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HSE CONTRACT RESEARCH REPORT No. 47/1992

A COMPARISON OF SHORT AND LONG PERIOD MONITORING FOR PARTICULATE WELDING FUME

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Particulate welding fume concentrations were monitored according to BS 6691 Part 1 1986 in 'on site' situations to ascertain the extent to which fume concentrations measured using short sampling periods (up to 4 hours) reflected the 8 hour TWA concentration. Fume concentrations measured on different days for similar tasks were also compared.

It was established that results from short period monitoring do not adequately reflect 8 hour TWA concentrations and that monitoring nominally the same task on different days may provide variable results.

It was recommended that welding fume should be monitored during periods of peak welding activity and fume control reflected on the basis of the results obtained.

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A COMPARISON OF SHORT AND LONG PERIOD MONITORING FOR PARTICULATE WELDING FUME

For: HSE

By: G J Carter

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1. INTRODUCTION

Particulate welding fume and its constituents are considered to be hazardous substances and must be controlled according to the Control of Substances Hazardous to Health (COSHH) regulations (1). The concentrations to which fume control must be exercised are known as Occupational Exposure Limits and are provided in Guidance Note EH40 (2) which is updated annually. The unit of measurement for Occupational Exposure Limits is a concentration, in mg/m^3, averaged over an 8 hour day and known as the 8 hour time weighted average (TWA). This concentration is established by monitoring, which for welding fume, is performed according to a specific standard BS6691 (3). It involves pumping fume laden air at a known rate through a filter placed in a sampling head fixed in the breathing zone of the welder by securing to the headband of his helmet. Thus, during periods of arcing, the sampling head is behind the headshield but remains in place when the headshield is raised. The 8 hour TWA is obtained by monitoring the worker throughout the working day. However, this may cause inconvenience because a welder would not usually wear a helmet throughout the day and alternative arrangements eg connection of the sampling head to a headband without a helmet, must be made for periods of other activity. Alternatively, it is generally considered acceptable to measure background fume levels in the workshop adjacent to the welder and assume that, during non arcing periods, exposure to background fume concentrations occurs. Personal sampling is then carried out to include all arcing periods and the 8 hour TWA is calculated using the formula:

$$\frac{C_1T_1 + C_2T_2 + CxTx}{8} \qquad [1]$$

where C is the occupational exposure and T is the associated exposure time in hours. Neither of the above methods is ideal because regular, day long, supervision, either to resecure sampling heads or to time monitored and background periods is required. Additionally, sampling equipment must be allocated to a single subject for a complete 8 hour period, thus making the monitoring exercise time consuming, both in equipment and personnel, and consequently expensive.

BS6691 recommends a sampling period of 1 hour but recognises the possible need to monitor for shorter or longer periods. This recommendation is based largely on the time required to collect a reasonable weight of fume and information enabling the conversion of the measurement for the short sampled period to the 8 hour TWA is not

provided. Thus, at the present time, sampling tends to be carried out either during peak arcing periods and fume is controlled to the required levels for this presumed worst case scenario or further measurements must be taken, at extra expense to ascertain the 8 hour TWA.

Monitoring costs could be greatly reduced if it were possible to select shorter sampling periods which were representative of the 8 hour TWA. It would be anticipated however, because of the intermittent nature of welding and the variability of tasks performed by a welder eg. work positioning and fit up, that careful selection of sampling periods would be required if the test results were to be comparable to the 8 hour TWA figure. However, the data required to make such selection are not presently available. This report sets out, therefore, by carefully monitoring different welders, in different 'on site' situations to provide the information required to examine the extent to which monitoring periods may be reduced and to determine the time periods most likely to provide results indicative of the 8 hour TWA.

2. EXPERIMENTAL APPROACH

Monitoring was carried out at different sites and examined different welders, work situations and base materials. In this way, it was expected that the data collected would be of general applicability. However emphasis was placed on the manual metal arc process because of its widespread industrial use and on welding of highly alloyed materials where the requirement for low fume control levels was expected to add critically to the monitoring results.

Personal sampling was performed to include all arcing periods but ceased when the welder removed his headshield. During non arcing periods, not occurring within a monitored period, exposure was presumed to be at background levels. Except in situations where fume concentrations in the workshop were obviously very low, background monitoring was performed in areas adjacent to the arcing activity. When background levels were obviously low exposure levels were assumed to be zero. Close observation of ancillary activities, eg grinding, was maintained to identify activities which might influence sampling results.

The above approach permitted maximum use of the measurements taken and made it possible using equation [1] to calculate and compare breathing zone concentrations for several time periods throughout the working day using the same monitoring results. An example of the methodology as applied to part of a morning of work is provided in Table 1.

Additionally a limited amount of monitoring of the same welder on consecutive days was carried out to establish between day variations of results.

3. EXPERIMENTAL DETAILS

Monitoring was carried out in accordance with BS6691 Part 1. PVC filters and Casella LS5 sampling pumps at a flow rate of 2L/min were employed.

Filter weighings were made on an analytical balance having a readability of five decimal places. Blank filters and filters loaded with fume were exposed to the balance room atmosphere for a thirty minute stabilisation period prior to weighing and each filter was treated with an anti static pistol immediately before weighing. Sufficient filters were weighed for each monitoring exercise to leave several filters unused. These filters were employed to determine between day weight corrections resulting from changes in temperature and humidity, their average weight difference between the two days being either added to or subtracted from the weights of the used filters.

4. MONITORING DETAILS

Three sites were visited and eleven working days were monitored relating to nine welders in four workshops. Tungsten Inert Gas (TIG), Manual Metal Arc (MMA), Flux Cored Arc (FCA), and Metal Inert Gas (MIG) welding were examined. The materials welded were stainless steel, monel, aluminium alloy and carbon manganese steel. Nominally the working day at each site was 8 hours commencing at 8.30am and finishing at 4.30pm with an hour for lunch. A degree of flexibility regarding coffee breaks existed at each site and breaks were taken dependent upon the work situation.

4.1. Site A

Three welders were monitored at Site A. Fig.1 provides an approximate diagram of the workshop and identifies the locations of the areas sampled.

At location 1 (Fig.2) the welder deposited an external seam weld in a stainless steel vessel using the FCA process. The sampling schedule is provided in Table 2. During Test 1 the welder sampled was receiving instruction, the instructor performing the greater part of any welding. Local ventilation was not used. On the day of sampling the workshop doors were open causing the fume to drift towards the outside air and generally into the welder's breathing zone.

The welder at location 2 welded internal and external seam welds into a monel workpiece using the MMA process. The sampling schedule is provided in Table 3. For Tests 1 and 3 the internal weld was deposited as shown in Fig.3 but for test 2 the external weld was deposited from a sitting position with the workpiece on a table. Local extraction equipment was used but considered inefficient. The extraction hose was unhooded and of small diameter and the welder, when in a standing position (Test 1 and 3), tended to place his head slightly inside the workpiece and therefore between the fume source and the extraction. However positioning himself between the fume source and extraction merely seemed to render the extraction less efficient and the fume drifted out of the top of the workpiece. For welding in the sitting position the same extraction equipment was hand held by the welder and not necessarily in the optimum extraction position.

At location 3 the workpiece was a carbon manganese steel vessel approximately 7m long and 2m in diameter. It was welded using the MMA process. Following deposition of internal seam welds (Fig.4) the

welder attached bosses to the outside of the vessel. Ventilation equipment, which employed 20cm diameter trunking connected to an extraction unit outside an open door, was used for the internal welding but not for boss attachment. The sampling schedule is provided in Table 4. Background monitoring was performed outside the vessel.

4.2. Site B

The approximate dimensions of the workshops and the sampling locations at Site B are shown in Figs.5 and 6. Five welders were monitored. Three were engaged in MMA welding of stainless steel and two welded aluminium alloy using the semi automatic MIG process.

At location 1 a stainless steel conical shaped workpiece was welded as depicted in Fig.7. Local extraction was not employed but a natural draught in the workshop, resulting from open doors, caused the fume to drift away from the welder. Welding was interspersed with removing completed workpieces and positioning new ones. Small amounts of grinding of edge preparations took place but were not monitored. (Table 5).

Ports were welded into an open ended stainless steel vessel using the MMA technique at location 2 (Fig.8). The welder alternated between the inside and outside of the vessel in a fairly random manner, some times internally welding all the ports before moving outside but on other occasions alternating between inside and outside for a single port. Welds were always deposited in the downhand position, this being achieved by rotation of the vessel. Ancillary activities consisted of changing vessels and positioning the jacks shown in Fig.8, which were used to maintain vessel dimensions. The welder was monitored on two consecutive days (Tables 6 and 7) to examine between day variability of measurements for a person nominally performing an identical task.

