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# **The Generation, Collection, and Analysis of Welding Fumes**

**By J. F. McIlwain and L. A. Neumeier**



**UNITED STATES DEPARTMENT OF THE INTERIOR**

Report of Investigations 8793

# The Generation, Collection, and Analysis of Welding Fumes

By J. F. McIlwain and L. A. Neumeier

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ac	alternating current	kg/hr	kilogram per hour
A	ampere	mg/m <sup>3</sup>	milligram per cubic meter
°C	degree Celsius	mm	millimeter
dc	direct current	pct	percent
Fe <sup>2+</sup>	divalent (ferrous) iron	sec	second
g/min	gram per minute	Cr <sup>3+</sup>	trivalent chromium
Cr <sup>6+</sup>	hexavalent chromium	v	volt
in/min	inch per minute	wt-pct	weight-percent

# THE GENERATION, COLLECTION, AND ANALYSIS OF WELDING FUMES

By J. F. McIlwain<sup>1</sup> and L. A. Neumeier<sup>1</sup>

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## ABSTRACT

The Bureau of Mines investigated fumes generated by selected welding materials used in mines in order to help determine their relative hazard potential. The initial phases of the study have been completed. A welding-fume generation and collection apparatus was designed, assembled, and calibrated. Five brands of coated, AWS-type E308-16 stainless steel electrodes were tested. Total fume generation rates of 0.39 to 0.51 g/min were measured. Quantitative chemical analyses were conducted for all of the principal fume constituents. Two analytical schemes were used to determine levels of the  $\text{Cr}^{6+}$  and  $\text{Cr}^{3+}$  species contained in the welding fumes; comparable results were obtained. The  $\text{Cr}^{6+}$  was found to be the most hazardous constituent, leading to a maximum allowable total fume exposure of 1 mg/m<sup>3</sup>. Fume generation rates and fume constituent analyses will be derived for other groups of welding electrodes using similar procedures.

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## INTRODUCTION

Arc-welding operations generate a mixture of smoke and gases. Gases may be toxic in themselves, or they may displace oxygen in the environment and lead to asphyxiation. Vaporized metallic particles from the arc, generally in the form of oxides, agglomerate to form aerosols in the size range of about 0.01 to 50  $\mu\text{m}$  (14).<sup>2</sup> It is these fine particles, rather than gases, which one sees emanating from welding operations. Particles in the upper end of this range and larger settle out relatively quickly as dust, but the lighter ones may remain suspended in the air. The term "fume" is sometimes used to refer to the smoke plus gases, and sometimes it refers to only the fine particles generated. In this report, unless otherwise stated, fume will refer to only the air-borne particulates and not to any gases generated during welding operations.

Exposure to welding-fume particulates by workers in the mining industry is of concern to the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, as well as mining industry personnel. Because welding may frequently be conducted in closed or confined quarters, the possibility of overexposure to fumes due to inadequate ventilation exists. Fumes from various types of electrodes are known to contain, or are suspected of containing, potentially hazardous substances such as Cr, Ni, Mn, V, Cu, or F. The effects of these elements individually on humans and laboratory animals have been partially documented, as have the effects on workers of uncontrolled exposure to welding fumes. The National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Labor, has prepared a criteria document draft for welding, brazing, and cutting (11).

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<sup>2</sup>Underlined numbers in parentheses refer to items in the list of references at the end of this report.

This document draws on existing data and information to develop criteria that could help establish standards to protect the safety and health of welders.

To help formulate standards for the mining industry, MSHA needs additional information specific to mining operations, such as the types and degree of welding performed, the electrodes used, the amount of contamination generated by those electrodes and their constituents, and the nature of controls used to protect the welder. Much of this information requires in-mine documentation such as surveys of welding products used, interviews with welders, air monitoring, etc. No comprehensive studies of welding practice in the mining industry exist, but limited surveys (2, 9) have identified more than 300 electrode types, by either brand name or American Welding Society (AWS) designation, that have been or are being used in mines and surface shops. Most of the data are qualitative, in that they neither indicate the relative amounts of each type used nor specify particular locations or environments where these electrodes are used. It can be surmised that shielded metal arc welding (SMAW)--popularly known as stick welding--with mild or low-alloy steel electrodes forms the bulk of the welding done. Nevertheless, welding is also performed with stainless steel and nickel-base alloys, and hardfacing and rebuilding are performed with highly alloyed iron-, nickel-, or cobalt-base alloys.

A second source of information is contained in the air-sampling data collected by MSHA inspectors since 1974 while monitoring welders and maintenance workers in mines and mine shops. These data have been computerized, edited, and organized by the Bureau of Mines (13). They indicate that, based on the fraction of samples indicating constituents that exceed the respective threshold limit value,

time-weighted average (TLV-TWA),<sup>3</sup> the principal contaminants are cobalt and chromium. The usefulness of these data is limited, however, because contaminant levels cannot be related to specific operational parameters such as electrode type, type of welding, ventilation, welding surface cleanliness, and related factors.

Recent Bureau research (7) involved with the ventilation of air-borne contaminants from welding fumes in surface mines included testing of four commercial exhaust units, which were found to be satisfactory in reducing contaminant levels to acceptable limits. A brief review of the adverse health effects of welding contaminants and associated control problems also is given, as well as air-borne contaminant levels from five low-alloy steel electrodes.

