North Carolina Department of Environmental Quality

Division of Air Quality

Risk Analysis and Acceptable Ambient Level Recommendation for Methyl Bromide

April 12, 2019

Presented to the Secretaries' Science Advisory Board

[blank page]

Risk Analysis and Acceptable Ambient Level (AAL) Recommendation for Methyl Bromide
North Carolina Department of Environmental Quality (DEQ)
Division of Air Quality (DAQ)
April 12, 2019

DAQ's Charge to the Secretaries' Science Advisory Board for Methyl Bromide

Methyl bromide is a Clean Air Act federally listed Hazardous Air Pollutant (HAP) used in North Carolina as a pesticide to fumigate whole logs. The log export market primarily requires either methyl bromide fumigation or debarking. Recently there has been an increase in the number of permit applications and inquiries from entities interested in using methyl bromide for log fumigation. The fumigation process is done in sealed containers generally with a treatment period of 60 to 72 hours, followed by degassing the container to the atmosphere. None of the current log fumigation operations in North Carolina capture the fumigant. All existing facilities are limited via their air quality permit to using ten tons per year of methyl bromide, but some may use all 10 tons in a matter of a few months if demand and logistics allow. Additionally, DAQ has received recent permit applications requesting up to 140 tons per year of emissions. Some of the facilities are within a few hundred feet of residential communities. Although listed as a HAP, there is no specific federal air quality standard or air quality regulation to protect the general public from log fumigation related methyl bromide releases. Similarly, since methyl bromide is not listed as a North Carolina Toxic Air Pollutant (TAP), there are no state air quality regulations.

The respiratory tract and the nervous system are the most sensitive targets to methyl bromide inhalation exposures, and adverse effects may not be evident until several hours after exposure. Chronic exposures to low concentrations in humans are associated with headache, nausea, weakness and neurological effects including muscle ache, fatigue and dizziness. Similar effects have been observed in chronic inhalation exposures to laboratory animals. Effects of acute inhalation to higher concentrations reported in humans include olfactory and respiratory tissue irritation and damage, lung edema, muscle tremors, seizures, neurotoxicity, kidney and liver damage and death (IRIS 1992, PPRTV 2007, ATSDR 1992, ATSDR 1995, ATSDR 2018a, ATSDR 2018b)

The DEQ Division of Air Quality has identified that the general public adjacent to log fumigation operations may experience both acute methyl bromide exposures (exposures of 24 hours or less), as well as longer-term chronic exposures. The DAQ has identified the United States Environmental Protection Agency (EPA) Integrated Risk Information System (IRIS) program chronic inhalation reference concentration (RfC) as the appropriate value to serve as the basis for developing an Acceptable Ambient Level (AAL) to protect the health of all persons that may live or work in areas subject to airborne releases of methyl bromide from log fumigation operations. DAQ is proposing a 24-hour averaging time for the methyl bromide AAL to reflect potential chronic systemic (non-cancer) effects associated with the chronic RfC endpoint and the state's regulations at 15A NCAC 02D .1104 which apply a 24-hour timeframe for all TAP non-carcinogen chronic toxicants. Other characteristics of methyl bromide exposures of relevance to the application of a 24-hour averaging time to protect the general public from fumigation operation releases includes the rapid adsorption and distribution to sensitive target organs following inhalation exposures, the steep inhalation exposure-effect curve, the potential for large segments of the human population to have increased sensitivity to neurotoxic effects that was not captured by animal studies used to develop the RfC, and the potential for delayed onset of adverse effects following exposures.

Introduction

Methyl bromide (also known as bromomethane or monobromomethane) is a fumigant that has historically been widely used to control pests in soil, fresh and dry agricultural products, and exports including logs. Due to restrictions, it is now limited to quarantine and pre-shipment uses and minimal critical use exemptions as approved through EPA rulemaking and by parties to the Montreal Protocol[1]. The acute and chronic health effects associated with methyl bromide inhalation exposure have been well documented (IRIS 1992, PPRTV 2007, ATSDR 1992, ATSDR 1995, ATSDR 2018a, ATSDR 2018b). Inhalation of low levels of methyl bromide causes headaches, weakness, nausea and neurological effects. Breathing higher concentrations or over longer periods may cause olfactory and respiratory tissue irritation and damage, lung edema, muscle tremors, kidney and liver damage, seizures, neurotoxicity and potentially mortality. Neurological and respiratory effects are of greatest concern.

AALs have been established for 97 TAPs in North Carolina. Those AALs are used exclusively in the air quality permitting process to address potential exposures that may lead to adverse effects as a result of stationary source emissions. Those sources must not emit concentrations of the TAPs that exceed the AAL at or beyond the source property boundary. An air quality dispersion model (AERMOD) is used to confirm adherence to the AALs at and beyond the property boundary. A permit may be conditioned to limit emission rates such that the modeling of the emission rate shows compliance with the AAL. Monitoring of specific process parameters is conducted relative to the unique process being permitted in order to ensure compliance with the emission rates used in the compliant modeling. Measured ambient air concentrations of TAPs are not comparable to the AALs since TAPs in the ambient air are the result of contributions from many different types of sources. AALs are relevant only for assessing stationary source emissions in the permitting process. For more information about AALs, please visit: https://files.nc.gov/ncdeq/Air%20Quality/toxics/risk/sab/aaldisc.pdf.

The origins of the State Toxics program date back to work done by the Air Toxics Panel of the North Carolina Academy of Sciences in 1986. While the specifics of risk assessment science have evolved and advanced since that time, the general approach of categorizing a toxic air pollutant among four categories of toxicity remains a practice today. Those four categories of toxicity are: acute irritants, acute systemic toxicants, chronic toxicants, and carcinogens.

To reduce potential harmful exposures to residents and bystanders near adjacent log fumigation operations, the DAQ is proposing 5 $\mu g/m^3$ methyl bromide (0.005 mg/m^3 or 1 ppbv)[2] in air as the 24-hour N.C. AAL. The proposed AAL is set at the chronic reference concentration (RfC) established by the U.S. EPA IRIS program. Persons living adjacent to log fumigation operations may be exposed to fumigants released to the ambient air in pulsed or nearly continuous exposures for short durations on a

[1] Information available at: *https://www.state.gov/e/oes/eqt/chemicalpollution/83007.htm*

[2] Air concentration units as $\mu g/m^3$ = micrograms per cubic meter; mg/m^3 = milligrams per cubic meter; ppbv = parts-per-billion by volume

daily basis; however, over time these exposures may be of a frequency and duration that reflect the EPA chronic exposure definition.

The DAQ identifies the IRIS chronic RfC as the most appropriate and scientifically valid human health value to provide protection for the long-term health of persons in North Carolina, including sensitive subpopulations that may live adjacent to a log fumigation facility that repeatedly releases methyl bromide to the ambient air during operations. Sensitive subpopulations to methyl bromide exposures include infants, children, the elderly and those persons with pre-existing health conditions that may pre-dispose them to the adverse health effects associated with the inhalation of methyl bromide. This document addresses only human health concerns associated with the potential exposure to methyl bromide in the ambient air and does not address concerns associated with the potential for ecological receptors.

Physical and Chemical Properties of Methyl Bromide

Chemical name: Methyl bromide (MeBr), Bromomethane, Monobromomethane
CAS Registry Number: 74-83-9
Molecular formula: CH_3Br
Molecular weight: 94.94 g/mole
Boling Point: 3.5 °C
Water solubility: 15,200 mg/L
Solubility in other solvents: Soluble in alcohol, chloroform, ether, carbon disulfide, carbon tetrachloride, benzene
Vapor pressure: 1620 mm Hg (20 °C)
Octanol/Water partition coefficient: 1.19 log K_{ow}
Conversion factor: 1 ppbv = 3.9 µg/m^3
1 µg/m^3 = 0.26 ppbv

Under normal environmental temperatures and pressures, methyl bromide is a colorless odorless gas. Methyl bromide in air breaks down slowly; the degradation half-life of methyl bromide is estimated at approximately 11 months in air and 1-month in groundwater (ATSDR 1992).

USEPA IRIS Program Review of Human Health Effects Associated with the Inhalation of Methyl Bromide

Derivation of the IRIS Chronic Reference Concentration for Methyl Bromide

The EPA IRIS[3] program (IRIS 2018) characterizes the health hazards of chemicals found in the environment. IRIS assessments are the preferred source of toxicity information used by the EPA and are an important source of toxicity information used by state and local health agencies, other federal agencies, and international health organizations. The EPA IRIS health values undergo extensive internal EPA and external technical and public peer review. IRIS health values are developed following a comprehensive review of all validated human and animal studies and are calculated using the most

[3] Accessible at: *https://www.epa.gov/iris*

current human health risk assessment methods. The N.C. Department of Environmental Quality references the IRIS program as its initial source of health-based toxicity values for human health risk assessment.

The IRIS program set a human population chronic inhalation reference concentration (RfC) for methyl bromide in their 1992 (IRIS) assessment (Appendix A) based on laboratory animal inhalation exposure studies. The EPA defines a human chronic exposure as a repeated exposure by the oral, dermal, or inhalation route for more than approximately 10% of the life span in humans (IRIS 2011). IRIS chronic reference concentrations are set at exposure levels to protect the most sensitive subpopulations from daily exposures that may result in an adverse health effects. Sensitive subpopulations may include infants, children, the elderly, or persons with pre-existing conditions that may result in increased susceptibility to inhalation hazards.

The EPA defines a chronic reference concentration (RfC) as "*an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime*" (IRIS 1992). The IRIS program methyl bromide chronic inhalation RfC is 5 µg/m^3 (0.005 mg/m^3 or 1 ppbv).

The non-cancer ("systemic") critical effect that is the basis of the IRIS methyl bromide chronic RfC is degenerative and proliferative lesions of the olfactory epithelium in the nasal cavity observed in a 29-month rat study performed by the National Institute of Public Health and Environmental Hygiene of the Netherlands (Reuzel et al., 1987, 1991). The chronic RfC was calculated from the rat study inhalation concentration that exhibited statistically-significant adverse effects to the study animals at the lowest-observed adverse effect level (LOAEL). Adverse effects were observed at all exposure concentrations, therefore a no-observed adverse effect level (NOAEL) was not available in this study. When available, a NOAEL is preferred to a LOAEL as the basis for calculation of IRIS RfCs. The IRIS principal study parameters are provided in Table 1. Additional adverse health effects observed in the IRIS principal rat study are listed in Table 2.

To better define inhalation concentrations that are expected to not pose adverse health hazards to humans, the IRIS reviewers adjusted the 6-hour/day and 5-day/week animal study LOAEL to a 24-hour/day and 7-day/week LOAEL concentration, followed by extrapolation of the rodent LOAEL ($LOAEL_{rat}$) to a human-equivalent concentration (HEC) LOAEL ($LOAEL_{HEC}$). In translating animal toxicity studies to health values protective of humans, humans are assumed to be more sensitive than animals. It is recognized that there is always a degree of scientific uncertainty in risk assessment. To acknowledge this, risk assessment errs on the side of health protection. To set a margin-of-safety intended to be protective of sensitive human subpopulations the adverse health effect concentration identified in the animal study was translated to a human exposure concentration (the RfC) after application of uncertainty factors. The IRIS methyl bromide RfC derivation includes an uncertainty factors (UF) of 3 for use of a LOAEL (UF_L) for "mild effects" and an UF of 3 for intraspecies extrapolation (UF_A) because dosimetric adjustments had been applied (the RGDR-based model), and an UF of 10 for intraspecies (UF_H, human population) variability. IRIS notes the factors of 3 represent operational application of a geometric half of the standard factor of 10, rounded to a single significant figure. As a result, multiplication of two factors of 3 results in a composite factor of 10, resulting in a composite UF = 100 for the methyl bromide chronic RfC. The RfC calculation, including the HEC adjustment and the applied

UFs, followed standard IRIS and EPA protocols. The IRIS assessment (1992) notes "high" confidence in the chronic RfC.

$$5\ \mu g/m^3 \text{ Human Chronic Inhalation RfC} = 480\ \mu g/m^3\ LOAEL_{HEC} / (\sqrt{10}\ UF_L \times \sqrt{10}\ UF_A \times 10\ UF_H)$$

Studies Evaluating Effects Associated with the Inhalation of Methyl Bromide

Human Health Effects Reported for Methyl Bromide Inhalation Exposures

There are limited studies evaluating long-term methyl bromide inhalation exposures to humans. Most reports are of accidental or intentional acute exposures, or occupational exposures involving a healthy worker population. Studies evaluating occupational exposures suffer from a number of limitations and uncertainties. Occupational studies relate effects observed in a healthy adult working population and may not be representative of the effects and effect-levels that would be observed for the general population that includes potentially-sensitive subpopulations. It is also difficult to define the exposure concentrations and eliminate confounding exposures in occupational studies. ATSDR (1992) suggested that while there were no studies at the time to evaluate the increased susceptibility of human subpopulations to adverse effects associated with the inhalation of methyl bromide, it would be expected that the young, the elderly, and people with lung, kidney, or neurological disease might be more readily affected than healthy adults. ATSDR also noted that animal studies indicate species differences in sensitivity and for some species gender-related sensitivity differences.

Methyl bromide is acutely toxic to humans (ATSDR 1992). IRIS (1992) identifies the most common signs of acute methyl bromide exposures in humans are neurotoxic in nature and include headache, dizziness, fainting, apathy, weakness, tiredness, giddiness, delirium, stupor, psychosis, loss of memory, mental confusion, speech impairment, visual effects, limb numbness, tremors, muscle twitching, paralysis, ataxia[4], seizures, convulsions, and unconscious.

Reports of neurological effects from occupational inhalation exposures reported in IRIS (1992) include the Anger et al. (1986) study that evaluated a fumigator population using both methyl bromide and sulfuryl fluoride. The study included workers exposed for at least 1 year and that had fumigated a field within the last 50 days. Indications of mild neurological effects associated with methyl bromide in the fumigant-exposed group were reported. Workers in the exposed group did not perform as well as the control group (control group = no exposure within the last 50 days) on behavioral tests including tests of cognitive function, reflexes, and sensory and visual effects. Another study (Herzstein and Cullen, 1990) reported in IRIS (1992) noted delayed on-set of some effects after four unprotected nursery workers were exposed to 98% methyl bromide and 2% chloropicrin following removal of polyethylene sheets covering fumigated soil. The following day all noted fatigue and lightheadedness. Three of the four workers reported severe coughing, chest tightness, nausea, vomiting, headaches, and tremulousness[5]

[4] Ataxia is the loss of muscle control or coordination of voluntary movements, potentially affecting speech, eye movement and swallowing. Source: https://www.mayoclinic.org/

[5] Tremulousness is characterized by trembling or tremors. Source: *https://www.merriam-webster.com/dictionary/tremulous*

during the night, along with ataxia and tremor. At 3-weeks post exposure two of the workers continued to experience reduced manual dexterity and paresthesia[6].

Studies Indicating Increased Neurotoxic Susceptibility in Segments of the Human Population

The EPA Superfund Program's 2007 *Provisional Peer Reviewed Toxicity Values for Bromomethane* (PPRTV 2007) includes an updated literature review (1989 through July 2001) relative to the IRIS (1992) methyl bromide assessment. The PPRTV review summarizes studies that identify a potentially sensitive human subpopulation (Schröder et al., 1992; Garnier et al., 1996). The human subpopulation sensitivity was associated with the Phase II glutathione (GSH) metabolism system and a human-specific glutathione-S-transferase (GST) methyl bromide conjugating isoenzyme. The human-specific GST conjugation generates methyl bromide metabolites reported to have more severe neurotoxic effects than the parent compound. These studies report this specific GST conjugating enzyme may be inactive in some human subpopulations, while other subpopulations will have lower or higher levels of the enzyme. The human-specific GST enzyme that generates methyl bromide conjugates with increased neurotoxicity was identified as Theta GST (*GSTT1*) by Pemble et al. (1994). This particular *GSSTT1* enzyme variant is not present in rodents and is estimated to be present in approximately 60-70% of the human population (Pemble et al., 1994).

An investigation of two accidently exposed fumigation workers (Garnier et al., 1996) reported a delayed onset of more severe neurotoxic symptoms in a worker identified with normal GST conjugating enzyme activity, while the enzyme was not detectable in the worker with the less severe effects. Both workers experienced nausea, vomiting, headaches, and dizziness at the time of the exposure. Two hours post exposure one of the workers that was later identified as having normal GST conjugating enzyme activity, experienced severe myoclonic seizures[7] and later developed "very severe poisoning". The other worker was reported to have developed only "mild neurotoxic symptoms". No detectable GST conjugating enzyme activity was identified in the worker with the mild symptoms. The authors suggested the severity of neurotoxic effects associated with exposure to methyl bromide was related to the level of the GST conjugating enzyme.

Another study summarized in the PPRTV (2007) assessment noted "marked differences in the severity of reaction" of nine greenhouse workers accidentally exposed to similar levels of methyl bromide (>200 ppm) over 6 hours (Hustinx et al., 1993). The authors reported that seven of the workers were discharged after overnight observation and had few residual symptoms while the other two required intensive care for several weeks due to severe muscle contractions and convulsions. The wide variation in effects observed in persons exposed in this incident may reflect variation associated with the GST conjugating enzyme.

These human-specific Phase II GSH enzyme based metabolism differences, which appear to be prevalent normal population genetic variations, support the hypothesis that large segments of the human population have enhanced susceptibility to methyl bromide induced neurotoxic effects that would not

[6] Paresthesia is defined as a sensation of pricking, tingling, or creeping on the skin usually associated with injury or irritation of a sensory nerve or nerve root. Source: *https://www.merriam-webster.com/dictionary/paresthesia*

[7] A myoclonic seizure is a seizure characterized by jerking (myoclonic) movements of a muscle or muscle group, without loss of consciousness. Source: *https://www.medicinenet.com/script/main/art.asp?articlekey=32955*

be captured in rodent toxicity assays. Human-health toxicity values developed from rodent toxicity studies and applying the default EPA uncertainty factors without specific consideration of this genetic variability would not have captured this risk component. The potential for human subpopulations with enhanced sensitivity to neurological effects associated with methyl bromide inhalation, along with the concern for the exposure to infants and children, support a 24-hour averaging time and the application of the IRIS chronic RfC as the basis of the proposed North Carolina AAL.

