

COMMITTEE ON CARCINOGENICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT

Updated draft Guidance Statement G05: Defining a Point of Departure and Potency Estimates in Carcinogenic Dose Response

The Committee has previously agreed to regularly review the published COC guidance statements to ensure they remain up to date. As part of this process G05 on points of departure and potency estimates has been updated.

Annex A contains the draft updated document and Members are invited to comment on the structure and contents of the revised statement, including some questions made in comment boxes.

In places newer references have been suggested, in most instances these have been incorporated in the text, but on some occasions a number of possible references could be added. It would be helpful for Members to advise on how they wish these new or additional references to be incorporated in the document.

Since publication of version 1 of this document EFSA has published new guidance on benchmark dose modelling and EFSA and WHO have jointly reviewed the Threshold of Toxicological Concern approach. These updated documents are provided in Annexes B and C respectively. It would be helpful if Members could indicate whether a more thorough discussion on each of these should be taken at a future meeting, before updating this guidance statement further.

Imperial College Toxicology Unit/Secretariat
July 2017

**COMMITTEE ON CARCINOGENICITY OF CHEMICALS IN FOOD, CONSUMER
PRODUCTS AND THE ENVIRONMENT**

**Updated draft Guidance Statement G05: Defining a Point of Departure and
Potency Estimates in Carcinogenic Dose Response**

Updated draft document

**Imperial College Toxicology Unit/Secretariat
July 2017**

Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment

Defining a Point of Departure and Potency Estimates in Carcinogenic Dose Response

<u>1.0 Introduction.....</u>	<u>1</u>
<u>2.0 Points of Departure and Potency Estimates.....</u>	<u>3</u>
2.1 <i>The Benchmark Dose approach.....</i>	<i>3</i>
2.2 <i>The T25 approach.....</i>	<i>7</i>
2.3 <i>Comparing BMD and T25 methodology for use in risk assessment.....</i>	<i>8</i>
2.4 <i>The TD50 approach.....</i>	<i>8</i>
2.5 <i>The NOAEL (No Observed Adverse Effect Level) approach.....</i>	<i>9</i>
<u>3.0 Potency Ranking of Genotoxic Carcinogens.....</u>	<u>10</u>
<u>4.0 The Threshold of Toxicological Concern (TTC).....</u>	<u>11</u>
4.1 <i>Development of the TTC.....</i>	<i>11</i>
4.2 <i>TTC decision tree.....</i>	<i>13</i>
4.3 <i>TTC endorsement by sister committees.....</i>	<i>15</i>
<u>5.0 New fields and Developments in Deriving Points of Departure.....</u>	<u>15</u>
5.1 <i>The Signal-to-Noise Crossover Dose (SNCD) approach.....</i>	<i>15</i>
<u>6.0 Summary.....</u>	<u>15</u>
<u>7.0 References.....</u>	<u>16</u>

1.0 Introduction

1. This guidance statement provides an overview of the various methods for deriving points of departure and potency estimates associated with exposures to chemical carcinogens. It is part of a series of guidance statements by the Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment. It should be read in conjunction with these, in particular G01 on the overall strategy of risk assessment of chemical carcinogenicity, G02¹ on the **interpretation of evidence of**

¹ This G02 guidance has yet to be published at time of the latest update of G05, 2017

carcinogenicity in humans, G03 on hazard identification and characterisation, and G06 on risk characterisation methods.

2. This guidance document describes how to derive points of departure (POD) such as the Benchmark Dose (BMD) and potency estimates such as the T25 and TD50, and describes how they can be used to estimate the relative potency of carcinogens. However, the BMDL² is the most widely preferred POD approach and the COC recommends its use. Similarly, in recent times, the BMDL is the preferred POD for thresholded non-genotoxic carcinogens. However, in certain situations, such as when it is not possible to apply the BMD methodology, the traditional approach of the no observed adverse effect level (NOAEL) can be adopted for non-genotoxic compounds. Indeed, this approach can be used for genotoxic carcinogens, although it would be important that use of the term 'NOAEL' in such cases does not necessarily imply the existence of a threshold in the dose-response relationship. This guidance document also details the Threshold of Toxicological Concern (TTC) approach which can help to identify priorities for more detailed carcinogenicity evaluation, particularly for chemicals not subject to regulatory approval schemes.

3. Hazard characterisation involves a qualitative description of the nature of the hazard and a quantitative description of the change in effect caused by differing doses of a chemical substance after a certain exposure time, i.e. the dose-response relationship. The purpose of analysing the dose-response relationship is to investigate the magnitude of response (in terms of severity or incidence) within the dose range used in an animal study or within the range of exposures experienced in a human study. This helps to estimate the response and, ultimately, the risk from exposure to the concentrations of the chemical in the environment, food etc. These are usually much lower than those used in animal studies and often also lower than those to which individuals have been exposed in human studies. The relationship between dose and response may be used to aid hazard characterisation by allowing a comparison of carcinogenic potency. Carcinogenic potency estimates give an indication of the dose of a substance administered over a standard animal lifespan that results in a fixed incidence of tumours, such as, 5, 25 or 50%, after correction for the spontaneous background incidence of tumours among controls (Barlow et al., 2006). However, other important factors that can affect this relationship in humans, and should be further considered, are species differences in absorption, distribution, metabolism and excretion (ADME), mode of action and variability in susceptibility between species and within humans.

4. There are a number of methods for the characterisation of hazard due to the carcinogenicity of genotoxic compounds. In all of these, chemicals are classified with regard to tumourigenicity on the basis of potency. In this context, potency is ideally represented by the overall position and shape of the dose-effect or dose-response curve, but the value (dose) at a particular point on the curve is often used as a surrogate. A POD is defined as the dose-response point that marks the beginning of a low-dose extrapolation. This point can be the lower bound on dose for an estimated incidence of a tumour or a change in response level from a dose-response model (BMD), or a NOAEL or LOAEL for an observed incidence, or change in level of response. An example is the dose level associated with a tumour incidence that is 10% above the incidence in the control group. The Committee

2 BMDL: Lower 95% confidence limit of the benchmark dose for a specific level of response (usually 10%)

recognises that where data on tumourigenicity *per se* are lacking, it may be possible to use continuous data as a surrogate measure of response, such as specific DNA damage observed in target organs, for determining a point of departure.

5. It should be noted that there is no difference in the methodology used for determining points of departure for genotoxic and non-genotoxic carcinogens. It is how the dose-response relationship and the POD are used in the final assessment of risk that varies, depending on whether or not a carcinogenic response occurs through a genotoxic or non-genotoxic mode of action (see Guidance Document G06 for further discussion of Risk Characterisation).

2.0 Points of Departure and Potency Estimates

2.1 Benchmark Dose (BMD) approach

6. The Benchmark Dose (BMD) methodology was initially introduced by Crump (1984) as an alternative to the use of NOAELs and LOAELs in dose–response assessment for setting regulatory levels such as reference doses (RfDs), reference concentrations (RfCs) and acceptable or tolerable daily intakes (ADIs or TDIs) for effects for which it is assumed there is a threshold. It was subsequently developed further within the US EPA (US EPA, 1995). Both the European Food Safety Authority (EFSA) and the World Health Organization (WHO) recommend the BMD approach for deriving a point of departure (POD) (also known as a reference point) to be used as a starting point for human health risk assessment, for all endpoints. This includes carcinogenicity by a genotoxic mode of action. The BMD approach has a number of advantages over the NOAEL approach. The BMD approach makes more complete use of the available dose–response data, it takes into account the shape of the dose–response curve more explicitly and it is less dependent on dose spacing. It also enables quantification of the uncertainties in the dose–response data using statistical methodology (EFSA, 2009, 2017). However, it should be noted that most studies are optimised in their design to identify the NOAEL.