The presence of chromium in most of the higher alloy electrodes and its suspected carcinogenicity has led to several investigations of stainless steel electrode fumes, with emphasis on the detection of hexavalent chromium ( $\text{Cr}^{6+}$ ), the suspected carcinogenic species. Of interest in the present report are the results of Miller (10), who studied AWS-type 308 stainless steel electrodes (SMAW). These were "burned" using alternating current and direct current, reverse polarity, and a modification of a Swedish fume box described by Rosendahl (12). In Miller's work neither the plate material nor the electrode flux cover was specified. Both of these would influence the fume

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<sup>3</sup>Threshold limit value, time-weighted average is defined as "the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect" (3). In this report, the term "TLV" will refer exclusively to this time-weighted average, expressed in milligrams per cubic meter.

generation rate and the fume composition. Fumes were collected on a membrane filter from which the deposit was subsequently acid leached. Analyses were principally by atomic absorption spectroscopy (AAS). Special attention was given to total chromium and  $\text{Cr}^{6+}$ , which were analyzed by the method of Abell and Carlberg (1). A fume generation rate (FGR) of 140 mg/min was given for 3.25-mm-diam electrodes used in the direct current (dc) mode. Neither voltage nor current was specified. A partial fume composition was listed as 32.6 pct iron oxide, 5.3 pct fluoride, and 4.7 pct chromium (total), of which 98 pct was water-soluble  $\text{Cr}^{6+}$ , although it was not clear whether this applied to fumes generated in the alternating current (ac) or the dc mode. The particular oxide of iron was also not specified.

In a second study, Kimura (8) generated a nearly complete chemical composition of type-E308 electrode fumes; the results are presented in table 1. These fumes were generated and collected inside a closed chamber, using mild steel plates on which one layer of weld material had been deposited. The electrodes studied were a 5-mm-diam, E308-16 type, presumably of Japanese manufacture. Chromium and chromium compounds were studied in some detail. Total chromium was determined by ammonium persulfate oxidation and potassium permanganate titration. Water-soluble  $\text{Cr}^{6+}$  was determined by water leaching followed by extraction with a methyl isobutyl ketone solution of tri-octylamine and analysis by AAS. A breakdown of the chromium fractions appears in table 2. Infrared absorption and X-ray analyses were also performed. The authors concluded that water-soluble chromium was present in the fumes as  $\text{K}_2\text{CrO}_4$ . Reduction of sodium and potassium in the flux cover of experimental electrodes led to not only a 90-pct reduction of  $\text{Cr}^{6+}$  in the fume, but also to a 22-pct reduction in FGR.



TABLE 1. - Chemical composition of type E308-16 electrode fumes, weight-percent

Constituent	Total	Water soluble
Al <sub>2</sub> O <sub>3</sub> .....	0.98	0.74
CaO.....	4.23	.14
Cr <sub>2</sub> O <sub>3</sub> .....	7.26	5.44
F.....	17.66	17.5
Fe <sub>2</sub> O <sub>3</sub> .....	6.89	.14
K <sub>2</sub> O.....	22.14	22.04
MgO.....	.12	.02
MnO.....	9.04	.59
Na <sub>2</sub> O.....	2.87	2.80
NiO.....	.59	.02
SiO <sub>2</sub> .....	6.67	4.66
TiO <sub>2</sub> .....	8.57	.28

Source: Kimura (8).

TABLE 2. - Fractional determination of chromium in type E308-16 electrode fumes, weight-percent

Cr fraction	Sample 1	Sample 2
Total Cr.....	4.92	5.01
Soluble Cr.....	3.83	3.70
Soluble Cr <sup>6+</sup> .....	3.80	3.79
Insoluble Cr.....	1.29	1.34

Source: Kimura (8).

The most recent investigation of type E308-16 electrodes involved a round-robin analysis to determine the chromium

species distribution (6). A premise for the investigation was the questionability of the acid extraction (Abell-Carlberg) method in maintaining Cr<sup>6+</sup> in the suspected presence of Fe<sup>2+</sup> in the fume. To avoid its reduction to Cr<sup>3+</sup>, an alkaline extraction, followed by AAS, was used. Seven laboratories analyzed fume samples from a single source, the origin of which was not given. Mean values reported were total Cr, 6.29 pct; water-soluble Cr<sup>6+</sup>, 4.70 pct; insoluble Cr<sup>6+</sup>, 0.13 pct; and "non-Cr<sup>6+</sup>," 1.33 pct. The last presumably is Cr<sup>3+</sup>, probably as Cr<sub>2</sub>O<sub>3</sub>.

To supplement these data and to provide data for specific electrodes that could be of use to mine inspectors, the Bureau endeavored to compile available information regarding welding materials used in mines and their compositions, and to conduct controlled laboratory arc-welding experiments, using electrodes selected on the basis of this information, to define their fume particulate constituents. This report describes a fume generation and collection apparatus assembled for this evaluation, and discusses the results of the investigation of the first group in a larger series of groups of electrodes that are planned for evaluation.

## EXPERIMENTAL PROCEDURE

### ELECTRODE SELECTION

Since not all electrodes could be studied, the more highly alloyed varieties, which present a greater hazard potential, comprised the selection pool. The MSHA data (13) suggested that those high in cobalt or chromium should be chosen. Additionally, a high-nickel group and a manganese-containing group were chosen since these elements are considered hazardous. Using the cited mine survey listings (2, 9) and other sources as a base, six groups of electrodes were chosen for evaluation: AWS 5.4, E308-16; AWS 5.4, E310-16; AWS 5.13, ECoCr-A; AWS 5.15, ENiCl; an iron-base, Mn-Cr surfacing alloy in SMAW form (not AWS specified); and approximately the same composition alloy in flux covered wire form.

Only the type E308-16 data are reported here, representing five commercial brands. The complete test results of all of these electrodes has not been compiled.

### FUME GENERATION AND COLLECTION

#### Apparatus

Fumes were produced and collected in an enclosed chamber (fig. 1). A motorized table supported and rotated a type A36 steel plate onto which weld beads were deposited. Figure 2 shows the positioning of the manually held stick electrode above the plate and the bead pattern. The rotation was adjusted to give constant linear speed at any position on the plate. The fumes generated were drawn to



FIGURE 1. - Operator preparing to strike an arc using an automatic wire feed. The welding operation inside the chamber is viewed through a filtered glass plate positioned across the view port. Fumes generated are swept up to a filter housed just above the operator's right hand by a suction blower (not shown). The power supply, strip chart recorder for voltage and current measurement, and wire feed unit are seen at left and below the chamber.

filters, situated at the top of the chamber, by a high-speed blower (not shown). Outside air entered the chamber through a 0.75-in gap around the base. A welding filter glass plate, when positioned across the view port, allowed safe visual observation of the welding.