Adverse Effects Identified in Animal Inhalation Exposure Studies

Controlled laboratory studies using animal models provide a more comprehensive review of health effects associated with inhalation exposures to methyl bromide. The 1992 IRIS methyl bromide assessment calculated the RfC for the most sensitive adverse health effect observed in the Reuzel et al. (1987, 1991) chronic inhalation rat studies. Other animal chronic exposure inhalation studies summarized in the IRIS assessment include a 1990 National Toxicology Program study (NTP 1992) which exposed mice to 0, 10, 33 and 100 ppm methyl bromide for 6 hours/day, 5 days/week for up to 103 weeks. This study included neurobehavioral assessments and neuropathological examinations at 20-weeks and 6, 15 and 24 months. Target organs of toxicity identified in the study were the brain, bone (sternum), heart and nose, with lesions in these organs occurring more frequently in the males. Concentration-related effects included an increased incidence of neurotoxic effects identified as cerebellar degeneration[8] in the brain of both sexes at the 100 ppm exposures that was statistically significant only in males. Other statistically-significant effects reported for both sexes of the 100 ppm-exposed animals included dysplasia[9] of the sternal bone marrow, myocardial degeneration and chronic cardiomyopathy[10], nasal cavity olfactory epithelial necrosis[11] and metaplasia[12]. A NOAEL of 33 ppm (HEC = 4.4 mg/m^3 for respiratory effects and 23 mg/m^3 for extra-respiratory effects) and a LOAEL of 100 ppm (HEC = 13 mg/m^3 for respiratory effects and 69 mg/m^3 for extra-respiratory effects) were identified by NTP based on toxicity in multiple organs. Significant mortality was also reported in the study at 20 weeks, 47% in the males and 10% in the females.

IRIS (1992) reviewed several animal studies that included short-term repeated exposures to study acute effects to the olfactory epithelium. In Hurtt et al. (1988), male rats were exposed to 0, 90 and 200 ppm methyl bromide for 6 hours/day for 1 to 5 days. After a single 6-hour exposure at 90 and 200 ppm extensive destruction of the olfactory epithelium, characterized by epithelial disruption, fragmentation,

---

[8] Cerebellar degeneration is a process in which neurons (nerve cells) in the cerebellum - the area of the brain that controls coordination and balance - deteriorate and die. Source: *https://www.ninds.nih.gov/Disorders/All-Disorders/Cerebellar-Degeneration-Information-Page*

[9] Dysplasia is abnormal growth or development (as of organs or cells) or an abnormal anatomical structure due to such growth. May develop into cancer. Source: *https://www.merriam-webster.com/dictionary/dysplasia* *and* *https://www.cancer.gov/publications/dictionaries*

[10] Myocardial degeneration is the deterioration of the heart muscle. Chronic cardiomyopathy is diseases of the heart characterized by the heart muscle becoming enlarged, thick, or rigid and the heart becoming weaker over time. In severe cases the muscle may be replaced by scar tissue. Source: *https://www.nhlbi.nih.gov/health-topics/cardiomyopathy*

[11] Necrosis is a form of cell injury which results in the premature death of cells in living tissue as opposed to the spontaneous natural death or wearing out of tissue. Source: *https://www.britannica.com/science/necrosis*

[12] Metaplasia is a change of cells to a form that does not normally occur in the tissue in which it is found. Source: *https://www.cancer.gov/publications/dictionaries/cancer-terms/def/metaplasia*

and exfoliation[13] was observed, with the most severe effects observed in the structural and mature sensory cells. Impaired olfactory function was reported in the 200-ppm exposed animals. Other studies report similar observations of extensive damage to the olfactory epithelium after single exposures in repeated exposure studies of 4 to 6-hours/day over 2 weeks or less (Hastings 1990).

The Hurtt et al. (1988) study also exposed male rats at 0, 90, 175, 250 and 325 ppm methyl bromide for 6 hours/day for 5 days. Partial mortality was reported in the 325 ppm treatment. In the 175 ppm treatment, observations included cellular degeneration of the adrenal gland[14] and the cerebellar cortex[15]. Degeneration of the nasal olfactory sensory cells affecting 50-80% of the olfactory mucosa characterized by complete or partial destruction of the olfactory epithelium was reported at 175 ppm and higher concentration groups. Diarrhea, hemoglobinuria[16], gait disturbances, convulsions and hepatocellular degeneration were observed in the 250 ppm treatment groups. Minor alterations in testicular histology and cerebral cortex degeneration were observed in the 350 ppm exposure group.

IRIS (1992) also summarizes several animal studies evaluating neurological effects associated with methyl bromide exposures. Kato et al. (1986) exposed male rats to 0, 200, 300, or 400 ppm bromomethane for 4 hours/day, 5-days/week for 6 weeks. Neurological dysfunction (ataxia[17] and paralysis) was reported beginning at the 300 ppm exposures and cerebral hemisphere cortex necrosis was reported at 400 ppm. Other effects reported included testicular atrophy and suppression of spermatogenesis at 400 ppm. Focal necrosis and fibrosis[18] of coronary ventricles and muscle were noted at all treatment levels. Neurobehavioral effects to rabbits were observed in studies by Anger et al. (1981), reported as decreased eye reflex and nerve conduction velocity at 65 ppm exposures for 7.5 hours/day, 4 days/week for 4 weeks. Signs of limb paralysis and decreased body weight gain were also reported.

Studies indicate that methyl bromide is rapidly taken up following inhalation exposures and rapidly distributed throughout the body. In animal studies methyl bromide is quickly distributed throughout the body following inhalation exposure, with the highest concentrations observed in the nasal passages, lungs, brain, adrenal gland, kidneys, liver, muscle and adipose tissue (IRIS 1992, ATSDR 2018b).

Some animal studies have indicated slower elimination of methyl bromide from the brain and liver compared to other compartments (ATSDR 201b). Inhalation exposure elimination studies report excretion is mainly by expiration of carbon dioxide or by urinary excretion of nonvolatile metabolites,

---

[13] Epithelial fragmentation and exfoliation is described as an irreversible process in which the two-dimensional epithelial tissue layer tends to break up forming smaller fragments, followed by exfoliation characterized by the complete detachment of single epithelial cells or groups of cells from an epithelial layer. Source: *http://rsif.royalsocietypublishing.org/content/14/128/20170032* and *https://link.springer.com/content/pdf/10.1007%2F978-3-642-27841-9_2056-2.pdf*

[14] The adrenal glands produce hormones that help regulate metabolism, the immune system, blood pressure and stress response. Source: https://www.hopkinsmedicine.org/

[15] The cerebellar cortex is part of the hindbrain that functions in motor commands, balance, coordination of movement and cognitive functions. Source: https://nba.uth.tmc.edu/neuroscience/

[16] Hemoglobinuria is the excretion of hemoglobin in the urine. Source: *https://www.medicinenet.com/script/main/art.asp?articlekey=3693*

[17] Ataxia is the lack of muscle control or coordination of voluntary movements. Source: *https://www.mayoclinic.org/diseases-conditions/ataxia/symptoms-causes/syc-20355652*

[18] Fibrosis is the thickening and scarring of connective tissue, usually due to injury. Source: *https://www.dictionary.com/*

with little excretion of the parent chemical (Bond et al. 1985, Jaskot et al. 1988; Medinsky et al. 1985). Half-lives reported for the parent chemical are 15-30 minutes, and 2-10 hours in most tissues for metabolites (Honma et al. 1985; Jaskot et al. 1988). A significant proportion (25%-35%) of inhaled methyl bromide was reported to remain in the tissues after 24-72 hours and is excreted more slowly, likely a result of turnover of intercellular metabolites or adducts. Honma et al. (1985) reported a half-life of 5 days for bromine from the blood, kidneys and liver in rats exposed to methyl bromide.

The higher accumulation levels and slower elimination rates are associated with target organ sensitivity in the nasal passages and lungs, as well as the liver and the brain. de Souza et al. (1985) reported the relative hydrophobicity of methyl bromide suggests it may cross the blood-brain barrier. There are no studies relating distribution of methyl bromide in humans following inhalation exposure (ATSDR 2018b).

Developmental and Reproduction Studies in Animals

IRIS (1992) summarized effects observed in developmental and reproduction laboratory studies exposing animals during gestational development. Maternal effects reported in rabbits exposed to 0, 20, 40, or 80 ppm treatments for 6 hours/day on gestational days 6-19 included reduced body weight and body weight gain, and signs of central nervous system (CNS) toxicity observed at 80 ppm (Breslin et al., 1990). Deficits in embryonic development of the gall bladder and sternum were reported in the young, along with reduced fetal body weights. A 2-generation reproduction study in rats exposed at 0, 3, 30, or 90 ppm during pre-mating, gestation and lactation reported decreased body weight and body weight gain in the parent animals (F0 generation) and decreased body weight in the second generation (F2) young.

Cancer-Effect Studies

The IRIS (1992) methyl bromide cancer classification is “Classification D; not classifiable as to human carcinogenicity” because of inadequate human and animal data to quantitatively assess the carcinogenicity. The human and animal cancer studies included in IRIS (1992) are summarized below.

- Human occupational exposures – An increased mortality for testicular cancer was reported in a study of >3500 male chemical workers exposed to a mixture of brominated chemicals in which methyl bromide was the only common brominated organic chemical exposure over the 21-year exposure period.
- *In vitro* and *in vivo* mutagenicity studies – Positive mutagenicity reported in –
    - *Salmonella* strains and in modified *Salmonella* strains following vapor phase exposures
    - *Escherichia coli* with and without metabolic activation
    - *Drosophilia* (fruit flies)
    - Mouse lymphoma cells

The PPRTV (2007) review includes summaries of additional studies evaluating the mutagenicity and genotoxic potential of methyl bromide, including a Vogel and Nivard (1994) study that identifies methyl

bromide as a "very reactive methylating agent" that readily methylates biomolecules critical to a wide range of physiological functions, including thiols, thioether sulfurs, nitrogen in amino groups and rings, and oxygen atoms in carboxylate ions and hydroxy groups. PPRTV references a study that involved 4-hour oral and inhalation exposures of male and female rats. The study reported methyl bromide was widely distributed throughout the body of the study animals with clear indications of DNA methylation (Gansewendt et al., 1991). Detection of DNA adducts in the liver and lung were reported, with the highest activity noted in the stomach and forestomach for both the inhalation and oral exposure routes.

In 1992 the National Toxicology Program (NTP) summarized a study by Bolt and Gansewendt (1993) that NTP stated clearly indicated methyl bromide exposure can cause genotoxic and/or mutagenic changes. NTP reported methyl bromide was positive for reverse mutation, with and without S9 activation, in two *Salmonella typhimurium* strains. It was also positive for mutation induction in two *Escherichia coli* strain assays and in the *Klebsiella pneumoniae* fluctuation test. It was negative in three other bacterial strains. Methyl bromide tested positive for mutagenicity in the *Drosophila melanogaster* sex-linked recessive lethal test, in the somatic recombination assay, and induced sister chromatid exchange (SCE) in human lymphocytes *in vitro* and in rats and mice *in vivo*. It tested positive for induction of 6-thioguanine and bromodeoxyuridine resistance in L5178Y mouse lymphoma cells, but negative in an assay in primary rat hepatocytes and for transformation by SA7 adenovirus in Syrian hamster embryo cells.

The EPA (2005) notes carcinogenesis involves a complex series and interplay of events that alter the signals a cell receives from its extracellular environment, promoting uncontrolled growth. The EPA identifies multiple modes of carcinogenic action include mutagenicity, mitogenesis[19], inhibition of cell death, cytotoxicity with reparative cell proliferation, and immune suppression. Evidence that a parent substance or its metabolite is DNA-reactive and/or has the ability to bind to DNA (a DNA adduct) is also evidence supportive of a mutagenic mode-of-action. Different carcinogenesis modes-of-action can operate in different dose ranges, with an agent acting predominantly by a cytotoxic mechanism at high doses and by a mutagenic mechanism at lower doses where cytotoxicity is not induced.

Several new reports of cancer-effect studies were included in ATSDR (2018b). Alavanja et al. (2003) found elevated odds ratios[20] (ORs) for prostate cancer among applicators with the two highest cumulative exposure quintiles in the Agricultural Health Study[21] cohort of male pesticide applicators (OR 2.73, 95% CI 1.18–6.33 and OR 3.47, 95% CI 1.37–8.76, respectively). A later analysis of data in the Agricultural Health Study cohort reported an increased risk of stomach cancer among applicators with high use (RR 3.13; 95% CI 1.25–7.80; RR 3.33, 95% CI 1.30–8.51 with a 15-year lag)[22] compared to those with no use (Barry et al. 2012). Mills and Yang (2003) reported an increased risk of prostate cancer in the highest use group in a nested case-control study when farm workers were categorized by estimated methyl bromide use amounts (OR 1.59; 95% CI 0.77–3.30). Cockburn et al. (2011) reported an increased

---

[19] Mitogenesis is the induction of mitosis. A mitogen is a chemical substance that encourages a cell to commence cell division, triggering mitosis. Source: *https://biology.stackexchange.com/questions/42819/growth-factors-vs-mitogens*

[20] An odds ratio (OR) is a measure of association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. Source: *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2938757/*

[21] The Agricultural Health Study began in 1993 and is a prospective study of cancer and other health outcomes in a cohort of licensed pesticide applicators and their spouses from Iowa and North Carolina. https://aghealth.nih.gov/

[22] The risk ratio (RR) is the ratio of incidence rates in the exposed and unexposed groups. Source: http://sphweb.bumc.bu.edu/otlt/MPH-Modules/EP/EP713_Association/EP713_Association3.html

risk of prostate cancer in a case-control study of exposed residents living near agricultural uses of methyl bromide in California (OR 1.62; 95% CI 1.02–2.59). ATSDR summarizes the epidemiological cancer studies by stating that the occupational studies provide some suggestive associations of an increased cancer risk and methyl bromide exposure, but the studies are not adequate for establishing causality. None of the studies measured exposure concentrations and possible exposure to other pesticides contributed to their conclusion. The lack of positive cancer studies in animals contributes to the lack of weight-of-evidence to adequately support a human cancer association with methyl bromide exposure.

Mechanisms of Methyl Bromide Toxicity

ATSDR (2018b) provides the most current comprehensive review of the mechanisms of methyl bromide toxicity. ATSDR notes that methyl bromide may induce direct cellular cytotoxicity through its lipid and protein binding capacity and has been shown to deplete glutathione in several tissues. Increased glutathione-S-transferase (GST) activity was observed in the lungs of exposed rats.

ATSDR reports that several mechanisms are proposed to explain methyl bromide's neurotoxicity, including the binding to proteins involved in oxidative reactions and energy production. Humans exposed to high levels of bromomethane exhibit MRI abnormalities that are characteristic of energy deprivation syndrome with signal transduction and recovery abnormalities observed in multiple structures in the brain and brain stem. ATSDR notes these abnormalities consist of strikingly symmetric changes in locations that are particularly susceptible to damage from energy deprivation.

ATSDR also reports that several metabolites of methyl bromide, including methanethiol and formaldehyde, are highly reactive compounds capable of inhibiting cellular respiration, and that methyl bromide has been reported to rapidly inhibit creatine kinase in the brain. Creatine kinase maintains cellular energy homeostasis by catalyzing the conversion of creatine and ATP to phosphocreatine and ADP. Methyl bromide is also reported to perturb brain neurotransmitter levels, with reduced norepinephrine and dopamine observed in rat brains post exposure. Inhibition of tyrosine hydroxylase activity has also been observed following exposure, and is postulated as a mechanism of perturbation of the dopaminergic system. The methyl bromide metabolite, *S*-methylcysteine, is structurally analogous to γ-amino butyric acid which has been observed to exert neurotoxic effects on the rat hippocampus.

Glutathione depletion is also indicated as contributing the neurotoxic potential of methyl bromide. Lower glutathione and reduced glutathione-S-transferase activity has been observed in the rat brain following inhalation exposures.

ATSDR Toxicological Profile for Bromomethane - Draft for Public Comment, April 2018

In late June 2018 the ATSDR released their *Toxicological Profile for Bromomethane* (methyl bromide) *Draft for Public Comment*, dated April 2018 (ATSDR 2018b). Following is a summary of information in that draft with relevance to the proposed North Carolina AAL.

ATSDR-Derived Provisional Inhalation Health Values

ATSDR (2018) identifies neurotoxicity as the most sensitive effect of acute exposures to animals. Neurological effects observed in laboratory animals included overt signs of neurotoxicity such as trembling, ataxia, lethargy, paralysis, and hyperactivity; decreases in brain neurotransmitter levels; impaired olfactory function; and histopathological damage in the cerebrum, cerebellum, and olfactory bulb. ATSDR's provisional Minimal Risk Level (MRL) for methyl bromide intermediate-duration inhalation exposures is 0.02 ppm (78 µg/m^3). ATSDR defines an intermediate exposure as 15-364 days, and an MRL is defined an estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects over a specified route and duration of exposure, with exceedances of an MRL indicating the need for further evaluation of the potential exposure conditions of frequency and duration, as well as the characteristics of the receptor population[23].

The intermediate inhalation MRL is based on a 10 ppm LOAEL for neurobehavioral effects from the NTP (1992) study that reported decreased locomotor activity in male mice at the 6-month evaluation period in the 2-year cancer bioassay. The LOAEL was adjusted to a Human Equivalent Concentration (HEC) of 1.8 ppm and divided by a composite uncertainty factor (UF) of 90 (UF 3 for LOAEL to NOAEL extrapolation, UF 3 for animal to human extrapolation with dosimetric adjustment, and UF 10 for human variability).

ATSDR's chronic inhalation exposure provisional MRL for methyl bromide is 0.001 ppm (5 µg/m^3) based on nasal lesions described as "very slight basal cell hyperplasia of the olfactory epithelium" in rats from a 2-year study (Reuzel et al., 1987, 1991). ATSDR's chronic MRL was derived from the same studies as the IRIS chronic RfC (IRIS 1992). The critical study parameters and chronic MRL derivation values are included in Table 1. When presented in the same units and reduced to one significant figure the ATSDR provisional chronic MRL is equal to the IRIS chronic RfC, 5 µg/m^3.

The chronic MRL was derived from a rat LOAEL of 3.1 ppm adjusted to a HEC LOAEL of 0.13 ppm and a composite UF of 90 (UF 3 for LOAEL to NOAEL extrapolation, UF 3 for animal to human extrapolation with dosimetric adjustment, and UF 10 for human variability; the 3 UFs are calculated as the square root of 10). ATSDR defines chronic exposures as 365 days or longer.

Discussion of Neurological Effects

ATSDR (2018) states inhalation exposures to methyl bromide frequently lead to a spectrum of neurological effects in humans, with initial symptoms typically including headache, dizziness, nausea/vomiting, confusion, weakness, numbness, slurred speech, visual disturbances, lack of inhibition, agitation and confusion. ATSDR further notes severe exposures may progress to ataxia, tremor, seizures and coma. ATSDR also confirms that in most acute exposures, there is a lag period of several hours before effects occur, and in some cases effects may not develop for several weeks after the exposure ceases (Herzstein and Cullen 1990).