An acid resistant tank fabricated from Monel was under construction at location 3 (Fig.9). The welder used the TIG process to deposit the root run in seam welds and MMA welding to deposit the fill passes. Periods between welding were spent repositioning the workpiece (Table 8). Local extraction was absent but the fume was carried towards the open workshop doors by a draught. Thus it was anticipated that fume exposures would be dependent upon the welders orientation relative to the draught and for most of the arcing periods the draught directed the fume towards his breathing zone.

In a second workshop at Site B devoted entirely to aluminium fabrication, mechanised MIG welding of aluminium/5% magnesium alloy took place at locations 4 and 5 (Fig.10 and 11). At location 4 the welder using a handshield made close observations of a longitudinal seam weld to make fine manual adjustments to the seam tracking mechanism. Sampling equipment was attached to the lapel of his overalls. Local fume extraction formed an integral part of the welding equipment. Approximately five minutes of continuous arcing were required to deposit each seam and 3 welds were made in the sampling period. The remainder of the sampling period was occupied with setting up workpieces. Following the monitored period the welder was transferred to general activities within the workshop and

breathing zone fume concentrations were presumed to be at the background levels.

At location 5 the morning period was used to prepare an aluminium cylinder for internal and external circumferential seam welding in the afternoon. This morning period consisted of positioning the cylinder on rollers and tack welding welding the seams using the TIG process. For the afternoon period two external and two internal welds were deposited in the IG position (welding head stationary but vessel rotating). Two weld runs were present in each weld. The root run involved continuous arcing for about eight minutes while the capping run took rather longer (14 mins) the larger bead produced resulting from a slower rotation of the vessel. Sampling equipment was attached to the welders lapel as neither a handshield or headshield were employed.

The sampling schedules at locations 4 and 5 have not been tabulated because monitoring subsequently revealed extremely low fume concentrations at each location (section 5.2.).

4.3. Site C

In the welding shop (Fig.12) of site C two welders performed multirun MMA welding on a girth weld between two stainless steel cylinders. Local extraction was used as shown in (Fig.13). The workpiece was a potential defect specimen for non destructive testing so the welding deliberately introduced defects at predetermined points. Each welder, commencing at diametrically opposite points, simultaneously welded half the circumference (Table 9). Small amounts of grinding took place at the end of each weld run but were not sampled because grinding dust was considered to be beyond the remit of the present survey. Only one welder was monitored.

The same welder was monitored on the following day but sampling was discontinued after the first test period (Table 10) because a totally different work pattern emerged. After an initial period of welding similar to that of the preceding day, the second day was devoted mainly to dye penetrant testing for defects and grinding. Very intermittent, short periods of welding of the defect areas was carried out.

5. RESULTS

Tables 11a-19a present the weights of fume collected, sampling times and breathing zone fume concentrations measured for each test period. Tables 11b-19b provide the 8 hour TWA concentration calculated at each location and breathing zone concentrations calculated for different time periods using equation 1. In general terms, the time periods enlisted for calculation were:

Complete morning period
Early morning period
Late morning period
Early afternoon period
Late afternoon period
Complete afternoon period

The early and late periods varied depending upon the particular welders work pattern but were within the 1 to 3 hour range. The lunch hour was divided equally between the late morning and early afternoon periods. Thus the complete morning period was 4.5 hours and the complete afternoon period 3.5 hours.

In assessing whether the results from the shorter sampling periods adequately reflected the 8 hour TWA an assessment criteria was necessary. Results for short period monitoring within 25% of the 8 hour TWA were considered acceptable. The OES for welding fume in general is 5mg/m^3 and an acceptable range of results from 3.75 to 6.25mg/m^3 could be considered undemanding. However, the predominantly highly alloyed materials welded here would have a control limit for total fume of about 1mg/m^3 (4) and the requirement for acceptable results to be within a range 0.75 to 1.25mg/m^3 was considered quite stringent.

Filter weights were variable on a day to day basis. Weight differences up to 0.17mg were observed between the first and second weighings of blank filters, although the differences were typically around 0.07mg. These differences were attributed to changes in humidity. However, more importantly the weight changes within a batch of filters varied by as much as 0.05mg so that by subtracting an average blank reading from filters used to collect fume, potential weighing errors of up to ±0.03mg could arise. The importance of such errors is discussed later in Section 6.

5.1. Site A

At locations 1 and 3 (Tables 11a and 13a) the breathing zone concentrations for the measured test periods were generally high and variable, ranging from 0-31mg/m^3 at location 1 and from 6-23mg/m^3 at location 3. At location 2 (Table 12a) where local ventilation was employed fume concentrations were lower and the range of results much smaller 0.96-1.6mg/m^3, although in percentage terms variations of ~70% were present. Test periods at the three locations varied from around 0.3 to 2 hours and as such were in broad agreement with the 1 hour suggested in BS6691. At location 1 the sampling periods were very close to 1 hour. It was apparent that, using ±25% as the criteria of acceptability, few of the test results approximated to the calculate 8 hour TWA and only one result at each location was within this limit.

However when breathing zone concentrations were calculated for longer time periods (Tables 11b, 12b, 13b) the similarity between results for a given time period and the 8 hour TWA improved. At location 2 all results were within ±25% of the 8 hour TWA and only one result was outside this range at location 3. Four from six results at location 1 were outside the permitted range but the result for the complete afternoon period, at 27% only marginally so. Except as described above, calculated concentrations for complete morning and afternoon periods at Site A were always within 25% of 8 hour figure and at locations 2 and 3 were within 1 and 7% respectively.

5.2. Site B

Breathing zone concentrations at location 1 were low and within the control limits of 1mg/m^3 for the stainless steel consumable employed, Table 14a. These low concentrations were a direct result of a workshop draught causing the fume to be blown away from the welder's breathing zone. The calculated 8 hour TWA was 0.4mg/m^3 and only one of the measured test periods provided concentrations within 25% of this figure. No data are presently available detailing the expected reproducibility of results using BS6691 Part 1 but the weights of fume collected here were small and weighing errors could be in part responsible for the poor observed reproducibility (section 6).

When breathing zone concentrations were calculated for different time periods (Table 14b) only the concentration for the complete afternoon time period was within 25% of the 8 hour TWA. This was because most of the fume was collected during the late afternoon sampling period and causing an uneven distribution of results.

On day 1 at location 2, breathing zone concentrations for the test periods varied from zero to 15mg/m^3 (Table 15a), although the lowest result stemmed from a very short sampling period, the welder having indicated that further welding, which subsequently did not materialise, would occur. None of the tests periods showed breathing zone concentrations within 25% of TWA. Breathing zone concentrations calculated for different time periods were all greater than 25% different to the 8 hour TWA (Table 15b). In other tests the full morning and afternoon periods tended to approximate most closely to the 8 hour TWA but this was not the case here and the late morning and early afternoon periods provided the closest resemblance.

On day 2 the early morning period was spent in work preparation and workpiece set up so that the fume concentration was zero (background level), Table 16a. For the following three sampling periods, breathing zone concentrations at 12,10 and 14mg/m^3 respectively were more uniform than results from the previous day.

The 8 hour TWA was 4.3mg/m^3 so that none of the test period results were within the 25% range but three of the six calculated time period concentrations (Table 16b) were within the acceptability limits. Concentrations for complete morning and afternoon periods again proved reliable and were within 12% and 16% of the 8 hour figure.

The 8 hour TWA concentrations for each day differed by only 0.4mg/m^3 and were within ~10% of each other.

Measured fume concentrations at location 3 (Table 17a) were very variable and either zero or around 20mg/m^3. Zero fume concentrations recorded in tests 1 and 4 may be readily explained because the TIG process, which produces negligible quantities of fume, was employed. The high concentrations measured in Test 2 and 3 stemmed from use of MMA welding without local extraction. None of the test results were within 25% of the calculated 8 hour TWA of 6.7mg/m^3.

The calculated fume concentrations for the complete morning and late morning periods (Table 17b) were within 25% of the 8 hour TWA and the results for the complete afternoon period only marginally outside the

range at 31%. Thus employment of complete morning or afternoon sampling periods almost compensated for the use of a high and low fume emitting process within the same period. However, roughly similar fume concentrations were measured from the MMA welding in each morning and afternoon period and it is unlikely that this will always be the case.

Sampling in the workshop allocated to aluminium welding failed to produce weighable quantities of fume. It is well known that MIG welding of aluminium produces substantial quantities of welding fume but the use of local extraction equipment, the remoteness of the operator from the work and a limited welding duty cycle meant that fume exposures were minimal as far as both breathing zone and background sampling were concerned. All results were therefore identical and within the ±25% definition of acceptability but have not been tabulated or used in further consideration of monitoring strategy.

