



EUROPEAN MEDICINES AGENCY  
SCIENCE MEDICINES HEALTH

23 July 2015  
EMA/CHMP/ICH/458894/2015  
Committee for Human Medicinal Products

## Application of the principles of the ICH M7 guideline to calculation of compound-specific acceptable intakes

### Step 2b

|   |                 |
|---|-----------------|
| Transmission to CHMP                          | July 2015       |
| Adoption by CHMP for release for consultation | 23 July 2015    |
| Start of public consultation                  | 4 August 2015   |
| End of consultation (deadline for comments)   | 3 February 2016 |

Comments should be provided using this [template](#). The completed comments form should be sent to [ich@ema.europa.eu](mailto:ich@ema.europa.eu)



# Application of the principles of the ICH M7 guideline to calculation of compound-specific acceptable intakes

## Table of contents

|  |           |
|--|-----------|
| <b>1. Application of the principles of the ICH M7 guideline to calculation of compound-specific acceptable intakes .....</b> | <b>6</b>  |
| 1.1. Introduction.....   | 6         |
| 1.2. Methods .....   | 6         |
| 1.2.1. Standard method.....  | 7         |
| 1.2.2. Consideration of alternative methods for calculation of AI .....  | 9         |
| 1.2.3. Non-linear (Threshold) mode of action and calculation of permissible daily exposure (PDE) .....                       | 9         |
| 1.2.4. Acceptable limit based on exposure in the environment, e.g., in the diet .....  | 10        |
| 1.3. References .....  | 10        |
| <b>2. Acceptable intakes (AIs) or permissible daily exposures (PDEs).....</b>  | <b>11</b> |
| <b>3. Acrylonitrile (CAS# 107-13-1) .....</b>  | <b>13</b> |
| 3.1. Potential for human exposure .....  | 13        |
| 3.2. Mutagenicity/g enotoxicity .....  | 13        |
| 3.3. Carcinogenicity .....   | 13        |
| 3.4. Mode of action for carcinogenicity.....   | 16        |
| 3.5. Regulatory and/or published limits .....  | 17        |
| 3.6. Acceptable Intake (AI) .....  | 17        |
| 3.6.1. Rationale for selection of study for AI calculation.....  | 17        |
| 3.6.2. Calculation of AI: .....  | 17        |
| 3.7. References .....  | 17        |
| <b>4. Aniline (CAS# 62-53-3) and Aniline Hydrochloride (CAS# 142-04-1)....</b>   | <b>19</b> |
| 4.1. Potential for human exposure .....  | 19        |
| 4.2. Mutagenicity/genotoxicity.....  | 19        |
| 4.3. Carcinogenicity .....   | 19        |
| 4.4. Mode of action for carcinogenicity.....   | 20        |
| 4.5. Regulatory and/or published limits .....  | 21        |
| 4.6. Permissible Daily Exposure (PDE) .....  | 21        |
| 4.7. Rationale for selection of study for PDE calculations.....  | 21        |
| 4.8. References .....  | 22        |
| <b>5. Benzyl Chloride (<math>\alpha</math>-Chlorotoluene, CAS# 100-44-7) .....</b>   | <b>25</b> |
| 5.1. Potential for human exposure .....  | 25        |
| 5.2. Mutagenicity/genotoxicity.....  | 25        |
| 5.3. Carcinogenicity .....   | 25        |
| 5.4. Mode of action for carcinogenicity.....   | 27        |
| 5.5. Regulatory and/or published limits .....  | 28        |

|   |           |
|---|-----------|
| 5.6. Acceptable Intake (AI) .....   | 29        |
| 5.6.1. Rationale for selection of study for AI calculation .....  | 29        |
| 5.6.2. Calculation of AI .....  | 29        |
| 5.7. References .....   | 29        |
| <b>6. Bis(chloromethyl)ether (BCME, CAS# 542-88-1) .....</b>  | <b>31</b> |
| 6.1. Potential for human exposure .....   | 31        |
| 6.2. Mutagenicity/genotoxicity .....  | 31        |
| 6.3. Carcinogenicity .....  | 31        |
| 6.4. Mode of action for carcinogenicity .....   | 33        |
| 6.5. Regulatory and/or Published Limits .....   | 33        |
| 6.6. Acceptable Intake (AI) .....   | 33        |
| 6.6.1. Rationale for selection of study for AI calculation .....  | 33        |
| 6.6.2. Calculation of AI .....  | 33        |
| 6.7. References .....   | 33        |
| <b>7. <i>p</i>-Chloroaniline (CAS# 106-47-8) and <i>p</i>-Chloroaniline HCl (CAS# 20265-96-7) .....</b> | <b>35</b> |
| 7.1. Potential for human exposure .....   | 35        |
| 7.2. Mutagenicity/genotoxicity .....  | 35        |
| 7.3. Carcinogenicity .....  | 35        |
| 7.4. Mode of action for carcinogenicity .....   | 37        |
| 7.5. Regulatory and/or Published Limits .....   | 38        |
| 7.6. Calculation of AI .....  | 38        |
| 7.6.1. Calculation of AI .....  | 38        |
| 7.6.2. References .....   | 39        |
| <b>8. 1-Chloro-4-nitrobenzene (para-Chloronitrobenzene, CAS# 100-00-5) ..</b>                           | <b>40</b> |
| 8.1. Potential for human exposure .....   | 40        |
| 8.2. Mutagenicity/genotoxicity .....  | 40        |
| 8.3. Carcinogenicity .....  | 40        |
| 8.4. Mode of action for carcinogenicity .....   | 42        |
| 8.4.1. Calculation of Permissible Daily Exposure (PDE) .....  | 43        |
| 8.4.2. Conclusion .....   | 44        |
| 8.5. Regulatory and/or published limits .....   | 44        |
| 8.6. Calculation of AI .....  | 44        |
| 8.7. References .....   | 44        |
| <b>9. <i>p</i>-Cresidine (2-Methoxy-5-methyl aniline, CAS# 120-71-8) .....</b>                          | <b>46</b> |
| 9.1. Potential for human exposure .....   | 46        |
| 9.2. Mutagenicity/genotoxicity .....  | 46        |
| 9.3. Carcinogenicity .....  | 46        |
| 9.4. Mode of action for carcinogenicity: .....  | 48        |
| 9.5. Regulatory and/or published limits .....   | 48        |
| 9.6. Acceptable intake (AI) .....   | 48        |
| 9.6.1. Rationale for selection of study for AI calculation: .....                                       | 48        |
| 9.6.2. Calculation of AI: .....   | 48        |

|  |           |
|--|-----------|
| 9.7. References .....  | 49        |
| <b>10. Dimethylcarbamyl chloride (CAS# 79-44-7) .....</b>          | <b>51</b> |
| 10.1. Potential for human exposure.....                            | 51        |
| 10.2. Mutagenicity/genotoxicity .....                              | 51        |
| 10.3. Carcinogenicity.....   | 51        |
| 10.4. Mode of action of carcinogenicity .....                      | 53        |
| 10.5. Regulatory and/or published limits.....                      | 53        |
| 10.6. Acceptable intake .....                                      | 53        |
| 10.7. Inhalation AI .....  | 54        |
| 10.8. References.....  | 54        |
| <b>11. Dimethyl Sulfate (CAS# 77-78-1) .....</b>                   | <b>56</b> |
| 11.1. Potential for human exposure.....                            | 56        |
| 11.2. Mutagenicity/genotoxicity .....                              | 56        |
| 11.3. Carcinogenicity.....   | 56        |
| 11.4. Mode of action of carcinogenicity: .....                     | 58        |
| 11.5. Regulatory and/or published limits.....                      | 58        |
| 11.6. Acceptable intake (AI) .....                                 | 58        |
| 11.7. References.....  | 59        |
| <b>12. Ethyl chloride (Chloroethane, CAS# 75-00-3).....</b>        | <b>59</b> |
| 12.1. Potential for human exposure.....                            | 59        |
| 12.2. Mutagenicity/genotoxicity .....                              | 59        |
| 12.3. Carcinogenicity.....   | 60        |
| 12.4. Mode of action of carcinogenicity .....                      | 61        |
| 12.5. Regulatory and/or published limits.....                      | 61        |
| 12.6. Acceptable Intake (AI) .....                                 | 61        |
| Rationale for selection of study for AI calculation .....          | 61        |
| 12.7. References.....  | 61        |
| <b>13. Glycidol (CAS# 556-52-5) .....</b>                          | <b>63</b> |
| 13.1. Potential for human exposure.....                            | 63        |
| 13.2. Mutagenicity/genotoxicity .....                              | 63        |
| 13.3. Carcinogenicity.....   | 63        |
| 13.4. Mode of Action .....   | 65        |
| 13.5. Regulatory and/or Published Limits .....                     | 65        |
| 13.6. Acceptable Intake (AI) .....                                 | 65        |
| 13.6.1. Rationale for selection of study for AI calculation: ..... | 65        |
| 13.6.2. Calculation of AI: .....                                   | 65        |
| 13.7. References.....  | 65        |
| <b>14. Hydrazine (CAS# 302-01-2) .....</b>                         | <b>67</b> |
| 14.1. Potential for human exposure.....                            | 67        |
| 14.2. Mutagenicity/genotoxicity .....                              | 67        |
| 14.3. Carcinogenicity.....   | 67        |
| 14.4. Mode of action of carcinogenicity .....                      | 69        |
| 14.5. Regulatory and/or published limits.....                      | 69        |

|   |           |
|---|-----------|
| 14.6. Acceptable Intake (AI) .....                                  | 69        |
| 14.6.1. Rationale for selection of study for AI calculation .....   | 69        |
| 14.6.2. Calculation of AI .....                                     | 70        |
| 14.7. References.....   | 70        |
| <b>15. Hydrogen peroxide (CAS# 7722-84-1) .....</b>                 | <b>73</b> |
| 15.1. Potential for human exposure.....                             | 73        |
| 15.2. Mutagenicity/genotoxicity .....                               | 73        |
| 15.3. Carcinogenicity.....  | 73        |
| 15.4. Mode of action for carcinogenicity.....                       | 75        |
| 15.5. Regulatory and/or published limits.....                       | 76        |
| 15.6. Permissible Daily Exposure (PDE) .....                        | 76        |
| 15.7. References.....   | 76        |
| <b>16. Hydroxylamine (CAS# 7803-49-8) .....</b>                     | <b>78</b> |
| 16.1. Potential for human exposure.....                             | 78        |
| 16.2. Mutagenicity/genotoxicity .....                               | 78        |
| 16.3. Carcinogenicity.....  | 78        |
| 16.4. Mode of action for carcinogenicity.....                       | 79        |
| 16.5. Regulatory and/or Published Limits .....                      | 80        |
| 16.6. Permissible Daily Exposure (PDE) .....                        | 80        |
| 16.6.1. Rationale for selection of study for PDE calculation: ..... | 80        |
| 16.6.2. Calculation of PDE: .....                                   | 80        |
| 16.7. References.....   | 81        |
| <b>17. Methyl chloride (Chloromethane, CAS# 74-87-3) .....</b>      | <b>83</b> |
| 17.1. Potential for human exposure.....                             | 83        |
| 17.2. Mutagenicity/genotoxicity .....                               | 83        |
| 17.3. Carcinogenicity.....  | 83        |
| 17.4. Regulatory and/or published Limits .....                      | 85        |
| 17.5. Acceptable Intake (AI) .....                                  | 85        |
| 17.6. References.....   | 85        |

# 1. Application of the principles of the ICH M7 guideline to calculation of compound-specific acceptable intakes

## 1.1. Introduction

The ICH M7 guideline discusses the derivation of acceptable intakes for mutagenic impurities with positive carcinogenicity data, (section 7.2.1) and states: *“Compound-specific risk assessments to derive acceptable intakes should be applied instead of the TTC-based [Threshold of Toxicological Concern-based] acceptable intakes where sufficient carcinogenicity data exist. For a known mutagenic carcinogen, a compound-specific acceptable intake can be calculated based on carcinogenic potency and linear extrapolation as a default approach. Alternatively, other established risk assessment practices such as those used by international regulatory bodies may be applied either to calculate acceptable intakes or to use already existing values published by regulatory authorities.”*

In this Addendum to ICH M7, acceptable intakes (AIs) have been derived for a set of chemicals that are considered to be mutagens and carcinogens and were selected because they are common in pharmaceutical manufacturing, or are useful to illustrate the principles for deriving compound-specific intakes described in ICH M7.<sup>1</sup> Compounds are included in which the primary method used to derive acceptable intakes for carcinogens with a likely mutagenic mode of action is the “default approach” from ICH M7 of linear extrapolation from the calculated cancer potency estimate, the TD<sub>50</sub>. Compounds are also included which highlight alternative principles to deriving compound-specific intakes (see below).

Chemicals that are mutagens and carcinogens (Classified as Class 1 in ICH M7) include chemicals that induce tumors through a non-mutagenic mode of action.

ICH M7 states in section 7.2.2: *“The existence of mechanisms leading to a dose response that is non-linear or has a practical threshold is increasingly recognized, not only for compounds that interact with non-DNA targets but also for DNA-reactive compounds, whose effects may be modulated by, for example, rapid detoxification before coming into contact with DNA, or by effective repair of induced damage. The regulatory approach to such compounds can be based on the identification of a No-Observed Effect Level (NOEL) and use of uncertainty factors (see ICH Q3C(R5), Ref. 7) to calculate a permissible daily exposure (PDE) when data are available.”*

Examples are provided in this Addendum to illustrate assessments of mode of action that justify exclusion of some Class 1 chemicals from the linear extrapolation approach, and derivation instead of a PDE calculated using uncertainty factors as described in ICH Q3C(R5). These include hydrogen peroxide, which induces oxidative stress, and compounds that induce tumors secondary to hemosiderosis as a consequence of methemoglobinemia, such as aniline and hydroxylamine.

It is emphasized that the AI or PDE values presented here address carcinogenic risk. Other toxicological considerations, along with quality standards, may affect final product specifications.

## 1.2. Methods

The general process for deriving acceptable intakes included a literature review, selection of cancer potency estimate [TD<sub>50</sub>, taken from the carcinogenicity potency database (CPDB) -

---

<sup>1</sup> Some chemicals are included whose properties (including chemical reactivity, solubility, volatility, ionizability) allow efficient removal during the steps of most synthetic pathways, so that a specification based on an acceptable intake will not typically be needed.

<http://toxnet.nlm.nih.gov/cpdb/>), or calculated from published studies using the same method as in the CPDB] and ultimately calculation of an appropriate AI or PDE in cases with sufficient evidence for a threshold mode of action (see section 3). The literature review focused on data relating to exposure of the general population (i.e., food, water, and air), mutagenicity/genotoxicity, and carcinogenicity. Any national or international regulatory values (e.g., US EPA, US FDA, EMA, ECHA, WHO, etc.) are described in the compound-specific assessments. Toxicity information from acute, repeat-dose, reproductive, neurological, and developmental studies was not reviewed in depth except to evaluate observed changes that act as a carcinogenic precursor event (e.g., irritation/inflammation, or methemoglobinemia).

### 1.2.1. Standard method

#### 1.2.1.1. Linear Mode of Action and Calculation of Acceptable Intake (AI)

Note 4 of ICH M7 states: *“It is possible to calculate a compound-specific acceptable intake based on rodent carcinogenicity potency data such as TD<sub>50</sub> values (doses giving a 50% tumor incidence equivalent to a cancer risk probability level of 1:2). Linear extrapolation to a probability of 1 in 100,000 (i.e., the accepted lifetime risk level used) is achieved by simply dividing the TD<sub>50</sub> by 50,000. This procedure is similar to that employed for derivation of the TTC.”*

Thus, linear extrapolation from a TD<sub>50</sub> value was considered appropriate to derive an AI for those Class 1 impurities (known mutagenic carcinogens) with no established “threshold mechanism”, that is, understanding of a mode of action that results in a non-linear dose-response curve. In many cases, the carcinogenicity data were available from the CPDB; the conclusions were based either on the opinion of the original authors of the report on the carcinogenicity study (“author opinion” in CPDB) or on the conclusions of statistical analyses provided in the CPDB. When a pre-calculated TD<sub>50</sub> value was identified in the CPDB for a selected chemical, this value was used to calculate the AI; the relevant carcinogenicity data were not reanalyzed and the TD<sub>50</sub> value was not recalculated.

If robust data were available in the literature but not in the CPDB, then a TD<sub>50</sub> was calculated based on methods described in the CPDB (<http://toxnet.nlm.nih.gov/cpdb/td50.html>). The assumptions for animal body weight, respiratory volume, and water consumption for calculation of doses were adopted from ICH Q3C and ICH Q3D.

#### 1.2.1.2. Selection of studies

The quality of studies in the CPDB is variable, although the CPDB does impose criteria for inclusion such as the proportion of the lifetime during which test animals were exposed. For the purposes of this Addendum further criteria were applied. Studies of lesser quality were defined here as those where one or more of the following scenarios were encountered:

- < 50 animals per dose per sex,
- < 3 dose levels,
- Lack of concurrent controls,
- Intermittent dosing (< 5 days per week),
- Dosing for less than lifetime

The more robust studies were generally used to derive limits. However studies that did not fulfill all of the above criteria were in some cases considered adequate for derivation of an AI when other aspects

of the study were robust, for example when treatment was for 3 days per week (e.g., benzyl chloride) but there was evidence that higher doses would not have been tolerated, i.e., a maximum tolerated dose (MTD) as defined by NTP or ICH S1C was attained. Calculations of potency take intermittent or less-than-lifetime dosing into account; for example, in the CPDB the dose levels shown have been adjusted to reflect the estimated daily dose levels, such that the daily dose given 3 times per week is multiplied by 3/7 to give an average daily dose; a comparable adjustment is made if animals are treated for less than 24 months. Use of less robust data can sometimes be considered acceptable when no more complete data exist, given the highly conservative nature of the risk assessment in which TD<sub>50</sub> was linearly extrapolated to a 1 in 100,000 excess cancer risk. In these cases, the rationale supporting the basis for the recommended approach is provided in the compound-specific assessments.

#### **1.2.1.3. Selection of tumor and site**

The lowest TD<sub>50</sub> of a particular organ site for an animal species and sex was selected from the most robust studies. When more than one study exists, the CPDB provides a calculated harmonic mean TD<sub>50</sub>, but in this Addendum the lowest TD<sub>50</sub> was considered a more conservative estimate. Data compiled as "all tumor bearing animals" (tba) were not considered in selecting an appropriate TD<sub>50</sub> from the CPDB; mixed tumor types (e.g., adenomas and carcinomas) in one tissue (e.g., liver) were used where appropriate as this often gives a more sensitive potency estimate.

#### **1.2.1.4. Route of administration**

Section 7.5 of ICH M7 states: *"The above risk approaches described in Section 7 are applicable to all routes of administration and no corrections to acceptable intakes are generally warranted. Exceptions to consider may include situations where data justify route-specific concerns that should be evaluated case-by-case."*

In this Addendum, when robust data were available from carcinogenicity studies for more than one route, and the tumor sites did not appear to be route-specific, the TD<sub>50</sub> from the route with the lower TD<sub>50</sub> was selected for the AI calculation and is thus usually considered suitable for all routes. Exceptions may be necessary case by case; for example, in the case of a potent site-of-contact carcinogen a route-specific AI or PDE might be necessary. Other toxicities such as irritation might also limit the acceptable intake for a certain route, but only tumorigenicity is considered in this Addendum. Here, if tumors were considered site-specific (e.g., inhalation exposure resulting in respiratory tract tumors with no tumors at distal sites) and the TD<sub>50</sub> was lower than for other routes, then a separate AI was developed for that route (e.g., dimethyl carbamoyl chloride, hydrazine).

#### **1.2.1.5. Calculation of AI from the TD<sub>50</sub>**

Calculating the AI from the TD<sub>50</sub> is as follows (see Note 4 of ICH M7 for example):

$$AI = TD_{50} / 50,000 \times 50 \text{ kg}$$

The weight adjustment assumes an arbitrary adult human body weight for either sex of 50 kg. This relatively low weight provides an additional safety factor against the standard weights of 60 kg or 70 kg that are often used in this type of calculation. It is recognized that some adult patients weigh less than 50 kg; these patients are considered to be accommodated by the inherent conservatism (i.e., linear extrapolation of the most sensitive organ site) used to determine an AI.

## 1.2.2. Consideration of alternative methods for calculation of AI

### 1.2.2.1. Human relevance of tumors

Note 4 of ICH M7 states: *“As an alternative of using the most conservative TD<sub>50</sub> value from rodent carcinogenicity studies irrespective of its relevance to humans, an in-depth toxicological expert assessment of the available carcinogenicity data can be done in order to initially identify the findings (species, organ, etc.) with highest relevance to human risk assessment as a basis for deriving a reference point for linear extrapolation.”*

Human relevance of the available carcinogenicity data was considered for deriving AIs. Effects in rodents associated with toxicities that occur with a non-linear dose response are not relevant to humans at the low, non-toxic concentrations associated with a pharmaceutical impurity. For example, in the case of p-chloroaniline, the most sensitive site for tumor induction was the spleen, but these tumors were associated with hemosiderosis, considered to be a mode of action with a non-linear dose response, and thus not relevant to humans at low doses. In the case of p-chloroaniline, liver tumors, with a higher TD<sub>50</sub>, were used for the linear extrapolation to calculate the AI.

A second category of tumors considered not to be relevant to humans is tumors associated with a rodent-specific mode of action e.g. methyl chloride.

### 1.2.2.2. Published regulatory limits

Note 4 of ICH M7 also states: *“Compound-specific acceptable intakes can also be derived from published recommended values from internationally recognized bodies such as World Health Organization (WHO, International Program on Chemical Safety [IPCS] Cancer Risk Assessment Programme) and others using the appropriate 10<sup>-5</sup> lifetime risk level. In general, a regulatory limit that is applied should be based on the most current and scientifically supported data and/or methodology.”*

In this Addendum, available regulatory limits are described (omitting occupational health limits as they are typically regional and may use different risk levels). However the conservative linear extrapolation from the TD<sub>50</sub> was generally used as the primary method to derive the AI, as the default approach of ICH M7, and for consistency across compounds. It is recognized that minor differences in methodology for cancer risk assessment can result in different recommended limits (for example adjusting for body surface area in calculations), but the differences are generally quite small when linear extrapolation is the basis of the calculation.

## 1.2.3. Non-linear (Threshold) mode of action and calculation of permissible daily exposure (PDE)

ICH M7 states in section 7.2.2: *“The existence of mechanisms leading to a dose response that is non-linear or has a practical threshold is increasingly recognized, not only for compounds that interact with non-DNA targets but also for DNA-reactive compounds, whose effects may be modulated by, for example, rapid detoxification before coming into contact with DNA, or by effective repair of induced damage. The regulatory approach to such compounds can be based on the identification of a No-Observed Effect Level (NOEL) and use of uncertainty factors (see ICH Q3C(R5)) to calculate a permissible daily exposure (PDE) when data are available.”*

An example of a DNA-reactive chemical for which a threshold has been established for mutagenicity in vitro and in vivo is ethyl methane sulfonate (Müller et al., 2009; Cao et al, 2014). A PDE calculation using uncertainty factors, instead of linear extrapolation is appropriate in such cases.

This threshold approach was considered appropriate in the compound-specific assessments for carcinogens with modes of action (section 2.1) that lack human relevance at low doses, based upon their association with a non-linear dose response for tumor induction:

- Chemicals that induce methemoglobinemia, hemosiderin deposits in tissues such as spleen, and subsequent inflammation and tumors (e.g., aniline and related compounds).
  - Supporting information includes evidence that mutagenicity was not central to the mode of action, such as weak evidence for mutagenicity e.g., aniline and hydroxylamine; and/or lack of correlation between sites or species in which in vivo genotoxicity (such as DNA adducts) and tumor induction were seen.
- Chemicals that induce tumors associated with local irritation/inflammation (such as rodent forestomach tumors) and are site-of-contact carcinogens may be considered not relevant to human exposure at low, non-irritating concentrations as potential impurities in pharmaceuticals (e.g., benzyl chloride).
- Chemicals that act through oxidative damage, so that deleterious effects do not occur at lower doses since abundant endogenous protective mechanisms exist, (e.g., hydrogen peroxide).

Acceptable exposure levels for carcinogens with a threshold mode of action were established by calculation of PDEs. The PDE methodology is further explained in ICH Q3C and ICH Q3D.

#### **1.2.4. Acceptable limit based on exposure in the environment, e.g., in the diet**

As noted in ICH M7 section 7.5, *“Higher acceptable intakes may be justified when human exposure to the impurity will be much greater from other sources e.g, food, or endogenous metabolism (e.g., formaldehyde).”* For example, formaldehyde is not a carcinogen orally, so that regulatory limits have been based on non-cancer endpoints. Health Canada, IPCS and US EPA (IRIS) recommend an oral limit of 0.2 mg/kg/day, or 10 mg/day for a 50 kg person.

### **1.3. References**

Cao, X., Mittelstaedt, R.A., Pearce, M.G., Allen, B.C., Soeteman-Hernández, .L.G., Johnson, G.E., Bigger, C.A., Heflich, R.H. (2014). Quantitative dose-response analysis of ethyl methanesulfonate genotoxicity in adult gpt-delta transgenic mice. *Environ Mol Mutagen.*55: 385-399.

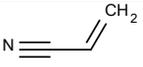
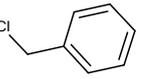
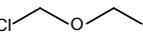
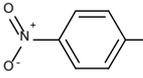
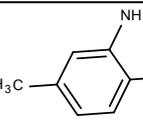
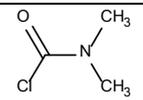
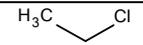
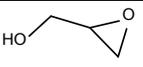
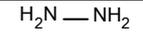
Health Canada. 2001. Priority substances list assessment report: Formaldehyde. Ottawa. Ministry of Public Works and Government Services. February. Searched October 10, 2013. Available at [http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/index\\_e.html](http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/index_e.html)

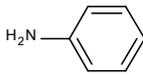
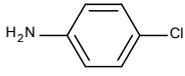
International Programme on Chemical Safety (IPCS). 2002. Concise International Chemical Assessment Document 40. Formaldehyde.

IRIS (1990). Integrated Risk Information System. U.S. Environmental Protection Agency. [http://punix1.srdev.com/iris/iris\\_dev/subst/0419.htm](http://punix1.srdev.com/iris/iris_dev/subst/0419.htm)

Müller, L., Gocke, E., Lave, T. Pfister, T. (2009). Ethyl methanesulfonate toxicity in Viracept-A comprehensive human risk assessment based on threshold data for genotoxicity. *Toxicol. Lett.* 190: 317-329.

