

# **Guidelines for Carcinogen Risk Assessment**

Risk Assessment Forum  
U.S. Environmental Protection Agency  
Washington, DC

## **PURPOSE OF THIS DOCUMENT**

The discussion in this document is intended solely as guidance. It is not a regulation, and does not confer legal rights or impose legal obligations on EPA, States, Tribes, local governments, regulated entities or any member of the public.

The predominant guidance provided in this document is for EPA risk assessors to use the best science and risk assessment techniques available to them at the time a cancer risk assessment is conducted. Any final cancer risk assessment may take an approach different from that described in this document based on factors such as evolving science, the facts of a particular case, or comments from peer reviewers, the public or others.

**GUIDELINES FOR  
CARCINOGEN RISK ASSESSMENT  
FRL-**

1  
2

[To Be Developed]

**CONTENTS**

1

2

3 LIST OF TABLES ..... viii

4

5 LIST OF FIGURES ..... ix

6

7 1. INTRODUCTION ..... 1-1

8 1.1. PURPOSE AND SCOPE OF THE GUIDELINES ..... 1-1

9 1.2. ORGANIZATION AND APPLICATION OF THE GUIDELINES ..... 1-2

10 1.2.1. Organization ..... 1-2

11 1.2.2. Application ..... 1-2

12 1.3. USE OF DEFAULT ASSUMPTIONS ..... 1-3

13 1.3.1. Default Assumptions ..... 1-4

14 1.3.2. Major Defaults ..... 1-10

15 1.4. CHARACTERIZATIONS ..... 1-19

16

17 2. HAZARD ASSESSMENT ..... 2-1

18 2.1. OVERVIEW OF HAZARD ASSESSMENT AND CHARACTERIZATION ..... 2-1

19 2.1.1. Analyses of Data ..... 2-1

20 2.1.2. Presentation of Results ..... 2-1

21 2.2. ANALYSIS OF TUMOR DATA ..... 2-2

22 2.2.1. Human Data ..... 2-2

23 2.2.1.1. Types of Studies ..... 2-3

24 2.2.1.2. Criteria for Assessing Adequacy of Epidemiologic Studies ..... 2-4

25 2.2.1.3. Criteria for Causality ..... 2-7

26 2.2.1.4. Assessment of Evidence of Carcinogenicity from Human Data . . 2-8

27 2.2.2. Animal Data ..... 2-9

28 2.2.2.1. Long-Term Carcinogenicity Studies ..... 2-9

29 2.2.2.2. Perinatal Carcinogenicity Studies ..... 2-15

30 2.2.2.3. Other Studies ..... 2-16

31 2.2.3. Structural Analogue Data ..... 2-17

32 2.3. ANALYSIS OF OTHER KEY DATA ..... 2-17

33 2.3.1. Physicochemical Properties ..... 2-17

34 2.3.2. Structure-Activity Relationships ..... 2-18

**CONTENTS (continued)**

1 2.3.3. Comparative Metabolism and Toxicokinetics . . . . . 2-19

2 2.3.4. Toxicological and Clinical Findings . . . . . 2-20

3 2.3.5. Events Relevant to Mode of Carcinogenic Action . . . . . 2-21

4 2.3.5.1. Direct DNA Reactive Effects . . . . . 2-21

5 2.3.5.2. Indirect DNA Effects or Other Effects on Genes/Gene

6 Expression . . . . . 2-22

7 2.3.5.3. Experimental Considerations in Evaluating Data

8 on Precursor Events . . . . . 2-24

9 2.3.5.4. Judging Data . . . . . 2-24

10 2.4. BIOMARKER INFORMATION . . . . . 2-25

11 2.5. MODE OF ACTION-GENERAL CONSIDERATIONS AND FRAMEWORK

12 FOR ANALYSIS . . . . . 2-26

13 2.5.1. General Considerations . . . . . 2-26

14 2.5.2. Evaluating a Postulated Mode of Action . . . . . 2-28

15 2.5.3. Framework for Evaluating a Postulated Carcinogenic

16 Mode(s) of Action . . . . . 2-29

17 2.5.3.1. Content of the Framework . . . . . 2-30

18 2.6. WEIGHT-OF-EVIDENCE EVALUATION FOR POTENTIAL HUMAN

19 CARCINOGENICITY . . . . . 2-34

20 2.6.1. Weight-of-Evidence Analysis . . . . . 2-35

21 2.6.2. Descriptors for Summarizing Weight of Evidence . . . . . 2-43

22 2.7. TECHNICAL HAZARD CHARACTERIZATION . . . . . 2-45

23 2.8. WEIGHT-OF-EVIDENCE NARRATIVE . . . . . 2-47

24

25 3. DOSE-RESPONSE ASSESSMENT . . . . . 3-1

26 3.1. HUMAN STUDIES . . . . . 3-2

27 3.2. MODE OF ACTION AND DOSE-RESPONSE APPROACH . . . . . 3-2

28 3.3. DOSE-RESPONSE ANALYSIS . . . . . 3-4

29 3.3.1. Modeling the Overall Process--Biologically Based Models . . . . . 3-4

30 3.3.2. Analysis in the Range of Observation . . . . . 3-5

31 3.3.2.1. Applying Information About Key Events . . . . . 3-5

32 3.3.2.2. Procedures for Analysis in the Range of Observation of Animal

33 Studies . . . . . 3-6

**CONTENTS (continued)**

1                    3.3.2.3. Point of Departure for Extrapolation from Observed  
2                                    Animal Data ..... 3-6  
3                    3.3.3. Analysis in the Range of Extrapolation--Default Procedures ..... 3-9  
4                                    3.3.3.1. Linear Procedure ..... 3-9  
5                                    3.3.3.2. Nonlinear Extrapolation ..... 3-10  
6                                    3.3.3.3. Linear and Nonlinear Extrapolations ..... 3-14  
7                                    3.3.3.4. Use of Toxicity Equivalence Factors and Relative Potency  
8    Estimates ..... 3-14  
9                    3.4. RESPONSE DATA ..... 3-15  
10                   3.5. DOSE DATA ..... 3-17  
11                                    3.5.1. Interspecies Adjustment of Dose ..... 3-18  
12                                    3.5.2. Adjustment of Dose for Children ..... 3-18  
13                                    3.5.3. Toxicokinetic Analyses ..... 3-20  
14                                    3.5.4. Route-to-Route Extrapolation ..... 3-21  
15                                    3.5.5. Dose Averaging ..... 3-22  
16                    3.6. DISCUSSION OF UNCERTAINTIES ..... 3-23  
17                    3.7. TECHNICAL DOSE-RESPONSE CHARACTERIZATION ..... 3-24  
18  
19                   4. TECHNICAL EXPOSURE CHARACTERIZATION ..... 4-1  
20  
21                   5. RISK CHARACTERIZATION ..... 5-1  
22                                    5.1. PURPOSE ..... 5-1  
23                                    5.2. APPLICATION ..... 5-2  
24                                    5.3. PRESENTATION OF RISK CHARACTERIZATION SUMMARY ..... 5-3  
25                                    5.4. CONTENT OF RISK CHARACTERIZATION SUMMARY ..... 5-3  
26                    6. REFERENCES ..... 6-1  
27  
28                   APPENDIX A. WEIGHT-OF-EVIDENCE NARRATIVES ..... A-1  
29  
30                   APPENDIX B. RESPONSES TO THE NATIONAL ACADEMY OF SCIENCES  
31                   NATIONAL RESEARCH COUNCIL REPORT *SCIENCE AND JUDGMENT IN RISK*  
32                   *ASSESSMENT* (NRC, 1994) ..... B-1  
33

**CONTENTS (continued)**

1 APPENDIX C. CASE STUDY EXAMPLES FOR HAZARD EVALUATION ..... C-1  
2  
3 APPENDIX D. CASE STUDY EXAMPLES FOR MODE-OF-ACTION EVALUATION . D-1  
4  
5 APPENDIX E. NONLINEAR DOSE-RESPONSE: MARGIN-OF-EXPOSURE  
6 ANALYSIS (TO BE DEVELOPED) ..... E-1  
7  
8 APPENDIX F. DOSE-RESPONSE ASSESSMENT FOR A CARCINOGEN POSING  
9 HIGHER RISKS AFTER CHILDHOOD EXPOSURE ..... F-1  
10  
11 APPENDIX G. RESPONSE TO COMMENTS ON OTHER SCIENCE ISSUES (TO BE  
12 DEVELOPED) ..... G-1  
13  
14

**LIST OF TABLES**

1

2

3

4 Table D-1. Thyroid follicular cell tumor incidence in male rats ..... D-2

5 Table D-2. Incidence of transitional cell lesions and stones

6 in males from a 2-year SD rat study ..... D-11

7 Table D-3. Incidence of bladder hyperplasia and stones in male SD rats

8 treated up to 13 weeks ..... D-13

9 Table D-4. Reversal of incidence of bladder hyperplasia and stones following

10 8 weeks treatment and 16 weeks recovery ..... D-15

11 Table D-5. Clinical chemistry values (urine) in male SD rats treated up to 13 weeks .. D-17

12 Table D-6. Summary results of chronic bioassays ..... D-25

13 Table F-1. Comparison of tumor incidence in male and female Sprague-Dawley rats

14 from 100 hour inhalation exposures to newborn and mature rats ..... F-6

15 Table F-2. Comparison of tumor incidence in male and female Sprague-Dawley rats

16 From 5-wk newborn exposure and 52-wk later life exposure . . . . . F-7

17 Table F-3. Results of PBPK modeling ..... F-8



**LIST OF FIGURES**

1  
2  
3  
4  
5  
6  
7  
8  
9

Figure 1-1. Risk characterization ..... 1-20

Figure 2-1. Factors for weighing human evidence ..... 2-36

Figure 2-2. Factors for weighing animal evidence ..... 2-38

Figure 2-3. Factors for weighing other key evidence ..... 2-40

Figure 2-4. Factors for weighing totality of evidence ..... 2-42

Figure 3-1. Graphical presentation of data and extrapolation ..... 3-8

# 1. INTRODUCTION

## 1.1. PURPOSE AND SCOPE OF THE GUIDELINES

1           These guidelines revise and replace United States Environmental Protection Agency  
2 (EPA) Guidelines for Carcinogen Risk Assessment published in 51 FR 33992, September 24,  
3 1986. The guidelines provide EPA staff and decision makers with guidance for developing and  
4 using risk assessments. They also provide basic information to the public about the Agency's risk  
5 assessment methods. These guidelines are used with other risk assessment guidelines that the  
6 Agency has developed, such as the Mutagenicity Risk Assessment Guidelines (U.S. EPA, 1986c).  
7 and the Exposure Assessment Guidelines (U.S. EPA, 1992a). Consideration of other Agency  
8 guidance documents is particularly important when procedures for evaluating specific target organ  
9 effects have been developed (e.g., assessment of thyroid follicular cell tumors (U.S. EPA,  
10 1998a)), or when there is a concern for a particular sensitive subpopulation for which the Agency  
11 has developed guidance, for example, EPA Guidelines for Developmental Toxicity Risk  
12 Assessment (U.S. EPA, 1991d). These guidelines discuss hazards to children that may result  
13 from exposures during preconception, prenatal, or postnatal development to sexual maturity.  
14 Similar guidelines exist for Reproductive Toxicant Risk Assessment (U.S. EPA, 1996c) and for  
15 Neurotoxicity Risk Assessment (U.S. EPA, 1998c). All of these guidelines should be consulted  
16 when conducting a risk assessment in order to insure that information from studies on  
17 carcinogenesis and other health effects are considered together in the overall characterization of  
18 risk. This is particularly true in the case in which a precursor effect to tumor is also a precursor  
19 or endpoint of other health effects and is used in dose-response assessment. The overall  
20 characterization of risk will be the basis for carrying out assessments of instances in which fetuses,  
21 infants, or children are at risk or disproportionately affected by economically significant Agency  
22 actions. Characterization for the latter purpose is outlined in the Agency guidance by the Office  
23 of Children's Health Protection to carry out E.O. 13045, "Protection of Children From  
24 Environmental Health Risks and Safety Risks" issued on April 21, 1997.

25           The guidelines encourage both regularity in procedures to support consistency in scientific  
26 components of Agency decision making and innovation to remain up-to-date in scientific thinking.  
27 In balancing these goals, the Agency relies on established scientific peer review processes (EPA,  
28 1998b). The guidelines incorporate basic principles and science policies based on evaluation of  
29 the currently available information. As more is discovered about carcinogenesis, the need will  
30 arise to make appropriate changes in risk assessment guidance. The Agency will revise these  
31 guidelines when extensive changes are due. In the interim, the Agency will issue special reports,

1 after appropriate peer review, to supplement and update guidance on single topics, (e.g., U.S.  
2 EPA, 1991b). The incorporation of new, peer-reviewed scientific understanding and data in an  
3 assessment is always consistent with the purposes of these guidelines.

## 4 **1.2. ORGANIZATION AND APPLICATION OF THE GUIDELINES**

### 5 **1.2.1. Organization**

6 Publications of the Office of Science and Technology Policy (OSTP, 1985) and the  
7 National Research Council (NRC, 1983, 1994) provide information and general principles about  
8 risk assessment. Risk assessment uses available scientific information on the properties of an  
9 agent<sup>1</sup> and its effects in biological systems to provide an evaluation of the potential for harm as a  
10 consequence of environmental exposure. The 1983 and 1994 NRC documents organize risk  
11 assessment information into four areas: hazard identification, dose-response assessment,  
12 exposure assessment, and risk characterization. This structure appears in these guidelines, which  
13 additionally emphasize characterization of evidence and conclusions in each part of the  
14 assessment. In particular, the guidelines adopt the approach of the NRC's 1994 report in adding a  
15 dimension of characterization to the hazard identification step. Added to the identification of  
16 hazard is an evaluation of the conditions under which its expression is anticipated. The risk  
17 assessment questions addressed in these guidelines are:

- 18 • For hazard--Can the agent present a carcinogenic hazard to humans, and if so,  
19 under what circumstances?
- 20 • For dose-response--At what levels of exposure might effects occur?
- 21 • For exposure--What are the conditions of human exposure?
- 22 • For risk--What is the character of the risk? How well do data support conclusions  
23 about the nature and extent of the risk?

### 24 **1.2.2. Application**

25 The guidelines apply within the framework of policies provided by applicable EPA statutes  
26 and do not alter such policies. The guidelines cover assessment of available data. They do not  
27 imply that one kind of data or another is prerequisite for regulatory action concerning any agent.  
28 Risk management applies directives of regulatory legislation, which may require consideration of  
29 potential risk, or solely hazard or exposure potential, along with social, economic, technical, and

---

<sup>1</sup>The term "agent" refers generally to any chemical substance, mixture, or physical or biological entity being assessed, unless otherwise noted (See sec. 1.2.2 for a note on radiation.).

1 other factors in decision making. Risk assessments support decisions, but to maintain their  
2 integrity as decision making tools, they are not influenced by consideration of the social or  
3 economic consequences of regulatory action.

4 The assessment of risk from radiation sources is based on continuing examination of  
5 human data by the National Academy of Sciences/National Research Council in its series of  
6 numbered reports: "Biological Effects of Ionizing Radiation". While the general principles of  
7 these guidelines apply to radiation risk assessments, their details are most focused on other kinds  
8 of agents. They do not attempt to guide the ongoing conduct of radiation risk assessment.

9 Not every EPA assessment has the same scope or depth. Agency staff often conduct  
10 screening-level assessments for priority-setting or separate assessments of hazard or exposure for  
11 ranking purposes or to decide whether to invest resources in collecting data for a full assessment.  
12 Moreover, a given assessment of hazard and dose-response may be used with more than one  
13 exposure assessment that may be conducted separately and at different times as the need arises in  
14 studying environmental problems in various media. The guidelines apply to these various  
15 situations in appropriate detail given the scope and depth of the particular assessment. For  
16 example, a screening assessment may be based almost entirely on structure-activity relationships  
17 and default assumptions. As more data become available, assessments can replace or modify  
18 default assumptions accordingly. These guidelines do not require that all of the kinds of data  
19 covered here be available for either assessment or decision making. The level of detail of an  
20 assessment is a matter of Agency management discretion regarding applicable decision making  
21 needs.

### 22 **1.3. USE OF DEFAULT ASSUMPTIONS**

23 The National Research Council, in its 1983 report on the science of risk assessment (NRC,  
24 1983), recognized that default assumptions are necessarily made in risk assessments where gaps  
25 exist in general knowledge or in available data for a particular agent. These default assumptions  
26 are inferences based on general scientific knowledge of the phenomena in question and are also  
27 matters of policy concerning the appropriate way to bridge uncertainties that concern potential  
28 risk to human health (or, more generally, to environmental systems) from the agent under  
29 assessment.

30 EPA's 1986 guidelines for cancer risk assessment (EPA, 1986b) were developed to be  
31 responsive to the principles of the 1983 NRC report. The guidelines contained a number of  
32 default assumptions. They also encouraged research and analysis that would lead to new risk  
33 assessment methods and data and anticipated that these would replace defaults. The 1986

1 guidelines did not explicitly discuss how to depart from defaults.