5.3. Site C

The monitored results from Site C are provided in Tables 18a and 19a. In spite of the fact that an apparently identically task was performed throughout the day, only one of the test results on day 1 was within 25% of the 8 hour TWA of 0.72mg/m^3. Again, the variability of results may stem from weighing errors of the small amounts of fume collected but differences in the welders posture and therefore the relationship of his breathing zone to the fume may be too great to permit precise results over short sampling periods.

Three of the fume concentrations calculated for different time periods (Table 18b) were within the 25% limit. Of these, two were from the complete morning and afternoon periods again demonstrating the greater reliability of results from longer sampling periods.

The single monitoring test performed on day 2 yielded a similar fume concentration to the monitored tests performed on day 1. However, the subsequent lack of welding activity during the day meant that neither the test result nor the results for any calculated time period adequately reflected the 8 hour TWA concentration.

Taken on its own, this second day would seem a poor choice for examination of short and long fume monitoring. However, a decision was made at the beginning of the project to monitor consecutive days in order to prevent bias. Day 2 was a 'typical' working day and as such could be potentially sampled by persons examining 'on site' fume levels. It serves to demonstrate the extreme care which must be exercised in selecting 'typical' work situations.

5.4. Results Summary

Table 20 summarises the acceptability of the results obtained relative to the 8hr TWA concentrations. Only 16% of the 32 monitored fume concentrations were within ±25% of the 8hr TWA. This percentage did not decrease significantly if the acceptability criterion was raised to ±15% but the small proportion of acceptable results dictates that monitored results for the time periods employed here (typically around 1hr) cannot be used to estimate worker fume exposures in workshop atmospheres.

Only eight results were used for the percentages reported for the calculated time periods, since the results from aluminium welding at Site B and day 2 at Site C were omitted. Thus, the numbers of results are low and a single result falling outside the required accuracy range caused a percentage change of approximately 13%. It may be seen that concentrations calculated for the complete morning and afternoon periods best reflected the 8hr TWA figure, although with only 75 and 63% of the results falling within a 25% envelope of the 8hr TWA concentration, insufficient confidence can be placed on the figures to permit fume exposure surveys to be conducted using sampling periods of less than 8hrs.

6. DISCUSSION

The present results show that, in general, short term monitoring will not adequately reflect 8hr TWA fume concentrations. However, the number of tests performed was relatively small and further assessments may increase the confidence in this preliminary finding. For several reasons the present results are not unexpected, and a number of factors seemed important in contributing to the inaccuracy of the short term results. These were the selection of the sampling period, the variability of a welders working day, the level of fume concentrations measured and weighing errors at low fume exposure levels.

Monitoring of a welder must, by definition, include periods of arcing but it was observed that periods spent arcing constituted a relatively small proportion of a welder's day. For example it was difficult to monitor more than four periods which included sustained welding during a day, such periods generally corresponding to early and late, morning and afternoon. Typically the arcing periods were of about one hour duration within a two hour work period so that only half the day was spent "welding". Consequently, concentrations measured during monitored periods tended to be higher than the 8hr TWA, but would be expected to approach the 8hr TWA as more non arcing periods were included in any sampled period. This was demonstrated by the fact that fume concentrations for the longest (complete morning and afternoon) calculated time periods best reflected the 8hr TWA figure. On occasions non arcing activity occupied a complete work period as defined in this programme. Thus, if welding was performed during another work period the fume concentrations for the work periods were very different and could be different to any averaged period.

A similar situation existed when both TIG and MMA welding were performed during a day by the same welder. The periods of TIG welding provided low fume concentrations whilst periods of MMA welding provided high exposure levels. However, on this occasion TIG and MMA welding was evenly distributed throughout the day and fume concentrations for the complete morning and afternoon periods showed reasonable agreement with the 8hr TWA.

The fume exposures measured could be divided broadly into high and low concentrations. In most cases high concentrations occurred when local extraction equipment was absent. Monitored fume concentrations were then variable and a range of results providing a spread of between 10 and 20mg/m^3 was not uncommon. This variability was

considered to stem from the welder being in close proximity to two adjacent but very different concentrations of fume. The plume itself provided an area of high fume concentration but the area immediately outside the plume was of low concentration. Thus very variable breathing zone concentrations could arise dependent upon the relative amounts of time the welder spends with his head in or out of the plume.

A smaller range of fume concentrations was measured when local extraction was employed or a fortuitous draught in the workshop directed fume away from the welder. In this situation the fume concentration surrounding the welder would be lower and more uniform and the large ranges of concentrations experienced at high fume levels would not be expected.

Whilst large ranges of fume concentrations were not measured at low exposure levels, the results could be very different in percentage terms. For example, results varying from 1 to 1.6mg/m^3 at Site A location 2 and 0.4-2.1mg/m^3 at Site C, differences of 60 and 500% respectively, were encountered. Part of these differences may have stemmed from weighing errors because using the formula

$$\text{Fume conc mg/m}^3 = \frac{1000xm}{Rt} \qquad \text{(Ref 3)}$$

where m = mass of fume collected in mg
R = pumping rate in l/min
t = time of sampling in min

it may be calculated that, when fume exposure is at the 1mg/m^3 level and a 1hour sampling period is employed, the weight of fume collected will be 0.12mg. Thus, a weighing error of 0.03mg (section 5) will provide an error equivalent to 25% at the 1mg/m^3 level and may be responsible in a number of cases for the observed variability of fume concentrations at low level.

It was demonstrated that, in addition to difficulties identifying short sampling periods which adequately reflected 8hr TWA fume concentrations, there could also be problems in identifying suitable days which represented an average fume exposure when performing a particular task. When consecutive days were monitored at Site B, location 2, similar fume concentrations were measured, but at Site C, measurements were different because of a changed work pattern, whilst performing nominally the same task. It will be necessary, therefore, for an investigator to familiarise himself intimately with work routines before attempting to conduct an "on site" fume survey and it may be necessary to sample on several occasions to ascertain average exposure levels.

In view of the identified need to sample for 8 hrs and perhaps on more than one occasion with the associated costs, it is recommended that worst case situations, eg periods of peak welding activity, are monitored and control effected on the basis of the results obtained. It is realised that in making this recommendation, situations will exist where monitoring dictates a requirement for fume control when use of the 8hr TWA concentration would not, and that this may involve the welding industry in extra expense. However, the extra expense is expected to be small when balanced against reduced monitoring costs and improved hygienic conditions.

7. CONCLUSIONS

1. Fume concentrations established by monitoring for short periods, typically 1 to 2 hours, did not adequately reflect the 8hr TWA concentrations. In general, longer sampling periods, eg complete morning and complete afternoon periods, provided closer approximation to the 8hr figure. Approximately 70% of measurements taken over complete morning and afternoon periods were within 25% of the 8hr TWA.

2. Fume control levels, as defined by the COSHH regulations, were generally exceeded when local extraction was not used.

3. The range of monitored fume concentrations was large (10-20mg/m^3) when fume concentrations were high but much smaller when fume concentrations were low. However, when expressed as a percentage, large differences in fume concentration at low level existed.

4. Errors in weighing the fume may be significant when monitoring low fume concentrations. A 25% error in the fume concentration at 1mg/m^3, caused by weighing, is possible for a 1 hour sampling period.

5. The working day of a welder may be very variable because he performs many different tasks. This variability may cause large differences in welding fume concentrations throughout a day and between days. Great care in selection of sampling periods and selection of typical days must therefore be observed.

8. RECOMMENDATIONS

It is recommended that worst case situations, eg periods of peak welding activity, are sampled and control effected on the basis of the results obtained.

9. REFERENCES

1 The Control of Substances Hazardous to Health Regulations 1988. Available from HMSO.

2 Occupational Exposure Limits 1991. EH40/91. Available from HMSO.

3 Fume from welding and allied processes, Part 1. Guide to methods for the sampling and analysis of particulate matter. BS6691: Part 1: 1986. Available from British Standards Institution.

4 Assessment of exposure to fume from welding and allied processes. Guidance Note EH54 from the Health & Safety Executive.