7. The BMD_x is defined as the dose that corresponds to a specific change (x%) in response compared to the (modelled) response in control animals, the benchmark response (BMR) (Crump, 1995). The BMD is determined by fitting a mathematical curve to the dose–response data over the range of observable responses from animal studies or human studies (if available), using a selection of different models. From each statistically acceptable modelled dose–response curve, values for the BMD and the lower and upper bound 95% confidence limits (BMDL and BMDU) are obtained (see paragraphs 12 and 13 on how to choose the most appropriate BMD). To take experimental uncertainty into account, the lower 95% confidence bound on the benchmark dose ($BMDL_x$) is used as the POD. Figure 1 illustrates the BMD approach.

8. Both dichotomous data and continuous data from animal and human dose–response studies can be evaluated using the BMD approach (EFSA, 2009, 2017). Dichotomous (quantal or incidence) data describe whether an effect has occurred in an individual or not, e.g. presence of tumour, death. The tumour data obtained from carcinogenicity studies fall into the dichotomous category. Continuous data are

typically quantitative measurements. The analysis of human dose-response data is generally more complicated than animal dose-response data due to the presence of confounders and imprecision in the exposure estimates (EFSA, 2009, 2017). For the purpose of this guidance statement on defining a POD in a carcinogenic dose response, only considerations of quantal data will be discussed, though it is acknowledged that for effects such as DNA damage an approach appropriate for continuous data would need to be used.

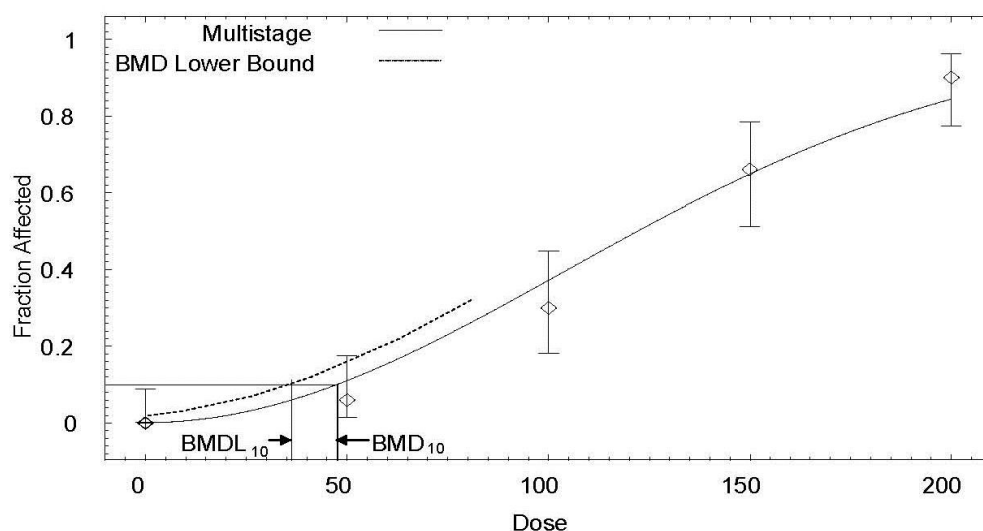


Figure 1. Example of a model fit to dichotomous data, with BMD and BMDL indicated. The fraction of animals affected in each group is indicated by diamonds, and the error bars indicate 95% confidence intervals for the fraction affected. The BMR in this example is an extra risk of 10% (or 0.1 fraction responding). The fitted model is shown by the solid curve, and the BMD corresponding to 10% extra risk on this curve is notated BMD₁₀. The lower bound on BMD₁₀, notated BMDL₁₀, comes from the dashed curve to the left of the fitted model curve, indicating the estimated lower bound on doses for a range of BMRs (taken from US EPA technical document, 2012).

9. Before a dataset is analysed using the BMD methodology, it is necessary to evaluate all available studies and potential critical effects, ensuring that the datasets meet minimum criteria, as outlined in the EFSA opinion (2009, 2017). There are two aspects here, and in part they depend on the BMD approach to be used. One is selection of tumour-response data relevant to risk assessment of a genotoxic carcinogen and the other is ensuring a dataset is suitable for modelling. In the BMD approach, one might model all suitable datasets or combinations thereof (accepting the need for caution in combining data) and then interpret the resulting BMDLs, or one may choose to model only what is considered to be the critical data set, the one likely to give the most conservative outcome from amongst those that are considered relevant.

10. In preparation for BMD modelling, the BMR must also be chosen. For quantal responses, the BMR is expressed in terms of a percent increase in risk³ of adverse

³ This can be expressed as 'extra' risk (the default in BMDS) or as 'added' risk. The BMR is calculated differently, depending on which risk type is chosen.

outcome above the modelled background. The BMR is typically set at the lower end of the range of responses that can be detected experimentally, or the observations in epidemiological studies. EFSA (2009, 2017) recommend that a default BMR value of 10% be used for quantal data from a guideline rodent carcinogenicity study, since the modelling of lower responses generally results in greater uncertainty. Based on statistical and toxicological considerations, a modified BMR can be used, for example a BMR of 1% has been used with epidemiological studies of large populations (US EPA, 2000 and EFSA 2009, 2017).

11. Both the WHO/IPCS and EFSA have produced guidance on dose–response modelling, including guidance on cancer dose-response data (IPCS, 2009b and EFSA, 2009, 2017). Table 1 lists the models for BMD analysis for quantal data recommended by EFSA (2017). It should be noted that the models outlined in the table may change over time and are therefore not exhaustive of all models that could be used. Different models that fit the data equally well, as judged by statistical comparison, can result in different BMDs and BMDLs, reflecting model uncertainty. The selection of the group of models to investigate is dependent on the endpoint being modelled (quantal or continuous) and the experimental design used to generate the data (e.g. number of dose groups utilised and nested study design (Davis et al., 2011)). The US EPA technical guidance document (2012) and the EFSA guidance (2009, 2017) both detail the various models that can be used in BMD modelling with existing software. Model selection and model constraints are important considerations in BMD estimation. The main option in model selection for BMD estimation using quantal data is the choice of model classes (Sand et al., 2008).

12. Once the selected models have been fitted to the data, a series of scientific judgements must be made to ensure the fitted models adequately describe the data. Different types of statistical testing can be utilised to assess the adequacy of model fit. For model selection, an important criterion is that the selected model should adequately describe the data, especially in the region of the BMR. The EFSA guidance (2009) for model fit involves two principles: deciding which model fits best within a nested family of increasingly complex models, where this is necessary, and then a determination of overall goodness-of-fit. Both principles are based on the likelihood-ratio test and EFSA (2009) recommended a minimum goodness of fit value of $p = 0.05$ for model acceptance based on log-likelihood. For dichotomous data, the US EPA software employs Pearson's chi-squared goodness of fit test (US EPA, 1995). The US EPA (2012) recommends a minimum goodness of fit p value of $p = 0.1$ for model acceptance. The Akaike information criterion (AIC) value, which is a measure of the degree of fit weighted by the number of free parameters in the model and/or Pearson's chi-squared goodness of fit test can also be used for selection within a nested series. The latest EFSA guidance recommends that the AIC should be used (instead of log-likelihood) to characterise goodness of fit (EFSA, 2017).