## 2. Acceptable intakes (AIs) or permissible daily exposures (PDEs)

| Compound   | CAS#     | Chemical Structure  | AI or PDE (µg/day)        | Comment  |
|--|----------|---|---------------------------|--|
| <b>Linear extrapolation from TD<sub>50</sub></b> |          |   |                           |  |
| Acrylonitrile                                    | 107-13-1 |    | 6                         | TD <sub>50</sub> linear extrapolation  |
| Benzyl Chloride                                  | 100-44-7 |    | 41                        | TD <sub>50</sub> linear extrapolation  |
| Bis(chloromethyl)ether                           | 542-88-1 |    | 0.004                     | TD <sub>50</sub> linear extrapolation  |
| 1-Chloro-4-nitrobenzene                          | 100-00-5 |    | 117                       | TD <sub>50</sub> linear extrapolation  |
| p-Cresidine                                      | 120-71-8 |  | 45                        | TD <sub>50</sub> linear extrapolation  |
| Dimethylcarbamoyl chloride                       | 79-44-7  |  | 5<br>0.6<br>(inhalation)* | TD <sub>50</sub> linear extrapolation  |
| Ethyl chloride                                   | 75-00-3  |  | 1,810                     | TD <sub>50</sub> linear extrapolation  |
| Glycidol   | 556-52-5 |  | 4                         | TD <sub>50</sub> linear extrapolation  |
| Hydrazine  | 302-01-2 |  | 42<br>Inhalation:<br>0.2* | TD <sub>50</sub> linear extrapolation  |
| Methyl Chloride                                  | 74-87-3  | Cl-CH <sub>3</sub>  | 1,360                     | Defaulted to TD <sub>50</sub> linear extrapolation even though tumors were likely species specific |

| <b>Threshold-based PDE</b>             |                        |   |       |  |
|--|------------------------|---|-------|--|
| Aniline<br>Aniline HCl                 | 62-53-3<br>142-04-1    |    | 720   | PDE based on threshold mode of action (hemosiderosis)  |
|  |                        |   |       |  |
| Hydrogen peroxide                      | 7722-84-1              | HO—OH   | 6,960 | PDE based on threshold (oxidant stress where protective antioxidant mechanisms overwhelmed)  |
| Hydroxylamine                          | 7803-49-8              | HO—NH <sub>2</sub>  | 2     | PDE based on threshold mode of action (hemosiderosis)  |
| <b>Endogenous and food exposure**</b>  |                        |   |       |  |
|  |                        |   |       |  |
| <b>Other Cases</b>                     |                        |   |       |  |
| p-Chloroaniline<br>p-Chloroaniline HCl | 106-47-8<br>20265-96-7 |  | 34    | AI based on liver tumors for which mutagenic mode of action cannot be ruled out (not most sensitive site, which was spleen tumors associated with hemosiderosis) |
| Dimethyl Sulfate                       | 77-78-1                |  | 1.5   | Carcinogenicity data available, but inadequate to derive AI. Default to TTC.   |
|  |                        |   |       |  |

\*Route specific limit

\*\* for future compounds

## 3. Acrylonitrile (CAS# 107-13-1)

### 3.1. Potential for human exposure

Industrial use. No data are available for exposure of the general population.

### 3.2. Mutagenicity/genotoxicity

Acrylonitrile is mutagenic and genotoxic *in vitro* and *in vivo*.

The World Health Organization (WHO) published Concise International Chemical

Assessment Document (CICAD) 39 in 2002, providing a thorough risk assessment of acrylonitrile. In this publication, the reviewers indicated that oxidative metabolism is a critical step for acrylonitrile to exert genotoxic effects, implicating cyanoethylene oxide as a DNA-reactive metabolite. A detailed review of genotoxicity testing in a range of systems is provided in CICAD 39 (WHO, 2002) with references, so only a few key conclusions are summarized here.

Acrylonitrile is mutagenic in:

- Microbial reverse mutation assay (Ames) in *Salmonella typhimurium* TA 1535 and TA 100 only in the presence of rat or hamster S9 and in several *E. coli* strains in the absence of metabolic activation
- Human lymphoblasts and mouse lymphoma cells, reproducibly with S9, in some cases without S9.
- Splenic T cells of rats exposed via drinking water

Studies of structural chromosome aberrations and micronuclei in rodent bone marrow and blood are negative or inconclusive. There are consistent reports of DNA binding in the liver following acrylonitrile administration, but reports are conflicting for the brain, which is the primary target of carcinogenesis.

### 3.3. Carcinogenicity

Acrylonitrile is classified as a Group 2B carcinogen, possibly carcinogenic to humans (IARC, 1999).

Acrylonitrile is a multi-organ carcinogen in mice and rats, with the brain being the primary target organ in rat. There are four oral carcinogenicity studies cited in the CPDB (Gold and Zeiger, 1997) and the results from three additional oral studies are summarized in CICAD 39 (WHO, 2002). Of these seven studies only one is negative but this study tested only a single dose administered for short duration (Maltoni et al., 1988).

The NCI/NTP study in the CPDB of acrylonitrile in mice was selected for derivation of the oral and inhalation AI, based on robust study design and the most conservative TD<sub>50</sub> value. In this 2 year study, 3 doses of acrylonitrile were administered by oral gavage to male and female mice. There were statistically significant increases in tumors of the Harderian gland and forestomach.

In the CPDB, it appears that the most sensitive TD<sub>50</sub>, slightly lower than that for forestomach tumors in mice, is for astrocytomas in female rats (5.31 mg/kg/d) in the study of Quast et al, 1980a, cited in the CPDB as a report from Dow Chemical. There were 46-48 animals per treatment group and 80 animals in controls. This study was later described in detail in a publication by Quast (2002) and the calculated doses in that published report are higher than those in the CPDB. Quast (2002) describes the

derivation of doses in mg/kg/d from the drinking water concentrations of 35, 100 and 300 ppm, adjusting for body weight and the decreased water consumption in the study. The TD<sub>50</sub> for astrocytomas derived from these numbers is 20.2 mg/kg/d for males and 20.8 for females, in contrast to the calculated values in the CPDB of 6.36 and 5.31 mg/kg/day.

Studies considered less robust included three rat drinking water studies. The largest (Bio/Dynamics, 1980b), included five acrylonitrile treated groups with 100 animals per dose and 200 control animals, but serial sacrifices of 20 animals per treatment group occurred at 6, 12, 18 and 24 months. Data summaries presented in CICAD 39 (WHO, 2002) and IRIS present tumor incidence based on data from all time points combined. Therefore, the incidence of tumors reported may be an underestimate of the total tumors that would be observed if all animals were kept on study for 2 years. Studies by Bigner et al (1986) and BioDynamics (1980a), had only two dose levels and individual tumor types are not reported (WHO, 2002), although tumors of stomach, Zymbal gland and brain were observed.

Acrylonitrile has also been studied by the inhalation route. The study by Quast et al., 1980b exposed 50 rats per sex per dose for 2 years to acrylonitrile, and observed brain tumors. This study however, tested only 2 doses. The other inhalation studies were deficient in number of animals per group, duration of exposure, or administration of a single dose, although brain tumors were observed.

#### Acrylonitrile – Details of carcinogenicity studies

| Study                                   | Animals/<br>dose<br>group        | Duration/<br>Exposure | Controls | Doses                             | Most<br>sensitive<br>tumor<br>site/sex | TD <sub>50</sub><br>(mg/kg/<br>d) |
|---|----------------------------------|-----------------------|----------|-----------------------------------|--|-----------------------------------|
| NCI/NTP*                                | 50 B6C3F1<br>Mice (F)            | 2 year/<br>Gavage     | 50       | 3:<br>1.79; 7.14; 14.3<br>mg/kg/d | Fore-<br>Stomach                       | 6.77 <sup>++</sup>                |
|   | 50 B6C3F1<br>Mice (M)            | 2 year/<br>Gavage     | 50       | 3:<br>1.79; 7.14; 14.3<br>mg/kg/d | Fore-<br>Stomach                       | 5.92 <sup>++</sup>                |
| Quast, et al.,<br>1980a<br><br>In CPDB  | ~50 SD<br>Spartan<br>rats<br>(F) | 2 year/<br>Water      | ~80      | 3:<br>2.00; 5.69; 15.4<br>mg/kg/d | CNS                                    | 5.31 <sup>++</sup>                |
|   | ~50 SD<br>Spartan<br>rats<br>(M) | 2 year/<br>Water      | ~80      | 3:<br>1.75; 4.98; 14.9<br>mg/kg/d | Stomach,<br>non-<br>glandular          | 6.36 <sup>++</sup>                |
| Quast, 2002<br>Report of<br>Quast 1980a | ~50 SD<br>Spartan<br>rats<br>(F) | 2 year/<br>Water      | ~80      | 3:<br>4.4; 10.8; 25<br>mg/kg/d    | Stomach,<br>non-<br>glandular          | 19.4                              |

| Study                                | Animals/<br>dose<br>group        | Duration/<br>Exposure                   | Controls | Doses  | Most<br>sensitive<br>tumor<br>site/sex               | TD <sub>50</sub><br>(mg/kg/<br>d) |
|--------------------------------------|----------------------------------|---|----------|--|--|-----------------------------------|
|                                      | ~50 SD<br>Spartan<br>rats<br>(M) | 2 year/<br>Water                        | ~80      | 3:<br>3.4; 8.5; 21.3<br>mg/kg/d                | Stomach,<br>non-<br>glandular                        | 9.0                               |
| Bio/Dynamics<br>1980b <sup>¥</sup>   | 100 male<br>rats                 | ~2 year/<br>Water                       | ~200     | 5:<br>0.1-8.4<br>mg/kg/d                       | Brain<br>astrocytoma                                 | (22.9) <sup>+</sup>               |
|                                      | 100 female<br>rats               | ~2 year/<br>Water                       | ~200     | 5:<br>0.1-10.9<br>mg/kg/d                      | Brain<br>astrocytoma                                 | (23.5) <sup>+</sup>               |
| Bio/Dynamics<br>1980a <sup>¥</sup>   | 100/sex<br>rats                  | 19-22<br>months/<br>Water               | ~98      | 2:<br>~0.09; 7.98<br>mg/kg/d                   | Stomach,<br>Zymbal's<br>gland, brain,<br>spinal cord | NC                                |
| Bigner, et al.,<br>1986 <sup>¥</sup> | 50/sex<br>rats                   | 18 months/<br>Water                     | No       | 2:<br>14; 70 mg/kg/d                           | Brain,<br>Zymbal's<br>gland,<br>forestomach          | NC <sup>^</sup>                   |
| Gallagher, et<br>al., 1988           | 20<br>CD rats (M)                | 2 year/<br>Water                        | No       | 3:<br>1; 5; 25<br>mg/kg/d                      | Zymbal's<br>gland                                    | 30.1                              |
| Maltoni et al.,<br>1988              | 40/sex<br>SD rats                | 1 year/<br>3d/week<br>Gavage            | 75/sex   | 1:<br>1.07 mg/kg/d                             | Neg in both<br>sexes                                 | NA                                |
| Quast, et al.,<br>1980b              | 100/sex<br>SD Spartan<br>rat     | 2 year<br>6 h/d;<br>5d/wk<br>Inhalation | ~100     | 2:<br>M: 2.27; 9.1<br>F: 3.24; 13.0<br>mg/kg/d | Brain<br>astrocytoma<br>Male                         | 32.4                              |

| Study                   | Animals/<br>dose<br>group | Duration/<br>Exposure                                    | Controls | Doses   | Most<br>sensitive<br>tumor<br>site/sex | TD <sub>50</sub><br>(mg/kg/<br>d) |
|-------------------------|---------------------------|--|----------|---|--|-----------------------------------|
| Maltoni et al.,<br>1988 | 30/sex<br>SD rats         | 1 yr<br>5d/wk;<br>1 yr<br>observation<br>.<br>Inhalation | 30       | 4:<br>M: 0.19; 0.38;<br>0.76; 1.52<br>F:<br>0.27; 0.54; 1.0;<br>2.17<br>mg/kg/d | Brain glioma<br>Male                   | 19.1                              |
| Maltoni et al.,<br>1988 | 54 female<br>SD rats      | 2 yr<br>5d/wk<br>inhalation                              | 60       | 1:<br>11.1 mg/kg/d  | Brain glioma                           | (132) <sup>ψ</sup>                |

Studies listed are in CPDB unless otherwise noted [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\* [Carcinogenicity study selected for AI calculation; in CPDB](#)

<sup>^</sup>NC= Not calculated as individual tumor type incidences not provided in WHO, 2002.

<sup>+</sup>TD<sub>50</sub> calculated based on astrocytoma incidence implied as most significant site in WHO, 2002. Serial sampling reduced number of animals exposed for 2 years, so tumor incidences may be underestimates.

<sup>++</sup>Taken from the CPDB. The TD<sub>50</sub> values represent the TD<sub>50</sub> from the most sensitive tumor site.

TD<sub>50</sub> values in parentheses are considered less reliable as explained in footnotes.

NA= Not applicable.

<sup>¥</sup> Not in CPDB. Summarized by WHO, 2002 and National Library of Medicine IRIS database.

<sup>ψ</sup> Single dose-level study.

### **3.4. Mode of action for carcinogenicity**

Although the mechanism of carcinogenesis remains inconclusive, a contribution of DNA interaction cannot be ruled out (WHO, 2002). CNS tumors were seen in multiple studies in rats, and forestomach tumors were also prominent; this was the most sensitive tumor type in mice.

Forestomach tumors are associated with local irritation and inflammation, and Quast (2002) notes the typical association between these tumors in rats and hyperplasia and/or dyskeratosis, with other inflammatory and degenerative changes. Forestomach tumors in rodents administered high concentrations orally, a type of site-of-contact effect, may not be relevant to human exposure to low concentrations that are non-irritating (for discussion see, for example, Proctor et al, 2007). However, acrylonitrile is not only a site-of contact carcinogen. Tumors were seen in the CNS, in addition to tissues likely to be exposed directly (such as the gastrointestinal tract, tongue and Zymbal gland).

Forestomach tumors were seen after administration of acrylonitrile to rats in drinking water, and by gavage. Thus, the AI was derived here based on mouse forestomach tumors.

### **3.5. Regulatory and/or published limits**

The US EPA (01/01/1991) calculated an oral slope factor of 0.54 /mg/kg/day and a drinking water limit of 0.6 µg/L at the 1/100,000 risk level, based on the occurrence of multi-organ tumors in a drinking water study in rats. This equates to a daily dose of ~1 µg/day for a 50 kg human.

### **3.6. Acceptable Intake (AI)**

#### **3.6.1. Rationale for selection of study for AI calculation**

Both inhalation and oral studies (gavage and drinking water) are available. Tumors of the CNS were seen by both route of administration, and acrylonitrile is rapidly absorbed via all routes of exposure and distributed throughout examined tissues (WHO, 2002), so that a specific inhalation AI was not considered necessary. All of the carcinogenicity studies that were used by the US EPA in the derivation of the drinking water limit for acrylonitrile were reviewed when selecting the most robust carcinogenicity study for the derivation of an AI. Here, the NCI/NTP study was selected to calculate the AI based on the TD<sub>50</sub> derived from administering acrylonitrile by oral gavage to male and female mice. The tumor type with the lowest TD<sub>50</sub> was forestomach tumors in male mice, with a TD<sub>50</sub> value of 5.92 mg/kg/day. As discussed in the Methods section 2.2, linear extrapolation from the TD<sub>50</sub> was used here to derive the AI, and it is expected that minor differences in methodology can result in different calculated limits; thus the AI calculated below for potential pharmaceutical impurities is slightly higher than that derived by US EPA for drinking water.

#### **3.6.2. Calculation of AI:**

Lifetime AI = TD<sub>50</sub>/50,000 x 50kg

Lifetime AI = 5.92 (mg/kg/day)/50,000 x 50 kg

**Lifetime AI = 5.9 µg/day (6 µg/day)**

### **3.7. References**

Bigner DD, Bigner SH, Burger PC, Shelburne JD, Friedman HS (1986) Primary brain tumors in Fischer 344 rats chronically exposed to acrylonitrile in their drinking water. Food and chemical toxicology, 24: 129–137.

Bio/Dynamics Inc. Monsanto Company, Division of Biology and Safety evaluation. 1980a. A twenty-four month oral toxicity/carcinogenicity study of acrylonitrile administered to Spartan rats in the drinking water. Final report. Two volumes. St. Louis, MO. Project No. 77-1745; BDN-77-28.

Bio/Dynamics Inc. Monsanto Company. 1980b. A twenty-four month oral toxicity/carcinogenicity study of acrylonitrile administered in the drinking water to Fischer 344 rats. Final report. Four volumes. St. Louis, MO. Project No. 77-1744; BDN-77-27.

Gallagher GT, Maull EA, Kovacs K, Szab S. 1988. Neoplasms in rats ingesting acrylonitrile for two years. J Am Coll Toxicol 7(5):603-615.

Gold S, Zeiger E, eds. (1997) Handbook of Carcinogenic Potency and Genotoxicity Databases, Boca Raton, FL: CRC Press. (<http://toxnet.nlm.nih.gov/cpdb/td50.html>).

International Agency for Research on Cancer (IARC), 1999. IARC monographs on the evaluation of carcinogenic risks to humans: Acrylonitrile, Volume 71, 43.

Maltoni C, Ciliberti A, Cotti G, Perino G (1988) Long-term carcinogenicity bioassays on acrylonitrile administered by inhalation and by ingestion to Sprague-Dawley rats. Annals of the New York Academy of Sciences, 534:179–202.

NTP (2001) Toxicology and Carcinogenesis Studies of Acrylonitrile (CAS No. 107-13-1) In B6C3F1 Mice (Gavage Studies). NTP TR 506 NIH Publication No. 02-4440. Research Triangle Park, NC: National Toxicology Program. 198 pp.

Proctor DM, Gatto NM, Hong SJ and Allamneni KP (2007) Mode-of-action framework for evaluation of the relevance of rodent forestomach tumors in cancer risk assessment. Toxicol. Sci, 98 :313-326

Quast, JF, Wade CE, Humiston CG, Carreon RM, Hermann EA, Park CN and Schwetz BA, eds (1980a) A Two-Year Toxicity and Oncogenicity Study with Acrylonitrile Incorporated in the Drinking Water of Rats, Final Report. Dow Chemical USA, Midland, MI.

Quast JF, Schuetz DJ, Balmer MF, Gushow TS, Park CN, McKenna MJ, eds(1980b) A Two-Year Toxicity and Oncogenicity Study with Acrylonitrile Following Inhalation Exposure of Rats, Final Report. Dow Chemical USA, Midland, MI.

Quast, J.F. (2002) Two-year toxicity and oncogenicity study with acrylonitrile incorporated in the drinking water of rats. Toxicol. Lett. 132:153-196.

U.S. EPA, Integrated Risk Information System (IRIS). (Revised 01/01/1991b) Carcinogenicity Assessment Acrylonitrile. Accessed via National Library of Medicine IRIS Database:

<http://toxnet.nlm.nih.gov/>

World Health Organization (WHO). (2002) CICADS 39: Concise International Chemical

Assessment Document 39 Acrylonitrile. Geneva.

<http://www.inchem.org/documents/cicads/cicads/cicad39.htm>

## 4. Aniline (CAS# 62-53-3) and Aniline Hydrochloride (CAS# 142-04-1)

### 4.1. Potential for human exposure

Aniline occurs naturally in some foods (i.e., corn, grains, beans, and tea), but the larger source of exposure is in industrial settings.

### 4.2. Mutagenicity/genotoxicity.

Aniline is not mutagenic in the microbial reverse mutation assay (Ames) in *Salmonella* and is considered weakly mutagenic and genotoxic. A discussion is included here because of the historical perception that aniline is a genotoxic carcinogen.

Aniline is not mutagenic in *Salmonella* with or without S9 or in *E. Coli* WP2 uvrA with S9 up to 3000 µg/plate (Chung et al., 1996; IARC Monographs, 1982, 1987a & b; Jackson et al., 1993). Further Ames study data are described in both the CCRIS and IRIS databases (Brams et al., 1987; Rashid et al., 1987; Gentile et al., 1987) and show aniline to be negative in all 5 standard strains.

Aniline was mutagenic in the mouse lymphoma L5178Y cell *tk* assay with and without S9 at quite high concentrations (Wangenheim and Bolcsfoldi, 1988; Amacher et al, 1980; McGregor et al 1991).

Chromosomal aberration tests gave mixed results; both negative and some weakly positive results are reported in hamster cell lines at very high, cytotoxic concentrations, e.g. about 5 to 30 mM, with or without S9 metabolic activation (Abe and Sasaki, 1977; Ishidate and Odashima, 1977; Galloway et al, 1987; Ishidate, 1983; Chung et al., 1996).

In vivo, chromosomal aberrations were not increased in the bone marrow of male CBA mice after two daily i.p. doses of 380 mg/kg (Jones and Fox, 2003), but a small increase in chromosomal aberrations 18 h after an oral dose of 500 mg/kg to male PVR rats was reported by Bomhard (2003).

Most studies of micronucleus induction are weakly positive in bone marrow after oral or i.p.treatment of mice (Westmoreland and Gatehouse, 1991; Ashby et al., 1991; Sicardi et al., 1991; Ress et al., 2002) or rats (George et al., 1990; Bomhard 2003), and most commonly at high doses, above 300 mg/kg. Dietary exposure to 500, 1000 and 2000 ppm for 90 days was associated with increases in micronuclei in peripheral blood of male and female B6C3F1 mice (Witt et al., 2000).

In vivo, a weak increase in Sister Chromatid Exchanges (SCE), reaching a maximum of 2-fold increase over the background, was observed in the bone marrow of male Swiss mice 24 h after a single i.p. dose of 61 to 420 mg/kg aniline (Parodi et al., 1982; 1983). DNA strand breaks were not detected in the mouse bone marrow by the alkaline elution assay in this study.

### 4.3. Carcinogenicity

Aniline is classified as Group 3, not classifiable as to its carcinogenicity in humans (IARC, 1987b).

Bladder cancers in humans working in the dye industry were initially thought to be related to aniline exposure but were later attributed to exposures to intermediates in the production of aniline dyes, such as β-naphthylamine, benzidine, and other amines.

The Chemical Industry Institute of Toxicology (CIIT, 1982) performed a study in which aniline hydrochloride was administered in the diet for 2 years to CD-F rats (130 rats/sex/group) at levels of 0,

200, 600, and 2000 ppm. An increased incidence of primary splenic sarcomas was observed in male rats in the high dose group only. This study was selected for derivation of the PDE for aniline based on the robust study design with 3 dose groups and a large group size (130/sex/group).

The results of the CIIT study are consistent with those of the dietary study by the US National Cancer Institute (NCI, 1978) of aniline hydrochloride in which male rats had increases in hemangiosarcomas in multiple organs including spleen, and a significant dose-related trend in incidence of malignant pheochromocytoma. In mice (NCI 1978), no statistically significant increase in any type of tumor was observed at very high doses.

With aniline itself, no tumors were seen in male rats, with a less robust study design (Hagiwara et al., 1980).

#### Aniline and Aniline HCl – Details of carcinogenicity studies

| Study                                  | Animals/<br>dose group             | Duration/<br>Exposure                                 | Controls | Doses  | Most sensitive<br>tumor<br>site/sex                                    | TD <sub>50</sub><br>(mg/kg/<br>d) |
|--|------------------------------------|---|----------|--|--|-----------------------------------|
| CIIT,<br>1982*<br>Aniline<br>HCl       | 130/sex/<br>group, CD-F<br>rats    | 2 years<br>(diet)                                     | 130      | 3: 200, 600<br>and 2000<br>ppm in diet<br>(M; 7.2; 22; 7<br>2 mg/kg/d)                 | Spleen (high<br>dose)<br>NOEL at low dose                              | Not<br>reported                   |
| NCI<br>1978**<br>Aniline<br>HCl        | 50/sex/grou<br>p, F344 rats        | 103 wk<br>treatment<br>(diet),<br>107-110 wk<br>study | 50       | 2: 3000 and<br>6000 ppm<br>in diet<br>(F: 144; 268<br>M: 115; 229<br>mg/kg/d)          | Hemangiosarcom<br>a in multiple<br>organs including<br>spleen/<br>Male | 146<br>(Male)                     |
| NCI,<br>1978**<br>Aniline<br>HCl       | 50/sex/grou<br>p<br>B6C3F1 mice    | 103 wk<br>treatment<br>(diet),<br>107-110 wk<br>study | 50       | 2: 6000 and<br>12000 ppm<br>in diet<br>(F:<br>741; 1500<br>M:<br>693; 1390<br>mg/kg/d) | Negative   | Not<br>applicable                 |
| Hagiwara<br>et al<br>1980**<br>Aniline | 10-18/group,<br>Wistar rats<br>(M) | 80 wk<br>Treatment<br>(diet)                          | Yes      | 2: 0.03,<br>0.06 and<br>0.12% in<br>diet<br>(15; 30; 60<br>mg/kg/d)                    | Negative   | Not<br>applicable                 |

\*Carcinogenicity study selected for PDE calculation. Not in CPDB.

++ Taken from CPDB. The TD<sub>50</sub> values represent the TD<sub>50</sub> from the most sensitive tumor site.

#### 4.4. Mode of action for carcinogenicity

In animal studies, aniline induces methemoglobinemia and hemolysis at high doses, the latter of which could indirectly lead to increases in micronuclei by inducing erythropoiesis (Steinheider et al., 1985; Ashby et al, 1991; Tweats et al, 2007). Micronuclei are induced in mice, while aniline induced tumors are seen in rats but not mice, adding to the evidence that genotoxicity is not key to the mode of action for aniline-induced tumors.

Aniline-induced toxicity in the spleen appears to be a contributory factor for its carcinogenicity via free radical formation and tissue injury (Khan et al., 1999). High doses (>10 mg/kg) of aniline lead to iron

accumulation in the spleen resulting from the preferential binding of aniline to red blood cells and damaged cells accumulating in the spleen. Iron-mediated oxidative stress in the spleen appears to induce lipid peroxidation, malondialdehyde-protein adducts, protein oxidation, and up-regulation of transforming growth factor- $\alpha$  1, all of which have been detected in the rat spleen following aniline exposure (Khan et al., 2003). Increased oxidative stress may be a continual event during chronic exposure to aniline and could contribute to the observed cellular hyperplasia, fibrosis, and tumorigenesis in rats (Weinberger et al., 1985; Khan et al., 1999). The lack of tumorigenicity in mice may be due to reduced toxicity observed in spleen compared to that in the rats (Smith et al., 1967; Bomhard, 2003).

In support of this toxicity-driven mode of action for carcinogenicity, the dose response for aniline-induced tumorigenicity in rats is non-linear (Bus and Popp, 1987). When considering the NCI and CIIT studies which both used the same rat strain, no tumours were observed when aniline hydrochloride was administered in the diet at a concentration of 0.02% (equal to approximately 7.2 mg/kg/day aniline in males). This, together with studies evaluating the pattern of accumulation of bound radiolabel derived from aniline in the spleen (Roberston et al., 1983) support the conclusion that a threshold exists for aniline carcinogenicity (Bus and Popp, 1987). The weight of evidence supports the conclusion that these tumours do not result from a primary mutagenic mode of action (Bomhard and Herbold 2005).

#### **4.5. Regulatory and/or published limits**

The US EPA IRIS database outlines a quantitative cancer risk assessment for aniline based on the CIIT study and use of a linearised multistage procedure (IRIS, 2008). The resulting cancer potency slope curve was 0.0057/mg/kg/day and the dose associated with a 1 in 100,000 lifetime cancer risk is calculated to be 120  $\mu$ g/day. However, the assessment states that this procedure may not be the most appropriate method for the derivation of the slope factor as aniline accumulation in the spleen is nonlinear (IRIS, 2008). Minimal accumulation of aniline and no hemosiderosis is observed at doses below 10 mg/kg and as already described, hemosiderosis may be important in the induction of the splenic tumours observed in rats.

#### **4.6. Permissible Daily Exposure (PDE)**

It is considered inappropriate to base an AI for aniline on linear extrapolation for spleen tumours observed in rats, since these have a non-linear dose response, and mutagenicity/genotoxicity is not central to the mode of action of aniline-induced carcinogenicity. The PDE is derived using the process defined in ICH Q3C.

#### **4.7. Rationale for selection of study for PDE calculations.**

Data from the CIIT 2-year rat carcinogenicity study have been used to derive risk-based dose levels. Dose levels of 200, 600 and 2000 ppm for aniline hydrochloride in the diet were equivalent to dose levels of aniline of 7.2, 22 and 72 mg/kg/day. Tumors were observed in high dose males and one stromal sarcoma of the spleen was identified at 22 mg/kg/day. Based on these data the lowest dose of 7.2 mg/kg/day was used to define the No Observed Adverse Effect Level (NOAEL).

