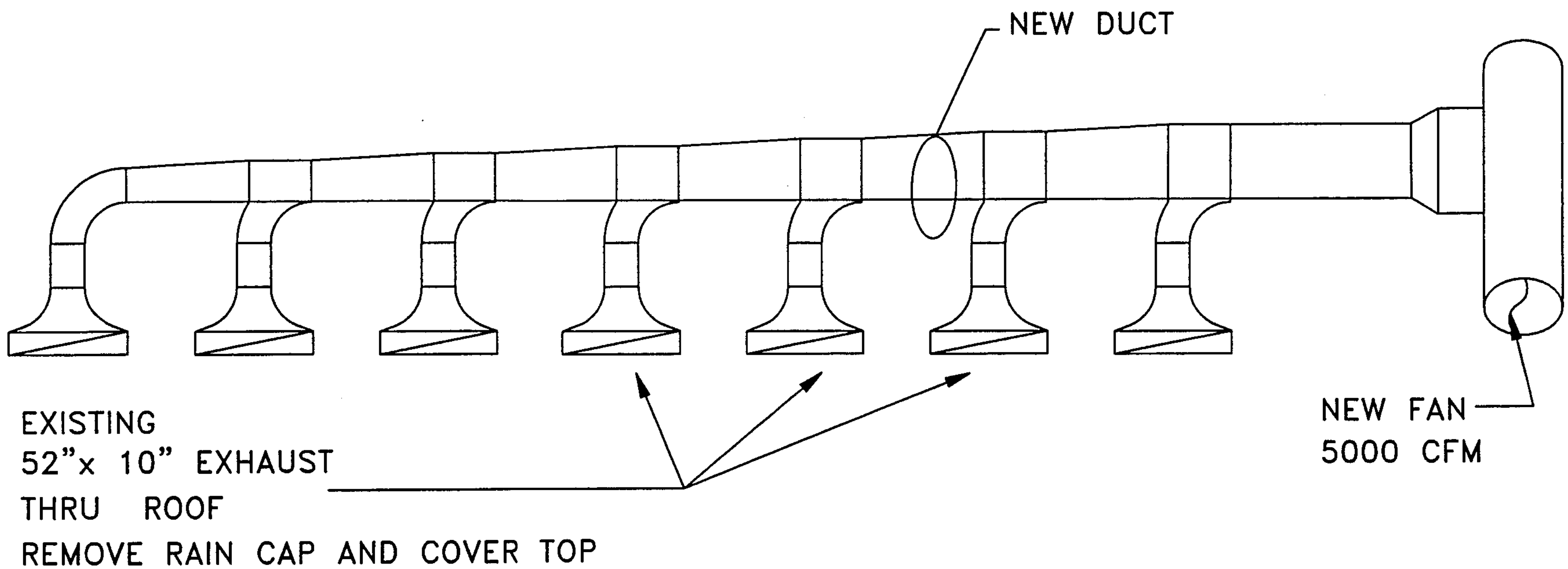


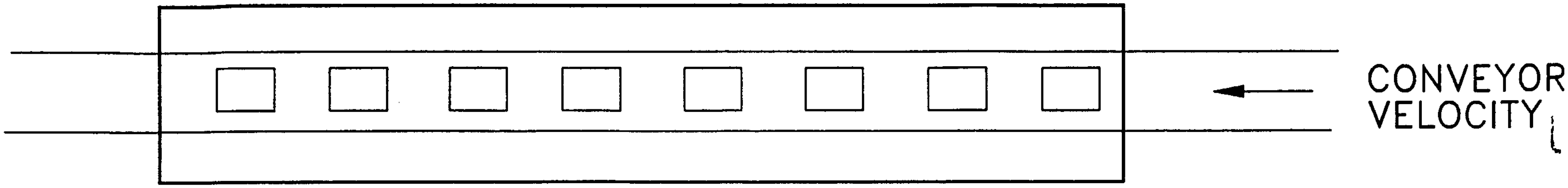
FIG.–6

ROOF LAYOUT

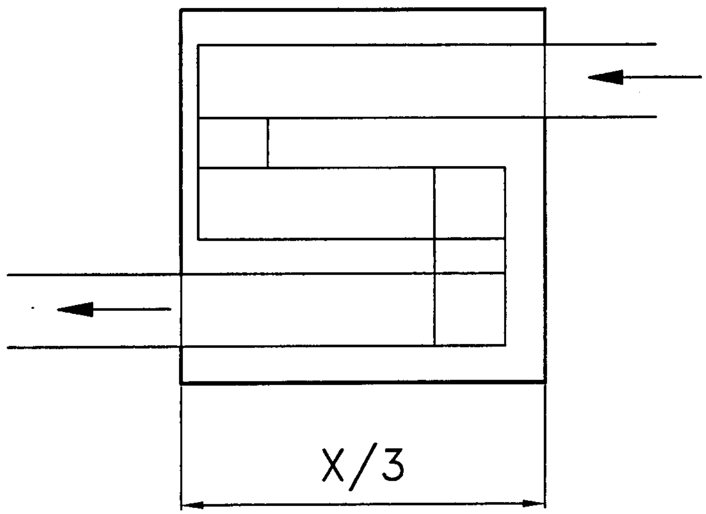
LEBARON FOUNDRY

N.T.S.

DATE: 01–30–01