Table 1 Calculation of breathing zone concentrations for different time periods

		Sample	
Time	Activity	Type	Duration, mins
8.30	Commence work		
8.30-9.00	Ancillary activities	Bgd	30
9.00-10.00	Welding	BZ	60
10.00-10.15	Ancillary activities	Bgd	15

Background measured 8.30-10.15 = 0.2mg/m^3

BZ sample = 5mg/m^3

BZ conc 8.30-10 = $\frac{5 \times 60 + 0.2 \times 30}{90}$

BZ conc 9.00-10.15 = $\frac{5 \times 60 + 0.2 \times 15}{75}$

BZ conc 8.30-10.15 = $\frac{5 \times 60 + 0.2 \times 45}{105}$

Table 2 Sampling schedule, Site A, Location 1

Time	Activity	Test detail	Sample	
			Type	Duration, min
8.30	Commence work	)	Bgd	37
9.07 10.00	Welding, but under instruction	Start Test 1) Stop Test 1)	BZ	53
10.00 10.20	Tea Break	))	Bgd	20
10.20 11.26	Welding	Start Test 2) Stop Test 2)	BZ	66
		)	Bgd	9
11.35 12.40	Welding	Start Test 3) Stop Test 3)	BZ	65
1.00 2.00	Lunch	))	Bgd	84
2.04 3.08	Welding	Start Test 4) Stop Test 4)	BZ	64
3.08 4.30	General duties End shift	))	Bgd	82

Table 3 Sampling schedule, Site A, Location 2

Time	Activity	Test detail	Sample	
			Type	Duration, min
8.30	Commence work	)	Bgd	55
9.25	Welding	Start Test 1)		
10.00	Tea break	)	BZ	95
10.20		)		
11.00		Stop Test 1)		
		)	Bgd	5
11.05	Welding	Start Test 2)	BZ	83
12.28		Stop Test 2)		
12.30	Lunch	)	Bgd	117
1.30		)		
2.25	Welding	Start Test 3)	BZ	65
3.30		Stop Test 3)		
		)	Bgd	5
3.35	Limited amount	Start Test 4)	BZ	40
4.15	of "tack" welding	Stop Test 4)		
4.30	End shift	)	Bgd	15
Background sample		Start 9.27 Stop 12.30		183

Table 4 Sampling schedule, Site A, Location 3

			Sample	
Time	Activity	Test detail	Type	Duration, min
8.30	Commence work	)	Bgd	90
10.00 10.55	Welding in vessel	Start Test 1) Stop Test 1)	BZ	55
		)	Bgd	3
10.58 12.14	Welding in vessel	Start Test 2) Stop Test 2)	BZ	77
12.30 1.30	Lunch	))	Bgd	105
2.00 3.50	Welding in vessel	Start Test 3) Stop Test 3)	BZ	110
		)	Bgd	5
3.55 4.15	Welding outside vessel	Start Test 4) Stop Test 4)	BZ	20
4.30	End shift	)	Bgd	15
Background sample		Start 9.50 Stop 12.20		150

Table 5 Sampling schedule, Site B, Location 1

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence Work	)	Bgd	40
9.10 9.52	Welding	Start Test 1) Stop Test 1)	BZ	42
10.00 10.10 10.50 10.55	Teabreak Grinding (not sampled)	))))	Bgd	65
10.57 12.03	Welding	Start Test 2) Stop Test 2)	BZ	66
12.30 1.30	Lunch	))	Bgd	99
1.42 2.18	Welding	Start Test 3) Stop Test 3)	BZ	36
		)	Bgd	36
2.54 4.15	Welding	Start Test 4) Stop Test 4)	BZ	81
4.30	End shift	)	Bgd	15
Background samples				
9.30 12.15		Start Stop		165
2.45 4.25		Start Stop		100

Table 6 Sampling schedule, Site B, Location 2, Day 1

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence work		Bgd	37
9.07	Welding			
	29min inside	Start Test 1	BZ	41
9.48	12min outside	Stop Test 1		
10.00	Teabreak		Bgd	52
10.10				
10.40	Welding inside	Start Test 2	BZ	69
11.49		Stop Test 2		
			Bgd	9
11.58	Welding outside	Restart Test 2	BZ	14
12.12		Stop Test 2		
12.30	Lunch		Bgd	93
1.30				
1.45	Welding inside	Start Test 3	BZ	18
2.03		Stop Test 3		
			Bgd	27
2.30	Welding inside			
	30 min	Restart Test 3	BZ	39
3.09	outside 9 min	Stop Test 3		
			Bgd	26
3.35	Welding outside	Start Test 4	BZ	7
3.42		Stop Test 4		
4.30	End shift		Bgd	48
Background samples				
9.15		Start		120
11.15		Stop		
1.40		Start		140
4.00		Stop		

Table 7 Sample schedule B, Location 2, Day 2

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence work	)		
	Work prep and setup	)		
		)	Bgd	134
10.00	Teabreak	)		
10.10		)		
	Work prep and setup	)		
10.44	Welding inside	Start Test 1)	BZ	86
12.10	vessel	Stop Test 1)		
12.30	Lunch	)	Bgd	105
1.30		)		
1.55	Welding inside/	Start Test 2)	BZ	40
2.35	Outside vessel	Stop Test 2)		
	Positioning jacks	)	Bgd	60
3.35	Welding outside	Start Test 3)	BZ	45
4.20	vessel	Stop Test 3)		
4.30	End shift	)	Bgd	10

Table 8 Sampling schedule, Site B, Location 3

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence work	)	Bgd	42
9.12 9.54	Welding (TIG)	Start Test 1) Stop Test 1)	BZ	42
10.00 10.10	Teabreak	)	Bgd	29
10.23 11.05	Welding (MMA)	Start Test 2) Stop Test 2)	BZ	42
		)	Bgd	20
11.25 11.46	Welding (MMA)	Restart Test 2) Stop Test 2)	BZ	21
		)	Bgd	12
11.58 12.20	Welding (MMA)	Restart Test 2) Stop Test 2)	BZ	22
12.30 1.30	Lunch	)	Bgd	85
1.45 3.05	Welding (MMA)	Start Test 3) Stop Test 3)	BZ	80
		)	Bgd	63
4.08 4.25	Welding (TIG)	Start Test 4) Stop Test 4)	BZ	17
4.30	End shift	)	Bgd	5

Table 9 Sampling schedule, Site C, Day 1

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence work Set up equipment		Bgd	65
9.35 10.26	Welding and grinding	Start Test 1 Stop Test 1	BZ	51
10.30 10.45	Teabreak		Bgd	24
10.50 12.01	Welding and grinding	Start Test 2 Stop Test 2	BZ	71
12.30 1.30	Lunch		Bgd	89
1.30 2.45	Welding and grinding	Start Test 3 Stop Test 3	BZ	75
2.45 3.00	Teabreak		Bgd	18
3.03 3.40	Welding and grinding	Start Test 4 Stop Test 4	BZ	37
			Bgd	2
3.42 4.32	Welding and grinding	Start Test 5 Stop Test 5	BZ	50
End shift				

Table 10 Sampling schedule, Site C, Day 2

Time	Activity	Test detail	Sample Type	Sample Duration, min
8.30	Commence work		Bgd	74
9.44	Welding	Start Test 1	BZ	42
10.26		Stop Test 1		
10.30	Teabreak			
10.45				
10.45	Dye penetrant testing			
12.30	Grinding		Bgd	364
12.30	Lunch			
1.30				
1.30	Dye penetrant testing			
4.30	Grinding			

Table 11 Test results, Site A, Location 1

(a) Monitored results

Test no	Wt fume collected, mg	Sampling time, min	hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0.03	53	0.9	0	-
2	1.10	66	1.1	8.3	6
3	3.31	65	1.1	25.5	189
4	4.02	64	1.1	31.4	256

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	8.8	-
8.30-1.30	300	5.0	7.3	17
8.30-10.10	100	1.7	0.15	98
10.10-1.30	200	3.3	11.0	25
1.30-3.08	98	1.6	20.5	133
3.08-4.30	82	1.4	0	-
1.30-4.30	180	3.0	11.2	27

Table 12 Test Results, Site A, Location 2

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0.30	95	1.6	1.6	70
2	0.16	83	1.4	0.96	2
3	0.21	65	1.1	1.6	70
4	0.13	40	0.67	1.6	70
Bgd	0.10	183	3.1	0.27	

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	0.94	-
8.30-1.00	270	4.5	0.95	1
8.30-11.00	150	2.5	1.1	18
11.00-1.00	120	2.0	0.74	21
1.00-3.30	150	2.5	0.84	11
3.30-4.30	60	1.0	1.2	23
1.00-4.30	210	3.5	0.93	1

Table 13 Test results, Site A, Location 3

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	2.48	55	0.9	22.5	221
2	1.51	77	1.3	9.8	40
3	2.50	110	1.8	11.4	63
4	0.23	20	0.3	5.8	17
Bgd	0.03	150	2.5	0.1	

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/cm^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	7.0	-
8.30-1.00	270	4.5	7.4	6
8.30-10.55	145	2.4	8.6	23
10.55-1.00	125	2.1	6.1	13
1.00-3.50	170	2.8	7.4	6
3.50-4.30	40	0.7	2.9	58
1.00-4.30	210	3.5	6.5	7

Table 14 Test results, Site B, Location 1

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0	42	0.7	0	-
2	0.06	66	1.1	0.45	13
3	0	36	0.6	0	-
4	0.17	81	1.4	1.1	162
Bgd 1	0.13	165	2.8	0.39	-
Bgd 2	0.05	100	1.7	0.25	-