The PDE calculation is: (NOAEL x body weight adjustment (kg)) / F1 x F2 x F3 x F4 x F5

The following safety factors as outlined in ICH Q3C have been applied to determine the PDE for aniline:

F1 = 5 (rat to human)

F2 = 10 (inter- individual variability)

F3 = 1 (study duration at least half lifetime)

F4 = 10 (severe toxicity – non-genotoxic carcinogenicity)

F5 = 1 (using a NOAEL)

Lifetime PDE =  $7.2 \times 50 \text{ kg} / (5 \times 10 \times 1 \times 10 \times 1)$

**Lifetime PDE = 720 µg/day**

#### **4.8. References**

Abe S., and Sasaki M. (1977) Chromosome aberrations and sister chromatic exchanges in Chinese hamster cells exposed to various chemicals. *J. Natl. Cancer Inst.*, 58: 1635-1641.

Amacher DE, Paillet SC, Turner, GN, Ray, VA, and Salsburg, DS (1980) Point mutations at the thymidine kinase locus in L5178Y mouse lymphoma cells. *Mutat. Res.*, 72: 447-474.

Asby J, Vlachos DA, and Tinwell H (1991) Activity of aniline in the mouse bone marrow micronucleus assay. *Mutat. Res.*, 263: 115-117.

Bomhard EM (2003) High-dose clastogenic activity of aniline in the rat bone marrow and its relationship to the carcinogenicity in the spleen of rats. *Arch. Toxicol.* 77: 291-297.

Bomhard EM and Herbold BA (2005) Genotoxic activities of aniline and its metabolites and their relationship to the carcinogenicity of aniline in the spleen of rats. *Crit. Rev. Toxicol.* 35(10): 783-835.

Brams A, Buchet JP, Crutzen-Fayt MC, De Meester C, Lauwerys R and Leonard A (1987) A Comparative Study, With 40 Chemicals, Of The Efficiency Of The Salmonella Assay And The SOS Chromotest (Kit Procedure). *Toxicol. Lett.* 38(1-2):123-133.

Bus JS and Popp JA (1987) Perspectives on the mechanism of action of the splenic toxicity of aniline and structurally-related compounds. *Food. Chem. Toxicol.* 25(8): 619-626.

Chung K-T, Murdock CA, Zhou Y, Stevens SE, Li Y-S, Wei C-I, Fernando SY, and Chou MW (1996) Effects of the nitro-group on the mutagenicity and toxicity of some benzamines. *Environ. Molecul. Mutagen.* 27: 67-74.

CIIT (Chemical Industry Institute of Toxicology). (1982) 104-week chronic toxicity study in rats with aniline hydrochloride. Final report. Report prepared for CIIT by Hazleton Laboratories America, Inc. CIIT Docket No. 11642. CIIT, Research Triangle Park, NC.

Galloway SM, Armstrong MJ, Reuben C, Colman S, Brown B, Cannon C, Bloom, AD, Nakamura F, Ahmed M., Duk S, Rimpo J., Margolin BH, Resnick MA, Anderson B and Zeiger E (1987) Chromosome Aberrations And Sister Chromatid Exchanges In Chinese Hamster Ovary Cells: Evaluations Of 108 Chemicals; *Environ. Mol. Mutagen.* 10 (Suppl. 10):1-175.

Gentile JM, Gentile GJ and Plewa M (1987) Mutagenicity Of Selected Aniline Derivatives To Salmonella Following Plant Activation And Mammalian Hepatic Activation; *Mutat. Res.* 188(3):185-196.

George E, Andrews M, and Westmoreland C. (1990) Effects of azobenzene and aniline in the rodent bone marrow micronucleus test. *Carcinogenesis*, 11: 1551-1555.

Hagiwara A, Arai M, Hirose M, Nakanowatari J-I, Tsuda H and Ito N. (1980) Chronic effects of nonharman in rats treated with aniline. *Toxicol Lett.* 1980. 6: 71-75.

IARC (1987a) Monographs on the evaluation of carcinogenic risks to humans: Genetic and related effects – an updating of selected IARC Monographs from volumes 1 to 42. IARC Publications, Addendum 6, pp. 68, Lyon, France.

IARC (1987b) Monographs on the evaluation of carcinogenic risks to humans: Overall evaluation of carcinogenicity – an updating of IARC Monographs volumes 1 to 42. IARC Publications, Addendum 7, pp. 99 and 362, Lyon, France.

IARC Monographs on the evaluation of the carcinogenic risk of chemicals to humans (1982) Some aromatic amines, anthraquinones and nitroso compounds, and inorganic fluorides used in drinking water and dental preparations. IARC Publications. Vol. 27, pp 39, Lyon, France.

IRIS (2008). United States Environmental Protection Agency Integrated Risk Information System monograph on aniline (CAS No 62-53-3). Version last updated January 10th 2008. Available on-line at <http://www.epa.gov/ncea/iris/subst/0350.htm>

Ishidate M Jr (1983) The data book of chromosomal aberration tests in vitro on 587 chemical substances using Chinese hamster fibroblast cell line (CHL cells). The Realize Inc., Tokyo, 607 pp.

Ishidate M, Jr, and Odashima S. (1977) Chromosome tests with 134 compounds on Chinese hamster cells in vitro – A screening for chemical carcinogens. *Mutat. Res.*, 48: 337-354.

Jackson MA, Stack HF, and Waters MD (1993) The genetic toxicology of putative nongenotoxic carcinogens. *Mutat. Res.*, 296: 241-277.

Jones E and Fox V (2003) Lack of clastogenicity activity of aniline in the mouse bone marrow. *Mutagenesis* 18: 283-286.

Khan MF, Wu X, and Wang JL (2003) Upregulation of transforming growth factor-beta 1 in the spleen of aniline-induced rats. *Toxicol. Appl. Pharmacol.* 187: 22-28.

Khan MF, Wu X, Boor PJ, and Ansari GAS (1999) Oxidative modification of lipids and proteins in aniline induced splenic toxicity. *Toxicological Sciences* 48: 134-140.

McGregor DB, Brown AG, Howgate S, McBride D, Riach C and Caspary WJ. (1991) Responses Of The L5178y Mouse Lymphoma Cell Forward Mutation Assay. V: 27 Coded Chemicals; *Environ. Mol. Mutagen.* 17(3):196-219.

NCI (National Cancer Institute) National Toxicology Program. 1978. Bio-assay for Aniline hydrochloride for possible carcinogenicity. CAS No., 142-04-1, NCI-CG-TR-130. US Department of Health, Education, and Welfare, National Institutes of Health. ITS. Carcinogenesis Technical Report Ser No. 130. US DHEW, PHS, NIH, Bethesda, MD. DHEW Publ. No (NIH) 78-1385.

Parodi S, Pala M, Russo P, Zunino A, Balbi C, Albini A, Valerio F, Cimberle MR, and Santi L (1982) DNA damage in liver, kidney, bone marrow, and spleen of rats and mice treated with commercial and purified aniline as determined by alkaline elution assay and sister chromatid exchange induction. *Cancer Res.*, 42: 2277-2283.

Parodi S, Zunino A, Ottaggio L, De Ferrari M and Santi L (1983) Lack of correlation between the capability of inducing sister chromatid exchanges in vivo and carcinogenic potency for 16 aromatic amines and azo derivatives. *Mutat. Res.*, 108: 225-238.

Rashid KA, Arjmand M, Sandermann H and Mumma RO (1987) Mutagenicity Of Chloroaniline / Lignin Metabolites In The Salmonella/Microsome Assay; *J. Environ. Sci. Health, Part B* B22(6): 721-729.

Ress NB, Witt KL, Xu J, Haseman JK, and Bucher JR (2002) Micronucleus induction in mice exposed to diazoaminobenzene or its metabolites, benzene and aniline: implications for diazoaminobenzene carcinogenicity. *Mutat Res.* 521: 201-208.

Robertson O, Cox MG, Bus JS (1983). Response of of the erythrocyte and spleen to aniline insult in Fischer 344 rats. *Toxicologist* 3: 128.

Sicardi SM, Martiarena JL and Iglesias MT (1991). Mutagenic and analgesic activities of aniline derivatives. *J. Pharm. Sci.*, 80: 761-764.

Smith RP, Alkaitis AA and Shafer PR (1967). Chemically induced methemoglobinemias in the mouse. *Biochem. Pharmacol.*, 16: 317-328.

Steinheider G, Neth R and Marguardt H (1985). Evaluation of nongenotoxic and genotoxic factors modulating the frequency of micronucleated erythrocytes in the peripheral blood of mice. *Cell Biol. Toxicol.*, 1: 197-211.

Tweats, D, Blakey, D, Heflich, RH, Jacobs, A, Jacobsen, SD, Nohmi, TT, O'Donovan, MR, Sasaki, YF, Sofuni, T, Tice, R (2007) Report of the IWGT working group on strategies and interpretation of regulatory in vivo tests. I. Increases in micronucleated bone marrow cells in rodents that do not indicate genotoxic hazards. *Mutat. Res.* 627 :78-91

Wangenheim J and Bolcsfoldi G (1988) Mouse Lymphoma L5178Y Thymidine Kinase Locus Assay Of 50 Compounds; *Mutagenesis* 3(3):193-205.

Weinberger MA, Albert RH, and Montgomery SB (1985) Splenotoxicity associated with splenic sarcomas in rats fed high doses of D & C Red No. 9 or aniline hydrochloride. *J. Natl. Cancer Inst.*, 75: 681-687.

Westmoreland C, and Gatehouse DG (1991) Effects of aniline hydrochloride in the mouse bone marrow micronucleus test after oral administration. *Carcinogenesis*, 12: 1057-1059.

Witt KL, Knapton A, Wehr CM, Hook GJ, Mirsalis J, Shelby MD and MacGregor JT (2000) Micronucleated erythrocyte frequency in peripheral blood of B6C3F1 mice from short-term, prechronic and chronic studies of the NTP carcinogenesis bioassay program. *Environ. Mol. Mutagen.*, 36, 163–194.

## 5. Benzyl Chloride ( $\alpha$ -Chlorotoluene, CAS# 100-44-7)

### 5.1. Potential for human exposure

Human exposure is mainly occupational via inhalation while less frequent is exposure from ingesting contaminated ground water.

### 5.2. Mutagenicity/genotoxicity

Benzyl chloride is mutagenic and genotoxic *in vitro* but not in mammalian systems *in vivo*.

The International Agency for Research on Cancer (IARC) published a monograph performing a thorough review of the mutagenicity / genotoxicity data for benzyl chloride (IARC, 1999). A few key conclusions are summarized here.

- Mutagenic in the microbial reverse mutation assay (Ames) in *Salmonella typhimurim* strain TA100 with and without metabolic activation produced weak and inconsistent increase in mutation frequency. The results are more convincing when testing in the gaseous phase (Fall et al, 2007).
- Benzyl chloride induced sister chromatid exchanges, chromosomal aberrations, mutations, and DNA strand breaks in cultured rodent cells and induced DNA strand breaks, but not chromosomal aberrations in cultured human cells. Benzyl chloride did not induce micronuclei *in vivo* in bone marrow of mice (IARC, 1999).

### 5.3. Carcinogenicity

Benzyl chloride is classified as Group 2A, probably carcinogenic to humans (IARC, 1982, 1987).

Lijinsky (1986) administered benzyl chloride in corn oil by gavage 3 times/week for 104 weeks to F-344 rats and B6C3F1 mice. Rats received doses of 0, 15, or 30 mg/kg (estimated daily dose: 0, 6.4, 12.85 mg/kg); mice received doses of 0, 50, or 100 mg/kg (estimated daily dose: 0, 21.4, 42.85 mg/kg). In rats, the only statistically significant increase in the tumor incidence was thyroid C-cell adenoma/carcinoma in the female high-dose group (27% versus 8% for control). Control incidence for this tumor type in males was 23% and there was no difference in C-cell hyperplasia with treatment between treated rats and controls of either sex. Several toxicity studies were conducted but C-cell hyperplasia was noted only in this lifetime study and only in female rats.

In mice, there were statistically significant increases in the incidence of forestomach papillomas and carcinomas (largely papillomas) at the high dose in both males and females (62% and 37%, respectively, compared with 0% in controls). Epithelial hyperplasia was observed in the stomachs of animals without tumors. There were also statistically significant increases in male but not female mice in hemangioma or hemangiosarcoma (10% versus 0% in controls) at the high dose and in carcinoma or adenoma in the liver but only at the low, not the high, dose (54% and 39%, respectively, versus 33% in controls). In female, but not male, mice there were significant increases in the incidence of alveolar-bronchiolar adenoma or carcinoma at the high dose (12% versus 1.9% in controls).

Additional studies to assess carcinogenic potential were conducted but were not considered to be adequate in terms of study design for use in calculating an AI. In one of three topical studies (Fukuda et al., 1981) skin carcinomas were increased, although not statistically significantly (15% versus 0% in benzene controls). Initiation-promotion studies to determine the potential of benzyl chloride to initiate

skin cancer, using croton oil and the phorbol ester TPA (12-O-tetradecanoyl-phorbol-13-acetate) as promoters (Ashby, 1982; Coombs, 1982a and b) were of limited duration and the published reports were presented as preliminary findings, but no final results have been located in the literature. Injection site sarcomas were seen after subcutaneous administration (Druckrey et al, 1970).

#### Benzyl chloride – Details of carcinogenicity studies

| Study                             | Animals/dose group                              | Duration/ Exposure   | Controls                    | Doses  | Most sensitive tumor site/sex                  | TD <sub>50</sub> (mg/kg/d) |
|-----------------------------------|---|--|-----------------------------|--|--|----------------------------|
| Lijinsky et al, 1986 <sup>*</sup> | 52/sex/group<br>F344 rat                        | 3 times/wk,<br>2 year.<br>Gavage                               | 52                          | 2: 15 and<br>30 mg/kg<br>(6 and 12<br>mg/kg/d)   | Thyroid<br>C-cell<br>neoplasm<br>Female        | 40.6 <sup>++</sup>         |
| Lijinsky et al, 1986              | 52/sex/group<br>B6C3F1 mouse                    | 3 times/wk,<br>2 year.<br>Gavage                               | 52                          | 2: 50 and<br>100 mg/kg<br>(21 and 42<br>mg/kg/d) | Forestomach<br>papilloma,<br>carcinoma<br>Male | 49.6 <sup>++</sup>         |
| Fukuda et al, 1981                | 11/ group<br>ICR mouse<br>female                | 3 times/wk<br>for 4 wks, 2<br>times/wk 9.8<br>months<br>Dermal | Yes<br>(benzene<br>treated) | 1:<br>10 µL                                      | No skin<br>tumors                              | NC <sup>^</sup>            |
| Fukuda et al, 1981                | 20/ group<br>ICR mouse<br>(F)                   | 2 times/wk<br>for 50 wks,<br>Dermal                            | 20<br>(benzene<br>treated)  | 1:<br>2.3 µL                                     | Skin<br>squamous<br>cell<br>carcinoma          | NC <sup>^</sup>            |
| Ashby 1982                        | 20 / group<br>ICI Swiss<br>albino mouse<br>(M)  | 2 times/wk<br>for >7<br>months<br>Dermal, in<br>toluene        | 20                          | 1:<br>100<br>µg/mouse                            | No skin<br>tumors                              | NC <sup>^</sup>            |
| Druckrey et al, 1970              | 14 (40 mg/kg),<br>and 8 (80<br>mg/kg)<br>BD rat | 1/wk for 51<br>wks<br>subcutaneous                             | Yes                         | 2:<br>40 and 80<br>mg/kg/wk                      | Injection site<br>scarcoma                     | NC <sup>^</sup>            |
| Coombs 1982a                      | 40/sex/ group<br>Theiler's                      | 1 dose (in<br>tolene); wait                                    | 40                          | 1:<br>1 mg/mouse                                 | No skin<br>tumors                              | NC <sup>^</sup>            |

| Study        | Animals/dose group | Duration/ Exposure  | Controls | Doses                           | Most sensitive tumor site/sex  | TD <sub>50</sub> (mg/kg/d) |
|--------------|--------------------|---|----------|---------------------------------|--|----------------------------|
|              | Original mouse     | 1 wk<br>Promoter (croton oil)<br>2 times/wk for 10 months |          |                                 |  |                            |
| Coombs 1982b | Sencar mice        | 1 dose;<br>Promoter (TPA)<br>2 times/wk for 6 months      | Yes      | 3:<br>10; 100 and 1000 µg/mouse | 20% skin tumors [5% in TPA controls] (DMBA controls had skin tumors by 11 weeks) | NC <sup>^</sup>            |

Studies listed are in CPDB [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\* Carcinogenicity study selected for AI calculation.

<sup>^</sup>NC= Not calculated; small group size, limited duration. Not included in CPDB as route with greater likelihood of systemic exposure is considered more relevant.

\*\* Taken from CPDB. The TD<sub>50</sub> values represent the TD<sub>50</sub> from the most sensitive tumor site.

#### 5.4. Mode of action for carcinogenicity

The tumor types with the lowest calculated TD<sub>50</sub> (highest potency) in the CPDB for benzyl chloride are forestomach tumors in mice and thyroid C-cell tumors in female rats. The relevance of the forestomach tumors to human risk assessment for low, non-irritating doses such as those associated with a potential impurity is highly questionable.

Forestomach tumors in rodents have been the subject of much discussion in assessment of risk to humans. With non-mutagenic chemicals, it is recognized that after oral gavage administration, inflammation and irritation related to high concentrations of test materials in contact with the forestomach can lead to hyperplasia and ultimately tumors. (Material introduced by gavage can remain for some time in the rodent forestomach before discharge to the glandular stomach, in contrast to the rapid passage through the human esophagus). Such tumor induction is not relevant to humans at non-irritating doses. The same inflammatory and hyperplastic effects are also seen with mutagenic chemicals, where it is more complex to determine relative contribution to mode of action of these non-mutagenic, high-dose effects compared with direct mutation induction. However, often a strong case can be made for site-of-contact tumorigenesis that is only relevant at concentrations that cause irritation/inflammation, potentially with secondary mechanisms of damage. Cell proliferation is

expected to play an important role in tumor development such that there is a non-linear dose response and the forestomach (or other site-of-contact) tumors are not relevant to low-dose human exposure.

Proctor et al (2007) propose a systematic approach to evaluating relevance of forestomach tumors in cancer risk assessment, taking into account whether any known genotoxicity is potentially relevant to human tissues (this would include whether a compound is genotoxic in vivo), whether tumors after oral administration of any type are specific to forestomach, and whether tumors are observed only at doses that irritate the forestomach or exceed the MTD.

As described above and in the table, benzyl chloride predominantly induces tumors at the site of contact in rats and mice following exposure to high doses by gavage (forestomach tumors), by injection (injection site sarcoma) and by topical application in a skin tumor initiation-promotion model in sensitive Sencar mice. An OECD report in the Screening Information Dataset (SIDS) for high volume chemicals describes benzyl chloride as intensely irritating to skin, eyes, and mucous membranes in acute and repeat dose studies. Groups of 10 Fischer 344 rats of both sexes died within 2 weeks from severe acute and chronic gastritis of the forestomach, often with ulcers, following oral administration 3 times/week of doses  $\geq 250$  mg/kg for males and  $\geq 125$  mg/kg for females (Lijinsky et al., 1986). Proliferative changes observed in female rats at lower doses included hyperplasia of the forestomach (62 mg/kg), and hyperkeratosis of the forestomach (30 mg/kg). The incidence of forestomach tumors was high in mice in the carcinogenicity study, and Lijinsky et al. (1986) also observed non-neoplastic lesions in the forestomach of the rat in the subchronic range-finding study, but few forestomach neoplasms developed in the rat carcinogenicity assay. Due to the steepness of the dose-response curve and the difficulty establishing the MTD for rats, the author speculates that it was possible that the dose used in the rat study was marginally too low to induce a significant carcinogenic effect in rats.

In the case of benzyl chloride, other tumor types were discussed as possibly treatment-related besides those at the site of contact. In the mouse oral bioassay, Lijinsky characterized the carcinogenic effects other than forestomach tumors as "marginal", comprising an increase of endothelial neoplasms in males, alveolar-bronchiolar neoplasms of the lungs only in female mice (neither of these is statistically significant) and hepatocellular neoplasms only in low dose male mice (this tumor type was discounted as not dose related). It is of note that OECD SIDS reports observations of severe to moderate dose-related liver hyperplasia in a 26-week oral toxicity study in mice.

Statistically significant increases were reported in hemangiomas/hemangiosarcomas of the circulatory system in the male mice (TD<sub>50</sub> 454 mg/kg/day), and in thyroid C-cell adenomas or carcinomas in the female rats (TD<sub>50</sub> 40.6 mg/kg/day). The levels of thyroid C-cell tumors in female rats in the high dose group, while higher than female concurrent controls, (14/52 versus 4/52 in controls) were similar to the levels in the male concurrent controls (12/52). In males, thyroid C- cell tumor levels were lower in treated than in control rats. In a compilation of historical control data from Fisher 344 rats in the NTP studies, Haseman et al (1984; 1998) show comparable levels of C-cell adenomas plus carcinomas in males and females in this rat strain, although the range is wider in males. Thus it is likely justifiable to compare the thyroid tumor levels in female rats treated with benzyl chloride with the concurrent controls of both sexes, and question whether the female thyroid tumors are treatment-related, although they were higher than the historical control range cited at the time (10%).

### **5.5. Regulatory and/or published limits**

The US EPA derived an Oral Slope Factor of  $1.7 \times 10^{-1}$  per (mg/kg)/day, which corresponds to a 1 in 100,000 risk level of approximately 4  $\mu$ g/day using US-EPA assumptions.

## 5.6. Acceptable Intake (AI)

### 5.6.1. Rationale for selection of study for AI calculation

The most robust evaluation of the carcinogenic potential of benzyl chloride was the Lijinsky et al., study (1986) that utilized oral (gavage) administration. In this study, the animals were treated 3 days a week rather than 5 days a week as in a typical NCI/NTP study. Overall, however, the rat study is considered adequate for calculation of an AI because there was evidence that the top dose was near the maximum tolerated dose. In a 26-week range finding study described in the same report (Lijinsky et al., 1986), all ten rats of each sex given 125 or 250 mg/kg (3 days per week) died within 2-3 weeks. The cause of death was severe gastritis and ulcers in the forestomach; in many cases there was also myocardial necrosis. At 62 mg/kg, only 4 of 26 females survived to 26 weeks, and myocardial necrosis and forestomach hyperplasia were seen; hyperkeratosis of the forestomach was seen in some females at 30 mg/kg. At 62 mg/kg benzyl chloride, there was a decrease in body weight gain in both sexes, which was statistically significant in males. Thus, the high dose chosen for the carcinogenicity study was 30 mg/kg (3 times per week). At this dose, there was no difference from controls in survival in the 2-year carcinogenicity study, but 3 male rats had squamous cell carcinomas and papillomas of the forestomach, so it is unlikely that a lifetime study could have been conducted at a higher dose.

As described in the Methods section 2.2., linear extrapolation from the TD<sub>50</sub> was used to derive the AI. As described above, it is highly unlikely that benzyl chloride poses a risk of site-of-contact tumors in humans exposed to low concentrations as impurities in pharmaceuticals, well below concentrations that could cause irritation/inflammation. Therefore, the observed forestomach tumors in male mice are not considered relevant for the AI calculation. The significance of the thyroid C-cell tumors in female rats is also questionable since these tumors occur commonly in control rats. However, given the uncertain origin of these tumors, the thyroid C-cell tumors were used to derive the AI since they were associated with the lowest TD<sub>50</sub>; 40.6 mg/kg/d.

### 5.6.2. Calculation of AI

Lifetime AI = TD<sub>50</sub>/50,000 x 50kg

Lifetime AI = 40.6 (mg/kg/day)/50,000 x 50 kg

**Lifetime AI = 40.6 µg/day (41 ug/day)**

## 5.7. References

Ashby J, Gaunt C, Robinson M (1982) Carcinogenicity bioassay of 4-chloromethylbiphenyl (4CMB), 4-hydroxymethylbiphenyl (4HMB) and benzyl chloride (BC) on mouse skin: Interim (7 month) report, *Mutat Res* 100: 399-401.

Coombs MM (1982a) Attempts to initiate skin tumours in mice in the 2-stage system using 4-chloromethylbiphenyl (4CMB), -hydroxymethylbiphenyl (4HMB) and benzyl chloride (BC), Report of the experiment at 10 months, *Mutat Res* 100:403-405.

Coombs MM (1982b) The UKEMS Genotoxicity Trial: A summary of the assays for skin tumour induction in mice, the subcutaneous implant test and the sebaceous gland suppression test, *Mutat Res* 100: 407-409.

Druckrey H, Kruse H, Preussmann R, Ivankovic S, and Landschuetz C (1970) Cancerogenic alkylating substances. III. Alkyl-halogenides, -sulfates, -sulfonates and strained heterocyclic compounds, Z. Krebsforsch 74(3): 241- 273

Fall M, Haddouk H, Morin J-P, Forster R (2007) Mutagenicity of benzyl chloride in the *Salmonella*/microsome mutagenesis assay depends on exposure conditions, Mutat Res 633:13-20.

Fukuda K, Matsushita H, Sakabe H, and Takemoto K, (1981) Carcinogenicity of benzyl chloride, benzal chloride, benzotrichloride and benzoyl chloride in mice by skin application, Gann. 72(5): 655-664.

Haseman JK, Huff J, Boorman GA (1984) Use of historical control data in carcinogenicity studies in rodents, Toxicol Pathol 12:126-135

Haseman JK, Hailey JR, Morris RW (1998) Spontaneous neoplasm incidence in Fischer 344 rats and B6C3F1 mice in two-year carcinogenicity studies: A National Toxicology Program update, Toxicol Pathol 26:428-441

IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: <http://monographs.iarc.fr/ENG/Monographs/vol71/mono71-19.pdf><http://monographs.iarc.fr/ENG/Monographs/vol71/volume71.pdf> (1999) Accessed on April 25, 2014.

Lijinsky W (1986) Chronic Bioassay of Benzyl Chloride in F344 Rats and (C57BL/6J X BALB/c)F1 Mice, JNCI 76(6): 1231-1236.

OECD Chemicals Screening Information Dataset (SIDS) for high volume chemicals benzyl chloride report published by the United Nations Environmental Programm (UNEP). <http://www.chem.unep.ch/irptc/sids/OECD/SIDS/100447.pdf> Accessed on April 25, 2014.

Proctor DM, Gatto NM, Hong SJ and Allamneni KP (2007) Mode-of-action framework for evaluation of the relevance of rodent forestomach tumors in cancer risk assessment. Toxicol. Sci, 98:313-326

## 6. Bis(chloromethyl)ether (BCME, CAS# 542-88-1)

### 6.1. Potential for human exposure

Potential for exposure is in industrial use, mainly via inhalation. Environmental exposure is predicted to be minimal, as result of its low industrial usage and rapid degradation in the environment, which is supported by the reported absence of BCME in ambient air or water (NIH ROC, 2011).

### 6.2. Mutagenicity/genotoxicity

BCME is mutagenic and genotoxic *in vitro* and *in vivo*.

- BCME is mutagenic in the microbial reverse mutation assay (Ames), *Salmonella typhimurium* (Nelson, 1976).
- *In vivo*, BCME did not cause chromosomal aberrations in bone-marrow cells of rats exposed to BCME vapors for six months (Leong et al., 1981). A slight increase in the incidence of chromosomal aberrations was observed in peripheral lymphocytes of workers exposed to BCME in the preparation of ion-exchange resins (IARC, 1987).

### 6.3. Carcinogenicity

BCME is classified as Group A, known human carcinogen (USEPA, 1999), and a Group 1 compound, carcinogenic to humans (IARC, 1982).