Power was supplied by a 600-amp source with constant current and constant voltage capabilities. A feed unit and gun are available for gas-metal arc welding (GMAW). Voltage and current levels were recorded on a strip chart.

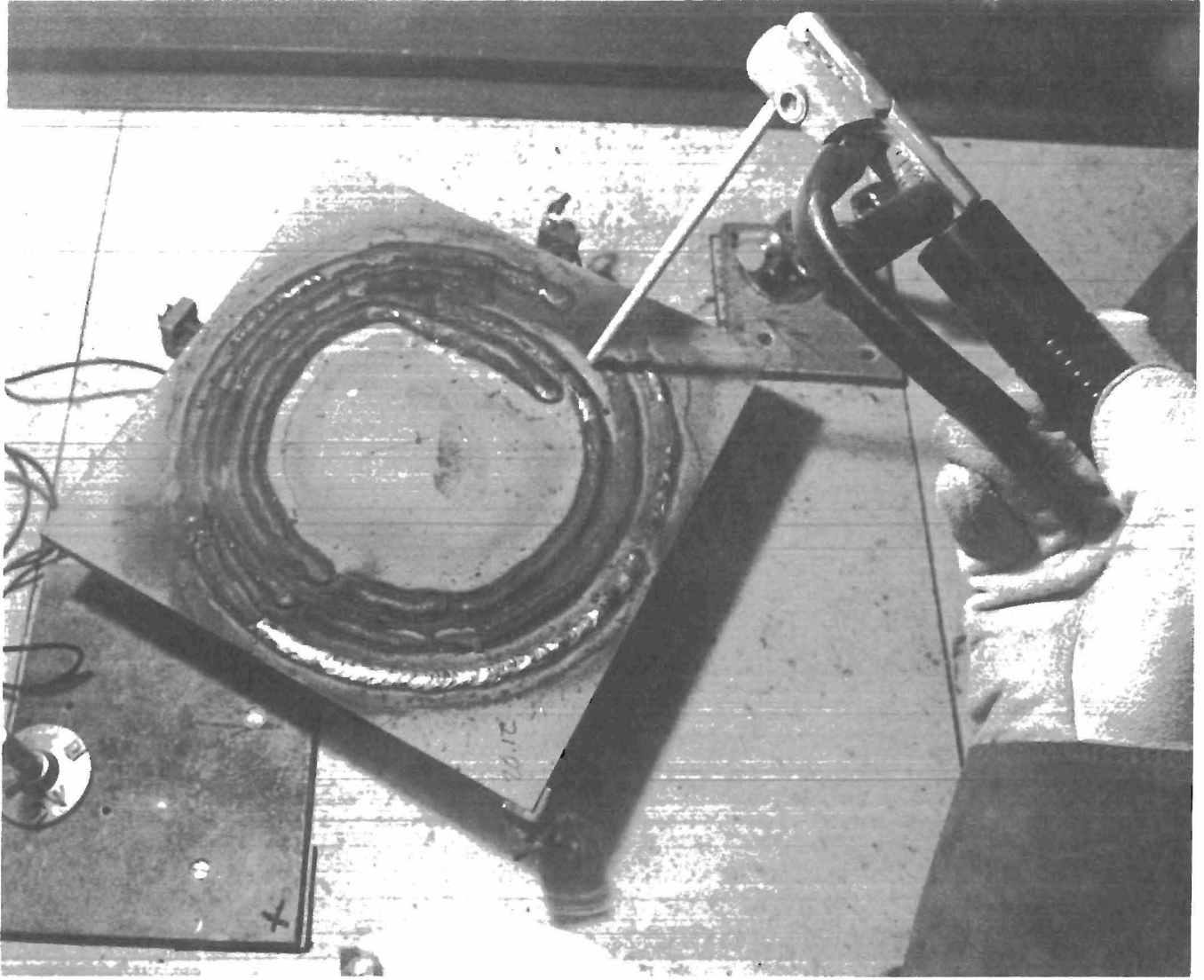


FIGURE 2. - Weld beads deposited on mild steel plate inside the chamber using manual shielded metal arc welding (SMAW). A turntable rotates the plate counterclockwise at a fixed linear rate.

Two types of filters were used. For FGR weight determinations, two layers of nominally 0.5-in-thick fiberglass aircraft insulation were employed. In separate runs, samples for chemical analysis were collected on Whatman 4<sup>4</sup> cellulose filters backed by one layer of the glass material. Filters, 11.5 in diam, were housed in a Plexiglas holder (figs. 3-4), which could be removed for easy handling. A 0.5-in-diam hole was cut in the chemical sampling filters to allow relatively "heavy" loading while still clearing the

chamber of fume within a reasonable period. Filter loading was uniform across the filter face (fig. 5). The glass filters were weighed on a top-loading balance sensitive to 1 mg.

#### Procedures

Calibration of the apparatus followed AWS guidelines (5). The fiberglass filters were heated 1 hr at 105° C prior to weighing, before and after loading, to drive off adsorbed moisture. Weights were recorded after a 4-min cooling period to minimize thermal effects on the balance. Copper-coated type ER70S-3 steel wire, 0.045 in diam, was used as

<sup>4</sup>Reference to specific equipment does not imply endorsement by the Bureau of Mines.

