

XIII. TABLES AND FIGURES

TABLE XIII-1

PROPERTIES OF NITRIC OXIDE AND NITROGEN DIOXIDE

	Nitric Oxide NO	Nitrogen Dioxide NO <sub>2</sub>
Formula weight	30.01	46.01
Density (gas)	1.3402	1.4494
Melting point C	-163.6	-11.2
Boiling point C	-151.8	21.2
Solubility per 100 cc hot water (60 C)	2.37 cc	----
cold water (0 C)	7.34	soluble, decomposes

Derived from Handbook of Chemistry and Physics [1]

TABLE XIII-2

OXIDATION RATE OF NITRIC OXIDE IN AIR (20% O<sub>2</sub>) AT 20 C

Concentration (ppm)	Oxidation Time		
	25%	50%	90%
10,000	8.4 sec	24 sec	3.6 min
1,000	1.4 min	4 min	36 min
100	14 min	40 min	6 hours
10	2.3 hours	7 hours	63 hours
1	24 hours	72 hours	648 hours

From Austin [167]

TABLE XIII-3  
 NITROGEN OXIDES FROM CUTTING WITH OXYACETYLENE TORCH

Sample No.	Collection Time (A.M.)*	Oxides of Nitrogen (ppm)		
		NO <sub>2</sub>	NO	NO <sub>2</sub> + NO
1	6:55	25	165	190
2	6:55	--	--	210
3	7:06	--	--	260
4	7:11	--	--	300
5	7:18	--	--	290
6	7:20	90	180	270
7	7:21	--	--	300
8	7:27	--	--	330
9	7:27	--	--	310
10	7:28	--	--	340

\*Cutting began at 6:40 A.M.

From Norwood et al [23]

TABLE XIII-4  
FORMATION OF OXIDES OF NITROGEN BY VICTOR TORCH

Sample No.	Torch Characteristics	Gas Evolution Rate (mg/min)		
		Nitrogen Dioxide	Nitric Oxide	Total
1m	Flame only	16	215	231
2m	Flame only	--	---	250
3m	Stainless-steel melting	--	---	47
5m	Stainless-steel melting	9	62	71
6m	Carbon steel cutting*	14	150	164

\*More oxygen is used during cutting than during melting

From Norwood et al [23]

TABLE XIII-5

## NITROGEN DIOXIDE CONCENTRATIONS FROM FLAME-CUTTING

Minutes after Completion of Cut	Mean Concentration of Nitrogen Dioxide (ppm)				Amine Adduct- Cured Primer
	Flame Only	Unprimed Plate	Polyamide-Cured Primer		
1	594	86	82	95	
2	518	90	99	97	
3	493	68	78	91	
4	465	78	87	67	
5	437	70	93	91	
6	382	74	79	68	
7	346	62	82	81	
8	333	64	77	67	
9	308	62	77	72	
10	288	68	70	59	
15	196	45	48	60	
20	100	30	32	37	

From Steel and Sanderson [19]

TABLE XIII-6

## CONCENTRATION OF NO, AND CO2 IN SILO

Days after Onset of Filling Silo		1	2	3	4	5	6	7	9	11	13	21	42
No. of Loads of Silage		12	18	22	32	48	64	90	93	93	93	93	93
Sampling sites													
Periphery of tower													
1 ft above surface	NO ppm	0	0.4	0.6	1	2	1	300	5	0.6	0.1		0.2
	NO2 ppm	0	1	2	2	9	1	280	5	0.6	0.1		0.0
	CO2 %v/v	2	4	2	1	2	0.4	41	0.1	0.0	0.0		0.4
5 ft above surface	NO ppm				0.5	2	0.3	150	5	0.4			
	NO2 ppm				1	5	0.6	220	4	0.4			
	CO2 %v/v				0.1	2	0.0	40	0.1	0.0			
6 in. below surface	NO ppm								395	10	0.6	0.6	
	NO2 ppm								200	1	0.2	0.6	
	CO2 %v/v								39	13	11	2	
Center of tower													
1 ft above surface	NO ppm	0	9	240	240	630	560	3					
	NO2 ppm	0	0.1	400	220	1920	360	2					
	CO2 %v/v	19	34	49	49	60	78	0.2					
5 ft above surface	NO ppm	0	3	29	3	30	3	2					
	NO2 ppm	0	0.2	24	4	35	4	2					
	CO2 %v/v	3	23	12	3	25	3	0					
6 ft below surface	NO ppm									4.5		0.2	
	NO2 ppm									0.1		0.0	
	CO2 %v/v									222		8	

Load covered with polyethylene sheet after 6th day, removed before tests on 11th day

From Commins et al [29]