Table 1: Recommended quantal models for use in the BMD approach (taken from EFSA guidance, 2017)			
Model	Number of model parameters	Model expression mean response (y) as function of dose (x)	Constraints
<i>Quantal data</i> ⁽²⁾			
Logistic	2	$y = 1 / (1 + \exp(-a - bx))$	$b > 0$
Probit	2	$y = \text{CumNorm}(a + bx)$	$b > 0$
Log-logistic	3	$y = a + (1-a) / (1 + \exp(-\log(x/b)/c))$	$0 \leq a \leq 1, b > 0, c > 1$
Log-probit	3	$y = a + (1-a) \text{CumNorm}(\log(x/b)/c)$	$0 \leq a \leq 1, b > 0, c > 0$
Weibull	3	$y = a + (1-a) \exp((x/b)^c)$	$0 \leq a \leq 1, b > 0, c > 1$
Gamma	3	$y = a + (1-a) \text{CumGam}(bx^c)$	$0 \leq a \leq 1, b > 0, c > 1$
Two-Stage	3	$y = a + (1-a) \exp(-bx - cx^2)$	$a > 0, b > 0, c > 0$
Latent variable models based on continuous models (1)	Depends on underlying continuous model	These models assume an underlying continuous response, which is dichotomised into yes/no response based on a (latent) cut-off value that is estimated from the data	As for continuous models (2)
a, b, c, d: unknown parameters that are estimated by fitting the model to the data. CumNorm: cumulative (standard) normal distribution function. CumGam: cumulative Gamma distribution function (1) The latent variable models are implemented in PROAST. (2) See EFSA (2017)			

13. It is often the case that a number of models will adequately fit the data, as judged on statistical considerations. One option then is to select the model with the lowest AIC value from all statistically acceptable models. However, applying this approach may lead to models being excluded, which would otherwise provide higher, or lower, risk estimates. A second option is to select the model that leads to the highest extra risk or lowest BMDL on the basis that this selection is likely to be more conservative. This option was recommended by EFSA (2009). A third option is to report a range of risk estimates from those models that provide an acceptable fit to the observed data. A fourth option is to average risk estimates/BMDLs based on the support for each model provided by the data ('Model Averaging') (Wheeler and Bailer, 2007). It should be noted that this is not the simple averaging of the individual BMDL estimates, but a pooled analysis of the data. This approach better characterises the uncertainty in the value of the BMDL that derives from ignorance of the true dose response (Wheeler and Bailer, 2007), and hence is expected to be numerically higher than the lowest BMDL value resulting from applying a suite of models (Benford et al., 2010). Revised EFSA guidance now recommends Model

Averaging as the preferred approach, combining results from each of the fitted models to establish a final BMD confidence interval. However, selection/rejection of models can be considered as a sub-optimal alternative in situations where Model Averaging tools are not available (EFSA, 2017)

14. Different software programs are currently available for BMD analysis. The US EPA developed the Benchmark Dose Software (BMDS). PROAST is another BMD software package, developed by the Dutch National Institute for Public Health and the Environment, and the basis on which EFSA now provide a web-based platform for performing BMD analysis. Both these software packages are suitable for dose-response analysis and deriving a BMDL from the dose-response data. The Dutch National Institute of Public Health and the Environment and EPA collaborate to achieve consistency between the BMDS and PROAST software.

15. Once the BMDL is derived as the POD, the risk assessor moves to the risk characterisation stage of the risk assessment which brings together the hazard identification and hazard characterisation stages and the exposure assessment process (see Risk Characterisation Guidance Statement G06).

2.2 The T25 approach

16. Although primarily used in carcinogenic potency estimates, the T25 approach can also be used to derive a POD. For example, although the European Chemicals Agency (ECHA) prefers $BMDL_x$ as a starting point, if the data do not permit BMD analysis, ECHA suggests that the T25 can be used. The T25 is defined as the dose eliciting a 25% increase in the incidence of a specific tumour above the background level within the standard lifespan of that species. It was originally proposed by Dybing et al. (1997) and further developed by Sanner et al. (2001). The methodology does not require elaborate statistical methods. The T25 is determined by simple linear interpolation or, in some cases, extrapolation beyond the data points. According to Dybing et al. (1997) the data used for calculating a T25 should preferentially be from long-term carcinogenicity bioassays. The estimation of T25 is dependent on the incidence of tumours at a selected site at a single dose level. The minimum data requirements to calculate a T25 are one incidence level significantly greater than the controls (Gillespie et al., 2011). The T25 is influenced by the quality of the bioassay information (e.g. design and evaluation of studies) and factors such as time to first tumour, the influence of toxicity on tumour induction and mortality, and the approach taken regarding statistical analysis of tumour data. The European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) has evaluated the use of T25 estimates for regulatory risk assessment of non-threshold carcinogens (ECETOC, 2002). There may also be uncertainties regarding the application of the T25 for potency ranking, particularly with regard to selection of the most sensitive site relevant for humans, the relevance of rodent tumours for humans, and different cancer susceptibilities between rodent species (ECETOC, 2002). The T25 is also the method used by the EU to assess relative potency for the setting of specific concentration limits of preparations and mixtures (EC, 1999). Using the T25 method, Sanner and Dybing (2005) found a good correlation between the values based on human epidemiological data and those based on animal experiments, although the data available for such comparison were limited. Previously, the T25 approach has

been used in risk assessment for regulation of non-food, genotoxic carcinogenic chemicals in the EU (EFSA, 2005).

2.3 Comparing BMD and T25 methodology for use in risk assessment

17. T25 and the BMD methodology differ in that the T25 is calculated from one data point on the dose-response curve whereas the BMD is derived from dose-response modelling of all available data on the dose-response curve (EFSA, 2005).

18. Dybing et al. (2008) compared the Margin of Exposure (MOE), the numerical value obtained by dividing a POD on the dose-response curve by estimated human exposure to the chemical, for 6 substances obtained using either the BMDL₁₀ or the T25. They found that MOEs obtained using the T25 as the POD were on average around 2.35 times higher than those derived using the BMDL₁₀ as the POD (Dybing et al., 2008). Benford et al. (2010) compared MOEs for 12 substances in food that are genotoxic and carcinogenic (5 of which were the same as those examined by Dybing et al., 2008) and found that the ratio of MOEs derived from a T25 value varied from those using a BMDL₁₀ value by between 0.9 and 4.6, with a mean of 2.9 and a median of 2.6. These results were in line with the expected ratio of 2.5 to account for the 25% vs. 10% risk, assuming linearity in the dose-response relationship, when comparing the T25 with the BMDL₁₀ (Benford et al., 2010).

19. In the Committee's discussion of the MOE approach for G06, the guidance document on Risk Characterisation, the Committee considered the use of the BMD approach as a means of deriving a POD to be superior to that of the T25.

20. In the case where the dose-response data are inadequate for deriving an estimate of the BMD₁₀ or BMDL₁₀, EFSA (2005) recommended the use of the T25 as a means of deriving a POD. However, use of this approach when it was not possible to derive a BMDL₁₀ was questioned by Benford et al. (2010). As the BMD methodology uses all the available data, if a dataset does not allow derivation of a BMDL, even at a dose rate higher than 10%, e.g. a BMDL₂₅, the dataset may not be suitable for derivation of a meaningful POD at all. An example would be if there is a very high incidence of tumours at all dose levels, in which case it would not be feasible to derive a BMDL but a T25 could still be calculated by dividing the lowest dose level by the ratio of the percentage response to 25%. However, the resultant T25 value would be meaningless. The Committee agrees with this view and, therefore, in the event that it is not possible to derive a BMDL₁₀, the Committee does not recommend the routine use of the T25.

2.4 The TD50 approach

21. The TD50 (Peto et al., 1984) is defined as the chronic dose rate which would induce tumours in a given target site(s) in 50% of the test animals at the end of a standard lifespan for the species, provided that there were no tumours in control animals. However, since the tumour(s) of interest often do occur in control animals, the TD50 is more precisely defined as the daily dose rate required to halve the probability of remaining without tumours at the end of a standard life span. TD50 values have been estimated for chemicals listed in the Carcinogenic Potency Database (CPDB) developed by Gold and Zeigler

(<https://toxnet.nlm.nih.gov/cpdb/cpdb.html>, accessed 09/05/17) (Gold et al., 1984, 1997).

22. The TD50 concept is based on the assumption that there is linearity between dose and hazard until tumour onset, which may be complicated by premature deaths from causes other than tumour formation. The concept also depends on the assumption that tumour onset times are observable prior to mortality and, as a result, the approach relies heavily on careful observation of the animals. Tumours that are discovered after death within the study period may cause confounding between mortality and tumour onset and would ultimately result in a biased TD50 estimate. Alternatively, tumours that do not significantly alter survival and remain undiscovered until death would result in the TD50 value relating to the 'rate of death with tumour', rather than the tumour incidence rate. This undermines the objective of the carcinogenicity study, which is to evaluate tumour incidence. A description of the TD50 methodology and the complex statistical analysis involved in the derivation is provided at <http://toxnet.nlm.nih.gov/cpdb/td50.html> (accessed 09/05/17).