2 In its 1994 report on risk assessment, the NRC supported continued use of default  
3 assumptions (NRC, 1994). The NRC report thus validated a central premise of the approach to  
4 risk assessment that EPA had evolved in preceding years--the making of science policy inferences  
5 to bridge gaps in knowledge--while at the same time recommending that EPA develop more  
6 systematic and transparent guidelines to inform the public of the default inferences EPA uses in  
7 practice. It recommended that the EPA review and update the 1986 guidelines in light of  
8 evolving scientific information and experience in practice in applying those guidelines, and that the  
9 EPA explain the science and policy considerations underlying current views as to the appropriate  
10 defaults and provide general criteria to guide preparers and reviewers of risk assessments in  
11 deciding when to depart from a default.

### 12 **1.3.1. Default Assumptions**

13 The 1994 NRC report contains several recommendations regarding flexibility and the use  
14 of default options:

- 15 • EPA should continue to regard the use of default options as a reasonable way to  
16 deal with uncertainty about underlying mechanisms in selecting methods and  
17 models for use in risk assessment.
- 18 • EPA should explicitly identify each use of a default option in risk assessments.
- 19 • EPA should clearly state the scientific and policy basis for each default option.
- 20 • The Agency should consider attempting to give greater formality to its criteria for  
21 a departure from default options in order to give greater guidance to the public and  
22 to lessen the possibility of ad hoc, undocumented departures from default options  
23 that would undercut the scientific credibility of the Agency's risk assessments. At  
24 the same time, the Agency should be aware of the undesirability of having its  
25 guidelines evolve into inflexible rules.
- 26 • EPA should continue to use the Science Advisory Board and other expert bodies.  
27 In particular, the Agency should continue to make the greatest possible use of peer  
28 review, workshops, and other devices to ensure broad peer and scientific  
29 participation to guarantee that its risk assessment decisions will be based on the  
30 best science available through a process that allows full public discussion and peer  
31 participation by the scientific community.

32 In the 1983 report (p. 28), NAS defined the use of "inference options" (default options) as  
33 a means to bridge inherent uncertainties in risk assessment. These options exist when the

1 assessment encounters either "missing or ambiguous information on a particular substance" or  
2 "gaps in current scientific theory." Since there is no instance in which a set of data on an agent or  
3 exposure is complete, all risk assessments must use general knowledge and policy guidance to  
4 bridge data gaps. Animal toxicity data are used, for example, to substitute for human data  
5 because we do not test human beings. The report described the components of risk assessment in  
6 terms of questions encountered during analysis for which inferences must be made. The report  
7 noted (p. 36) that many components ". . . lack definitive scientific answers, that the degree of  
8 scientific consensus concerning the best answer varies (some are more controversial than others),  
9 and that the inference options available for each component differ in their degree of conservatism.  
10 The choices encountered in risk assessment rest, to various degrees, on a mixture of scientific fact  
11 and consensus, on informed scientific judgment, and on policy determinations (the appropriate  
12 degree of conservatism). . . ." The report did not note that the mix varies significantly from case  
13 to case. For instance, a question that arises in hazard identification is how to use experimental  
14 animal data when the routes of exposure differ between animals and humans. A spectrum of  
15 inferences could be made: The most protective, or risk adverse one is that effects in animals from  
16 one route may be seen in humans by another route. An intermediate one is a conditional inference  
17 that such translation of effects will be assumed if the agent is absorbed by humans through the  
18 second route. A nonprotective one that no inference is possible and the agent's effects in animals  
19 must be tested by the second route. The choice of an inference, as the report observed, comes  
20 from more than scientific thinking alone. While the report focused mainly on the idea of  
21 conservatism of public health as a science policy rationale for making the choice, it did not  
22 evaluate other considerations.

23 These revised guidelines retain the use of default assumptions as recommended in the  
24 1994 report. Since the primary goal of EPA actions is public health protection and that,  
25 accordingly, as an Agency policy, the defaults used in the absence of scientific data to the contrary  
26 have been chosen to be health protective. The defaults described below remain public health  
27 conservative when applied in combination in risk assessment, however, any individual default  
28 may not constitute the most conservative position vis-a-vis that position. To do so would lead to  
29 risk assessments that far exceed the actual risks and this would not be in keeping with the  
30 principles discussed in the NAS 1994 report.

31 In addition, the guidelines reflect evaluation of experience in practice in applying defaults  
32 and departing from them in individual risk assessments conducted under the 1986 guidelines. The  
33 application and departure from defaults and the principles to be used in these judgments have been  
34 matters of debate among practitioners and reviewers of risk assessments. The guidelines here are

1 intended to be both explicit and more flexible than in the past concerning the basis for making  
2 departures from defaults, recognizing that expert judgment and peer review are essential elements  
3 of the process.

4 In response to the recommendations of the 1994 report, these guidelines call for  
5 identification of the default assumptions used within assessments and for highlighting significant  
6 issues about defaults within characterization summaries of component analyses in assessment  
7 documents. As to the use of peer review to aid in making judgments about applying or departing  
8 from defaults, we agree with the NRC recommendation. The Agency has long made use of  
9 workshops, peer review of documents and guidelines, and consultations as well as formal peer  
10 review by the Science Advisory Board (SAB). In 1998, the Administrator of EPA published a  
11 peer review guidance for EPA scientific work products that increases the amount of peer review  
12 for risk assessments as well as other work, continuing a series of guidance actions in response to  
13 the NRC report and to SAB recommendations (U.S. EPA, 1994b, 1997b, 1998b).

14 The 1994 NRC report recommended that EPA should consider adopting principles or  
15 criteria that would give greater formality and transparency to decisions to depart from defaults.  
16 The report named several possible criteria for such principles (p. 7): ". . . [P]rotecting the public  
17 health, ensuring scientific validity, minimizing serious errors in estimating risks, maximizing  
18 incentives for research, creating an orderly and predictable process, and fostering openness and  
19 trustworthiness. There might be additional relevant criteria. . . ." The report indicated, however,  
20 that the committee members had not reached consensus on a single criterion to address the key  
21 issue of how much certainty or proof a risk assessor must have in order to justify departing from a  
22 default. Appendix N of the report contains two presentations of alternative views held by some  
23 committee members on this issue. One view, known as "plausible conservatism," suggested that  
24 departures from defaults should not be made unless new information improves the understanding  
25 of a biological process to the point that relevant experts reach consensus that the protective  
26 default assumption concerning that process is no longer plausible. The same criterion was  
27 recommended where the underlying scientific mechanism is well understood, but where a default  
28 is used to address missing data. In this case, the default should not be replaced with case-specific  
29 data unless it is the consensus of relevant experts that the proffered data make the default  
30 assumption no longer plausible. Another view, known as the "maximum use of scientific  
31 information" approach, acknowledged that the initial choice of defaults should be protective, but  
32 argued that conservatism should not be a factor in determining whether to depart from the default  
33 in favor of an alternate biological theory or alternate data. According to this view, it should not  
34 be necessary to reach expert consensus that the default assumption had been rendered implausible;

1 it should be sufficient that risk assessors find the alternate approach more plausible than the  
2 default.

3 The EPA is not adopting a general list of formal decision criteria in the sense of a checklist  
4 applicable to departures from defaults. It would not be helpful to generate a checklist of uniform  
5 criteria. Risk assessments are highly variable in content and purpose. Screening assessments may  
6 be purposely "worst case" in their default assumptions to eliminate problems from further  
7 investigation. Subsequent risk assessments based on a fuller data set can discard worst-case  
8 default assumptions in favor of plausibly protective assumptions and progressively replace or  
9 modify the latter with data. No uniform checklist will fit all cases or all kinds of data. Moreover,  
10 some departures from defaults are controversial, some are not. Generic checklists would likely  
11 become more a source of rote discussion than of enlightenment about the process.

12 Nonetheless, for one issue, the EPA has adopted principles to give greater formality and  
13 transparency to decisions to depart from defaults. The EPA has developed a framework for  
14 evaluating a postulated mode of action which appears in section 2.5, below. The use of mode of  
15 action information to make decisions about human relevance of animal data, to assist in  
16 identifying sensitive subpopulations, and to decide upon approaches to high dose to low dose  
17 extrapolation in dose-response assessment is a fundamental part of these guidelines. The  
18 framework of section 2.5. contains principles derived from Bradford Hill criteria for considering  
19 causation in human epidemiologic studies and is meant to weigh the question whether empirical  
20 data support a mode of action that is proposed in a particular case.

21 The guidelines use a combination of principles and process in the application of and  
22 departure from default assumptions. The framework of default assumptions allows risk  
23 assessment to proceed when current scientific theory or available case-specific data do not  
24 provide firm answers in a particular case, as the 1983 NRC report outlined. Some of the default  
25 assumptions bridge large gaps in fundamental knowledge which will be filled by basic research on  
26 the causes of cancer and on other biological processes, rather than by agent-specific testing.  
27 Other default assumptions bridge smaller data gaps that can feasibly be filled for a single agent,  
28 such as whether a metabolic pathway in test animals is like (default) or unlike that in humans.

29 The decision to use a default, or not, is a choice considering available information on an  
30 underlying scientific process and agent-specific data, depending on which kind of default it is.  
31 Generally, if a gap in basic understanding exists, or if agent-specific data are missing, the default is  
32 used without pause. If data are present, their evaluation may reveal inadequacies that also lead to  
33 use of the default. If data support a plausible alternative to the default, but no more strongly than  
34 they support the default, both the default and its alternative are carried through the assessment



1 and characterized for the risk manager. If the alternative to the default are strongly supported by  
2 data, the alternative may be used in place of the default. These guidelines provide a framework  
3 for making such decisions. Note that, as discussed above, there is a spectrum of difficulty in  
4 replacing default positions with empirical data. In the case of showing a mode of action, there is  
5 need for extensive experimentation to support an hypothesis as to mode of action for a specific  
6 tumor response, including coverage of the issue whether other modes of action are plausible.

7 Note that screening assessments may appropriately use "worst case" inferences to  
8 determine if, even under those conditions, risk is low enough that a problem can be eliminated  
9 from further consideration.

10 Scientific peer review, peer consultative workshops and similar processes are the principal  
11 ways determining the strength of thinking and generally accepted views within the scientific  
12 community about the application of and departure from defaults and about judgments concerning  
13 the plausibility and persuasiveness of data in a particular case.

14 The discussion of major defaults below together with the explicit discussion of the choice  
15 of inferences within the assessment and the processes of peer review and peer consultation (U.S.  
16 EPA, 1998b) will serve the several goals stated in the 1994 NRC report. One is to encourage  
17 research, since results of research efforts will be considered. Another is to allow timely decision  
18 making, when time is a constraint, by supporting completion of the risk assessment using defaults  
19 as needed. Another is to be flexible, using new science as it develops. Finally, the use of public  
20 processes of peer consultation and peer review will ensure that discipline of thought is maintained  
21 to support trust in assessment results.

22 There is no one set of rules for making the judgment of whether a data analysis is both  
23 biologically plausible and persuasive as applied to the case at hand. Two criteria that apply in  
24 these guidelines are that the underlying scientific principle has been generally accepted within the  
25 scientific community and that supportive experiments are available that test the application of the  
26 principle to the agent under review. For example, mutagenicity through reactivity with DNA has  
27 been generally accepted as a carcinogenic influence for many years. This acceptance, together  
28 with evidence of such mutagenicity in experiments on an agent, provides plausible and persuasive  
29 support for the inference that mutagenicity is a mode of action for the agent.

30 Judgments about plausibility and persuasiveness of analyses vary according to the  
31 scientific nature of the default. An analysis of data may replace a default or modify it. An  
32 illustration of the former is development of EPA science policy on the issue of the relevance for  
33 humans of male rat kidney neoplasia involving  $\alpha$ 2u-globulin (U.S. EPA, 1991b). The 1991 EPA  
34 policy gives guidance on the kind of experimental findings that demonstrate whether the

1  $\alpha$ 2u-globulin mechanism is present and responsible for carcinogenicity in a particular case.  
2 Before this policy guidance was issued, the default assumption was that neoplasia in question was  
3 relevant to humans and indicated the potential for hazard to humans. A substantial body of data  
4 was developed by public and private research groups as a foundation for the view that the  $\alpha$ 2u-  
5 globulin induced response was not relevant to humans. These studies first addressed the  $\alpha$ 2u-  
6 globulin mechanism in the rat and whether this mechanism has a counterpart in the human being,  
7 both were large research efforts. The resulting data presented difficulties; some reviewers were  
8 concerned that the mechanism in the rat appeared to be understood only in outline, not in detail,  
9 and felt that the data were insufficient to show the lack of a counterpart mechanism in humans. It  
10 was particularly difficult to support a negative such as the nonexistence of a mechanism in humans  
11 because so little is known about what the mechanisms are in humans. Despite these concerns, in  
12 its 1991 policy guidance, EPA concluded that the  $\alpha$ 2u-globulin induced response in rats should be  
13 regarded as not relevant to humans (i.e., as not indicating human hazard).

14 One conclusion from the development and peer review of this policy is that if the default  
15 concerns an inherently complex biological question such as mode of action, large amounts of  
16 work will be required to replace the default. A second is that "proof" in the strict sense of having  
17 proved a negative is neither reasonable nor required. Rather the alternative may displace the  
18 default when it is supported by clear and convincing evidence and is generally accepted in peer  
19 review. The issue of relevance may not always be so difficult. It would be an experimentally  
20 easier task, for example, to determine whether carcinogenesis in an animal species is due to a  
21 metabolite of the agent in question that is not produced in humans.

22 When scientific processes are understood but case-specific data are missing, defaults can  
23 be constructed to be modified by experimental data, even if data do not suffice to replace them  
24 entirely. For example, the approaches adopted in these guidelines for scaling dose from  
25 experimental animals to humans are constructed to be either modified or replaced as data become  
26 available on toxicokinetic parameters for the particular agent being assessed. Similarly, the  
27 selection of an approach or approaches for dose-response assessment is based on a series of  
28 decisions that consider the nature and adequacy of available data in choosing among alternative  
29 modeling and default approaches.

30 The 1994 NRC report notes (p. 6) that "[a]s scientific knowledge increases, the science  
31 policy choices made by the Agency and Congress should have less impact on regulatory decision  
32 making. Better data and increased understanding of biological mechanisms should enable risk  
33 assessments that are less dependent on protective default assumptions and more accurate as

1 predictions of human risk." Undoubtedly, this is the trend as scientific understanding increases.  
2 However, some gaps in knowledge and data will doubtless continue to be encountered in  
3 assessment of even data-rich cases, and it will remain necessary for risk assessments to continue  
4 using defaults within the framework set forth here.

### 5 **1.3.2. Major Defaults**

6 This discussion covers the major default assumptions commonly employed in a cancer risk  
7 assessment and adopted in these guidelines. They are predominantly inferences necessary to use  
8 data observed under empirical conditions to estimate events and outcomes under environmental  
9 conditions. Several inferential issues arise when effects seen in a subpopulation of humans or  
10 animals are used to infer potential effects in the population of environmentally exposed humans.  
11 Several more inferential issues arise in extrapolating the exposure-effect relationship observed  
12 empirically to lower-exposure environmental conditions. The following issues cover the major  
13 default areas. Typically, an issue has some sub-issues; they are introduced here, but are discussed  
14 in greater detail in later sections.

- 15 • Is the presence or absence of effects observed in a human population predictive of  
16 effects in another exposed human population?
- 17 • Is the presence or absence of effects observed in an animal population predictive of  
18 effects in exposed humans?
- 19 • How do metabolic pathways relate across species? Among different age groups,  
20 between sexes in humans?
- 21 • How do toxicokinetic processes relate across species? Among different age groups,  
22 between sexes in humans?
- 23 • What is the correlation of the observed dose-response relationship to the relationship  
24 at lower doses?

#### 25 **1.3.2.1. *Is the Presence or Absence of Effects Observed in a Human Population Predictive of*** 26 ***Effects in Another Exposed Human Population?***

27 *When cancer effects in exposed humans are attributed to exposure to an exogenous*  
28 *agent, the default assumption is that such data are predictive of cancer in any other exposed*  
29 *human population.* Studies either attributing cancer effects in humans to exogenous agents or  
30 reporting no effects are often studies of occupationally exposed humans. By sex, age, and general  
31 health, workers are not representative of the general population exposed environmentally to the  
32 same agents. In such studies there is no opportunity to observe those who are likely to be under

1 represented, e.g., fetuses, infants and children, women, or people in poor health, who may  
2 respond differently from healthy workers. Therefore, it is understood that this assumption could  
3 still underestimate the response of certain human subpopulations. (NRC, 1993a, 1994).