TABLE XIII-7

SUMMARY OF EPIDEMIOLOGIC AND EXPERIMENTAL STUDIES ON  
HUMAN EXPOSURE TO NITROGEN DIOXIDE

Concentration in ppm	Length of Exposure	Type of Exposure	Observed Effects	Remarks	Reference
38-345	Working lifetime	Occupational: Shotfiring operations in coal miners	Forced Expiratory Volume (FEV 0.75) and vital capacity reduced, residual volume and total lung capacity increased relative to controls	Inappropriate control sample. Exposure to high levels of carbon monoxide and carbon dioxide in addition to "nitrous fumes"	Kennedy [28]
62-158	3 separate exposures ranging from 10 min to 2 hrs	Experimental: Continuous inhalation	62 ppm for 1 hour: Laryngeal irritation, but no other effects. 25-100 ppm for 2 hours: Marked mucosal irritation, increased pulse and respiratory rates. 158 ppm for 10 minutes: Coughing, irritation of nasal and laryngeal mucosa, lacrimation, headache, nausea, and vomiting. No delayed or long-term illness	Probable exposure to nitric oxide and airborne nitric acid in addition to nitrogen dioxide	Lehman & Hasegawa [39]
4-20	Acute, duration not stated	Occupational: Open arc welding	Conjunctivitis and pharyngitis which subsided 18 hrs after exposure	Exposure to oxides of nitrogen	Morley & Silk [63]
2.0-10.3	Unknown	Occupational: Arc welding	Slight increase in methemoglobin levels in blood	Exposure to oxides of nitrogen	McCord et al [56]
4-5	10 min	Experimental: Continuous inhalation	Decrease in effective lung compliance with corresponding increase in expiratory and inspiratory maximum viscous response	5 healthy adult male subjects	Abe [67]
0.0-5.0	30 breaths or 15 min	Experimental: Continuous inhalation.	Exposure at 1.5-5.0 ppm increased airway resistance. Significant decrease in arterial oxygen tension, and significant increase of end-expiratory arterial pressure at 4-5 ppm. No effects noted below 1.5 ppm	88 chronic bronchitis patients	Von Nieding et al [68]
0.5-5.0	15-60 min	Experimental: Continuous inhalation	Significant reduction in carbon monoxide diffusing capacity in 16 healthy male subjects exposed for 15 min at 5 ppm. Significant decrease in arterial oxygen partial pressure with corresponding increase in alveoloarterial oxygen pressure gradients in 14 chronic bronchitis patients exposed for 15 min at 5 ppm. Continued exposure to 60 min did not significantly change findings at 15 min. Increased airway resistance in 70 chronic bronchitis patients exposed at and above 1.5 ppm		Von Nieding et al [69]

TABLE XIII-7 (CONTINUED)

SUMMARY OF EPIDEMIOLOGIC AND EXPERIMENTAL STUDIES ON  
HUMAN EXPOSURE TO NITROGEN DIOXIDE

Concentration in ppm	Length of Exposure	Type of Exposure	Observed Effects	Remarks	Reference
0.4-2.7	4-6 years	Occupational: Chemical works	Complaints of sporadic cough, mucopurulent expectoration, and dyspnea on exertion. Normal chest X-ray, spirometry, and blood pH. Carbon dioxide partial pressure and total carbonic acid in blood increased. Significant decrease in serum proteins and significant increase in urinary amino acids and glycoproteins	Conflicting results on the presence of chronic obstructive pulmonary disease. Total lack of environmental data	Kosmider et al [71]
Less than 2.8	Unknown	Occupational: Printing shop and sulfuric acid plant	Dental erosion and gingivitis; emphysema and pulmonary tuberculosis; cardiovascular hypotonia and bradycardia; polycythemia rubra, granulocytosis, basophilia; decreased osmotic fragility of red blood cells, accelerated agglutination of the blood cells; reduced catalase index, reduced alkali reserve, reduced blood sugar	Workers probably exposed to sulfuric acid mists and sulfur dioxide at unknown concentrations	Vigdortschik et al [70]
Low Exposure= 0.106 High Exposure= 0.711	24 hrs/day	Community: Ambient air near TNT plant	Higher incidence of acute respiratory disease in high exposure community compared with low exposure community, particularly in children below age 12. No difference in chronic respiratory disease between communities	Suspended nitrates and total suspended particulates higher in high exposure community compared with other communities. Concentrations of sulfur dioxide and other contaminants not reported	French [74]



TABLE XIII-8

SUMMARY OF CLINICAL AND EPIDEMIOLOGIC STUDIES ON  
HUMAN EXPOSURE TO NITRIC OXIDE

Concentration in ppm	Length of Exposure	Type of Exposure	Observed Effects	Remarks	Reference
#112	3 min	Anesthesia acci- dent	One patient showed signs of cyanosis and methemoglobi- nemia, followed 18 1/2 hours later by death. Autopsy indicated severe pul- monary edema. Second patient showed signs of cyanosis, but recovered fully fol- lowing proper medical treatment.	Accidents due to contamination of nitrous oxide by nitric oxide, the analysis of which was not described.	Clutton-Brock [58]
#3	Working lifetime	Occupational: Nitrogen ferti- lizer production	Exposed workers had higher carboxy - and methemoglobin levels in their blood compared with controls. Ex- posed workers de- veloped pyroxidine deficiency.	Exposure to carbon monoxide, ammonia, and mixed oxides of nitrogen	Nizhegorodov & Markhotskii [57]
2-10	Unknown	Occupational: Arc-welding	Slight increase in methemoglobin levels	Exposure to mixed oxides of nitrogen	McCord et al [56]

TABLE XIII-9

SUMMARY OF EFFECTS OF EXPOSURE TO NITRIC OXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Observed Effects	Reference
5000-20000	Dog	Up to 50 min	Continuous	5000 ppm: Decreased arterial oxygen tension, rise in methemoglobin and arterial carbon dioxide tension. If exposure greater than 24 min, death occurred 7-120 min after exposure. 20000 ppm: Death in 15-50 minutes	Greenbaum et al [81]
2500-5000	White mice	Up to 12 min	"	Animals exposed at 5000 ppm died after 6-8 min. Animals exposed at 2500 ppm died after 12 min of exposure.	Flury and Zernik [86]
310-3500	"	Up to 8 hrs	"	LC50 = 320 ppm All animals survived an 8-hr exposure at 310 ppm. At high concentrations, nitric oxide 4 times more toxic than nitrogen dioxide	Pflesser [47]
175-2100	Mice, guinea pig	Up to 6 hrs	"	Mice exposed at 2100 ppm for 30 min produced 80% methemoglobin. Exposure at 322 ppm for 6 hrs produced 60% methemoglobin. No change in recovery of resting respiratory rhythm in guinea pigs at 175 ppm for 120-150 min	Paribok and Grokholskaya [87]