As described in the above reviews, numerous epidemiological studies have demonstrated that workers exposed to BCME (via inhalation) have an increased risk for lung cancer. Following exposure by inhalation, BCME is carcinogenic to the respiratory tract of rats and mice as described in the following studies:

The study of Leong et al. (1981) was selected for derivation of the AI based on the most robust study design and the lowest TD<sub>50</sub> value. Groups of male Sprague-Dawley rats and Ha/ICR mice were exposed by inhalation to 1, 10 and 100 ppb of BCME 6 hr/day, 5 days/week for 6 months and subsequently observed for the duration of their natural lifespan (about 2 years). Evaluation of groups of rats sacrificed at the end of the 6 month exposure period revealed no abnormalities in hematology, exfoliative cytology of lung washes, or cytogenetic parameters of bone marrow cells. However, 86.5% of the surviving rats which had been exposed to 100 ppb (7780 ng/kg/d, or 8 µg/kg/d) of BCME subsequently developed nasal tumors (esthesioneuroepitheliomas, which are similar to the rare human neuroblastoma) and approximately 4% of the rats developed pulmonary adenomas. Tumors were not observed in rats exposed to 10 or 1 ppb of BCME. Mice exposed to 100 ppb of BCME did not develop nasal tumors, but showed a significant increase in incidence of pulmonary adenomas over the control mice. Mice exposed to 10 or 1 ppb of BCME did not show a significant increase in incidence of pulmonary adenomas.

Kuschner et al. (1975) conducted an inhalation study of male Sprague-Dawley rats exposed to BCME at a single dose level of 0.1 ppm (100 ppb) 6 hours/day, 5 days/week for 10, 20, 40, 60, 80, or 100 days, then observed the animals for the remainder of their lifetimes. There was a marked increase in the incidence of several types of respiratory tract tumors in the treated animals compared with the controls.

BCME is a site of contact carcinogen, producing injection site sarcomas (Van Duuren et al., 1969) and skin tumors in mice, (Van Duuren et al., 1975); it also induces lung adenomas in newborn mice following skin application (Gargus et al., 1969).

#### Bis(chloromethyl)ether (BCME) – Details of carcinogenicity studies

| Study                   | Animals/dose group  | Duration/Exposure   | Controls | Doses   | Most sensitive tumor site/sex             | TD <sub>50</sub> (mg/kg/d) |
|-------------------------|---|---|----------|---|---|----------------------------|
| Leong et al., 1981*     | ~104/group<br>Rat, Sprague-Dawley, (M).   | 6 h/d, 5 d/wk 28 wk.<br>Inhalation                                    | 104      | 3:<br>1; 10; 100 ppb<br><br>(53; 528; 7780 ng/kg/day)   | Nasal passage - esthesioneuroepitheliomas | 0.00357                    |
| Leong et al., 1981      | 138-144/group<br>Mouse, ICR/Ha, (M).  | 6 h/d, 5 d/wk 25 wk.<br>Inhalation                                    | 157      | 3:<br>1; 10; 100 ppb<br><br>(0.295; 2.95; 33.6 ng/kg/d) | Lung adenomas                             | No significant increases   |
| Kuschner et al., 1975   | 30 – 50 treated for different durations with same concentration,<br>Sprague Dawley rats, (M). | 6h/d, 5d/wk, for 10, 20, 40, 60, 80, and 100 exposures.<br>Inhalation | 240      | 1:<br>0.1 ppm   | Lung and nasal cancer                     | NC <sup>^</sup>            |
| Kuschner et al., 1975   | 100/group<br>Golden Syrian Hamsters, (M),   | 6h/d, 5d/wk, for a lifetime.<br>Inhalation                            | NA       | 1:<br>1 ppm   | One undifferentiated in the lung          | NC <sup>^</sup>            |
| Van Duuren et al., 1975 | 50/group<br>ICR/Ha Swiss mice (F).  | 424-456 d<br>Intra-peritoneal injection, once weekly.                 | 50       | 1:<br>0.114 mg/kg/d                                     | Sarcoma (at the injection site)           | 0.182                      |

Studies listed are in CPDB unless otherwise noted [Cancer Potency Database

<http://toxnet.nlm.nih.gov/cpdb/>].

\*Carcinogenicity study selected for AI calculation

^NC= Not calculated due to non-standard carcinogenicity design. Not in CPDB.

NA= Not available since controls were not reported in the study

#### **6.4. Mode of action for carcinogenicity**

Not defined.

#### **6.5. Regulatory and/or Published Limits**

The US EPA IRIS database (EPA 1988), calculated an oral cancer slope factor of 220 per mg/kg/d based on linearised multistage modelling of the inhalation study data by Kuschner et al., 1975. The inhaled (and oral) dose associated with a 1 in 100,000 lifetime cancer risk is 3.2 ng/day ( $1.6 \times 10^{-8}$  mg/m<sup>3</sup> for inhalation,  $1.6 \times 10^{-6}$  mg/L for oral exposure).

#### **6.6. Acceptable Intake (AI)**

##### **6.6.1. Rationale for selection of study for AI calculation**

BCME is an *in vitro* mutagen, causes cancer in animals and humans and is classified as a known human carcinogen. Oral carcinogenicity studies were not conducted, therefore, intraperitoneal injection and inhalation studies are considered as a basis for setting an AI. The most sensitive endpoint was an increase in nasal tumors (esthesioneuroepitheliomas, tumors of the olfactory epithelium) in male rats in the inhalation carcinogenicity study of Leong et al (1981), with a TD<sub>50</sub> of 3.57µg/kg/day. The AI derived by linear extrapolation from the TD<sub>50</sub> from Leong et al., 4 ng/day, is essentially the same as the 3.2 ng/day recommendation of the USEPA. The Leong et al. (1981) study is a reliable study with multiple dose levels and >50 animals per dose group.

Evidence for tumors at other sites than those exposed by inhalation is lacking; the study cited above (Gargus et al., 1969) that describes lung tumors in newborn mice following skin application may not be definitive if inhalation may have occurred as a result of skin application. However, the AI derived here from inhalation data is considered applicable to other routes, because it is highly conservative (orders of magnitude below the default TTC of 1.5 µg/day). The AI is also similar to the limit derived by US EPA (based on inhalation data) that is recommended both for inhalation and ingestion (drinking water) of BCME (4 ng /day vs 3.2 ng/day).

##### **6.6.2. Calculation of AI**

$$\text{Lifetime AI} = \text{TD}_{50}/50,000 \times 50\text{kg}$$

$$\text{Lifetime AI} = 3.57 \mu\text{g/kg/day}/50,000 \times 50$$

**Lifetime AI = 0.004 µg/day or 4 ng/day**

#### **6.7. References**

EPA (1988) Integrated risk information system (IRIS). Printout for bis(chloromethyl) ether. Washington, DC: U.S. Environmental Protection Agency. November

- Gargus JL, Reese WH, Rutter HA (1969) Induction of lung adenomas in newborn mice by bis(chloromethyl) ether. *Toxicol Appl Pharmacol* 15:92-96.
- IARC (1982) IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. Chemicals, industrial processes and industries associated with cancer in humans. IARC Monographs, volumes 1 to 29, Addendum 4.
- IARC (1987) Bis(chloromethyl)ether and chloromethyl methyl ether (technical-grade). In *Overall Evaluations of Carcinogenicity*. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, Addendum 7. Lyon, France: International Agency for Research on Cancer. pp. 131-133.
- Kuschner M, Laskin S, Drew RT, Cappiello V and Nelson N (1975) Inhalation carcinogenicity of alpha halo ethers. III. Lifetime and limited period inhalation studies with bis(chloromethyl)ether at 0.1 ppm. *Arch. environ. Health*, 30, 73-77
- Leong BKJ, Kociba RI, Jersey GC. (1981). A lifetime study of rats and mice exposed to vapors of bis(chloromethyl) ether. *Toxicol Appl Pharmacol* 58:269-281
- Nelson N (1976) The chloroethers - occupational carcinogens: A summary of laboratory and epidemiology studies. *Ann. NY Acad. Sci.* 271: 81-90
- NIH ROC (2011) National Institutes of Health. Report on Carcinogens, Twelfth Edition [http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/bis\(chloromethyl\)ether.pdf](http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/bis(chloromethyl)ether.pdf) Accessed May 1 2014
- U.S. Environmental Protection Agency. [\*Integrated Risk Information System \(IRIS\) on Bis\(chloromethyl\)ether\*](#). National Center for Environmental Assessment, Office of Research and Development, Washington, DC. 1999.
- Van Duuren BL, Goldschmidt BM, Seidman I (1975) Carcinogenic activity of di- and trifunctional  $\alpha$ -chloro ethers and of 1,4-dichlorobutene-2 in ICR/HA swiss mice. *Cancer Research* 35:2553-2557.
- Van Duuren BL, Sivak A, Goldschmidt BM, Katz C, Melchionne S (1969) Carcinogenicity of halo-ethers. *J Nat Cancer Inst.* 43: 481-486.

## 7. *p*-Chloroaniline (CAS# 106-47-8) and *p*-Chloroaniline HCl (CAS# 20265-96-7)

### 7.1. Potential for human exposure

Industrial exposure to *p*-Chloroaniline is primarily derived from the dye, textile, rubber and other industries (Beard and Noe, 1981). If released into the environment, it is inherently biodegradable in water under aerobic conditions (BUA, 1995).

### 7.2. Mutagenicity/genotoxicity

*p*-Chloroaniline is weakly mutagenic in vitro, with limited evidence for genotoxicity in vivo.

A detailed review of genotoxicity testing in a range of systems is provided in CICAD 48 (WHO, 2003) with references, so only key conclusions are summarized here.

- *p*-Chloroaniline was reproducibly mutagenic in the microbial reverse mutation assay (Ames), *Salmonella typhimurium* only in strain TA98 with S9 metabolic activation, although there are conflicting data in multiple studies.
- Weak mutagenicity has been reported in several mouse lymphoma (L6178Y) cell *tk* mutation assays in the presence of metabolic activation (WHO 2003); however the increases were very small, associated with substantial cytotoxicity, and do not meet the up-to-date criteria for a positive assay using the "global evaluation factor" (Moore et al, 2006).
- Small increases in chromosomal aberrations in Chinese hamster ovary cells were not consistent between two laboratories.
- *In vivo*, a single oral treatment did not induce micronuclei in mice at 180 mg/kg, but a significant increase was reported at 300 mg/kg/day after 3 daily doses in mice.

### 7.3. Carcinogenicity

*p*-Chloroaniline is classified as Group 2B, possibly carcinogenic to humans with adequate evidence of carcinogenicity in animals and inadequate evidence in humans (IARC, 1993).

Carcinogenicity studies in animals have been conducted for *p*-chloroaniline or its hydrochloride salt, *p*-chloroaniline HCl.

The NTP (1989) oral gavage study was used to calculate the AI, where *p*-chloroaniline HCl was carcinogenic in male rats, based on the increased incidence of spleen tumors: (Combined incidence of sarcomas: vehicle control, 0/49; low dose, 1/50; mid dose, 3/50; high dose, 38/50). Fibrosis of the spleen, a preneoplastic lesion that may progress to sarcomas, was seen in both sexes (Goodman et al., 1984; NTP, 1989). In female rats, splenic neoplasms were seen only in one mid-dose rat and one high-dose rat. Increased incidences of pheochromocytoma of the adrenal gland in male and female rats may have been related to *p*-chloroaniline administration; malignant pheochromocytomas were not increased. In male mice, the incidence of hemangiosarcomas of the liver or spleen in high dose group was greater than that in the vehicle controls (4/50; 4/49; 1/50; 10/50). The incidences of hepatocellular adenomas or carcinomas (combined) were increased in dosed male mice; of these, the numbers of hepatocellular carcinomas were (3/50; 7/49; 11/50; 17/50). The female mouse study was negative. The final conclusion of NTP (1989) was that there was clear evidence of carcinogenicity in

male rats, equivocal evidence of carcinogenicity in female rats, some evidence of carcinogenicity in male mice, and no evidence of carcinogenicity in female mice.

An earlier study used *p*-chloroaniline administered in feed to rats and mice (NCI, 1979). Splenic neoplasms were found in dosed male rats and hemangiomas in mice. While the incidences of these tumors are strongly suggestive of carcinogenicity, NCI concluded that sufficient evidence was not found to establish the carcinogenicity of *p*-chloroaniline in rats or mice under the conditions of these studies. Since *p*-chloroaniline is unstable in feed, the animals may have received the chemical at less than the targeted concentration (WHO, 2003). Therefore, this study is deemed inadequate.

#### **p-Chloroaniline and p-Chloroaniline HCl – Details of carcinogenicity studies**

| <b>Study</b>                                 | <b>Animals/<br/>dose<br/>group</b> | <b>Duration/<br/>Exposure</b> | <b>Controls</b> | <b>Doses</b>  | <b>Most sensitive<br/>tumor<br/>site/sex</b>                 | <b>TD<sub>50</sub><br/>(mg/kg/d<br/>)</b> |
|--|------------------------------------|-------------------------------|-----------------|---|--|---|
| NTP, 1989*<br><i>p</i> -chloroaniline<br>HCl | 50/group<br>B6C3F1<br>mice (M)     | Gavage<br>5X/wk,<br>103 wk    | 50              | 3:<br>3; 10; 30<br>mg/kg<br><br>(2.1; 7;<br>21.1<br>mg/kg/d)  | Hepatocellular<br>adenomas or<br>carcinomas                  | 33.8                                      |
| NTP, 1989<br><i>p</i> -chloroaniline<br>HCl  | 50/group<br>B6C3F1<br>mice (F)     | Gavage<br>5X/wk,<br>103 wk    | 50              | 3:<br>3; 10; 30<br>mg/kg<br><br>(2.1; 7;<br>21.1<br>mg/kg/d)  | Negative   | NA  |
| NTP, 1989<br><i>p</i> -chloroaniline<br>HCl  | 50/group<br>Fischer<br>344 rat (M) | Gavage<br>5X/wk,<br>103 wk    | 50              | 3:<br>2; 6; 18<br>mg/kg<br><br>(1.4; 4.2;<br>12.6<br>mg/kg/d) | Spleen<br>fibrosarcoma,<br>haemangiosarcoma,<br>osteosarcoma | 7.62                                      |
| NTP, 1989<br><i>p</i> -chloroaniline<br>HCl  | 50/group<br>Fischer<br>344 rat (F) | Gavage<br>5X/wk,<br>103 wk    | 50              | 3:<br>2; 6; 18<br>mg/kg<br><br>(1.4; 1.2;<br>12.6<br>mg/kg/d) | No significant<br>increases; equivocal                       | NA  |
| NCI, 1979                                    | 50/group                           | 78 wk                         | 20              | 2:  | Mesenchymal  | 72  |

| Study     | Animals/<br>dose<br>group              | Duration/<br>Exposure                               | Controls | Doses  | Most sensitive<br>tumor<br>site/sex  | TD <sub>50</sub><br>(mg/kg/d<br>) |
|-----------|--|---|----------|--|--|-----------------------------------|
|           | Fischer<br>344 rat (M)                 | (study<br>duration:<br>102 wk)<br><br>Diet          |          | 250; 500<br>ppm<br><br>(7.7;<br>15.2<br>mg/kg/d)         | tumours (fibroma,<br>fibrosarcoma,<br>haemangiosarcoma,<br><br>osteosarcoma,<br>sarcoma not<br>otherwise specified)<br>of the spleen or<br>splenic capsule |                                   |
| NCI, 1979 | 50/group<br><br>Fischer<br>344 rat (F) | 78 wk<br>(study<br>duration:<br>102 wk)<br><br>Diet | 20       | 2:<br><br>250; 500<br>ppm<br><br>(9.6, 19<br>mg/kg/d)    | Negative   | NA                                |
| NCI. 1979 | 50/group<br><br>B6C3F1<br>mice (M)     | 78 wk<br>(study<br>duration:<br>91 wk)<br><br>Diet  | 20       | 2:<br><br>2500;<br>5000 ppm<br><br>(257; 275<br>mg/kg/d) | Haemangiosarcoma<br>s (subcutaneous<br>tissue, spleen, liver,<br>kidney)<br><br>Increased incidence<br>of all vascular<br>tumours                          | Not<br>significant<br>(CPDB)      |
| NCI, 1979 | 50/group<br><br>B6C3F1<br>mice (F)     | 78 wk<br>(study<br>duration:<br>102 wk)<br><br>Diet | 20       | 2:<br><br>2500;<br>5000 ppm<br><br>(278, 558<br>mg/kg/d) | Haemangiosarcoma<br>s (liver and spleen)<br><br>Increased incidence<br>of combined<br>vascular tumours   | 1480                              |

Studies listed are in CPDB [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\*Carcinogenicity study selected for AI calculation.

NA = Not applicable

#### **7.4. Mode of action for carcinogenicity**

*p*-Chloroaniline induced tumors in male rats, such as spleen fibrosarcomas and osteosarcomas, typical for aniline and related chemicals. Repeated exposure to *p*-chloroaniline leads to cyanosis and methemoglobinemia, followed by effects in blood, liver, spleen, and kidneys, manifested as changes in hematological parameters, splenomegaly, and moderate to severe hemosiderosis in spleen, liver, and kidney, partially accompanied by extramedullary hematopoiesis (NCI, 1979; NTP, 1989). These effects occur secondary to excessive compound-induced hemolysis and are consistent with a regenerative

anemia (WHO, 2003). The evidence supports an indirect mechanism for tumorigenesis, secondary to methemoglobinemia, splenic fibrosis and hyperplasia (e.g., Bus and Popp, 1987), and not tumor induction related to a direct interaction of *p*-chloroaniline or its metabolites with DNA.

The tumor type with the lowest TD<sub>50</sub> was spleen tumors in male rats. However, since this tumor type is associated with a non-linear dose relation, a PDE calculation was done (see below). The result (143 µg/day) is comparable to the recommendation for a level of 0.2 µg/kg/day, based on non-neoplastic (hematotoxic) effects (WHO 2003), i.e., 100 µg/day for a 50 kg human.

For male mouse liver tumors, the TD<sub>50</sub> based on the combined numbers of adenomas and carcinomas was 33.8 mg/kg/day. *p*-chloroaniline is not reproducibly mutagenic. There is one positive study in vivo (micronucleus test), but this was positive only at a dose level in the range of the LD<sub>50</sub> and given the known methemoglobinemia, this might be secondary to regenerative anemia/altered erythropoiesis, as with aniline (Ashby et al, 1991; Tweats et al, 2007).

A Permissible Daily Exposure (PDE) for *p*-chloroaniline was calculated as follows:

(NOEL x body weight adjustment (kg) / F1 x F2 x F3 x F4 x F5

The following safety factors as outlined in ICH Q3C have been applied:

F1 = 5 (rat to human)

F2 = 10 (inter- individual variability)

F3 = 1 (study duration at least half lifetime)

F4 = 10 (severe toxicity – non-genotoxic carcinogenicity)

F5 = 1 (using a NOEL)

In the rat study of *p*-chloroaniline HCl (NTP, 1989) the lowest dose was clearly a No Observed Effect Level (NOEL): (2 mg/kg 5 days per week, or 1.43 mg/kg/day).

On this basis the PDE is calculated as follows:

Lifetime PDE = 1.43 x 50 kg / (5 x 10 x 1 x 10 x 1)

**Lifetime PDE = 143 µg/day**

#### Conclusion

Overall, there is very limited evidence for a mutagenic mode of action, but in vivo information is lacking. Thus, a mutagenic mode of action cannot be entirely ruled out and calculation of an AI was considered appropriate. Other single-ring aromatic amines have been associated with tumors in liver, urinary bladder and kidney (CPDB). Because a mutagenic component to the mode of action for liver tumors cannot be ruled out, the linear extrapolation AI is recommended.

### **7.5. Regulatory and/or Published Limits**

No regulatory limits have been published for *p*-chloroaniline or the hydrochloride salt.

### **7.6. Calculation of AI**

#### **7.6.1. Calculation of AI**

Based on male mouse liver tumors for *p*-chloroaniline HCl

Lifetime AI =  $TD_{50}/50,000 \times 50\text{kg}$

Lifetime AI =  $33.8\text{mg/kg/day} / 50,000 \times 50\text{ kg}$

**Lifetime AI = 34 µg/day**

## 7.6.2. References

Ashby J, Vlachos DA, and Tinwell H (1991) Activity of aniline in the mouse bone marrow micronucleus assay. *Mutat. Res.*, 263: 115-117.

Beard RR and Noe JT (1981) Aromatic nitro and amino compounds, G.D. Clayton, F.E. Clayton (Eds.), *Patty's Industrial Hygiene and Toxicology* John Wiley, New York, pp. 2A: 2413–2489.

BUA (1995) p-Chloroaniline. Beratergremium für Umweltrelevante Altstoffe (BUA) der Gesellschaft Deutscher Chemiker. Weinheim, VCH, 171 pp. (BUA Report 153).

Bus JS and Popp JA, (1987) Perspectives on the mechanism of action of the splenic toxicity of aniline and structurally-related compounds, *Food Chem Toxicol* 25: 619–626.

Goodman DG, Ward JM and Reichardt WD (1984) Splenic fibrosis and sarcomas in F344 rats fed diets containing aniline hydrochloride, p-chloroaniline, azobenzene, o-toluidine hydrochloride, 4,4'-sulfonyldianiline, or D & C Red No. 9; *J Natl Cancer Inst* 73(1):265-273.

IARC (1993) Para-chloroaniline. In: *Occupational exposures of hairdressers and barbers and personal use of hair colourants; some hair dyes, cosmetic colourants, industrial dyestuffs and aromatic amines.* Lyon, International Agency for Research on Cancer, pp. 305-321 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 57).

NCI (1979) Bioassay of p-chloroaniline for possible carcinogenicity, CAS No. 106-47-8. Bethesda, MD, US National Cancer Institute, 88 pp. (NCI-CG-TR-189).

NTP (1989) Toxicology and carcinogenesis studies of para-chloroaniline hydrochloride (CAS No. 20265-96-7) in F344/N rats and B6C3F1 mice (gavage studies). Research Triangle Park, NC, National Toxicology Program (NTP TR 351; NIH Publication No. 89-2806).

Tweats, D, Blakey, D, Heflich, RH, Jacobs, A, Jacobsen, SD, Nohmi, TT, O'Donovan, MR, Sasaki, YF, Sofuni, T, Tice, R (2007) Report of the IWGT working group on strategies and interpretation of regulatory in vivo tests. I. Increases in micronucleated bone marrow cells in rodents that do not indicate genotoxic hazards. *Mutat. Res.* 627 :78-91

World Health Organization (WHO). (2003) *CICADS 48: Concise International Chemical*

*Assessment Document 48 p=chloroaniline.* Geneva.

<http://www.inchem.org/documents/cicads/cicads/cicad48.htm>

## 8. 1-Chloro-4-nitrobenzene (para-Chloronitrobenzene, CAS# 100-00-5)

### 8.1. Potential for human exposure

Potential for exposure is in industrial use. No data are available for exposure of the general population.

### 8.2. Mutagenicity/genotoxicity

1-Chloro-4-nitrobenzene is mutagenic and genotoxic *in vitro* and *in vivo*.

- 1-Chloro-4-nitrobenzene was mutagenic in the microbial reverse mutation assay (Ames) *Salmonella typhimurium* strains TA100 and TA1535 in the presence of S9 metabolic activation, and was negative in TA1537, TA1538, TA98, and *E.coli* WP2uvrA (Haworth et al., 1983; Japan, 2005; Kawai et al., 1987; NTP, 1993). It was also weakly positive without metabolic activation in TA1535 in 2 of 4 studies (NTP, 1993).
- Positive results have been reported for induction of structural chromosome aberrations and sister chromatid exchanges in Chinese hamster ovary (CHO) cells; the increase was weaker without than with S9 (Galloway et al., 1987; NTP 1993). Structural chromosome aberrations were also reported in CHL cells with and without S9 (Japan, 1996).
- It induced single-strand DNA breaks, measured by the alkaline elution technique, in rat hepatocytes *in vitro*, and in the liver, kidney, and brain of male Swiss mice when administered intraperitoneally (Cesarone et al., 1983; 1984).

### 8.3. Carcinogenicity

1-Chloro-4-nitrobenzene is classified as a Group 2 carcinogen, not classifiable as to its carcinogenicity in humans (IARC, 1996) and US EPA considers it to be a Group B2 carcinogen or probable human carcinogen (US EPA, 1995).

Animal carcinogenicity studies have been conducted with 1-chloro-4-nitrobenzene by administration in the feed in rats and mice (Matsumoto et al, 2006; Weisburger et al., 1978; CPDB) or by gavage in male rats (Schroeder and Daly, 1984).

In the study of Matsumoto et al. (2006), there were significant increases in spleen tumors (fibroma, fibrosarcoma, osteosarcoma and sarcoma) in rats of both sexes, and there were increases in spleen hemangiosarcomas in both sexes, that were statistically significant in males at the mid and high doses (7.7 and 41.2 mg/kg/day). Non-neoplastic changes of the spleen such as fibrosis, and capsule hyperplasia were seen. An increase in adrenal medullary pheochromocytomas was seen at the high dose that was statistically significant in females (53.8 mg/kg/day). In mice, the only significant increase in tumors was in liver hemangiosarcomas at the high dose in females (275.2 mg/kg/day). Hematologic disturbances such as decreases in red blood cell numbers and haematocrit, and extramedullary hematopoiesis, were seen both in rats and in mice.

In the study of Weisburger et al. (1978), 1-chloro-4-nitrobenzene did not induce tumors in male CD-1 rats when fed in the diet for 18 months. The concentration in the feed was adjusted during the 18-month period due to toxicity as follows: The low dose group received 2000 ppm for the first 3 months, 250 ppm for next 2 months, and 500 ppm from 6 to 18 months; the high dose group received 4000 ppm for the first 3 months, 500 ppm for next 2 months, and 1000 ppm from 6 to 18 months. The

average daily exposure was approximately 17 and 33 mg/kg for the low and high dose groups, respectively. Rats were sacrificed 6 months after the last dose and examined for tumors. No treatment-related increases in tumors were observed in the 11 tissues examined (lung, liver, spleen, kidney, adrenal, heart, bladder, stomach, intestines, testes and pituitary).

Weisburger et al. (1978) also investigated the carcinogenic potential of 1-chloro-4-nitrobenzene in male and female CD-1 mice, given in the feed for 18 months. Mice were sacrificed 3 months after the last exposure and 12 tissues (lung, liver, spleen, kidney, adrenal, heart, bladder, stomach, intestines, and reproductive organs) were examined for tumors. A dose-dependent increase in vascular tumors (hemangiomas or hemangiosarcomas) of liver, lung, and spleen was observed in both male and female mice.

In another study (Schroeder and Daly, 1984), male and female Sprague-Dawley rats (n = 60) were given 1-chloro-4-nitrobenzene by gavage 5 days/week for 24 months. In both sexes, toxicity was observed: methemoglobinemia in mid- and high-dose groups, and hemosiderin and anemia in the high-dose group.