[23] Minimal Risk Levels (MRLs) – For Professionals. Toxic Substances Portal. Agency for Toxic Substances & Disease Registry (ATSDR). Accessed at: *https://www.atsdr.cdc.gov/mrls/index.asp*

ATSDR (2018) notes neurotoxicity in animal studies characterized as changes to neurotransmitter levels in rat brains after single 8-hour exposures (Honma 1987; Honma et al. 1987). An 8-hour exposure to 31 ppm methyl bromide resulted in significant decreases in norepinephrine levels in the hypothalamus and the 100 ppm exposure resulted in decreases in dopamine and serotonin in the striatum and decreased norepinephrine levels in the striatum, hypothalamus, frontal cortex and midbrain. Continuous exposure at 10 ppm for 3 weeks resulted in decreases in norepinephrine levels in the hypothalamus (Honma et al. 1982). Honma et al. (1985) reported decreased locomotor activity in a rat 8-hour exposure at 188 ppm and decreased motor activity and changes in performance on a suite of neurobehavioral assessment tests (Functional Observational Battery ("FOB") tests) following a 6-hour exposure at 350 ppm. An FOB assessment evaluates neurotoxic effects measured as gross functional deficits in rats. Changes were observed in measurements of activity levels, muscular coordination and muscle strength.

An 8-hour exposure to methyl bromide resulted in decreased locomotor activity at 188 ppm, decreased body temperature at 125 ppm, and increased sleep potency of thiopental at 63 ppm in rats exposed at 350 ppm for 6 hours, a decrease in motor activity and a number of alterations in FOB test performance, including inactivity, decreased rearing, uncoordinated righting response and decreased hind limb grip strength (EPA 1993). Gotoh et al. (1994) reported slight atrophy in the cerebellum in a 2-year study exposing mice at 64 ppm.

ATSDR (2018) also reports more recent studies with observed effects to the olfactory system, including olfactory bulb neuron damage. Death in 90-98% of olfactory bulb neurons were reported by Schwob et al. (1999) and Youngentob and Schwob (2006) following 6-hour exposures at 330 ppm methyl bromide.

Developmental Effects

Developmental effect studies not included in the 1992 ATSDR review included an epidemiological study by Gemmill et al. (2013) which reported an association between residential proximity to methyl bromide application and developmental outcomes. Moderate or high methyl bromide use during the second trimester was associated with decreased birth weight, birth length and head circumference for women living within 3-, 5-, or 8-km radius from the source. Decreased pup weights were also reported in a multi-generation rat study exposed to 30 ppm methyl bromide for 5 days per week for 6 hours per day (Enloe et al., 1986). The NOAEL for the pup weight effect was 3 ppm and the LOAEL was 30 ppm.

Discussion of Public Health versus Occupational Health Values for Methyl Bromide

While occupational exposure limits are available for methyl bromide and similar values have been used historically to develop AALs for the protection of the general public, DAQ considers the IRIS RfC as a more appropriate health-based value for protection of public health. The EPA IRIS RfC has gone through extensive EPA internal technical team review, external-to-the-EPA technical peer review, and public comment. Additionally, as defined above the RfC is intended to be health-protective for the general population, including subpopulations that may have increased sensitivity to development of adverse health effects associated with specific exposures. Occupational exposure limits are intended to be protective of a healthy adult working population which may have different sensitivity to exposures than does the general public. In the context of public health, the "general public" encompasses

subpopulations, such as infants, children, the elderly and persons with pre-existing conditions or a genetic predisposition that may manifest as increased susceptibility to the adverse effects associated with inhalation to methyl bromide and other toxicants. For these reasons, DAQ identifies the EPA IRIS RfC as the most appropriate health-based value protective of inhalation exposures for all persons that may be repeatedly exposed to methyl bromide at locations adjacent to log fumigation operations.

DAQ's Recommendation on a Range of Risk Values and Confidence in the IRIS RfC as the Basis of the AAL

DAQ has high confidence in the application of the IRIS RfC as the basis of the AAL value to protect the general public from adverse effects associated with the inhalation exposures to methyl bromide released from fumigation operations. The EPA's IRIS RfC was developed using current risk science and calculation methods and is further supported by ATSDR's 2018 review (ATSDR 2018b) and derivation of their provisional chronic MRL. The IRIS RfC process identifies the most sensitive effect to be protective of other less sensitive endpoints. The EPA's definition of a chronic RfC is "*an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure for a chronic duration (up to a lifetime) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime* (IRIS 2011). Using the IRIS chronic RfC as the basis of the AAL eliminates the elevated level of uncertainty inherent in extrapolating an occupational exposure guideline to be protective of exposures to all segments of the population ("public health") which encompasses subgroups with potentially enhanced sensitivities relative to a healthy adult occupational population. As discussed above, ATSDR noted an expectation of increased sensitivity to the adverse effects of methyl bromide, relative to healthy adults, of population subgroups that include the young, the elderly, and people with lung, kidney, or neurological disease (ATSDR 1992).

Whether based on human or animal studies, the occupational values are not inclusive of all validated studies in the current database of methyl bromide toxicity studies and do not apply health-value derivation methods appropriate for protection of the general public. An IRIS RfC is developed with a margin-of-safety to be protective over a life-time of exposures to all segments of the population. Occupational values were developed to be protective of a "healthy worker" population over a very reduced exposure duration.

Relevant to the range of risk value consideration is the confidence in the IRIS RfC value. IRIS (1992) notes medium confidence in the study, high confidence in the database and high confidence in the chronic RfC. The medium confidence rating for the database was related to the lack of a NOAEL defined by the critical studies. The current applicability and certainty of IRIS RfC is confirmed by the 2018 ATSDR review and ATSDR's draft chronic MRL which identified the same critical studies, critical effect, POD and final MRL level as the IRIS review. ATSDR's review included a Benchmark Dose modeling (BMD) effort which indicated a 10% effect level point of departure (POD) at a higher exposure concentration (less protective) than that identified with the LOAEL approach. As a result, ATSDR used the LOAEL as the POD, as did IRIS.

DAQ's in-depth review of the critical studies selected by IRIS and ATSDR as the basis of the chronic RfC and MRL, as well as other comprehensive reviews of chronic and other exposure duration values undertaken by other groups, including the Superfund program (PPRTV), the ATSDR, the NRC (AEGLs) and

California (OEHHA), support the IRIS RfC (1992) as the appropriate basis of the AAL at this time. Remaining uncertainty is associated with the unquantified level of enhanced neurotoxic potential associated with the human sub-population-specific GSH enzyme variant that produces bioactivated metabolites. Exposure-response studies using rodent populations, which do not possess this specific GSH enzyme variant, would not indicate the response-level variability associated with this human population genetic variation. In order to account for the increased sensitivity to the applicable human population subgroup that would be impacted by the GSTT1 Phase II metabolites and increased neurotoxic potential, DAQ's recommendation is to apply an additional UF of 3 ($\sqrt{10}$) to the IRIS chronic RfC to represent the lower bound of a range of AAL values for consideration.

0.0048 mg/m^3 RfC = 0.005 mg/m^3 RfC Upper-bound Methyl Bromide AAL
0.0048 mg/m^3 RfC / UF 3 = 0.0016 mg/m^3 = 0.002 mg/m^3 Lower-bound Methyl Bromide AAL

Discussion of Available Acute Effect Levels for Methyl Bromide

The DAQ has confirmed that neither the EPA, the EPA's IRIS program or the ATSDR provide acute health values protective of the general public for methyl bromide inhalation exposures. Acute inhalation values that may exist for occupational exposures are developed for a healthy adult working population and are not developed to be protective of the general population which includes infants, children, the elderly and persons that may have pre-existing health conditions that increase their susceptibility to adverse inhalation exposures associated with specific contaminants (ATSDR 1992).

ATSDR had previously provided an acute inhalation Minimal Risk Level (MRL)[24] for methyl bromide[25] in their 1992 review, but the acute MRL was removed with the release of their 2018 draft methyl bromide review update (ATSDR 2018a). In their 2018 draft review update ATSDR noted they considered the available toxicity database for methyl bromide to be inadequate to develop an acute inhalation POD and an acute-duration inhalation MRL. ATSDR defines an acute exposure duration as that occurring up to 14 days[26]. They reference the NTP 1992 study as having identified the lowest duration-adjusted LOAEL, but suggest there is considerable uncertainty with this value. ATSDR noted the NTP study (1992) reported "*neurological signs including trembling, jumpiness, and paralysis were observed in all groups but were most pronounced in the three highest dose groups (50, 100, 200 ppm)*", but noted NTP did not include incidence data for these effects and it is unclear whether any or all of the effects were observed at the lowest concentration tested. ATSDR does affirm that neurotoxicity is the most sensitive effect observed in animal studies.

[24] A Minimal Risk Level (MRL) is an ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). Source: https://www.atsdr.cdc.gov/glossary.html

[25] The removed ATSDR acute inhalation MRL was 0.05 ppm methyl bromide, based on a neurological endpoint (ATSDR 1992). 0.05 ppm = 190 µg/m^3. This value was not included with the 2018 draft update.

[26] ATSDR acute exposure duration definition source: https://www.atsdr.cdc.gov/glossary.html

In addition to the uncertainty noted above, ATSDR (2018) also notes acute inhalation health values may not be protective when the adverse effects of an exposure may be delayed or result from repeated exposures, such as hypersensitivity reactions, asthma, or chronic bronchitis. This is relevant to the adverse effects associated with the inhalation of methyl bromide which is odorless, colorless and tasteless, and it is well documented that there may be a delay in the development of the negative effects associated with both low-level and acute inhalation exposures (ATSDR 1992, ATSDR 2018a, Garnier et al., 1996, IRIS 1992). The steep dose-response curve noted for methyl bromide inhalation effects also likely contributes to the uncertainty in developing an acute inhalation exposure level protective for the general public (ASTDR 2018). A steep dose-response curve (or exposure-response curve) indicates that the increase in the severity of effects is substantial for relatively small changes in exposure concentration. This characteristic would suggest that to be protective of chronic exposures to the general public, a conservative set of no-effect or low-effect PODs and robust margin-of-safety parameters are appropriate, as are inherent in the IRIS RfC derivation methodology.

In developing their recommendations for the methyl bromide AAL the DAQ applied the most health-protective inhalation exposure level intended to be protective of the general public including sensitive sub-groups, the IRIS chronic RfC, and a 24-hour averaging time. The scientific basis for DAQ's AAL recommendation includes:

- The IRIS chronic RfC[27] is the most health-protective final value intended to be protective of the general public.
- The 24-hour averaging time reflects the application of the chronic RfC as the daily continuous exposure concentration that over a lifetime of exposure is expected to not result in deleterious health effects.
- The 24-hour averaging time reflects the concerns associated with the:
    - rapid uptake and distribution of methyl bromide following inhalation exposures,
    - lack of odor, taste or color to alert persons to a methyl bromide exposure,
    - provides protection for delayed recognition of exposures at harmful concentrations, and
    - concerns associated with segments of the human population to have increased susceptibility to neurotoxic effects due to genetic polymorphisms that do not exist in the critical study test species (rats) and was not captured in the RfC development and the lack of data to quantify this increased human sensitivity
- The 24-hour averaging time reflects recommendations for "chronic systemic toxicants" as referenced in the *NCSAB Risk Assessment Guidelines* (NCSAB 1997) and the state's air toxics regulations at 15A NCAC 02D .1104.

[27] The EPA defines a chronic reference concentration (RfC) as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure for a chronic duration (up to a lifetime) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Source: https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/home.do

Science Advisory Board Deliberations

Expanded Detail on Animal-to-Human Extrapolation Methods Utilized by IRIS and ATSDR

As a follow-up to the initial presentation of the DAQ's methyl bromide AAL recommendations which included the discussion of the critical study that was the basis of the IRIS chronic RfC and the ATSDR draft chronic MRL, the SAB requested more detail on extrapolation of the rodent-to-human POD concentrations used. In response to that request, DAQ expanded the detail provided in the critical study parameters as outlined by both IRIS and ATSDR in their methyl bromide review documents (IRIS 1992, ATSDR 2018a). This expanded information is reflected in Table 1 and the following text that accompanied the revised Table (DAQ 2018b)

Method of Extrapolation of Animal-to-Human Inhalation Exposures in the Derivation of the IRIS Chronic RfC and the ATSDR Chronic MRL

Both the current IRIS chronic inhalation RfC and the ATSDR chronic MRL were developed from the same National Institute of Public Health and Environmental Hygiene of the Netherlands rat studies (Reuzel et al., 1987, 1991) and identified the same critical effect, degenerative effects to the olfactory epithelium. Table 1 provides parameter details of the critical studies and the data analysis and extrapolations intrinsic in the development of the IRIS and ATSDR chronic inhalation health values. The following address the SAB's questions regarding the development of the IRIS and ATSDR chronic health values:

- *Both IRIS (1992) and ATSDR (2018) mathematically converted the rodent exposure scenarios (6-hours per day for 5-days per week) to continuous exposure levels (24-hour per day, 7-days per week)*
- *Both ultimately used a LOAEL for the point of departure (POD). ATSDR initially applied Benchmark Dose (BMD) modeling to the data, but the resulting benchmark response level was greater than the POD using the LOAEL approach.*
- *Both used the Regional Gas Dose Ratio (RGDR) approach to extrapolate animal exposure levels to human-equivalent concentrations (HEC) and both referenced the current U.S. EPA documents describing the RGDR methodology at the time of their reviews.*
- *Differences in the RGDR extrapolation parameters utilized are indicated, likely a result of the modifications resulting from the length of time between the two reviews. The RGDR parameters and references are noted in the Table supplemental information.*
- *Both reviews applied the same uncertainty factors (UFs) to the POD, with ATSDR rounding the* $\sqrt{10}$ *to 3 in their composite UF calculation (ATSDR ∑UF = 90), while IRIS used* $\sqrt{10}\ x\ \sqrt{10} = 10$ in their composite UF calculation *(IRIS ∑UF = 100)*.

Both IRIS and ATSDR rounded the final chronic inhalation value to one significant figure. If carried to two significant figures, the calculated $LOAEL_{HEC}$ *for the two studies are 0.48 mg/m*^{3} *(IRIS) and 0.54 mg/m*^{3} *(ATSDR), with the difference attributable to slight differences in the RGDR values and the composite Uncertainty Factors.*

Discussion of Occupational Health Values

During their October 22, 2018 SAB meeting discussions, the Board requested a discussion of occupational health measures for methyl bromide and occupational exposure guidelines in relation to IRIS exposure guidance levels developed to be protective of the general public. In response, DAQ invited DHHS Division of Public Health (DPH) staff to present a discussion of the state of occupational health values to the Board at the December 4, 2018 meeting. DPH staff Mr. Pierre Lauffer, CSPA, presented the history of occupational health values. Mr. Lauffer discussed the development in the 1970s of the OSHA Permissible Exposure Limit (PEL) tables designed to protect workers during an 8-hour workday and a 40-hour work week, and the plan that these tables would be periodically updated. He noted that the methyl bromide standard was not one that was updated in the 1990s and the current OSHA methyl bromide occupational level was set in 1969 and is based on research done in the 1950s-1960s. He also noted there are recommendations for occupational levels that are lower than OSHA's 20 ppm regulatory limit and the NIOSH 250 ppm IDLH value (IDLH = "immediately dangerous to life and health"). Mr. Lauffer also noted the current ACGIH recommended 8-hour workday exposure level is 1 ppm (3.9 mg/m^3) and that NIOSH recommends wearing respirators at any detectable exposure of methyl bromide due to cancer concerns. He stated the current occupational regulatory standard in North Carolina is 25 ppm (8-hour average) with a ceiling limit of 250 ppm.

DAQ again noted that while occupational exposure limits are available for methyl bromide and similar values have been used historically to develop AALs for the protection of the general public, DAQ has recommended the IRIS RfC as more appropriate for protection of public health. The EPA IRIS RfC has gone through extensive EPA internal technical team review, external-to-the EPA technical peer review, and public comment. Additionally, the RfC is derived as a level intended to be health-protective for the general population, including subpopulations that may have increased sensitivity to development of adverse health effects associated with specific exposures. Occupational exposure limits are intended to be protective of a healthy adult working population which may have different sensitivity to exposures than does the general public. In the context of public health, the "general public" encompasses subpopulations, such as infants, children, the elderly and persons with pre-existing conditions or a genetic predisposition that may manifest as increased susceptibility to the adverse effects associated with inhalation to methyl bromide and other toxicants. For these reasons, DAQ identifies the EPA IRIS RfC as the most appropriate health-based value protective of inhalation exposures for all persons that may be repeatedly exposed to methyl bromide at locations adjacent to log fumigation operations.

Discussion of Available Methyl Bromide Acute Inhalation Guideline Values

NRC AEGL inhalation values: During the Board's deliberations DAQ was asked about available acute inhalation exposure data and acute exposure health concentrations for methyl bromide and whether an acute level should be considered in addition to the 24-hour averaging time recommendation for the IRIS RfC-based AAL. Additionally, the Board asked if there were AEGL values for methyl bromide. The following information was prepared by DAQ in response to these questions and provided to the Board at the December 4, 2018 SAB meeting.

The National Research Council releases acute exposure guideline levels (AEGLs) for "high-priority, acutely toxic chemicals" identified as "extremely hazardous substances" (EHS). The AEGLs are intended

for the protection of "*workers and residents in communities surrounding industrial facilities where EHSs are manufactured, used, or stored*…." Three levels of AEGLs may be developed (NRC 2012). The level one AEGLs (AEGL-1) are the most health-protective of the three levels, and are referenced as "non-disabling" exposure levels. AEGL-2 and AEGL-3 levels are identified as "disabling" and "lethal", respectively. The NRC's expanded definition of an AEGL-1 value is an air concentration "*above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure*" (NRC 2012). Persons exposed at AEGL-2 concentrations "*above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape*", and persons exposed at exposures above the AEGL-3 levels "*could experience life-threatening health effects or death*".

DAQ considers only AEGL-1 level values as potentially appropriate references to be considered in the protection of the general public. The NRC chose to not establish AEGL-1 levels for methyl bromide, reasoning that methyl bromide has no odor or irritation properties at concentrations below those that define the AEGL-2 values. Additionally, the NRC noted the dose-response curve for methyl bromide lethality is steep and the margin of safety between no-effect and lethal values is small. Table 5-1 following is taken from the NRC 2012 document that lists the AEGL values derived for methyl bromide.

AEGL-2 and AEGL-3 levels are developed for a severity of effects not appropriate to protect the general public, particularly is the circumstances of methyl bromide exposures that may not be apparent to the exposed population, including infants and children, that could be exposed without recognition of their exposures due to the lack of odor and likely delayed effects.