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	0.40	-
8.30-1.00	270	4.5	0.11	73
8.30-10.05	95	1.6	0	-
10.05-1.00	175	2.9	0.17	58
1.00-2.30	90	1.5	0	-
2.30-4.30	120	2.0	0.7	75
1.00-4.30	210	3.5	0.41	3

Table 15 Test results, Site B, Location 2, Day 1

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	1.24	41	0.7	15.1	288
2	1.79	83	1.4	10.8	176
3	0.68	57	1.0	6.0	53
4	0	7	0.1	0	-
Bgd 1	0	120	2.0	0	-
Bgd 2	0	140	2.3	0	-

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	3.9	-
8.30-1.00	270	4.5	5.6	44
8.30-10.05	95	1.6	6.5	67
10.05-1.00	175	2.9	5.1	31
1.00-3.09	129	2.2	2.6	33
3.09-4.30	81	1.4	0	-
1.00-4.30	210	3.5	1.6	59

Table 16 Test results, Site B, Location 2, Day 2

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	2.05	86	1.4	11.9	177
2	0.83	40	0.7	10.4	141
3	1.26	45	0.8	14.0	226

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	4.3	-
8.30-1.00	270	4.5	3.8	12
8.30-10.10	100	1.7	0	-
10.10-1.00	170	2.8	6.0	40
1.00-2.35	95	1.6	4.4	2
2.35-4.30	115	1.9	5.5	28
1.00-4.30	210	3.5	5.0	16

Table 17 Test results, Site B, Location 3

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0	42	0.7	0	-
2	2.75	85	1.4	16.2	141
3	3.71	80	1.3	23.2	246
4	0	17	0.3	0	-

Bgd - As for Location 2, which was adjacent to Location 3

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	6.7	-
8.30-1.00	270	4.5	5.1	24
8.30-10.05	95	1.6	0	-
10.05-1.00	175	2.9	7.9	18
1.00-3.05	125	2.1	14.8	121
3.05-4.30	85	1.4	0	-
1.00-4.30	210	3.5	8.8	31

Table 18 Test results, Site C, Day 1

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0.12	51	0.9	1.2	67
2	0.30	71	1.2	2.1	192
3	0.16	75	1.3	1.1	53
4	0.03	37	0.6	0.4	44
5	0.08	50	0.8	0.8	11

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	0.72	-
8.30-1.00	270	4.5	0.77	7
8.30-10.37	127	1.1	0.47	35
10.37-1.00	143	2.4	1.04	44
1.00-2.48	108	1.8	0.74	3
2.48-4.32	104	1.7	0.52	28
1.00-4.32	212	3.5	0.64	11

Table 19 Results, Site C, Day 2

(a) Monitored results

Test no	Wt fume collected, mg	Sampling min	Sampling hr	Breathing zone fume concentration mg/m^3	% Difference from 8 hr TWA
1	0.09	42	0.7	1.07	1088

(b) Calculated breathing zone concentrations for different time periods

Time period	Duration min	Duration hr	Breathing zone fume concentration mg/m^3	% Difference from 8hr TWA
8 hr TWA	480	8.0	0.09	-
8.30-1.00	270	4.5	0.17	89
8.30-10.30	120	2.0	0.37	311
10.30-1.00	150	2.5	0	-
1.00-3.00	120	2.0	0	-
3.00-4.30	90	1.5	0	-
1.00-4.30	210	3.5	0	-

Table 20 Percentage of all results within certain limits of 8 hr TWA

	Monitoring tests (total 32)	Complete am	Early am	Late am	Early pm	Late pm	Complete pm
Within 25%	16	75	25	50	50	13	63
Within 20%	16	63	13	25	50	0	63
Within 15%	13	50	0	13	50	0	50
Within 10%	6	38	0	0	38	0	38

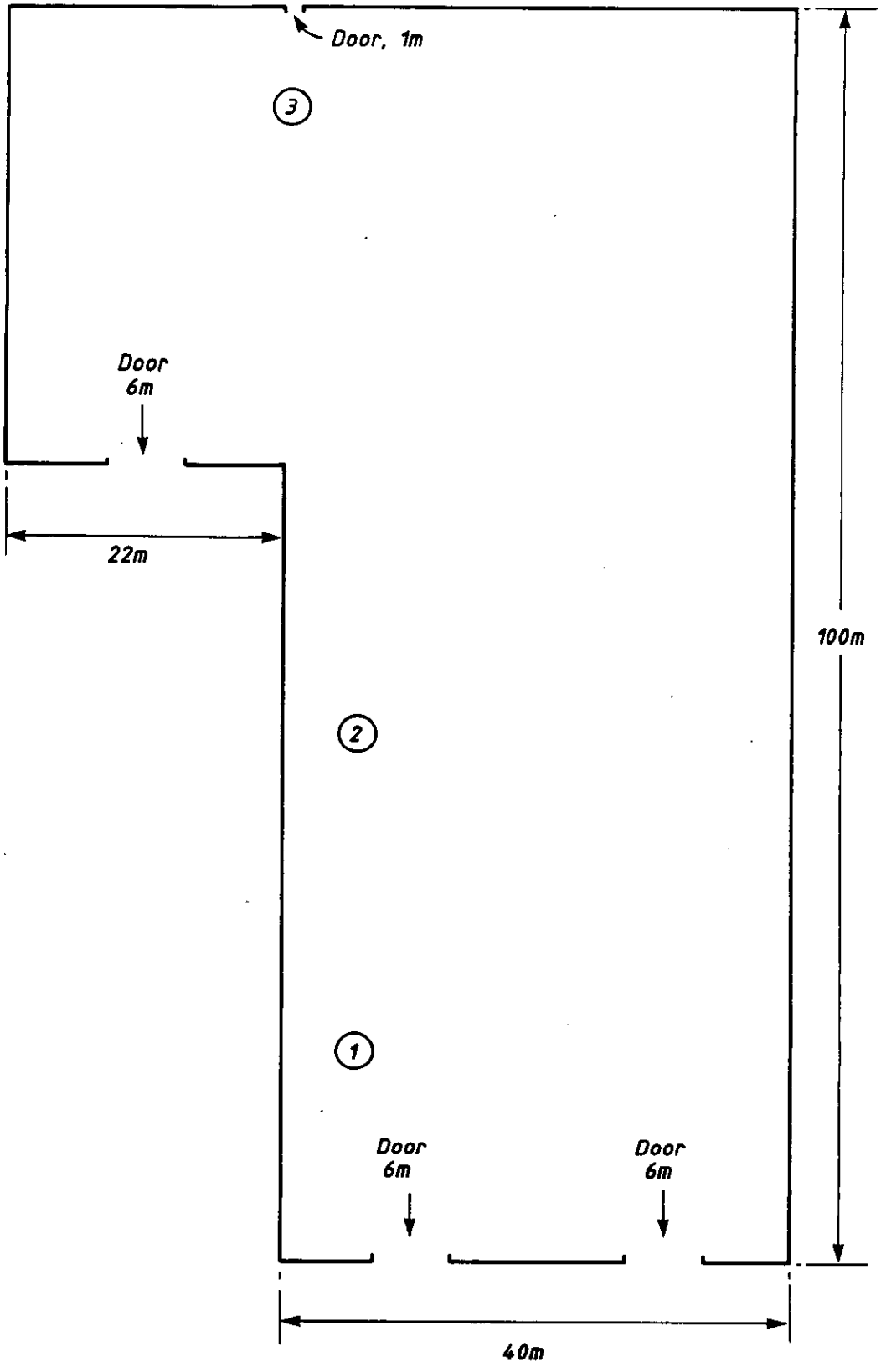

Fig.1 Plan of Site A.