### 1-Chloro-4-nitrobenzene – Details of carcinogenicity studies

| Study                                      | Animals/<br>dose<br>group           | Duration<br>/<br>Exposure | Controls | Doses  | Most sensitive<br>tumor<br>site/sex         | TD <sub>50</sub><br>(mg/kg/d<br>) |
|--|-------------------------------------|---------------------------|----------|--|---|-----------------------------------|
| Matsumoto<br>et al,<br>2006 <sup>*,+</sup> | 50/ group<br>F344 rats<br>(SPF) (M) | 2 years<br>(diet)         | 50       | 3<br>40; 200;<br>1000 ppm.<br><br>(1.5; 7.7;<br>41.2<br>mg/kg/d)     | Spleen<br>hemangiosarcomas<br>7.7 mg/kg/day | 173.5                             |
|  | 50/ group<br>F344 rats<br>(SPF) (F) | 2 years<br>(diet)         | 50       | 3<br>40; 200;<br>1000 ppm.<br><br>(1.9;<br>9.8; 53.8<br>mg/kg/d)     | Female<br>pheochromocytoma<br>53.8 mg/kg/d  | 116.9                             |
|  | 50/ group<br>Crj:BDF1<br>(SPF) (M)  | 2 years<br>(diet)         | 50       | 3<br>125; 500;<br>2000 ppm.<br><br>(15.3;<br>60.1; 240.1<br>mg/kg/d) | Not applicable                              |                                   |

|   |   |   |        |   |   |                       |
|---|---|---|--------|---|---|-----------------------|
|   | 50/ group<br>Crj: BDF1<br>(SPF) (F)       | 2 years<br>(diet)                                       | 50     | 3<br>125; 500;<br>2000 ppm.<br>(17.6;<br>72.6; 275.2<br>mg/kg/d)                    | Hepatic<br>hemangiosarcomas<br>275.2 mg/kg/d            | 1919.9                |
| Weisberger<br>et al, 1978                   | 14-15/<br>group<br>CD-1 rats<br>(M)       | 18 mo<br>diet;<br>sacrificed<br>6 mo after<br>last dose | 16     | 2:<br>Average 17<br>and 33<br>mg/kg;<br>(see text)<br>(22.6 and<br>45.2<br>mg/kg/d) | Not applicable  | Negative <sup>^</sup> |
|   | 14-20/sex<br>group<br>CD-1 mice           | 18 mo<br>diet;<br>sacrificed<br>3 mo after<br>last dose | 15/sex | 2:<br>M: 341;<br>720.<br>F: 351; 780<br>mg/kg/d                                     | Vascular<br>(hemangiomas/<br>Hemangiosarcomas)<br>/Male | 430 <sup>^</sup>      |
| Schroeder<br>and Daly,<br>1984 <sup>+</sup> | 60/sex/<br>group<br>Sprague<br>Dawley rat | Gavage,<br>5 d/wk:<br>24 mo                             | Yes    | 3/<br>0.1; 0.7; 5<br>mg/kg/d  | Not applicable  | Negative              |

Studies listed are in CPDB unless otherwise noted. [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\*Carcinogenicity study selected for AI/PDE calculation.

<sup>+</sup>Not in CPDB.

<sup>^</sup> Histopathology limited to 11-12 tissues.

#### **8.4. Mode of action for carcinogenicity**

1-Chloro-4-nitrobenzene is significantly metabolized by reduction to 4-chloroaniline (*p*-chloroaniline) in rats (Yoshida et al., 1991), rabbits (Bray et al., 1956) and humans (Yoshida et al., 1993). *p*-Chloroaniline has been shown to produce hemangiosarcomas and spleen tumors in in rats and mice, similar to 1-chloro-4-nitrobenzene (IARC, 1993). Like aniline, an indirect mechanism for vascular tumorigenesis in liver and spleen is indicated, secondary to oxidative erythrocyte injury and splenic fibrosis and hyperplasia, both for 4-chloroaniline (IARC, 1993) and 1-chloro-4-nitrobenzene (Travlos et al., 1996). Methemoglobinemia and associated toxicity is a notable effect of 1-chloro-4-nitrobenzene. A non-linear mechanism for tumor induction is supported by the fact that in the study of Schroeder

and Daly (1984), carried out at lower doses than the studies of Matsumoto et al (2006) and Weisberger et al (1978), methemoglobinemia and hemosiderin were seen but there was no increase in tumors.

The tumor type with the lowest TD<sub>50</sub> was adrenal medullary pheochromocytomas in female rats (Matsumoto et al., 2006). This tumor type is common as a background tumor in F344 rats, especially males, and is seen after treatment with a number of chemicals, many of them non-mutagenic (Greim et al, 2009). It has been proposed that they are associated with various biochemical disturbances, and the mode of action for induction of pheochromocytomas by chemicals such as aniline and p-chloroaniline that are toxic to red blood cells may be secondary to uncoupling of oxidative phosphorylation (Greim et al., 2009) or perhaps hypoxia.

Two models were considered for deriving an acceptable intake for 1-chloro-4-nitrobenzene. First is the linear extrapolation model. It was noted that in mutagenicity studies in *Salmonella*, 1-chloro-4-nitrobenzene was mutagenic in *Salmonella* TA100 and TA1535 (but not TA98 and other strains). This may indicate a mutagenic component to the mode of action for tumor induction by 1-chloro-4-nitrobenzene, but the pattern of mutagenicity is different from its metabolite p-chloroaniline, which was reproducibly mutagenic only in *Salmonella* TA98 with rat liver S9 (WHO, 2003) indicating differences in mutagenic metabolites or mechanism. In vivo genotoxicity data are lacking to help assess potential for a mutagenic mode of action.

Second, a non linear model was considered based on the following:

- The most notable types of tumors induced were those associated with methemoglobinemia, (spleen and vascular tumors);
- Adrenal medullary pheochromocytomas may be associated with the same perturbations;
- There is clearly a non-linear dose relation (based on no-effect doses and on the the negative results of the lower-dose study of Schroeder and Daly (1984).

Thus a PDE calculation was performed.

#### **8.4.1. Calculation of Permissible Daily Exposure (PDE)**

The PDE calculation is: (NOEL x body weight adjustment (kg)) / F1 x F2 x F3 x F4 x F5

The following safety factors as outlined in ICH Q3C have been applied to determine the PDE:

F1 = 5 (rat to human)

F2 = 10 (inter- individual variability)

F3 = 1 (study duration at least half lifetime)

F4 = 10 (severe toxicity – non-genotoxic carcinogenicity)

F5 = 1 (using a NOEL)

The NOAEL for changes in red blood cell parameters and for male rat spleen hemangiosarcomas in the study of Matsumoto et al. (2006) was 1.5 mg/kg/day. This is also below the no-effect dose for female rat pheochromocytomas.

Lifetime PDE = 1.5 x 50 kg / (5 x 10 x 1 x 10 x 1)

**Lifetime PDE = 150 µg/day**

## 8.4.2. Conclusion

The linear and non-linear models in this case result in similar values, 117 and 150 ug/day, although the safety factor used for non-genotoxic carcinogenicity ( $F_4 = 10$ ) may be higher than necessary, and the PDE correspondingly lower. Because we cannot rule out a mutagenic component to the mode of action for pheochromocytomas, the linear extrapolation AI is recommended.

## 8.5. Regulatory and/or published limits

No regulatory limits have been published, for example by US EPA, WHO, or ATSDR.

## 8.6. Calculation of AI

### Calculation of AI

The most sensitive  $TD_{50}$  is that for adrenal medullary pheochromocytomas in female rats (Matsumoto et al., 2006).

Lifetime AI =  $TD_{50}/50,000 \times 50\text{kg}$

Lifetime AI =  $117 \text{ mg/kg/day} /50,000 \times 50 \text{ kg}$

**Lifetime AI = 117  $\mu\text{g/day}$**

## 8.7. References

Bray HG, James SP, and Thorpe WV (1956). The metabolism of the monochloronitrobenzenes in the rabbit. *Biochem J*, 64: 38-44.

Cesarone CF, Bolognesi C, and Santi L (1983). DNA damage induced in vivo in various tissues by nitrobenzene derivatives. *Mutat Res*, 116: 239-246.

Cesarone CF, Fugassa E, Gallo G, Voci A, and Orunesu M (1984). Influence of the culture time on DNA damage and repair in isolated rat hepatocytes exposed to nitrochlorobenzene derivatives. *Mutat Res*, 131: 215-222.

CPDB (Carcinogenic Potency Database) data on 1-chloro-4-nitrobenzene.

<http://toxnet.nlm.nih.gov/cpdb/chempages/1-CHLORO-4-NITROBENZENE.html>

Galloway S, Armstrong M, Reuben C, Colman S, Brown B, Cannon C, Bloom A, Nakamura F, Ahmed M, Duk S, Rimpo J, Margolin B, Resnick M, Anderson B, and Zeiger E (1987) Chromosome aberration and sister chromatid exchanges in Chinese hamster ovary cells: Evaluations of 108 chemicals. *Environ. Molec. Mutagen.* 10 (Suppl 10), 1-176.

Greim, H., Hartwig, A., Reuter, U., Richter-Reichelm, H-B., Thielman, H-W. (2009) Chemically induced pheochromocytomas in rats: mechanisms and relevance for human risk assessment. *Crit Rev Toxicol* 39:695-718.

Haworth S, Lawlor T, Mortelmans K, Speck W, and Zeiger E (1983) Salmonella mutagenicity test results for 250 chemicals *Environ. Mutagen.* Vol. 5 (Suppl 1) 3-142

International Agency for Research on Cancer (IARC) (1993) IARC monographs on the evaluation of carcinogenic risks to humans. Occupational exposures of hairdressers and barbers and personal use of

hair colourants; some hair dyes, cosmetic colourants, industrial dyestuffs and aromatic amines. Vol. 57. World Health Organization, Lyon, France.

International Agency for Research on Cancer (IARC) (1996) IARC monographs on the evaluation of carcinogenic risks to humans. Printing processes and printing inks, carbon black and some nitro compounds. Vol. 65. World Health Organization, Lyon, France.

Japan Chemical Industry Ecology-Toxicology & information Center (JETOC) (2005) Japan: Mutagenicity test data of existing chemical substances based on the toxicity investigation system of the industrial safety and health law. Addendum 3.

Japan Chemical Industry Ecology-Toxicology & information Center (JETOC) (1996) Japan: Mutagenicity test data of existing chemical substances based on the toxicity investigation system of the industrial safety and health law.

Kawai A, Goto S, Matsumoto Y, and Matsushita H (1987) Mutagenicity of aliphatic and aromatic nitro compounds. *Sangyoigaku* 29: 34-55

Matsumoto, M., Aiso, S., Senoh, H., Yamazaki, K., Arito, H., Nagano, K., Yamamoto, S., Matsushima, T. (2006). Carcinogenicity and chronic toxicity of *para*-chloronitrobenzene in rats and mice by two-year feeding. *J. Env Path Tox Oncol* 25:571-584

National Toxicology Program (NTP) (1993) NTP Technical Report on Toxicity Studies on 2-Chloronitrobenzene and 4-Chloronitrobenzene (CAS Nos. 88-73-3 and 100-00-5) Administered by Inhalation to F344/N Rats and B6C4F1 Mice. NTP Toxicity Report Series No, 33: NIH Publication 93-3382. Research Triangle Park, NC

Schroeder RE, and Daly JW (1984) A chronic oral gavage study in rats with p- nitrochlorobenzene. Biodynamics Inc. Project No. 80-2487. NTIS/OTS 0536382.

Travlos, G. S., Mahler, J., Ragan, H. A., Chou, B. J., Bucher, J. R. (1996). Thirteen-week inhalation toxicity of 2- and 4-chloronitrobenzene in F344/N rats and B6C3F1 mice. *Fundam Appl Toxicol*, 30: 75-92.

U.S. Environmental Protection Agency (USEPA) (1995) Health Effects Assessment Summary Tables. Office of Solid Waste and Emergency Response, US Environmental Protection Agency, Washington DC. Pub. No. PB95-921199.

Weisburger EK, Russfield AB, Homburger F, Weisburger JH, Boger E, Van Dongen, CG, and Chu KC (1978) Testing of twenty-one environmental aromatic amines or derivatives for long-term toxicity or carcinogenicity. *J Environ Pathol Toxicol*, 2:325-356.

World Health Organization (WHO). (2003) CICAD 48: Concise International Chemical

Assessment Document 48 p-chloroaniline. Geneva.

<http://www.inchem.org/documents/cicads/cicads/cicad48.htm>

Yoshida T, Andoh K, and Tabuchi T (1991) Identification of urinary metabolites in rats treated with p-chloronitrobenzene. *Arch Toxicol*, 65: 52-58.

Yoshida T, Tabuchi T, and Andoh K (1993) Pharmacokinetic study of p-chloronitrobenzene in humans suffering from acute poisoning. *Drug Metab Dispos*, 21: 1142-1146.

## 9. p-Cresidine (2-Methoxy-5-methyl aniline, CAS# 120-71-8)

### 9.1. Potential for human exposure

Potential for exposure is in industrial use. No data are available for exposure of the general population.

### 9.2. Mutagenicity/genotoxicity

p-Cresidine is mutagenic/genotoxic *in vitro* with equivocal evidence for genotoxicity *in vivo*.

p-Cresidine is mutagenic in:

- Several *Salmonella* strains in the presence of metabolic activation (Zeiger et al, 1988; Dunkel et al 1985; Japan 1997).
- Big Blue transgenic mouse model with the lamda cII gene; p-cresidine administered a diet of 0.25 and 0.5%, comparable to the doses in the carcinogenicity study, for 180 days (Jakubczak et al, 1996).

Weakly positive results were reported for induction of structural chromosome aberrations and sister chromatid exchanges in CHO cells with rat liver S9 U.S. National Toxicology Program (NTP) and structural chromosome aberrations in CHL cells (Japan 2005).

*In vivo*, p-cresidine did not induce micronuclei in bone marrow of male B6C3F1 mice given 3 daily intraperitoneal injections in two separate studies up to 300 mg/kg/day (NCI), or in p53 heterozygous or nullizygous mice after oral gavage treatment for 7 weeks (Delker et al, 2000).

Increases in micronuclei were seen in blood polychromatic erythrocytes (PCE) after dosing with p-cresidine by oral gavage to p53+/- mice for 39 to 183 days (Stoll et al, 2006). Since there were indications of the well characterized methemobolinemia and regenerative anemia associated with aniline and related compounds, (decreased hematocrit, dark urine, increased percentage of circulating PCEs) the authors noted it is not possible to determine whether the increase in micronuclei reflects hematological disturbance rather than genotoxicity (Stoll et al, 2006).

Extensive experiments in multiple strains of rodents by oral and IP routes after 1 to 6 administrations failed to demonstrate *in vivo* genotoxicity in several tissues including bladder, by induction of DNA single-strand breaks measured by the alkaline elution assay, or of micronuclei (Ashby et al, 1991; Morita et al, 1997). Concomitant methemoglobinemia demonstrated that the p-cresidine was absorbed and oxidized in these negative studies. However, DNA strand breaks assessed by the Comet assay were reported in bladder mucosa, but not other tissues, after oral treatment of mice with p-cresidine (Sasaki et al., 1998).

### 9.3. Carcinogenicity

p-Cresidine is classified as a Group 2B carcinogen, or possibly carcinogenic in humans (IARC 1982; 1987).

There is only one set of carcinogenicity studies in the standard rodent model. In NTP studies (NCI technical report 142) p-cresidine induced tumors in lifetime studies in Fischer 344 rats and B6C3F1

mice, with p-cresidine administered in the feed. No carcinogenicity data are available for other routes of exposure.

p-Cresidine was administered in the feed, to groups of 50 male and 50 female animals of each species. There were also 50 control animals of each sex. The concentrations of p-cresidine were 0.5 or 1.0 percent in the diet, but in mice the concentrations administered were reduced after 21 weeks to 0.15 and 0.3 percent. The dose levels, converted to mg/kg/day in the CPDB, were 198 and 368 mg/kg/day for male rats; 245 and 491 mg/kg/day for female rats; 260 and 552 mg/kg/day for male mice and 281 and 563 mg/kg/day for female mice.

All dosed animals, except for high dose male mice, were administered p-cresidine in the diet for 104 weeks and observed for an additional period of up to 2 weeks. All high dose male mice were dead by the end of week 92. Mortality rates were dose-related for both sexes of both species. That incidences of certain tumors were higher in low dose than in high dose groups was probably due to accelerated mortality in the high dose groups.

In dosed rats of both sexes, statistically significant incidences of bladder carcinomas (combined incidences of papillary carcinomas, squamous-cell carcinomas, transitional-cell papillomas, transitional-cell carcinomas, and undifferentiated carcinomas) and olfactory neuroblastomas were observed. The combined incidence of neoplastic nodules of the liver, hepatocellular carcinomas, or mixed hepato/cholangio carcinomas was also significant in low dose male rats. In both male and female dosed mice, the incidence of bladder carcinomas (combined incidence of carcinomas, squamous-cell carcinomas, and transitional-cell carcinomas) was significant. The incidence of hepatocellular carcinomas was significant in dosed female mice.

In summary, p-cresidine was carcinogenic to Fischer 344 rats, causing increased incidences of carcinomas and of papillomas of the urinary bladder in both sexes, increased incidences of olfactory neuroblastomas in both sexes, and of liver tumors in males. p-Cresidine was also carcinogenic in B6C3F1 mice, causing carcinomas of the urinary bladders in both sexes and hepatocellular carcinomas in females.

Induction of bladder tumors was also seen in a short-term carcinogenicity model in p53+/- hemizygous mice. p-Cresidine was used as a positive control in a large inter-laboratory assessment of the mouse model (Storer et al, 2001). Increases in bladder tumors were seen in 18 of 19 studies in which p-cresidine was administered by gavage at 400 mg/kg/day for 26 weeks, and in the single study where compound as given in feed.

## p-Cresidine – Details of carcinogenicity studies

| Study   | Animals/<br>dose<br>group              | Duration<br>/<br>Exposure | Controls | Doses   | Most<br>sensitive<br>tumor<br>site/sex | TD <sub>50</sub><br>(mg/kg/<br>d) |
|---------|--|---------------------------|----------|---|--|-----------------------------------|
| NCI*    | 50/sex/<br>group<br>B6C3F1<br>mice     | Feed<br>2 yr              | 50       | 2: 0.5 and 1%<br>Reduced after 21<br>wk to 0.15 and<br>0.3%.<br>M: 260;552.<br>F: 281; 563<br>mg/kg/d | Urinary<br>Bladder<br>/Male            | 44.7                              |
| NCI/NTP | 50/sex/<br>Group<br>Fisher 344<br>rats | Feed<br>2 yr              | 50       | 0.5 and 1%<br>M: 198;396.<br>F: 245;491<br>mg/kg/d  | Urinary<br>Bladder<br>/Male            | 88.4                              |

\*Carcinogenicity study selected for AI calculation.

Studies listed are in CPDB [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

### 9.4. Mode of action for carcinogenicity:

Not defined.

### 9.5. Regulatory and/or published limits

No regulatory limits have been published

### 9.6. Acceptable intake (AI)

#### 9.6.1. Rationale for selection of study for AI calculation:

The only adequate carcinogenicity studies of p-cresidine were those reported in the CPDB and conducted by NTP/NCI. The study in mice was selected for derivation of the AI since the most sensitive TD<sub>50</sub> was based on urinary bladder tumors in male mice.

#### 9.6.2. Calculation of AI:

The most sensitive TD<sub>50</sub> values from the NTP/NCI studies are for the urinary bladder in both sexes of rats and mice; in rats the TD<sub>50</sub> was 110 mg/kg/day for females and 88.4 mg/kg/day for males; in mice the TD<sub>50</sub> was 69 mg/kg/day for females and 44.7 mg/kg/day for males. The most conservative value is that identified for male mice.

The lifetime AI is calculated as follows:

Lifetime AI =  $TD_{50}/50,000 \times 50 \text{ kg}$

Lifetime AI =  $44.7 \text{ mg/kg/day} /50,000 \times 50 \text{ kg}$

**Lifetime AI = 45 µg/day**

## 9.7. References

Ashby J, Lefevre PA, Tinwell H, Brunborg G, Schmezer P, Pool-Zobel B, Shanu-Wilson R, Holme JA, Soderlund EJ, Gulati D and Wojciechowski JP. (1991) The non-genotoxicity to rodents of the potent rodent bladder carcinogens *o*-anisidine and *p*-cresidine. *Mutat. Res.* 250: 115-133.

CPDB data on p-cresidine <http://toxnet.nlm.nih.gov/cpdb/chempages/p-CRESIDINE.html>

Delker DA, Yano BL and Gollapudi BB. (2000) Evaluation of cytotoxicity, cell proliferation, and genotoxicity induced by p-cresidine in hetero- and nullizygous transgenic p53 mice. *Toxicolog. Sci.* 55: 361-369.

Dunkel VC, Zeiger E, Brusick D, McCoy E, McGregor D, Mortelmans K, Rosenkranz HS and Simmon VF. (1985) Reproducibility of microbial mutagenicity assays: II. Testing of carcinogens and noncarcinogens in *Salmonella typhimurium* and *Escherichia coli*. *Environ. Molec. Mutagen.* 7(suppl. 5): 1-248

IARC para-Cresidine 27, 92, 1982; reviewed in Suppl 7 1987

Jakubczak JL. et al. (1996) Analysis of genetic instability during mammary tumor progression using a novel selection-based assay for in vivo mutations in a bacteriophage lambda transgene target. *Proc. Natl. Acad. Sci. U. S. A.*, 93(17): 9073–9078.

Jakubczak JL, Merlino G, French JE, Muller WJ, Paul B, Adhya S and Garges S. (1996). Analysis of genetic instability during mammary tumor progression using a novel selection-based assay for in vivo mutations in a bacteriophage λ transgene target. *Proc Natl Acad Sci (USA)* 93: 9073-9078

Japan Chemical Industry Ecology-Toxicology and Information center (1997) Japan; Mutagenicity test data of existing chemical substances based on the toxicity investigation of the Industrial Safety and Health law; (suppl).

Japan Chemical Industry Ecology-Toxicology and Information center (2005) Japan; Mutagenicity test data of existing chemical substances based on the toxicity investigation of the Industrial Safety and Health law; (suppl 3).

Morita T, Norihide A, Awogi T, Sasaki Yu F, Sato-S-I, Shimada H, Sutou S, Suzuki T, Wakata A, Sofuni T, Hayashi M. (1997) Evaluation of the rodent micronucleus assay in the screening of IARC carcinogens (Groups 1, 2A and 2B). The summary report of the 6<sup>th</sup> collaborative study by CSGMT/JEMS.MMS. *Mutat Res.* 389: 3-122.

NCI (National Cancer Institute) Carcinogenesis Technical Report Series No. 142 (1979) Bioassay of p-cresidine for possible carcinogenicity.

NTP; <http://ntp.niehs.nih.gov/testing/status/agents/ts-10556-y.html>

Sasaki YF, Nishidate E, Su YQ, Matsusaka N, Tsuda S, Susa N, Furukawa Y and Ueno S. (1998) Organ-specific genotoxicity of the potent rodent bladder carcinogens *o*-anisidine and *p*-cresidine. *Mutat. Res.* 412: 155-160.

Storer RD, French JE, Haseman J, Hajian G, LeGran EK, Long GD, Mixson L, Ochoa R, Sagartz JE and Soper KA. (2001) p53<sup>+/-</sup> hemizygous knockout mouse: Overview of available data. *Toxicologic Pathol.* 29(suppl): 30-50.

Stoll RE, Blanchard KT, Stoltz JH, Majeski JB, Furst S, Lilly PD and Mennear JH. (2006) Phenolphthalein and nisacodyl: Assessment of genotoxic and carcinogenic responses in heterozygous p53<sup>(+/-)</sup> mice and Syrian hamster embryo (SHE) assay. *Toxicological Sciences* 90(2): 440-50.

Zeiger E, Anderson B, Haworth S, Lawlor T and Mortelmans K. (1988) *Salmonella* mutagenicity tests: IV. Results from the testing of 300 chemicals. *Environ. Molec. Mutagen.* 11(suppl.12): 1-158.

## 10. Dimethylcarbamyl chloride (CAS# 79-44-7)

### 10.1. Potential for human exposure

Potential for exposure is in industrial use. No data are available for exposure of the general population.

### 10.2. Mutagenicity/genotoxicity

DMCC is considered mutagenic and genotoxic *in vitro* and *in vivo*.

DMCC was mutagenic in:

- *Salmonella typhimurium* TA100, TA1535, TA1537, TA98 and TA1538 Ames positive with and without metabolic activation (Dunkel et al 1984, Kier et al 1986),
- Mouse lymphoma L5178Y cell *tk* mutation assay (Myhr et al 1988)

DMCC was positive in a chromosomal aberration test with CHO cells (Galloway et al 1985) and the micronucleus assay *in vivo* (Heddle et al 1983).

### 10.3. Carcinogenicity

DMCC is classified as a Group 2A compound, or probably carcinogenic to humans (IARC, 1999).

No deaths from cancer were reported in a small study of workers exposed for periods ranging from six months to 12 years, and there is inadequate evidence in humans for the carcinogenicity of DMCC. There is evidence that DMCC induced tumors in rodents.

Since oral studies are lacking, the studies considered for AI derivation used inhalation and intraperitoneal administration.

Syrian golden hamsters were exposed to 1 ppm DMCC by inhalation for 6 hours/day, 5 days/week until the end of their lives or sacrifice due to moribundity (Sellakumar et al., 1980). Squamous cell carcinoma of the nasal cavity was seen in 55% of the animals whereas no spontaneous nasal tumors were seen in the controls, or historical controls. When early mortality was taken into consideration, the percentage of tumor bearing animals was calculated to be 75% (Sellakumar et al., 1980).

DMCC was tested for carcinogenic activity in female ICR/Ha Swiss mice by skin application, subcutaneous injection and intraperitoneal injection (Van Duuren et al., 1974; this study was selected to calculate the AI). In the skin application, 2 mg of DMCC was applied 3 times a week for 492 days; this was seen to induce papillomas in 40/50 mice and carcinomas in 30/50 mice. Subcutaneous injection once weekly was continued for 427 days at a dose of 5 mg/week. Sarcomas and squamous cell carcinomas were seen in 36/50 and 3/50 mice, respectively, after the subcutaneous injection. In the intraperitoneal experiment, the mice were injected weekly with 1 mg DMCC for a total duration of 450 days. The treatment induced papillary tumors of the lung in 14/30 animals and local malignant tumors in 9/30 animals (8/30 were sarcomas). In the control groups, no tumors were seen by skin application, 1/50 sarcoma by subcutaneous injection, and 1/30 sarcoma and 10/30 papillary tumors of lung by intraperitoneal injection. Overall, only the local (injection site) tumors were significantly increased; tumors at distant sites were not statistically significantly increased compared with controls.