TABLE 5-1 Summary of AEGL Values for Methyl Bromide

Classification	10 min	30 min	1 h	4 h	8 h	End Point (Reference)
AEGL-1 (nondisabling)	NR[a]	NR[a]	NR[a]	NR[a]	NR[a]	
AEGL-2 (disabling)	940 ppm (3,657 mg/m^3)	380 ppm (1,478 mg/m^3)	210 ppm (817 mg/m^3)	67 ppm (261 mg/m^3)	67 ppm (261 mg/m^3)	NOAEL for clinical signs in rats and dogs (Hurtt et al. 1988; Hastings 1990; Japanese Ministry of Labour 1992; Newton 1994a)
AEGL-3 (lethal)	3,300 ppm (12,837 mg/m^3)	1,300 ppm (5,057 mg/m^3)	740 ppm (2,879 mg/m^3)	230 ppm (895 mg/m^3)	130 ppm (506 mg/m^3)	$BMCL_{05}$ in rats (Kato et al. 1986)

[a]Numerical values are not recommended because the data indicate that toxic effects might occur below the odor threshold for methyl bromide. Absence of an AEGL-1 value does not imply that exposure below the AEGL-2 value is without adverse effects.
Abbreviations: $BMCL_{05}$, benchmark concentration, 95% lower confidence limit with 5% response; NOAEL, no-observed-adverse-effect level; NR, not recommended.

Source: NRC 2012.

California's 1-hour REL value: DAQ's review of appropriate public health-protective methyl bromide acute inhalation guideline levels included discussion of an acute occupational exposure level commonly referenced for methyl bromide, 3.9 mg/m^3 (1 ppm) level referenced in the 1999 California Office of Environmental Health Hazard Assessment (OEHHA) Acute RELs (OEHHA 1999). The OEHHA acute inhalation value is identified as a 1-hour REL (Reference Exposure Level). This acute REL value is derived from a 1942 study reported by Watrous with the data collected from a 1940 inhalation exposure to 90 "worker" subjects. The study noted "symptoms developed during the workshift" and theorized a 2-hour exposure was sufficient to cause the reported symptoms. A 2-hour LOAEL of 59 ppm was reported, with no indication of the method of quantitation of the exposure concentrations. Using the Haber's Law equation, they extrapolated the 2-hour exposure concentration that induced the reported adverse effects to a 1-hour exposure LOAEL of 35 ppm. The critical effects noted for the LOAEL were "anorexia, nausea, headache". No additional information of the adverse effects or the proportion of subjects exhibiting the critical effects was indicated. An uncertainty factor (UF) of 6 was applied to extrapolate the LOAEL to a NOAEL for "mild adverse effects". An additional UF of 10 was applied to human population sensitivity variability. The resulting acute REL = 1 ppm (3.9 mg/m3).

This inaccuracy was compounded by the extrapolation of an estimation that a 2-hour exposure resulted in the observed effects and was used to estimate a 1-hour exposure concentration. Additionally, DAQ

noted that current risk assessment methods apply a default UF of 10 to adjust a LOAEL to a NOAEL when a NOAEL is not defined by the study data. An UF of 6 used to derive the 1 ppm level is less health protective than an UF of 10.

Because of the uncertainty of the exposure concentration measurement, the small number of subjects, the severity of the adverse effects utilized as the critical effects for the LOAEL, the extrapolation methods and the lack of documentation available, the DAQ does not judge this as an appropriate reference for an acute inhalation level protective of public health.

Status of ATSDR Acute Inhalation Values: In continuation of their efforts to identify an appropriate public health-protective acute inhalation guidance level for methyl bromide DAQ reviewed the status of an ATSDR-derived acute exposure guideline value. DAQ noted that in ATSDR's 1992 review (ATSDR 1992) they derived an acute exposure guideline, but the acute value was removed in the updated review (ATSDR 2018a, ATSDR 2018b). ATSDR noted (ATSDR 2018b) that the acute exposure database was inadequate to develop an acute MRL and noted a concern that acute values may not be protective due to the well-documented delayed effect recognition associated with methyl bromide exposures, as well as the implications of the steep dose-response curve. A steep dose-response curve suggests that there is a substantial increase in the severity of effects over a relatively small range of increasing exposure concentrations.

The SAB's Discussion of Range of Risk

At the February 4, 2019 SAB meeting, the DAQ requested the Board's thoughts and recommendations on the topic of the range of risk as it is referenced in the *NCSAB Risk Assessment Guidelines* document on the prior SAB's webpage (NCSAB 1997a). In response, the Board asked what is the rationale for providing a range of risk values for methyl bromide. The DAQ Environmental Toxicologist identified her recommendation was that a range of risk values was not relevant to the methyl bromide AAL recommendation when using an IRIS chronic RfC, a health value protective of the general population, developed using the current health risk methods, and confirmed as the best science by the ATSDR 2018 review. DAQ noted IRIS identified "high" confidence in the chronic RfC. It was identified that the 1997 SAB document that makes reference to a range of risk values reflected the AAL methodology in place in the 1980s and early 1990s that derived public health protective values by applying "risk adjustment factors" to occupational health values available at the time, when the IRIS database was not as extensive as it is currently. DAQ reminded the Board that the general public includes infants, children, the elderly and persons with pre-existing health conditions, and is a group potentially more sensitive to the adverse effects associated with exposures to specific toxicants than the healthy adult worker ("occupational") population. General public exposures must consider the possibility that persons will be exposed daily over their lifetime, which is not the exposure pattern considered in occupational value derivations which as assume 8-hour per day, 5-day per week exposures to healthy adults over less than a lifetime.

The SAB Chair discussed the benefit in providing a range of risk, while noting it is not essential when the number is coming from an IRIS risk assessment. There was agreement that range of risk may include numbers below the RfC when considering the studies indicating the increased neurotoxic susceptibility

in segments of the human population. It was stated this could be addressed by putting a bound on the increased sensitivity based on best professional judgement since there was not data to provide a quantitative estimate of this genetic profile.

A Board member referenced the EPA definition of a RfC: "…*an estimate (with uncertainty span spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used.*" The Board commented that while the RfC definition represents the uncertainty, the importance of the confidence levels expressed in the IRIS assessment for methyl bromide includes a judgement of medium confidence because there is no NOAEL, but high confidence in the database and RfC.

Following the SAB meeting a Board member provided a written summary of their comments on the range of risk issue, noting that in the current risk science context the term "range of risk" implies a probabilistic[28] approach. The Board member further noted: "*If a range of recommended AALs is to be provided, it should be done in a way that is clear and consistent across chemicals within endpoint(s). When a NOAEL or LOAEL is divided by uncertainty factors, you can come up with a range of values depending upon the choice of uncertainty factors and the endpoints used. This really is not a quantifiable range of risk however. When benchmark dose modeling is used, it is possible to come up with a range of PODs based on the probability of observing an effect; however, this still is not a truly probabilistic approach. In the case of cancer risk assessment for a DNA-reactive or directly mutagenic agent, where the LMS model is used, it is common to specify risk levels in the range of 10E-4 to 10E-6 which is probabilistic. My feeling is that coming up with a single recommended value (or multiple values if multiple endpoints are being considered) is a reasonable approach when a truly probabilistic approach is not possible. There is nothing preventing any state group from setting a lower number based on technical or other pragmatic feasibility considerations. If there is a desire to have multiple proposed AALs, then the phrase "range of risk" should not be used because it really is misleading. Far better to have a summary table of final values organized by endpoint with study cited and dosimetric adjustments and uncertainty factors used clearly specified so the basis for multiple numbers is clear and transparent.*"

The DAQ has recommended the 1992 IRIS chronic RfC and a 24-hour averaging period as the best available science protective of the general public to long-term inhalation exposures to methyl bromide emitted from log fumigation operations. The IRIS chronic RfC represents the most sensitive endpoint of the range of adverse health effects observed in the current methyl bromide inhalation toxicity database (damage to the olfactory epithelial tissues leading to degenerative and proliferative lesions), an effect deemed of concern to public health. In response to the EMC's desire for a range of risk values, DAQ further recommends a factor of 3 (3 = the square root of an UF = 10) placed on the IRIS chronic RfC as an appropriate adjustment factor to reduce the potential for adverse health effects to the subpopulation

[28] The EPA defines probabilistic risk assessment (PRA) as a group of techniques that incorporate variability and uncertainty into risk assessments. Variability refers to the inherent natural variation, diversity and heterogeneity across time, space or individuals within a population or lifestage, while uncertainty refers to imperfect knowledge or a lack of precise knowledge of the physical world, either for specific values of interest or in the description of the system. PRA provides estimates of the range and likelihood of a hazard, exposure or risk, rather than a single point estimate. Source: https://www.epa.gov/sites/production/files/2014-11/documents/raf-pra-faq-final.pdf

that possess the Phase II GSTT1 enzyme variant that predisposes them to increased neurotoxic effects. This specific genetic variation is not a characteristic of the animal models used to derive the chronic RfC and the default UF = 10 applied for intra-species human variability may not adequately account for GSTT1-specific response variability. This could represent a lower bound in range of AAL values to be considered by the EMC.

At the April 1, 2019 meeting, SSAB members voted unanimously to support the 2 to 5 $\mu g/m^3$ proposed range for the AAL. Some members expressed more confidence in the upper end of the 2 to 5 $\mu g/m^3$ range.

SUMMARY

DAQ has identified the U.S. EPA IRIS program chronic inhalation reference concentration (RfC) as the appropriate value for the Acceptable Ambient Level (AAL) to protect all persons that may live or work in areas subject to repeated airborne releases of methyl bromide from fumigation operations. Protecting public health includes protecting segments of the population that may have greater sensitivity to the adverse effects associated with toxicant exposures, including infants, children, the elderly and persons with pre-existing health conditions that may result in increased susceptibility to toxicants, such as persons with asthma or chronic cardiac or lung disease. Protecting public health also includes protection of subpopulations that may have genetic or physiological variations that influence their susceptibility, such as is the case with persons that possess the human-specific Phase II glutathione (GSH) enzyme that increases the sensitivity and severity of neurotoxic effects to this subpopulation when exposed to methyl bromide. This genetic variant is not a characteristic of the animal models used to study effects associated with methyl bromide inhalation and the default human intraspecies UFs may not adequately capture the range of human response. DAQ offers an adjustment factor of 3 as an appropriate level of protection for the unquantified influence on neurotoxic effects associated with the Phase II GSTT1 genetic variant subpopulation. This could represent a lower bound in the range of AAL values that could be considered by the EMC. Based on a combination of the professional judgment of DAQ's Environmental Toxicologist and input and feedback from the SAB, the range of AAL values that could be considered by the EMC are 0.002 mg/m^3 to 0.005 mg/m^3. DAQ is proposing a 24-hour averaging time for the methyl bromide AAL to reflect the lack of odor and taste recognition at potentially harmful exposure concentrations, the rapid adsorption and distribution of methyl bromide following inhalation exposures, the slower elimination from target organs, and the delayed onset of adverse effects following both acute and chronic exposures.

Table 1. Summary of Critical Study Specifications, Methyl Bromide Chronic RfC (IRIS 1992) and ATSDR Draft Chronic MRL (2018)

Parameter	**IRIS Chronic RfC (1992)**	**ATSDR Chronic MRL (Draft 2018)**
Study reference	Reuzel et al., 1987, 1991 - National Institute of Public Health and Environmental Hygiene of the Netherlands	Reuzel et al., 1987, 1991 - National Institute of Public Health and Environmental Hygiene of the Netherlands
Test species	50 male, 60 female Wistar rats per treatment	50 male, 60 female Wistar rats per treatment
Test concentrations, as 98.8% methyl bromide	0, 11.7, 117, 350 mg/m^3 (= **3, 30, 90 ppm**) (verified every 30 minutes by GC)	0, 11.7, 117, 350 mg/m^3 (= **3.1, 29.6, 89.1 ppm**) (verified every 30 minutes by GC)
Study exposure scenario	Inhalation, 6 hours per day, 5 days per week	Inhalation, 6 hours per day, 5 days per week
Study length	29 months	29 months
Observations	Body Weight, Hematology, Clinical Chemistry, Urinalyses, 11 Organ Weights and Necropsy, Histological exam of 36 tissues, including the nose, trachea, lungs, heart, brain, and adrenal glands	Body Weight, Hematology, Clinical Chemistry, Urinalyses, 11 Organ Weights and Necropsy, Histological exam of 36 tissues, including the nose, trachea, lungs, heart, brain, and adrenal glands
Identified target organs	Nose, heart, esophagus, forestomach	Not noted
Critical effect description	Degenerative and proliferative lesions of the olfactory epithelium; **Males and Females**	Basal cell hyperplasia the olfactory epithelium; **Males and Females**
$LOAEL_{rat}$	11.7 mg/m^3 "for nasal effects" (3.01 ppm)	12.0 mg/m^3 (3.1 ppm)
Continuous exposure adjustment	$LOAEL_{rat}$(Adjusted) = 2.08 mg/m^3 (Adjusted exposure concentrations: 2.08, 20.9, 62.5 mg/m^3)	$LOAEL_{rat}$(Adjusted) = 2.1 mg/m^3 (0.55 ppm)
BMD modeling	Not applied	Calculated $BMCL_{10}$ = Male, 14.2 mg/m^3 (3.65 ppm) Female, 16.0 mg/m^3 (4.13 ppm); **$BMCL_{10}$ value not used - Higher than empirical 3.1 ppm LOAEL**
Human Equivalent Concentration (HEC) extrapolation method	Regional Gas Dose Ratio (RGDR), Extrathoracic region **RGDR = 0.23 F**	Regional Gas Dose Ratio (RGDR), Extrathoracic region **RGDR = 0.280 M, 0.200 F**
$LOAEL_{HEC}$	$LOAEL_{HEC}$ = 0.48 mg/m^3 (0.12 ppm)	**Mean $LOAEL_{HEC}$ = 0.512 mg/m^3** (Mean = 0.132 ppm) (0.598 M, 0.427 mg/m^3 F; or, 0.154 M, 0.110 F ppm)
Uncertainty Factors	**Composite UF = 100**; UF 3 - LOAEL for mild effects, UF 3 - interspecies extrapolation w/ dosimetric adjustments, UF 10 – human variability UF (100 = √10 x √10 x 10)	**Composite UF = 90**; UF 3 – minimal LOAEL, UF 3 - interspecies extrapolation w/ dosimetric adjustments, UF 10 – human variability (UF 90 = 3 x 3 x 10)
Chronic Inhalation Value	**RfC = 0.005 mg/m^3** (0.0048 mg/m^3; or, 0.0012 ppm rounded)	**Calculated MRL = 0.005 mg/m^3** (0.0014 ppm; or, 0.0054 mg/m^3 rounded) **Presented as 0.001 ppm Provisional MRL**
Confidence in toxicity value	Study – Medium (no NOAEL) Database – High RfC - High	Not noted

RGDR = Regional gas dose ratio is the ratio of the inhalation volume to surface area for animals and humans used to convert animal exposure concentrations to human-equivalent concentrations (HECs).

$$RGDR_r = (V_E / SA_r)_A / (V_E / SA_r)_H$$

where:

r = specific respiratory tract region
V_E = ventilation rate (L/min)
SA_r = surface area of exposed respiratory tract region (cm^2)
A = animal
H = human

Reference: 2012 EPA, *Advances in Inhalation Gas Dosimetry for Derivation of a Reference Concentration (RfC) and Use in Risk Assessment, EPA/600/R-12/044*RGDR calculation, IRIS (1992) –

IRIS (1992) – Rat LOAEL extrapolation to Human LOAEL using RGDR model -

$$RGDR(ET) = (MV_a/S_a)/(MV_h/S_h) = 0.23$$
$$LOAEL(HEC) = LOAEL(ADJ) \times RGDR = 0.48\ mg/m^3$$

where:

MV_a (chronic, Wistar rats) = 0.30 m^3/day
MV_h = 20 m^3/day
$S_a(ET)$ = 11.6 cm^2
$S_h(ET)$ = 177 cm^2
ET = extrathoracic region

IRIS (1992) reference: "*Inhalation RfCs were derived according to the Interim Methods for Development of Inhalation Reference Doses (EPA/600/8-88/066F August 1989) and subsequently, according to Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry (EPA/600/8-90/066F October 1994).*"

ATSDR (Draft 2018) - RGDR(ET) male rats = 0.280; female rats = 0.200

$$RGDR_{ET} = (V_E/SA_{ET})_{Rat} / (V_E/SA_{ET})_{Human}$$

where:

V_E = ventilation rate, m^3/day: humans 20; male Wistar rats 0.42; female Wistar rats 0.30 (Reference: EPA 1988b)

SA_{ET} = surface area of extrathoracic region of the respiratory tract, cm^2: humans 200; male and female rats 15 (Reference: EPA 1994b)

References:

EPA 1988b. Recommendations for and documentations of biological values for use in risk assessment. Cincinnati, OH: U.S. Environmental Protection Agency.

EPA 1994b. Methods for derivation of inhalation reference concentrations and applications of inhalation dosimetry. Washington, DC: U.S. Environmental Protection Agency. EPA600890066F.

Table 1 notes:

LOAEL = lowest observed adverse effect level (the lowest exposure concentration indicating a statistically-significant adverse effect)
NOAEL = no observed adverse effect level (highest exposure concentration with no statistically-significant observed adverse effect level)
MRL = Minimal Risk Level
RfC = reference concentration
UF = uncertainty factor

Table 2. Adverse health effects identified in the Reuzel et al. (1991) methyl bromide rat inhalation study that was the IRIS reference concentration (RfC) principle study. Inhalation exposures concentrations were 0, 3, 30, 90 ppm methyl bromide.

Statistically Significant Concentration-Related Adverse Health Effect	**Exposure Duration**	**Methyl Bromide Inhalation Effect Concentration**
Degenerative and proliferative lesions of the olfactory epithelium in the nasal cavity (Critical effect)	29 months	3 ppm ($LOAEL_{rat}$)
Decrease in relative kidney weight	29 months	30 ppm, males
Decrease in mean absolute brain weight	53 weeks	90 ppm, females
Hyperplastic changes in basal cells with degeneration of olfactory epithelium of the nasal cavity	29 months	3 ppm
Heart lesions, metaplasia and thrombus	29 months	90 ppm, males
Heart lesions, myocardial degeneration and thrombus	29 months	90 ppm, females
Hyperkeratosis of the esophagus	29 months	90 ppm, males
Non-Statistically Significant Concentration-Related Adverse Health Effect	**Exposure Duration**	**Methyl Bromide Inhalation Effect Concentration**
Basal cell hyperplasia	53 weeks	30 ppm
Decreased body weight gains	29 months	90 ppm
Mortality	29 months	90 ppm
Forestomach lesions	29 months	Not indicated

References

Alavanja MC, Samanic C, Dosemeci M, et al. 2003. Use of agricultural pesticides and prostate cancer risk in the Agricultural Health Study cohort. Am J Epidemiol 157(9):800-814.