23. The Committee reiterates its previous position that the TD50 is a practical quantitative estimate of carcinogenic potency for the ranking of genotoxic carcinogens.

2.5 The NOAEL (No Observe Adverse Effect Level) approach

24. For the majority of toxicological effects, with the exception of most genotoxic effects or where extensive testing has failed to identify a threshold (e.g. lead), it is generally assumed that there is an exposure threshold below which no adverse effects occur. The NOAEL (no-observed-adverse-effect-level) approach was traditionally the method of choice for determining a point of departure for such effects, including carcinogenicity by a non-genotoxic mode of action. In human risk assessment, the NOAEL has been used to establish health-based guidance values such as acceptable daily intakes (ADIs) for food additives and pesticide residues, and tolerable daily intakes (TDIs) or tolerable weekly intakes (TWIs) for contaminants. These health-based guidance values are derived from the highest NOAEL for the most sensitive effect identified in human epidemiological studies or from sub-chronic or chronic studies in laboratory animals.

25. The highest administered dose at which no statistically significant adverse difference from the concurrent control group is observed is designated the NOAEL. To avoid unnecessarily conservative risk estimates, risk assessment is based on adverse effects rather than on minor or adaptive effects and hence the NOAEL is used as the POD. If a statistically significant adverse effect is observed at all dose levels, the lowest dose used in the study, i.e. the LOAEL (lowest-observed-adverse-effect-level), may be used as the POD. Typically the NOAEL (or if one is not available, the corresponding LOAEL) is identified for the most sensitive relevant effect in the most sensitive species, with the adverse effect associated with the lowest NOAEL regarded as the critical effect of human relevance. The associated NOAEL is used as the POD. The NOAEL approach has been the standard method for deriving PODs for a long time and it is familiar to most risk assessors (US EPA, 2000).

26. However, the NOAEL approach has a number of limitations. A major limitation is the constraint for the NOAEL to be one of the experimental doses. The approach does not take into consideration dose spacing, the shape of the dose-response curve, the number of animals per group, or the statistical variation in the response and its measurement. The NOAEL approach tends to give lower health-based guidance values for studies with a higher power to detect adverse effects, which in effect 'penalizes' better-designed studies (IPCS, 2009a). It should also be noted that studies with low power (e.g. small group sizes) and/or insensitive methods may only detect relatively large effects, resulting in higher NOAELs. This is in contrast to the BMDL, which 'rewards' better-designed studies.

27. Despite the adoption of the BMD approach as an alternative to the NOAEL in determining a POD, there continues to be a need for the NOAEL/LOAEL approach. Not all data sets are amenable to BMD modelling, such as those resulting from incomplete data availability or from a lack of models that can describe a dataset adequately (US EPA, 2012) and the NOAEL approach can be used in this instance. A typical situation where the NOAEL approach is applicable whereas the BMD approach is not is when there is a response only in the highest dose group.

3.0 Potency Ranking of Genotoxic Carcinogens

28. Data from animal bioassays can be used to rank carcinogenic potency without reference to human intake. Carcinogenic potency estimates, as described in paragraph 3, make use of the available dose-response data, and points of departure can be derived from TD50, T25 or BMD approaches for use in potency ranking. For example, in a series of publications Gold et al. tabulated data on a large number of compounds allowing their carcinogenic potencies to be expressed as the TD50 (Gold et al., 1997). These values can be used to indicate the relative potencies of a series of compounds.

29. Relative potency estimates could have some pragmatic use in carcinogenic risk assessment as an aid in the prioritisation of genotoxic carcinogenic substances, but are not considered adequate for quantifying cancer risks. The uncertainties inherent in potency ranking mean that relative potencies should not be over-interpreted. For example, it is unclear whether the relative ranking identified in the observed dose range would be maintained at low doses, and whether the relative potency in animal studies would be applicable to humans. Potency Equivalence Factors (PEFs) have been suggested in circumstances where there is a good surrogate compound for comparison, e.g. inhalation of polycyclic aromatic hydrocarbons (PAHs) (Collins, 1998; Pufulete et al., 2004). Pufulete et al. (2004) suggested that an approach based on PEFs could be developed to include highly potent PAHs provided an appropriate reference data set for relevant PAHs using a route acceptable for inhalation risk assessment is selected. The US EPA (2010) also developed an approach to assessing cancer risk for PAH mixtures using relative potency factors (RPFs), which estimates the cancer risk of individual PAHs relative to that of benzo[a]pyrene (BaP). The US EPA suggests that their RPFs are applicable to all routes of exposure, but acknowledges that there is appreciable uncertainty in doing this. The COC notes that PHE has adopted a surrogate marker approach rather than the use of PEFs for

assessment of the public health risk of PAHs in contaminated land (HPA, 2010). Otherwise, to date, there has been little use of PEFs for carcinogenicity.

30. Comparing the TD50 and T25 approaches for estimating potency, the TD50 has an advantage in that it takes account of effects of chemicals on survival, however it requires specific software to undertake its derivation. In contrast, the T25 is quick and easy to calculate. There is evidence of a good correlation between rank order produced by TD50 and T25 (Dybing, 1997). In 2006, the COC compared the TD50 with the T25 in an attempt to **develop an approach for potency ranking of genotoxic carcinogens for single exposure. Very limited data** were available for this purpose and little correlation was found among those substances for which it was possible to obtain chronic TD50 and T25 values, compared to acute T25 values (COC, 2006).

31. The Committee acknowledges that the T25 approach can be used in potency ranking of genotoxic carcinogens, but is of the view that the statistics should not be over-interpreted. The reason for this is that there are a number of basic uncertainties, such as whether the relative ranking identified in the observed dose range would be maintained at low doses, and whether the relative potency in animal studies would be applicable to humans. Currently, there is no need to use the T25 to rank non-genotoxic carcinogens, for which tolerable exposure levels can be derived using an approach based on knowledge of mode of action, identification of a NOAEL, and the use of uncertainty factors.

4.0 The Threshold of Toxicological Concern (TTC)

4.1 Development of the TTC

32. The use of *de minimis* exposure values as a means of identifying substances of low concern was first proposed by Frawley (1967). This was further developed by the US Food and Drug Administration (FDA) (Rulis, 1986) for application to substances that do not contain a structural alert for genotoxicity/ carcinogenicity. Analysis of the 500 carcinogens then in the Cancer Potency Database (CPDB), based on virtually safe doses (for a 1 in 10⁶ excess cancer risk) derived from the TD50s, led to the adoption by the FDA (1995) of a Threshold of Regulation of 0.5 µg/kg of diet (equivalent to an intake of 1.5 µg/person/day) for substances used in food contact materials. At this level, it was intended that consumers would be protected 'with reasonable certainty of no harm', even if that substance was later shown to be a carcinogen. Cheeseman et al. (1999) later analysed and validated the approach using the expanded CPDB containing information on 700 chemicals (Gold et al., 1997). Cheeseman et al. (1999) identified certain categories of potent carcinogens which would not be covered by the Threshold of Regulation of 0.5 µg/kg of diet. These were azoxy compounds, benzidines, N-nitrosamines and aflatoxin-like compounds. A number of other groups were excluded, but these were not genotoxic and potency was estimated using linear extrapolation from the TD50, which would result in an appreciable overestimate. With the exclusion of these structural classes, it was considered unlikely that an unstudied compound would be both carcinogenic and have a potency far greater than the typical potency of studied compounds.