4         There is not enough knowledge yet to form a basis for any generally applicable, qualitative  
5 or quantitative inference to compensate for this knowledge gap. In these guidelines, this problem  
6 is left to analysis in individual cases, to be attended to with further general guidance as future  
7 research and information allow. When information on a sensitive subpopulation exists, it will be  
8 used. For example, an agent such as diethylstilbestrol (DES) causes a rare form of vaginal cancer  
9 (clear-cell adenocarcinoma) (Herbst, 1971) in about 1 per thousand of adult women whose  
10 mothers were exposed during pregnancy (Hatch et al., 1998). When cancer effects are not found  
11 in an exposed human population, this information by itself is not generally sufficient to conclude  
12 that the agent poses no carcinogenic hazard to this or other populations of potentially exposed  
13 humans including sensitive subpopulations. This is because epidemiologic studies usually have  
14 low power to detect and attribute responses, and typically evaluate cancer potential in a restricted  
15 population (e.g., by age, occupation, etc.). The topic of susceptibility and variability is addressed  
16 further in the discussion of quantitative default assumptions about dose-response relationships  
17 below.

### 18 ***1.3.2.2. Is the Presence or Absence of Effects Observed in an Animal Population Predictive of*** 19 ***Effects in Exposed Humans?***

20         The default assumption is that positive effects in animal cancer studies indicate that the  
21 agent under study can have carcinogenic potential in humans. Thus, if no adequate human data  
22 are present, positive effects in animal cancer studies are a basis for assessing the carcinogenic  
23 hazard to humans. This assumption is a public health conservative policy, and it is both  
24 appropriate and necessary given that we do not test for carcinogenicity in humans. The  
25 assumption is supported by the fact that nearly all of the agents known to cause cancer in humans  
26 are carcinogenic in animals in tests with adequate protocols (IARC, 1994; Tomatis et al., 1989;  
27 Huff, 1994). Moreover, almost one-third of human carcinogens were identified subsequent to  
28 animal testing (Huff, 1993). Further support is provided by research on the molecular biology of  
29 cancer processes, which has shown that the mechanisms of control of cell growth and  
30 differentiation are remarkably homologous among species and highly conserved in evolution.  
31 Nevertheless, the same research tools that have enabled recognition of the nature and  
32 commonality of cancer processes at the molecular level also have the power to reveal differences  
33 and instances in which animal responses are not relevant to humans (Linjinsky, 1993; U.S.

1 EPA,1991b). Under these guidelines, available mode of action<sup>2</sup> information is studied for its  
2 implications in both hazard and dose-response assessment and its effect on default assumptions.

3 There may be instances in which the use of an animal model would identify a hazard in  
4 animals that is not truly a hazard in humans (e.g., the  $\alpha$ 2u-globulin association with renal  
5 neoplasia in male rats (U.S. EPA, 1991b)). The extent to which animal studies may yield false  
6 positive indications for humans is a matter of scientific debate. To demonstrate that a response in  
7 animals is not relevant to any human situation, adequate data to assess the relevancy issue must be  
8 available.

9 *The default assumption is that effects seen at the highest dose tested are appropriate for*  
10 *assessment, but it is necessary that the experimental conditions be scrutinized.* Animal studies  
11 are conducted at high doses in order to provide statistical power, the highest dose being one that  
12 is minimally toxic (maximum tolerated dose). Consequently, the question often arises whether a  
13 carcinogenic effect at the highest dose may be a consequence of cell killing with compensatory  
14 cell replication or of general physiological disruption, rather than inherent carcinogenicity of the  
15 tested agent. There is little doubt that this may happen in some cases, but skepticism exists  
16 among some scientists that it is a pervasive problem (Ames and Gold, 1990; Melnick et al., 1993a;  
17 Melnick et al., 1993b; Barrett, 1993). If adequate data demonstrate that the effects are solely the  
18 result of excessive toxicity rather than carcinogenicity of the tested agent per se, then the effects  
19 may be regarded as not appropriate to include in assessment of the potential for human  
20 carcinogenicity of the agent. This is a matter of expert judgment, considering all of the data  
21 available about the agent including effects in other toxicity studies, structure-activity relationships,  
22 and effects on growth control and differentiation.

23 *When cancer effects are not found in well-conducted animal cancer studies in two or*  
24 *more appropriate species and other information does not support the carcinogenic potential of*  
25 *the agent, these data provide a basis for concluding that the agent is not likely to possess human*  
26 *carcinogenic potential, in the absence of human data to the contrary.* This default assumption  
27 about lack of cancer effects has limitations. It is recognized that animal studies (and  
28 epidemiologic studies as well) have very low power to detect cancer effects. Detection of a 10%

---

<sup>2</sup>Understanding an agent's "mode of action" means understanding the general sequence of events by which it causes effects on cell growth control that result in cancer. "Mode of action" is used rather than "mechanism of action" which is a term that implies complete knowledge of the steps of carcinogenesis at the molecular level, a level of understanding that currently does not exist for any agent.

1 tumor incidence is generally the limit of power with standard protocols for animal studies (with  
2 the exception of rare tumors that are virtually markers for a particular agent, e.g., angiosarcoma  
3 caused by vinyl chloride). In some situations, the tested animal species may not be predictive of  
4 effects in humans; for example, arsenic shows only minimal or no effect in animals, while it is  
5 clearly positive in humans. Therefore, it is important to consider other information as well;  
6 absence of mutagenic activity or absence of carcinogenic activity among structural analogues, can  
7 increase the confidence that negative results in animal studies indicate a lack of human hazard.  
8 Another limitation is that standard animal study protocols are not yet available for effectively  
9 studying perinatal effects. The potential for effects on the very young generally must be  
10 considered separately. Perinatal studies accomplished by modification of existing adult bioassay  
11 protocols need to be required in special circumstances under existing Agency policy (U.S. EPA,  
12 1997a,b)

13 *The default assumption is that target organ concordance is not a prerequisite for*  
14 *evaluating the implications of animal study results for humans.* Target organs of carcinogenesis  
15 for agents that cause cancer in both animals and humans are most often concordant at one or  
16 more sites (Tomatis et al., 1989; Huff, 1994). However, concordance by site is not uniform.  
17 The mechanisms of control of cell growth and differentiation are concordant among species, but  
18 there are marked differences among species in the way control is managed in various tissues. For  
19 example, in humans, mutations of the tumor suppressor genes p53 and retinoblastoma are  
20 frequently observed genetic changes in tumors. These tumor suppressor genes are also observed  
21 to be operating in some rodent tissues, but other growth control mechanisms predominate in other  
22 rodent tissues. Thus, an animal response may be due to changes in a control that are relevant to  
23 humans, but appear in animals in a different way. However, it is appropriate under these  
24 guidelines to consider the influences of route of exposure, metabolism, and, particularly, some  
25 modes of action that may either support or not support target organ concordance between animals  
26 and humans. When data allow, these influences are considered in deciding whether the default  
27 remains appropriate in individual instances (NRC, 1994, p. 121). Another exception to the basic  
28 default of not assuming site concordance exists in the context of toxicokinetic modeling. Site  
29 concordance is inherently assumed when these models are used to estimate delivered dose in  
30 humans based on animal data.

31 *The default is to include benign tumors observed in animal studies in the assessment of*  
32 *animal tumor incidence if they have the capacity to progress to the malignancies with which they*  
33 *are associated.* This default is consistent with the approach of the National Toxicology Program  
34 and the International Agency for Research on Cancer and is somewhat more protective of public

1 health than not including benign tumors in the assessment. This treats the benign and malignant  
2 tumors as representative of related responses to the test agent (McConnell et al., 1986), which is  
3 scientifically appropriate. Nonetheless, in assessing findings from animal studies, a greater  
4 proportion of malignancy is weighed more heavily than a response with a greater proportion of  
5 benign tumors. Greater frequency of malignancy of a particular tumor type in comparison with  
6 other tumor responses observed in an animal study is also a factor to be considered in selecting  
7 the response to be used in dose-response assessment.

8 *Benign tumors that are not observed to progress to malignancy are assessed on a case-*  
9 *by-case basis.* There is a range of possibilities for their overall significance. They may deserve  
10 attention because they are serious health problems even though they are not malignant; for  
11 instance, benign tumors may be a health risk because of their effect on the function of a target  
12 tissue such as the brain. They may be significant indicators of the need for further testing of an  
13 agent if they are observed in a short term test protocol, or such an observation may add to the  
14 overall weight of evidence if the same agent causes malignancies in a long term study.  
15 Knowledge of the mode of action associated with a benign tumor response may aid in the  
16 interpretation of other tumor responses associated with the same agent.

### 17 **1.3.2.3. How Do Metabolic Pathways Relate Across Species? Among different age groups,** 18 ***between sexes in humans?***

19 *The default assumption is that there is a similarity of the basic pathways of metabolism*  
20 *and the occurrence of metabolites in tissues in regard to the species-to-species extrapolation of*  
21 *cancer hazard and risk.* If comparative metabolism studies were to show no similarity between  
22 the tested species and humans and a metabolite(s) were the active form, there would be less  
23 support for an inference that the animal response(s) relates to humans. In other cases, parameters  
24 of metabolism may vary quantitatively between species; this becomes part of deciding on an  
25 appropriate human equivalent dose based on animal studies, optimally in the context of a  
26 toxicokinetic model. While the basic pathways are assumed to be the same among humans, the  
27 presence of polymorphisms and the maturation of the pathways in infants needs to be considered.  
28 The active form of an agent may be present to differing degrees, or completely absent, which may  
29 result in greater or lesser risk for subpopulations.

1 **1.3.2.4. How Do Toxicokinetic Processes Relate Across Species? Among different age**  
2 **groups, between sexes in humans?**

3 A major issue is how to estimate human equivalent doses in extrapolating from animal  
4 studies. *As a default for oral exposure, a human equivalent dose for adults is estimated from*  
5 *data on another species by an adjustment of animal applied oral dose by a scaling factor of body*  
6 *weight to the 0.75 power.* This adjustment factor is used because it represents scaling of metabolic  
7 rate across animals of different size. Because the factor adjusts for a parameter that can be  
8 improved on and brought into more sophisticated toxicokinetic modeling, when such data become  
9 available, the default assumption of 0.75 power can be refined or replaced. *The same factor is*  
10 *used for children because it is slightly more protective than using children's body weight (see*  
11 *section 1.3.5.2).*

12 *For inhalation exposure, a human equivalent dose for adults is estimated by default*  
13 *methodologies that provide estimates of lung deposition and of internal dose.* The methodologies  
14 can be refined to more sophisticated forms with data on toxicokinetic and metabolic parameters of  
15 the specific agent. This default assumption, like the one with oral exposure, is selected in part  
16 because it lays a foundation for incorporating better data. *Because of the differences for infants*  
17 *and children, for gases and aerosols, an adjustment is made for their breathing rate and their*  
18 *body weight.* For inhaled particles, the adjustment does not take into account the different size  
19 and spacing of airways of children and adults; this difference could result in children and adults  
20 retaining particles with a different size distribution and different toxicologic properties. To reduce  
21 this uncertainty, EPA is developing a default dosimetry model for children that is based on  
22 children's inhalation parameters. The use of information to improve dose estimation from applied  
23 to internal to delivered dose is encouraged, including use of toxicokinetic modeling instead of any  
24 default, where data are available.

25 The processes of absorption, distribution, and elimination have important differences  
26 among infants, adults, and older adults, e.g., infants tend to absorb metals through the gut more  
27 rapidly and more efficiently than older children or adults (Calabrese, 1986). Renal elimination is  
28 also not as efficient in infants. While these processes reach adult competency at about the time  
29 of weaning, they may have important implications, particularly when the dose-response  
30 relationship for an agent is considered to be nonlinear and there is an exposure scenario  
31 disproportionately affecting infants, because in these cases the magnitude of dose is more  
32 pertinent than the usual approach in linear extrapolation, of averaging dose across a lifetime.  
33 Efficiency of intestinal absorption in older adults tends to be generally less overall for most  
34 chemicals. Another notable difference is that, post-weaning (about one year), children have a



1 higher metabolic rate than adults (Renwick, 1999) and may toxify or detoxify agents at a  
2 correspondingly higher rate..

3  
4 For a route-to-route of exposure extrapolation, *the default assumption is that an agent*  
5 *that causes internal tumors by one route of exposure will be carcinogenic by another route if it is*  
6 *absorbed by the second route to give an internal dose.* This is a qualitative assumption and is  
7 considered to be public health conservative. The rationale is that for internal tumors an internal  
8 dose is significant no matter what the route of exposure. Additionally, the metabolism of the  
9 agent will be qualitatively the same for an internal dose. The issue of quantitative extrapolation of  
10 the dose-response relationship from one route to another is addressed case by case. Quantitative  
11 extrapolation is complicated by considerations such as first-pass metabolism, but is approachable  
12 with empirical data. Adequate data are necessary to demonstrate that an agent will act differently  
13 by one route versus another route of exposure.

#### 14 15 **1.3.2.5. What Is the Correlation of the Observed Dose-Response Relationship to the** 16 **Relationship at Lower Doses?**

17 If sufficient data are available, a biologically based model for both the observed range and  
18 extrapolation below that range may be used. While no standard biologically based models are in  
19 existence, one may be developed if extensive data exist in a particular case and the purpose of the  
20 assessment justifies the investment of resources needed. *The default procedure for the observed*  
21 *range of data, when a biologically based model is not used, is to use a curve-fitting model for*  
22 *incidence data.*

23 In the absence of data supporting a biologically based model for extrapolation outside of  
24 the observed range, the choice of approach is based on the view of mode of action of the agent  
25 arrived at in the hazard assessment.

26 *The basic default is to assume linearity and use a linear default approach when the mode*  
27 *of action information is supportive of linearity or mode of action is not understood.* The linear  
28 approach is used when a view of the mode of action indicates a linear response, for example,  
29 when a conclusion is made that an agent directly causes alterations in DNA, a kind of interaction  
30 that not only theoretically requires one reaction, but also is likely to be additive to ongoing,  
31 spontaneous gene mutation. Other kinds of activity may have linear implications, e.g., linear rate-  
32 limiting steps, that support a linear procedure also. The linear approach is to draw a straight line  
33 between a point of departure from observed data, generally, as a default, the LED<sub>10</sub>, and the  
34 origin (zero incremental dose, zero incremental response). Other points of departure may be

1 more appropriate for certain data sets; these may be used instead of the LED<sub>10</sub>. This approach is  
2 generally considered to be public health protective. The LED<sub>10</sub> is the lower 95% limit on a dose  
3 that is estimated to cause a 10% response. This level is chosen to account (protectively) for  
4 experimental variability. Additionally, it is chosen because it rewards experiments with better  
5 designs in regard to number of doses and dose spacing, since these generally will have narrower  
6 confidence limits. It is also an appropriate representative of the lower end of the observed range  
7 because the limit of detection of studies of tumor effect is about 10%.

8 The linear default is thought to generally provide an upper bound calculation of potential  
9 risk at low doses. e.g., a 1/100,000 to 1/1,000,000 risk; the straight line approach gives numerical  
10 results about the same as a linearized multistage procedure. This upper bound is thought to be  
11 public health conservative at low doses for the range of human variability considering the typical  
12 Agency target range for risk management of 1/1,000,000 to 1/10,000, although it may not  
13 completely do so (Bois et al., 1995) if pre-existing disease or genetic constitution place a  
14 percentage of the population at risk from any exposure above zero to xenobiotics, natural or  
15 manmade. The question of what may be the actual variability in human sensitivity is one that the  
16 1994 NRC report discussed as did the 1993 NRC report on pesticides in children and infants. The  
17 NRC has recommended research on the question, and the EPA and other agencies are conducting  
18 such research. Given the current state of knowledge, the EPA will assume that the linear default  
19 procedure adequately accounts for human variability unless there is case-specific information for a  
20 given agent that indicates a particularly sensitive subpopulation, in which case the special  
21 information will be used.

22 *When adequate data on mode of action show that linearity is not plausible, and provide*  
23 *sufficient evidence to support a nonlinear mode of action for the general population and any*  
24 *subpopulations of concern, the default changes to a different approach-- a margin of exposure*  
25 *analysis--which assumes that nonlinearity is more reasonable. The departure point is again*  
26 *generally the LED<sub>10</sub> when incidence data are modeled. When the data available are continuous*  
27 *data such as blood levels of hormones or organ weight, a NOAEL/LOAEL procedure is typically*  
28 *used since modeling approaches for deriving a point of departure from continuous data are not yet*  
29 *available. Until these modeling approaches are developed and adopted, continuous data and data*  
30 *sets that are a mixture of incidence and continuous data can be examined by the NOAEL/LOAEL*  
31 *procedure. In the nonlinear approach, the margin that exists between a human exposure of interest*  
32 *and the point of departure is examined for adequacy to protect public health. A margin of*  
33 *exposure analysis may be used as the basis to consider the protectiveness of a possible*  
34 *environmental criterion for regulation or to judge whether an existing exposure might present risk.*

1 A sufficient basis to support this nonlinear procedure will include data on responses that  
2 are key events<sup>3</sup> integral to the carcinogenic process. This means that the point of departure  
3 mostly will be from these precursor response data, e.g., hormone levels, mitogenic effects, rather  
4 than tumor incidence data.

5 The mode of action may have specific implications to be considered for risk potential of  
6 certain exposure scenarios. For instance, stimulus of cell growth through hormonal or other signal  
7 disruption or as a result of damage from toxicity are reversible if the exposure is for a short time  
8 since homeostasis brings a return to normal levels after cessation of exposure. Another feature of  
9 a specific exposure scenario may be the exposure of a sensitive subpopulation. If the population  
10 exposed in a particular scenario is wholly or largely composed of a subpopulation for whom  
11 evidence indicates a special sensitivity to the agent's mode of action, an adequate margin of  
12 exposure would be larger than for general population exposure.