STRAIGHT LINE



(3) TURNS

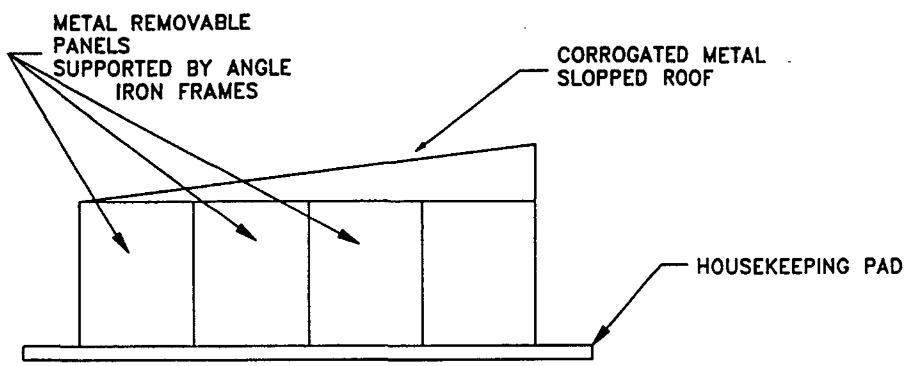
Figure 7

PROPOSED SMOKE HOUSE PLANS

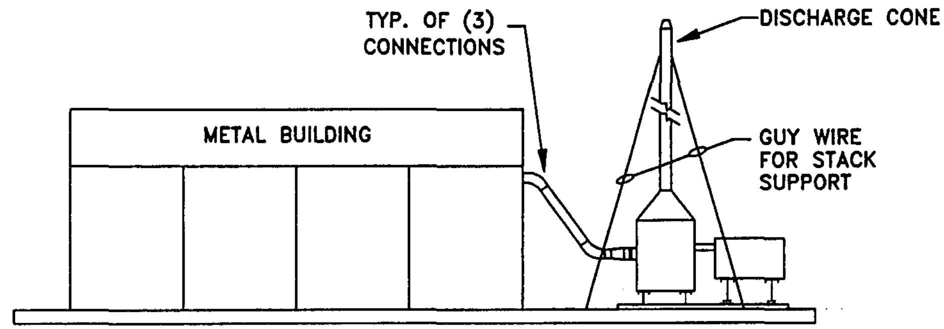
LEBARON FOUNDRY

N.T.S.

