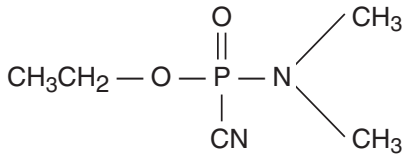
Appendix B

DATA ON NERVE AGENTS

The following tables present detailed information on the chemical and physical properties, as well as additional exposure-effect relations and symptoms from occupational exposures. Much of the latter information is derived from Holmes (1959).

Table B.1

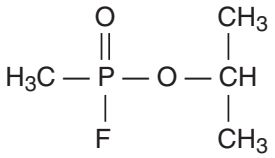
Chemical and Physical Properties of Tabun

Agent	Tabun GA ethyl N,N-dimethylphosphoroamidocyanidate
Chemical structure	
Molecular weight	162.13
Physical state (20°C)	Colorless to brownish liquid giving off a colorless vapor
Vapor density (compared to air)	5.63
Liquid density (g/cc)	1.073 at 25°C
Boiling point (°C, 760 mm Hg)	220–246, with decomposition
Melting point (°C)	–14 to –50
Vapor pressure (mm Hg)	0.07 at 25°C
Volatility (mg/m^3)	400 to 600 at 20°C 610 at 25°C (1/20th of that of water) 858 at 30°C, 90 at O°C
Viscosity (cp at 20°C)	Not found
Surface tension (dynes/cm at 20°C)	Not found
Solubility	Miscible in both polar and nonpolar solvents; 9.8 percent in water at 25°; very soluble in alcohols and other organic solvents
Decomposition temperature (°C)	150 (complete in 3-1/4 hours)
Odor	Almond to faintly fruity; none when pure
Thickening	Possible, but unlikely; has low volatility in any case

SOURCES: U.S. Army (1990); SIPRI (1973); Karakchiev (1973); OSRD (1946); AD Little (1986), Ch. 5.

Table B.2

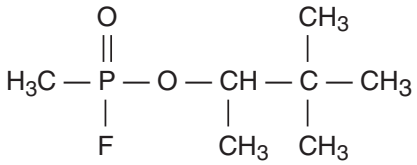
Chemical and Physical Properties of Sarin

Agent	Sarin GB Isopropyl methylphosphonofluoridate Trilon 46
Chemical structure	
Molecular weight	140.10
Physical state (20°C)	Colorless liquid giving off a colorless vapor
Vapor density (compared to air)	4.86
Liquid density (g/cc)	1.102 at 20°C
Boiling point (°C, 760 mm Hg)	147–158, with decomposition
Melting point (°C)	–56
Vapor pressure (mm Hg)	2.9 at 25°C, 2.10 at 20°C
Volatility (mg/m^3)	4,100 at 0° 6,091 at 20° 29,800 at 30°
Viscosity (cp at 20°C)	Not found
Surface tension (dynes/cm at 20°C)	Not found
Solubility	Miscible in both polar and nonpolar solvents Infinitely soluble in water at 20°C Readily soluble in fats, lipids, and all other organic solvents
Decomposition temperature (°C)	150 (complete in 2-1/2 hours)
Odor	Weak, fruity; almost none in pure state
Thickening	Possible

SOURCES: U.S. Army (1990); SIPRI (1973); Karakchiev (1973); OSRD (1946); AD Little (1986), Ch. 5.

Table B.3

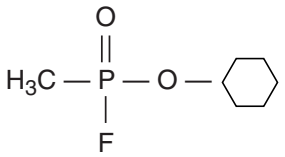
Chemical and Physical Properties of Soman