TABLE XIII-10

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference																
88-1445	Rats	2-240 min	Continuous	Mortality	<table> <tr> <td><u>Time</u></td> <td><u>LC50</u></td> </tr> <tr> <td>2 min</td> <td>1445 ppm</td> </tr> <tr> <td>5 "</td> <td>833 "</td> </tr> <tr> <td>15 "</td> <td>420 "</td> </tr> <tr> <td>30 "</td> <td>174 "</td> </tr> <tr> <td>60 "</td> <td>168 "</td> </tr> <tr> <td>240 "</td> <td>88 "</td> </tr> </table>	<u>Time</u>	<u>LC50</u>	2 min	1445 ppm	5 "	833 "	15 "	420 "	30 "	174 "	60 "	168 "	240 "	88 "	Gray et al [89]		
<u>Time</u>	<u>LC50</u>																					
2 min	1445 ppm																					
5 "	833 "																					
15 "	420 "																					
30 "	174 "																					
60 "	168 "																					
240 "	88 "																					
115-416	Rats, dogs, guinea pigs	5-60 min	"	"	<table> <tr> <td><u>Time</u></td> <td><u>LC50</u></td> </tr> <tr> <td></td> <td><u>Rat</u></td> </tr> <tr> <td>5 min</td> <td>416 ppm</td> </tr> <tr> <td>15 "</td> <td>201 "</td> </tr> <tr> <td>30 "</td> <td>162 "</td> </tr> <tr> <td>60 "</td> <td>115 "</td> </tr> <tr> <td></td> <td><u>Guinea Pig</u></td> </tr> <tr> <td>15 min</td> <td>315 ppm</td> </tr> </table> <p>Threshold of toxicity approximately 25% of LC50 levels for rats. At these levels, dogs showed no gross or microscopic changes, rats showed some pulmonary edema.</p>	<u>Time</u>	<u>LC50</u>		<u>Rat</u>	5 min	416 ppm	15 "	201 "	30 "	162 "	60 "	115 "		<u>Guinea Pig</u>	15 min	315 ppm	Carson et al [90]
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12.5-100	Rats	Until animals died or arbitrary ter- mination of exposure	Continuous 24 hrs/day, 7 days/wk	Microscopic changes in pulmonary system	Exposure at 100 ppm resulted in death within 24 hrs. Rats exposed at 12.5 ppm had moderate hypertrophy and hyperplasia of bronchial and bronchiolar epithelium as well irregular alveolar ducts and alveoli after 40 days of exposure.	Freeman and Haydon [97]																
20-70	Guinea pigs	30 min	Continuous	Antigen sen- sitzation	Exposure at 70 ppm enhanced sensitiza- tion, 40 ppm and less did not.	Matsumura [122]																
50	Hamsters	1-10 wks	Intermit- tent: 21- 23 hrs/day	Microscopic changes in lung tissue	1/3 of animals died within first 3 days. Epithelial hyper- plasia and hypertro- phy of bronchial and alveoli noted in animals killed im- mediately after ex- posure. Regression of inflammatory and epithelial hyper- plastic changes ob- served in animals killed 4 wks after termination of ex- posure.	Kleinerman and Cowdrey [91]																