DATE: 01-30-01



SIDE ELEVATION



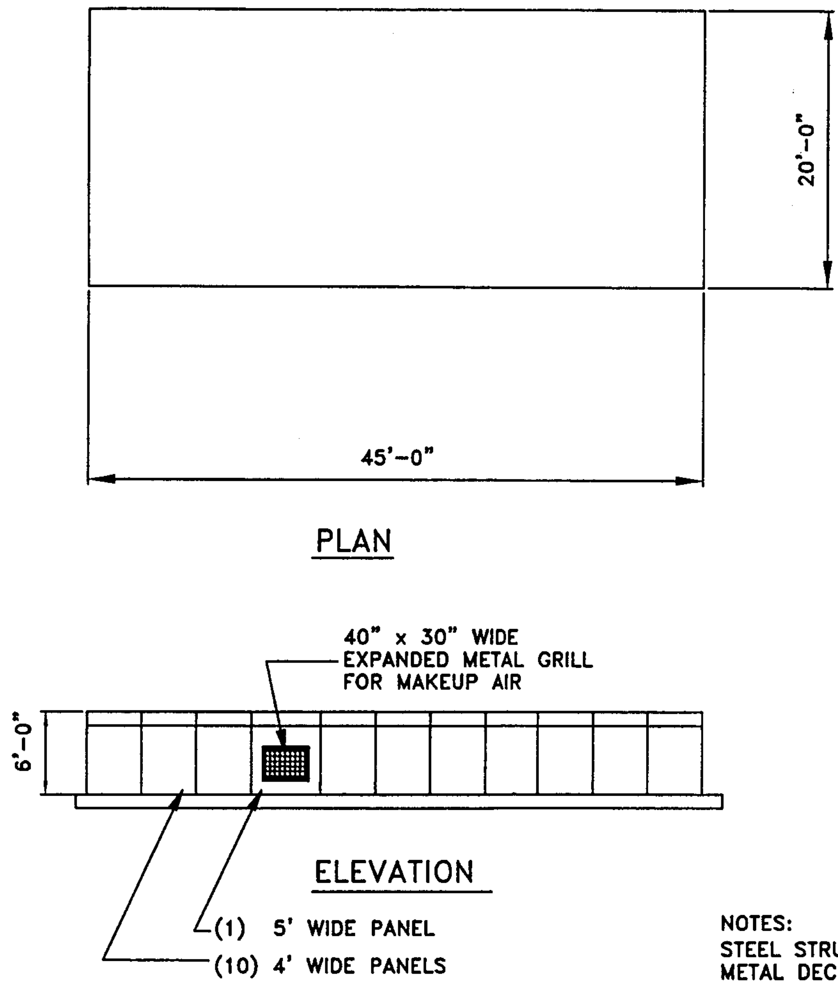
SIDE ELEVATION

Figure 8

PROPOSED SMOKE HOUSE ELEVATIONS

LEBARON FOUNDRY N.T.S. DATE: 01-30-01

Figure 9

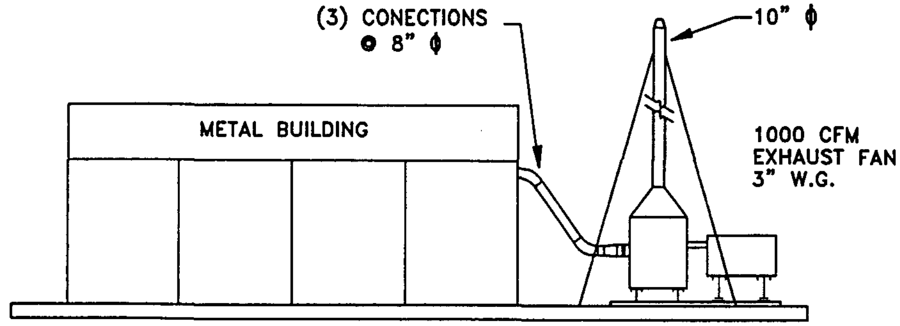


METAL DECK ROOF

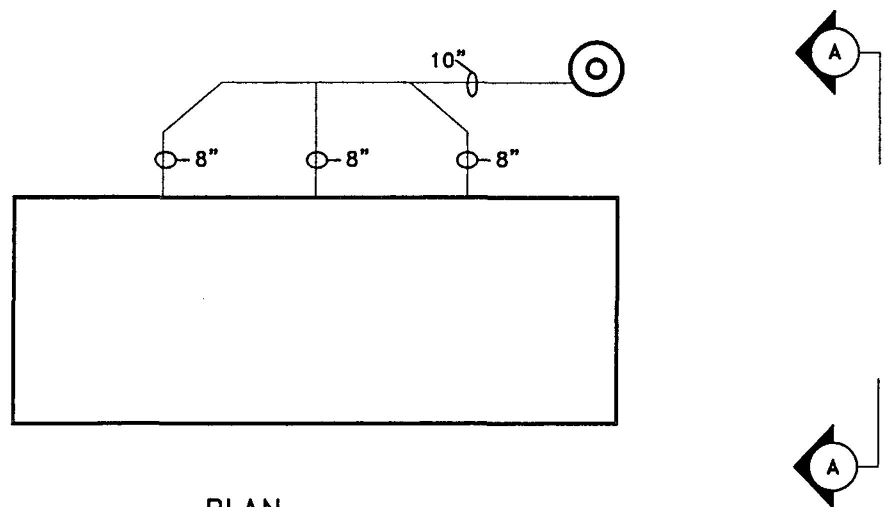
NOTES:
STEEL STRUCTURE – LIGHT FRAME WITH METAL DECK ROOF. REMOVABLE PANELS ON TWO SIDES (LONG).
THE ASSEMBLY MOUNTED ON SLAB ON GRADE.
MAKE UP AIR INTAKE ON THE SIDE.