33. Subsequently, Kroes et al. (2004) re-evaluated the distribution of virtual safe doses (VSDs) for carcinogens, grouped into structural classes, e.g. aromatic amines, benzidines. They concluded that, with a few exceptions, adequate protection would be provided (i.e. there was low probability that the risk from an untested chemical would be > 1 in 10^6), even from compounds that were genotoxic or carcinogenic, using a TTC value of $0.15 \mu\text{g}/\text{person}/\text{day}$. Groups of compounds that would not be covered by this value were aflatoxin-like, azoxy and N-nitroso-compounds, as well as steroids and dioxins, because of their very high potencies, thus largely confirming the conclusions of Cheeseman et al. (1999). In their recent opinion, the EU DG SANCO committees added benzidines and hydrazines to this list.

34. When considered by the COC for the 2004 version of the guidelines, the application of the TTC to carcinogens was a relatively new approach and the Committee concluded that *“careful consideration was needed of the biological, analytical and mathematical issues as well as a much wider database for validation. The Committee consider that it should not currently be used as a generic approach, as the proposed exclusions covered some important classes of genotoxic carcinogens (such as aflatoxin-like compounds, azoxy compounds and N-nitroso compounds) and a number of classes of other carcinogens, such as heavy metals and TCDD (Kroes et al., 2004). However, as it is based on ranking by theoretical risk and exposure the Committee agree that it could be used, along with hazard identification and characterisation data, for prioritisation of chemicals, particularly for chemicals that are not subject to regulatory approval schemes.”* (COC, 2004). Since 2004, experience on the application of the TTC approach has increased, and the approach itself has been refined, including proposals for use both for inhalation (Carthew et al., 2009; Escher et al., 2010; Tluczkiewicz et al., 2016) and dermal (Safford et al., 2008; Safford et al., 2011) exposure. The TTC approach has recently been reviewed by EU committees (DG SANCO, 2012; EFSA, 2012b; EFSA/WHO, 2016). A paper describing the development of the TTC concept since its introduction in 1995 and the respective EU committee opinions was presented at COC in 2012 (Paper CC/2012/18, available from: <http://webarchive.nationalarchives.gov.uk/20140506122048/http://www.iacoc.org.uk/papers/index.htm>).

35. In their analysis, Munro et al. (1996) utilised a dataset comprising repeat dose oral toxicity data for 613 organic chemicals with 2941 associated NOEL values derived from a variety of non-cancer endpoints from sub-chronic, chronic, reproductive and developmental toxicity studies carried out in rodents and rabbits. NOELs for sub-chronic studies were adjusted to chronic exposure using a factor of 3. The 5th percentiles of the NOELs, grouped according to their respective Cramer et al. (1978) class (i.e. Class 1, 2 or 3), were used to derive TTC values by multiplying by 60 (assuming an average individual weighs 60 kg) and then dividing by a safety factor of 100, mirroring the ADI approach. This resulted in TTC values of $1800 \mu\text{g}/\text{person}/\text{day}$ ($30 \mu\text{g}/\text{kg bw per day}$) for Class 1 chemicals, $540 \mu\text{g}/\text{person}/\text{day}$ ($9 \mu\text{g}/\text{kg bw per day}$) for Class 2 chemicals and $90 \mu\text{g}/\text{person}/\text{day}$ ($1.5 \mu\text{g}/\text{kg bw per day}$) for Class 3 chemicals, respectively. EFSA has recommended that the TTC values should be expressed per kg body weight so that they are applicable to different age groups, differing in body weight. It is considered that at oral lifetime exposures below the respective TTC value there is a low probability of any risk, even for a chemical with little or no toxicological data. The EU Joint Research Centre has

developed a free software package, ToxTree, to enable Cramer classification of a chemical (<http://toxtree.sourceforge.net/>).

4.2 TTC decision tree

36. Kroes et al. (2004) combined considerations of structural alerts for genotoxicity with the approach developed by Munro et al. (1996) for *de minimis* exposure values for non-cancer endpoints, based on the structural classification scheme of Cramer et al. (1978) to develop a decision tree for application of the TTC approach to chemicals in food. This scheme proposed by EFSA in 2012 is shown in Figure 1. First, compounds to which the TTC approach is not currently applicable are excluded. These are the groups of potent genotoxic carcinogens discussed above (the cohort of concern), metals, metal-containing compounds, other inorganic compounds, substances known or predicted to bioaccumulate, including polyhalogenated dibenzodioxins, dibenzofurans and biphenyls, proteins, substances with a steroid structure, insoluble nanomaterials, radioactive substances, mixtures of substances of unknown structure, substances acting locally and chemicals displaying pharmacological effects for which no readily accessible database is available.

37. The potential for genotoxicity of the compound is then determined, using predictive software, such as DEREK and ToxBoxes. A number of approaches are used by these packages to predict genotoxic potential, such as the scheme for structural alerts developed by Ashby and Tennant (1991). If there is no alert for genotoxicity, the chemical is assessed according to its Cramer classification, with the addition of an additional class for organophosphates. The resultant output is either that the compound in question is unlikely to represent a safety concern, or that chemical-specific toxicological data are required to carry out a risk assessment (Kroes et al., 2004; EFSA, 2012b).

38. In 2009, Felter et al. proposed further refinements to the TTC decision tree, including consideration for chemicals that have structural alerts for genotoxicity but negative data from genotoxicity tests. They proposed using a higher threshold value of 1.5 µg/person/day as an appropriate TTC exposure limit in such cases. This was based on the work by Cheeseman et al. (1999) on carcinogenic potency and results from Ames tests. This paper also suggested that in circumstances where exposures were unlikely to be over a lifetime, a value of 1.5 µg/person/day may be appropriate for exposures which will not be longer than 1 year (Felter et al., 2009). The concept of a staged TTC was proposed by Müller et al. (2006) and takes into account the fact that duration of exposure is a key factor impacting on the probability of a carcinogenic response. In 2010, the European Medicines Agency (EMA) agreed to the use of a staged TTC approach during clinical development of medicines for a less than lifetime exposure and recommended limits for daily intake of genotoxic impurities (GTIs) of 1.5, 5, 10, 20 and 60 µg/day for greater than 12 months, 6-12 months, 3-6 months, 1-3 months and less than 1 month, respectively. For single doses, an intake of 120 µg/day was agreed to be acceptable (EMA, 2010).