13 *When the mode of action information indicates that the dose-response may be adequately*  
14 *described by both a linear and a nonlinear approach, then the default is to present both the*  
15 *linear and margin of exposure analyses.* An assessment may use both linear and nonlinear  
16 approaches if linearity is not plausible and nonlinearity has support, but a mode of action is not  
17 defined, or different responses are thought to result from different modes of action or a response  
18 appears to be very different at high and low doses due to influence of separate modes of action.  
19 The results may be needed for assessment of combined risk from agents with common modes of  
20 action.

21 *A default assumption is made that cumulative dose received over a lifetime, expressed as*  
22 *a lifetime average daily dose, is an appropriate measure of dose.* This assumes that a high dose  
23 of such an agent received over a shorter period of time is equivalent to a low dose spread over a  
24 lifetime. This is thought to be a relatively public health protective assumption and has empirical  
25 support (Monro, 1992). An example of effects of short-term, high exposure that results in  
26 subsequent cancer development is treatment of cancer patients with certain chemotherapeutic  
27 agents. An example of cancer from long-term exposure to an agent of relatively low potency is  
28 smoking. When sufficient information is available indicating that the carcinogenic mode of action  
29 supports a nonlinear dose-response approach, a different approach may be used. Such an  
30 approach includes considering the margin of exposure that exists between exposure and the point  
31 of departure from the observed data range. In these cases, short-term exposure estimates (several  
32 days to several months may be more appropriate than the lifetime average daily dose. In these

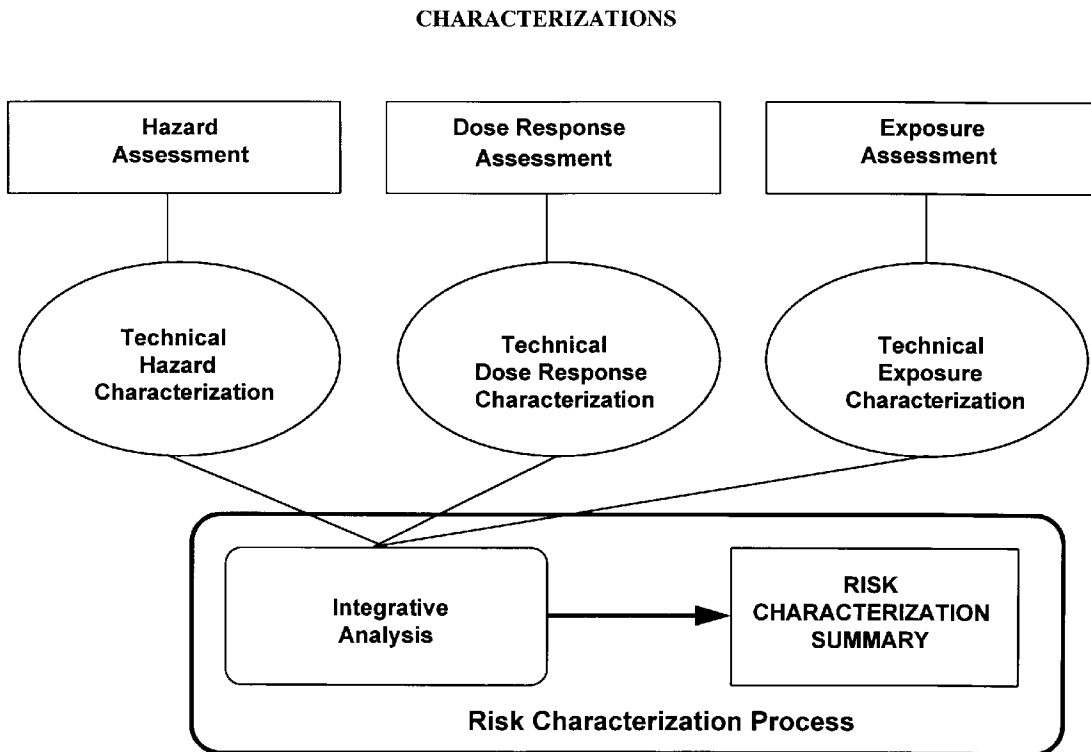
---

<sup>3</sup>A “key event” is an empirically observed precursor consistent with a mode of action.

1 cases both agent concentration and duration are likely to be important, because such effects are  
2 generally observed to be reversible at cessation of very short-term exposure.

### 3 **1.4. CHARACTERIZATIONS**

4 The risk characterization process first summarizes findings on hazard, dose-response, and  
5 exposure characterizations, then develops an integrative analysis of the whole risk case. It ends in  
6 a non technical Risk Characterization Summary. The Risk Characterization Summary is a  
7 presentation for risk managers who may or may not be familiar with the scientific details of cancer  
8 assessment. It also provides information for other interested readers. The initial steps in the risk  
9 characterization process are to make building blocks in the form of characterizations of the  
10 assessments of hazard, dose-response, and exposure. The individual assessments and  
11 characterizations are then integrated to arrive at risk estimates for exposure scenarios of interest.  
12 As part of the characterization process, explicit evaluations will be made of the hazard and risk  
13 potential for susceptible populations, including children (U.S EPA 1995a,b). There are two  
14 reasons for individually characterizing the hazard, dose-response, and exposure assessments. One  
15 is that they are often done by different people than those who do the integrative analyses. The  
16 second is that there is very often a lapse of time between the conduct of hazard and dose-  
17 response analyses and the conduct of exposure assessment and integrative analysis. Thus, it is  
18 necessary to capture characterizations of assessments as the assessments are done to avoid the  
19 need to go back and reconstruct them. Finally, frequently a single hazard assessment is used by  
20 several programs for several different exposure scenarios. Figure 1-2 shows the relationships of  
21 analyses. The figure does not necessarily correspond to the number of documents involved; there  
22 may be one or several. "Integrative analysis" is a generic term. At EPA, the documents of  
23 various programs that contain integrative analyses have other names such as the "Staff Paper" that  
24 discusses air quality criteria issues. In the following sections, the elements of this figure are  
25 discussed.



**Figure 1-1. Risk Characterization**

## 2. HAZARD ASSESSMENT

### 2.1. OVERVIEW OF HAZARD ASSESSMENT AND CHARACTERIZATION

#### 2.1.1. Analyses of Data

The purpose of hazard assessment is to review and evaluate data pertinent to two questions: (1) whether an agent may pose a carcinogenic hazard to human beings and (2) under what circumstances an identified hazard may be expressed (NRC, 1994, p. 142). Hazard assessment is composed of analyses of a variety of data that may range from observations of tumor responses to analysis of structure-activity relationships. The purpose of the assessment is not simply to assemble these separate evaluations; its purpose is to construct a total case analysis examining the biological story the data reveal as a whole about carcinogenic effects, mode of action, and implications of these for human hazard and dose-response evaluation. Weight-of-evidence conclusions come from the combined strength and coherence of inferences appropriately drawn from all of the available evidence. To the extent that data permit, hazard assessment addresses the question of mode of action as both an initial step in identifying human hazard potential and as a part of considering appropriate approaches to dose-response assessment.

The topics in this chapter include analysis of tumor data, both animal and human, and analysis of other key information about properties and effects that relate to carcinogenic potential. The chapter addresses how information can be used to evaluate potential modes of action. It also provides guidance on performing a weight-of-evidence evaluation.<sup>4</sup>

#### 2.1.2. Presentation of Results

Presentation of the results of hazard assessment follows Agency guidance as discussed in Section 2.7. The results are presented in a technical hazard characterization that serves as a support to later risk characterization. It includes:

- a summary of the evaluations of hazard data,
- the rationales for its conclusions, and
- an explanation of the significant strengths or limitations of the conclusions.

Another presentation feature is the use of a weight-of-evidence narrative that includes

---

<sup>4</sup>“Mode” of action is contrasted with “mechanism” of action, which implies a more detailed, molecular description of key processes and events than is meant by mode of action.

1 both a conclusion about the weight-of-evidence of carcinogenic potential and a summary of the  
2 data on which the conclusion rests. This narrative is a brief summary that replaces the  
3 alphanumeric classification system used in EPA's previous guidelines.  
4

## 5 **2.2. ANALYSIS OF TUMOR DATA**

6 Evidence of carcinogenicity comes from finding tumor increases in humans or laboratory  
7 animals exposed to a given agent, or from finding tumors following exposure to structural  
8 analogues to the compound under review. The significance of observed or anticipated tumor  
9 effects is evaluated in reference to all the other key data on the agent. This section contains  
10 guidance for analyzing human and animal studies to decide whether there is an association  
11 between exposure to an agent or a structural analogue and occurrence of tumors. Note that the  
12 use of the term "tumor" here is generic, meaning malignant neoplasms or a combination of  
13 malignant and corresponding benign neoplasms.

14 Observation of only **benign neoplasia** may or may not have significance. Benign tumors  
15 that are not observed to progress to malignancy are assessed on a case-by-case basis. There is a  
16 range of possibilities for their overall significance. They may deserve attention because they are  
17 serious health problems even though they are not malignant; for instance, benign tumors may be a  
18 health risk because of their effect on the function of a target tissue such as the brain. They may be  
19 significant indicators of the need for further testing of an agent if they are observed in a short-  
20 term test protocol, or such an observation may add to the overall weight of evidence if the same  
21 agent causes malignancies in a long-term study. Knowledge of the mode of action associated with  
22 a benign tumor response may aid in the interpretation of other tumor responses associated with  
23 the same agent. In other cases, observation of a benign tumor response alone may have no  
24 significant health hazard implications when other sources of evidence show no suggestion of  
25 carcinogenicity.  
26

### 27 **2.2.1. Human Data**

28 Human data may come from epidemiologic studies or case reports. Epidemiology is the  
29 study of the distributions and causes of disease within human populations. The goals of cancer  
30 epidemiology are to identify differences in cancer risk between different groups in a population or  
31 between different populations, and then to determine the extent to which these differences in risk  
32 can be attributed causally to specific exposures to exogenous or endogenous factors.  
33 Epidemiologic data are extremely useful in risk assessment because they provide direct evidence  
34 that a substance produces cancer in humans, thereby avoiding the problem of species-to-species

1 inference. Thus, when available human data are extensive and of good quality, they are generally  
2 preferable over animal data and should be given greater weight in hazard characterization and  
3 dose-response assessment, although both are utilized.

4 Null results from a single epidemiologic study cannot prove the absence of carcinogenic  
5 effects because they can arise either from being truly negative or from inadequate statistical  
6 power, inadequate design, imprecise estimates, or confounding factors. However, null results  
7 from a well-designed and well-conducted epidemiologic study that contains usable exposure data  
8 can help to define upper limits for the estimated dose of concern for human exposure if the overall  
9 weight of the evidence indicates that the agent is potentially carcinogenic in humans.

10 Epidemiology can also complement experimental evidence in corroborating or clarifying  
11 the carcinogenic potential of the agent in question. For example, observations from epidemiologic  
12 studies that elevated cancer incidence occurs at sites corresponding to those at which laboratory  
13 animals experience increased tumor incidence can strengthen the weight of evidence of human  
14 carcinogenicity. On the other hand, strong nonpositive epidemiologic data alone or in conjunction  
15 with compelling mechanistic information can lend support to a conclusion that animal responses  
16 may not be predictive of a human response. Furthermore, the advent of biochemical or molecular  
17 epidemiology may help improve understanding of the mechanisms of human carcinogenesis.

#### 18 19 **2.2.1.1. *Types of Studies***

20 The major types of cancer epidemiologic studies are analytical studies and descriptive or  
21 correlation studies. Each study type has well-known strengths and weaknesses that affect  
22 interpretation of results as summarized below (Kelsey et al., 1986; Lilienfeld and Lilienfeld, 1979;  
23 Mausner and Kramer, 1985; Rothman, 1986).

24 Analytical epidemiologic studies are most useful for identifying an association between  
25 human exposure and adverse health effects. Analytical study designs include case-control studies  
26 and cohort studies. In case-control studies, groups of individuals with (cases) and without  
27 (controls) a particular disease are identified and compared to determine differences in exposure.  
28 In cohort studies, a group of “exposed” and “nonexposed” individuals are identified and studied  
29 over time to determine differences in disease occurrence. Cohort studies can either be performed  
30 prospectively, or retrospectively from historical records.

31 Descriptive or correlation epidemiologic studies (sometimes called ecological studies)  
32 examine differences in disease rates among populations in relation to age, gender, race, and  
33 differences in temporal or environmental conditions. In general, these studies can only identify  
34 patterns or trends in disease occurrence over time or in different geographical locations, but



1 cannot ascertain the causal agent or degree of exposure. These studies, however, are often very  
2 useful for generating hypotheses for further research.

3 Biochemical or molecular epidemiologic studies are studies in which laboratory methods  
4 are incorporated in analytical investigations. The application of techniques for measuring cellular  
5 and molecular alterations due to exposure to specific environmental agents may allow conclusions  
6 to be drawn about the mechanisms of carcinogenesis. The use of biological biomarkers in  
7 epidemiology may improve assessment of exposure and internal dose.

8 Case reports describe a particular effect in an individual or group of individuals who were  
9 exposed to a substance. These reports are often anecdotal or highly selected in nature and are of  
10 limited use for hazard assessment. However, reports of cancer cases can identify associations,  
11 particularly when there are unique features such as an association with an uncommon tumor (e.g.,  
12 vinyl chloride and angiosarcoma or diethylstilbestrol and clear-cell carcinoma of the vagina).

#### 14 ***2.2.1.2. Criteria for Assessing Adequacy of Epidemiologic Studies***

15 Criteria for assessing the adequacy of epidemiologic studies are well recognized.  
16 Characteristics that are desirable in these studies include (1) clear articulation of study objectives  
17 or hypothesis; (2) proper selection and characterization of the exposed and control groups; (3)  
18 adequate characterization of exposure; (4) sufficient length of follow-up for disease occurrence;  
19 (5) valid ascertainment of the causes of cancer morbidity and mortality; (6) proper consideration  
20 of bias and confounding factors; (7) adequate sample size to detect an effect; (8) clear, well-  
21 documented, and appropriate methodology for data collection and analysis; (9) adequate response  
22 rate and methodology for handling missing data; and (10) complete and clear documentation of  
23 results. Ideally, these conditions should be satisfied, where appropriate, but rarely can a study  
24 meet all of them. No single criterion determines the overall adequacy of a study. The following  
25 discussions highlight the major factors included in an analysis of epidemiologic studies.

#### 27 ***Population Issues***

28 The ideal comparison would be between two populations that differ only in exposure to  
29 the agent in question. Because this is seldom the case, it is important to identify sources of bias  
30 inherent in a study's design or data collection methods. Bias can arise from several sources,  
31 including noncomparability between populations of factors such as general health (McMichael,  
32 1976), diet, lifestyle, or geographic location; differences in the way case and control individuals  
33 recall past events; differences in data collection that result in unequal ascertainment of health  
34 effects in the populations; and unequal follow-up of individuals. Both acceptance of studies for

1 assessment and judgment of their strengths or weaknesses depend on identifying their sources of  
2 bias and the effects on study results.

### 5 *Exposure Issues*

6 For epidemiologic data to be useful in determining whether there is an association between  
7 health effects and exposure to an agent, there must be adequate characterization of exposure  
8 information. In general, greater weight should be given to studies with more precise and specific  
9 exposure estimates.

10 Questions to address about exposure are: What can one reliably conclude about the level,  
11 duration, route, and frequency of exposure of individuals in one population as compared with  
12 another? How sensitive are study results to uncertainties in these parameters?

13 Actual exposure measurements are not available for many retrospective studies.  
14 Therefore, surrogates are often used to reconstruct exposure parameters. These may involve  
15 attributing exposures to job classifications in a workplace or to broader occupational or  
16 geographic groupings. Use of surrogates carries a potential for misclassification in that  
17 individuals may be placed in an incorrect exposure group. Misclassification generally leads to  
18 reduced ability of a study to detect differences between study and referent populations.

19 When either current or historical monitoring data are available, the exposure evaluation  
20 includes consideration of the error bounds of the monitoring and analytic methods and whether  
21 the data are from routine or accidental exposures. The potentials for misclassification and  
22 measurement errors are amenable to both qualitative and quantitative analysis. These are essential  
23 analyses for judging a study's results because exposure estimation is the most critical part of a  
24 retrospective study.

25 Biological markers potentially offer excellent measures of exposure (Hulka and Margolin,  
26 1992; Peto and Darby, 1994). Validated markers of exposure such as alkylated hemoglobin from  
27 exposure to ethylene oxide (van Sittert et al., 1985) or urinary arsenic (Enterline et al., 1987) can  
28 greatly improve estimates of dose. Markers closely identified with effects promise to greatly  
29 increase the ability of studies to distinguish real effects from bias at low levels of relative risk  
30 between populations (Taylor et al., 1994; Biggs et al., 1993) and to resolve problems of  
31 confounding risk factors.