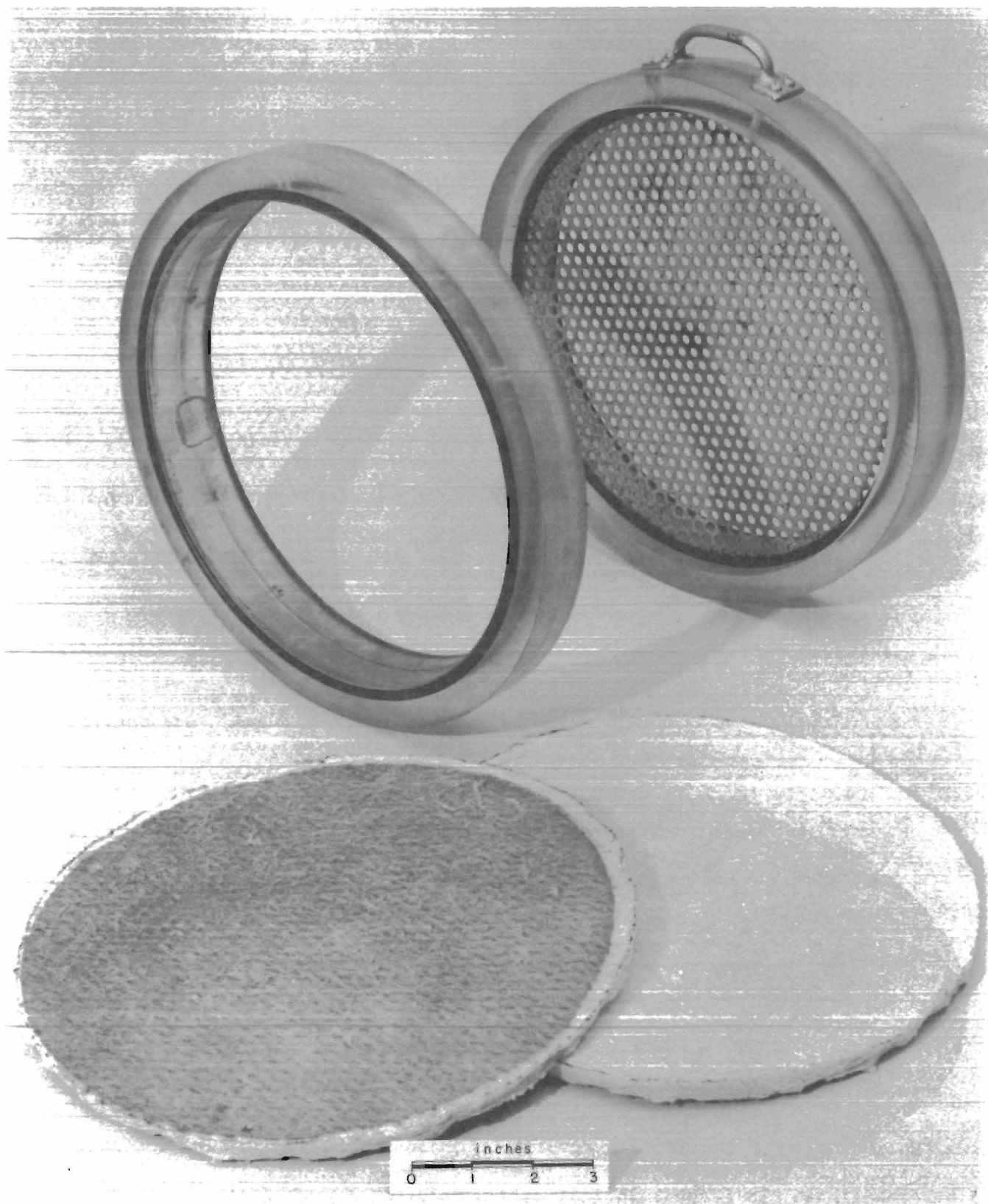


FIGURE 3. - Primary and backing fiberglass filter pair, used for fume weight measurements, and the removable housing. The perforated steel plate supports the filters against the air flow. The primary filter has been loaded with fume from 1 min of arc time.