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
30-50	Guinea pigs	30-45 min	Continuous	Mortality due to inhaled acetylchlorine	Exposure at 50 ppm resulted in significantly higher mortality in animals pretreated with nitrogen dioxide than in controls. No differences in mortality between controls and pretreated groups at lower concentrations of nitrogen dioxide	Matsumura et al [123]
5-50	Rabbits	3 hrs	"	Phagocytic activity	Suppression of virus-induced resistance and phagocytic activity	Acton and Myrvik [121]
10,22,36,45	Rats	Single 4-hr periods	"	Microscopic changes in tracheal and lung tissue	Normal trachea and lungs 4-8 days after exposure	Diggie and Gage [94]
15 and 40	Guinea pigs	Continuous for 10 wks or interrupted for 4 1/2 hrs	15 ppm-cont. 40 ppm-int.: 1/2 hr every 2 hrs for 4 1/2 hrs	Oxygen consumption of tissue homogenates	No increase in lung tissue, but marked increase in liver tissues	Buckley and Balchum [112]
8-40	Rabbits	3 hrs	"	Cellular distribution in lung tissue	Significant increase in intraalveolar heterophiles from exposure at 8 ppm	Gardner et al [110]
40	Mice	6-8 wks	"	Oxygen consumption and LDH activity in lung	Increase in oxygen consumption and LDH activity at sites of nitrogen dioxide lung lesions	Buckley and Loosli [114]
4-30	Mice	14 days at 4-7 ppm, 24 hrs at 30 ppm.	"	Lung capillary permeability and epithelial cell damage	Leakage of tritiated serum into pulmonary lavage fluid	Sherwin and Richters [115]
26	Dogs	191 days	"	Macro- and microscopic changes in pulmonary system	1 dog showed bullous emphysema. Others showed a striking increase in the firmness of the lungs and emphysema, microscopically.	Lewis et al [101]
20-25	Rats, rabbits, guinea pigs	3 wks-18 mon	Intermittent 2 hrs/day, 3-4 days/wk	Macro- and microscopic pulmonary changes	Changes judged equivalent to microbullous emphysema observed in guinea pigs exposed for 15-18 mon. No such changes observed in rats or rabbits.	Kleinerman and Wright [96]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
15-25	Rats, guinea pigs, rabbits	2-hr exposures for 1 or 5 days	Continuous	Macro- and microscopic pulmonary changes	Pulmonary edema noted after one 2-hour exposure. Repair noted 2 wks after ex- posure. Edema and inflammation less severe after multiple 2-hr exposures than to single 2-hr ex- posure. Degree of morphologic change related to exposure concentration	Kleinerman and Wright [95]
25	Mice	4 1/2 mon	Intermit- tent: 30 min/day, 5 days/wk	Microscopic changes of lung tissue due to expo- sure to nitrogen di- oxide alone and to carbon particles with absorbed nitrogen dioxide	Lung lesions such as destruction of alveolar walls was apparent in animals exposed to combined carbon-nitrogen di- oxide. No lesions noted in animals exposed only to nitrogen dioxide	Boren [124]
25	Dogs	6 mon	Continuous	Macro- and microscopic changes in pulmonary system	1 dog showed macro- scopic bullous em- physema. All dogs showed enlargement of alveoli	Riddick et al [100]
2-25	Rats	Natural lifetime except for 1 ex- periment in which rats were sacrificed at daily intervals during the 1st week of exposure at 18 ppm	"	Microscopic changes of pulmonary system and lung weights	Terminal bronchiolar epithelial hyper- trophy was observed to begin on the 5th day of exposure at 18 ppm. Widespread hypertrophy of respiratory epithe- lium indicative of emphysema resulted from continuous exposure at 10- 25 ppm. Exposure at 2 ppm resulted in a reduction of bron- chiolar cilia, in- hibition of normal exfoliation and blebbing of epithelial cells, and appearance of cytoplasmic crystalloid inclu- sions.	Freeman et al [99]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
1-25	Dogs, mice, rabbits, guinea pigs, rats, and hamsters	Up to 18 mon	Intermit- tent: 6 hrs/day, 5 day/wk	Macro- and microscopic changes of the pulmon- ary system	Dogs exposed at 1 ppm for 1 year had moderately dilated alveolar ducts and sacs which contained some edematous fluid and an occasional macrophage. After 18 mon of exposure some thickening of alveolar septa and chronic inflammatory cells were noted. Hamsters exposed at 25 ppm for 3-6 mon showed minor changes in bronchiolar epithelium. No changes noted in rabbits and mice exposed for up to 18 mon at 5 and 25 ppm, respectively	Wagner et al [93]
15-17	Rats	48 hrs	Continuous	Macrophage division	Large increase in no. of dividing macrophages, as well as total no. of macrophages.	Evans et al [111]
2 and 17	"	1 hr - 43 days	"	Microscopic changes in lung tissue	Increased lung weight and severe injury to bronchiole epithelium in animals exposed at 17 ppm. Animals exposed at 2 ppm showed no in- crease in lung weights compared with controls. Loss of cilia, hypertrophy, and focal hyperplasia noted after 3 days of exposure. Tissue recovery observed in animals killed after 21 days of exposure	Stephens et al [130]
2 and 17	"	Up to 360 days	"	Microscopic changes in bronchioles and terminal alveoli	Increased cell pro- liferation during the first 3-5 days, returning to normal after this time	Evans et al [131]
5-16	Dogs and rabbits	1 hr	"	Microscopic changes of capillary en- dothelium and alveolar epi- thelium	Exposure had greatest effect on capillary endo- thelium. Findings included bleb formation, endo- thelial cell organ- elles in the capil- lary lumens, and appearance of plate- lets and poly- morphonuclear leukocytes in lumens of capillaries adjoining blebs.	Kilburn and Dowell [104]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
3-16	Dogs	1 hr	Continuous	Microscopic changes of endothelial cells	Bleb formation, loss of pinocytic vesicles, and mitochondrial swelling. Exposure at 3 ppm resulted in bleb formation without other changes.	Dowell et al [105]
15 ± 2	Rats	1, 2, & 7 days	"	Ultrastructural changes of lung tissue	Bronchiolar epithelium was less columnar, brush cells increased in number, microvilli became smaller, and number of macrophages increased.	Parkinson and Stephens [107]
15	Guinea pigs	3 mon	"	Quantitative change in alveolar cells	Both an increase in the number of alveolar cells and the number of cells per alveolar space resulted from exposure.	Sherwin et al [108]
5-15	"	1 year	5 ppm: 4 hrs/ day, 5 days/wk 15 ppm: 7 1/2 hrs/ day, 5 days/wk	Antibody titers	Minimal microscopic change of lung tissue. Serum antibodies appeared within 160 hrs, and increased with continued exposure.	Balchum et al [116]
15	Rats	Natural life-time	Continuous	Pulmonary changes	Animals had voluminous dry lungs, microscopic signs of epithelial hypertrophy emphysema, and loss of cilia.	Freeman et al [102]
15	Guinea pigs	26-40 days	23 hrs/day	Enzyme activity in lung	Decrease in aerobic isozyme and increase in anaerobic isozyme in lung tissue.	Buckley and Balchum [113]
1-14.8	Mice	1.9-14.8 ppm for 4 hours and 1, 2.3, 6.6 ppm for 17 hrs	Continuous	Antibacterial activity of animals infected with radiophosphorus labeled Staphylococcus aureus	Decreased bactericidal activity in animals infected then exposed to 7 ppm. Exposure at 2.3 ppm for 17 hrs prior to infection also resulted in reduced bactericidal response.	Goldstein et al [139]
9.3-14.3	Rats	10-24 days	Intermittent: 4 hrs/day, 5 days/wk	Pulmonary changes	Immediately after exposure, rats showed severe rhinitis and tracheitis with less severe pneumonitis. Animals killed 8 wks after exposure showed signs that the inflammatory process had subsided. However, localized areas of emphysema were noted.	Gray et al [92]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
0.5-14	Mice	Ct = 7; continuous at 0.5, 1.5, 3.5 ppm; 7 hrs/day at 3.5 ppm for up to 288 hrs	Continuous and inter- mittent	Mortality due to challenge by Strepto- coccus pyo- genes	Ct was not a con- stant. Lower mor- tality with inter- mittent exposure. Linear regression of % mortality versus exposure time significantly different from zero slope for exposure at 0.5 ppm, not so for exposure at 1.5 ppm	Coffin et al [140]
8-12	Rabbits	3-4 mon	Continuous	Microscopic changes of pulmonary system	Emphysema-like dilations of peri- pheral alveoli were noted.	Haydon et al [98]
0.5-12	Monkeys, dogs, rabbits, guinea pigs, rats	90 days	"	Hematologic changes, weight gain, gross lung pathology	Bronchitis, broncho- pneumonitis, pneu- monia, and foci of multinucleated cells noted in animals ex- posed at 12 ppm. No lung pathology observed in animals exposed at and below 5 ppm	Steadman et al [145]
10	Guinea pigs	6 wks	"	Ultrastruc- tural changes of lung tissue	Thickening of blood- gas barrier by re- placement of ultrathin type 1 cells by cuboidal or columnar type 2 pneumocytes.	Yuen and Sherwin [106]
10	"	7 wks	"	Macrophage congregation	Exposed animals showed an in- crease in macro- phage congregation as well as an in- crease in the number of macrophages/epi- thelial cell.	Sherwin et al [109]
5-10	Squirrel monkeys	5 ppm: 2 mon 10 ppm: 1 mon	"	Susceptibility to infection	Increased suscepti- bility to infection by K. pneumonia and influenza virus	Henry et al [117]
5	Rats, mice, monkeys	90 days	"	Mortality	No significant mor- tality. No remark- able changes in growth or blood chemistry	MacEwen and Geckler [128]
5	Squirrel monkeys	169 days	"	Antibody pro- duction due to intratracheal injections of mouse-adapted influenza virus	Hemagglutination- inhibition anti- body not affected. Serum neutralizing antibody increased initially, but no differences between experimental and control animals by 169th day.	Fenters et al [137]



TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
Mean = 4.5	Rats, mice, monkeys	90 days	Continuous	Hematologic and urinary changes as well as micro- scopic changes of the liver, kidneys, lungs, heart, pan- creas, spleen, adrenals, cortex, medulla, and spinal cord	Mortality was low. Reduced weight gain, but no other sig- nificant pathologic findings	House [127]
4	Rats, mice, guinea pigs	6 mon	Intermit- tent: 4 hrs/ day, 5 days/ week.	Incidence of pulmonary ob- structive di- sease	No significant difference between experimental and control groups	Gray et al [126]
0.8-4	Rats	16 wks	Continuous	Macro- and microscopic changes of lung tissue	No macroscopic signs of chronic obstruc- tive disease. Only minimal microscopic changes	Haydon et al [143]
2.5 and 3.5	Mice	2 hrs	"	Susceptibility to <i>Klebsiella</i> <i>pneumoniae</i>	Increased suscepti- bility at 3.5 ppm, not at 2.5 ppm.	Purvis and Erich [135]
1.5, 2.5, 3.5	"	"	"	Mortality due to challenge by <i>Klebsiella</i> <i>pneumoniae</i>	Significant increase at 3.5 ppm, but not at 2 lower levels.	Erich et al [136]
0.5-3.5	"	2 hrs and 9 mon	Continuous or Intermit- tent (6 hrs/ day, 5 days/ wk)	Mortality re- sulting from exposure to airborne <i>Klebsiella</i> <i>pneumoniae</i>	No effect following 2-hr exposure at 3.5 ppm. Significant increase in mortality in animals exposed continuously for 3 mon or intermit- tently for 1 mon at 0.5 ppm	Ehrlich [155]
2.9 ± 0.71	Rats	9 mon	24 hrs/day, 5 days/wk.	Changes in lung weights and physi- ology	12.7% mean increase in lung weights. 13% mean decrease in lung compliance. Reduction of sur- face-active properties of lung- wash fluid	Arner and Rhodes [134]
2 ± 1	"	Natural lifetime	Continuous	Changes in respiratory function as well as microscopic changes of lung tissue	Persistent tachyp- nea in all animals. No changes in air- flow resistance or dynamic compliance. Microscopic changes including reduced blebbing of cytoplasm into airways, loss of cilia, and appearance of intracytoplasmic crystalloid inclu- sions.	Freeman et al [129]
2	Guinea pigs	1, 2, or 3 wks	"	Ratios of lactate de- hydrogenase- positive wall cells to alveoli	Exposed animals showed changes of LDH activity sug- gesting increases in type 2 pneumo- cytes as compared with controls	Sherwin et al [132]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
0.1-2	Mice	3 1/2-7 mon	Continuous at 0.5 and 2 ppm. Intermittent: 0.5 ppm with 1-hr peaks at 2 ppm, 5 days/wk, or 0.1 ppm with 3-hr peaks of 1 ppm, 5 days/wk	Cellular morphology of lungs, phagocytic activity and oxygen consumption of alveolar macrophages	Cell counts, macrophage viabilities at isolation, and oxygen consumption of macrophages unaffected. In vitro phagocytic activity reduced in animals exposed intermittently at 0.5/2 ppm for 3 1/2 or 7 mon. No such change noted in animals exposed continuously at 2 ppm. Changes in morphology of macrophages noted in animals exposed intermittently at 0.5/2 ppm. No such changes observed in other exposure groups	Aranyi and Port [147]
0.5-2.0	"	Up to 40 wks	Continuous at 2.0 ppm or intermittent (5 days/wk) at 0.5 ppm with 1-hr peaks at 2.0 ppm (0.5/2)	Immune response	No difference between experimental and control animals in HI antibody titers. SN titers significantly depressed in animals exposed at 0.5/2. Significant increase in IgA, IgM, IgG, and IgG2 immunoglobulin levels in animals exposed to nitrogen dioxide, particularly in those animals exposed at 0.5/2 ppm	Erlich et al [158]
1-1.5	"	1 Mon	Continuous	Microscopic changes in trachea and lungs	Desquamative bronchitis observed in animals killed immediately after exposure. Infiltration of lymphocytes seen in lungs of animals killed 1 and 3 months after exposure. No controls	Chen et al [133]
1	Guinea pigs	180 days	8 hrs/day	Macro- and microscopic changes in the lung. Hematologic, urinary, and immunologic changes	Evidence of chronic respiratory disease such as bronchitis bronchopneumonia, extravasation of blood in lungs, and foci of emphysema. Urinary hydroxproline and acid mucopolysaccharides were increased. Decreased serum proteins, immunoglobulins, and weight gain	Kosmider et al [71]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
1.0	Rabbits	1 hr	Continuous	Changes in protein structure of lung tissue	Peak shift in absorbance spectrum in animals killed immediately after exposure. Absorbance spectrum returned to normal in animals killed 24-48 hrs after exposure	Buell et al [151]
1.0	Rats	1-6 days	4 hrs/day	Changes in lung lipid structure	Absorption spectra indicative of dienne conjugation	Thomas et al [153]
1.0	Squirrel monkeys	493 days	Continuous	Microscopic changes in lung tissue and immune responses resulting from challenge with A/PR18/34 virus	No difference between experimental and control animals in hemagglutination-inhibition antibody titers, body temperatures, respiratory function, body weights, hematologic values, and ultrastructural changes. Monkeys exposed to nitrogen dioxide produced serum neutralization antibody within 21 days of exposure as well as signs of chronic pulmonary obstructive disease by the end of exposure.	Fenters et al [157]
0.5-1.0	Rats	1 hr at 1 ppm, 4 hrs at 0.5 ppm	"	Changes in mast cells of lung	Exposure at 1 ppm resulted in loss of cytoplasmic granules, rupture, and reduction in number of mast cells. Exposure at 0.5 ppm for 4 hours resulted in degranulation of mast cells.	Thomas et al [152]
0.2-1.0 in combination with 0.2-2.0 ppm nitric oxide.	Dogs	4 1/2 years	16 hrs/day	Cardiovascular changes	No significant effects	Bloch et al [149]
0.1-1.0 in combination with 0.1-2.0 ppm nitric oxide	"	18 mon	"	Pulmonary function	No change in single-breath carbon monoxide diffusing capacity, dynamic pulmonary compliance, or total pulmonary resistance.	Vaughn et al [148]
0.8	Rats	Natural lifetime	Continuous	Respiratory physiology and microscopic changes of lung tissue	Sustained tachypnea 20% above controls. Minimal morphologic changes. No gross or microscopic signs of obstructive disease	Freeman et al [144]