### 33 *Confounding Factors*

34 Because epidemiologic studies are mostly observational, it is not possible to guarantee the

1 control of confounding variables, which may affect the study outcome. A confounding variable is  
2 a risk factor, independent of the putative agent, that is distributed unequally among the exposed  
3 and unexposed populations (e.g., smoking habits, lifestyle). Adjustment for possible confounding  
4 factors can occur either in the design of the study (e.g., matching on critical factors) or in the  
5 statistical analysis of the results. The influence of a potential confounding factor is limited by the  
6 effect of the exposure of interest. For example, a twofold effect of an exposure requires that the  
7 confounder effect be at least as big. The latter may not be possible owing to the presentation of  
8 the data or because needed information was not collected during the study. In this case, indirect  
9 comparisons may be possible. For example, in the absence of data on smoking status among  
10 individuals in the study population, an examination of the possible contribution of cigarette  
11 smoking to increased lung cancer risk may be based on information from other sources such as  
12 the American Cancer Society's longitudinal studies (Hammond, 1966; Garfinkel and Silverberg,  
13 1991). The effectiveness of adjustments contributes to the ability to draw inferences from a  
14 study.

15 Different studies involving exposure to an agent may have different confounding factors.  
16 If consistent increases in cancer risk are observed across a collection of studies with different  
17 confounding factors, the inference that the agent under investigation was the etiologic factor is  
18 strengthened, even though complete adjustment for confounding factors cannot be made and no  
19 single study supports a strong inference.

20 It also may be the case that the agent of interest is a risk factor in conjunction with another  
21 agent. This relationship may be revealed in a collection of studies such as in the case of asbestos  
22 exposure and smoking.

### 23 *Sensitivity*

24 Sensitivity, or the ability of a study to detect real effects, is a function of several factors.  
25 Greater size of the study population(s) (sample size) increases sensitivity, as does greater  
26 exposure (levels and duration) of the population members. Because of the often long latency  
27 period in cancer development, sensitivity also depends on whether adequate time has elapsed  
28 since exposure began for effects to occur. A unique feature that can be ascribed to the effects of  
29 a particular agent (such as a tumor type that is seen only rarely in the absence of the agent) can  
30 increase sensitivity by permitting separation of bias and confounding factors from real effects.  
31 Similarly, a biomarker particular to the agent can permit these distinctions. Statistical re-analyses  
32 of data, particularly an examination of different exposure indices, can give insight on potential  
33 exposure-response relationships. These are all factors to explore in statistical analysis of the data.  
34

1 *Statistical Considerations*

2 The analysis applies appropriate statistical methods to ascertain whether or not there is  
3 any significant association between exposure and effects. A description of the method or methods  
4 should include the reasons for their selection. Statistical analyses of the potential effects of bias or  
5 confounding factors are part of addressing the significance of an association, or lack of one, and  
6 whether a study is able to detect any effect.

7 The analysis augments examination of the results for the whole population with  
8 exploration of the results for groups with comparatively greater exposure or time since first  
9 exposure. This may support identifying an association or establishing a dose-response trend.  
10 When studies show no association, such exploration may apply to determining an upper limit on  
11 potential human risk for consideration alongside results of animal tumor effects studies.

12  
13 *Combining Statistical Evidence Across Studies*

14 Meta-analysis is a means of comparing and synthesizing studies dealing with similar health  
15 effects and risk factors. It is intended to introduce consistency and comprehensiveness into what  
16 otherwise might be a more subjective review of the literature. When utilized appropriately, meta-  
17 analysis can enhance understanding of associations between sources and their effects that may not  
18 be apparent from examination of epidemiologic studies individually. Whether to conduct a meta-  
19 analysis depends on several issues. These include the importance of formally examining sources  
20 of heterogeneity, the refinement of the estimate of the magnitude of an effect, and the need for  
21 information beyond that provided by individual studies or a narrative review. Meta-analysis may  
22 not be useful in some circumstances. These include when the relationship between exposure and  
23 disease is obvious without a more formal analysis; when there are only a few studies of the key  
24 health outcomes; when there is insufficient information from available studies related to disease,  
25 risk estimate, or exposure classification; or when there are substantial confounding or other biases  
26 that cannot be adjusted for in the analysis (Blair et al., 1995; Greenland, 1987; Peto, 1992).

27  
28 **2.2.1.3. *Criteria for Causality***

29 A causal interpretation is enhanced for studies to the extent that they meet the criteria  
30 described below. None of the criteria is conclusive by itself, and the only criterion that is essential  
31 is the temporal relationship. These criteria are modeled after those developed by Bradford Hill in  
32 the examination of cigarette smoking and lung cancer (Rothman, 1986), and they need to be  
33 interpreted in the light of all other information on the agent being assessed.

- 1 • Temporal relationship: The development of cancers requires certain latency  
2 periods, and while latency periods vary, existence of such periods is generally  
3 acknowledged. Thus, the disease has to occur within a biologically reasonable  
4 time after initial exposure. This feature must be present if causality is to be  
5 considered.
- 6 • Consistency: Associations occur in several independent studies of a similar  
7 exposure in different populations, or associations occur consistently for different  
8 subgroups in the same study. This feature usually constitutes strong evidence for a  
9 causal interpretation when the same bias or confounding is not also duplicated  
10 across studies.
- 11 • Magnitude of the association: A causal relationship is more credible when the risk  
12 estimate is large and precise (narrow confidence intervals).
- 13 • Biological gradient: The risk ratio (i.e., the ratio of the risk of disease or death  
14 among the exposed to the risk of the unexposed) increases with increasing  
15 exposure or dose. Statistical significance is important, and a strong dose-response  
16 relationship across several categories of exposure, latency, and duration is  
17 supportive for causality, given that confounding is unlikely to be correlated with  
18 exposure. The absence of a dose-response relationship, however, is not by itself  
19 evidence against a causal relationship.
- 20 • Specificity of the association: The likelihood of a causal interpretation is increased  
21 if an exposure produces a specific effect (one or more tumor types also found in  
22 other studies) or if a given effect has a unique exposure.
- 23 • Biological plausibility: The association makes sense in terms of biological  
24 knowledge. Information is considered from animal toxicology, toxicokinetics,  
25 structure-activity relationship analysis, and short-term studies of the agent's  
26 influence on events in the carcinogenic process considered.
- 27 • Coherence: The cause-and-effect interpretation is in logical agreement with what  
28 is known about the natural history and biology of the disease, i.e., the entire body  
29 of knowledge about the agent.

#### 30 31 **2.2.1.4. Assessment of Evidence of Carcinogenicity from Human Data**

32 In the evaluation of carcinogenicity based on epidemiologic studies, it is necessary to  
33 critically evaluate each study for confidence in findings and conclusions as discussed under  
34 Section 2.2.1.2. All studies that are properly conducted, whether yielding positive or null results,

1 or even suggesting protective carcinogenic effects, should be considered in assessing the totality  
2 of the human evidence. Although a single study may be indicative of a cause-effect relationship,  
3 confidence in inferring a causal relationship is increased when several independent studies are  
4 concordant in showing the association, when the association is strong, and when other criteria for  
5 causality are also met. Conclusions about the overall evidence for carcinogenicity from available  
6 studies in humans should be summarized along with a discussion of strengths or limitations of the  
7 conclusions.

## 8 9 **2.2.2. Animal Data**

10 Various whole-animal test systems are currently used or are under development for  
11 evaluating potential carcinogenicity. Cancer studies involving chronic exposure for most of the  
12 lifespan of an animal are generally accepted for evaluation of tumor effects (Tomatis et al., 1989;  
13 Rall, 1991; Allen et al., 1988; but see Ames and Gold, 1990). Other studies of special design are  
14 useful for observing formation of preneoplastic lesions or tumors or investigating specific modes  
15 of action. Their applicability is made on a case-by-case basis.

### 16 17 **2.2.2.1. Long-Term Carcinogenicity Studies**

18 The objective of long-term carcinogenesis bioassays is to determine the potential  
19 carcinogenic hazard and dose-response relationships of the test agent. Carcinogenicity rodent  
20 studies are designed to examine the production of tumors as well as preneoplastic lesions and  
21 other indications of chronic toxicity that may provide evidence of treatment-related effects and  
22 insights into the way the test agent produces tumors. Current standardized carcinogenicity  
23 studies in rodents test at least 50 animals per sex per dose group in each of three treatment groups  
24 and in a concurrent control group, usually for 18 to 24 months, depending on the rodent species  
25 tested (OECD, 1981; U.S. EPA, 1983a-c). The high dose in long-term studies is generally  
26 selected to provide the maximum ability to detect treatment-related carcinogenic effects while not  
27 compromising the outcome of the study through excessive toxicity or inducing inappropriate  
28 toxicokinetics (e.g., overwhelming absorption or detoxification mechanisms). The purpose of two  
29 or more lower doses is to provide some information on the shape of the dose-response curve.  
30 Similar protocols have been and continue to be used by many laboratories worldwide.

31 All available studies of tumor effects in whole animals are considered, at least  
32 preliminarily. The analysis discards studies judged to be wholly inadequate in protocol, conduct,  
33 or results. Criteria for the technical adequacy of animal carcinogenicity studies have been  
34 published and should be used as guidance to judge the acceptability of individual studies (NTP,

1 1984; OSTP, 1985). Care is taken to include studies that provide some evidence bearing on  
2 carcinogenicity or that help interpret effects noted in other studies, even if they have some  
3 limitations of protocol or conduct. Such limited, but not wholly inadequate, studies can  
4 contribute as their deficiencies permit. The findings of long-term rodent bioassays are always  
5 interpreted in conjunction with results of prechronic studies along with metabolism toxicokinetic  
6 metabolism studies and other pertinent information, if available. Evaluation of tumor effects  
7 requires consideration of both biological and statistical significance of the findings (Haseman,  
8 1984, 1985, 1990, 1995). The following sections highlight the major issues in the evaluation of  
9 long-term carcinogenicity studies.

### 10 *Dosing Issues*

11  
12 Among the many criteria for technical adequacy of animal carcinogenicity studies is the  
13 appropriateness of dose selection. The selection of doses for chronic bioassays requires scientific  
14 judgments and must be based on sound toxicologic principles. Dose selection should be made on  
15 the basis of relevant toxicologic information from prechronic, mechanistic, and toxicokinetic and  
16 mechanistic studies. How well the dose selection is made can be evaluated only after the  
17 completion of the bioassay. A scientific rationale for dose selection should be clearly articulated  
18 (ILSI, 1997).

19 In order to obtain the most relevant information from a long-term carcinogenicity study, it  
20 is important to maximize exposure conditions to the test material. At the same time, there is a  
21 need for caution in using excessive high-dose levels that would confound the interpretation of  
22 study results to humans. The middle and lowest doses should be selected to characterize the shape  
23 of the dose-response curve as much as possible. It is important that the doses are adequately  
24 spaced so that the study would provide relevant dose-response data for assessing human hazard  
25 and risk. If the testing of potential carcinogenicity is being combined with an evaluation of  
26 noncancer chronic toxicity, the study should be designed to include one dose that does not elicit  
27 adverse effects.

28 With regard to the appropriateness of the high dose, an adequate high dose would be one  
29 that produces some toxic effects without either unduly affecting mortality from effects other than  
30 cancer or producing significant adverse effects on the nutrition and health of the test animals  
31 (OECD, 1981; NRC, 1993b). If the test agent does not appear to cause any specific target organ  
32 toxicity or perturbation of physiological function, an adequate high dose would be one that causes  
33 no more than 5%-10% reduction of body weight gain over the lifespan of the animals. The high  
34 dose would be considered inadequate if no toxicity is observed. On the other hand, significant

1 increases in mortality from effects other than cancer generally indicate that an adequate high dose  
2 has been exceeded. Other signs of treatment-related toxicity associated with an excessive high  
3 dose may include the following: (a) reduction of body weight gain greater than 10%, (b)  
4 significant increases in abnormal behavioral and clinical signs, (c) significant changes in  
5 hematology or clinical chemistry, (d) saturation of absorption and detoxification mechanisms, or  
6 (e) marked changes in organ weight, morphology, and histopathology. It should be noted that  
7 practical upper limits have been established to avoid the use of excessively high doses in long-  
8 term carcinogenicity studies of environmental chemicals (e.g., 5% of the test substance in the feed  
9 for dietary studies or 1 g/kg of body weight for oral gavage studies [OECD, 1981]).

10 For dietary studies, weight gain reductions should be evaluated as to whether there is a  
11 palatability problem or an issue with food efficiency; certainly, the latter is a toxic manifestation.  
12 In the case of inhalation studies with respirable particles, evidence of impairment of normal  
13 clearance of particles from the lung should be considered along with other signs of toxicity to the  
14 respiratory airways to determine whether the high exposure concentration has been appropriately  
15 selected. For dermal studies, evidence of skin irritation may indicate that an adequate high dose  
16 has been reached (U.S. EPA, 1989d).

17 Interpretation of carcinogenicity study results is profoundly affected by study exposure  
18 conditions, especially by inappropriate dose selection. This is particularly important in studies  
19 that are nonpositive for carcinogenicity, since failure to reach a sufficient dose reduces the  
20 sensitivity of the studies. A lack of tumorigenic responses at exposure levels that cause significant  
21 impairment of animal survival may also not be acceptable. In addition, overt toxicity or  
22 inappropriate toxicokinetics due to excessively high doses may result in tumor effects that are  
23 secondary to the toxicity rather than directly attributable to the agent.

24 There are several possible outcomes regarding the study interpretation of the significance  
25 and relevance of tumorigenic effects associated with exposure or dose levels below, at, or above  
26 an adequate high dose. General guidance is given here that should not be taken as prescriptive;  
27 for each case, the information at hand is evaluated and a rationale should be given for the position  
28 taken.

- 29
- 30 • Adequate high dose: If an adequate high dose has been utilized, tumor effects are  
31 judged positive or negative depending on the presence or absence of significant tumor  
32 incidence increases, respectively.
  - 33 • Excessive high dose: If toxicity or mortality is excessive at the high dose,  
34 interpretation depends on the finding of tumors or not.



- 1 (a) Studies that show tumor effects only at excessive doses may be compromised  
2 and may or may not carry weight, depending on the interpretation in the context  
3 of other study results and other lines of evidence. Results of such studies,  
4 however, are generally not considered suitable for dose-response extrapolation if  
5 it is determined that the mode(s) of action underlying the tumorigenic responses  
6 at high doses are not operative at lower doses.
- 7 (b) Studies that show tumors at lower doses, even though the high dose is excessive  
8 and may be discounted, should be evaluated on their own merits.
- 9 (c) If a study does not show an increase in tumor incidence at a toxic high dose and  
10 appropriately spaced lower doses are used without such toxicity or tumors, the  
11 study is generally judged as negative for carcinogenicity.
- 12 • Inadequate high dose: Studies of inadequate sensitivity where an adequate high dose  
13 has not been reached may be used to bound the dose range where carcinogenic effects  
14 might be expected.

### 15 16 17 *Statistical Considerations*

18 The main aim of statistical evaluation is to determine whether exposure to the test agent is  
19 associated with an increase of tumor development. Statistical analysis of a long-term study should  
20 be performed for each tumor type separately. The incidence of benign and malignant lesions of  
21 the same cell type, usually within a single tissue or organ, are considered separately and are  
22 combined when scientifically defensible (McConnell et al., 1986).

23 Trend tests and pairwise comparison tests are the recommended tests for determining  
24 whether chance, rather than a treatment-related effect, is a plausible explanation for an apparent  
25 increase in tumor incidence. A trend test such as the Cochran-Armitage test (Snedecor and  
26 Cochran, 1967) asks whether the results in all dose groups together increase as dose increases. A  
27 pairwise comparison test such as the Fisher exact test (Fisher, 1950) asks whether an incidence in  
28 one dose group is increased over the control group. By convention, for both tests a statistically  
29 significant comparison is one for which  $p < 0.05$  that the increased incidence is due to chance.  
30 Significance in either kind of test is sufficient to reject the hypothesis that chance accounts for the  
31 result. A statistically significant response may or may not be biologically significant and vice  
32 versa. The selection of a significance level is a policy choice based on a trade-off between the  
33 risks of false positives and false negatives. A significance level of greater or less than 5% is  
34 examined to see if it confirms other scientific information. When the assessment departs from a

1 simple 5% level, this should be highlighted in the risk characterization. A two-tailed test or a one-  
2 tailed test can be used. In either case a rationale is provided.

3 Considerations of multiple comparisons should also be taken into account. Haseman  
4 (1983) analyzes typical animal bioassays testing both sexes of two species and concludes that,  
5 because of multiple comparisons, a single tumor increase for a species-sex-site combination that is  
6 statistically significant at the 1% level for common tumors or 5% for rare tumors corresponds to a  
7 7%-8% significance level for the study as a whole. Therefore, animal bioassays presenting only  
8 one significant result that falls short of the 1% level for a common tumor must be treated with  
9 caution.