**Dimethylcarbamyl chloride – Details of carcinogenicity studies**

| Study                        | Animals/<br>dose<br>group                     | Duration/<br>Exposure   | Controls                                       | Doses                            | Most sensitive<br>tumor<br>site/sex   | TD <sub>50</sub><br>(mg/kg/<br>d) |
|------------------------------|---|---|--|----------------------------------|---|-----------------------------------|
| Van Duuren<br>et al., 1974*  | 30<br>ICR/Ha<br>Swiss mice<br><br>(F)         | Intra-<br>peritoneal<br><br>64 wk<br><br>once/wk                                      | 30   | 1: 1 mg<br><br>5.71<br>mg/kg/d   | Injection site:<br>malignant<br>tumors/Female                               | 4.59 <sup>^^^</sup>               |
| Sellakumar<br>et al., 1980** | 99<br>Syrian<br>golden<br>hamsters<br><br>(M) | Inhalation<br><br>Lifetime<br><br>6 h/d,<br><br>5 d/wk                                | 50 sham<br>treated<br><br>200<br>untreat<br>ed | 1: 1 ppm<br><br>0.553<br>mg/kg/d | Squamous cell<br>carcinoma of nasal<br>cavity                               | 0.625                             |
| Van Duuren<br>et al. 1974    | 50<br><br>ICR/Ha<br>Swiss mice<br><br>(F)     | Skin.<br><br>70 wk<br><br>3 times/wk  | 50   | 1: 2 mg,                         | Skin: Papillomas<br>and carcinomas<br>/Female                               | NA <sup>^</sup>                   |
| Van Duuren<br>et al. 1974    | 50<br><br>ICR/Ha<br>Swiss mice<br><br>(F)     | Subcutaneous<br><br>61 wk<br><br>once/wk  | 50   | 1: 5 mg                          | Injection site:<br>Fibrosarcomas;<br><br>Squamous cell<br>carcinomas/Female | NA <sup>^</sup>                   |
| Snyder et al.<br>1986        | Sprague-<br>Dawley rats<br><br>(M)            | Inhalation<br><br>6 wk.<br><br>6 h/d,<br><br>5 d/wk<br><br>Examined at<br>end of life | Yes  | 1: 1 ppm                         | Nasal tumors/Male   | NA <sup>^^^^</sup>                |
| Van Duuren<br>et al. 1987    | 30 - 50<br>ICR/Ha<br>Swiss mice<br><br>(F)    | Skin<br><br>18 – 22 mo<br><br>3 times/wk  | Yes  | 2: 2 and<br>4.3 mg               | Skin.<br><br>Mainly skin<br>squamous<br>carcinoma/Female                    | NA <sup>^</sup>                   |

| Study                     | Animals/<br>dose<br>group   | Duration/<br>Exposure   | Controls | Doses                 | Most sensitive<br>tumor<br>site/sex  | TD <sub>50</sub><br>(mg/kg/<br>d) |
|---------------------------|-----------------------------|---|----------|-----------------------|--|-----------------------------------|
| Van Duuren<br>et al. 1987 | ICR/Ha<br>Swiss mice<br>(F) | Subcutaneous<br>once/wk<br>18 – 22 mo                           | Yes      | 1: 4.3 mg             | Site of<br>administration.<br>Mainly sarcoma.<br><br>Hemangioma,<br>squamous<br>carcinoma and<br>papilloma also<br>seen/Female | NA <sup>^^</sup>                  |
| Van Duuren<br>et al. 1987 | ICR/Ha<br>Swiss mice<br>(F) | Subcutaneous<br>12 mo;<br>once/wk<br>examined at<br>end of life | Yes      | 2: 0.43<br>and 4.3 mg |  | NA <sup>^^</sup>                  |

Studies listed are in CPDB unless otherwise noted. [Cancer Potency Database  
<http://toxnet.nlm.nih.gov/cpdb/>].

\*Carcinogenicity study selected for non-inhalation AI. In CPDB.

\*\*Carcinogenicity study selected for inhalation AI. In CPDB.

NA= Not applicable

<sup>^</sup>Did not examine all tissues histologically. Subcutaneous and skin painting studies are not included in CPDB as route with greater likelihood of whole body exposure is considered more valuable.

<sup>^^</sup>Subcutaneous and skin painting studies are not included in CPDB as route with greater likelihood of whole body exposure is considered more valuable.

<sup>^^^</sup>Histopathology only on tissues that appeared abnormal at autopsy.

<sup>^^^^</sup>Examined only for nasal cancer. Does not meet criteria for inclusion in CPDB of exposure for at least one fourth of the standard lifetime

#### **10.4. Mode of action of carcinogenicity**

Not defined.

#### **10.5. Regulatory and/or published limits**

No regulatory limits have been published

#### **10.6. Acceptable intake**

Based on the above data, DMCC is considered to be a mutagenic carcinogen. As a result, linear extrapolation from the most sensitive TD<sub>50</sub> in carcinogenicity studies is an appropriate method with which to derive an acceptable risk dose. Since DMCC appears to be a site-of-contact carcinogen, it was appropriate to derive a separate acceptable intake for inhalation exposure compared with other routes of exposure.

No information from oral administration is available, so that for routes of exposure other than inhalation, the study by Van Duuren et al (1974), with administration by intraperitoneal injection, was used. The TD<sub>50</sub> was 4.59 mg/kg/day based on mixed tumor incidences (CPDB).

Lifetime AI = TD<sub>50</sub>/50,000 X 50kg

Lifetime AI = 4.59 mg/kg/day /50,000 X 50 kg

**Lifetime AI = 5 µg/day**

### **10.7. Inhalation AI**

After inhalation of DMCC, nasal cancer in hamsters is the most sensitive endpoint and the TD<sub>50</sub> was 0.625 mg/kg/day.

Lifetime AI = TD<sub>50</sub>/50,000 X 50kg

Lifetime AI = 0.625 mg/kg/day /50,000 X 50 kg

**Lifetime AI = 0.6 µg/day**

### **10.8. References**

Dunkel V, Zeiger E, Brusick D, McCoy E, McGregor D, Mortelmans K, Rosenkranz H, Simmon V (1984), Reproducibility of microbial mutagenicity assays. I. Tests with *Salmonella typhimurium* and *Escherichia coli* using a standardized protocol. Environ. Mutagen. 6 (Suppl. 2): 1-251.

Heddle JA, Hite M, Kirkhart B, Mavournin K, MacGregor JT, Newell GW, Salamone MF (1983) The induction of micronuclei as a measure of genotoxicity. A report of the U.S. Environmental Protection Agency Gene-Tox Program. Mutat. Res. 123:61-118.

IARC (1999) Monographs on the evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). <http://monographs.iarc.fr/index.php> V71 539 (1999)

Kier LD, Brusick DJ, Auletta AE, Von Halle ES, Brown MM, Simmon VF, Dunkel V, McCann J, Mortelmans K, et al. (1986) The *Salmonella typhimurium*/mammalian microsomal assay. A report of the U.S. Environmental Protection Agency Gene-Tox Program. Mutat. Res. 168: 69-240.

Myhr BC, Caspary WJ (1988) Evaluation of the L5178Y mouse lymphoma cell mutagenesis assay: Intralaboratory results for sixty-three coded chemicals tested at Litton Bionetics, Inc. Environ. Molec. Mutagen. Vol. 12 (Suppl 13) 103-194.

NTP (2012) DHHS/National Toxicology Program; Report on Carcinogens, twelfth edition: Dimethylcarbamoyl Chloride (79-44-7). Available from, as of September 30, 2013: <http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/DimethylcarbamoylChloride.pdf>

Galloway S, Bloom A, Resnick M, Margolin B, Nakamura F, Archer P, Zeiger E (1985) Development of a standard protocol for in vitro cytogenetic testing with CHO cells: Comparison of results for 22 compounds in two laboratories. Environ. Mutagen. Vol. 7 1-52.

Sellakumar AR, Laskin S, Kuschner M, Rush G, Katz GV, Snyder CA, Albert RE (1980) Inhalation carcinogenesis by dimethylcarbamoyl chloride in Syrian golden hamsters, J Environ Pathol Toxicol, 4, 107-115.

Snyder CA, Garte SJ, Sellakumar AR, Albert RE (1986) Relationships between the levels of binding to DNA and the carcinogenic potencies in rat nasal mucosa for three alkylating agents, *Cancer Letters*, 33, 175-181.

Van Duuren BL, Goldschmidt BM, Katz C, Seidman I, Paul JS (1974) Carcinogenic activity of alkylating agents, *J Natl Cancer Inst*, 53, 695-700.

Van Duuren BL, Melchionne S, Seidman I (1987) Carcinogenicity of acylating agents: chronic bioassays in mice and structure-activity relationships (SARC), *J Am Col Toxicol*, 6, 479-487.

## 11. Dimethyl Sulfate (CAS# 77-78-1)

### 11.1. Potential for human exposure

In 1983, the U.S. EPA compiled ambient air data from one United States urban location and the mean ambient air concentration for DMS was measured at 7.4 µg per cubic meter or 1.4 ppb (U.S. EPA, 1985).

### 11.2. Mutagenicity/genotoxicity

DMS is mutagenic/genotoxic *in vitro* and *in vivo*.

Results have been extensively reviewed by Hoffmann (1980). DMS is mutagenic in:

- The microbial reverse mutation assay (Ames), *Salmonella typhimurium* strains TA98, TA100, TA1535, TA1537 and TA1538 with and without activation (Skopek et al., 1978).
- DMS is a potent alkylating agent for cellular macromolecules and forms a variety of alkylated bases with DNA *in vitro* and the same alkylated bases are formed *in vivo* (IARC, 1999).

DMS has also consistently produced positive responses in the small number of *in vivo* tests to which it has been subjected. Workers exposed to DMS have developed chromosomal aberrations are reported to be increased in their circulating lymphocytes of workers exposed to DMS (IARC, 1999).

### 11.3. Carcinogenicity

DMS is classified as a Group 2A carcinogen, probably carcinogenic to humans (IARC, 1999).

No epidemiological studies were available for DMS although a small number of cases of human exposure and bronchial carcinoma have been reported. DMS has tested positive for carcinogenicity in animals by chronic and subchronic inhalation, and single and multiple subcutaneous injection. DMS is carcinogenic in rats, mice, and hamsters (IARC, 1999). DMS has not been tested by oral exposure. The carcinogenicity studies for DMS were limited for a variety of reasons and this is likely why DMS is not listed on the Carcinogenicity Potency Database (CPDB). The studies evaluating carcinogenicity of DMS are described below (excerpted from IRIS):

#### DMS- Details of carcinogenicity studies

| Study                                      | Animals   | Duration/<br>Exposure   | Controls | Doses                 | Most sensitive<br>site/sex                  | TD <sub>50</sub> (mg/kg/d) |
|--|---|---|----------|-----------------------|---|----------------------------|
| Schlogel and Bannasch, 1972 (in ECHA 2002) | Golden hamsters, Wistar rats, and NMRI mice<br>male and female<br>(number | Inhalation, 6 h/d,<br>2 d/wk for 15 mo<br>15-mo<br>observation<br>period. | Yes      | 2:<br>0.5; 2.0<br>ppm | Tumors in lungs, thorax and nasal passages. | NA <sup>^</sup>            |

| Study                   | Animals  | Duration/<br>Exposure  | Controls         | Doses                           | Most sensitive<br>site/sex  | TD <sub>50</sub> (mg/kg/d) |
|-------------------------|--|--|------------------|---------------------------------|---|----------------------------|
|                         | not<br>clearly<br>specified)                   |  |                  |                                 |   |                            |
| Druckrey et al. (1970)  | 20 – 27<br>BD rats<br><br>Sex not<br>specified | Inhalation 1 h/d,<br>5 d/wk, and 130<br>d; followed for<br>643 d   | No               | 2:<br><br>3; 10<br>ppm          | Squamous cell<br>carcinoma in nasal<br>epithelium at 3 ppm.<br>Squamous cell<br>carcinomas in nasal<br>epithelium and<br>lympho-sarcoma in<br>the thorax with<br>metastases to the<br>lung at 10 ppm. | NA <sup>^^</sup>           |
| Druckrey et al. (1966)  | 8 – 17 BD<br>Rats<br><br>Sex not<br>specified  | Subcutaneously<br>for up to 394 d.<br>The duration of<br>the study was<br>not reported but<br>mean tumor<br>induction time<br>was 500 d. | No               | 2:<br><br>8; 16<br>mg/kg/w<br>k | Injection-site<br>sarcomas in 7/11 at<br>low dose and 4/6 at<br>high dose; occasional<br>metastases to the<br>lung. One hepatic<br>carcinoma.   | NA <sup>^^^</sup>          |
| Druckrey et al., (1970) | 15 BD<br>Rats<br><br>Sex not<br>specified      | Single<br>Subcutaneous<br>injection up to<br>740 d evaluation  | No               | 1:<br><br>50<br>mg/kg           | Local sarcomas of<br>connective tissue in<br>7/15 rats; multiple<br>metastases to the<br>lungs in three cases   | NA <sup>^^^</sup>          |
| Druckrey et al., (1970) | 12 BD<br>rats<br><br>Sex not<br>specified      | Intravenous, for<br>800 d once/wk  | No               | 2:<br><br>2; 4<br>mg/kg         | No tumors reported  | NA <sup>^^^</sup>          |
| Druckrey et al., (1970) | 8 BD rats<br>(pregnant<br>females,)            | Single<br>intravenous<br>dose, gestation<br>day 15, offspring<br>observed for 1 yr   | No               | 1:<br><br>20<br>mg/kg           | 4/59 offspring had<br>malignant tumors of<br>the nervous system<br>while 2/59 had<br>malignant hepatic<br>tumors.   | NA <sup>^^^</sup>          |
| Fomenko et al. (1983)   | 90<br><br>CBAX57BI<br>/6 mice                  | Inhalation,<br>duration not<br>reported.   | Not<br>indicated | 3:<br><br>0.4; 1;<br>20         | increase in lung<br>adenomas at high<br>dose  | NA <sup>*</sup>            |

| Study                | Animals                                    | Duration/<br>Exposure                    | Controls         | Doses             | Most sensitive<br>site/sex | TD <sub>50</sub> (mg/kg/d) |
|----------------------|--|--|------------------|-------------------|----------------------------|----------------------------|
|                      | (F)  | 4 h/d, 5 d/wk                            |                  | mg/m <sup>3</sup> |                            |                            |
| Van Duuren<br>(1974) | 20<br>ICR/Ha<br>Swiss<br>mice <sup>¥</sup> | Dermal, 3<br>times/wk for up<br>to 475 d | Not<br>indicated | 1:<br>0.1 mg      | No findings                | NA <sup>**</sup>           |

Studies listed are in not in CPDB.

NA = Not applicable

<sup>^</sup> Control data not reported. Tumor incidences not tabulated by species or dose

<sup>^^</sup> Small group size. No concurrent control group. One rat at high dose had a cerebellar tumor and two at low dose had nervous system tumors which are very rare and distant from exposure.

<sup>^^^</sup> Small group size, no concurrent control group.

<sup>^^^^</sup> No concurrent control group.

\* Duration not reported

\*\* Limited number of animals. Only one dose tested. Even when DMS was combined with tumor promoters no tumors were noted.

<sup>¥</sup> Sex not specified

#### **11.4. Mode of action of carcinogenicity:**

Not defined.

#### **11.5. Regulatory and/or published limits**

The European Union Institute for Health and Consumer Protection developed a carcinogenicity slope curve based on the inhalation carcinogenicity data for DMS (ECHA 2002). Using the Druckrey inhalation study to assess a more systemic exposure by the EU calculated estimated a T25 (dose that resulted in a 25% increase in tumors). Systemic effects (nervous system) and local nasal tumors were observed in this limited carcinogenicity study. However, as with other studies listed, this study was severely limited with high death level, no control animals, few dose groups and minimal pathological evaluations, and therefore, not suitable for linear extrapolation.

#### **11.6. Acceptable intake (AI)**

While DMS is considered to be a likely oral carcinogen and probable human carcinogen, there are no oral carcinogenicity studies from which to derive a TD<sub>50</sub> value. Moreover, the inhalation studies that are available are limited for a variety of reasons and are not suitable for TD<sub>50</sub> extrapolation. Given this, it is reasonable to limit DMS to the threshold of toxicological concern level (TTC) of 1.5 µg/day.

**Lifetime AI = 1.5 µg/day**

## 11.7. References

Druckrey H (1966) Carcinogenic alkylating compounds: I. Dimethyl sulfate, carcinogenic effect in rats and probable cause of occupational cancer. (in German) Z. Krebsforsch. 68:103–111.

Druckrey H (1970) Carcinogenic alkylating compounds: III. Alkyl halogenids, sulfates, sulfonates, and heterocyclics. (in German) Z. Krebsforsch. 74:241–273.

ECHA (European Chemical Agency). European Union Risk Assessment Report: Institute for Health and Consumer Protection (2002). Dimethyl Sulphate. Vol. 12.

<http://echa.europa.eu/documents/10162/3d2e4243-8264-4d09-a4ab-92dde5abfadd>

Fomenko VN et al, (1983); USSR Minist Health All-Union Sci Soc Med Genet 1: 348-49 as cited in WHO; Environ Health Criteria: Dimethyl Sulfate p.36 (1985)

Hoffmann GR (1980) Genetic effects of dimethyl sulfate, diethyl sulfate, and related compounds. Mutat. Res. 75: 63-129.

IARC (International Agency for Research on Cancer). Vol 71 (1999) p. 575

Schlogel FA, and Bannasch P (1972) Carcinogenicity and Chronic Toxicity of Inhaled Dimethyl Sulfate. (In German) (Inaugural Dissertation) Julius-Maximilians University, Würzburg (data shown in ECHA 2002).

Skopek TR, Liber HL, Kaden DA and Thilly WG (1978) Relative sensitivities of forward and reverse mutation assays in *Salmonella typhimurium*. Proc. Natl. Acad. Sci. (USA) 75: 4465-4469.

U.S. EPA. 1985. Health and Environmental Effects Profile for Dimethyl Sulfate. 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.

Van Duuren BL, Goldschmidt BM, Katz C, Seidman I, Paul JS (1974) Carcinogenic activity of alkylating agents. J Natl Cancer Inst. 53: 695-700.

## 12. Ethyl chloride (Chloroethane, CAS# 75-00-3)

### 12.1. Potential for human exposure

The general population may be exposed to low levels (parts-per-trillion, ppt) of ethyl chloride through inhalation of contaminated ambient air and consumption of contaminated drinking water. Dermal contact can occur as a result of the intentional use of ethyl chloride as a topical anesthetic. It is possible that ethyl chloride forms in some waste-water streams as a result of disinfection by chlorination. Because of its volatility, the majority of ethyl chloride released to surface water is expected to enter the atmosphere. This compound can leach into groundwater from waste disposal sites, and it may form in groundwater as an anaerobic biodegradation product of chlorinated solvents (e.g., 1, 1, 1-trichloroethane and cis-1, 1-dichloroethylene). No data were located that indicate that ethyl chloride is found in food.

### 12.2. Mutagenicity/genotoxicity

Ethyl chloride is mutagenic and genotoxic *in vitro* but not *in vivo*. IARC (1999) has reviewed the mutagenicity data for ethyl chloride; key points are summarized here.

Ethyl chloride was mutagenic in:

- Microbial reverse mutation assay (Ames), *Salmonella typhimurium* strains TA100 and TA1535 and in *E. coli* WP2 uvrA with and without metabolic activation when tested in conditions that enable exposure to gas (Goto et al, 1995; Zeiger et al, 1992; Araki et al 1994).
- CHO cell *hprt* assay with and without metabolic activation.

Ethyl chloride was not genotoxic in B6C3F1 mice following 6 hour exposures for 3 consecutive days via nose-only inhalation at approximately 25000 ppm in a male and female bone marrow micronucleus test and in a Unscheduled DNA Synthesis (UDS) female mouse liver test (2-4 h and 12-14 h time points) (Ebert et al., 1994).

### 12.3. Carcinogenicity

IARC considers ethyl chloride to be an IARC Class 3 compound, or not classifiable as to its carcinogenicity (IARC, 1999).

Only one carcinogenicity study was found for ethyl chloride, NTP studies in rats and mice of both sexes via inhalation for 6 hr/day, 5 days/week for 100 weeks. The exposure concentration (15,000 ppm) was limited by safety concern (explosion risk) and on the lack of obvious effect in a 3 month range-finding study up to 19,000 ppm. These data were later published by Holder (2008) comparing ethyl chloride with ethyl bromide. Ethyl chloride was notable because, along with structurally similar ethyl bromide, it induced very high numbers of uncommon uterine tumors (endometrial carcinomas) in mice, but not rats. Ethyl chloride produced clear evidence of carcinogenicity in female mice (uterus) and equivocal evidence of carcinogenicity in male and female rats. Due to poor survival, the male mouse study was considered inadequate although there was an increased incidence of lung tumors.

#### Ethyl Chloride – Details of carcinogenicity studies

| Study                         | Animals/<br>dose group                  | Duration/<br>Exposure                        | Controls | Doses                               | Most sensitive tumor site/sex | TD <sub>50</sub> (mg/kg/d) |
|-------------------------------|---|--|----------|-------------------------------------|-------------------------------|----------------------------|
| NCI/NTP TR-346; Holder, 2008* | 50/sex/<br>group<br>B6C3F1<br>Mice      | Inhalation<br>6 h/d,<br>5 d/wk for<br>100 wk | 50       | 1:<br>M: 10.4<br>F: 12.4<br>g/kg/d  | Uterus/Female                 | 1810                       |
| NCI/NTP TR-346; Holder, 2008  | 50/sex/<br>group<br>Fischer 344<br>Rats | Inhalation<br>6 h/d,<br>5 d/wk for<br>100 wk | 50       | 1 :<br>M: 2.01 F:<br>2.88<br>g/kg/d | Negative                      | Not Applicable             |

\*Carcinogenicity study selected for AI calculation. Studies listed are in CPDB [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

## **12.4. Mode of action of carcinogenicity**

Holder (2008) proposes reactive metabolites may contribute to carcinogenicity, but notes female mice have a marked stress response to ethyl chloride exposure at the high concentrations used in the carcinogenicity study; such stress has been shown to stimulate adrenal stimulation. He proposes high corticosteroid production could promote development of endometrial cancers in mice.

## **12.5. Regulatory and/or published limits**

The US EPA established an inhalation reference concentration (RfC) for non-carcinogenic effects of 10 mg/m<sup>3</sup>, or 288 mg/day assuming a respiratory volume of 28,800 L/day (USEPA, 1991).

## **12.6. Acceptable Intake (AI)**

### **Rationale for selection of study for AI calculation**

Although the studies are not robust in design, having a single dose group, the high level of a specific rare type of uterine carcinoma of endometrial origin in mice (43/50 compared with 0/49 controls), suggest a strong carcinogenic response. A comparator molecule, ethyl bromide, was tested in a more robust carcinogenicity study (3 doses and a control) and had a similar response in female mouse uterine tumors (NTP, 1989). The lowest TD<sub>50</sub> for ethyl bromide uterine tumors was 535 mg/kg.

Ethyl chloride was considered to be a mutagenic carcinogen. Based on the NTP inhalation study the most sensitive species/site is female mouse uterus. The CPDB converted 0 and 15,000 ppm to doses of 0 and 12.4 g/kg and calculated a TD<sub>50</sub> = 1810 mg/kg/day for mouse uterus.

Lifetime AI = TD<sub>50</sub>/50,000 X 50kg

Lifetime AI = 1810 mg/kg/day /50,000 X 50 kg

**Lifetime AI = 1,810 µg/day**

## **12.7. References**

Araki A, Noguchi T, Kato F and Matsushima T (1994) Improved Method For Mutagenicity Testing of Gaseous Compounds by Using a Gas Sampling Bag; *Mutat. Res.* 307(1): 335-344

Ebert R, Fedtke N, Certa H, Wiegand HJ, Regnier JF, Marshall R and Dean SW (1994) Genotoxicity Studies With Chloroethane; *Mutat. Res.* 322(1):33-43

Goto S, Shiraishi F, Tanabe K, Endo O, Machii K, Tezuka Y, Ishii T and Matsushita H (1995). Mutagenicity Detection Method for Vinyl Chloride and Vinylidene Chloride Gases; *Kankyo Kagaku* 5(2):235-240

Holder JW (2008) Analysis of Chloroethane Toxicity and Carcinogenicity Including a Comparison With Bromoethane. *Toxicology and Industrial Health.* 24(10): 655-675

IARC (1999) Chloroethane. Volume 71. p. 1345

NTP (1989) Toxicology and Carcinogenesis Studies of Ethyl Bromide. Technical Report Series No. 363. [http://ntp.niehs.nih.gov/ntp/htdocs/lt\\_rpts/tr363.pdf](http://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr363.pdf)

NCI/NTP Carcinogenesis Technical Report Series; National Cancer Institute/National Toxicology Program; U.S. Department Of Health And Human Services, Tr-346 Y89

USEPA (1991) Integrated Risk Information System. Ethyl Chloride.

Zeiger E, Anderson B, Haworth S, Lawlor T and Mortelmans K (1992) *Salmonella* Mutagenicity Tests. V. Results From The Testing of 311 Chemicals; Environ. Mol. Mutagen. 19(Suppl.21): 2-141

## 13. Glycidol (CAS# 556-52-5)

### 13.1. Potential for human exposure

The primary routes of potential human exposure to glycidol are inhalation, eye and dermal contact, and ingestion (NTP Report on Carcinogens, 12<sup>th</sup> Edition, 2011). Heating of glycerol and sugars causes the formation of glycidol. Glycidol is a metabolite of 3-monochloropropane-1, 2-diol, a chloropropanol found in many foods and food ingredients, including soy sauce and hydrolyzed vegetable protein. Toxicological assessments for glycidol in food have calculated a potential daily glycidol exposure to be 20-80 µg/day (Bakhiya et al., 2011). Glycidol has been detected in the urine of rats exposed to 1-bromopropane by inhalation (Ishidao et al., 2002).

### 13.2. Mutagenicity/genotoxicity

Glycidol is mutagenic/genotoxic *in vitro* and *in vivo*.

IARC (2000) and CCRIS (2013) contain reviews of the mutagenicity/genotoxicity data for glycidol; key conclusions are summarized here.

Glycidol is mutagenic in:

- Microbial reverse mutation assay (Ames), *Salmonella* strains TA100, TA1535, TA98, TA97 and TA1537 both with and without rat liver S9 activation and in standard plate and preincubation assays
- *E.coli* strain WP2uvrA/pKM101 in a preincubation assay with and without rat liver S9
- Mouse lymphoma I5178Y cell *tk* assay without metabolic activation

Glycidol was positive in an *in vitro* chromosome aberration assay in CHL cells with and without rat liver S9, and *in vivo* in a mouse micronucleus assay by oral gavage in male and female P16Ink4a/p19Arf haploinsufficient mice.

### 13.3. Carcinogenicity

Glycidol is classified as Group 2A, or probably carcinogenic in humans (IARC, 2000).

In NTP studies (also published by Irwin et al., 1996), glycidol was administered by gavage in water to male and female F344/N rats and B6C3F1 mice. Rats received 0, 37.5 or 75 mg/kg and mice received 0, 25 or 50 mg/kg daily, 5 days per week for 2 yr. The average daily doses were calculated by multiplying the administered dose by 5/7 to account for the 5 days per week dosing schedule and 103/104 to account for the less-than-lifetime duration of dosing. The resulting average daily doses were 0, 26.5, and 53.1 mg/kg/day in male and female rats, and 0, 17.7, and 35.4 mg/kg/day in male and female mice.

Exposure to glycidol was associated with dose-related increases in the incidences of neoplasms in various tissues in both rats and mice. Survival of treated rats and mice was markedly reduced compared to controls because of the early induction of neoplastic disease.

The oral gavage study in hamsters was less robust due to small group size, single dose levels and shorter duration. Further oral gavage chronic studies with glycidol were conducted by the NTP in genetically modified mice lacking two tumor suppressor genes (*i.e.*, haploinsufficient p16Ink4a/p19Arf

mice) (NTP, 2007). Although there was clear evidence of carcinogenic activity in males (based on the occurrence of histiocytic sarcomas and alveolar/bronchiolar adenomas) and some evidence of carcinogenic activity in female mice (based on the occurrence of alveolar/bronchiolar adenomas), these studies are considered less suitable for dose-response assessment than the two-year bioassays (NTP, 1990) for reasons including the short duration, the small number of animals used per treatment group, and limited understanding of how dose-response relationships observed in genetically modified animals correspond with those observed in standard long-term carcinogenicity bioassays (CalEPA, 2010).