TABLE XIII-10 (CONTINUED)

SUMMARY OF EFFECTS OF EXPOSURE TO NITROGEN DIOXIDE  
IN EXPERIMENTAL ANIMALS

Concentration in ppm	Species	Duration of Exposure	Type of Exposure	Dependent Variable(s)	Results	Reference
0.5	Mice	3-12 mon	6, 18, 24 hrs/day	Alveolar size	Lung alveoli ex- panded in all mice exposed to nitrogen dioxide as compared with controls	Blair et al [146]
0.5	"	1-12 mon	Continuous or intermit- tent (6 or 18 hrs/day)	Mortality, rate of bac- terial clearance, serum lactic dehydrogenase resulting from exposure to Klebsiella pneumoniae	Reduced rate of clearance. LDH showed shift from anaerobic to aerobic bands. Significant increase in mortality in animals contin- uously exposed for 3 mon or longer, and in animals intermittently ex- posed for 6 mon	Ehrlich and Henry [156]
0.4	Guinea pigs	1 wk	Continuous	Protein level in lung lavage fluid	Animals exposed to nitrogen dioxide showed higher protein levels in lung lavage fluid than controls	Sherwin and Carlson [154]

TABLE XIII-11

INCIDENCE OF PULMONARY TUMORS IN NO<sub>2</sub>  
EXPOSED AND IN CONTROL MICE

Duration of Exposure (MO)	5 ppm NO <sub>2</sub>		Control		% Difference of Tumor Incidence in Exposed versus Control Animals
	<u>No. with Tumors</u> No. Examined	% Tumor Incidence	<u>No. with Tumors</u> No. Examined	% Tumor Incidence	
12	$\frac{7}{10}$	70	$\frac{4}{10}$	40	+30
14	$\frac{7}{15}$	47	$\frac{8}{15}$	53	-6
16	$\frac{15}{24}$	62	$\frac{15}{24}$	62	0