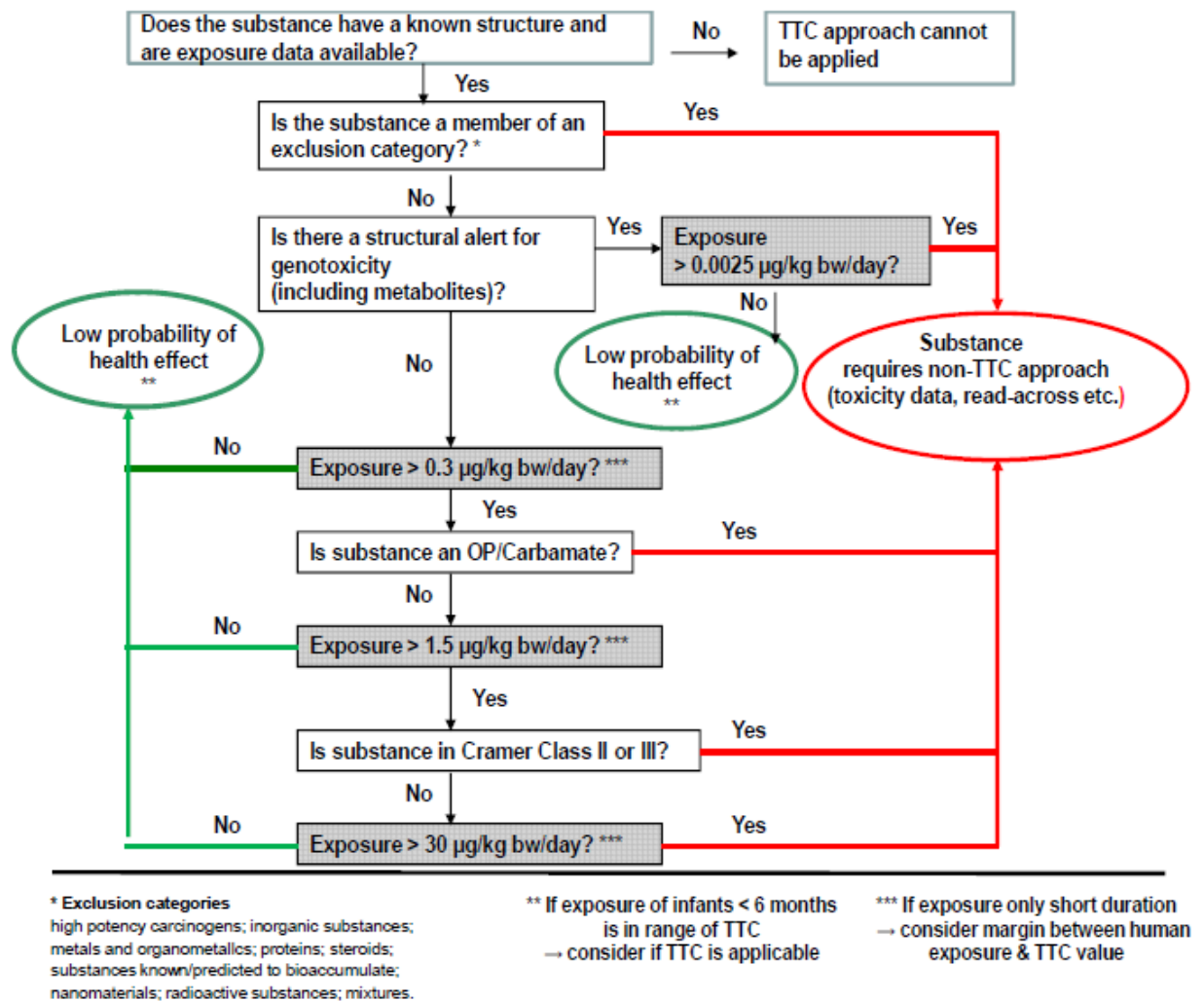


Figure 2: The TTC decision tree suggested by EFSA (2012b).

39. TTC values derived from the Cramer et al. classes are used by EFSA and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) for flavouring substances. A TTC of 1.5 µg/day is used for different reasons as part of a staged assessment for the acceptability of known genotoxic impurities present in pharmaceuticals (EMA, 2006). This value (1.5 µg/day) is considered appropriate under such circumstances, as a risk of 1 in 10⁵ (assuming linear extrapolation) is considered acceptable for human medicines. The use of a TTC of 1.5 µg/day by the EMA applies even to compounds that show evidence of genotoxicity in *in vitro* tests. A similar approach is used for genotoxic constituents of herbal medicinal products/preparations (EMA, 2008).

40. The use of the TTC approach, covering both potential genotoxic and non-genotoxic endpoints, has been proposed for the assessment of metabolites and degradates of pesticide active substances (EFSA, 2012a). The TTC approach has also been proposed for household and personal care products (Blackburn et al., 2005), for skin sensitising substances (Safford, 2008) and for industrial chemicals assessed under REACH (ECHA, 2008).

4.3 TTC endorsement by sister committees

41. The COM published a statement in April 2012 on the genotoxicity testing and hazard assessment of impurities. As part of this, Members agreed that the TTC was a useful concept in identifying impurities requiring genotoxicity assessment, although reference needed to be made to the excluded classes of most concern, e.g. aflatoxin-like, azoxy and N-nitroso compounds, which are potent genotoxic carcinogens (COM, 2012).

42. The COC endorses the views of the COM and the views of EFSA and the DG SANCO Committees on the TTC.

5.0 New fields and Developments in Deriving Points of Departure

5.1 The Signal-to-Noise Crossover Dose (SNCD) approach

43. Sand et al. (2011) developed a new approach for derivation of a POD based on the concept of a signal-to-noise crossover dose (SNCD) and compared it with other methods for deriving the POD. The SNCD provides an estimate of the lowest dose that can be derived as a POD for risk assessment without low-dose extrapolation. It is defined as the dose at which the additional risk equals the 'background noise' or a specified fraction thereof. Background noise is defined as the difference between the upper and lower bounds of the two-sided 90% confidence interval (CI) on absolute risk. Sand et al. (2011) concluded their comparison of the different methods by noting that, if the standard BMD approach is used, then the BMDL₁₀ is the most appropriate POD and that the SNCD should be developed further. Responding to the new SNCD approach, Chiu et al. (2012) proposed augmenting the statistical approach for human risk assessment by additional steps so that inter- and intra-species differences and other biological considerations relating to the key end points are addressed.

44. The SNCD approach gives equivalence with the BMDL₁₀ approach using a default uncertainty factor of 100. The SNCD-based exposure guideline was derived by linear extrapolation from the upper bound on extra risk at the SNCD (UERSNCD) down to a target risk of 1 in 10³. However, it should be noted that for a genotoxic carcinogen it is likely that target risk values would be appreciably lower than this (typically 1 in 10⁵ or 1 in 10⁶). The Committee will continue to keep a watching brief on the developments of the SNCD approach as an alternative approach to deriving a POD but notes that there have been no further publications on this methodology since 2011.

6.0 Summary

45. The Committee recommends the use of the BMDL as the POD for all carcinogens. For genotoxic carcinogens, the likeliest use of the BMDL would be to calculate a MOE as outlined in Guidance Statement G06. For non-genotoxic carcinogens, the BMDL can be used to establish guideline values such as Tolerable Daily Intakes/Acceptable Daily Intakes (TDI/ADI) using uncertainty factors, if

carcinogenicity is the critical endpoint. If a BMDL cannot be set for a chemical, the Committee agrees that, although it might be possible to derive a T25 from the dataset, this is not recommended.

46. The Committee is of the view that potency estimates can be of pragmatic use in carcinogenic risk assessment as an aid to prioritising carcinogenic substances (e.g. for risk re-evaluation), but considers that such potency estimates do not provide a quantitative estimate of risk. Although potency estimates can be used to rank chemicals within a particular group (such as structurally related groups of putative genotoxic chemicals), extrapolating from high to low dose and from animals to humans introduces sources of uncertainty.

47. The Committee recognises that the TTC approach provides a pragmatic means of assessing whether exposure to a chemical is of low concern or whether further testing is required. However, the Committee reiterates that the TTC is not a replacement for data on any chemical under consideration, but could be used where data are lacking or insufficient, to help in reaching an informed decision.

COC

tbc 2017

7.0 References

Ashby J, Tennant RW (1991). Definitive relationships among chemical structure, carcinogenicity and mutagenicity for 301 chemical tested by the U.S. NTP. *Mutat Res.* 257: 229–306.

Barlow S, Renwick AG, Kleiner J, Bridges JW, Busk L, Dybing E, Edler L, Eisenbrand G, Fink-Gremmels J, Knaap A, Kroes R, Liem D, Müller DJG, Page S, Rolland V, Schlatter J, Tritscher A, Tueting W, Würtzen G, (2006). Risk assessment of substances that are both genotoxic and carcinogenic—report of an International Conference organized by EFSA and WHO with support of ILSI Europe. *Food Chem Toxicol.* 44: 1636–1650.

Benford D, Bolger PM, Carthew P, Coulet M, DiNovi M, Leblanc J-C, Renwick AG, Setzer RW, Schlatter J, Smith B, Slob W, Williams G, Wildemann T (2010). Application of the Margin of Exposure (MOE) approach to substances in food that are genotoxic and carcinogenic. *Food Chem Toxicol.* 48 Suppl 1: S2–S24.

Blackburn K, Stickney JA, Carlson-Lynch SL, McGinnis PM, Chappell L, Felter SP (2005). Application of the threshold of toxic concern approach to ingredients in personal and household care products. *Reg Toxicol Pharmacol.* 43: 249-259.