Anger WK, Moody L, Burg J, et al. 1986. Neurobehavioral evaluation of soil and structural fumigators using methyl bromide and sulfuryl fluoride. Neurotoxicology 7:137-156.

Anger, K.W., Setzer, J.V., Russo, J.M., Brightwell, W.S., Wait, R.G., Johnson, B.L. 1981. Neurobehavorial effects of methyl bromide inhalation exposures. Scand j work environ health 7 (1981): Suppl 4, 40-47

ATSDR 1992. Toxicological Profile for Bromomethane. September 1992. Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, U.S. Department of Health & Human Services, Atlanta, GA. Accessed at: https://www.atsdr.cdc.gov/substances/index.asp

ATSDR 1995. ToxFAQs™ for Bromomethane. September 1995. Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, U.S. Department of Health & Human Services, Atlanta, GA. Accessible at: https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=821&tid=160

ATSDR 2018a. Minimal Risk Levels (MRLs) – For Professionals. Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, U.S. Department of Health & Human Services, Atlanta, GA. Accessed at: https://www.atsdr.cdc.gov/mrls/index.asp

ATSDR 2018b. Toxicological Profile for Bromomethane Draft for Public Comment. April 2018. Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, U.S. Department of Health & Human Services, Atlanta, GA. Accessed at: https://www.atsdr.cdc.gov/substances/index.asp

Breslin WJ, Zublotny CL, Bradley GJ, et al. 1990. Methyl bromide inhalation teratology study in New Zealand white rabbits with cover letter and attachment (declassified). Dow Chemical Company. Submitted to the U.S. Environmental Protection Agency under TSCA Section 8E. OTS0522340-3.

Bond JA, Dutcher JS, Medinsky MA, et al. 1985. Disposition of [14C]methyl bromide in rats after inhalation. Toxicol Appl Pharmacol 78:259-267.

Cockburn M, Mills P, Zhang X, et al. 2011. Prostate cancer and ambient pesticide exposure in agriculturally intensive areas in California. Am J Epidemiol 173(11):1280-1288. 10.1093/aje/kwr003.

de Souza A, Narvencar KP, Sindhoora KV. 2013. The neurological effects of methyl bromide intoxication. J Neurol Sci 335(1-2):36-41. 10.1016/j.jns.2013.09.022.

Enloe PV, Salamon CM, Becker SV. 1986. Two-generation reproduction study via inhalation in albino rats using methyl bromide. American Biogenics Corp. Submitted to the U.S. Environmental Protection Agency under TSCA Section 8d. OTS0515364. EPA Doc. ID 86-870000926.

DAQ 2018a. *Acceptable Ambient Level (AAL) Recommendation for Methyl Bromide* Submitted to the Secretaries' Science Advisory Board. North Carolina Department of Environmental Quality (DEQ) Division of Air Quality (DAQ). October 22, 2018.

DAQ 2018b. *Addendum to the Acceptable Ambient Level (AAL) Recommendation for Methyl Bromide Submitted to The Secretaries' Science Advisory Boar*d. North Carolina Department of Environmental Quality (DEQ) Division of Air Quality (DAQ). Original Release November 20, 2018, Revised December 10, 2018

DAQ 2018c. *Discussion of Methyl Bromide AEGL Acute Inhalation Levels and Discussion of Commonly Referenced 3.9 mg/m^3 Occupational Acute Inhalation Value for Methyl Bromide*. Submitted to the Secretaries' Science Advisory Board December 4, 2018. North Carolina Department of Environmental Quality (DEQ) Division of Air Quality (DAQ).

EPA 2005. U.S. Environmental Protection Agency (EPA). *Guidelines for Carcinogen Risk Assessment*. Risk Assessment Forum, Washington, DC. EPA/630/P-03/001B. March 2005.

Gansewendt, B., U. Foest, D. Xu et al. 1991. Formation of DNA adducts in F-344 rats after oral administration or inhalation of [14C]methyl bromide. Food Chem. Toxicol. 29: 557-563.

Garnier, R., M. Rambourg-Schepens, A. Müller and E. Hallier. 1996. Glutathione transferase activity and formation of macromolecular adducts in two cases of acute methyl bromide poisoning. Occup. Environ. Med. 53: 211-215.

Gemmill A, Gunier RB, Bradman A, et al. 2013. Residential proximity to methyl bromide use and birth outcomes in an agricultural population in California. Environ Health Perspect 121(6):737-743. 10.1289/ehp.1205682.

Gotoh K, Nishizawa T, Yamagucki T, et al. 1994. Two-year toxicological and carcinogenesis studies of methyl bromide in F344 rats and BDF1 mice - Inhalation studies. In: Proceedings of the ICMR Seminar, 2; Environmental and occupational chemical hazards 2nd Asia-Pacific symposium on environmental and occupational health, Environmental and occupational chemical hazards, 185-192.

Herzstein, J. and M.R. Cullen. 1990. Methyl bromide intoxication in four field-workers during removal of soil fumigation sheets. Am. J. Ind. Med. 17: 321-326.

Honma T. 1987. Alteration of catecholamine metabolism in rat brain produced by inhalation exposure to methyl bromide. Jpn J Ind Health 29:218-219.

Honma T, Miyagawa M, Sato M, et al. 1985. Neurotoxicity and metabolism of methyl bromide in rats. Toxicol Appl Pharmacol 81:183-191.

Honma T, Sudo A, Miyagawa M, et al. 1982. Significant changes in monoamines in rat brain induced by exposure to methyl bromide. Neurobehav Toxicol Teratol 4:521-524.

Hurtt, M.E. and P.K. Working. 1988. Evaluation of spermatogenesis and sperm quality in the rat following acute inhalation exposure to methyl bromide. Fund. Appl. Toxicol. 10: 490-498.

Hustinx, W.N.M., R.T.H. Van de Laar, A.C. Van Huffelen et al. 1993. Systemic effects of inhalation methyl bromide poisoning: A study of nine cases occupationally exposed due to inadvertent spread during fumigation. Br. J. Ind. Med. 50: 155-159.

IRIS 1992. Bromomethane Integrated Risk Information System (IRIS) Chemical Assessment Summary. U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, D.C. Last updated: April 1, 1992. Accessed at: https://www.epa.gov/iris

IRIS 2011. U.S. EPA IRIS Glossary. Last updated August 31, 2011. Accessed at: https://iaspub.epa.gov/sor_internet/registry/termreg/searchandretrieve/home.do

IRIS 2018. U.S. EPA IRIS website, accessed at: https://www.epa.gov/iris

Jaskot RH, Grose EC, Most BM, et al. 1988. The distribution and toxicological effects of inhaled methyl bromide in the rat. J Am Coll Toxicol 7:631-642.

Kato N, Morinobu S, Ishizu S. 1986. Subacute inhalation experiment for methyl bromide in rats. Ind Health 24(2):87-103.

Medinsky MA, Dutcher JS, Bond JA, et al. 1985. Uptake and excretion of [14C]methyl bromide as influenced by exposure concentration. Toxicol Appl Pharmacol 78:215-225.

Mills PK, Yang R. 2003. Prostate cancer risk in California farm workers. J Occup Environ Med 45(3):249-258.

NCSAB 1997a. NCSAB Risk Assessment Guidelines – Secretary's Science Advisory Board on Toxic Air Pollutants: Internal guidelines for toxicological evaluation of chemicals released to the air. Available on the prior NCSAB structure website at: https://deq.nc.gov/about/divisions/air-quality/science-advisory-board-toxic-air-pollutants

NCSAB 1997b. NCSAB Practices and Policies – Practices and Policies of the Department of Environment and Natural Resources: Policies Concerning the Secretary's Science Advisory Board on Toxic Air Pollutants (NCSAB). Available on the prior NCSAB structure website at: https://deq.nc.gov/about/divisions/air-quality/science-advisory-board-toxic-air-pollutants

NTP 1992. National Toxicology Program. Toxicology and carcinogenesis studies of methyl bromide (CAS No. 74-83-9) in B6C3F1 mice (inhalation studies). NTP TR 385, NIH Publication No. 92-2840.

NTP (National Toxicology Program). 2002. Management Status Report. Online. http://ntp-server.niehs.nih.gov/cgi/iH_Indexes/ALL_SRCH/iH_ALL_SRCH_Frames.html

National Research Council. 2012. Acute Exposure Guideline Levels for Selected Airborne Chemicals, Volume 12. Accessed at: https://www.nap.edu/catalog/13377/acute-exposure-guideline-levels-for-selected-airborne-chemicals-volume-12

OEHHA 1999. Appendix D.2 Acute RELs and toxicity summaries using the previous version of the Hot Spots Risk Assessment guidelines. Accessed at: https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary

Pemble, S., Schroeder, K.R., Spencer, S.R., Meyer, D.J., Hallier, E., Bolt, H.M., Brian Ketterer, B. and Taylor, J.B. Human glutathione S-transferase Theta (GSTT1): cDNA cloning and the characterization of a genetic polymorphism. Biochem. J. (1994) 300, 271-276 (Printed in Great Britain).

PPRTV 2007. Provisional Peer Reviewed Toxicity Values for Bromomethane (CASRN 74-83-9). Superfund Health Risk Technical Support Center National Center for Environmental Assessment Office of Research

and Development U.S. Environmental Protection Agency Cincinnati, OH 45268. EPA/690/R-07/004F Final 6-05-2007. https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments

Reuzel, P.G.J., C.F. Kuper, H.C. Dreef-van der Meulen and V.M.H. Hollanders. 1987. Chronic (29-month) inhalation toxicity and carcinogenicity study of methyl bromide in rats. Report No. V86.469/221044. Netherlands Organization for Applied Scientific Research, Division for Nutrition and Food Research, TNO. EPA/OTS Document No. 86-8700001202.

Reuzel PG, Dreef-van der Meulen HC, Hollanders VM, et al. 1991. Chronic inhalation toxicity and carcinogenicity study of methyl bromide in Wistar rats. Food Chem Toxicol 29(1):31-39.

Schröder, K.R., E. Hallier, H. Peter and H.M. Bolt. 1992. Dissociation of a new glutathione S-transferase activity in human erythrocytes. Biochem. Pharmacol. 43: 1671-1674.

Schwob JE, Youngentob SL, Ring G, et al. 1999. Reinnervation of the rat olfactory bulb after methyl bromide-induced lesion: Timing and extent of reinnervation. J Comp Neurol 412(3):439-457.

Youngentob SL, Schwob JE. 2006. Odorant identification and quality perception following methyl bromide-induced lesions of the olfactory epithelium. Behav Neurosci 120(6):1346-1355. 10.1037/0735-7044.120.6.1346.

Appendix A

Secretaries' Science Advisory Board's Final Recommendations Statement on the Division of Air Quality's Methyl Bromide Acceptable Ambient Level (AAL) for Log Fumigation Operations

The North Carolina Department of Environmental Quality
and The Department of Health & Human Services
Secretaries' Science Advisory Board

Subject: The Secretaries' Science Advisory Board's Final recommendations on the Department of Environmental Quality Division of Air Quality's Methyl Bromide Acceptable Ambient Level (AAL) Recommendation for Log Fumigation Operations

The N.C. Department of Environmental Quality (DEQ) and Department of Health and Human Services (DHHS) Secretaries' Science Advisory Board (SSAB) has heard presentations by agency staff and reviewed materials submitted by the DEQ Division of Air Quality (DAQ) concerning their proposal to protect all persons that may live or work in areas subject to repeated airborne releases of methyl bromide from log fumigation operations. DAQ has identified the current U.S. EPA IRIS program chronic inhalation reference concentration (0.005 mg/m^3 RfC) as the appropriate upper-bound value for the Acceptable Ambient Level (AAL) to protect public health. Protecting public health includes protecting segments of the population that may have greater sensitivity to the adverse effects associated with toxicant exposures, including infants, children, the elderly, persons with pre-existing health conditions that may result in increased susceptibility to toxicants, such as persons with asthma or chronic cardiac or lung disease, and subpopulations with genetic profiles that may enhance their sensitivity. DAQ is proposing a 24-hour averaging time for the methyl bromide AAL to reflect the rapid adsorption and distribution of methyl bromide following inhalation exposures, the slower elimination from target organs, and due to the potential for delayed onset of adverse effects following exposures. DAQ offers an adjustment factor of 3 as an appropriate level of protection for the unquantified influence on increased neurotoxic effects associated with the Phase II GSTT1 genetic variant subpopulation to represent the lower-bound range AAL value. This genetic variant is not a characteristic of the animal models used to derive the RfC and the default human intraspecies UF of 10 may not adequately capture the range of human response.

Proposed Acceptable Ambient Level (AAL) Range for Methyl Bromide
0.005 mg/m^3 Upper-bound AAL
0.002 mg/m^3 Lower-bound AAL
24-hour Averaging Time

On the basis of the information reviewed by the SSAB concerning the current methyl bromide toxicological and risk science, the current IRIS chronic inhalation reference concentration and the chronic exposure characteristics associated with log fumigation operations, the SSAB recommends a range of Acceptable Ambient Level (AAL) values to be considered by the EMC for methyl bromide as 0.002 mg/m^3 to 0.005 mg/m^3 and a 24-hour averaging time for the protection of public health.

T Augspurger — April 27, 2019

Tom Augspurger, Ph.D., Chair — date
N.C. Secretaries' Science Advisory Board

Appendix B

Chemical Assessment Summary – Bromomethane (CASN 74-83-9)

Integrated Risk Information System (IRIS)
U.S. Environmental Protection Agency National Center for Environmental Assessment

Last Revised April 1, 1992

Bromomethane; CASRN 74-83-9

Human health assessment information on a chemical substance is included in the IRIS database only after a comprehensive review of toxicity data, as outlined in the IRIS assessment development process. Sections I (Health Hazard Assessments for Noncarcinogenic Effects) and II (Carcinogenicity Assessment for Lifetime Exposure) present the conclusions that were reached during the assessment development process. Supporting information and explanations of the methods used to derive the values given in IRIS are provided in the guidance documents located on the IRIS website.

STATUS OF DATA FOR Bromomethane

File First On-Line 01/31/1987

Category (section)	Assessment Available?	Last Revised
Oral RfD (I.A.)	yes	09/26/1988
Inhalation RfC (I.B.)	yes	04/01/1992
Carcinogenicity Assessment (II.)	yes	06/01/1989

I. Chronic Health Hazard Assessments for Noncarcinogenic Effects

I.A. Reference Dose for Chronic Oral Exposure (RfD)

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide
Last Revised — 09/26/1988

The oral Reference Dose (RfD) is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. It is expressed in units of mg/kg-day. In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Please refer to the Background Document for an

elaboration of these concepts. RfDs can also be derived for the noncarcinogenic health effects of substances that are also carcinogens. Therefore, it is essential to refer to other sources of information concerning the carcinogenicity of this substance. If the U.S. EPA has evaluated this substance for potential human carcinogenicity, a summary of that evaluation will be contained in Section II of this file.

I.A.1. Oral RfD Summary

Critical Effect	Experimental Doses*	UF	MF	RfD
Epithelial hyperplasia of the forestomach **Rat Subchronic Gavage Study** **Danse et al., 1984**	NOAEL: 1.4 mg/kg/day LOAEL: 7.1 mg/kg/day	1000	1	1.4E-3 mg/kg/day

*Conversion Factors and Assumptions — doses adjusted for gavage schedule (5 days/week)

I.A.2. Principal and Supporting Studies (Oral RfD)

Danse, L.H.J.C., F.L. van Velsen and C.A. van der Heijden. 1984. Methylbromide: Carcinogenic effects in the rat forestomach. Toxicol. Appl. Pharmacol. 72: 262-271.

Treatment of groups of 10 male and 10 female Wistar rats by gavage 5 days/week for 13 weeks with bromomethane at 0, 0.4, 2, 10, or 50 mg/kg resulted in severe hyperplasia of the stratified squamous epithelium in the forestomach at a dose of 50 mg/kg/day and slight epithelial hyperplasia in the forestomach at a dose of 10 mg/kg/day (Danse et al., 1984). At the 50 mg/kg/day dose level, decreased food consumption, body weight gain and anemia were observed in the male rats. Slight pulmonary atelectasis was observed, at the two higher dose levels, in both male and female rats; however, the investigators stated that the possible inhalation of bromomethane-containing oil during the gastric intubation procedure might have been responsible for this effect. No neurotoxic effects were observed at any dose level tested. Renal histopathology was not evaluated. Adverse effects were not observed at 0.4 or 2 mg/kg.

I.A.3. Uncertainty and Modifying Factors (Oral RfD)

UF — The UF includes the standard uncertainty factors for interspecies and intrahuman variability and a factor of 10 for extrapolation to lifetime exposure from an intermediate exposure duration.

MF — None

I.A.4. Additional Studies/Comments (Oral RfD)

The current RfD is based on the Danse et al. (1984) study, which uses the preferred oral route of exposure for deriving an oral RfD. The previous oral RfD (4E-4 mg/kg/day) was based on the inhalation studies by Irish et al. (1940). Inhalation studies are inappropriate for oral risk assessment extrapolation for bromomethane because portal-of-entry effects are observed for both the inhalation route (lung pathology) and oral route (stomach hyperplasia). In addition, neurological effects reported after inhalation exposures have not been reported after oral exposures.

Beagle dogs of either sex were fed methyl bromide fumigated food ad libitum for 1 year so that groups of four dogs each ingested approximately 35, 75, or 150 mg/kg/day of bromide, or adjusting for molecular weight, 41.6, 89.1, or 178.2 mg/kg/day of methyl bromide, assuming all the bromide was present as methyl bromide (Rosenblum et al., 1960). The control group consisted of three male and three female dogs fed only dog chow, ad libitum. The dogs ingesting 178.2 mg/kg/day methyl bromide gained more weight than the controls or the two lower treatment groups; they also became lethargic and displayed excessive salivation and occasional diarrhea. Methyl bromide was reported to have no effect on hematological values, urinalysis, blood chemistry (including BUN levels) or mortality rate. Mild chronic renal inflammation was reported in two dogs in the high-dose group and in one dog in the control group. Mild hepatic focal inflammation was reported in three dogs in the high-dose group, two dogs in the low-dose group and one dog in the control group. No other histological lesions were reported.

No adverse developmental effects were observed in the fetuses of Wistar rats exposed to 20 ppm (78 mg/cu.m) or 70 ppm (272 mg/cu.m) of bromomethane for 7 hours/day on days 1-19 of gestation (Hardin et al., 1981; Sikov et al., 1980). Exposure to 20 ppm (78 mg/cu.m) or 70 ppm (272 mg/cu.m) for 7 hours/day, 5 days/week for 3 weeks prior to mating, and gestation, did not result in developmental toxicity in the offspring. No maternal toxic effects were observed.