From Wagner et al [93]

TABLE XIII-12

## CORRELATION OF OXIDES OF NITROGEN WITH TORCH SIZE

Size of Tip	Acetylene Consumption (cu ft/hr) (1)	Time After Ignition of Torch (minutes)	Concentration of Nitrogen (as NO <sub>2</sub> ) (ppm)	Average Concentration (ppm)
#4	15.9	1	25	38
		3	50	
		4	40	
#6	31.6	1	65	80
		3	75	
		4	100	
#8	60.0	1	150	210
		2	210	
		3	240	
		4	240	
#10	88.5	1	210	280
		2	270	
		3	320	
		4	320	
#12	175	1	240	352
		4	370	
		5	430	
		7	370	

(1) Rated capacity of tip

From Adley [11]

TABLE XIII-13

## OXIDES OF NITROGEN IN LARGE, VENTILATED COMPARTMENTS

Volume of Compartment  (cu ft)	Remarks	Number of Samples	Oxides of Nitrogen (Expressed as NO <sub>2</sub> )	
			Average Concen- tration (ppm)	Maximum Concen- tration (ppm)
7200	Operator shrinking intermittently. Fair natural ventilation.	5	48	89
8700	Operator working on deck plates adjacent to fresh air supply hose.	5	19	32
8700	Operator shrinking in compartment having one fresh air supply hose about 20 feet away.	3	34	38
9000	Operator shrinking near outside hatch. Good natural ventilation.	3	4	4
10000	Two operators shrinking. Two fresh air supply hoses introducing a total of about 1,000 cfm.	12	17	27

Note: #10 torch tips being used during all sampling.

From Adley [11]

TABLE XIII-14

## NITROGEN OXIDES EXPOSURES FROM WELDING OPERATIONS IN SEVEN SHIPYARDS

Location		Total Number Samples	Nitrogen Oxides (ppm)					Mean over	
Major	Minor		0-4	5-9	10-14	15-19	20-24		
Hull	Inner bottoms	172	98	51	18	1	1	3	5.2
	Fore- and after- peaks and small tanks	166	90	43	22	7	3	1	5.8
	Cargo holds, superstructure and other large spaces	661	364	180	68	22	13	14	5.9
	Top deck and outside shell	104	58	23	10	6	1	6	7.3
Sub- assembly	Inner bottoms	48	22	11	5	4	1	5	8.9
	Fore- and after- peaks	136	87	34	11	2	1	1	4.6
	Superstructure	69	34	24	4	7	0	0	5.8
	Open, flat sheets	257	170	59	13	10	3	2	4.7
Shop	Fabrication	295	176	67	39	9	3	1	5.2
	Pipe	111	56	30	11	3	6	5	7.4

From Dreessen et al [13]