Agent:	Soman GD 1,2,2-trimethylpropyl methylphosphonofluoridate; Pinacolyl methylphosphonofluoridate Trilon
Chemical structure	
Molecular weight	182.178
Physical states (20°C)	Colorless liquid giving off a colorless vapor
Vapor density (compared to air)	6.33
Liquid density (g/cc)	1.0222 at 25°C
Boiling point (°C, 760 mm Hg)	197.8 (calculated); 167 (with decomposition)
Melting point (°C)	–30 to –80 (depending on source)
Vapor pressure (mm Hg)	0.40 at 25°C
Volatility (mg/m^3)	2,650 at 20°C; 3,900 at 25°; 5,570 at 30°—comparable to engine oil
Viscosity (cp at 20°C)	Not found
Surface tension (dynes/cm)	24.5 at 26.5°C
Solubility	Miscible in both polar and nonpolar solvents—2.1 percent in water at 20°C, 20 percent at 25°C; readily soluble in fats, lipids and organic solvents; soluble in sulfur mustard
Decomposition temperature (°C)	130 (unstabilized, 4 hours; stabilized, 200 hours)
Odor	With impurities, weak odor of camphor, or pinacolyl alcohol, nutmeg, orange peel; none to weakly fruity in pure state

SOURCES: U.S. Army (1990); SIPRI (1973); Karakchiev (1973); AD Little (1986), Ch. 5.

Table B.4

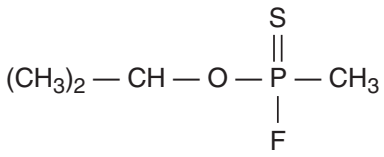
Chemical and Physical Properties of Cyclosarin

Agent	Cyclosarin GF CMPF O-cyclohexylmethylfluorophosphonate
Chemical structure	
Molecular weight	180.2
Physical state (20°C)	Liquid
Vapor density	6.2
Boiling point (°C)	239
Melting point (°C)	–30
Vapor pressure (mm Hg)	0.044 at 20°C
Volatility (mg/m^3)	438 at 20°C; 581 at 25°C
Viscosity and surface tension	Not found
Solubility	Insoluble in water 0.37 percent at 20°C
Rate of hydrolysis	Very stable, only hydrolyzes when heated or with alkalis
Odor—variable reports	65 percent of subjects detected at 14.8 mg/m^3, but descriptions varied (Marrs et al., 1996)
Evaporates	20 times slower than water

SOURCES: U.S. Army (1990), Marrs et al. (1996).

Table B.5

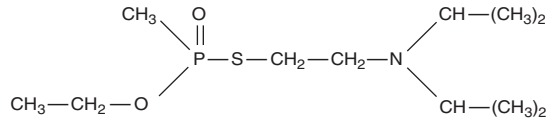
Chemical and Physical Properties of Thiosarin

Agent	Thiosarin
Chemical Structure	

NOTE: The properties can only be speculated upon. It is assumed to be a liquid, with some properties similar to sarin, with hydrolysis of P–F bond expected. Some P=S pesticides require metabolic activation by oxidative enzymes to P=O form for activity. A delayed effect would be expected if this applied to thiosarin. There is reason to doubt this, however, from the slight information available on the analog thiosoman (SIPRI, 1973). This chemical is said to inhibit AChE *in vitro* with a log inhibition constant pI_{50} of 8.9, which is somewhat less potent an inhibitor than soman, whose pI_{50} is 9.2. Since this is an *in vitro* study, there is no ability for metabolic conversion in the usual manner.

Table B.6

Chemical and Physical Properties of VX

Agent	VX V-agents Ethyl-S-diisopropylaminoethylmethylthiosphosphonate;
Chemical structure	
Molecular weight	267.38
Physical state (20°C)	Amber-colored liquid; colorless in pure form
Vapor density (compared to air)	9.2
Liquid density (g/cc)	1.0124 at 20°C
Boiling point (°C, 760 mm Hg)	298.4 (calculated), with decomposition
Melting point (°C)	–39
Vapor pressure (mm Hg)	0.0007 at 20°
Volatility (mg/m^3)	10.5 at 25°C (1/2000 as volatile as sarin)
Viscosity (cp at 20°C)	Not found
Surface tension (dynes/cm at 20°C)	32.011 (extrapolated)
Solubility	Poorly soluble (3 percent) in water at 25°C; very soluble in organic solvents, fats, and lipids
Decomposition temperature (°C)	150 (half-life is 36 hours); 700 to 800
Odor	None in the pure state; with impurities, reminiscent of rotten fish, mercaptanlike

SOURCES: U.S. Army (1990); SIPRI (1971); Karakchiev (1973); AD Little (1986), Ch. 5.