PROPOSED SMOKE HOUSE DETAILS

LEBARON FOUNDRY N.T.S. DATE: 01-30-01



SECTION A–A

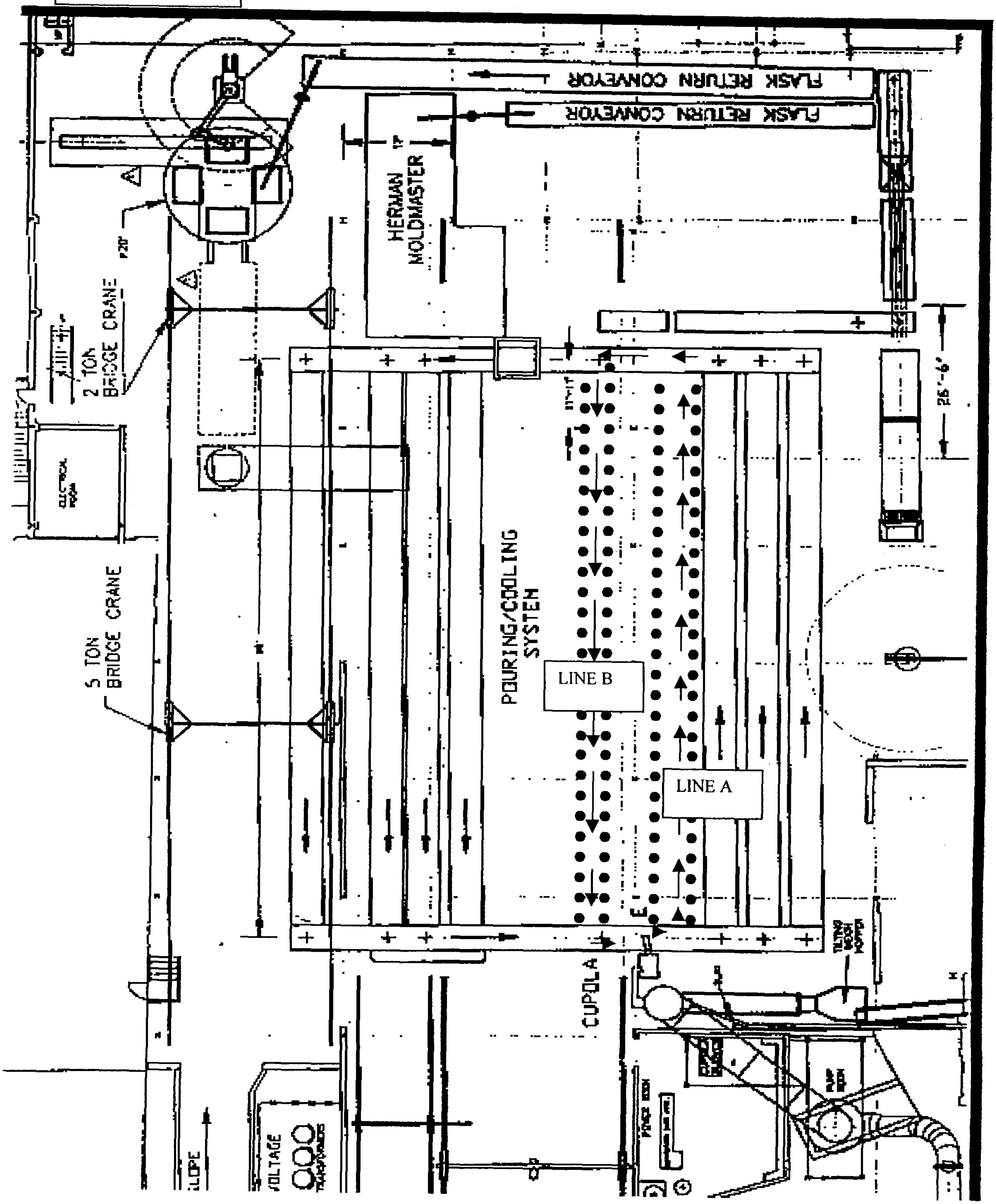


PLAN

PROPOSED SMOKE HOUSE PLAN AND SECTION