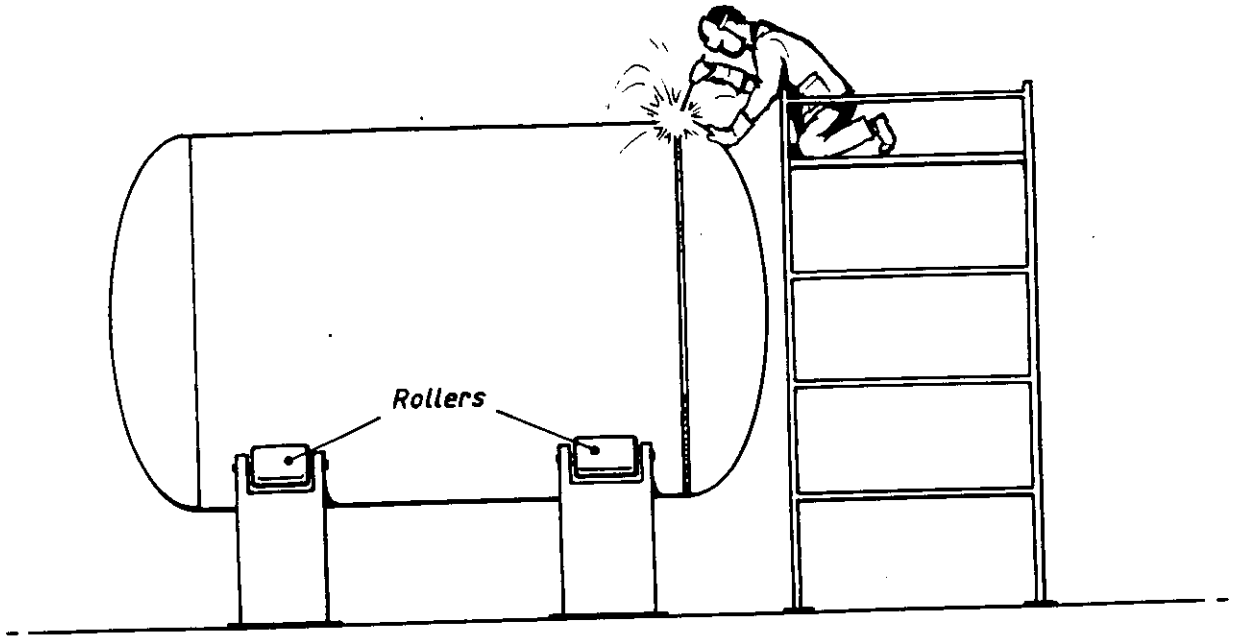

Fig.2 Location 1 Site A.

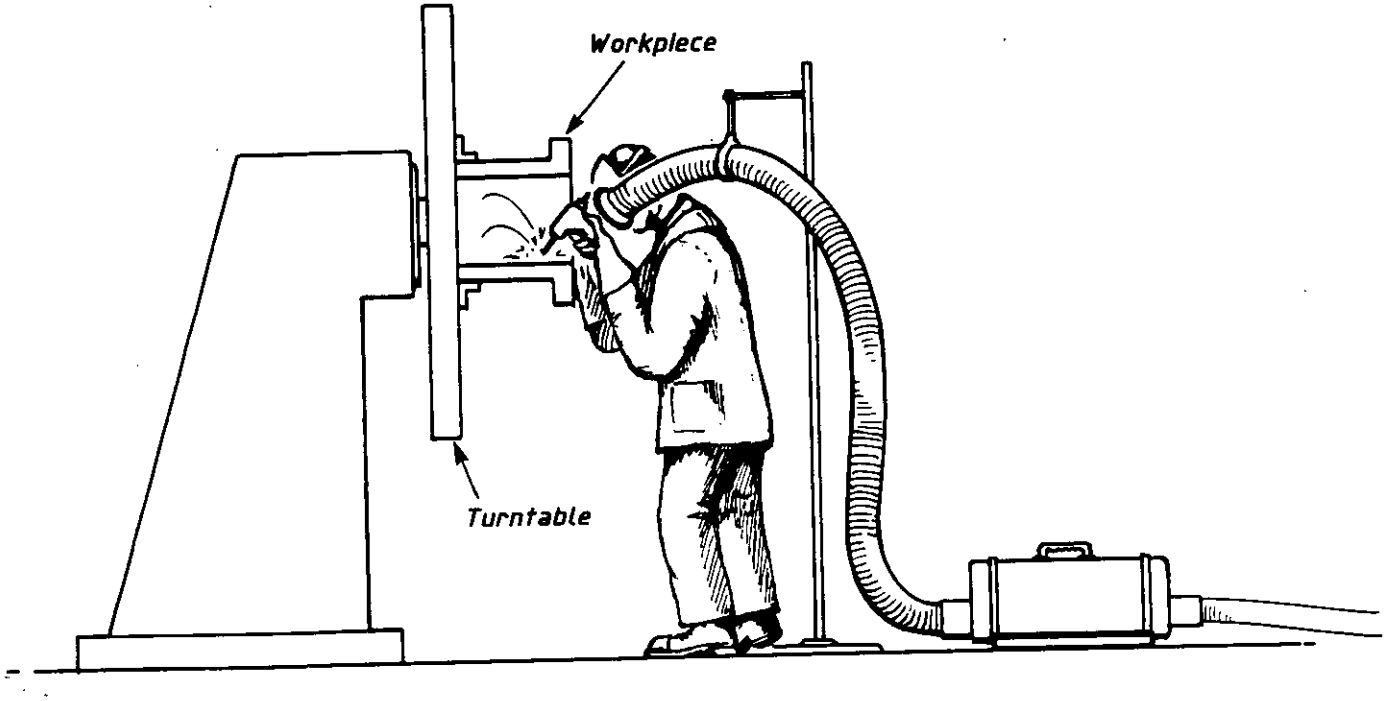

Fig.3 Location 2 Site A.

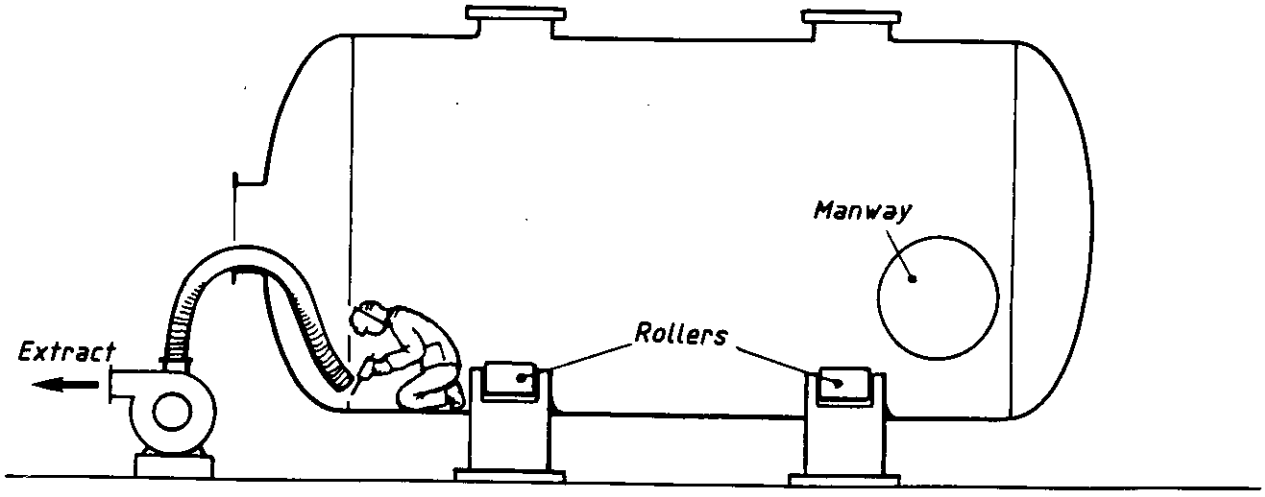

Fig.4 Location 3 Site A.

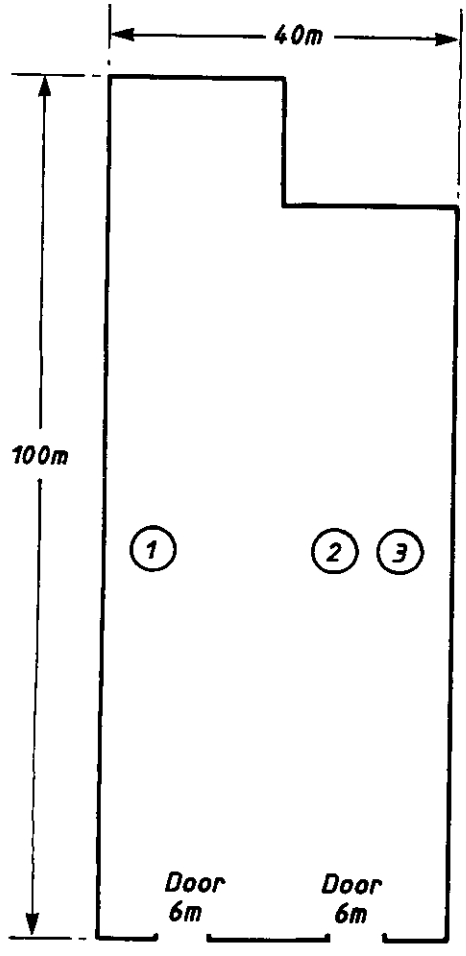

Fig.5 Steel workshop Site B.