Table B.7

Dermal Exposures to Nerve Agent Required for Lethality to Humans

Agent	Vapor (CT)	Liquid	
	(mg-min/m^3)	µg/person	mg/kg
Tabun	20,000–40,000	1,000–1,500	50–70
	15,000[a]		
Sarin	12,000–15,000	1,000–1,700	25–50
	10,000[a]		
Soman	10,000	600	5–20
	2,500[a]	350[a]	
Cyclosarin	15,000		
	2,500[a]	350	—
VX	600–700	3.4–6.0	0.1–0.2
	150[a]	<5[a]	

SOURCES: SIPRI (1973), U.S. Army (1990), OSRD (1946), Karakchiev (1973), McNamara et al. (1973), Oberst (1959), NAS (1997).

NOTE: Contact with skin normally provokes sweating for a week or two, but persistence for 95 days has been reported (Freeman et al., 1954).

[a]Revised estimate from NAS (1997).

Table B.8

Dermal Exposures to Nerve Agent: Other Effect Thresholds for Humans

Agent	Threshold
Tabun	No effect at or below 2,000 CT, except for slight changes in plasma and AChE levels
Sarin	ICT_{50} at 8,000; incapacitating liquid dose is 20 mg/person or 0.1 mg/kg; no effect at or below 1.6 mg/person
Soman	Incapacitating liquid dose is 3–6 mg/person

SOURCES: Grob (1953), Neitlich (1965), U.S. Army (1990), Krakow and Fuhr (1949), SIPRI (1973).

Table B.9

Exposures to Nerve Agent Vapor Required for Lethality or Incapacitation of Rhesus Monkeys

Agent	LCT_{50}	ICT_{50}
Tabun	135–187	102–110
Sarin	42–74	30–60
Cyclosarin	75–130	62–100

SOURCE: Cresthull (1957).

NOTE: Exposures were 2 min and 10 min.

Table B.10

Animal Performance Effects of Nerve Agent Exposures

Agent	Dose	Animal	Effect
Sarin, soman	1/48 to 1/9 of LD_{50}	Rodents or rats	Anxiety and (sarin only) impairment of coordination and balance
Soman	53 µg/kg	Rodents	Impaired performance on sensitive behavioral tests for 50 percent of rodents
Tabun, sarin, soman, VX	0.5–0.9 LD_{50} (48 hr)	Rats, guinea pigs[a]	Soman and VX are more disruptive of avoidance conditioning than tabun or sarin
Soman	4.5 µg/kg	Baboons	Impaired discriminant responses
Sarin	0.5 LD_{50}	Rhesus monkeys	Little disruption

SOURCES: Gause et al. (1985), Sirkka (1990), Hartgraves and Murphy in Somani (1992), Lattal et al. (1971), Mays (1985).

[a]All four were given to rats, but only sarin and soman were given to guinea pigs.