Bromomethane was highly toxic to pregnant New Zealand White rabbits exposed to 70 ppm (272 mg/cu.m) for 7 hours/day, 5 days/week on days 1 to 15 of gestation; 24/25 rabbits died by day 30 of gestation (Hardin et al., 1981; Sikov et al., 1980). No adverse developmental effects were

observed in the one remaining litter or in a group of rabbits exposed to 20 ppm (78 mg/cu.m) of bromomethane for 7 hours/day, 5 days/week on days 1 to 30 of gestation.

I.A.5. Confidence in the Oral RfD

Study — Medium
Database — Medium
RfD — Medium

The study by Danse et al. (1984) used the preferred route of administration for derivation of an oral RfD. The study was adequately conducted, and the determination of epithelial hyperplasia of the forestomach was independently confirmed.

I.A.6. EPA Documentation and Review of the Oral RfD

U.S. EPA. 1986. Health and Environmental Effects Profile for Methyl Bromide. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington DC.

U.S. EPA. 1987. Drinking Water Health Advisory for Bromomethane. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Drinking Water, Washington DC.

Agency Work Group Review — 12/02/1985, 02/05/1986, 09/29/1986, 04/15/1987, 05/26/1988

Verification Date — 05/26/1988

Screening-Level Literature Review Findings — A screening-level review conducted by an EPA contractor of the more recent toxicology literature pertinent to the RfD for Bromomethane conducted in November 2001 identified one or more significant new studies. IRIS users may request the references for those studies from the IRIS Hotline at hotline.iris@epa.gov or (202)566-1676.

I.A.7. EPA Contacts (Oral RfD)

Please contact the IRIS Hotline for all questions concerning this assessment or IRIS, in general, at (202)566-1676 (phone), (202)566-1749 (FAX) or hotline.iris@epa.gov (internet address).

I.B. Reference Concentration for Chronic Inhalation Exposure (RfC)

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide
Last Revised — 04/01/1992

The inhalation Reference Concentration (RfC) is analogous to the oral RfD and is likewise based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. The inhalation RfC considers toxic effects for both the respiratory system (portal-of-entry) and for effects peripheral to the respiratory system (extrarespiratory effects). It is expressed in units of mg/cu.m. In general, the RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Inhalation RfCs were derived according to the Interim Methods for Development of Inhalation Reference Doses (EPA/600/8-88/066F August 1989) and subsequently, according to Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry (EPA/600/8-90/066F October 1994). RfCs can also be derived for the noncarcinogenic health effects of substances that are carcinogens. Therefore, it is essential to refer to other sources of information concerning the carcinogenicity of this substance. If the U.S. EPA has evaluated this substance for potential human carcinogenicity, a summary of that evaluation will be contained in Section II of this file.

I.B.1. Inhalation RfC Summary

Critical Effect	Exposures*	UF	MF	RfC
Degenerative and proliferative lesions of the olfactory epithelium of the nasal cavity **Rat 29-month Inhalation Study** **Reuzel et al., 1987, 1991**	NOAEL: None LOAEL: 11.7 mg/cu.m (3 ppm) LOAEL (ADJ): 2.08 mg/cu.m LOAEL (HEC): 0.48 mg/cu.m	100	1	5E-3 mg/cu.m

*Conversion Factors: MW = 94.95. Assuming 25 degrees C and 760 mmHg, LOAEL(mg/cu.m) = 3 ppm x 94.95/24.45 = 11.7 mg/cu.m. LOAEL(ADJ) = 11.7 x 6 hours/24 hours x 5 days/7 days = 2.08 mg/cu.m. The LOAEL(HEC) was calculated for a gas:respiratory effect in the extrathoracic region. MVa (chronic, female Wistar rats) = 0.30 cu.m/day, MVh = 20 cu.m/day, Sa(ET) = 11.6 sq. cm., Sh(ET) = 177 sq. cm. RGDR(ET) = (MVa/Sa)/(MVh/Sh) = 0.23. LOAEL(HEC) = LOAEL(ADJ) x RGDR = 0.48 mg/cu.m.

I.B.2. Principal and Supporting Studies (Inhalation RfC)

Reuzel, P.G.J., C.F. Kuper, H.C. Dreef-van der Meulen and V.M.H. Hollanders. 1987. Chronic (29-month) inhalation toxicity and carcinogenicity study of methyl bromide in rats. Report No. V86.469/221044. Netherlands Organization for Applied Scientific Research, Division for Nutrition and Food Research, TNO. EPA/OTS Document No. 86-8700001202.

Reuzel, P.G.J., H.C. Dreef-van der Meulen, V.M.H. Hollanders, C.F. Kuper, V.J. Feron and C.A. van der Heijden. 1991. Chronic inhalation toxicity and carcinogenicity study of methyl bromide in Wistar rats. Fd. Chem. Toxic. 29(1): 31-39.

A series of inhalation toxicity studies of bromomethane were conducted under the sponsorship of the National Institute of Public Health and Environmental Hygiene of the Netherlands. In a chronic inhalation study conducted by Reuzel et al. (1987, 1991), 50 male and 60 female Wistar rats were exposed to 0, 3, 30, or 90 ppm (0, 11.7, 117, or 350 mg/cu.m, respectively) 98.8 % pure bromomethane 6 hours/day, 5 days/week (duration- adjusted concentrations are 0, 2.08, 20.9, or 62.5 mg/cu.m, respectively) for up to 29 months. Three satellite groups of 10 animals/sex/exposure level were sacrificed at 14, 53, and 105 weeks of exposure. Animals were observed daily, and body weight was recorded weekly for the first 12 weeks and monthly thereafter. Hematology, clinical chemistry, and urinalyses were conducted at 12-14 weeks and 52-53 weeks in the satellite groups. Eleven organs were weighed at necropsy, and approximately 36 tissues, including the lungs with trachea and larynx; 6 cross-sections of the nose; heart; brain; and adrenal glands were examined histopathologically. The test atmosphere was measured by gas chromatography every 30 minutes during exposure.

Males and females exposed to 90 ppm exhibited decreased body weight gains; no treatment-related changes in hematological, biochemical, or urine parameters were observed. A significant concentration-related decrease in relative kidney weights was reported in the 30- and 90-ppm males. A decrease in mean absolute brain weight was reported to occur in the 90-ppm females at weeks 53 and 105, but there was no change in relative brain weight or in brain histology. Microscopic evaluation revealed that the nose, the heart, and the esophagus and forestomach were the principle targets of bromomethane toxicity in this study. Very slight to moderate

hyperplastic changes in the basal cells accompanied by degeneration in the olfactory epithelium in the dorso- medial part of the nasal cavity were observed in all exposed groups of both sexes at 29 months of exposure. At the lowest concentration, the lesion is described as very slight. These changes were concentration-related in both incidence and severity and were statistically significant at 29 months. Incidence of basal cell hyperplasia in control, 3-, 30-, and 90-ppm groups were 4/46, 13/48, 23/49, and 31/48 in males and 9/58, 19/58, 25/59, and 42/59 in females, respectively. Slight increases in incidence of basal cell hyperplasia in the 30- and 90-ppm groups (n=7-10) at 53 and 105 weeks were not statistically significant. Lesions in the heart were statistically significant in the males (cartilaginous metaplasia and thrombus), and the females (myocardial degeneration and thrombus) exposed to 90 ppm. The authors attributed part of the increased mortality in the high-concentration animals to the cardiac lesions. A statistically significant increase in hyperkeratosis of the esophagus was observed in the 90-ppm males after 29 months of exposure. Slight increases in forestomach lesions were not statistically significant. No effects were observed in the tracheobronchial or pulmonary regions of the respiratory tract. No other exposure-related effects were noted. Based on these results, a LOAEL of 3 ppm (HEC = 0.48 mg/cu.m) for nasal effects is established.

I.B.3. Uncertainty and Modifying Factors (Inhalation RfC)

UF — The uncertainty factor of 100 reflects a factor of 10 for intraspecies uncertainty, a factor of 3 for the use of a LOAEL for a mild effects and a factor of 3 for interspecies extrapolation because dosimetric adjustments have been applied. The factors of 3 represent operational application of a geometric half of the standard factor of 10, rounded to a single significant figure. As a result, multiplication of two factors of 3 results in a composite factor of 10.

MF — None

I.B.4. Additional Studies/Comments (Inhalation RfC)

NTP conducted a 13-week subchronic study in B6C3F1 mice and F344 rats and a 6-week target organ study (Eustis et al., 1988; NTP, 1990). A chronic study on the toxicology and carcinogenesis of bromomethane following inhalation exposure to B6C3F1 mice was also conducted (NTP, 1990).

In the 13-week study, 18 rats/sex/group were exposed to target concentrations of 0, 30, 60, or 120 ppm (0, 117, 233, or 466 mg/cu.m, respectively) bromomethane 6 hours/day, 5 days/week (duration-adjusted concentrations are 0, 20.9, 41.6, and 83.2 mg/cu.m, respectively). Mice (18-27/sex/group) were exposed to 0, 10, 20, 40, 80, or 120 ppm (0, 38.8, 77.6, 155, 311, or 466 mg/cu.m, respectively) bromomethane 6 hours/day, 5 days/week (duration-adjusted concentrations are 0, 6.93, 13.9, 27.7, 55.5, or 83.2 mg/cu.m, respectively). Hematological

parameters were measured and organ weights were determined for the adrenals (rats only), brain, heart, kidney, lung, spleen (rats only), testis, and thymus (mice only). Pseudocholinesterase activity was measured in the mice only. Neurobehavioral testing was conducted on 8 rats and 8 mice/sex/group at weeks 0, 6, and 12, and neuromorphological studies were conducted on 4 rats/sex from the control and 120-ppm group and on 4 mice/sex for each concentration. Histopathological examination of approximately 40 tissues from control and 120-ppm animals were carried out, including lungs, bronchi, and nasal turbinates. Exposure-related changes seen in the mice were a significant (58%) body weight gain reduction and a 17% increase in mortality in mice exposed to 120 ppm bromomethane. Mice exposed to this level exhibited severe curling and crossing of the hindlimbs and twitching of the forelimbs; these effects were more severe in the males. Hematological parameters that were found to be statistically significantly different from control values in mice included decreased mean cell hemoglobin, decreased mean cell count, and increased erythrocyte count in males exposed to 40, 80, and 120 ppm; and increased hemoglobin in males exposed to 120 ppm. No exposure-related effects were seen upon histopathological examination. In the rats there was no increase in mortality, but the males exposed to 120 ppm and the females exposed to 60 and 120 ppm bromomethane exhibited significant decreases in body weight gain. Mild neurobehavioral effects were noted in the high-concentration rats of both sexes. Females exposed to 120 ppm were found to have significantly lower hematocrit, hemoglobin, and erythrocytes counts, but the males did not exhibit these changes. The only exposure-related effect noted at histopathological examination was an increase in the incidence of olfactory epithelial dysplasia and cysts in the rats of both sexes exposed to 120 ppm [LOAEL(HEC) = 12 mg/cu.m]. Based on these results a NOAEL of 80 ppm [NOAEL(HEC) = 8 mg/cu.m] for nasal olfactory epithelial changes in rats is established.

Because no significant target organ toxicity was noted in the 14-day or 13-week studies, a special 6-week target organ toxicity study at a near lethal concentration was conducted in F344 rats and B6C3F1 mice (Eustis et al., 1988; NTP, 1990). Groups of 5 animals/sex were exposed to 0 or 160 ppm (621 mg/cu.m) bromomethane 6 hours/day for either 3 consecutive days (rats), or 5 days/week over 2 weeks (rats and mice) or 6 weeks (rats). Fifteen mice/sex/dose were exposed to 0 or 160 ppm (621 mg/cu.m) 6 hours/day, 5 days/week, for 6 weeks. Endpoints studied included clinical observations, mortality, body and organ weights, hematology, clinical chemistry, urinalysis, gross pathology, and histopathology of a standard set of tissues, including the lungs and nasal turbinates. The female rats were the only group to demonstrate more than 50% survival, with mice being more sensitive than rats (mortality exceeded 50% after 6-8 exposures in both the male and female mice and after 14 exposures in the male rats). Because of the high mortality, the male and female mice and male rats were killed after 10, 8, or 14 exposures, respectively. Neurological signs exhibited by both rats and mice, but to a lesser extent in the rats, included lethargy and curling and crossing of hindlimbs, forelimb twitching, and tremors. Decreases in body weight gain were observed in the exposed animals as compared to controls (18% in the mice and 32% in the rats). The mean organ weights of most organs were

significantly reduced in both species. Notable hematological effects were seen mostly in the female mice and included decreased RBC and increased WBC counts. Target organs affected by exposure to 160 ppm bromomethane were the brain, kidney, nasal cavity, heart, adrenal gland, liver, and testes. Species differences were noted in the responses of these organs. For example, neuronal necrosis in the cerebral cortex, hippocampus, and thalamus of the brain were seen in the rats whereas neuronal necrosis was seen predominantly in the internal granular layer of the cerebellum of the mice. Nephrosis, characterized by degeneration, necrosis, and sloughing of the epithelium of the cortical convoluted tubules was seen in all of the exposed mice and was considered by the authors to be partially responsible for the increase in mortality, but these lesions were not observed in the rats. Degeneration and atrophy of the seminiferous tubules was observed in several of the exposed rats and mice, but was less severe in the mice. Olfactory epithelial degeneration was observed in the rats of both sexes, and this was seen to a lesser degree in the male mice, with only one female mouse exhibiting this lesion. Myocardial degeneration was seen in rats of both sexes, and to a lesser degree in the male mice. Atrophy of the inner zone of the adrenal cortex was observed in the female mice, and cytoplasmic vacuolation of the adrenal cortex was seen in rats.

In the chronic study (NTP, 1990), a total of 86 mice/sex/concentration were exposed to 0, 10, 33, or 100 ppm (0, 38.8, 128, or 388 mg/cu.m, respectively) bromomethane 6 hours/day, 5 days/week (duration-adjusted concentrations are 0, 6.93, 22.9, or 69.3 mg/cu.m, respectively). Exposures to 10 and 33 ppm were for 103 weeks, with interim sacrifices at 6 and 11 months. Exposure to 100 ppm produced 47% mortality in the males and 10% mortality in the females by 20 weeks, so exposure was discontinued in this group at this time and the surviving animals were observed for an additional 84 weeks, except for the females scheduled for the 15-month sacrifice. The endpoints studied were the same as those described for the 6-week target organ toxicity study in addition to neurobehavioral assessments in 16 mice/sex/group and neuropathological examination on 3-8 animals/sex/group at 20 weeks and 6, 15, and 24 months. Body weights were significantly depressed in the animals exposed to 100 ppm (33% in the males and 31% in the females) beginning at week 11 and persisting until study termination. Significant body weight changes were not observed in the lower exposure groups. Because of the reduced body weight in the 100-ppm animals, organ weight changes were difficult to interpret, but reduced absolute and relative thymus weights were observed in both the males and females exposed to 100 ppm bromomethane. Clinical signs of toxicity observed almost exclusively in the 100-ppm animals that persisted throughout the 103 weeks included tremors, abnormal posture, and limb paralysis. Functional neurobehavioral changes consisting of hypoactivity, a heightened startle response, and higher hindlimb grip scores and hot plate latency were observed in both sexes exposed to 100 ppm at various times during exposure, but were more pronounced in the males. The target organs of toxicity identified in this study were the brain, bone (sternum), heart, and nose, with lesions in these organs occurring more frequently in the males. In the brain, there was a statistically significant increase in the incidence of cerebellar degeneration in the animals

exposed to 100 ppm. Cerebral degeneration was also observed in these animals, but the incidence of this lesion was statistically significant in the males only. Because this lesion was observed more frequently in the animals that died prior to study termination, it may have contributed to the early mortality in this group. Dysplasia of the sternal bone marrow was observed at a statistically significantly increased rate in both the males and the females exposed to 100 ppm, but because it was observed more frequently in the animals that survived to study termination than in those that died early, it was not considered to be a contributing factor to the death of these animals. Myocardial degeneration and chronic cardiomyopathy were also observed at a statistically higher incidence in both males and females exposed to 100 ppm bromomethane, and occurred at a higher incidence in those animals dying early. Finally, a statistically significant increase in the incidence of olfactory epithelial necrosis and metaplasia was seen in the nasal cavities of both the male and female mice exposed to 100 ppm. Necrosis was seen only in the animals dying early, whereas metaplasia was exhibited mainly in those animals surviving until study termination. Histopathological changes in other organs were observed and considered to be secondary to stress and weight loss rather than a direct toxic effect of bromomethane. Animals exposed to lower concentrations did not exhibit significant increases in any of the lesions described above. Based on the results of this study, a NOAEL of 33 ppm (HEC = 4.4 mg/cu.m for respiratory effects and 23 mg/cu.m for extrarespiratory effects) and a LOAEL of 100 ppm (HEC = 13 mg/cu.m for respiratory effects and 69 mg/cu.m for extrarespiratory effects) are established based on toxicity in multiple organs.

Male Fischer 344 rats (10/group) were exposed to 0, 90, 175, 250, or 325 ppm (0, 350, 680, 971, or 1,262 mg/cu.m, respectively) bromomethane (99.9% pure) 6 hours/day for 5 days (Hurtt et al., 1987). The brain, nasal cavity, liver, kidney, adrenal glands, testes, and epididymides were examined histopathologically. The lungs were not examined. Three animals exposed to 325 ppm died after the fourth exposure. Diarrhea, hemoglobinuria, gait disturbances, convulsions and hepatocellular degeneration were observed in animals exposed to 250 ppm or greater; vacuolar degeneration of the zona fasciculata of the adrenal gland and cerebellar granule cell degeneration were observed in rats exposed at 175 ppm and greater. Minor alterations in testicular histology and cerebrocortical degeneration were observed in the 350-ppm exposure group. A concentration-dependent degeneration of the nasal olfactory sensory cells was observed in rats exposed to 175 ppm bromomethane or greater. This degeneration affected 50-80% of the olfactory mucosa, and was characterized by complete or partial destruction of the olfactory epithelium at the higher concentrations. Small foci of hepatocellular coagulative necrosis were observed in animals exposed to the two highest concentrations. No exposure-related lesions were noted in the kidneys.