#### Glycidol – Details of carcinogenicity studies

| Study  | Animals/<br>dose<br>group                                 | Duration/<br>Exposure                    | Controls | Doses                               | Most sensitive<br>tumor<br>site/sex | TD <sub>50</sub><br>(mg/kg/<br>d) |
|--|---|--|----------|-------------------------------------|-------------------------------------|-----------------------------------|
| NTP 1990*  | 50/sex/<br>group<br>F344/N<br>rats                        | Oral gavage,<br>5 d/wk for<br>2 yr       | 50       | 2 :<br>26.5; 53.8<br>mg/kg/d        | Mammary gland<br>/Female            | 4.15                              |
| NTP 1990   | 50/sex/<br>group<br>B6C3F1<br>mice                        | Oral gavage,<br>5 d/wk for<br>2 yr       | 50       | 2:<br>17.7; 35.4<br>mg/kg/d         | Harderian gland<br>/Female          | 32.9                              |
| Lijinsky<br>and<br>Kovatch,<br>1992                            | 12 –<br>20/sex/<br>group<br>Syria<br>n Golden<br>Hamsters | Gavage<br>Twice/wk for<br>60 wk          | Yes      | 1:<br>M: 15.8<br>F: 17.9<br>mg/kg/d | Spleen / Female                     | 56.1 <sup>^</sup>                 |
| Van<br>Duuren et<br>al., 1967<br>(* Cited in<br>IARC,<br>2000) | 20<br>ICR/Ha<br>Swiss mice                                | Skin Painting<br>3 times/wk<br>for 520 d | Yes      | 1<br>5%                             | No Tumors                           | NA <sup>^</sup>                   |

Studies listed are in CPDB unless otherwise noted. [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\*Carcinogenicity study selected for AI calculation.

\*\*Not in CPDB.

NA= Not applicable.

<sup>^</sup>Not a standard carcinogenicity design. Only one dose, intermittent dosing, and small sample size (CalEPA, 2010).

### **13.4. Mode of Action**

Not defined.

### **13.5. Regulatory and/or Published Limits**

No regulatory limits have been published, for example by US EPA, WHO, or ATSDR.

### **13.6. Acceptable Intake (AI)**

#### **13.6.1. Rationale for selection of study for AI calculation:**

The most suitable carcinogenicity data for human cancer potency assessment come from the two-year oral studies conducted in F344/N rats and B6C3F1 mice by NTP (1990). The most sensitive organ site was female mammary glands with a TD<sub>50</sub> of 4.15 mg/kg/day.

#### **13.6.2. Calculation of AI:**

Lifetime AI = TD<sub>50</sub>/50,000 x 50kg

Lifetime AI = 4.15 (mg/kg/day)/50,000 x 50 kg

**Lifetime AI = 4 µg/day**

Note that this is lower than the estimated daily glycidol exposure from food of 20-80 µg/day (Bakhiya et al., 2011).

### **13.7. References**

Bakhiya N, Abraham K, Gürtler R, Appel KE and Lampen A (2011) Toxicological assessment of 3-chloropropane-1,2-diol and glycidol fatty acid esters in food. *Mol. Nutr. Food Res.* 55: 509-521.

CalEPA (2010) No Significant Risk Level (NSRL) for the Proposition 65 carcinogen Glycidol.

Available at: [http://www.oehha.ca.gov/prop65/CRNR\\_notices/pdf\\_zip/GlycidolINSRL073010.pdf](http://www.oehha.ca.gov/prop65/CRNR_notices/pdf_zip/GlycidolINSRL073010.pdf)

CCRIS (2013) Chemical Carcinogenesis Research Information System. National Library of Medicine. <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?CCRIS> and search on CAS number. Last accessed: 10/10/13.

IARC (2000) Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: <http://monographs.iarc.fr/index.php> p. v77 P 469.

Irwin RD, Eustis SL, Stefanski S and Haseman JK (1996). Carcinogenicity of Glycidol in F344 rats and B6C3F<sub>1</sub> mice. *J Appl Toxicol* 16 (3): 201-9.

Ishidao T, Kunugita N, Fueta Y, Arashidani K, Hori H (2002) Effects of inhaled 1-bromopropane vapor on rat metabolism. *Toxicol Lett* 134(1-3): 237-243.

Lijinsky W, and Kovatch RM (1992) A study of the carcinogenicity of glycidol in Syrian hamsters. *Toxicol. Ind. Health* 8(5): 267-271.

NTP (1990) Toxicology and Carcinogenesis Studies of Glycidol (CAS No. 556-52-5) In F344/N Rats and B6C3F1 Mice (Gavage Studies). NTP Technical Report Series no. 374. Research Triangle Park, NC: National Toxicology Program. 229 pp.

NTP (2007) National Toxicology Program. Toxicology and carcinogenesis study of glycidol (CAS No. 556-52-5) in genetically modified haploinsufficient p16(Ink4a)/p19(Arf) mice (gavage study). *Natl Toxicol Program Genet Modif Model Rep* **13**: 1-81.

NTP (2011) DHHS/National Toxicology Program; Twelfth Report on Carcinogens: Glycidol (556-52-5). Available from: <http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/Glycidol.pdf>, as of October 2013.

Van Duuren, B.L., Langseth, L., Goldschmidt, B.M. & Orris, L. (1967) Carcinogenicity of epoxides, lactones, and peroxy compounds. VI. Structure and carcinogenic activity. *J. natl Cancer Inst.*, 39, 1217–1228. (data in IARC 2000)

## 14. Hydrazine (CAS# 302-01-2)

### 14.1. Potential for human exposure

Hydrazine has been used as fuel for rockets and spacecraft, to treat boiler water to reduce corrosion, as a reducing agent, and to speed up chemical reactions (Choudary and Hansen, 1998). It is also used in the synthesis of pharmaceuticals, pesticides and plastic foams (Choudary and Hansen, 1998). Hydrazine sulphate has been used in the treatment of tuberculosis, sickle cell anemia and other chronic illnesses (von Burg and Stout, 1991). There is limited information on the natural occurrence of hydrazine and derivatives (Toth, 2000). Humans may be exposed to hydrazine from environmental contamination of water, air and soil (Choudary and Hansen, 1998); however, the main source of human exposure is in the workplace (HSDB, 2005). Small amounts of hydrazine have also been reported in tobacco products and cigarette smoke (Choudary and Hansen, 1998; Lui et al, 1974).

### 14.2. Mutagenicity/genotoxicity

Hydrazine is mutagenic/genotoxic *in vitro* and *in vivo*.

IARC (1999) has reviewed the mutagenicity of hydrazine. Key observations are summarized here.

Hydrazine was mutagenic in:

- Microbial reverse mutation assay (Ames), *Salmonella typhimurium* strains TA 1535, TA 102, TA 98 and TA 100, and in *Escherichia coli* strain WP2 uvrA, with and without activation
- In vitro mouse lymphoma L5178Y cells, in *tk* and *hprt* genes

Hydrazine induced sister chromatid exchanges and chromosomal aberrations in Chinese Hamster cells and *in vivo*, induced micronuclei but not chromosome aberrations, in mouse bone marrow (IARC, 1999). DNA adducts have been reported in several tissues *in vivo*.

### 14.3. Carcinogenicity

Hydrazine is classified as Group 2B, or possibly carcinogenic to humans (IARC, 1999). Group B2 or a probable human carcinogen (U.S. EPA, 1991).

There are seven hydrazine carcinogenicity studies cited in the Carcinogenic Potency Database (CPDB); three inhalation studies that included 1 year dosing duration, three studies in drinking water and one by oral gavage (Gold and Zeiger, 1997). Five of the seven hydrazine carcinogenicity studies were deemed positive by the authors of the original reports.

The main target organs for oral carcinogenicity of hydrazine in rodents are the liver and lungs. The most robust oral study based on group size and dose levels was that of Stienhoff and Mohr (1988). The most robust inhalation study with the lowest TD50 was that of Vernot et al. (1985). The most sensitive targets for inhalation carcinogenicity of hydrazine in rodents are sites of initial contact such as the nasal cavity and lungs.

The studies done on hydrazine sulphate in the CPDB are not shown here as they included <50 animals per group (and a single dose level in one case), and the calculated TD<sub>50</sub>'s were higher (less potent) than those for the drinking water study of hydrazine (Stienhoff and Mohr, 1988) that was selected as the most robust for AI calculation.

## Hydrazine – Details of carcinogenicity studies

| Study                   | Animals/<br>dose group                                     | Duration/<br>Exposure                               | Controls            | Doses   | Most sensitive<br>tumor<br>site/sex | TD <sub>50</sub><br>(mg/kg/d ) |
|-------------------------|--|---|---------------------|---|-------------------------------------|--------------------------------|
| Steinhoff & Mohr, 1988* | 50/sex/<br>group Wistar rats                               | Lifetime,<br>water                                  | 50                  | 3:<br><br>M: 0.1; 1.5,<br>2.5.<br><br>F: 0.11, 0.57,<br>2.86 mg/kg/d                  | Liver/Female                        | 41.6                           |
| Vernot et al, 1985**    | 100/sex/<br>group<br><br>F344 rats                         | 1 yr<br>inhalation<br>with 18 mo<br>observatio<br>n | 150                 | 4:<br><br>M: 1.37, 6.87,<br>27.5, 137<br><br>F: 1.96, 9.81,<br>39.3, 196 µg/<br>/kg/d | Nasal<br>adenomatous<br>polyps/Male | 0.194                          |
| Steinhoff et al, 1990   | 50/sex/<br>group<br><br>Bor:NMRI,<br>SPF-bred<br>NMRI mice | 2 yr, water   | 50                  | 3:<br><br>M: 0.33, 1.67,<br>8.33.<br><br>F: 0.4, 2.0,<br>10.0 mg/kg/d                 | Negative                            | NA,<br>negative<br>study       |
| Vernot et al, 1985      | 200<br><br>Golden<br>Syrian<br>hamsters (M)                | 1 yr<br>inhalation<br>with 12 mo<br>observatio<br>n | Yes                 | 3:<br><br>0.02, 0.08,<br>0.41 mg/kg/d   | Nasal<br>adenomatous<br>polyps/Male | 4.16                           |
| Vernot et al, 1985      | 400 C57BL/6<br><br>Mice (F)                                | 1 yr<br>inhalation<br>with 15 mo<br>observatio<br>n | Yes                 | 1:<br><br>0.18 mg/kg/d  | Negative                            | NA                             |
| Toth, 1972              | 50/sex/<br>group Swiss<br>mice                             | Lifetime,<br>water                                  | Not<br>concurrent   | 1:<br><br>~1.7-2<br>mg/kg/d   | Lung/Male                           | 2.20 <sup>Y</sup>              |
| Roe et al, 1967         | 25<br><br>Swiss mice<br><br>(F)                            | Gavage<br>5X/wk,<br><br>40 wk                       | 85<br><br>Untreated | 1:<br><br>~5 mg/kg/d  | Lung/Female                         | 5.67 <sup>YY</sup>             |

Studies listed are in CPDB [Cancer Potency Database <http://toxnet.nlm.nih.gov/cpdb/>].

\* [Carcinogenicity study selected for non-inhalation AI calculation.](#)

\*\* [Carcinogenicity study selected for inhalation AI calculation.](#)

NA= Not applicable.

¥ Excluded by U.S. EPA (no concurrent controls). Liver negative.

¥¥ Animal survival affected; Liver negative.

Vernot et al 1985 = MacEwen et al, 1981 & summarized in U.S. EPA IRIS database, last revision 04/01/1991.

Used by U.S. EPA (1986) for derivation of inhalation unit risk.

#### **14.4. Mode of action of carcinogenicity**

Not defined. DNA adducts have been detected in vivo, (Becker, et al., 1981; Bosan and Shank, 1983; Bosan et al., 1987; Saffhill et al., 1988; Leakakos and Shank, 1994; Mathison et al., 1994) although they are reported in tissues that do not develop tumors, so their contribution to tumorigenicity is not known.

#### **14.5. Regulatory and/or published limits**

The U.S. EPA (1991) has published an oral slope factor of 3.0 per mg/kg/day and a drinking water unit risk of 8.5E-5 per  $\mu\text{g/L}$ . At the 1 in 100,000 risk level, this equates to a concentration of 0.1  $\mu\text{g}$  of hydrazine/L of water or  $\sim 0.2$   $\mu\text{g/day}$  for a 50 kg/ extrapolation based on the observation of hepatomas in a multi-dose gavage study (Biancifiori, 1970) where hydrazine sulfate was administered to mice for 25 weeks and observed throughout their lifetime (U.S. EPA, 1991). In a U.S. EPA (2002) literature review for hydrazine and hydrazine sulphate, three additional studies were identified that were published after the oral slope factor was calculated (Steinhoff and Mohr, 1988; FitzGerald and Shank, 1996; Bosan et al., 1987). It was noted that these studies could potentially produce a change in the oral slope factor but it has not been re-evaluated.

The U.S. EPA (1986) has also published an inhalation slope factor of 17 per mg/kg/day and an inhalation unit risk of  $4.9 \times 10^{-3}$  per  $\mu\text{g}/\text{m}^3$ . At the 1 in 100,000 risk level, this equates to an air concentration of  $2 \times 10^{-3}$   $\mu\text{g}/\text{m}^3$  of hydrazine or or 0.04  $\mu\text{g/day}$  assuming a person breathes 20  $\text{m}^3/\text{day}$ . This limit is a linearized multistage extrapolation based on the observation of nasal cavity adenoma or adenocarcinoma in male rats in a multi-dose inhalation study (MacEwen et al, 1986) where hydrazine was administered 6 hours/day, 5 days/week for 1 year followed by an 18 month observation period (U.S. EPA, 1986). Only the U.S. EPA review of this data was accessible; however, the results appear to be very similar to, if not the same as, those of Vernot et al (1985).

#### **14.6. Acceptable Intake (AI)**

##### **14.6.1. Rationale for selection of study for AI calculation**

Both oral and inhalation carcinogenicity studies for hydrazine were reviewed to determine if a separate limit is required specific for inhalation carcinogenicity. Given the more potent carcinogenicity specific to the first site of contact observed in inhalation studies, it was determined that a separate AI for inhalation exposure was appropriate.

For oral hydrazine, carcinogenicity has been reported in 3 mouse studies and one rat study. Only one mouse study (Steinhoff et al, 1990) and the rat study (Steinhoff and Mohr, 1988) meet currently acceptable study design criteria (50 animals per sex/group, minimum of 3 treatment groups, both sexes included, and concurrent controls). The mouse study by Steinhoff and Mohr (1988) was negative with a high dose of 10 mg/kg/day. The rat study included doses of up to 3 mg/kg/day and was positive for hepatocellular neoplasms in both sexes at a similar dose level. The rat study (Steinhoff and Mohr, 1988) is deemed the most sensitive robust study available, with a TD<sub>50</sub> of 41.6 mg/kg/day. Both of these studies were conducted after the U.S. EPA oral slope factor and drinking water limit was derived.

All of the inhalation carcinogenicity studies that were used by the U.S.EPA in the derivation of the inhalation carcinogenicity limit for hydrazine were taken into consideration when selecting the most robust carcinogenicity study for the derivation of an AI for inhaled pharmaceuticals. The critical study used by U.S. EPA was proprietary (i.e., MacEwen et al., 1981), but is likely the same data as in Vernot et al., 1985. Given that the TTC was derived via linear extrapolation from TD<sub>50</sub> values for hundreds of carcinogens, that same approach was used in the derivation of a compound specific AI for hydrazine. The methodology used by the U.S. EPA and the method used here are both highly conservative in nature. However, given that the methodologies do differ, it is reasonable to expect some slight differences. The AI was calculated based on the TD<sub>50</sub> derived from a study in which male and female rats were administered hydrazine via inhalation for one year with an 18 month observation period (Vernot et al., 1985). While a 1- year study is not a standard design for carcinogenicity, a positive response was observed demonstrating that the window for carcinogenicity was not missed. The most sensitive target tissue was the male nasal region, with a TD<sub>50</sub> value of 0.194 mg/kg/day, which was lowered as standard practice to account for 2-year lifetime exposure.

## 14.6.2. Calculation of AI

### 14.6.2.1. AI

Lifetime AI = TD<sub>50</sub>/50,000 x 50kg

Lifetime AI =41.6 (mg/kg/day)/50,000 x 50 kg

**Lifetime AI = 42 µg/day**

### 14.6.2.2. Inhalation AI

Lifetime AI = TD<sub>50</sub>/50,000 x 50 kg

Lifetime AI =0.194 (mg/kg/day)/50,000 x 50 kg

**Lifetime AI = 0.2 µg/day**

## 14.7. References

Becker RA, Barrows LR, Shank RC (1981) Methylation of liver DNA guanine in hydrazine hepatotoxicity: dose-response and kinetic characteristics of 7-methylguanine and O<sup>6</sup>-methylguanine formation and persistence in rats. *Carcinogenesis*. 2(11):1181-1188.

Bosan WS, Shank RC (1983) Methylation of liver DNA guanine in hamsters given hydrazine. *Toxicology and Applied Pharmacology*. 70:324-334.

- Bosan WS, Shank RC, Douglas J, et al. (1987) Methylation of DNA guanine during the course of induction of liver cancer in hamsters by hydrazine or dimethylnitrosamine. *Carcinogenesis*. 8(3):439-444.
- Choudary G and Hansen H (1998) Human health perspective on environmental exposure to hydrazines: A review. *Chemosphere*. 37(5):801-843.
- FitzGerald BE and Shank RC (1996) Methylation status of DNA cytosine during the course of induction of liver cancer in hamsters by hydrazine sulphate. *Carcinogenesis*. 17(12):2703-2709.
- Gold S and Zeiger E (Eds.) (1997) *Handbook of Carcinogenic Potency and Genotoxicity Databases*. CRC Press, Boca Raton, FL.
- Hazardous Substance Database (HSDB): Hydrazine (302-01-2); last revision date: 2005-06-24. Available from, as of 27 February 2013: <http://toxnet.nlm.nih.gov/>
- IARC. (1999) *Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man*. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: <http://monographs.iarc.fr/index.php> p. V71 1006.
- Leakakos T and Shank RC (1994) Hydrazine genotoxicity in the neonatal rat. *Toxicol Appl Pharmacol* 126 (2): 295-300.
- Lui YY, Schmeltz I, Hoffman D (1974) Chemical studies on tobacco smoke. Quantitative analysis of hydrazine in tobacco and cigarette smoke. *Anal. Chem.* 46: 885–889.
- Mathison B, Murphy SE, Shank RC (1994) Hydralazine and other hydrazine derivatives and the formation of DNA adducts. *Toxicol Appl Pharmacol* 127 (1): 91-8.
- Roe FJC, Grant GA, Millican DM (1967) Carcinogenicity of hydrazine and 1,1-dimethylhydrazine for mouse lung. *Nature*. 216:375-376.
- Saffhill R, Fida S, Bromley M et al. (1988) Promutagenic alkyl lesions are induced in the tissue DNA of animals treated with isonizid. *Human Toxicology*. 7:311-317.
- Steinhoff D and Mohr U (1988) The question of carcinogenic effects of hydrazine. *Exp. Pathol.* 33: 133-140.
- Steinhoff D, Mohr U, Schmidt WM (1990) On the question of the carcinogenic action of hydrazine - evaluation on the basis of new experimental results. *Exp. Pathol.* 39: 1-9.
- Toth B (1972) Hydrazine, methylhydrazine and methylhydrazine sulfate carcinogenesis in Swiss mice. Failure of ammonium hydroxide to interfere in the development of tumors. *Int. J. Cancer*. 9: 109-118.
- Toth B (2000) A review of the natural occurrence, synthetic production and use of carcinogenic hydrazines and related chemicals. *In Vivo*. 14(2):299-319.
- U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS). Last revision: 04/01/1991. Summary on Hydrazine/Hydrazine sulfate (302-01-2). Available from, as of 27 February, 2013: <http://www.epa.gov/iris/>.
- U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS) Screening-Level Literature Review. 1/1/2002. Hydrazine/Hydrazine sulfate, CASRN: 302-01-2. Available upon request from, as of 30 August, 2012: IRIS Hotline at [hotline.iris@epa.gov](mailto:hotline.iris@epa.gov)

Vernot EH, MacEwen JD, Bruner RH, Haun CC, Kinkead ER, Prentice DE, Hall A 3rd, Schmidt RE, Eason RL, Hubbard GB, Young JT. (1985) Long-term inhalation toxicity of hydrazine. *Fundamental and Applied Toxicology*. 5:1050- 1064.

Von Burg R. and Stout T (1991) Hydrazine. *J. Appl. Toxicol.* 11: 447–450.

## 15. Hydrogen peroxide (CAS# 7722-84-1)

### 15.1. Potential for human exposure

Hydrogen peroxide (HSDB, 2005) can be present in green tea and instant coffee, in fresh fruits and vegetables and naturally produced in the body (Halliwell et al., 2000). It is estimated up to 6.8 g is produced endogenously per day (Desesso et al., 2000). Other common sources of exposure are from disinfectants, some topical cream acne products, and oral care products up to which can contain up to 4% hydrogen peroxide (Desesso et al., 2000).

### 15.2. Mutagenicity/genotoxicity

Hydrogen peroxide is mutagenic/genotoxic *in vitro* but not *in vivo*.

IARC (1999) and JRC (2003) reviewed the mutagenicity data for hydrogen peroxide, and key observations are summarized here.

Hydrogen peroxide is mutagenic in:

- *Salmonella typhimurium* strains TA96, TA97, SB1106p, SB1106, and SB1111 and *Escherichia coli* WP2 in the absence of exogenous metabolic activation.
- L5178Y mouse lymphoma cell sublines at the *hprt* locus (weak increase)
- Chinese hamster V79 cells at the *hprt* locus, in only one of six studies

*In vivo*, micronuclei were not induced after administration of hydrogen peroxide to mice intraperitoneally at up to 1000 mg/kg, or to catalase- deficient C57BL/6Ncr1BR mice in drinking water at 200, 1,000, 3,000, and 6,000 ppm for two weeks.

### 15.3. Carcinogenicity

Hydrogen peroxide is classified as Group 3 (not classifiable as to its carcinogenicity to humans) (IARC, 1999).

There is only one carcinogenicity report cited in the CPDB (Ito et al., 1981), in which mice were treated with hydrogen peroxide in drinking water for approximately 2 years. The study included two treatment groups and about 50 animals per dose group. Hydrogen peroxide induced small intestinal tumours in C57BL female mice (Ito et al., 1981). Statistically significant increases in tumours ( $p < 0.005$ ) were observed in both dose groups in the mouse carcinogenicity study (Ito et al., 1981) although only the duodenal tumors at the high dose in females are noted as significant in the CPDB. Thus, 0.1% hydrogen peroxide administered in drinking water was defined as the LOAEL, equivalent to an average daily dose-rate per kg body weight per day of 200 mg/kg/day (CPDB).

Several carcinogenicity studies are not reported in the CPDB. Studies of 6 months duration or longer are summarised in the following table (adapted from Desesso et al., 2000); they are limited in the numbers of animals and used a single dose level.

The results of the Ito mouse carcinogenicity studies, conducted in 1981, 1982, 1984, 1986, were thoroughly evaluated by the Cancer Assessment Committee (CAC) of the US Food and Drug Administration (FDA) and published in the Federal Register. The conclusion was that the studies did not provide evidence that hydrogen peroxide is a carcinogen (FDA, 1988).

In Europe the Scientific Committee on Consumer Products, now the Scientific Committee on Consumer Safety (SCCS), reviewed the available carcinogenicity data for hydrogen peroxide and concluded the carcinogenic mechanism of action is unknown and believe that a genotoxic mechanism cannot be excluded (SCCP, 2005). In contrast, Desesso et al (2000) suggested that dilute hydrogen peroxide would not reach the target site and that the hyperplastic lesions seen at the LOAEL dosage were due to irritation from food pellets accompanying a decrease in water consumption which is often noted with exposure to hydrogen peroxide in drinking water. This is supported by life time studies in the hamster in which hydrogen peroxide was administered by gastric intubation (water uptake was not affected) in which the duodenal epithelia appeared normal; this was the basis for the CAC conclusion above (FDA, 1988).

#### Hydrogen Peroxide – Details of carcinogenicity studies

| Study                 | Animals/<br>dose group                      | Duration/<br>Exposure       | Controls | Doses   | Notes   |
|-----------------------|---|-----------------------------|----------|---|---|
| Ito et al.,<br>1981*  | 48-<br>51/sex/group<br>C57BL/6J mice        | 100 wk<br>Drinking<br>water | Yes      | 2;<br><br>0.1;<br>0.4%<br><br>M: 200;<br>800<br><br>F: 167;<br>667<br><br>mg/kg/d | CPDB study with TD <sub>50</sub> of 7.54 g/kg/d for female duodenal carcinoma..   |
| Ito et al.,<br>1982** | 29 mice (No. of<br>M and F not<br>reported) | 700 d<br>Drinking<br>water  | No       | 1:<br><br>0.4%  | Cessation of H <sub>2</sub> O <sub>2</sub> treatment decreased percent of mice with stomach erosions and percent of mice with duodenal lesions (plaques and nodules). |
| Ito et al.,<br>1984** | 18 mice (No. of<br>M and F not<br>reported) | 6 mo<br>Drinking<br>water   | No       | 1:<br><br>0.4%  | 2 duodenal tumours (11.1%)  |
| Ito et al.,<br>1984** | 22 mice (No. of<br>M and F not<br>reported) | 6 mo<br>Drinking<br>water   | No       | 1:<br><br>0.4%  | 7 duodenal tumours (31.8%)  |
| Ito et al.,<br>1984** | 21 mice (No. of<br>M and F not<br>reported) | 7 mo<br>Drinking<br>water   | No       | 1:<br><br>0.4%  | 21 duodenal tumours (100%)  |
| Ito et al.,<br>1984** | 24 mice (No. of<br>M and F not<br>reported) | 6 mo<br>Drinking<br>water   | No       | 0.4%<br>only  | 22 duodenal tumours (91.7%)   |
| Ito et al.,           | Female mice                                 | 6 mo                        | Yes      | 1:  | No duodenal tumours in  |

|                    |  |                     |     |         |  |
|--------------------|--|---------------------|-----|---------|--|
| 1986**             | (11 control, 21 treatment)             | Drinking water      |     | 0.4%    | control mice, 2 (9.5%) in treatment group                          |
| Ito et al., 1986** | Female mice (12 control, 22 treatment) | 6 mo Drinking water | Yes | 1: 0.4% | No duodenal tumours in control mice, 7 (31.8%) in treatment group  |
| Ito et al., 1986** | Female mice (28 control, 24 treatment) | 6 mo Drinking water | Yes | 1: 0.4% | No duodenal tumours in control mice, 22 (91.7%) in treatment group |

[\\*Carcinogenicity study selected for PDE calculation](#)

[\\*\\*All other studies are not in the CPDB but are discussed in the reference FDA, 1988 and not cited separately.](#)

#### **15.4. Mode of action for carcinogenicity**

Hydrogen peroxide is a reactive oxygen species (ROS) that is formed as part of normal cellular metabolism (JRC, 2003). The toxicity of hydrogen peroxide is attributed to the production of ROS and subsequent oxidative damage resulting in cytotoxicity, DNA strand breaks and genotoxicity (Tredwin et al., 2006). Due to the inevitable endogenous production of ROS, the body has evolved defense mechanisms to limit their levels, involving catalase, superoxide dismutases and glutathione peroxidase.

Oxidative stress occurs when the body's natural antioxidant defense mechanisms are exceeded, causing damage to macromolecules such as DNA, proteins and lipids. ROS also inactivate antioxidant enzymes, further enhancing their damaging effects (De Bont and Larebeke, 2004). During mitochondrial respiration, oxygen undergoes single electron transfer, generating the superoxide anion radical. This molecule shows limited reactivity but is converted to hydrogen peroxide by the enzyme superoxide dismutase. Hydrogen peroxide is then reduced to water and oxygen by catalase and glutathione peroxidase (Finkel and Holbrook, 2000). However, in the presence of transition metals, such as iron and copper, hydrogen peroxide is reduced further to extremely reactive hydroxyl radicals. They are so reactive they do not diffuse more than one or two molecular diameters before reacting with a cellular component (De Bont and Larebeke, 2004). Therefore, they must be generated immediately adjacent to DNA to oxidize it. Antioxidants provide a source of electrons that reduce hydroxyl radicals back to water, thereby quenching their reactivity. Clearly, antioxidants and other cellular defenses that protect against oxidative damage are limited within an in vitro test system. Consequently, following treatment with hydrogen peroxide these protective mechanisms are readily overwhelmed inducing cytotoxicity and genotoxicity in bacterial and mammalian cell lines. Diminution of the in vitro response has been demonstrated by introducing elements of the protective mechanisms operating in the body; for example, introducing hydrogen peroxide degrading enzymes, such as catalase or adjusting the level of transition metals (SCCP, 2005). Unsurprisingly in vivo, where the cellular defense mechanisms are intact, hydrogen peroxide is not genotoxic following short-term exposure. This suggests that a threshold exists below which the cellular defense mechanisms can regulate ROS maintaining homeostasis.