LEBARON FOUNDRY　　N.T.S.　　DATE: 01–30–01

LeBaron Foundry
January 14, 1999



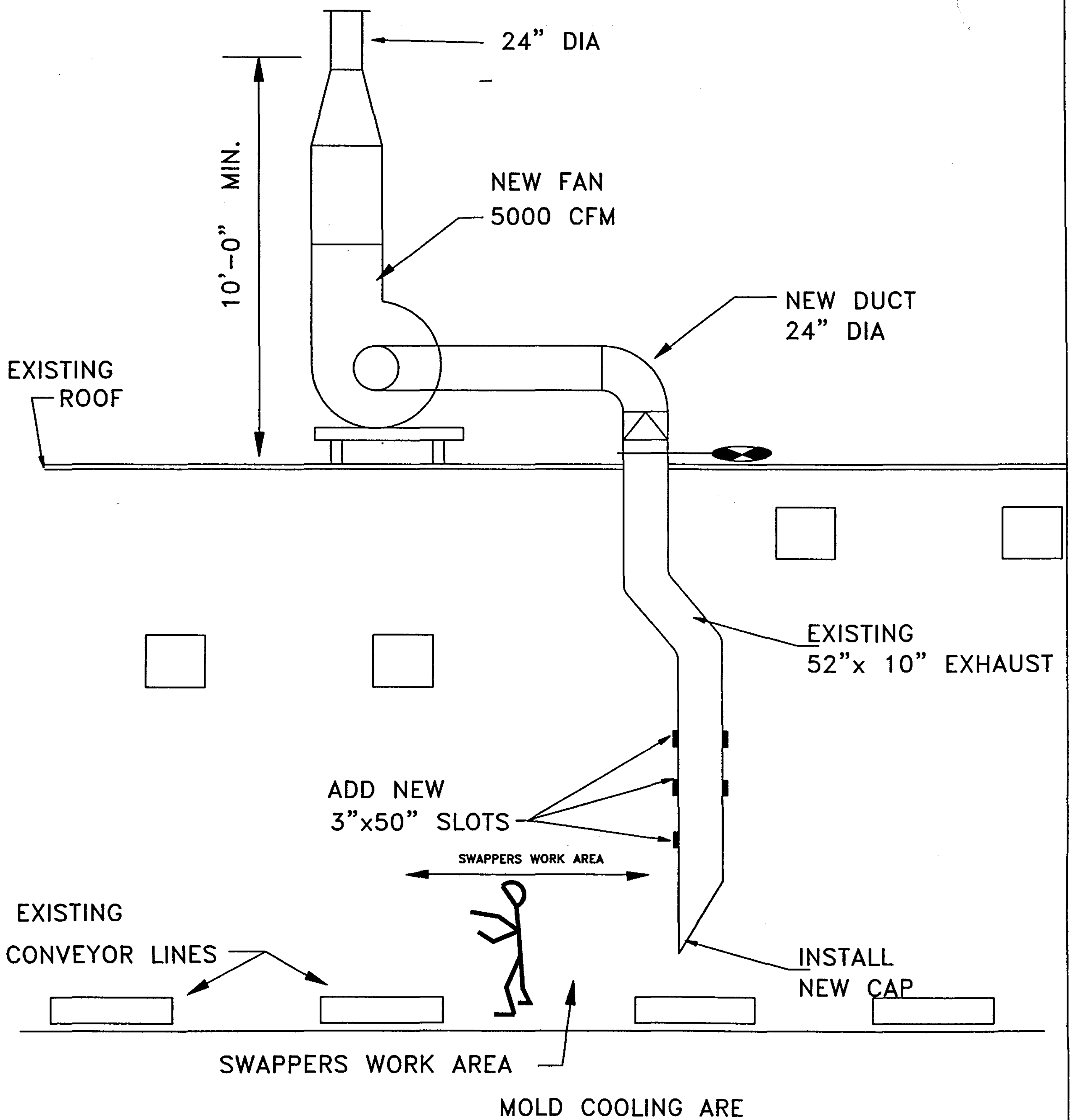
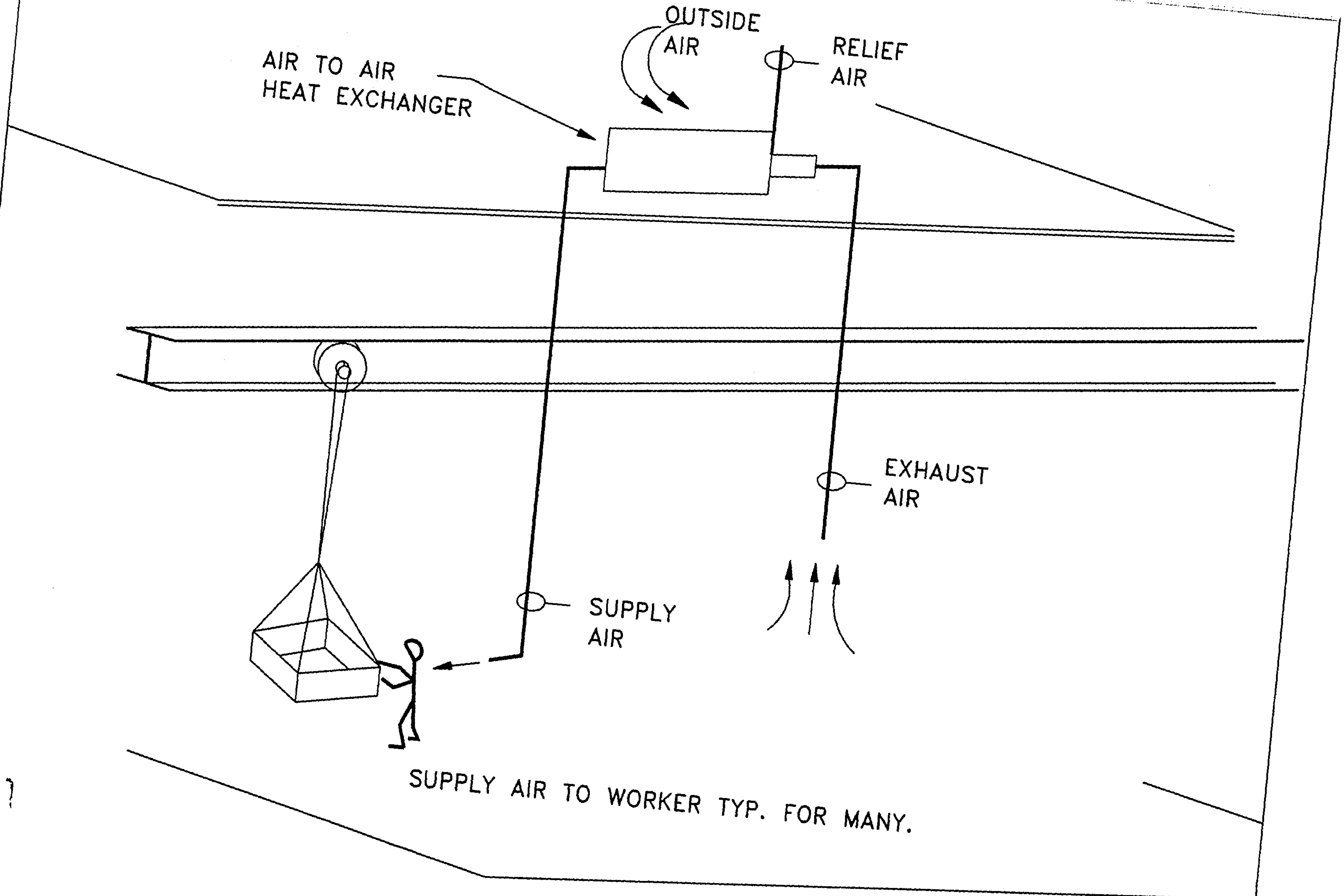


FIG.–11

LEBARON FOUNDRY N.T.S. DATE: 01–30–01



LEBARON FOUNDRY

FIG.–12

N.T.S.

DATE: 01–30–01

Z CONFIGURATION OPTION SHOWN
Standard setting for damper changes is 70 seconds