### 10 *Concurrent and Historical Controls*

11 The standard for determining statistical significance of tumor incidence comes from a  
12 comparison of tumors in dosed animals as compared with concurrent control animals. Additional  
13 insights about both statistical and biological significance can come from an examination of  
14 historical control data (Tarone, 1982; Haseman, 1995). Historical control data can add to the  
15 analysis, particularly by enabling identification of uncommon tumor types or high spontaneous  
16 incidence of a tumor in a given animal strain. Identification of common or uncommon situations  
17 prompts further thought about the meaning of the response in the current study in context with  
18 other observations in animal studies and with other evidence about the carcinogenic potential of  
19 the agent. These other sources of information may reinforce or weaken the significance given to  
20 the response in the hazard assessment. Caution should be exercised in simply looking at the  
21 ranges of historical responses because the range ignores differences in survival of animals among  
22 studies and is related to the number of studies in the database.

23 In analyzing results for uncommon tumors in a treated group that are not statistically  
24 significant in comparison to concurrent controls, the analyst can use the experience of historical  
25 controls to conclude that the result is in fact unlikely to be due to chance. In analyzing results for  
26 common tumors, a different set of considerations comes into play. Generally speaking,  
27 statistically significant increases in tumors should not be discounted simply because incidence  
28 rates in the treated groups are within the range of historical controls or because incidence rates in  
29 the concurrent controls are somewhat lower than average. Random assignment of animals to  
30 groups and proper statistical procedures provide assurance that statistically significant results are  
31 unlikely to be due to chance alone. However, caution should be used in interpreting results that  
32 are barely statistically significant or in which incidence rates in concurrent controls are unusually  
33 low in comparison with historical controls.  
34

1 In cases where there may be reason to discount the biological relevance to humans of  
2 increases in common animal tumors, such considerations should be weighed on their own merits  
3 and clearly distinguished from statistical concerns.

4 When historical control data are used, the discussion needs to address several issues that  
5 affect comparability of historical and concurrent control data. Among these issues are the  
6 following: genetic drift in the laboratory strains, differences in pathology examination at different  
7 times and in different laboratories (e.g., in criteria for evaluating lesions; variations in the  
8 techniques for preparation or reading of tissue samples among laboratories), and comparability of  
9 animals from different suppliers. The most relevant historical data come from the same laboratory  
10 and same supplier, gathered within 2 or 3 years one way or the other of the study under review;  
11 other data should be used only with extreme caution.

### 12 *Assessment of Evidence of Carcinogenicity from Long-Term Animal Studies*

13 In general, observation of tumor effects under different circumstances lends support to the  
14 significance of the findings for animal carcinogenicity. Significance is a function of the number of  
15 factors present and, for a factor such as malignancy, the severity of the observed pathology. The  
16 following observations add significance to the tumor findings:  
17

- 18 • uncommon tumor types;
- 19 • tumors at multiple sites;
- 20 • tumors by more than one route of administration;
- 21 • tumors in multiple species, strains, or both sexes;
- 22 • progression of lesions from preneoplastic to benign to malignant;
- 23 • reduced latency of neoplastic lesions;
- 24 • metastases;
- 25 • unusual magnitude of tumor response;
- 26 • proportion of malignant tumors; and
- 27 • dose-related increases.
- 28

29  
30 These guidelines adopt the science policy position that tumor findings in animals indicate  
31 that an agent may produce such effects in humans. Moreover, the absence of tumor findings in  
32 well-conducted, long-term animal studies in at least two species provides reasonable assurance  
33 that an agent may not be a carcinogenic concern for humans. Each of these is a default  
34 assumption that may be adopted, when appropriate, after evaluation of tumor data and other key

1 evidence.

### 2 *Site Concordance*

3 Site concordance of tumor effects between animals and humans is an issue to be  
4 considered in each case. Thus far, there is evidence that growth control mechanisms at the level  
5 of the cell are homologous among mammals, but there is no evidence that these mechanisms are  
6 site concordant. Moreover, agents observed to produce tumors in both humans and animals have  
7 produced tumors either at the same (e.g., vinyl chloride) or different sites (e.g., benzene) (NRC,  
8 1994). Hence, site concordance is not assumed a priori. On the other hand, certain processes  
9 with consequences for particular tissue sites (e.g., disruption of thyroid function) may lead to an  
10 anticipation of site concordance.

#### 11 12 **2.2.2.2. *Perinatal Carcinogenicity Studies***

13 The objective of perinatal carcinogenesis studies is to determine the carcinogenic potential  
14 and dose-response relationships of the test agent in the developing organism. Some investigators  
15 have postulated that the age of initial exposure to a chemical carcinogen may influence the  
16 carcinogenic response (Vesselinovitch et al., 1979; Rice, 1979; McConnell, 1992). Current  
17 standardized long-term carcinogenesis bioassays generally begin dosing animals at 6-8 weeks of  
18 age and continue dosing for the lifespan of the animal (18-24 months). This protocol has been  
19 modified in some cases to investigate the potential of the test agent to induce transplacental  
20 carcinogenesis or to investigate the potential differences following perinatal and adult exposures;  
21 but currently there is not a standardized protocol for testing agents for carcinogenic effects  
22 following prenatal or early postnatal exposure.

23 Several cancer bioassay studies have compared adult and perinatal exposures (see  
24 McConnell, 1992; U.S. EPA, 1996a). A review of these reveals that perinatal exposure rarely  
25 identifies carcinogens that are not found in standard animal bioassays. Exposure that is perinatal  
26 sometimes slightly increases the incidence of a given type of tumor. The increase may reflect an  
27 increased length of exposure and a higher dose for the developing organism relative to the adult,  
28 or an increase in sensitivity in some cases. Additionally, exposure that is perinatal through  
29 adulthood sometimes reduces the latency period for tumors to develop in the growing organism  
30 (U.S. EPA, 1996a).

31 Because the perinatal exposure studies done to date provide only marginal additions to  
32 knowledge as compared with standard bioassay protocols, EPA evaluates the need for such a  
33 study agent-by-agent (U.S. EPA, 1997a,b). Perinatal study data analysis follows the principles  
34 discussed above for evaluating other long-term carcinogenicity studies. When differences in

1 responses in perinatal animals compared to adult animals suggest an increased susceptibility or  
2 sensitivity of perinatal or postnatal animals, such as the ones below, a separate evaluation of the  
3 response is prepared:

- 4
- 5 • a difference in dose-response relationship
- 6 • presence of different tumor types
- 7 • an earlier onset of tumors
- 8 • an increase in the incidence of tumors

9 An illustrative case study appears in Appendix E.

### 10

### 11 **2.2.2.3. Other Studies**

12 Various intermediate-term studies often use protocols that screen for carcinogenic or  
13 preneoplastic effects, sometimes in a single tissue. Some involve the development of various  
14 proliferative lesions, like foci of alteration in the liver (Goldsworthy et al., 1986). Others use  
15 tumor endpoints, like the induction of lung adenomas in the sensitive strain A mouse (Maronpot  
16 et al., 1986) or tumor induction in initiation-promotion studies using various organs such as the  
17 bladder, intestine, liver, lung, mammary gland, and thyroid (Ito et al., 1992). In these tests, the  
18 selected tissue is, in a sense, the test system rather than the whole animal. Important information  
19 concerning the steps in the carcinogenic process and mode of action can be obtained from  
20 “start/stop” experiments. In these protocols, an agent is given for a period of time to induce  
21 particular lesions or effects, then stopped to evaluate the progression or reversibility of processes  
22 (Todd, 1986; Marsman and Popp, 1994).

23 Assays in genetically engineered rodents may provide insight into the chemical and gene  
24 interactions involved in carcinogenesis (Tennant et al., 1995). These mechanistically based  
25 approaches involve activated oncogenes that are introduced (transgenic) or tumor suppressor  
26 genes that are deleted (knocked out). If appropriate genes are selected, not only may these  
27 systems provide information on mechanisms, but the rodents typically show tumor development  
28 earlier than the standard bioassay. Transgenic mutagenesis assays also represent a mechanistic  
29 approach for assessing the mutagenic properties of agents as well as developing quantitative  
30 linkages between exposure, internal dose, and mutation related to tumor induction (Morrison and  
31 Ashby, 1994; Sisk et al., 1994; Hayward et al., 1995). These systems use a stable genomic  
32 integration of a lambda shuttle vector that carries a *lacI* target gene and a *lacZ* reporter gene.

33 The support that these studies give to a determination of carcinogenicity rests on their  
34 contribution to the consistency of other evidence about an agent. For instance, benzoyl peroxide

1 has promoter activity on the skin, but the overall evidence may be less supportive (Kraus et al.,  
2 1995). These studies also may contribute information about mode of action. One needs to  
3 recognize the limitations of these experimental protocols such as short duration, limited histology,  
4 lack of complete development of tumors, or experimental manipulation of the carcinogenic  
5 process that may limit their contribution to the overall assessment. Generally, their results are  
6 appropriate as aids in the assessment for interpreting other toxicological evidence (e.g., rodent  
7 chronic bioassays), especially regarding potential modes of action. With sufficient validation,  
8 these studies may partially or wholly replace chronic bioassays in the future (Tennant et al., 1995).

### 9 10 **2.2.3. Structural Analogue Data**

11 For some chemical classes, there is significant information available on the carcinogenicity  
12 of analogues, largely in rodent bioassays. Analogue effects are instructive in investigating  
13 carcinogenic potential of an agent as well as identifying potential target organs, exposures  
14 associated with effects, and potential functional class effects or modes of action. All appropriate  
15 studies are included and analyzed, whether indicative of a positive effect or not. Evaluation  
16 includes tests in various animal species, strains, and sexes; with different routes of administration;  
17 and at various doses, as data are available. Confidence in conclusions is a function of how similar  
18 the analogues are to the agent under review in structure, metabolism, and biological activity. This  
19 confidence needs to be considered to ensure a balanced position.

## 20 21 **2.3. ANALYSIS OF OTHER KEY DATA**

22 The physical, chemical, and structural properties of an agent, as well as data on endpoints  
23 that are thought to be critical elements of the carcinogenic process, provide valuable insights into  
24 the likelihood of human cancer risk. The following sections provide guidance for analyses of  
25 these data.

### 26 27 **2.3.1. Physicochemical Properties**

28 Physicochemical properties affect an agent's absorption, tissue distribution  
29 (bioavailability), biotransformation, and degradation in the body and are important determinants  
30 of hazard potential (and dose-response analysis). Properties to analyze include, but are not  
31 limited to, the following: molecular weight, size, and shape; valence state; physical state (gas,  
32 liquid, solid); water or lipid solubility, which can influence retention and tissue distribution; and  
33 potential for chemical degradation or stabilization in the body.

34 An agent's potential for chemical reaction with cellular components, particularly with

1 DNA and proteins, is also important. The agent's molecular size and shape, electrophilicity, and  
2 charge distribution are considered in order to decide whether they would facilitate such reactions.  
3

### 4 **2.3.2. Structure-Activity Relationships**

5 Structure-activity relationship (SAR) analyses and models can be used to predict  
6 molecular properties, surrogate biological endpoints, and carcinogenicity. Overall, these analyses  
7 provide valuable initial information on agents, may strengthen or weaken concern, and are part of  
8 the weight of evidence.

9 Currently, SAR analysis is most useful for chemicals and metabolites that are believed to  
10 initiate carcinogenesis through covalent interaction with DNA (i.e., DNA-reactive, mutagenic,  
11 electrophilic, or proelectrophilic chemicals) (Ashby and Tennant, 1991). For organic chemicals,  
12 the predictive capability of SAR analysis combined with other toxicity information has been  
13 demonstrated (Ashby and Tennant, 1994). The following parameters are useful in comparing an  
14 agent to its structural analogues and congeners that produce tumors and affect related biological  
15 processes such as receptor binding and activation, mutagenicity, and general toxicity (Woo and  
16 Arcos, 1989):

- 17 • nature and reactivity of the electrophilic moiety or moieties present;
- 18 • potential to form electrophilic reactive intermediate(s) through chemical,  
19 photochemical, or metabolic activation;
- 20 • contribution of the carrier molecule to which the electrophilic moiety(ies) is attached;
- 21 • physicochemical properties (e.g., physical state, solubility, octanol-water partition  
22 coefficient, half-life in aqueous solution);
- 23 • structural and substructural features (e.g., electronic, steric, molecular geometric);
- 24 • metabolic pattern (e.g., metabolic pathways and activation and detoxification ratio);  
25 and
- 26 • possible exposure route(s) of the agent.

27  
28 Suitable SAR analysis of non-DNA-reactive chemicals and of DNA-reactive chemicals  
29 that do not appear to bind covalently to DNA requires knowledge or postulation of the probable  
30 mode(s) of action of closely related carcinogenic structural analogues (e.g., receptor-mediated,  
31 cytotoxicity-related). Examination of the physicochemical and biochemical properties of the  
32 agent may then provide the rest of the information needed in order to make an assessment of the  
33 likelihood of the agent's activity by that mode of action.  
34

### 2.3.3. Comparative Metabolism and Toxicokinetics

Studies of the absorption, distribution, biotransformation, and excretion of agents permit comparisons among species to assist in determining the implications of animal responses for human hazard assessment, supporting identification of active metabolites, identifying changes in distribution and metabolic pathway or pathways over a dose range, and making comparisons among different routes of exposure.

If extensive data are available (e.g., blood/tissue partition coefficients and pertinent physiological parameters of the species of interest), physiologically based pharmacokinetic models can be constructed to assist in a determination of tissue dosimetry, species-to-species extrapolation of dose, and route-to-route extrapolation (Connolly and Andersen, 1991; see Section 3.2.2). If it is not contrary to available data, it is assumed as a default that toxicokinetic and metabolic processes are qualitatively comparable between species. Discussion of the defaults regarding quantitative comparison and their modifications appears in Chapter 3.

The *qualitative* question of whether an agent is absorbed by a particular route of exposure is important for weight-of-evidence classification, discussed in Section 2.7.1. Decisions whether route of exposure is a limiting factor on expression of any hazard, in that absorption does not occur by a route, are based on studies in which effects of the agent, or its structural analogues, have been observed by different routes, on physical-chemical properties, or on toxicokinetics studies.

Adequate metabolism and pharmacokinetic data can be applied toward the following as data permit. Confidence in conclusions is enhanced when *in vivo* data are available.

- Identifying metabolites and reactive intermediates of metabolism and determining whether one or more of these intermediates are likely to be responsible for the observed effects. This information on the reactive intermediates will appropriately focus SAR analysis, analysis of potential modes of action, and estimation of internal dose in dose-response assessment (D'Souza et al., 1987; Krewski et al., 1987).
- Identifying and comparing the relative activities of metabolic pathways in animals with those in humans as well as different ages. This analysis can provide insights for extrapolating results of animal studies to humans.
- Describing anticipated distribution within the body and possibly identifying target organs. Use of water solubility, molecular weight, and structure analysis can support qualitative inferences about anticipated distribution and excretion. In addition, describing whether the agent or metabolite of concern will be excreted rapidly or



1 slowly or will be stored in a particular tissue or tissues to be mobilized later can  
2 identify issues in comparing species and formulating dose-response assessment  
3 approaches.

- 4 • Identifying changes in toxicokinetics and metabolic pathways with increases in dose.  
5 These changes may result in important differences in disposition of the agent or its  
6 generation of active forms of the agent between high and low dose levels. These  
7 studies play an important role in providing a rationale for dose selection in  
8 carcinogenicity studies.
- 9 • Identifying and comparing metabolic process differences by age, sex, or other  
10 characteristic so that sensitive subpopulations can be recognized. For example,  
11 metabolic capacity with respect to P450 enzymes in newborn children is extremely  
12 limited compared to adults, so that a requirement for metabolic activation of a  
13 carcinogen will limit its effect in young, whereas a requirement for metabolic  
14 deactivation will result in increased sensitivity of this subpopulation (Cresteil, 1998).  
15 A variety of changes in toxicokinetics and physiology occur from fetal to post-  
16 weaning, to young child. Any of these may make a difference to risk (Renwick, 1998)
- 17 • Determining bioavailability via different routes of exposure by analyzing uptake  
18 processes under various exposure conditions. This analysis supports identification of  
19 hazards for untested routes. In addition, use of physicochemical data (e.g., octanol-  
20 water partition coefficient information) can support an inference about the likelihood  
21 of dermal absorption (Flynn, 1990).

22  
23 In all of these areas, attempts are made to clarify and describe as much as possible the  
24 variability to be expected because of differences in species, sex, age, and route of exposure. The  
25 analysis takes into account the presence of subpopulations of individuals who are particularly  
26 vulnerable to the effects of an agent because of toxicokinetic or metabolic differences (genetically  
27 or environmentally determined) (Bois et al., 1995), and is a special emphasis for assessment of  
28 risks to children.