Based on the comprehensive European Commission (EC) risk assessment, the weight of evidence suggests hydrogen peroxide is mutagenic in vitro when protective mechanisms are overwhelmed. However, it is not genotoxic in standard assays in vivo. Its mode of action has a non-linear, threshold effect.

### **15.5. Regulatory and/or published limits**

Annex III of the European Cosmetic Regulation (EC (No) 1223/2009) was updated to include acceptable levels of hydrogen peroxide with regard to tooth whitening products. For oral products sold over the counter, including mouth rinse, tooth paste and tooth whitening or bleaching products, the maximum concentrations of hydrogen peroxide allowed (present or released) is 0.1%. Higher levels up to 6% are also permitted providing products are prescribed by dental practitioners to persons over 18 years old. Cosmetics Europe estimated that 1 g of mouthwash is ingested per application, and that frequency of application is 5 per day. Therefore, assuming mouthwash products contain 0.1% hydrogen peroxide, the daily exposure is 5 mg/day, or 0.1 mg/kg of body weight per day for a 50 kg adult. According to the Scientific Committee on Consumer Safety (SCCS) Notes for Guidance on the Safety Evaluation of Cosmetic Products ((EC) No 1223/2009), a typical amount of toothpaste per application is 2.75g. The Joint Research Centre published Risk Assessment Report considers 17% a reasonable value for accidental ingestion. This is equivalent to 9.35 mg/day, assuming a frequency of application of twice per day or 0.19 mg/kg/day for a 50 kg adult. These estimated ingestion values are considered conservative as it is likely that most of the hydrogen peroxide is decomposed after using oral care products and is not ingested (JRC, 2003).

US FDA - hydrogen peroxide is generally recognized as safe (GRAS) up to 3% for long-term over the counter use as an anti-gingivitis/anti-plaque agent (FDA 2003).

### **15.6. Permissible Daily Exposure (PDE)**

It is considered that hydrogen peroxide acts via a mode of action with a threshold (i.e., oxidative stress). An increase in tumors was observed in female mice at  $\geq 167$  mg/kg/day (0.1% dose group). Thus, the lowest observed adverse effect level (LOAEL) in the 2 year rat studies was 0.2 mg/kg/day.

The PDE calculation is:  $(\text{NOEL} \times \text{body weight adjustment (kg)}) / F1 \times F2 \times F3 \times F4 \times F5$

The following safety factors as outlined in ICH Q3C have been applied to determine the AI for hydrogen peroxide, these are:

F1 = 12 (mouse to man)

F2 = 10 (inter- individual variability)

F3 = 1 (study duration at least half lifetime)

F4 = 1 (endogenous product, so severe toxicity not expected at low doses)

F5 = 10 (using a LOAEL)

On this basis the PDE is calculated as follows:

Lifetime PDE =  $167 \text{ mg/kg/day} \times 50 \text{ kg} / (12 \times 10 \times 1 \times 1 \times 10)$

**Lifetime PDE = 6,960  $\mu\text{g/day}$**

### **15.7. References**

De Bont R and Larebeke N (2004) Endogenous DNA damage in humans: a review of quantitative data. *Mutagenesis* 19 (3), 169-185.

Desesso JM, Lavin AL, Hsia SM, Mavis RD (2000) Assessment of the carcinogenicity associated with oral exposures to hydrogen peroxide. *Food and Chemical Toxicology* 38, 1021-1041.

FDA, Food and Drug Administration (1988) Irradiation in the production, processing, and handling of food. Food and Drug Administration. Federal Register 53, 251; 53198-9.

FDA, Food and Drug Administration (2003) Oral health care drug products for over-the-counter human use; antigingivitis/antiplaque drug products; establishment of a monograph. Federal Register 68:32232-32286.

Finkel T, Holbrook NJ (2000) Oxidants, oxidative stress and the biology of ageing. *Nature* 408, 239-247.

CPDB, Gold S, Zeiger E, eds. (1997) Handbook of Carcinogenic Potency and Genotoxicity Databases, Boca Raton, FL: CRC Press.

Halliwell B, Clement MV, Long LH (2000) Hydrogen peroxide in the human body. *FEBS Letters* 486, 10-13.

HSDB, Hazardous Substance Data Bank. Hydrogen Peroxide. Last Revised 24/06/2005.  
<http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~6kxo2y:1>. Searched 4<sup>th</sup> October, 2013.

International Agency for Research on Cancer (IARC) (1999) Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide. Vol. 71.

Ito A, Watanabe H, Naito M and Naito Y (1981) Induction of duodenal tumours in mice by oral administration of hydrogen peroxide. *Gann The Japanese Journal of Cancer Research* 7 (2), 174-175.

Joint Research Centre (JRC) (2003) Hydrogen Peroxide. Summary Risk Assessment Report, Special Publication I.03.148.

Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products.

SCCP (2005): European Commission Health & Consumer Directorate General Scientific Committee on Consumer Products Opinion on Hydrogen Peroxide in Tooth Whitening Products. SCCP/0844/04.

Tredwin CJ, Naik S, Lewis NJ, Scully C (2006) Hydrogen peroxide tooth-whitening (bleaching) products: Review of adverse effects and safety issues. *British Dental Journal* 200, 371-376.

## 16. Hydroxylamine (CAS# 7803-49-8)

### 16.1. Potential for human exposure

The most common source of exposure is in industrial settings, and there are no data available for exposure to the general population. Hydroxylamine is reported to be a product of normal cellular metabolism (Gross, 1985,).

### 16.2. Mutagenicity/genotoxicity

Based on weight of evidence from genotoxicity assays generally used in standard test batteries, hydroxylamine is not mutagenic in the *in vitro* bacterial reverse mutation test, has weak or no genotoxic activity *in vitro* in mammalian cells, it is not genotoxic in bone marrow when given orally to rodents.

Hydroxylamine has little or no mutagenic activity in the *Salmonella* and *E. coli* reverse mutation assay (Ames), and has not been shown to be genotoxic *in vivo*. However, hydroxylamine is often described as a mutagen because at high molar concentrations it has been used as a diagnostic mutagen (Freese et al., 1961) and the compound has been reported to be positive in diverse genotoxicity assays (Marfey and Robinson, 1981) that are not in the standard set of assays used for regulatory purposes (e.g., those described in OECD guidelines).

In contrast, hydroxylamine was reported to be negative in the majority of "standard" genotoxicity assays (namely the bacterial reverse mutation assay (Ames), and the *in vivo* rodent bone marrow micronucleus test). Hydroxylamine sulphate (CAS No: 10039-54-0) was not mutagenic in *Salmonella typhimurium* strains TA97, TA98, TA100, TA1535 and TA102 with and without metabolic activation at test concentrations limited by toxicity to  $\leq 1000$   $\mu\text{g}/\text{plate}$  (NTP, 1991). Hydroxylamine hydrochloride (CAS No: 5470-11-1) was reported to be weakly mutagenic (dose related increases  $< 2$  fold) in the presence, but not absence, of metabolic activation in TA100 at concentrations of  $> 100$  and  $< 330$   $\mu\text{g}/\text{plate}$  (NTP, 1988). Hydroxylamine hydrochloride was not mutagenic in TA98, TA100, TA1535, TA1537, TA1538 and *Escherichia coli* WP2 *uvrA* in the presence and absence of metabolic activation  $\leq 333$   $\mu\text{g}/\text{plate}$  – the highest dose tested in the assay (Dunkel et al., 1984).

Hydroxylamine hydrochloride was reported to be mutagenic in the mouse lymphoma *tk* mutation assay, with and without metabolic activation (NTP, 1988), but the data do not convincingly meet the up-to-date criteria for positive results in this assay (Moore et al, 2006). Hydroxylamine hydrochloride was not genotoxic in an oral bone-marrow micronucleus assay when tested in male and female rats at doses  $\leq 125$   $\text{mg}/\text{kg}/\text{day}$ , where the maximum dose was limited by adverse clinical signs (Getman, 2014). Hydroxylamine sulfate was not genotoxic in an oral bone-marrow micronucleus assay when tested in male and female mice at doses  $\leq 1200$   $\text{mg}/\text{kg}/\text{day}$  where the maximum dose was limited by adverse clinical signs (ECHA, no date).

### 16.3. Carcinogenicity

No studies were identified in the CPDB. The details of a 2-year drinking water study are described in a European Union Risk Assessment Report (ECHA, 2008). Hydroxylamine sulphate (bis [hydroxylammonium] sulphate; CAS 10039-54-0) was carcinogenic in male and female rats via the oral route (hydroxylamine was administered by giving bis (hydroxylammonium) sulphate, which dissociates in water to a hydroxyl-ammonium ion which converts to the reactive free hydroxylamine

base). The administration of hydroxylamine sulphate in the drinking water for 2 years to rats was associated with an increased incidence of hemangiosarcomas in males and hemangioma development in females, both in the spleen. In groups of 50 rats, the incidence of hemangiosarcomas in males was 4 in controls, and 7, 9 and 8 in the 0.2, 1.0 and 3.7 mg/kg/day treated groups. Although the increase in number of tumours in the spleen of male and female rats was low, not dose-related and the difference did not attain statistical significance, the levels were above those in the concurrent control groups and above the ranges of historical control background data (ECHA, 2008).

#### 16.4. Mode of action for carcinogenicity

A critical review of the data concluded that the mechanism of carcinogenicity had a threshold and that there was no indication that these tumors were related to a primary genotoxic mechanism (ECHA, 2008). The tumor induction is not related to initial mutagenicity, but secondary to methemoglobinemia and accumulation of hemosiderin in the spleen. This can lead to iron overload of the spleen resulting in iron-catalyzed free radical reactions, damage, and corresponding hyperplasia (Bus and Popp, 1987). Evidence for this also comes from short-term and long-term studies demonstrating that hydroxylamine induces hemolytic anemia and hemosiderosis that results in precursor damage to the spleen. In subacute and 90-day rat studies, exposure to hydroxylamine induced hemolytic anemia, and splenomegaly with changes to red blood parameters (enhanced levels of methemoglobin, Heinz bodies and a shift in blood cell pattern, e.g. increase in reticulocytes and leukocytes). Increased decomposition of erythrocytes was seen as hemosiderin deposits and iron pigment deposition in the spleen. Damage to the spleen was observed by sinus dilation together with congestion, splenomegaly, and increased organ weight (ECHA, 2008). Administration over 1-2 years in rats also resulted in hemosiderin storage in the spleen, and signs of hemolysis. No hematotoxic effects or other systemic effects were detected at a dose of 0.2 mg/kg/day in male rats or 0.4 mg/kg/day in female rats. An increased incidence of a precursor lesion (i.e., angiomatous hyperplasia) was observed in low and high male dose groups and the high female dose group (ECHA, 2008).

In addition, hydroxylamine is the reactive moiety for the hemosiderosis-induced spleen tumors observed with aniline and its analogues. These effects occur mainly in male rats, and exhibit a non-linear response. Aniline and related structures form phenylhydroxylamine which is taken up by erythrocytes resulting in hemosiderosis and ultimately spleen tumors (Bus and Popp, 1987).

#### Hydroxylamine – Details of carcinogenicity studies

| Study  | Animals/<br>dose<br>group          | Duration<br>/<br>Exposure       | Controls | Doses  | Most sensitive<br>tumor<br>site/sex     | TD <sub>50</sub><br>(mg/kg/<br>d) |
|--|------------------------------------|---------------------------------|----------|--|---|-----------------------------------|
| ECHA,<br>2008 <sup>*^</sup><br><br>Bis<br>(hydroxylammonium)<br>sulphate,<br>CAS | 50/sex/<br>group<br><br>Wistar rat | Drinking<br>water<br><br>104 wk | Yes      | 3:<br><br>5; 20; 80 ppm<br><br>M: 0.2; 1; 3.7<br>mg/kg/d.<br><br>F: 0.4, 1.6,<br>6.2 mg/kg/d | Spleen<br><br>Hemangiosarcomas/<br>Male | 22 <sup>**¥</sup>                 |

|                       |  |                          |     |                        |                         |                    |
|-----------------------|--|--------------------------|-----|------------------------|-------------------------|--------------------|
| [10039-54-0]          |  |                          |     |                        |                         |                    |
| Yamamoto et al., 1967 | Mice: Swiss Webster (5 M) and C3H/HeN (10 F) | Drinking Water<br>52 wk  | Yes | 2:<br>100; 200 mg/kg/d | No Tumors Found         | NA <sup>^^</sup>   |
| Stenbäck et al., 1987 | 40 C3H/HeN (F)                               | Drinking Water<br>105 wk | Yes | 1:<br>246 mg/kg/d      | Hemangioma (Spleen)     | 524 <sup>^^^</sup> |
|                       | 50/sex C3H/HeJ(+)                            | Drinking Water<br>105 wk | Yes | 1:<br>246 mg/kg/d      | Hemangioma (Lymph Node) | 540 <sup>^^^</sup> |

Note: Studies in the table are not in the CPDB.

\* [Carcinogenicity study selected for AI calculation.](#)

\*\*TD<sub>50</sub> calculated based on carcinogenicity data.

‡Small increase in number of tumours, not dose-related & not statistically significant. However, levels above control groups and historical control background data.

^ Study details given in ECHA 2008.

NA= Not applicable.

^^ Limited number of animals and duration.

^^^ Limited number of doses, mice carry germinal provirus (MMTV; mouse mammary tumor virus) and develop a moderately high incidence of mammary tumors late in life.

### 16.5. Regulatory and/or Published Limits

No regulatory limits have been published, for example by U.S. EPA, WHO.

### 16.6. Permissible Daily Exposure (PDE)

#### 16.6.1. Rationale for selection of study for PDE calculation:

It is considered that hydroxylamine induces tumors via a mode of action with a threshold (i.e., hemosiderosis of the spleen). An increase in tumors was observed in male rats at  $\geq 5$  ppm or 0.2 mg/kg/day for hemangiosarcomas and females at the high dose of 80 ppm or 6.2 mg/kg/day (hemangiosarcomas and hemangiomas). Thus, the lowest observed adverse effect level (LOAEL) in the 2 year rat study was 0.2 mg/kg/day in males.

#### 16.6.2. Calculation of PDE:

The PDE calculation is: (NOEL x body weight adjustment (kg)) / F1 x F2 x F3 x F4 x F5

The following safety factors as outlined in ICH Q3C guideline Appendix 3 have been applied to determine the PDE for hydroxylamine, these are:

F1 = 5 (rat to man)

F2 = 10 (inter-individual variability)

F3 = 1 (study duration at least half lifetime)

F4 = 10 (severe toxicity – non-genotoxic carcinogenicity)

F5 = 10 (using a LOAEL, but percent response close to threshold 4% versus 7%)

On this basis the PDE is calculated as follows:

Lifetime PDE = 0.2 mg/kg/day x 50 kg / (5 x 10 x 1 x 10 x 10)

**Lifetime PDE = 2 µg/day**

## **16.7. References**

Bus JS and Popp JA (1987) Perspectives on the mechanism of action of the splenic toxicity of aniline and structurally-related compounds, *Food Chem Toxicol* 25: 619–626.

Dunkel VC, Zeiger E, Brusick D, McCoy E, McGregor D, Mortelmans K, Rosenkranz HS, Simmon VF (1984) Reproducibility of Microbial Mutagenicity Assays: I. Tests With *Salmonella typhimurium* and *Escherichia coli* using a Standardized Protocol. *Environmental Mutagenesis* 6, 2, 1-254.

Freese E, Bautz- Freese E, Bautz E (1961) Hydroxylamine as a mutagenic and inactivating agent. *Journal of Molecular Biology*, 3, 133-143.

ECHA (European Chemicals Agency). (2008) European Union Risk Assessment Report - [bis(hydroxylammonium)sulphate] CAS [10039-54-0]

<http://echa.europa.eu/documents/10162/a94c5d98-4ecb-459d-9dab-594fd516e30a>

ECHA (European Chemicals Agency). Registered Substances. <http://echa.europa.eu/information-on-chemicals/registered-substances>. Accessed [bis(hydroxylammonium)sulphate] CAS [10039-54-0] on March 19, 2015.

Getman SM (2014) Hydroxylamine: Oral micronucleus study in rats (Study No. DS03096). Bristol-Myers Squibb Company.

Gross P (1985) Biologic activity of hydroxylamine: a review. *Critical Reviews in Toxicology*, 14, 87-99.

Marfey P and, Robinson E (1981) The genetic toxicology of hydroxylamines. *Mutation Research*, 86, 155-191

Moore MM, Honma M, Clements J, Bolcsfoldi G, Burlinson B, Cifone M, Clarke J, Delongchamp R, Dirward R, Fellows M, Gollapudi B, Hou S, Jenkinson P, Lloyd M, Majeska J, Myhr B, O'Donovan M, Omori T, Riach C, San R, Stankowski LF, Thakur AK, van Goethem F, Wakuri, A, Yoshimura I (2006) Mouse lymphoma thymidine kinase mutation assay: Follow-up meeting of the International Workshop on Genotoxicity Testing- Aberdeen Scotland, 2003- Assay Acceptance Criteria, Positive controls and Data Evaluation, *Environ. Mol. Mutagen.*, 47:105

NTP (1991) [http://tools.niehs.nih.gov/ntp\\_tox/index.cfm](http://tools.niehs.nih.gov/ntp_tox/index.cfm) NTP study 689679, accessed 1 May 2014

NTP (1988) <http://ntp.niehs.nih.gov/testing/status/agents/ts-m20240.html>

Stenbäck F, Weisburger JH, Williams GM (1987) Hydroxylamine effects on cryptogenic neoplasm development in C3H mice. *Cancer Letters* 38: 73-85.

Yamamoto R.S., Weisburger E.K., Korzis J. (1967): Chronic administration of Hydroxylamine and derivatives in mice. *Proceedings of the Society for Experimental Biology and Medicine* 124: 1217.

## 17. Methyl chloride (Chloromethane, CAS# 74-87-3)

### 17.1. Potential for human exposure

Methyl chloride is found ubiquitously in nature. Low levels of methyl chloride occur naturally in the environment (thousands of tons of methyl chloride are produced naturally every day). The vast majority comes from natural sources. Methyl chloride is formed in the oceans by natural processes (e.g., marine phytoplankton), by microbial fermentation and from biomass fires (burning in grasslands and forest fires) and volcanoes.

Methyl chloride has been detected at low levels all over the world in air, in groundwater, surface water, streams, lakes, seawater, effluents, and sediments. It has also been detected at low levels in drinking water, in fish samples and in human milk. Methyl chloride is present in the troposphere at a concentration of approximately  $1.2 \mu\text{g}/\text{m}^3$  (0.6 ppb). The methyl chloride concentration in the air in rural sites is in general below  $2.1 \mu\text{g}/\text{m}^3$  (1.0 ppb) while in urban cities it is equal to  $1.0\text{-}35 \mu\text{g}/\text{m}^3$  (0.5-17 ppb), corresponding to approximately 20 - 700  $\mu\text{g}$  daily intake (human respiratory volume of  $20 \text{ m}^3$  per day). The maximum concentration found in drinking water is  $44 \mu\text{g}/\text{litre}$  which is an exposure of  $88 \mu\text{g}/\text{day}$  assuming a person drinks 2 L of water a day.

### 17.2. Mutagenicity/genotoxicity

Methyl chloride is mutagenic and genotoxic *in vitro* but equivocal *in vivo*. WHO (2000) and U.S. EPA (2001) reviewed the mutagenicity data for methyl chloride; key observations are summarized here.

Methyl chloride is mutagenic in:

- Microbial reverse mutation assay (Ames), *Salmonella typhimurium* TA100, TA1535 and in *Escherichia coli* WP2 uvrA both in the presence and absence of metabolic activation
- TK6 human lymphoblasts

*In vivo*, WHO 2000 concluded that "though data from standard *in vivo* genotoxicity studies are not available, methyl chloride might be considered a very weak mutagen *in vivo* based on some evidence of DNA-protein crosslinking at higher doses". For other genotoxicity endpoints, induction of SCE by methyl chloride has been observed in human lymphoblasts (U.S. EPA, 2001).

### 17.3. Carcinogenicity

Methyl chloride is classified as Group 3 "inadequate evidence for the carcinogenicity of methyl chloride to humans" (IARC, 1999). Category D compound not classifiable as to human carcinogenicity (U.S. EPA 2001).

In animals, the only evidence of carcinogenicity comes from a single 2-year bioassay that used the inhalation route of administration. A statistically significant increased incidence of renal benign and malignant tumors was observed only in male B6C3F1 mice at the high concentration (1,000 ppm). Although not of statistical significance, cortical adenoma was also seen at  $464 \text{ mg}/\text{m}^3$  (225 ppm), and development of renal cortical microcysts in mice was seen in the  $103 \text{ mg}/\text{m}^3$  (50 ppm) dose group and to some extent in the  $464 \text{ mg}/\text{m}^3$  (225 ppm) group (CIIT, 1981). However, no concentration-response relationship could be established. Renal cortical tubuloepithelial hyperplasia and karyomegaly were also confined to the 1,000-ppm group of male mice. Neoplasias were not found at lower concentrations or at any other site in the male mouse, or at any site or concentration in female mice or

F-344 rats of either sex. Renal adenocarcinomas have been shown to occur only in male mice at a level of exposure unlikely to be encountered by people.

These renal tumors of the male mouse are not likely to be relevant to humans. Renal tumors in the male mouse are thought to be related to the production of formaldehyde during methyl chloride metabolism. The cytochrome P-450 (CYP) isozyme believed to be responsible, CYP2E1, is present in male mouse kidney and is androgen-dependent; female mice had CYP2E1 levels only 20%-25% of those in males. Generation of formaldehyde has been demonstrated in renal microsomes of male CD-1 mice that exceed that of naive (androgen-untreated) female mice, whereas kidney microsomes from the rat did not generate formaldehyde. Additionally, species-specific metabolic differences in how the kidney processes methyl chloride strongly suggest that renal mouse neoplasms via P-450 oxidation are not biologically relevant to humans given that human kidney lacks the key enzyme (CYP2E1) known to convert methyl chloride to toxic intermediates having carcinogenic potential. In the rat, renal activity of CYP2E1 was very low. No CYP2E1 activity was detected in human kidney microsomal samples, nor was it detected in freshly isolated proximal tubular cells from human kidney. CYP4A11 was detected in human kidney, but its ability to metabolize methyl chloride is unknown. In addition to CYP4A11, the only other P-450 enzymes found at significant levels in human renal microsomes are CYP4F2 and CYP3A. Moreover no commonly known environmental chemicals appear to be metabolized by the CYP4A family. The lack of detectable CYP2E1 protein in human kidney (in contrast to mice, which have high levels) suggests that the metabolism of methyl chloride by P450 (presumably leading to elevated formaldehyde concentrations) that is likely responsible for the induction of male mouse kidney tumors are not likely relevant to humans.

However, as highlighted by the U.S. EPA and WHO, the role of hepatic (and/or kidney) metabolism (leading to potential genotoxic metabolites) via the predominant glutathione (GSH)- dependent pathway (metabolism of methyl chloride to formate in liver is GSH-dependent, via the GSH-requiring formaldehyde dehydrogenase that oxidizes formaldehyde to formate) or even by P450 isozymes other than CYP2E1 in this regard cannot be discounted. Nonetheless, production of formaldehyde via low doses of methyl chloride would be negligible compared with the basal formation of formaldehyde in the body (i.e., 878 – 1310 mg/kg/day; EFSA, 2014). In addition, based on the limitations of human relevance, U.S. EPA classified methyl chloride as a group D compound, that is, "Not Classifiable as to Human Carcinogenicity".

**Methyl Chloride – Details of carcinogenicity studies (only inhalation studies available)**

| <b>Study</b>   | <b>Animals/<br/>dose<br/>group</b>  | <b>Duration/<br/>Exposure</b>                 | <b>Controls</b> | <b>Doses</b>  | <b>Most sensitive<br/>tumor<br/>site/sex</b>                 | <b>TD<sub>50</sub><br/>(mg/kg/d)</b> |
|--|-------------------------------------|---|-----------------|---|--|--------------------------------------|
| CIIT 1981<br>(summarized<br>by WHO<br>2000 and<br>EPA 2001)* | 120/sex/<br>group<br>B6C3F1<br>mice | Inhalation<br>for 6h/d,<br>5d/wk<br><br>24 mo | Yes             | 3:<br><br>103; 464;<br>2064 mg/m <sup>3</sup><br>(50; 225;<br>1000 ppm) | Kidney tumors<br>in males only.<br>No finding in<br>females. | 1,360** <sup>^</sup>                 |

|   |   |   |     |   |  |    |
|---|---|---|-----|---|--|----|
| CIIT 1981<br>(summarized<br>by WHO<br>2000 and<br>EPA 2001) | 120/sex/<br>group<br>Fisher 344<br>rats | Inhalation<br>for 6h/d,<br>5d/wk<br><br>24 mo | Yes | 3:<br><br>103; 464;<br>2064 mg/m <sup>3</sup><br>(50; 225;<br>1000 ppm) | No findings in<br>males and<br>females | NA |
|---|---|---|-----|---|--|----|

Note: Studies not listed in CPDB.

\*[Carcinogenicity study selected for AI calculation.](#)

\*\*TD<sub>50</sub> calculated based on carcinogenicity data.

^ Not statistically significant at 225 ppm but considered induced by methyl chloride because similar to those seen at 1000 ppm where a clear significant increase was noted.

NA = Not applicable

#### **17.4. Regulatory and/or published Limits**

WHO developed a guideline value for the general population of 0.018 mg/m<sup>3</sup> and U.S. EPA developed a reference concentration of 0.09 mg/m<sup>3</sup>. Both were based on the potential for adverse central nervous system effects following inhaled methyl chloride.

#### **17.5. Acceptable Intake (AI)**

While the data indicate the tumors observed in male mice are likely not relevant to humans, an AI was developed because of the uncertainties in data.

Lifetime AI = TD50/50,000 X 50kg

Lifetime AI = 1,360 mg/kg/day /50,000 X 50 kg

**Lifetime AI = 1,360 µg/day**

#### **17.6. References**

Chemical Industry Institute of Toxicology (CIIT). (1981) Final report on a chronic inhalation toxicology study in rats and mice exposed to methyl chloride. Report prepared by Battelle Columbus Laboratories for the Chemical Industry Institute of Toxicology. EPA/OTS Doc #878212061, NTIS/OTS0205952.

European Food Safety Authority (EFSA). (2014) Endogenous formaldehyde turnover in humans compared with exogenous contribution from food sources. EFSA Journal 12(2):3550.

International Agency for the Research of Cancer (IARC). (1999) Methyl Chloride. Volume 71.

United States Environmental Protection Agency (U.S. EPA). (2001) Toxicological review of methyl chloride. (CAS No. 74-87-3). In Support of Summary Information on the Integrated Risk Information System (IRIS). EPA/635/R01/003

World Health Organization (WHO). (2000) Concise International Chemical Assessment Documents (CICADS) n°28, Methyl chloride. <http://www.inchem.org/documents/cicads/cicads/cicad28.htm>