FIGURE XIII - 1, NITROGEN DIOXIDE/NITRIC OXIDE SAMPLING TUBE

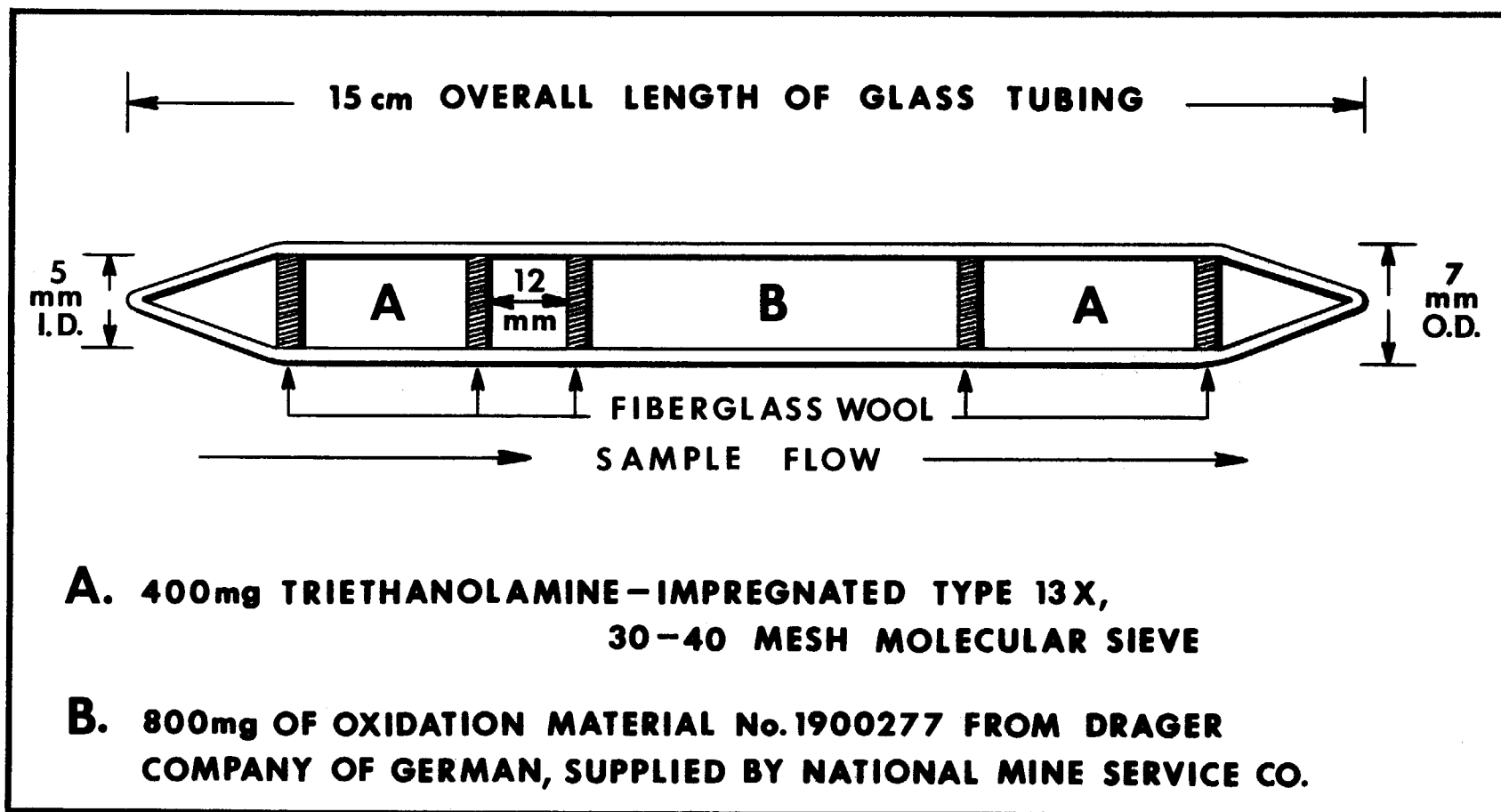
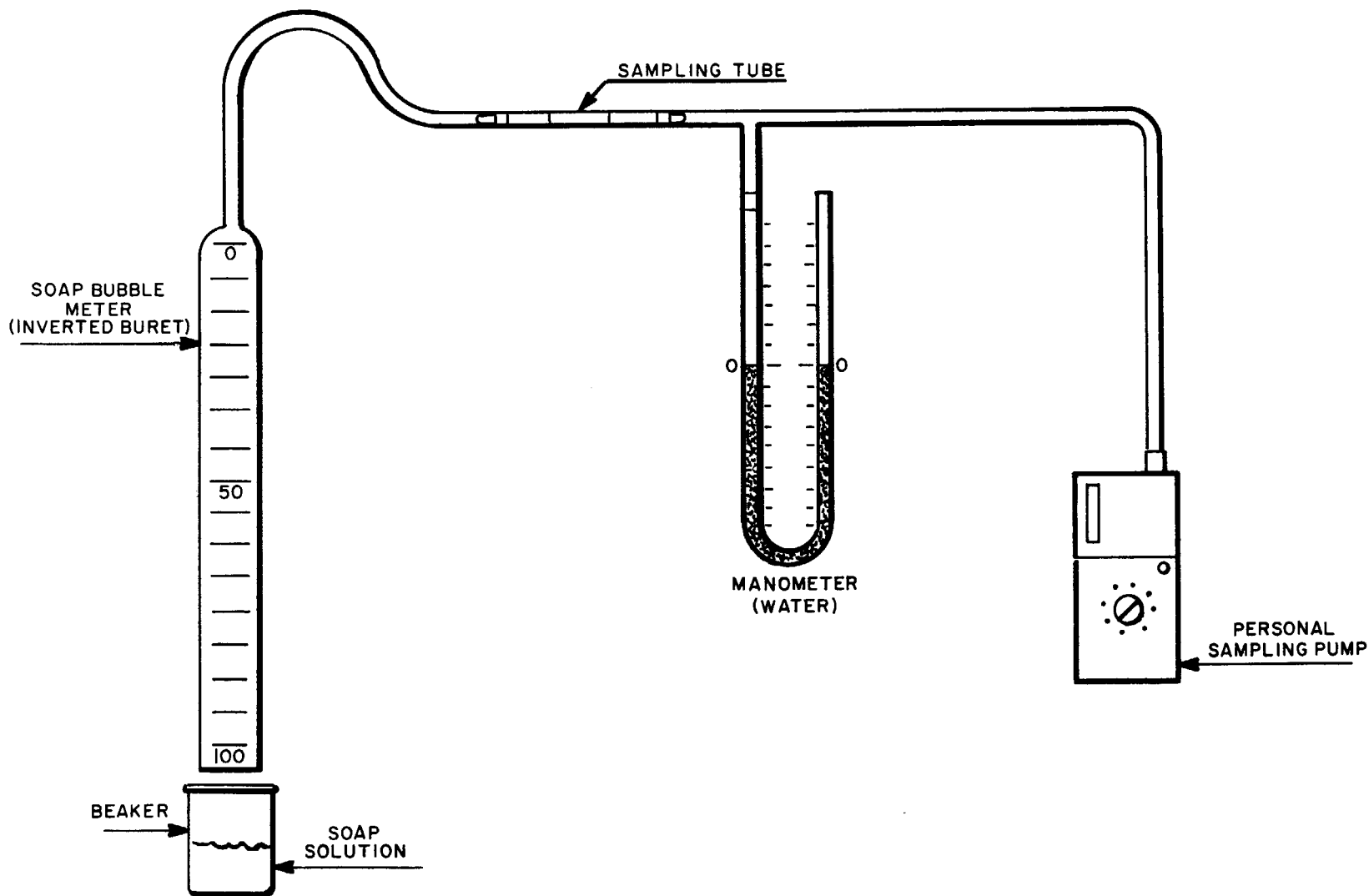


FIGURE XIII - 2. CALIBRATION SCHEME FOR PERSONAL SAMPLING PUMP AND SAMPLING TUBE



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