Carthew P, Clapp C, Gutsell S (2009). Exposure based waiving: the application of the toxicological threshold of concern (TTC) to inhalation exposure for aerosol ingredients in consumer products. *Food Chem Toxicol.* 47: 1287-1295.

Cheeseman MA, Machuga EJ, Bailey AB (1999). A tiered approach to threshold of regulation. *Food Chem Toxicol.* 37: 387-412.

Chiu WA, Guyton KZ, Hogan K, Jinot J (2012). Approaches to human health risk assessment based on the signal-to-noise crossover dose. *Environ Health Perspect.* 120: A264.

COC (2004). Guidance on a Strategy for the Risk Assessment of Chemical Carcinogens. Available from: <http://webarchive.nationalarchives.gov.uk/20140506122055/http://www.iacoc.org.uk/publications/index.htm> (accessed 13/07/2017)

COC (2006). Acute T25 – Possible approach to potency ranking of single exposure genotoxic carcinogens. In COT, COM and COC Joint Annual Report 2006, p279. Available from: <https://cot.food.gov.uk/cotreports/cotcomcocrep2006> (accessed 13/07/2017).

COM (2012). Interim Guidance on a Strategy for Genotoxicity Testing and Mutagenic Hazard Assessment of Impurities in Chemical Substances. Available from <https://www.gov.uk/government/publications/genotoxicity-assessment-of-impurities-in-chemical-substances> (accessed 13/07/2017).

Collins JF, Brown JP, Alexeeff GV, Salmon AG (1998). Potency equivalency factors for some polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbon derivatives. *Regul Toxicol Pharmacol.* 28: 45-54.

Cramer GM, Ford RA, Hall RL (1978). Estimation of toxic hazard – a decision tree approach. *Food Cosmet Toxicol.* 16: 255-276.

Crump KS (1984). An improved procedure for low-dose carcinogenic risk assessment from animal data. *J Environ Pathol Toxicol Oncol.* 5: 339–348.

Crump K, Viren J, Silvers A, Clewell H, Gearhart J, Shipp A (1995). Reanalysis of dose-response data from the Iraqi methylmercury poisoning episode. *Risk Anal.* 15: 523–532.

Davis JA, Gift JS, Zhao QJ (2011). Introduction to benchmark dose methods and U.S. EPA's benchmark dose software (BMDS) version 2.1.1. *Toxicol Appl Pharmacol.* 254:181-191.

DG SANCO (SCCS/SCHER/SCENIHR) (2012). Joint Opinion on the Use of the Threshold of Toxicological Concern (TTC) Approach for Human Safety Assessment of Chemical Substances with focus on Cosmetics and Consumer Products. http://ec.europa.eu/health/scientific_committees/consumer_safety/docs/sccs_o_092.pdf (accessed 11/05/17).

Dybing E, O'Brien J, Renwick AG, Sanner T (2008). Risk assessment of dietary exposures to compounds that are genotoxic and carcinogenic—an overview. *Toxicol Lett* 180: 110–117.

Dybing E, Sanner T, Roelfzema H, Kroese D, Tennant RW (1997). T25: a simplified carcinogenic potency index: description of the system and study of correlations between carcinogenic potency and species/site specificity and mutagenicity. *Pharmacol Toxicol.* 80: 272-279.

EC (1999). Commission Working Group on the classification and labelling of dangerous substances. Guidelines for setting specific concentration limits for carcinogens in Annex 1 of Directive 67/548/EEC. Inclusion of Potency Considerations. <http://ec.europa.eu/environment/archives/dansub/pdfs/potency.pdf> (accessed 09/05/17).

ECETOC (2002). The Use of T25 Estimates and Alternative Methods in the Regulatory Risk Assessment of Non-threshold Carcinogens in the European Union. Technical Report No. 83, ISSN-0773-8072-83, Brussels, January 2002. <http://www.ecetoc.org/wp-content/uploads/2014/08/ECETOC-TR-083.pdf> (accessed 09/05/17).

ECHA (2008). Guidance on information requirements and chemical safety assessment; Endpoint specific guidance. Appendix R.7-1 Threshold of Toxicological Concern (TTC) – a concept in toxicological and environmental risk assessment. Chapter R.7.

EFSA (2005). Opinion of the Scientific Committee on a request from EFSA related to a harmonized approach for risk assessment of substances which are both genotoxic and carcinogenic. *EFSA Journal* 282, 1–31.

EFSA (2009). Guidance of the Scientific Committee on use of the benchmark dose approach in risk assessment. *The EFSA Journal* 1150, 40-47.

EFSA (2011). Use of BMDS and PROAST software packages by EFSA Scientific Panels and Units for applying the Benchmark Dose (BMD) approach in risk assessment. EN-113. [190 pp].

EFSA (2012a). Scientific Opinion on Evaluation of the Toxicological Relevance of Pesticide Metabolites for Dietary Risk Assessment. EFSA Panel on Plant Protection Products and their Residues (PPR). *EFSA Journal* 10, 2799.

EFSA (2012b). Scientific Opinion on Exploring options for providing advice about possible human health risks based on the concept of Threshold of Toxicological Concern (TTC). *EFSA Journal* 10 (7): 2750 [103 pp].

EFSA (2017). EFSA Scientific Committee, Hardy A, Benford D, Halldorsson T, Jeger MJ, Knutsen KH, More S, Mortensen A, Naegeli H, Noteborn H, Ockleford C, Ricci A, Rychen G, Silano V, Solecki R, Turck D, Aerts M, Bodin L, Davis A, Edler L, Gundert-Remy U, Sand S, Slob W, Bottex B, Abrahantes JC, Marques DC, Kass G,

Schlatter JR. Update: Guidance on the use of the benchmark dose approach in risk assessment. EFSA Journal; 15(1): 4658, 41 pp.

EFSA (European Food Safety Authority) and WHO (World Health Organization) (2016). Review of the Threshold of Toxicological Concern (TTC) approach and development of new TTC decision tree. EFSA supporting publication 2016: EN-1006. 50 pp. <https://www.efsa.europa.eu/en/supporting/pub/1006e> (accessed 11/05/17).

EMA (2006). Committee for Medicinal Products for Human Use. Guideline on the Limits of Genotoxic Impurities, CPMP/SWP/5199/02, EMEA/CHMP/QWP/251344/2006. http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2009/09/WC500002903.pdf (accessed 11/05/17).

EMA (2008). Committee on Herbal Medicinal Products (HMPC). Guideline on the assessment of genotoxicity of herbal substances/preparations. EMEA/HMPC/107079/2007.

EMA (2010). Committee for Medicinal Products for Human Use (CHMP) Safety Working Party (SWP). Questions and answers on the 'Guideline on the limits of genotoxic impurities'. EMA/CHMP/SWP/431994/2007. http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2009/09/WC500002907.pdf (accessed 11/05/17).

Escher SE, Tluczkiewicz I, Batke M, Bitsch A, Melber C, Kroese ED, Buist HE, Mangelsdorf I (2010). Evaluation of inhalation TTC values with the database RepDose. Regul Toxicol Pharmacol. 58: 259-274.

FDA (1995). Food Additives: Threshold of Regulation of Substances Used in Food-Contact Articles; Final Rule. Federal Register, 60, 36582–36596.

Felter S, Lane RW, Latulippe ME, Llewellyn GC, Olin SS, Scimeca JA, Trautman TD (2009). Refining the threshold of toxicological concern (TTC) for risk prioritization of trace chemicals in food. Food Chem Toxicol. 47: 2236-2245.

Frawley JP (1967). Scientific evidence and common sense as a basis for food-packaging regulations. Food Cosmet Toxicol. 5: 293-308.

Gillespie Z, Pulido O, Vavasour E (2011). Risk Assessment Approaches for Carcinogenic Food Contaminants. International Food Risk Analysis Journal 1: 1-18.