#### 29 30 31 **2.3.4. Toxicological and Clinical Findings**

32 Toxicological findings in experimental animals and clinical observations in humans are an  
33 important resource to the cancer hazard assessment. Such findings provide information on  
34 physiological effects and effects on enzymes, hormones, and other important macromolecules, as

1 well as on target organs for toxicity. Given that the cancer process represents defects in terminal  
2 differentiation, growth control, and cell death, developmental studies of agents may provide an  
3 understanding of the activity of an agent that carries over to cancer assessment. Toxicity studies  
4 in animals by different routes of administration support comparison of absorption and metabolism  
5 by those routes. Data on human variability in standard clinical tests may provide insight into the  
6 range of human sensitivity and common mechanisms to agents that affect the tested parameters.  
7

### 8 **2.3.5. Events Relevant to Mode of Carcinogenic Action**

9 Information on the biochemical and biological changes that precede tumor development  
10 (which includes but is not limited to mutagenesis, increased cell proliferation, inhibition of  
11 programmed cell death, and receptor activation) may provide important information in  
12 determining whether a cancer hazard exists and may help inform the dose-response relationship  
13 below the range of observable tumor response. Because cancer is the result of a series of genetic  
14 defects in genes controlling cell growth, division, and differentiation (Vogelstein et al., 1988), the  
15 ability of an agent to affect genes or gene expression is of obvious importance in evaluating its  
16 influence on the carcinogenic process. Initial and key questions to examine are: Does the agent (or  
17 its metabolite) interact directly with and mutate DNA to bring about changes in gene expression?  
18 Does the agent bring about effects on gene expression via other processes? Furthermore,  
19 carcinogenesis involves a complex series and interplay of events that alter the signals a cell  
20 receives from its extracellular environment to promote growth. Many, but not all, mutagens are  
21 carcinogens, and some, but not all, agents that induce cell proliferation lead to tumor  
22 development. Thus, understanding the range of key influences that the chemical may have on the  
23 carcinogenic process is essential for evaluating mode of action. Endpoints that provide insight  
24 into an agent's ability to alter genes and gene expression and other features of an agent's potential  
25 mode of carcinogenic action are discussed below.  
26

#### 27 **2.3.5.1. Direct DNA Reactive Effects**

28 It is well known that many carcinogens are electrophiles that interact with DNA, resulting  
29 in DNA adducts and breakage (referred to in these guidelines as direct DNA effects). Following  
30 DNA replication, these DNA lesions can be converted into mutations and stable cytogenetic  
31 alterations, which then may initiate and contribute to the carcinogenic process (Shelby and Zeiger,  
32 1990; Tinwell and Ashby, 1991). Thus, studies of mutations and other genetic lesions continue to  
33 be important in the assessment of potential human cancer hazard and in the understanding of an  
34 agent's mode of carcinogenic action. EPA has published testing guidelines for detecting the

1 ability of an agent to damage DNA and produce mutations and chromosomal aberrations. Briefly,  
2 standard tests for gene mutations in bacteria and mammalian cells in vitro and in vivo, and for  
3 structural chromosomal aberrations in vitro and in vivo are important examples of relevant  
4 methods. New molecular approaches such as mouse mutations and cancer transgenic models are  
5 providing a means to examine mutation at tissue sites where the tumor response is observed  
6 (Heddle and Swiger, 1996). Additionally, continued improvements in fluorescent-based  
7 chromosome staining methods (FISH, fluorescent in situ hybridization) will allow the detection of  
8 specific chromosomal abnormalities in relevant target tissues (Tucker and Preston, 1998).

9       Endpoints indicative of DNA damage but not measures of mutation per se, such as DNA  
10 adducts or strand breakage, can be detected in relevant target tissues and thus contribute to  
11 evaluating an agent's mutagenic potential. Evidence of chemical-specific DNA adducts (e.g.,  
12 reactions at oxygen sites in DNA bases or with ring nitrogens of guanine and adenine) provides  
13 information on a mutagen's ability to directly interact with DNA (La and Swenberg, 1996). It  
14 should be noted that an increase in DNA binding shown with a radioactive label incorporated in  
15 the chemical (e.g., C<sup>14</sup>) may reflect a direct DNA reactive mechanism, but needs to be examined  
16 because the label may reflect reuse of C<sup>14</sup> in the synthesis of DNA rather than binding. Some  
17 planar molecules (e.g., 9-aminoacridine) intercalate between base pairs of DNA, which results in a  
18 physical distortion in DNA that may lead to mutations when DNA replicates. As discussed  
19 below, some carcinogens do not interact directly with DNA, but can produce increases in  
20 endogenous levels of DNA adducts (e.g., 8-hydroxyguanine) by indirect mechanisms.

### 21 22 **2.3.5.2. Indirect DNA Effects or Other Effects on Genes/Gene Expression**

23       Although some carcinogens may result in an elevation of mutations or cytogenetic  
24 anomalies as detected in standard assays, they may do so by indirect mechanisms. These effects  
25 may be brought about by chemical-cell interactions rather than the chemical (or its metabolite)  
26 directly interacting with DNA. An increase in mutations might be due to cytotoxic exposures  
27 causing regenerative proliferation or to mitogenic influences (Cohen and Ellwein, 1990).  
28 Increased cell division may elevate mutation by clonal expansion of initiated cells or by increasing  
29 the number of genetic errors by rapid cell division and reduced time for DNA repair. Some agents  
30 might result in an elevation of mutations by interfering with the enzymes involved in DNA repair  
31 and recombination (Barrett and Lee, 1992). Damage to certain critical DNA repair genes or other  
32 genes (e.g., the p53 gene) may result in genomic instability, which predisposes cells to further  
33 genetic alterations and increases the probability of neoplastic progression (Harris and Hollstein,  
34 1993; Levine, 1994). Likewise, DNA repair processes may be saturated at certain doses of a

1 chemical, and thus result in an elevation of genetic alterations. Programmed cell death (apoptosis)  
2 can potentially be blocked by an agent, thereby permitting replication of cells carrying genetic  
3 errors. For example, peroxisome proliferators may act by suppressing apoptotic pathways  
4 (Shulte-Hermann et al., 1993; Bayly et al., 1994). At certain doses an agent may also generate  
5 reactive oxygen species that produce oxidative damage to DNA and other important  
6 macromolecules (Kehrer, 1993; Clayson et al., 1994; Chang et al., 1988). The role of these  
7 adducts, attributable to oxidative damage (e.g., 8-hydroxyguanine), in tumorigenesis is currently  
8 unclear.

9         Several carcinogens have been shown to induce aneuploidy (Gibson et al., 1995; Barrett,  
10 1992). The loss or gain of chromosomes (i.e., aneuploidy) can result in the loss of heterozygosity  
11 or genomic instability (Fearon and Vogelstein, 1990; Cavenee et al., 1986). Agents that cause  
12 aneuploidy typically interfere with the normal process of chromosome segregation by interacting  
13 with non-DNA targets such as the proteins needed for chromosome movement. All tumors  
14 (except leukemias and lymphomas) are aneuploid, but whether this is the cause or the effect of  
15 tumorigenesis is not clear. Thus, it is important to understand whether the agent induces  
16 aneuploidy as a key early event in the carcinogenic process or is necessary for tumor progression.

17         It is possible for an agent to alter gene expression by transcriptional, translational, or post-  
18 translational modifications (Barrett, 1995). For example, perturbation of DNA methylation  
19 patterns may cause effects that contribute to carcinogenesis (Jones, 1986; Goodman and Counts,  
20 1993; Holliday, 1987; Chuang et al., 1996). Overexpression of genes by DNA amplification has  
21 been observed in certain tumors (Vainio et al., 1992). Gene amplification may result from  
22 disproportionate DNA replication. Other mechanisms of altering gene expression may involve  
23 cellular reprogramming through hormonal or receptor-mediated mechanisms (Ashby et al., 1994;  
24 Barrett, 1992).

25         Both cell proliferation and programmed cell death are mandatory for the maintenance of  
26 homeostasis in normal tissue, and when altered become important elements of the carcinogenic  
27 process. The balance between the two directly affects the survival and growth of initiated cells, as  
28 well as preneoplastic and tumor cell populations (i.e., increase in cell proliferation or decrease in  
29 cell death) (Bellamy et al., 1995; Cohen and Ellwein, 1990, 1991; Cohen et al., 1991). Thus,  
30 measures of these events contribute to the weight of the evidence for cancer hazard and to mode-  
31 of-action understanding. In studies of proliferative effects, distinctions should be made between  
32 mitogenesis and regenerative proliferation (Cohen and Ellwein, 1990, 1991; Cohen et al., 1991).  
33 In applying information from studies on cell proliferation and apoptosis to risk assessment, it is  
34 important to identify the tissues and target cells involved, to measure effects in both normal and

1 neoplastic tissue, to distinguish between apoptosis and necrosis, and to determine the dose that  
2 affects these processes. Gap-junctional intercellular communication is believed to play a role in  
3 tissue and organ development and in the maintenance of a normal cellular phenotype within  
4 tissues. A growing body of evidence suggests that chemical interference with gap-junctional  
5 intercellular communication is a contributing factor in tumor development (Swierenga and  
6 Yamasaki, 1992; Yamasaki, 1995).

### 7 8 **2.3.5.3. *Experimental Considerations in Evaluating Data on Precursor Events***

9 Most testing schemes for mutagenicity and other short-term assays were designed for  
10 hazard identification purposes; thus, these assays are generally conducted using acute exposures.  
11 For data on “precursor steps” to be useful in informing the dose-response curve for tumor  
12 induction below the level of observation, it is important that data come from in vivo studies where  
13 exposure is repeated or given over an extended period of time. Although consistency of results  
14 across different assays and animal models provides a stronger basis for drawing conclusions, it is  
15 desirable to have data on the precursor event in the same target organ, sex, animal strain, and  
16 species as the tumor data. In evaluating an agent’s mode of action, it is usually not sufficient to  
17 determine that some event commences upon dosing. It is important to understand whether it is a  
18 causal event that plays a key role in the process that leads to tumor development, versus an effect  
19 of the cancer process itself or simply an associated event.

### 20 21 **2.3.5.4. *Judging Data***

22 Criteria that are applicable for judging the adequacy of mechanistically based data include  
23 the following:

- 24
- 25 • mechanistic relevance of the data to carcinogenicity,
- 26 • number of studies of each endpoint,
- 27 • consistency of results in different test systems and different species,
- 28 • similar dose-response relationships for tumor and mode of action-related effects,
- 29 • tests conducted in accordance with generally accepted protocols, and
- 30 • degree of consensus and general acceptance among scientists regarding interpretation  
31 of the significance and specificity of the tests.
- 32

33 Although important information can be gained from in vitro test systems, a higher level of  
34 confidence is generally given to data that are derived from in vivo systems, particularly those

1 results that show a site concordance with the tumor data.

## 3 **2.4. BIOMARKER INFORMATION**

4 Various endpoints can serve as biological markers of events in biological systems or  
5 samples. In some cases, these molecular or cellular effects (e.g., DNA or protein adducts,  
6 mutation, chromosomal aberrations, levels of thyroid stimulating hormone) can be measured in  
7 blood, body fluids, cells, and tissues to serve as biomarkers of exposure in both animals and  
8 humans (Callemen et al., 1978; Birner et al., 1990). As such, they can do the following:

- 9
- 10 • act as an internal surrogate measure of chemical dose, representing as appropriate,  
11 either recent (e.g., serum concentration) or accumulated (e.g., hemoglobin adducts)  
12 exposure;
- 13 • help identify doses at which elements of the carcinogenic process are operating;
- 14 • aid in interspecies extrapolations when data are available from both experimental  
15 animal and human cells; and
- 16 • under certain circumstances, provide insights into the possible shape of the dose-  
17 response curve below levels where tumor incidences are observed (e.g., Choy, 1993).
- 18

19 Genetic and other findings (like changes in proto-oncogenes and tumor suppressor genes  
20 in preneoplastic and neoplastic tissue or, possibly, measures of endocrine disruption) can indicate  
21 the potential for disease and as such serve as biomarkers of effect. They, too, can be used in  
22 different ways:

- 23
- 24 • The spectrum of genetic changes in proliferative lesions and tumors following chemical  
25 administration to experimental animals can be determined and compared with those in  
26 spontaneous tumors in control animals, in animals exposed to other agents of varying  
27 structural and functional activities, and in persons exposed to the agent under study.
- 28 • They may provide a linkage to tumor response.
- 29 • They may help to identify subpopulations of individuals who may be at an elevated risk  
30 for cancer, e.g., cytochrome P450 2D6/debrisoquine sensitivity for lung cancer  
31 (Caporaso et al., 1989) or inherited colon cancer syndromes (Kinzler et al., 1991;  
32 Peltomäki et al., 1993).
- 33 • As with biomarkers of exposure, it may be justified in some cases to use these  
34 endpoints for dose-response assessment or to provide insight into the potential shape

1 of the dose-response curve at doses below those at which tumors are induced  
2 experimentally.

3  
4 In applying biomarker data to cancer assessment (particularly assessments based on  
5 epidemiologic data), one should consider the following:

- 6  
7 • routes of exposure,  
8 • exposure to mixtures,  
9 • time after exposure,  
10 • sensitivity and specificity of biomarkers, and  
11 • dose-response relationships.

12  
13 **2.5. MODE OF ACTION-GENERAL CONSIDERATIONS AND FRAMEWORK FOR**  
14 **ANALYSIS**

15 **2.5.1. General Considerations**

16 The interaction of the biology of the organism and the chemical properties of the agent  
17 determine whether there is an adverse effect. Thus, mode-of-action analysis is based on physical,  
18 chemical, and biological information that helps to explain key events<sup>5</sup> in an agent's influence on  
19 development of tumors. The entire range of information developed in the assessment is reviewed  
20 to arrive at a reasoned judgment. An agent may work by more than one mode of action both at  
21 different sites and at the same tumor site. It is felt that at least some information bearing on mode  
22 of action (e.g., SAR, screening tests for mutagenicity) is present for most agents undergoing  
23 assessment of carcinogenicity, even though certainty about exact molecular mechanisms may be  
24 rare.

25 Inputs to mode-of-action analysis include tumor data in humans, animals, and among  
26 structural analogues as well as the other key data. The more complete the data package and  
27 generic knowledge about a given mode of action, the more confidence one has and the more one  
28 can replace or refine default science policy positions with relevant information. Making reasoned  
29 judgments is generally based on a data-rich source of chemical, chemical class, and tumor type-  
30 specific information. Many times there will be conflicting data and gaps in the information base;  
31 one must carefully evaluate these uncertainties before reaching any conclusion.

---

<sup>2</sup>A "key event" is an empirically observable, precursor step that is itself a necessary element of the mode of action, or is a marker for such an element.

1 In making decisions about potential modes of action and the relevance of animal tumor  
2 findings to humans (Ashby et al., 1990), very often the results of chronic animal studies may give  
3 important clues. Some of the important factors to review include the following:

- 4
- 5 • tumor types, e.g., those responsive to endocrine influence or those produced by
- 6 reactive carcinogens (Ashby and Tennant, 1991);
- 7 • number of tumor sites, sexes, studies, and species affected or unaffected (Tennant,
- 8 1993);
- 9 • influence of route of exposure, spectrum of tumors, and local or systemic sites;
- 10 • target organ or system toxicity, e.g., urinary chemical changes associated with stone
- 11 formation, effects on immune surveillance;
- 12 • presence of proliferative lesions, e.g., hepatic foci, hyperplasias;
- 13 • progression of lesions from preneoplastic to benign to malignant with dose and time;
- 14 • ratio of malignant to benign tumors as a function of dose and time;
- 15 • time of appearance of tumors after commencing exposure;
- 16 • tumors invading locally, metastasizing, producing death;
- 17 • tumors at sites in laboratory animals with high or low spontaneous historical incidence;
- 18 • biomarkers in tumor cells, both induced and spontaneous, e.g., DNA or protein
- 19 adducts, mutation spectra, chromosome changes, oncogene activation; and
- 20 • shape of the dose response in the range of tumor observation, e.g., linear vs. profound
- 21 change in slope.
- 22

23 Some of the myriad of ways that information from chronic animal studies influences mode-  
24 of-action judgments include the following. Multisite and multispecies tumor effects are often  
25 associated with mutagenic agents. Tumors restricted to one sex/species may suggest an influence  
26 restricted to gender, strain, or species. Late onset of tumors that are primarily benign or are at  
27 sites with a high historical background incidence or show reversal of lesions on cessation of  
28 exposure may point to a growth-promoting mode of action. The possibility that an agent may act  
29 differently in different tissues or have more than one mode of action in a single tissue must also be  
30 kept in mind.

31 Simple knowledge of sites of tumor increase in rodent studies can give preliminary clues  
32 as to mode of action. Experience at the National Toxicology Program (NTP) indicates that  
33 substances that are DNA reactive and produce gene mutations may be unique in producing  
34 tumors in certain anatomical sites, while tumors at other sites may arise from both mutagenic or



1 nonmutagenic influences (Ashby and Tennant, 1991; Huff et al., 1991).

2 Effects on tumor sites in rodents and other mode-of-action information has been explored  
3 for certain agents (Alison et al., 1994; Clayson, 1989; ECETOC, 1991; MacDonald et al., 1994;  
4 McClain, 1994; Tischler et al., 1991; ILSI, 1995; Cohen and Ellwein, 1991; FASEB, 1994; Havu  
5 et al., 1990; U.S. EPA, 1991c; Li et al., 1987; Grasso and Hinton, 1991; Larson et al., 1994;  
6 IARC, 1990; Jack et al., 1983; Stitzel et al., 1989; Ingram and Grasso, 1991; Bus and Popp,  
7 1987; Prahalada et al., 1994; Yamada et al., 1994; Hill et al., 1989; Burek et al., 1988).