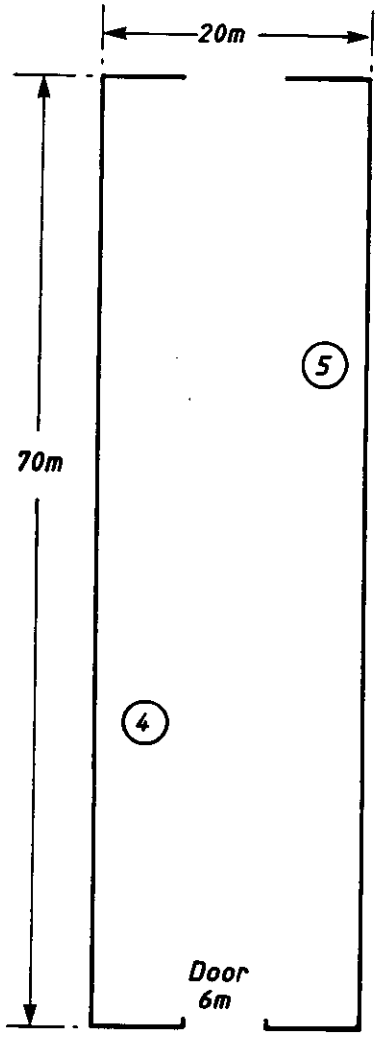

Fig.6 Aluminium workshop Site B.

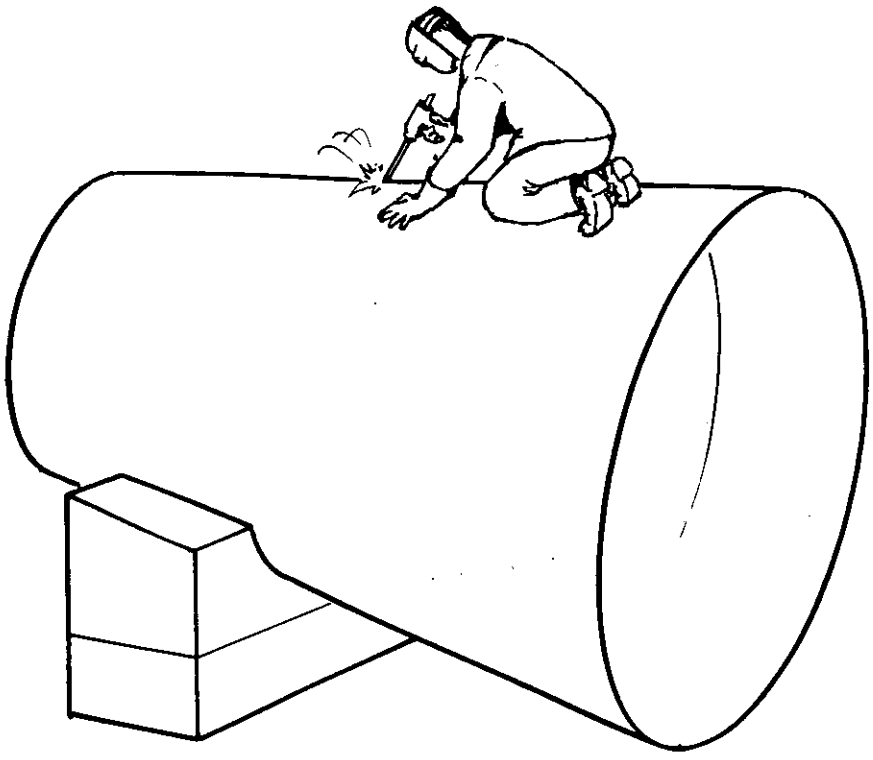

Fig.7 Location 1 Site B.

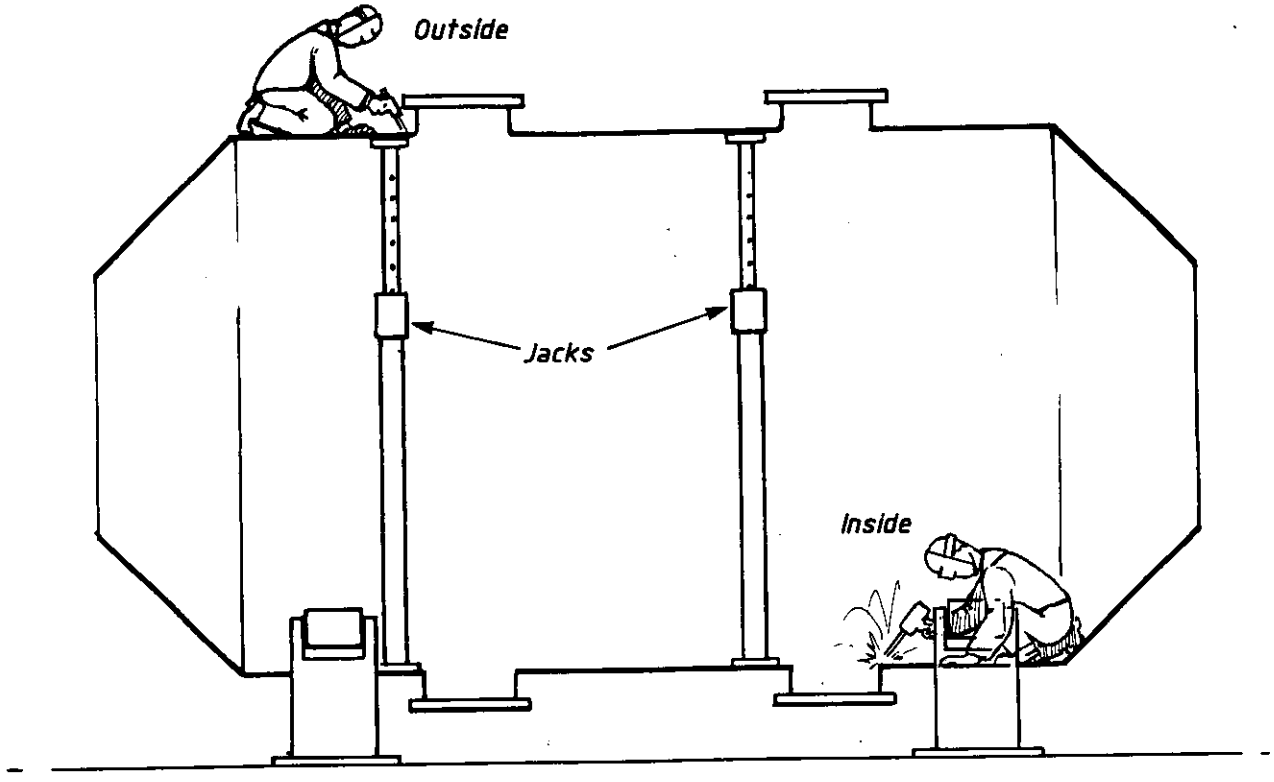

Fig.8 Location 2 Site B.

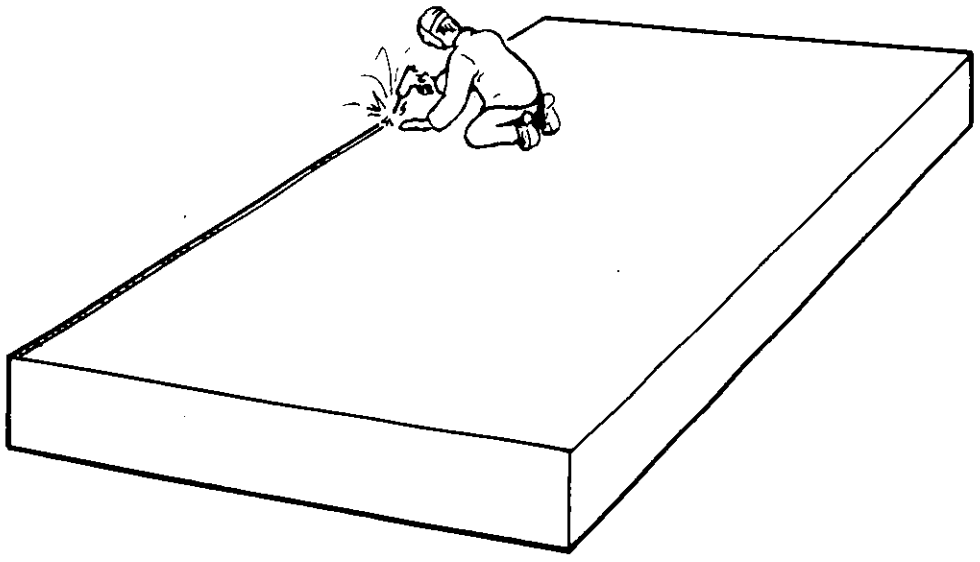

Fig.9 Location 3 Site B.