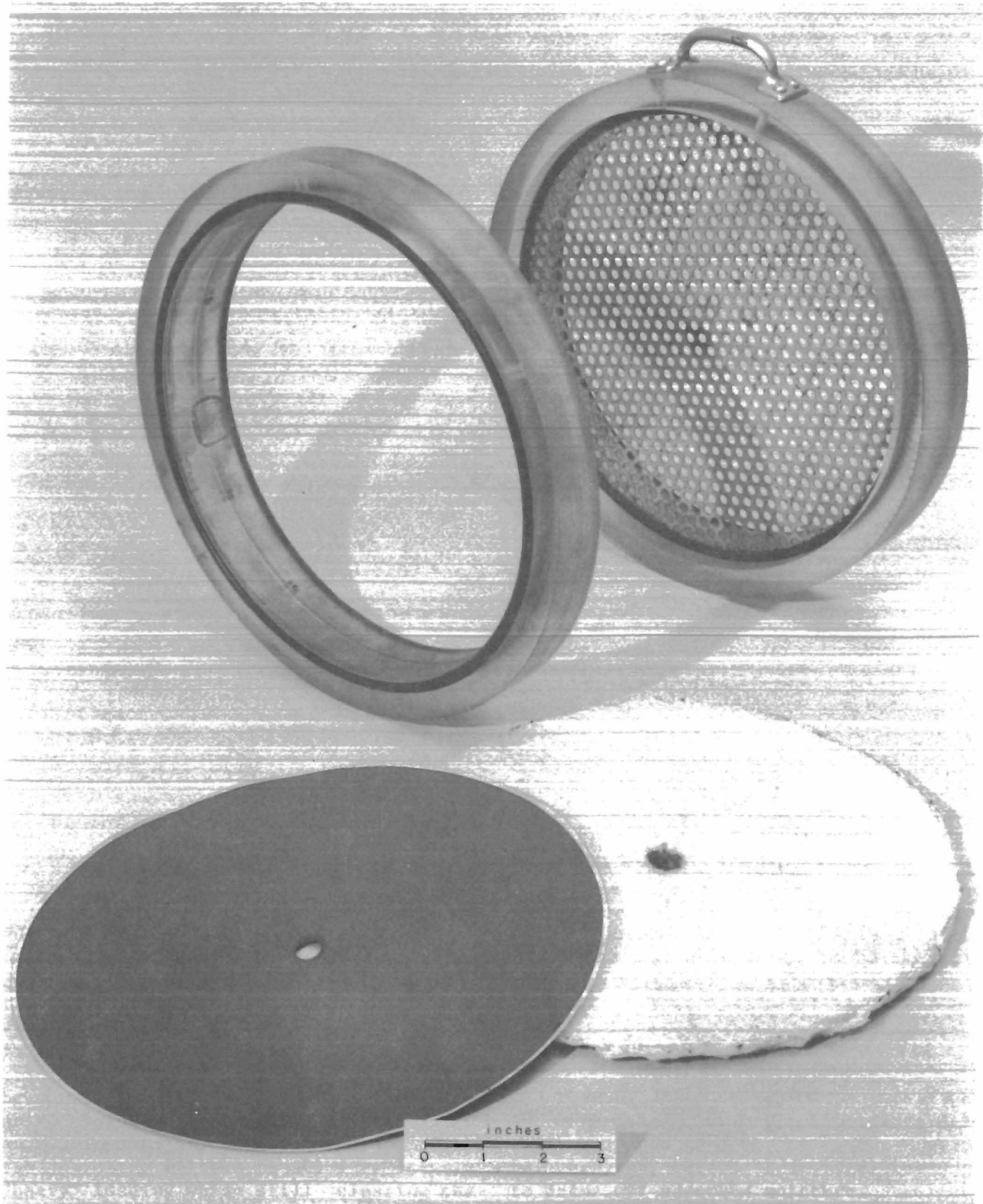


FIGURE 4. - Cellulose filter with fiberglass backing used to collect bulk fume samples for chemical analysis. After loading, the loose fume is brushed from the filter into a container.

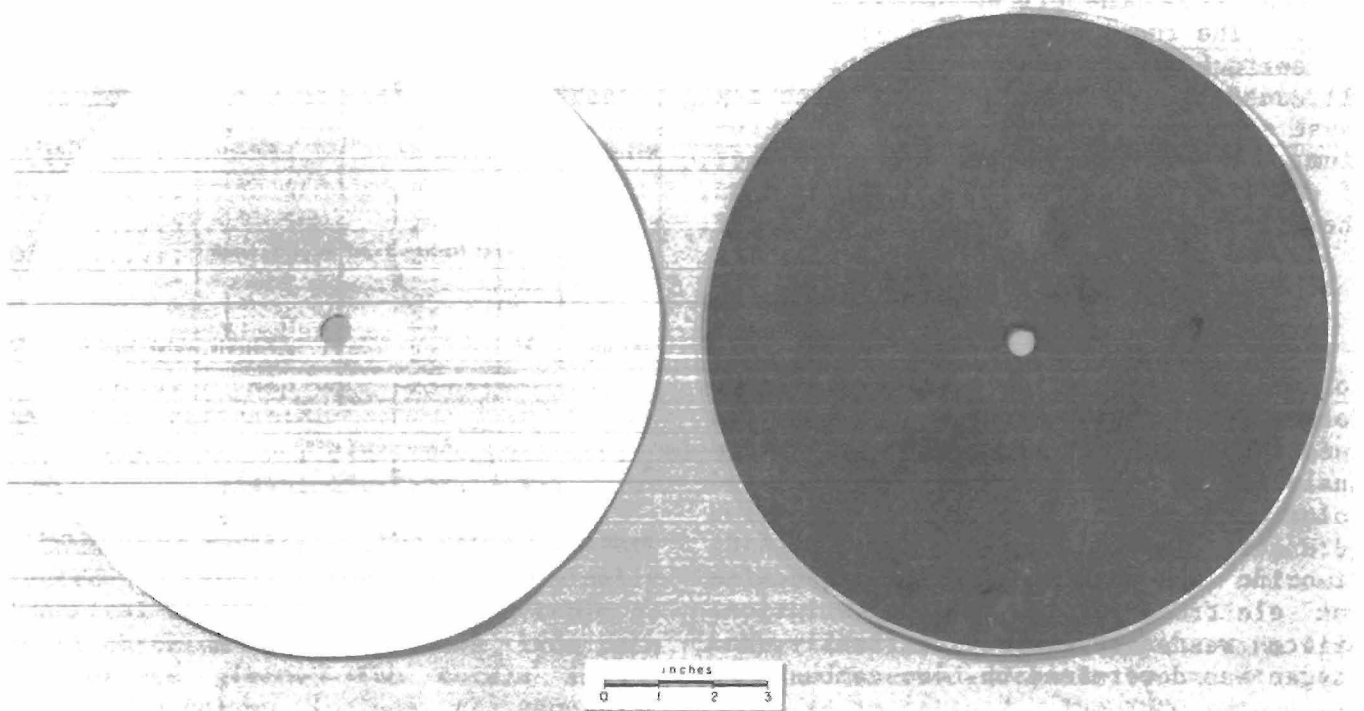


FIGURE 5. - Loaded filter (on the right), and new filter. Despite the 0.5-in hole, fume distribution is uniform across the filter.

the calibration electrode standard (5). The wire was fed at 300 in/min under  $\text{CO}_2$  shielding gas. The gun was fixed to assume constant arc length and angle. A plate speed of 14 in/min was used. Runs of 60 sec were made with the blower on. An additional 30-sec exhaust was sufficient to clear the chamber of fume. Data were taken at 24 and 26 v, as measured between the wire-feed adapter and the steel plate. Wire consumption was determined from the feed rate, run time, and a measured linear density. Results of at least three runs at each voltage appear in table 3. The values of FGR, fume weight generated per electrode unit weight consumed, and melt-off rate fell within the stipulated calibration standard values.

Procedures for the SMAW were similar to those described. Electrodes were kept at 125° C after removal from sealed packages and prior to use. Electrode consumption was determined from starting and finishing weight and length.