In a subsequent study, Hurtt et al. (1988) investigated the ability and time-course of the olfactory epithelium to regenerate following acute exposure to bromomethane. Male Fischer 344 rats were exposed to 0 (n=5) or 200 ppm (n=40) 99.9% pure bromomethane (777 mg/cu.m) 6 hours/day

for 1-5 days. Five animals/group were killed after 1, 3, or 5 days of exposure and 1, 2, 3, 5, or 10 weeks after cessation of treatment. In a companion study, 6 animals/group were exposed to 0, 90, or 200 ppm (0, 350, or 777 mg/cu.m) bromomethane for 6 hours and olfactory function was studied by determining the effects of bromomethane on the ability of food-deprived animals to locate buried food pellets. Additional animals similarly exposed were killed at various times following the single 6-hour exposure to assess the state of morphological regeneration at the time of functional recovery. Only the nasal cavities were examined histopathologically in these studies. No clinical signs of toxicity were observed in the exposed animals. Extensive destruction of the olfactory epithelium, characterized by epithelial disruption, fragmentation, and exfoliation, was evident after a single 6-hour exposure to 90 or 200 ppm, with the most severe effects observed in the sustentacular and mature sensory cells, and the basal cell remaining intact. Regeneration of the olfactory epithelium, characterized at first by replacement with a squamous cell layer that increased in thickness, began by the third day of exposure and was essentially complete by 10 weeks after the last exposure. It is important to note that regeneration began even though exposure to bromomethane was still ongoing. Olfactory function was impaired in animals exposed to 200 ppm bromomethane, but not 90 ppm. Recovery of this function was evident by 4-6 days after exposure, which preceded morphological regeneration.

Similar results were obtained by Hastings (1990). In this study, rats were exposed to 200 ppm (777 mg/cu.m) bromomethane 4 hours/day 2 days/week for 2 weeks. Prior to exposure, rats were food-deprived and trained to find buried food pellets. Morphological as well as biochemical (carnosine content in the olfactory bulb, which is an indication of the integrity of the olfactory primary sensory neurons) studies were performed as well to assess the integrity of the olfactory epithelium. Extensive damage to the olfactory epithelium was seen, as evidenced by both morphological analysis and decreased carnosine content after a single 4-hour exposure. Olfactory function was also impaired after 4 hours, as evidenced by the inability of the rats to find the buried food pellets. However, olfactory function began to return after the second week of exposure and the animals performed as well as their controls by the end of the exposure period whereas regeneration of the olfactory epithelium, as indicated by morphological and biochemical analysis was not complete until 30 days from the start of exposure.

The most common signs of acute intoxication with bromomethane in humans are neurotoxic in nature and include headache, dizziness, fainting, apathy, weakness, tiredness, giddiness, delirium, stupor, psychosis, loss of memory, mental confusion, speech impairment, visual effects, limb numbness, tremors, muscle twitching, paralysis, ataxia, seizures, convulsions, and unconscious. Several studies have been conducted on the longer-term effects of occupational exposure to bromomethane. None of these studies can serve as the basis for the derivation of an RfC for bromomethane because of concurrent exposures to other chemicals, inadequate quantitation of exposure levels and/or durations, and other deficits in study design.

In a cross-sectional occupational study conducted by Anger et al. (1986), soil and structural fumigators underwent a neurological examination. The exposure group was blinded to the physician giving the examination. Most of the structural fumigators used both bromomethane (MB) and sulfuryl fluoride (SF). The formation of the study groups was based on the estimated time devoted to bromomethane and sulfuryl fluoride fumigation activities, and estimated length of time in the occupation. Four groups were formed: the MB group (n=32) consisted of structural fumigators using MB 80% or more of the time and soil fumigators using the mixture MB and chloropicrin; the SF group (n=24) consisted of structural fumigators who used SF 80% or more of the time; group COMB (n=18) consisted of workers using both MB and SF 40-60% of the time, the reference group (Group R, n=29) consisted of those workers who were not directly exposed to fumigants, but worked in the fumigation industry. The workers in the exposed groups had been in the profession for 1 or more years and had fumigated a house or field within the last 50 days. More symptoms were reported in the exposed groups than in the reference population: 78-83% and 41% respectively showed symptoms. The difference was significant for the MB and COMB groups when compared to Group R. The MB group did not perform as well as referents on several behavioral tests, including tests of cognitive function, reflexes, sensory and visual effects. Although this study suggests mild neurological effects of exposure to methyl bromide, it is difficult to draw any conclusions between exposure and effect because of the confounding factors. The exposed and reference groups were not well matched for age; use of prescription medication, alcohol, or illegal drugs within 2 days of the testing; education; or ethnic group. In addition, participation in the study was voluntary and no information is provided on the use of personal protective equipment in these groups.

Herzstein and Cullen (1990) reported on 4 cases of bromomethane toxicity at a nursery following the removal of polyethylene sheets covering soil fumigated with 98% bromomethane and 2% chloropicrin. Four workers involved in removing the tarp wore no respiratory protection, and had no training in the handling or Hazards of bromomethane. On the second day, all four workers noted fatigue and lightheadedness. After arriving home, three of the workers developed severe coughing, chest tightness, nausea, vomiting, headaches, and tremulousness during the night. Three workers were found to have either ataxia, tremor, or both. Blood bromide levels were not performed. The symptoms continued to improve without treatment. Upper- and lower-extremity paresthesias and reduced hand dexterity were reported in two workers at 3 weeks post-exposure. There were no long-term adverse effects after 18 months of follow-up.

The first reported study on the effects of short-term and repeated exposure to bromomethane in experimental animals was conducted by Irish et al. (1940). In the first set of experiments, rats and rabbits were exposed once to 420-50,000 mg/cu.m bromomethane for varying lengths of time. Concentrations of bromomethane greater than or equal to 10,000 mg/cu.m were lethal to 100% of the animals within 6-132 minutes. Deaths also occurred at 6-36 hours after exposure to concentrations less than 10,000 mg/cu.m. Clinical signs observed in rats exposed to less than

10,000 mg/cu.m included roughening of the fur, hunching of the back, drowsiness, heavy breathing, and lacrimation. Nasal irritation and lacrimation were observed, in addition to the signs mentioned above, at higher concentrations. Rabbits did not exhibit these signs. However, in rats exposed to greater than 1000 mg/cu.m for 20 hours, a hyperexcitable state was observed, whereas rabbits exposed to the same concentration exhibited paralysis. Evidence of pulmonary irritation (congestion and edema) was found (predominantly in the rat) following exposures to 1,000-20,000 mg/cu.m.

In subsequent studies, rats (n=135), rabbits (n=104), guinea pigs (n=98) and female rhesus monkeys (n=13) were exposed to 0, 17, 33, 66, 100, or 220 ppm (0, 66, 128, 256, 388, or 853 mg/cu.m, respectively) 7-8 hours/day, 5 days/week for 6 months or until the majority exhibited severe reactions or died. The frank-effect-levels (increased mortality) were 100 ppm for rats, guinea pigs, and monkeys and 133 ppm for rabbits (Irish et al., 1940). Rabbits and monkeys exhibited paralysis after exposure to 66 ppm whereas rats and guinea pigs exhibited no adverse effects. Pulmonary damage was still seen in rabbits exposed to 33 ppm, but the monkeys appeared normal. None of the species exhibited adverse effects following repeated exposure to 17 ppm (66 mg/cu.m; Irish et al. 1940).

The brain and heart also appeared to be target organs following inhalation exposure to bromomethane in a study conducted by Kato et al. (1986). Male Sprague-Dawley rats (10-12/group) were exposed to 150 ppm (583 mg/cu.m) bromomethane (purity unspecified) 4 hours/day, 5 days/week for 11 weeks (duration-adjusted to 69.3 mg/cu.m). Focal necrosis and fibrosis of coronary ventricles and papillary muscle disorders were observed in the exposed animals. In the same study, male Sprague-Dawley rats (10-12/group) were exposed to 0, 200, 300, or 400 ppm (0, 777, 1,165, or 1,553 mg/cu.m) 4 hours/day, 5 days/week for 6 weeks (duration-adjusted concentrations are 0, 92.5, 139, and 185 mg/cu.m, respectively). Focal necrosis and fibrosis of coronary ventricles and papillary muscle were observed in all exposed animals. Neurological dysfunction (ataxia, paralysis) were reported at levels at and exceeding 300 ppm; necrosis in the bilateral regions of the dorso-external cortex of the cerebral hemisphere was observed in animals exposed at 400 ppm. Testicular atrophy with suppression of spermatogenesis was apparent in 6 of the 8 the animals exposed to 400 ppm. Although the lungs appeared to be one of the tissues examined histopathologically, respiratory effects were not addressed in the descriptions of either experiment.

Neurobehavioral effects of bromomethane inhalation were studied in rats and rabbits by Anger et al. (1981). In one set of experiments, Sprague-Dawley rats and New Zealand white rabbits were exposed to 0 (n=2) or 65 ppm (252 mg/cu.m, n=6) 7.5 hours/day, 4 days/week for 4 weeks. Neurobehavioral testing, consisting of conduction velocity in the sciatic and ulnar nerves (rats and rabbits), eye-blink reflex (rabbits), open field activity (rats), and grip/coordination (rats) were conducted weekly. Exposed rabbits exhibited depressed body weight gain as compared

with the controls, and signs of hind limb paralysis were evident during the last week of exposure. Statistically significant decreases in the eyeblink reflex magnitude and in nerve conduction velocity were also observed in the exposed rabbits. In contrast, no effects on weight gain, grip/coordination, or nerve conduction velocity were observed in the rats exposed to 65 ppm for 4 weeks. The LOAEL for neurological effects in rabbits and the NOAEL for rats is 65 ppm. In another experiment that was performed as part of this study, Sprague-Dawley rats were exposed to 0 or 55 ppm (214 mg/cu.m) bromomethane 6 hour/day, 5 day/week for 36 weeks. Neurobehavioral tests (conduction velocity in the sciatic and ulnar nerves, open-field activity, and grip/coordination) conducted at 25- to 30-day intervals did not reveal any exposure-related effects.

In a subsequent study performed by this group (Russo et al., 1984) that was designed to assess the neurotoxic effects of bromomethane in rabbits following longer-term exposure at lower concentration, male New Zealand white rabbits were exposed to 0 (n=2) or 26.6 ppm (103 mg/cu.m, n=6) 99% pure bromomethane 7.5 hours/day, 4 days/week for 8 months (Russo et al., 1984). Exposure concentrations were monitored every 12 minutes by an infrared analyzer. Neurobehavioral tests examined the latency rates of the sciatic and ulnar nerves and the amplitude of the eyeblink reflex of the orbicularis oculi muscle. No other parameters, including respiratory effects, were monitored. No exposure-related neurological effects were observed [NOAEL(HEC) = 23 mg/cu.m]. As part of this study, the animals exposed to 252 mg/cu.m bromomethane for 4 weeks (previously discussed; Anger et al., 1981) were allowed to recover for 6-8 weeks and the neurological tests were repeated. The animals demonstrated partial, but not complete recovery within the 6-week period. Therefore rabbits, which are sensitive to the neurotoxic effects of high-level exposure to bromomethane, can tolerate long-term low-level exposure to bromomethane, and appear to be able to recover from severe neurological effects after cessation of exposure.

Morrissey et al. (1988), using data obtained from the 13-week NTP (1990) study in rats and mice, evaluated testis, epididymis, and cauda epididymis weights; caudal sperm motility and count; sperm head morphology; average estrous cycle length; and relative frequency of different estrous stages to assess the potential reproductive effects of bromomethane. In mice, they found that inhalation exposure to bromomethane resulted in an increase in the relative weights of the epididymis and testis, a decrease in sperm density, and an increase in the percentage of abnormal sperm. In the rats, a decrease in absolute cauda epididymis and absolute and relative epididymis weights, an increase in relative testis weight, and a decrease in sperm motility occurred as a result of subchronic inhalation exposure to bromomethane. No effects on estrous cycle length were noted. This study is an evaluation of a screening method for reproductive toxicants and was applied to 50 subchronic studies carried out by the NTP. The exposure levels at which these effects were found were not specified.

Male Fischer 344 rats (75/group) were exposed to 0 or 200 ppm bromomethane (777 mg/cu.m) 6 hours/day for 5 consecutive days and sacrificed on various days beginning on day 1 of exposure through 68 days after termination of exposure. Plasma testosterone and testicular glutathione levels were depressed, but returned to control levels within 3 days after exposure had ended. No effects on spermatogenesis, sperm quality, or testicular weight or histology were noted (Hurtt and Working, 1988).

Female Wistar rats (n=39-45) were exposed to 0, 20, or 70 ppm (0, 78, or 272 mg/cu.m, respectively) bromomethane 7 hours/day, 5 days/ week for 3 weeks, mated and exposed during gestational days 1-19. The study design included groups at each exposure level exposed pregestationally, during gestation, and both, as well as a control. At gestational day 21, litters were evaluated for fetotoxicity and live fetuses were examined for external, visceral (about 1/2 of fetuses), and skeletal abnormalities. Maternal organ weights for liver, kidney, and lung, and histopathology on 8 animals/group on ovaries, uterus, kidney, lung, and trachea were performed. No mortality or change in organ weights were observed and body weight was decreased during gestation but was not different than controls at full term. Histological effects observed in the lung and kidney were not clearly exposure-related due to the small sample size and high control incidence. There was no effect on pregnancy rate or fetal size. There were 31-38 litters/group examined and no effect on embryotoxicity, fetal viability, or fecundity measures was observed. There was no increase in malformations. The NOAEL for reproductive toxicity (changes in fertility rate) and maternal and fetal toxicity in rats is 70 ppm (Sikov et al., 1981; Hardin et al., 1981).

Female New Zealand white rabbits (25/group) were exposed to 0, 20, or 70 ppm (0, 78, or 272 mg/cu.m, respectively) bromomethane 7 hours/day, 5 days/week for 3 weeks during gestational days 1-24. Evaluation of developmental effects was the same as in the rat study except that all fetuses were evaluated for visceral abnormalities. In the 70-ppm group, severe neurotoxic effects occurred and 24/25 animals died. No effects on body weight, organ weight, or histology were observed in maternal animals exposed to 20 ppm. There was no effect on pregnancy rate or fetal size. There were 13 litters in the group exposed to 20 ppm examined and no effect on embryotoxicity, fetal viability, or fecundity measures was observed. There was no increase in malformations. The NOAEL for maternal and fetal toxicity in rabbits is 20 ppm (Sikov et al., 1981; Hardin et al., 1981).

Breslin et al. (1990) performed a developmental study in rabbits in which New Zealand rabbits (26/group) were exposed to 0, 20, 40, or 80 ppm (0, 78, 155, or 311 mg/cu.m, respectively) methyl bromide 6 hours/day on gestation days 6-19. Maternal toxicity at 80 ppm included reduced body weight and weight gain. Clinical signs of central nervous system toxicity were observed at 80 ppm. There was no effect on pre- or postimplantation loss, litter size, or fetal body weights. There was an increase in agenesis of the gall bladder and fused sternebrae at 80

ppm. The NOAEL for maternal toxicity and developmental effects in this study is 40 ppm [NOAEL(HEC) = 155 mg/cu.m].

American Biogenics Corporation (1986) conducted a two-generation reproduction study in Sprague-Dawley rats. Groups of 25 rats/sex/dose were exposed by inhalation to methyl bromide vapor at 0, 3, 30, or 90 ppm (0, 12, 117, or 350 mg/cu.m) 6 hours/day, 5 days/week during the premating, gestation, and lactation periods for 2 generations. In F0 male rats, exposure at 90 ppm caused statistically significant decreases in body weight gain during the premating period, final body weight, and total weight gain. No treatment- related changes in reproductive organs were noted. Also, no adverse effects were found on the progeny and reproductive parameters examined. In second generation (F1) animals, no adverse effects were found on body weights, histopathology of reproductive organs, or reproductive parameters measured. However, a statistically significant concentration-related reduction in body weights at 28 days was noted in F2 males and females at 30 ppm and 90 ppm. Although significant changes were seen in some of the mean organ weights and organ-to-body weight ratios in F0, F1, and F2 generation animals, no histopathology changes were seen in these organs. Therefore, the biological significance of these findings if any is not clear. Under the conditions of the study, exposure to methyl bromide did not affect fertility in rats but decreased the body weights of parental rats and reduced the growth of neonatal rats. The NOAEL and LOAEL for these effects were 30 and 90 ppm for adult rats and 3 and 30 ppm for neonates, respectively.

Medinsky et al. (1985) and Bond et al. (1985) conducted a series of experiments to assess the uptake, distribution, and excretion of bromomethane in rats following inhalation exposure. In one experiment, F344 rats were exposed to 1.6, 9, 170, or 310 ppm (6, 35, 660, or 1,203 mg/cu.m) radiolabeled bromomethane (nose-only) for 6 hours (Medinsky et al., 1985), and in the other, F344 rats were exposed to 9 ppm radiolabeled bromomethane for 6 hours (Bond et al., 1985). The percentage of total volume of inhaled radiolabeled bromomethane that was absorbed decreased in a concentration-related manner from 48+/-2% at the two lower concentrations to 27+/-4% at the highest concentration, which indicates that uptake of bromomethane is a saturable process. In both studies, inhaled bromomethane was distributed quickly throughout the body, and the highest concentrations were found in the lung, adrenal, kidney, liver, and nasal turbinates. By 65-66 hours after exposure, 75% of the radiolabel had been eliminated. The amount of bromomethane eliminated was linearly related to the amount absorbed (Medinsky et al., 1985). Excretion of bromomethane and its metabolites does not appear to be a concentration dependent (i.e., saturable) process, once absorbed.

I.B.5. Confidence in the Inhalation RfC

Study — Medium
Database — High
RfC -- High

The Reuzel et al. (1987, 1991) chronic study was well conducted, used an appropriate number of animals and exposure levels, and included thorough histopathological examination of the respiratory tract; however, it is given a medium confidence rating because it did not identify a NOAEL. The LOAEL identified in this study is supported by the effects seen in rats in the subchronic NTP (1990) study and mice in the chronic NTP (1990) study, as well as in subacute and subchronic studies in rats (Hastings, 1990; Hurtt et al., 1987, 1988). The database is given a high confidence rating because there is a chronic inhalation study in two species supported by subchronic inhalation studies in several species, and because data are available on the developmental and reproductive effects of bromomethane as well as its pharmacokinetics following inhalation exposure. Based on the confidence in the database and study, high confidence in the RfC follows.

I.B.6. EPA Documentation and Review of the Inhalation RfC

Source Document — This assessment is not presented in an existing U.S. EPA document.

Other EPA Documentation — U.S. EPA, 1986, 1987

Agency Work Group Review — 10/13/1988, 09/19/1989, 08/15/1991, 12/10/1991

Verification Date — 12/10/1991

Screening-Level Literature Review Findings — A screening-level review conducted by an EPA contractor of the more recent toxicology literature pertinent to the RfC for Bromomethane conducted in November 2001 identified one or more significant new studies. IRIS users may request the references for those studies from the IRIS Hotline at hotline.iris@epa.gov or (202)566-1676.