Table B.11

Signs and Symptoms Comparison, Percentage Reduction in AChE Activity

	Group B Analysis (356 cases)					Group A Analysis (635 cases)					
	0–25	25–40	40–60	>60	Total	0–10	10–25	25–40	40–60	>60	Total
Sign or Symptom											
Miosis	75.5	87.5	88.8	100.0	79.8	75.2	88.9	92.3	97.0	100.0	85.4
Dim or blurred vision	52.5	84.0	80.7	93.7	62.2	44.4	62.0	73.1	69.7	100.0	59.4
Lachrymation	25.0	28.6	27.8	37.5	26.4	29.6	24.2	41.0	48.5	50.0	31.9
Unequal pupils	36.3	53.6	38.9	62.5	40.5						
Photophobia	25.4	41.2	47.3	56.3	31.5						
Eye ache or pain	29.8	48.3	38.9	50.0	34.6	5.9	7.2	11.5	27.3	43.7	10.2
Conjunctivitis	23.8	33.9	52.8	56.3	29.8	8.9	13.1	15.4	33.3	62.5	15.2
Difficulty focusing	22.6	48.3	44.5	75.0	31.2	7.1	13.1	10.3	33.3	43.7	12.9
Cough	63.8	64.4	47.2	87.5	63.3	66.9	61.4	64.1	69.7	50.0	54.3
Distress from smoking	46.0	51.7	38.8	37.5	45.8						
Nausea or anorexia	25.0	34.0	30.6	68.8	29.0	26.0	28.1	30.8	45.4	62.5	30.3
Vomiting	6.5	3.6	2.8	25.0	6.5	5.3	1.3	2.6	21.2	25.2	5.4
Diarrhea	8.9	11.1	2.8	37.5	9.8	3.5	6.5	6.4	6.0	12.5	5.6
Backache	8.9	10.7	16.6	18.7	10.4	4.7	7.8	11.5	6.0	6.2	7.1
Frequency or dysuria	8.1	12.5	11.1	31.1	10.1						
Headache	45.7	57.2	61.0	81.2	50.0	43.2	45.7	61.5	75.7	68.7	50.5
Dizziness	20.6	30.4	27.8	56.3	24.4	11.2	11.8	15.4	30.3	31.3	14.2
Disturbed sleep	27.0	41.2	47.2	75.0	32.4	33.1	27.4	33.3	54.5	75.0	34.4
Dreams	15.7	21.5	16.6	68.7	19.1						
Confusion, grogginess	12.5	21.5	36.2	62.7	18.5						
Impaired memory	8.9	10.7	25.0	31.1	11.8						
Syncope	2.0	1.8	2.8	12.5	2.5						
Rhinorrhea	80.0	84.0	86.0	87.7	81.5	84.0	89.5	85.9	93.9	81.3	87.3

Table B.11—Continued

	Group B Analysis (356 cases)					Group A Analysis (635 cases)					
	0–25	25–40	40–60	>60	Total	0–10	10–25	25–40	40–60	>60	Total
Increased sweating	24.2	32.2	55.7	68.8	30.7	13.0	17.6	29.5	30.3	62.5	20.5
Increased salivation	13.1	12.5	16.7	31.2	14.0						
Impaired taste or smell	14.9	21.5	16.7	31.2	16.8						
Weakness	26.6	26.8	33.3	68.7	29.2						
Fatigability	43.6	42.9	50.0	75.0	45.5	34.3	31.4	32.0	33.3	31.3	32.8
Pallor	2.8	7.2	11.1	43.7	6.2						
Cold or hot extremities	11.3	12.5	35.5	56.3	15.4						
Paresthesia, numbness, or hypesthesia	9.7	17.9	25.0	37.5	13.7	5.9	6.5	11.5	21.2	25.0	9.0
Twitch or fasciculation	11.3	14.3	16.7	50.0	14.0	3.5	3.3	6.4	3.0	25.0	4.7
Sore joints or muscles	10.1	8.9	8.3	18.7	10.1						
Common cold before exposure	24.2	25.1	39.0	12.5	25.2						
Common cold after exposure	27.4	26.8	36.2	0	27.0						
History of hay fever, asthma, or allergy	14.5	8.9	22.2	6.3	14.0						
Duration of signs and symptoms											
1 day	14.5	7.1	8.3	0	12.0	17.9	17.9	9.5	3.1	0	15.9
2 days	19.7	7.1	2.8	0	15.2						
3 days	20.6	12.5	13.8	6.3	18.0	37.7	37.7	33.4	9.4	12.5	35.1
4–7 days	24.5	41.0	36.2	25.0	28.4	15.3	15.3	20.7	18.7	12.5	15.9
7–14 days	3.2	8.9	13.8	12.5	5.6	0.2	0.2	14.3	6.3	25.0	2.5
2 weeks or more	4.4	17.9	25.0	56.3	10.9	0	0	11.1	3.1	31.2	2.0

SOURCE: Holmes (1959).

NOTES: This table compares signs and symptoms in Groups A and B; When group B was started, many additional signs and symptoms were included. These are all mild occupational exposures to sarin. Groups A and B were studied at different times using somewhat different recording methods. This is the largest compendium of clinical data on sarin exposures of humans found. Note that the prevalence of findings increases at greater levels of cholinesterase inhibition, but there are many findings at the lowest levels. Note the cases of sore joints and muscles. At the bottom of the table is information about duration of symptoms and relationship to degree of cholinesterase inhibition. Although more inhibition relates to longer duration, some low-inhibition cases were prolonged.