Gold LS, Sawyer CB, Magaw R, Backman GM, de Veciana M, Levinson R, Hooper NK, Havender WR, Bernstein L, Peto R, Pike MC, Ames BN (1984). A carcinogenic potency database of the standardized results of animal bioassays. Environ Health Perspect, 58: 9-319.

Gold LS, Slone TH, Manley NB, Garfinkel GB, Rohrbach L, Ames BN (1997). Carcinogenic Potency Database. In: Handbook of Carcinogenic Potency and Genotoxicity Databases (L. S. Gold & E. Zeiger, eds.), Boca Raton, FL: CRC Press, pp. 1-605.

HPA (2010). HPA Contaminated Land Information Sheet. Risk Assessment Approaches for Polycyclic Aromatic Hydrocarbons (PAHs). http://webarchive.nationalarchives.gov.uk/20140714084352/http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1287147342113 (accessed 11/05/17).

IPCS (2009a). Principles and Methods for the Risk Assessment of Chemicals in Food. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 240). http://www.inchem.org/documents/ehc/ehc/ehc240_index.htm (accessed 08/05/17).

IPCS (2009b). Principles for Modelling Dose-Response for the Risk Assessment of Chemicals. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 239).

Kroes R, Renwick AG, Cheeseman M, Kleiner J, Mangelsdorf I, Piersma A, Schilter B, Schlatter J, van Schothorst F, Vos JG, Würtzen G; European branch of the International Life Sciences Institute (2004). Structure-based thresholds of toxicological concern (TTC): guidance for application to substances present at low levels in the diet. *Food Chem Toxicol.* 42: 65-83.

Kroes R, Renwick AG, Feron V, Galli CL, Gibney M, Greim H, Guy RH, Lhuguenot JC, van de Sandt JJM (2007). Application of the threshold of toxicological concern (TTC) to the safety evaluation of cosmetic ingredients. *Food Chem Toxicol.* 45: 2533-2562.

Müller L, Mauthe RJ, Riley CM, Andino MM, De Antonis D, Beels C, DeGeorge J, De Knaep AKM, Ellison D, Fagerland JM, Frank R, Fritschel B, Galloway S, Harpur E, Humfrey CDN, Jacks AS, Jagota N, MacKinnon J, Mohan G, Ness DK et al. (2006). A rationale for determining, testing, and controlling specific impurities in pharmaceuticals that possess potential for genotoxicity. *Regul Toxicol Pharmacol.* 44: 198-211.

Munro IC, Ford RA, Kennepohl E, Sprenger JG (1996). Correlation of a structural class with no-observed-effect levels: a proposal for establishing a threshold of concern. *Food Chem Toxicol.* 34: 829–867.

Munro IC, Renwick AG, Danielewska-Nikiel B (2008). The threshold of toxicological concern (TTC) in risk assessment. *Toxicol. Lett.* 180: 151-156

Peto R, Pike MC, Bernstein L., Gold LS, Ames BN (1984). The TD50: a proposed general convention for the numerical description of the carcinogenic potency of chemicals in chronic-exposure animal experiments. *Environ. Health Perspect.* 58: 1–8.

Pufulete M, Battershill J, Boobis A, Fielder R (2004). Approaches to carcinogenic risk assessment for polycyclic aromatic hydrocarbons: a UK perspective. *Regul Toxicol Pharmacol.* 40: 54-66.

Renwick AG (2005). Structure-based thresholds of toxicological concern - guidance for application to substances present at low levels in the diet. *Toxicol Appl Pharmacol* 207: S585-S591.

Rulis AM (1986). *De minimis* and the threshold of regulation. C.W. Felix (Ed.), *Food Protection Technology*, Chelsea/Lewis, Michigan (1986), pp. 29–37.

Safford RJ (2008). The Dermal Sensitisation Threshold - A TTC approach for allergic contact dermatitis. *Regul Toxicol Pharmacol* 51: 195-200.

Safford RJ, Aptula AO, Gilmour N (2011). Refinement of the Dermal Sensitisation Threshold (DST) approach using a larger dataset and incorporating mechanistic chemistry domains. *Regul Toxicol Pharmacol* 60: 218-224.

Sand S, Portier CJ Krewsk D (2011). A signal-to-noise crossover dose as the point of departure for health risk assessment. *Environ Health Perspect.* 119: 1766–1774.

Sand S, Victorin K, Filipsson AF (2008). The current state of knowledge on the use of the benchmark dose concept in risk assessment. *J Appl Toxicol* 28: 405–421.

Sanner T, Dybing E (2005). Comparison of carcinogen hazard characterisation based on animal studies and epidemiology. *Basic Clin Pharmacol Toxicol* **96**: 66–70.

Sanner T, Dybing E, Willems MI, Kroese ED (2001). A simple method for quantitative risk assessment of non-threshold carcinogens based on the dose descriptor T25. *Pharmacol Toxicol.* 88: 331–341.

Pluczkiewicz I, Kühne R, Ebert RU, Batke M, Schüürmann G, Mangelsdorf I, Escher SE (2016) Inhalation TTC values: A new integrative grouping approach considering structural, toxicological and mechanistic features. *Regul Toxicol Pharmacol.* 78: 8-23.

US EPA (1995). The use of the benchmark dose approach in health risk assessment. EPA/ 630/R-94/007. Risk Assessment Forum, Washington DC.

US EPA (2000). Benchmark Dose Technical Guidance Document (BMDTG). External review draft. EPA/630/R-00/001. Risk Assessment Forum, U.S. Environmental Protection Agency: Washington, DC.

US EPA (2010). Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon (PAH) Mixtures (External Review Draft). U.S. Environmental Protection Agency, Washington, DC, EPA/635/R-08/012A.

US EPA (2012). Benchmark Dose Technical Guidance Document (BMD TG). External review draft. EPA/100/R-12/100. Risk Assessment Forum, U.S. Environmental Protection Agency: Washington, DC.
<https://www.epa.gov/risk/benchmark-dose-technical-guidance> (accessed 08/05/17).

Wheeler MW, Bailer AJ (2007). Properties of model-averaged BMDLs: a study of model averaging in dichotomous response risk estimation. *Risk Anal* 27:

659–670.

Wheeler MW, Bailer AJ, (2008). Model averaging software for dichotomous dose–response risk estimation. *Journal of Statistical Software* Vol 26 Issue 5: 1–15.

COMMITTEE ON CARCINOGENICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT

Updated draft Guidance Statement G05: Defining a Point of Departure and Potency Estimates in Carcinogenic Dose Response

EFSA Scientific Committee, Hardy A, Benford D, Halldorsson T, Jeger MJ, Knutsen KH, More S, Mortensen A, Naegeli H, Noteborn H, Ockleford C, Ricci A, Rychen G, Silano V, Solecki R, Turck D, Aerts M, Bodin L, Davis A, Edler L, Gundert-Remy U, Sand S, Slob W, Bottex B, Abrahantes JC, Marques DC, Kass G and Schlatter JR, 2017. Update: Guidance on the use of the bench mark dose approach in risk assessment. EFSA Journal 2017;15(1):4658, 41 pp. doi:10.2903/j.efsa.2017.4658.

Available from: <https://www.efsa.europa.eu/en/efsajournal/pub/4658> (accessed 13/07/2017)

This document is attached; it is not being made publicly available for copyright reasons.

**Imperial College Toxicology Unit/Secretariat
July 2017**

COMMITTEE ON CARCINOGENICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT

Updated draft Guidance Statement G05: Defining a Point of Departure and Potency Estimates in Carcinogenic Dose Response

EFSA (European Food Safety Authority) and WHO (World Health Organization), 2016. Review of the Threshold of Toxicological Concern (TTC) approach and development of new TTC decision tree. EFSA supporting publication 2016: EN-1006. 50 pp.

Available from: <https://www.efsa.europa.eu/en/supporting/pub/1006e> (accessed 13/07/2017)

This document is attached, it is not being made publicly available for copyright reasons.

**Imperial College Toxicology Unit/Secretariat
July 2017**