I.B.7. EPA Contacts (Inhalation RfC)

Please contact the IRIS Hotline for all questions concerning this assessment or IRIS, in general, at (202)566-1676 (phone), (202)566-1749 (FAX) or hotline.iris@epa.gov (internet address)

II. Carcinogenicity Assessment for Lifetime Exposure

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide
Last Revised — 06/01/1989

Section II provides information on three aspects of the carcinogenic assessment for the substance in question; the weight-of-evidence judgment of the likelihood that the substance is a human carcinogen, and quantitative estimates of risk from oral exposure and from inhalation exposure. The quantitative risk estimates are presented in three ways. The slope factor is the result of application of a low-dose extrapolation procedure and is presented as the risk per (mg/kg)/day. The unit risk is the quantitative estimate in terms of either risk per ug/L drinking water or risk per ug/cu.m air breathed. The third form in which risk is presented is a drinking water or air concentration providing cancer risks of 1 in 10,000, 1 in 100,000 or 1 in 1,000,000. The rationale and methods used to develop the carcinogenicity information in IRIS are described in The Risk Assessment Guidelines of 1986 (EPA/600/8-87/045) and in the IRIS Background Document. IRIS summaries developed since the publication of EPA's more recent Proposed Guidelines for Carcinogen Risk Assessment also utilize those Guidelines where indicated (Federal Register 61(79):17960-18011, April 23, 1996). Users are referred to Section I of this IRIS file for information on long-term toxic effects other than carcinogenicity.

II.A. Evidence for Human Carcinogenicity

II.A.1. Weight-of-Evidence Characterization

Classification — D; not classifiable as to human carcinogenicity

Basis — Inadequate human and animal data: a single mortality study from which direct exposure associations could not be deduced and studies in several animal species with too few animals, too brief exposure or observation time for adequate power. Bromomethane has shown genotoxicity.

II.A.2. Human Carcinogenicity Data

Inadequate. A prospective mortality study was reported for a population of 3579 white male chemical workers. The men, employed between 1935 and 1976, were potentially exposed to 1,2-dibromo-3-chloropropane, 2,3-dibromopropyl phosphate, polybrominated biphenyls, DDT, and several brominated organic and inorganic compounds (Wong et al., 1984). Overall mortality for the cohort, as well as for several subgroups, was less than expected. Of the 665 men exposed to methyl bromides (the only common exposure to organic bromides), two died from testicular

cancer, as compared with 0.11 expected. This finding may be noteworthy as testicular cancer is usually associated with a low mortality rate. Therefore, there could be more cancer cases than there appear to be based on mortality. The authors noted that it was difficult to draw definitive conclusions as to causality because of the lack of exposure information and the likelihood that exposure was to many brominated compounds.

II.A.3. Animal Carcinogenicity Data

Inadequate. Bromomethane was administered by gavage to groups of 10 male and female Wistar rats (Danse et al., 1984). Animals were administered doses of 0, 0.4, 2, 10, or 50 mg/kg/day bromomethane in arachis oil 5 days/week for 13 weeks, at which time the experiment was terminated. There was an apparent dose-related increase in diffuse hyperplasia of the forestomach. The authors reported a forestomach papilloma incidence of 2/10 in the high-dose males and forestomach carcinoma incidences of 7/10 and 6/10 in the high-dose males and females, respectively. These results were subsequently questioned (U.S. EPA, 1985; Schatzow, 1984). A panel of NTP scientists reevaluated the histological slides and concluded that the lesions were hyperplasia and inflammation rather than neoplasia.

Rosenblum et al. (1960) reported a 1-year study in which beagle dogs (4/treatment group, 6/control) were provided diets fumigated to residue levels of 0, 35, 75, or 150 ppm bromomethane. No tumors were observed at any dose level; however, there was no indication that the dogs were examined for tumors. In addition, 1-year observation is considered to be inadequate by the EPA for tumor induction in dogs.

In an earlier study (Irish et al., 1940) small numbers of rats, guinea pigs, rabbits and monkeys were exposed by inhalation to bromomethane at doses ranging from 0.065 to 0.85 mg/L air. Exposures were for 7.5 to 8 hours/day, 5 days/week for up to 6 months. The authors reported that the highest dose produced acutely toxic effects in all species, but no tumors were observed at any dose level. The short duration of exposure and observation are considered inadequate by the EPA.

Bromomethane is currently on test at NTP.

II.A.4. Supporting Data for Carcinogenicity

Bromomethane has been shown to produce mutations in Salmonella strains sensitive to alkylating agents and to E. coli both with and without the addition of a metabolic activation system (Voogd et al., 1982; Moriya et al., 1983; Kramers et al.,1985; Djalali-Behzad et al., 1981). Bromomethane was also mutagenic in a modification of the standard Salmonella assay employing vapor phase exposure (Simmon and Tardiff, 1978; Simmon, 1978, 1981; Simmon et

al., 1977). Bromomethane was observed to be mutagenic for Drosophila and for mouse lymphoma cells (Voogd et al., 1982; Kramers et al., 1985).

Bromomethane is structurally related to bromoethane which, when tested in mice and rats of both sexes, has shown clear evidence of carcinogenicity in some cases and equivocal in others. NTP (1988) conducted an inhalation bioassay on bromoethane, and the results were recently released in a draft report. Groups of F344/N rats (50/sex) and B6C3F1 mice (50/sex) were exposed to 0, 100, 200 or 400 ppm bromoethane 6 hours/day for 5 days/week. A statistically significant increase in uterine adenomas, adenocarcinomas, or squamous cell carcinomas was observed in female mice exposed to 200 and 400 ppm, indicating clear evidence of carcinogenic activity. Equivocal evidence of carcinogenic activity was reported for male and female rats and male mice. While alveolar/bronchiolar adenomas or carcinomas and pheochromocytomas were observed in male rats, the incidences were not dose-related and were within the historical ranges for NTP studies. Granular cell tumors of the brain were also observed in male rats and, although not statistically significant, the incidence was higher than historical incidence in either the study lab or NTP studies. The incidence of alveolar/bronchiolar neoplasms in exposed male mice was marginally greater than control or historical incidence. An increased incidence of gliomas in exposed female rats was significant by the trend test; however, the incidence was not significantly greater when compared with the controls in the study and the controls used in NTP studies.

II.B. Quantitative Estimate of Carcinogenic Risk from Oral Exposure

Not available

II.C. Quantitative Estimate of Carcinogenic Risk from Inhalation Exposure

Not available

II.D. EPA Documentation, Review, and Contacts (Carcinogenicity Assessment)

II.D.1. EPA Documentation

Source Document — U.S. EPA, 1985, 1986, 1987

The Health and Environmental Effects Profile for Methyl Bromide and the Health Effects Assessment for Bromoethane received Agency Review.

II.D.2. EPA Review (Carcinogenicity Assessment)

Agency Work Group Review — 02/01/1989, 03/01/1989

Verification Date — 03/01/1989

Screening-Level Literature Review Findings — A screening-level review conducted by an EPA contractor of the more recent toxicology literature pertinent to the cancer assessment for Bromomethane conducted in November 2001(revised May 2003) identified one or more significant new studies. IRIS users may request the references for those studies from the IRIS Hotline at hotline.iris@epa.gov or (202)566-1676.

II.D.3. EPA Contacts (Carcinogenicity Assessment)

Please contact the IRIS Hotline for all questions concerning this assessment or IRIS, in general, at (202)566-1676 (phone), (202)566-1749 (FAX) or hotline.iris@epa.gov (internet address).

III. [reserved]
IV. [reserved]
V. [reserved]

VI. Bibliography

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide

VI.A. Oral RfD References

Danse, L.H.J.C., F.L. van Velsen and C.A. van der Heijden. 1984. Methylbromide: Carcinogenic effects in the rat forestomach. Toxicol. Appl. Pharmacol. 72: 262-271.

Hardin, B.D., G.P. Bond, M.R. Sikov, F.D. Andrew, R.P. Beliles and R.W. Niemeier. 1981. Testing of selected workplace chemicals for teratogenic potential. Scand. J. Work Environ. Health. 7: 66-75.

Irish, D.D., E.M. Adams, H.C. Spencer and V.K. Rowe. 1940. The response attending exposure of laboratory animals to vapors of methyl bromide. J. Ind. Hyg. Toxicol. 22: 218-230.

Rosenblum, I., A.A. Stein, and G. Eisinger. 1960. Chronic ingestion by dogs of methyl bromide-fumigated food. Arch. Environ. Health. 1: 316-323.

Sikov, M.R., W.C. Cannon, D.B. Carr, R.A. Miller, L.F. Montgomery and D.W. Phelps. 1980. Teratologic assessment of butylene oxide, styrene oxide and methyl bromide. NTIS PB 81-16851. 87 p.

U.S. EPA. 1986. Health and Environmental Effects Profile for Methyl Bromide. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington DC.

U.S. EPA. 1987. Drinking Water Health Advisory for Bromomethane. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Drinking Water, Washington DC.

VI.B. Inhalation RfC References

American Biogenics Corporation. 1986. Two-generation reproduction study via inhalation in albino rats using methyl bromide. Final Report. American Biogenics Corporation Study 450-1525, OTS 0515364, sponsored by the Methyl Bromide Panel.

Anger, W.K., J.V. Setzer, J.M. Russo, W.S. Brightwell, R.G. Wait and B.L. Johnson. Neurobehavioral effects of methyl bromide inhalation exposures. Scand. J. Work Environ. Health. 7(Suppl. 4): 40-47.

Anger, W.K., L. Moody, J. Burg, W.S. Brightwell, B.J. Taylor, J.M. Russo, et al. 1986. Neurobehavioral evaluation of soil and structural fumigators using methyl bromide and sulfuryl fluoride. Neurotoxicology. 7(3): 137-156.

Bond, J.A., J.S. Dutcher, M.A. Medinsky, R.F. Henderson and L.S. Birnbaum. 1985. Disposition of [14C]methyl bromide in rats after inhalation. Toxicol. Appl. Pharmacol. 78: 259-267.

Breslin, W.J., C.L. Zablotny, G.J. Brabley and L.G. Lomax. 1990. Methylbromide inhalation teratology study in New Zealand white rabbits. Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI. Study No. K-000681-033. OTS Number 8EHQ-1189- 0844 S.

Eustis, S.L., S.B. Haber, R.T. Drew and R.S.H. Yang. 1988. Toxicology and pathology of methyl bromide in F344 rats and B6C3F1 mice following repeated inhalation exposure. Fund. Appl. Toxicol. 11: 594-610.

Hardin, B.D., G.P. Bond, M.R. Sikov, F.D. Andrew, R.P. Beliles and R.W. Niemeier. 1981. Testing of selected workplace chemicals for teratogenic potential. Scand. J. Environ. Health. 7(Suppl. 4): 66-75.

Hastings, L. 1990. Sensory neurotoxicology: Use of the olfactory system in the assessment of toxicity. Neurotoxicol. Teratol. 12: 455-459.

Herzstein, J. and M.R. Cullen. 1990. Methyl bromide intoxication in four field-workers during removal of soil fumigation sheets. Am. J. Ind. Med. 17: 321-326.

Hurtt, M.E. and P.K. Working. 1988. Evaluation of spermatogenesis and sperm quality in the rat following acute inhalation exposure to methyl bromide. Fund. Appl. Toxicol. 10(3): 490-498.

Hurtt, M.E., K.T. Morgan and P.K. Working. 1987. Histopathology of acute toxic responses in selected tissues from rats exposed by inhalation to methyl bromide. Fund. Appl. Toxicol. 9: 352-365.

Hurtt, M.E., D.A. Thomas, P.K. Working, T.M. Monticello and K.T. Morgan. 1988. Degeneration and regeneration of the olfactory epithelium following inhalation exposure to methyl bromide: Pathology, cell kinetics, and olfactory function. Toxicol. Appl. Pharmacol. 94: 311-328.

Irish, D.D., E.M. Adams, H.C. Spencer and V.K. Rowe. 1940. The response attending exposure of laboratory animals to vapors of methyl bromide. J. Ind. Hyg. Toxicol. 22(6): 218-230.

Kato, N., S. Morinobu and S. Ishizu. 1986. Subacute inhalation experiment for methyl bromide in rats. Indust. Health. 24: 87-103.

Medinsky, M.A., J.S. Dutcher, J.A. Bond, R.F. Henderson, J.L Mauderly, M.B. Snipes, et al. 1985. Uptake and excretion of [14C]methyl bromide as influenced by exposure concentration. Toxicol. Appl. Pharmacol. 78: 215-225.

Morrissey, R.E., B.A. Schwetz, J.C. Lamb IV, M.D. Ross, J.L. Teague and R.W. Morris. 1988. Evaluation of rodent sperm, vaginal cytology, and reproductive weight data from National Toxicology Program 13-week studies. Fund. Appl. Toxicol. 11: 343-358.

NTP (National Toxicology Program). 1990. Toxicology and carcinogenesis studies of methyl bromide (CAS No. 74-83-9) in B6C3F1 mice (inhalation studies). NTP TR 385, NIH Publication No. 91-2840. Peer Review Draft.

Reuzel, P.G.J., C.F. Kuper, H.C. Dreef-van der Meulen and V.M.H. Hollanders. 1987. Chronic (29-month) inhalation toxicity and carcinogenicity study of methyl bromide in rats. Report No. V86.469/221044. Netherlands Organization for Applied Scientific Research, Division for Nutrition and Food Research, TNO. EPA/OTS Document No. 86-8700001202.

Reuzel, P.G.J., H.C. Dreef-van der Meulen, V.M.H. Hollanders, C.F. Kuper, V.J. Feron and C.A. van der Heijden. 1991. Chronic inhalation toxicity and carcinogenicity study of methyl bromide in Wistar rats. Fd. Chem. Toxic. 29(1): 31-39.

Russo, J.M., W.K. Anger, J.V. Setzer and W.S. Brightwell. 1984. Neurobehavioral assessment of chronic low-level methyl bromide exposure in the rabbit. J. Toxicol. Environ. Health. 14: 247-255.

Sikov, M.R., W.C. Cannon, D.B. Carr, R.A. Miller, L.F. Montgomery and D.W. Phelps. 1981. Teratologic assessment of butylene oxide, styrene oxide and methyl bromide. Battelle Pacific Northwest Laboratory, Richland, WA, for the National Institute for Occupational Safety and Health, Cincinnati, OH.

U.S. EPA. 1986. Health and Environmental Effects Profile for Methyl Bromide. Final Draft. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 1987. Health Effects Assessment for Bromomethane. Final Draft. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for the Office of Solid Waste and Emergency Response, Washington, DC.

VI.C. Carcinogenicity Assessment References

Danse, L.H.D.C., F.L. van Velsen and C.A. Van der Heijden. 1984. Methylbromide: Carcinogenic effects in the rat forestomach. Toxicol. Appl. Pharmacol. 72: 262-271.

Djalali-Behzad, G., S. Hussain, S. Osterman-Golker and D. Segerback. 1981. Estimation of genetic risks of alkylating agents. VI. Exposure of mice and bacteria to methyl bromide. Mutat. Res. 84(1): 1-10.

Irish, D.D., E.M. Adams, H.C. Spencer and V.K. Rowe. 1940. The response attending exposure of laboratory animals to vapors of methyl bromide. J. Ind. Hyg. Toxicol. 22: 218-230.

Kramers, P.G.N, C.E. Voogd, A.G.A.C. Knaap and C.A. Van der Heijden. 1985. Mutagenicity of methyl bromide in a series of short-term tests. Mutat. Res. 155(1-2): 41-47.

Moriya, M., T. Ohta, K. Watanabe, T. Miyazawa, K. Kato and Y. Shirasu. 1983. Further mutagenicity studies on pesticides in bacterial reversion assay systems. Mutat. Res. 116(3-4): 185-216.

NTP (National Toxicology Program). 1988. NTP technical report on the toxicology and carcinogenesis studies of bromomethane (CAS No. 74-96-4) in F344/N rats and B6C3F1 mice (inhalation studies). NIH Publication No. 89- 2818. Peer Review Date: October 3, 1988.

Rosenblum, I., A.A. Stein and G. Eisinger. 1960. Chronic ingestion by dogs of methyl bromide-fumigated food. Arch. Environ. Health. 1: 316-323.

Schatzow, S. 1984. Memorandum to D. Clay, November 9, 1984. FXI-OTS-1184- 0327. Supplement, Sequence D.

Simmon, V.F. 1978. Structural correlations of carcinogenic and mutagenic alkyl halides. FDA Publ(US); (FDA-78-1046): 163-171.

Simmon, V.F. 1981. Applications of the Salmonella/Microsome Assay. Short- Term Tests. Chem. Carcinog. p.\120-126.

Simmon, V.F. and R.G. Tardiff. 1978. The mutagenic activity of halogenated compounds found in chlorinated drinking water. Water Chlorination: Environ. Impact Health Eff. Proc. Conf. 2: 417-431.

Simmon, V.F., K. Kauhanen and R.G. Tardiff. 1977. Mutagenic activity of chemicals identified in drinking water. Dev. Toxicol. Environ. Sci. 2: 249-258.

U.S. EPA. 1985. Chemical Hazard Information Profile. Draft Report. Methyl Bromide. Rev. Feb. 20, 1985. U.S. EPA, OTS, Washington, DC.

U.S. EPA. 1986. Health and Environmental Effects Profile for Methyl Bromide. Final Draft. ECAO-CIN-P182, June, 1986.

U.S. EPA. 1987. Health Effects Assessment for Bromoethane. Final Draft. ECAO-CIN-H090. June, 1987.

Voogd, C.E., A.G.A.C. Knaap, C.A. Van der Heijden and P.G. Kramers. 1982. Genotoxicity of methylbromide in short-term assay systems. Mutat. Res. 97: 233.

Wong, O., W. Brocker, H.V. Davis and G.S. Nagle. 1984. Mortality of workers potentially exposed to organic and inorganic brominated chemicals, DBCP, TRIS, PBB, and DDT. Br. J. Ind. Med. 41: 15-24.

VII. Revision History

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide

Date	Section	Description
06/30/1988	I.A.	Withdrawn; new RfD verified (in preparation)

Date	Section	Description
09/26/1988	I.A.	Oral RfD summary replaced
06/01/1989	II.	Carcinogen summary on-line
04/01/1992	I.B.	Inhalation RfC summary on-line
12/03/2002	I.A.6., I.B.6., II.D.2.	Screening-Level Literature Review Findings message has been added.

VIII. Synonyms

Substance Name — Bromomethane
CASRN — 74-83-9
Primary Synonym — Methyl bromide
Last Revised — 01/31/1987

- 74-83-9
- Brom-o-gas
- Bromomethane
- Curafume
- Dowfume MC-2 Soil Fumigant
- Dowfume MC-33
- Edco
- Embafume
- Halon 1001
- Haltox
- Iscobrome
- Kayafume
- MB
- MBX
- MEBR
- Metafume
- Methane, Bromo-
- Methogas

- Methyl bromide
- Monobromomethane
- Pestmaster
- Profume
- R40B1
- Rotox
- Terabol
- Terr-o-gas 100
- Zytox