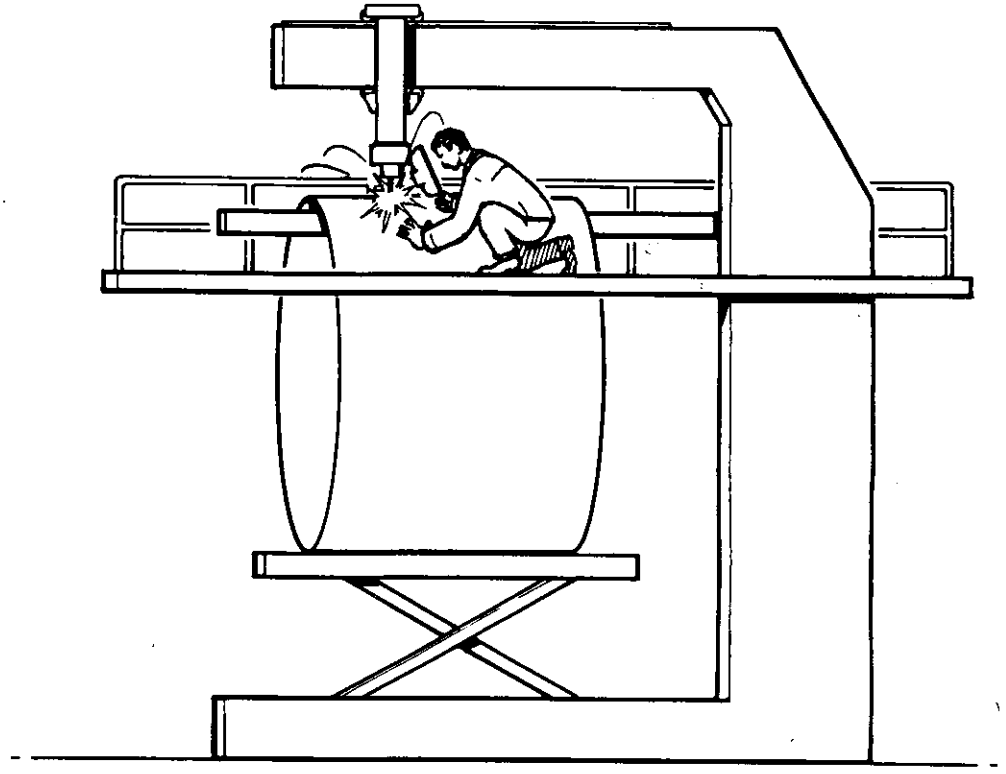

Fig.10 Location 4 Site B.

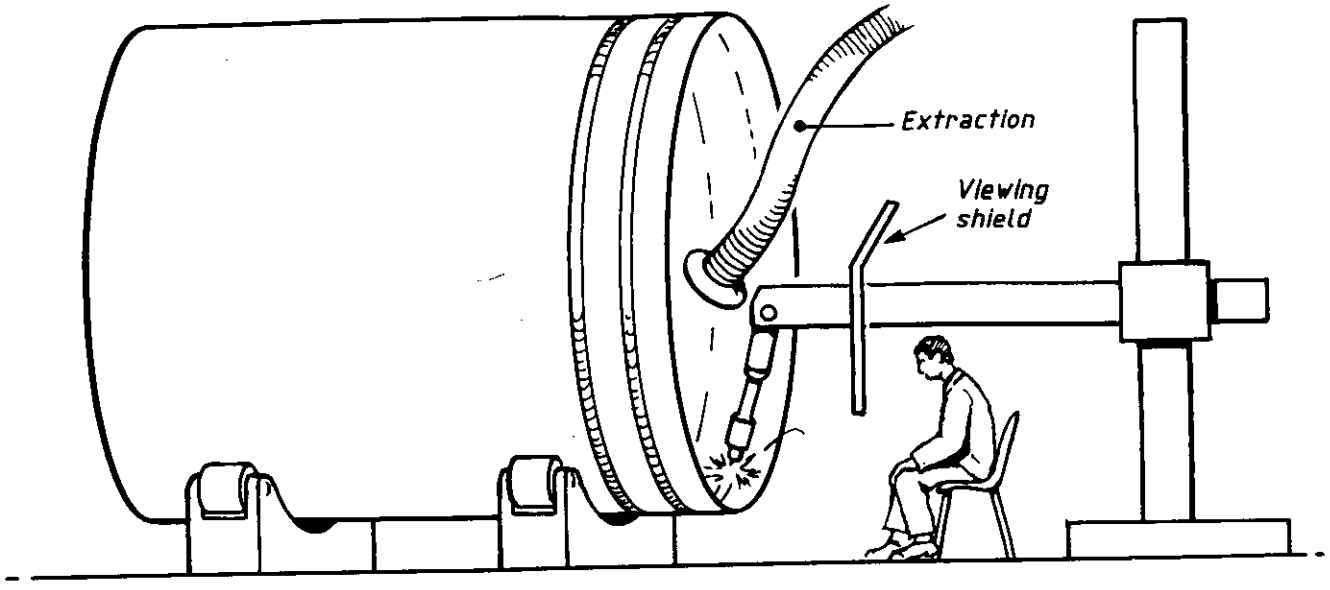

Fig.11 Location 5 Site B.

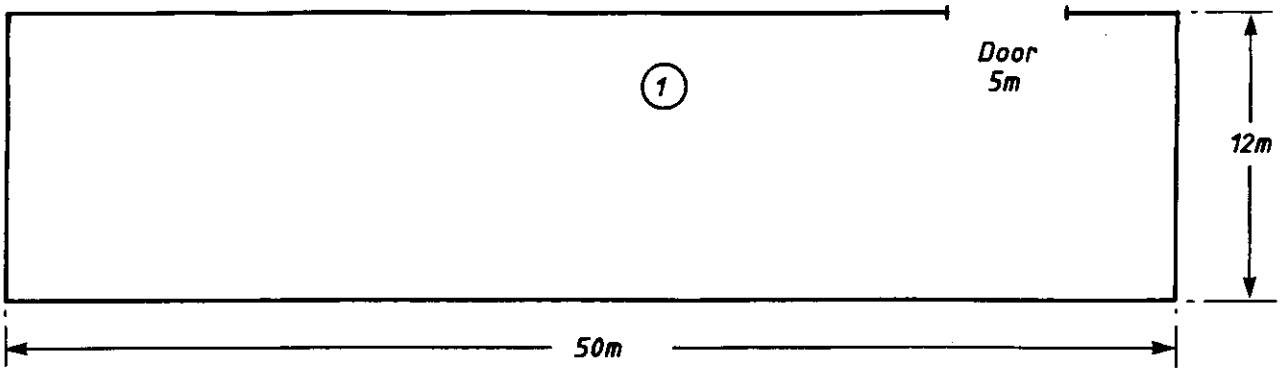

Fig.12 Welding shop Site C.

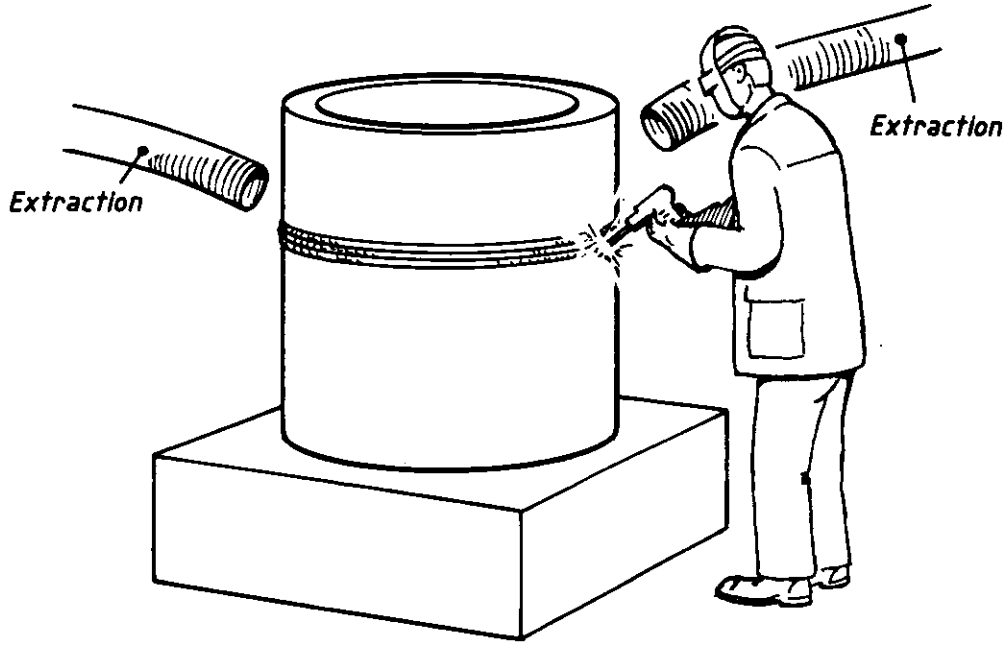

Fig.13 Location 1 Site C.

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