TABLE 3. - Calibration parameters for the Bureau welding fume chamber using a wire electrode<sup>1</sup>

Property	24 v	26 v
FGR, g/min:		
Measured.....	0.40	0.56
Standard.....	0.39-0.47	0.49-0.60
Weight ratio, fume to electrode, pct:		
Measured.....	0.66	0.92
Standard.....	0.60-0.74	0.79-0.97
Melt-off rate, kg/hr:		
Measured.....	3.6	3.6
Standard.....	3.4-4.2	3.4-4.2

<sup>1</sup>ER70S-3 wire, 0.045 in diam.

As stated above, the hole in the cellulose filter allowed sufficient fume to be collected in a reasonable period for chemical analysis. Typically, three to five runs of about 2 min each generated a total of about 1.2 g of fume. After each 2-min run, the agglomerated fume was

brushed from the filter into a glass vial. The fume, accumulated on the filter surface, has relatively little overall contact with the cellulose, which may cause some reduction of hexavalent chromium. Despite the hole, roughly 35 pct of the fume generated was collected on the filter.

#### CHEMICAL ANALYSIS

The Fe, Ni, Mn, Cu, Ti, Ca, and Al were solubilized with a sulfuric acid leach followed by fusion with  $\text{Na}_2\text{O}_2$  for the acid insolubles. All but titanium were analyzed by AAS; titanium was analyzed colorimetrically. Sodium and potassium were acid leached and analyzed by AAS. Fluorine was determined with a specific ion electrode in the sodium solution. Silicon was analyzed gravimetrically, and oxygen was determined by Leco combustion.

Two methods were used for chromium determination. The first used Rinehart's solution (equal parts  $\text{H}_2\text{SO}_4$ ,  $\text{MnSO}_4$ , and  $\text{H}_3\text{PO}_4$ ) to extract  $\text{Cr}^{6+}$ . Total chromium was extracted from a separate sample fraction with an  $\text{H}_2\text{SO}_4$  leach followed by  $\text{Na}_2\text{O}_2$  fusion of the residue. The combined solutes were titrated. Determination of the  $\text{Cr}^{6+}$  was also by appropriate titration. The  $\text{Cr}^{3+}$  content was calculated by difference.

The second method for chromium analysis, outlined in figure 6, is essentially the basic leach described by Andrews (6), and otherwise known as the INCO method (named for its place of origin). The initial step is a slightly alkaline water leach to extract soluble  $\text{Cr}^{6+}$ . From the residue, water-insoluble

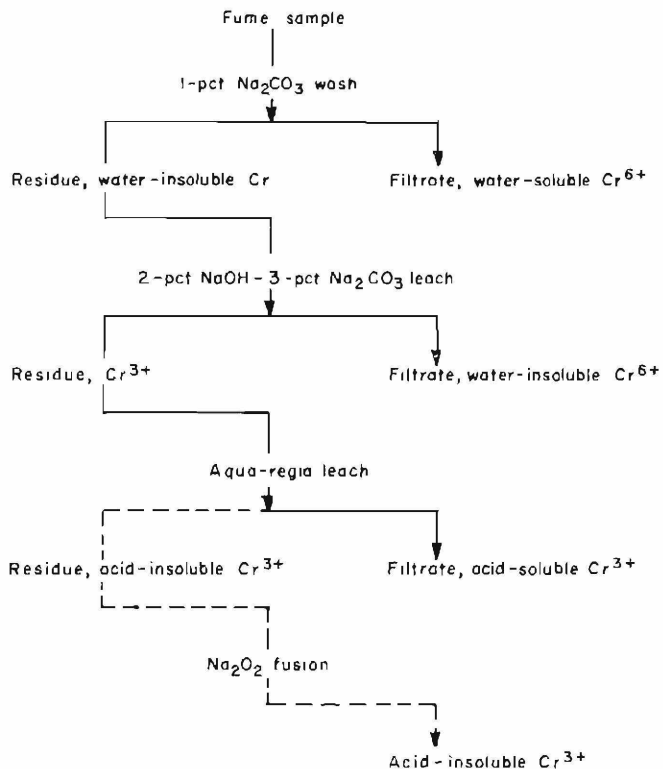


FIGURE 6. - Modified INCO method (6) using 100-mg samples, for determining chromium species in welding fumes from type E308-16 electrodes. The dashed line represents an additional analytical step to measure acid-insoluble chromium.

(actually slightly soluble)  $\text{Cr}^{6+}$  is then extracted by a caustic leach. The INCO method ends with an acid leach of this residue to extract  $\text{Cr}^{3+}$ . In the present study, some residue remained after the acid leach; this residue was  $\text{Na}_2\text{O}_2$ -fused to extract the remaining chromium. All solutions were then acidified and analyzed by AAS. Total chromium was taken as the sum of the products of these four steps.

#### RESULTS

Fume generation rates, in terms of grams of fume generated per minute of arc time and per gram of electrode used, are listed in table 4. For this report, each brand of electrode was given a code letter, and the data are listed by these code letters. Included are replicate

data for code D electrodes. Only individual points at voltages within 5 pct of the values listed, approximately  $\pm 1$  v, are included in the data. The mean values for the group were determined from the means for each brand, rather than from the 35 individual data points.

TABLE 4. - Fume generation rates<sup>1</sup> for type E308-16 electrodes

Electrode code	Number of runs	Average voltage, v	Average current, A	FGR, g/min	Standard deviation	Fume wt per wt of electrode used, pct	Standard deviation
A.....	5	23	171	0.39	0.051	0.88	0.10
B.....	4	24	175	.48	.013	1.21	.18
C.....	5	24	173	.51	.027	1.31	.04
D.....	5	22	173	.42	.058	1.06	.14
	5	23	176	.40	.030	.95	.07
	6	23	174	.42	.013	1.04	.07
E.....	5	23	173	.47	.031	1.22	.07
Mean....	NAp	23	174	.44	.055	1.09	.16

NAp Not applicable.

<sup>1</sup>Parameters: dc, electrode positive; electrode core diameter of 3/16-in; travel speed of 11 in/min; arc time, 1 min.

Chemical compositions of the fume, collected in separate runs under nominally identical conditions, appear in table 5. Total chromium determinations from both methods are given. The totals in the right-hand column include the generally higher chromium values from the INCO method. The values for code D are means from three replicate samples. The total fractions of near 100 pct indicate that all principal constituents of the fumes have been accounted for in the analysis.

The replicate values for code D electrodes (this brand chosen arbitrarily), shown in table 6 together with the sample standard deviations, give an indication of the relative reproducibility of the chemical sampling and analysis. It should be noted that, although individual constituent variations of 13 pct are

seen, the sum deviate from 100 pct by only 2 pct.

The distribution of the chromium species as determined by the two methods are compared in table 7. The INCO method was applied to separately generated fume samples, of which there was but one for the code D electrode. Water-soluble and insoluble Cr<sup>6+</sup> species were not determined in the acid-leach scheme, but this could be done. The resulting values are in good agreement with those in the literature for water-soluble Cr<sup>6+</sup> and acid-soluble Cr<sup>3+</sup>. The principal difference is with the total Cr values. Relatively good agreement is found also between the two methods. Note that there is no indication of systematic reduction of hexavalent chromium in the acid solution, despite 17 to 20 pct Fe in the fume.

TABLE 5. - Chemical compositions of fumes generated from type E308-16 electrodes

Electrode code	Chemical constituent, wt-pct														Total, <sup>3</sup> pct
	Cr <sup>1</sup>	Cr <sup>2</sup>	Ni	Fe	Mn	Cu	Ca	K	Na	F	Al	Si	Ti	O	
A.....	9.4	9.3	1.7	18.1	4.9	0.1	5.5	10.7	4.1	8.8	0.5	5.4	2.4	29.6	101.1
B.....	9.2	9.9	2.0	19.5	9.6	0	4.9	11.0	2.8	6.3	.8	4.8	2.6	35.8	110.0
C.....	9.4	9.5	1.9	17.3	6.4	.2	3.2	13.0	4.8	7.8	.4	4.5	2.7	23.1	94.8
D <sup>4</sup> .....	9.5	10.6	1.9	17.8	6.6	0	3.1	8.4	6.9	7.7	.3	5.3	2.4	30.3	101.3
E.....	8.7	9.0	2.0	18.8	7.5	.1	3.3	11.9	3.5	7.1	1.0	4.4	2.4	31.4	102.4
Mean..	9.3	9.7	1.9	18.2	6.9	.1	3.8	10.2	5.1	7.6	.5	5.0	2.5	30.1	101.5

<sup>1</sup>Acid leach.

<sup>2</sup>INCO method, separate fume samples.

<sup>3</sup>Based on Cr values by INCO method.

<sup>4</sup>Mean of 3 samples.



TABLE 6. - Replicate analyses of code D fume

Trial	Chemical constituent, wt-pct													Total, pct
	Cr <sup>†</sup>	Ni	Fe	Mn	Cu	Ca	K	Na	F	Al	Si	Ti	O	
1.....	9.9	1.9	17.6	6.7	0.05	3.6	8.0	6.3	8.0	0.3	5.3	2.2	32.4	102.2
2.....	9.2	1.8	17.5	6.6	.05	2.8	8.7	8.0	7.8	.3	5.4	2.6	28.5	99.2
3.....	9.3	1.9	18.3	6.4	.05	3.0	8.5	6.5	7.3	.4	5.1	2.5	30.0	99.2
Mean.....	9.5	1.9	17.8	6.6	.05	3.1	8.4	6.9	7.7	.3	5.3	2.4	30.3	100.2
Std. dev. (SD)....	.38	.06	.44	.15	0	.42	.36	.93	.36	.02	.15	.21	1.97	Nap
SD/mean.....pct..	4.0	3.2	2.4	2.3	0	13.3	4.3	13.4	4.7	4.5	2.9	8.6	6.5	Nap

Nap Not applicable.

<sup>†</sup>Acid leach.

TABLE 7. - Chromium species in type E308-16 electrode welding fumes by acid and basic leach schemes, weight-percent

Electrode	INCO method, Cr <sup>6+</sup>			Acid leach: total Cr <sup>6+</sup>	INCO method, Cr <sup>3+</sup>			Acid leach: <sup>†</sup> total Cr <sup>3+</sup>
	Water-soluble	Water-insoluble	Total		Acid-soluble	Acid-insoluble	Total	
A.....	5.1	0.38	5.48	4.7	1.2	2.6	3.8	4.7
B.....	4.1	.33	4.43	4.2	1.9	3.6	5.5	5.0
C.....	5.1	.38	5.48	5.6	1.3	2.7	4.0	3.8
D.....	4.8	.37	5.17	{ 5.3 5.3 5.6	} 1.7	3.7	5.4	{ 4.6 3.9 3.7
E.....	4.6	.25	4.85	5.3	1.5	2.7	4.2	3.4
Mean.....	4.7	.34	5.04	5.1	1.5	3.1	4.6	4.2

<sup>†</sup>Values by difference.

## DISCUSSION

Fume compositions are significant only when translated into welder exposure. Since exposure to the fume, that is, the actual inhalation of the fume by the welder or other nearby workers, will vary with welding practice, ventilation, and a number of other variables, a specific exposure value cannot be determined for a particular electrode. A relative exposure index can be calculated, however, based on the fraction of a component in the fume and its degree of toxicity, as expressed by its TLV. The threshold limit values for most of the fume components have been established (3). They are given in terms of milligrams of air-borne material per cubic meter ( $\text{mg}/\text{m}^3$ ) of ambient air to which the worker is exposed. The exposure to an individual component,  $E_i$ , is

$$E_i(\text{mg}/\text{m}^3) = C(\text{mg}/\text{m}^3)f_i, \quad (1)$$

where  $C$  is the total welding fume exposure, and  $f_i$  is the elemental fume fraction. By setting a maximum allowable exposure to a component,  $E_{i,\text{max}} = \text{TLV}_i$ , a maximum allowable total fume exposure,  $C_{im}$ , can be calculated for each constituent, as

$$C_{im}(\text{mg}/\text{m}^3) = \frac{E_{i,\text{max}}(\text{mg}/\text{m}^3)}{f_i} = \frac{(\text{TLV})_i}{f_i}. \quad (2)$$

Maximum allowable values for total welding fume exposure (the  $C_{im}$  values) have been calculated from the mean fume data in tables 5 and 7 and appear in

table 8. The numbers establish the relative hazard potential of the various elements; for example, a total fume exposure of  $>27 \text{ mg}/\text{m}^3$  is required before the current recommended TLV for iron is exceeded, whereas an exposure of only  $\sim 5 \text{ mg}/\text{m}^3$  total fume is sufficient to reach the TLV for total chromium. In these fumes,  $\text{Cr}^{6+}$  clearly presents the greatest hazard, requiring the welder to breathe only one-tenth the allowable MSHA total fume exposure. Silicon is assumed to be present as relatively innocuous amorphous  $\text{SiO}_2$  (4); crystalline silica has an order-of-magnitude lower TLV and so would present a more serious exposure condition. The values in table 8 may be compared to a total welding fume TLV, which for the most part has been established for carbon- and low-alloy steel welding. The MSHA standard is  $10 \text{ mg}/\text{m}^3$  for 8-hr exposure, whereas the American Conference of Governmental Industrial Hygienists (ACGIH) recommends  $5 \text{ mg}/\text{m}^3$  (3). For these electrodes, observance of these exposure standards is sufficient to protect the welder from all of the components except chromium.

From the FGR and constituent data, the individual constituent generation can be calculated. The five brands produced 22, 21, 28, 22, and 23  $\text{mg}/\text{min}$  of  $\text{Cr}^{6+}$  under the welding conditions tested. From this standpoint, electrode code C is about 25 pct more hazardous to use than the others.

TABLE 8. - Calculated maximum allowable exposure values ( $C_{im}$ ) for type E308-16 electrode fumes, milligrams per cubic meter

Constituent	TLV <sup>1</sup>	$C_{im}$	Constituent	TLV <sup>1</sup>	$C_{im}$
Al.....	10	2,000	K.....	ND	ND
Ca.....	21.4	38	Mn.....	1	14
Cr.....	.5	5.2	Na.....	ND	ND
$\text{Cr}^{6+}$ .....	.05	31.0	Ni.....	1	53
Cu.....	.2	200	Si.....	41.4	28
F.....	2.5	33	Ti.....	10	400
Fe.....	5	27			

ND Not determined.

<sup>1</sup>1982 ACGIH recommended values (3).

<sup>2</sup>Based on a TLV of  $2 \text{ mg}/\text{m}^3$  for  $\text{CaO}$ .

<sup>3</sup>Calculated from data in table 7.

<sup>4</sup>Based on a TLV of  $3 \text{ mg}/\text{m}^3$  for respirable amorphous  $\text{SiO}_2$ .

## CONCLUSIONS

This report documents the establishment of a facility within the Bureau for generating, collecting, and analyzing welding particulate fumes. It shows that fume composition data can be produced and how the data may be translated into fume exposure indices. Type E308-16 electrodes were shown to have an index of  $C_{1m} = 1.0 \text{ mg/m}^3$ , compared to

a mild steel index of  $5 \text{ mg/m}^3$  (ACGIH) or  $10 \text{ mg/m}^3$  (MSHA). Further analysis of these data, together with those generated for additional groupings of electrodes in ongoing work, is expected to yield additional relationships between fumes and electrodes, which may be used to advantage by MSHA or mining personnel in monitoring welding operations.

## REFERENCES

1. Abell, M. T., and J. R. Carlberg. A Simple Reliable Method for the Determination of Airborne Hexavalent Chromium. *Am. Ind. Hyg. J.*, v. 35, No. 4, 1974, pp. 229-233.
2. Albers, A. Mining Environmental Target Investigation. Welding Operations at Underground and Surface Coal Mines. Final Report (draft), NIOSH, Rockville, Md., March 1982, 76 pp.
3. American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances in Work Air. 1982, 93 pp.
4. American Welding Society. Fumes and Gases in the Welding Environment, ed. by F. Y. Speight and H. C. Campbell. 1979, 232 pp.
5. \_\_\_\_\_. Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes, Standard Fl.2-79. 1979, 7 pp.
6. Andrews, L. R. (School of Public Health, Columbia Univ., New York). Private communication, 1981; available for consultation at the Bureau of Mines, Rolla, Mo.
7. Derby, G. K. Reduction of Airborne Contaminants From Welding Exhaust at Surface Mines. BuMines IC 8868, 1982, 11 pp.
8. Kimura, S., M. Kobayashi, T. Godai, and S. Minato. Investigations on Chromium in Stainless Steel Welding Fumes. *Weld. J.*, v. 58, No. 7, Res. Suppl., July 1979, pp. 195s-204s.
9. LFE Corporation. Handbook for Surveys of Inhalation Contaminants in Above Ground Metal and Nonmetal Mining and Processing Areas (LFE contract J0255001). BuMines Open File Rept. 9(1)-80, 1977, 87 pp.
10. Miller, T. M., and R. C. Jones. An Assessment of the Fume Characteristics of Australian Electrodes for Manual Metal Arc Welding. *Australian Weld. Res.*, v. 6, January 1979, pp. 1-9.
11. National Institute for Occupational Safety and Health Criteria Document on Welding (draft). 1980, 247 pp.
12. Rosendahl, C. H. Welding Fume: Its Measurement and Removal in Industry. Exploiting Welding in Production Technology International Conference. Welding Institute, London, 1975, pp. 249-252.
13. Watts, W. F., R. L. Johnson, D. J. Donaven, and D. R. Parker. An Introduction to the Mine Inspection Data Analysis System (MIDAS). BuMines IC 8859, 1981, 41 pp.
14. The Welding Institute (Cambridge, England). The Facts About Fume. 1976, 31 pp.