## 9 **2.5.2. Evaluating a Postulated Mode of Action**

### 11 *Peer Review*

12 This section contains a framework for evaluating a postulated mode of action. In reaching  
13 conclusions, the question of “general acceptance” of a mode of action will be tested as part of the  
14 independent peer review that EPA obtains for its assessment and conclusions. In some cases the  
15 mode of action may have already been established by development of a large body of research  
16 information and characterization of the phenomenon over time. In some cases there will have  
17 been development of an Agency policy, e.g., male rat thyroid disruption, or a series of previous  
18 assessments in which both the mode of action and its applicability to particular cases has been  
19 explored, e.g., urinary bladder stones. If so, the assessment and its peer review can be focused on  
20 the evidence that a particular agent acts in this mode.

21 In other cases, the mode of action previously may not have been the subject of an Agency  
22 document. If so, the data to support both the mode of action and the activity of the agent with  
23 respect to it will be the subjects of EPA assessment and subsequent peer review.

### 25 *Use of the Framework*

26 The framework supports a full analysis of mode-of-action information, but can also be  
27 used as a screen to decide whether sufficient information is available to evaluate or the data gaps  
28 are too substantial to justify further analysis. Mode-of-action conclusions are used to address the  
29 question of human relevance of animal tumor responses, to address differences in anticipated  
30 response among humans such as between children and adults or men and women, and as the basis  
31 of decisions about the anticipated shape of the dose-response relationship. Guidance on the latter  
32 appears in Section 3.

### 2.5.3. Framework for Evaluating a Postulated Carcinogenic Mode(s) of Action

This framework is intended to be an analytic tool for judging whether available data support a mode of carcinogenic action postulated for an agent. It is based upon considerations for causality in epidemiologic investigations originally articulated by Hill, but later modified by others and extended to experimental studies. The original Hill criteria were applied to epidemiologic data, while this framework is applied to a much wider assortment of experimental data, so it retains the basic principles of Hill but is much modified in content.

A mode of action is composed of key events and processes starting with the interaction of an agent with a cell, through operational and anatomical changes, resulting in cancer formation. “Mode” of action is contrasted with “mechanism” of action, which implies a more detailed, molecular description of events than is meant by mode of action. There are many examples of possible modes of carcinogenic action, such as mutagenicity, mitogenesis, inhibition of cell death, cytotoxicity with reparative cell proliferation, and immune suppression. All pertinent studies are reviewed in analyzing a mode of action, and an overall weighing of evidence is performed, laying out the strengths, weaknesses, and uncertainties of the case as well as potential alternative positions and rationales. Identifying data gaps and research needs is also part of the assessment.

To show that a postulated mode of action is operative, it is generally necessary to outline the sequence of events leading to cancer, to identify key events that can be measured, and to weigh information to determine whether there is a causal relationship between events and cancer formation. In no case will it be expected that the complete sequence is known at the molecular level. Instead, empirical observations made at different levels of biological organization are analyzed: biochemical, cellular, physiological, tissue, organ, and system levels.

Several important points should be kept in mind when working with the framework:

- The topics listed for analysis should *not* be regarded as a checklist of necessary “proofs.” The judgment whether a postulated mode of action is supported by available data takes account of the analysis as a whole.
- The framework provides a structure for organizing the facts upon which conclusions as to mode of action rest. The purpose of using the framework is to make analysis transparent and allow the reader to understand the facts and reasoning behind a conclusion.
- The framework does not dictate an answer. The weight of evidence that is sufficient to support a decision about a mode of action may be less or more depending on the purpose of the analysis, e.g., screening, research needs identification, or full risk

1 assessment. To make the reasoning transparent, the purpose of the analysis ought to  
2 be made apparent to the reader.

- 3 • Toxicokinetic studies may contribute to mode-of-action analysis by identifying the  
4 active form of an agent that is central to the mode of action. Apart from contributing  
5 in this way, toxicokinetics studies may reveal effects of saturation of metabolic  
6 processes. These are not considered key events in a mode of action, but are given  
7 separate consideration in assessing dose metrics and potential nonlinearity of the dose-  
8 response relationship.
- 9 • Generally, “sufficient” support is a matter of scientific judgment in the context of the  
10 requirements of the decision maker or in the context of science policy guidance  
11 regarding a certain mode of action.
- 12 • While a postulated mode of action may be supported for a described response in a  
13 specific tissue, it may not explain other tumor responses observed. The latter will need  
14 separate consideration in hazard and dose-response assessment.

15  
16 It is anticipated that in a risk assessment document, the analysis of a postulated mode of  
17 action will be presented before or with the characterization of an agent’s potential hazard to  
18 humans.

### 19 20 **2.5.3.1. Content of the Framework**

21 The framework analysis begins with a summary description of the postulated mode of  
22 action for a tumor type. (Each postulated mode of action requires separate analysis.) This is  
23 followed by topics for analysis and presentation in a convenient order. For illustration, the  
24 explanation of each topic includes typical questions to be addressed to the available empirical data  
25 and experimental observations anticipated to be pertinent. The latter will vary from case to case.  
26 For a particular mode of action, certain observations may be established as essential in practice or  
27 policy, e.g., measures of thyroid hormone levels in supporting thyroid hormone elevation as a key  
28 event in carcinogenesis. A conclusion and an analysis of human relevance including  
29 subpopulations are the the final parts of the analysis.

#### 30 31 *1. Summary Description of Postulated Mode of Action*

32 This description briefly explains the sequence of events and processes that are considered  
33 to lead to cancer formation. For example, for thyroid disruption and thyroid follicular cell tumors:  
34 Thyroid hormone production is regulated by actions of the hypothalamus,

1 pituitary, and thyroid gland. Homeostasis of thyroid hormone is maintained by  
2 a feedback loop between the hypothalamus and pituitary and the thyroid gland.  
3 The hypothalamus produces thyrotrophin reducing hormone (TRH), which  
4 stimulates the pituitary to produce thyroid stimulating hormone (TSH) which,  
5 in turn, stimulates the thyroid to produce thyroid hormone. The hypothalamus  
6 and pituitary respond to high levels of circulating thyroid hormone by  
7 suppressing TRH and TSH production, and to a low level by increasing them.  
8 The mode of action considered is continuous elevation of TSH levels that  
9 stimulates the thyroid gland to deplete its stores of thyroid hormone and  
10 continues to push production resulting in hypertrophy of the production cells  
11 (follicular cells) leading to hyperplasia, nodular hyperplasia, and, eventually,  
12 tumors of these cells. In rats, the chain of events may be induced by direct  
13 effects on hormone synthesis or by metabolic removal of circulating hormone.

14 2. “*Identification of key events*” is a consideration devised for this framework. A “key  
15 event” is an empirically observed precursor step consistent with a mode of action. In order to  
16 judge how well data support involvement of an event in carcinogenic processes, the experimental  
17 definition of the event or events must be clear and repeatable. To support an association,  
18 experiments need to define and measure an event consistently.

- 19
- 20 • Can a list of events be identified that are key to the carcinogenic process?
- 21 • Are the events well defined?
- 22

23 Pertinent observations: e.g., increased cell growth, organ weight, histology, proliferation assays,  
24 hormone or other protein perturbations, receptor-ligand changes, DNA or chromosome effects,  
25 cell cycle effects.

26

27 3. “*Strength, consistency, specificity of association*”: A statistically significant  
28 association between events and a tumor response observed in well-conducted studies is  
29 supportive of causation. Consistent observations in a number of such studies with differing  
30 experimental designs increases that support, since different designs may reduce unknown biases.  
31 Studies showing “recovery,” i.e., absence or reduction of carcinogenicity when the event is  
32 blocked or diminished, are particularly important tests of the association. Specificity of the  
33 association, without evidence of other modes of action, strengthens a causal conclusion.

- 1 • What is the level of statistical and biological significance for each event and for
- 2 cancer?
- 3 • Do independent studies and different experimental hypothesis-testing approaches
- 4 produce the same associations?
- 5 • Does the agent produce effects other than postulated?
- 6 • Is the key event associated with precursor lesions?
- 7

8 Pertinent observations: e.g., tumor response associated with events (site of action logically relates  
9 to event[s]), precursor lesions associated with events, initiation-promotion studies, stop/recovery  
10 studies.

11  
12 4. “*Dose-response relationship*”: If a key event and tumor endpoints increase with dose,  
13 a causal association can be strengthened. Dose-response associations of the key event with other  
14 precursor events can add further strength. Difficulty arises when an event is not causal, but  
15 accompanies the process generally. Dose-response studies coupled with mechanistic studies can  
16 assist in clarifying these relationships.

- 17
- 18 • What are the correlations among doses producing events and cancer?
- 19

20 Pertinent observations: e.g., 2-year bioassay observation of lesions correlated with observations of  
21 hormone changes and the same lesions in shorter term studies or in interim sacrifice.

22  
23 5. “*Temporal relationship*”: If an event is a cause of tumorigenesis, it must precede  
24 tumor appearance. An event may also be observed contemporaneously or after tumor  
25 appearance; these observations may add to the strength of association, but not to the temporal  
26 association.

- 27
- 28 • What is the ordering of events that underlie the carcinogenic process?
- 29 • Is this ordering consistent among independent studies?
- 30

31 Pertinent observations: Studies of varying duration observing the temporal sequence of  
32 events and tumorigenicity.

- 33
- 34 6. “*Biological plausibility and coherence*”: The postulated mode of action and the

1 events that are part of it need to be based on current understanding of the biology of cancer to be  
2 accepted. If the body of information under scrutiny is consistent with other examples (including  
3 structurally related agents) for which the postulated mode of action is accepted, the case is  
4 strengthened. Since some modes of action can be anticipated to evoke effects other than cancer,  
5 the available toxicity database on noncancer effects can contribute to this evaluation, e.g.,  
6 reproductive effects of certain hormonal disturbances.

- 7
- 8 • Is the mode of action consistent with what is known about carcinogenesis in general  
9 and for the case specifically?
  - 10 • Are carcinogenic effects and events consistent across structural analogues?
  - 11 • Is the database on the agent internally consistent in supporting the purported mode of  
12 action, including relevant noncancer toxicities?
- 13

14 Pertinent observations: Scientific basis for considering a postulated mode of action generally,  
15 given current state of knowledge of carcinogenic processes; previous examples of data sets  
16 showing the mode of action; data sets on analogues; coherence of data in this case from cancer  
17 and noncancer toxicity studies.

18

19 7. “*Other modes of action*”: This discussion covers alternative modes of action for the  
20 tumor response considered and whether they are supported by the data. In addition, it provides a  
21 place to discuss other tumor observations that may be arising from a different mode of action than  
22 postulated.

23

24 8. “*Conclusion*”: This is a brief conclusion and rationale as to whether the postulated  
25 mode of action is supported, also reflecting the purpose of the evaluation. The conclusion that a  
26 mode of action is supported is stronger as more of the above topic analyses point in the same  
27 direction, and weaker as fewer do so. The testing of the mode of action hypothesis by various  
28 experimental approaches with the same result creates a stronger basis for conclusions.  
29 Characteristics of strength of support include data showing that all key events are in sequence  
30 prior to tumor formation, dose and timing are consistent with the sequence, and reversal or  
31 reduction of key events and effects occurs upon cessation of dosing. The conclusion should  
32 address whether key event or associated metabolic information allows identification of rate-  
33 limiting measures of either the mode of action or of toxicokinetics.

34

1           9. “*Human relevance, including subpopulations*” : This is an analysis of data on the  
2 question whether a mode of action found to be operative in animals is also operative in humans  
3 and whether any human subpopulation is apt to qualitatively respond to the mode of action  
4 differently than the general population. Relevance to humans of animal responses is the default  
5 assumption since metazoans appear to share the basic modes of carcinogenic action.

6           When sufficient information is developed in mature animals to show a mode of action for a  
7 specific tumor type, an evaluation will be made of whether the mode of action is qualitatively  
8 applicable to children (including infants and fetuses), i.e., same sequence of key events is  
9 anticipated to be involved. Ideally we would have data pertinent to the question with respect to  
10 the agent under assessment. In the absence of such data, a cogent biological rationale needs to  
11 be developed regarding whether the mode of action is applicable to children. For the latter, the  
12 evaluation would cover the scientific information at large, including such considerations as  
13 age-related similarities and differences in the occurrence of the specific tumor type in the U.S.  
14 population, in occurrence of identified key events of the mode of action, in pertinent biochemical,  
15 physiological and toxicological processes, and in metabolism and excretion of the agent.  
16 Examples are given in case examples for chemicals T and Z in Appendix D. Based on the  
17 similarities of tumors following exposure to radiation, pharmaceuticals and viruses, from a  
18 qualitative standpoint, it may be anticipated that the same kind of tumors may develop following  
19 childhood or adult exposure to environmental chemicals. However, when there are no  
20 agent-specific data or there is not a cogent rationale supporting the comparability between  
21 responses in children and adults, the mode of action will not be considered to be applicable for  
22 children. It should also be noted that from a quantitative perspective, the same key events may  
23 lead to greater or lesser occurrence at different agents due to toxicokinetic and exposure  
24 considerations. These considerations need separate evaluation and may result in separate risk  
25 estimates for the young or for that portion of a lifetime.

## 26 27 28 29 **2.6. WEIGHT-OF-EVIDENCE EVALUATION FOR POTENTIAL HUMAN** 30 **CARCINOGENICITY**

31           A weight-of-evidence evaluation is a collective evaluation of all pertinent information so  
32 that the full impact of biological plausibility and coherence is adequately considered.  
33 Identification and characterization of human carcinogenicity is based on human and experimental  
34 data, the nature, advantages, and limitations of which have been discussed in the preceding

1 sections.

2 The subsequent sections outline: (1) the basics of weighing individual lines of evidence  
3 and combining the entire body of evidence to make an informed judgment, and (2) classification  
4 descriptors of cancer hazard.

### 6 **2.6.1. Weight-of-Evidence Analysis**

7 Judgment about the weight of evidence involves considerations of the quality and  
8 adequacy of data and consistency of responses induced by the agent in question. The weight-of-  
9 evidence judgment requires combined input of relevant disciplines. Initial views of one kind of  
10 evidence may change significantly when other information is brought to the interpretation. For  
11 example, a positive animal carcinogenicity finding may be diminished by other key data; a weak  
12 association in epidemiologic studies may be bolstered by consideration of other key data and  
13 animal findings. Factors typically considered are illustrated in figures below. Generally, no single  
14 weighing factor on either side determines the overall weight. The factors are not scored  
15 mechanically by adding pluses and minuses; they are judged in combination.

#### 17 *Human Evidence*

18 Analyzing the contribution of evidence from a body of human data requires examining  
19 available studies and weighing them in the context of well-accepted criteria for causation (see  
20 Section 2.2.1). A judgment is made about how closely the studies satisfy these criteria,  
21 individually and jointly, and how far they deviate from them. Existence of temporal relationships,  
22 consistent results in independent studies, strong association, reliable exposure data, presence of  
23 dose-related responses, freedom from biases and confounding factors, and high level of statistical  
24 significance are among the factors leading to increased confidence in a conclusion of causality.

25 Generally, the weight of human evidence increases with the number of adequate studies  
26 that show comparable results on populations exposed to the same agent under different  
27 conditions. The analysis takes into account all studies of high quality, whether showing positive  
28 associations or null results, or even protective effects. In weighing positive studies against null  
29 studies, possible reasons for inconsistent results should be sought, and results of studies that are  
30 judged to be of high quality are given more weight than those from studies judged to be  
31 methodologically less sound. See Figure 2-1.



Increase weight	Decrease weight
Number of independent studies with consistent results	Few studies
Most causal criteria satisfied:	Equally well-designed and conducted studies with null results
Temporal relationship	Few causal criteria satisfied
Strong association	
Reliable exposure data	
Dose-response relationship	
Freedom from bias and confounding	
Biological plausibility	
High statistical significance	



**Figure 2-1. Factors for weighing human evidence.**



Increase weight	Decrease weight
Number of independent studies with consistent results	Single study
	Inconsistent results
Same site across species, structural analogues	
Multiple observations	Single site/species/sex
Species	
Sites	
Sexes	
Severity and progression of lesions	Benign tumors only
Early-in-life tumors/malignancy	
Dose-response relationships	High background of incidence tumors
Lesion progression	
Uncommon tumor	
Route of administration like human exposure	Route of administration unlike human exposure

△

**Figure 2-2. Factors for weighing animal evidence.**

1 *Other Key Data*

2 Additional information bearing on the qualitative assessment of carcinogenic potential may  
3 be gained from comparative pharmacokinetic and metabolism studies, genetic toxicity studies,  
4 SAR analysis, and other studies of an agent's properties. See Figure 2-3. Information from these  
5 studies helps to elucidate potential modes of action and biological fate and disposition. The  
6 knowledge gained supports interpretation of cancer studies in humans and animals and provides a  
7 separate source of information about carcinogenic potential.

Increase weight	Decrease weight
A rich set of other key data are available	Few or poor data
Physicochemical data	or
Data indicate reactivity with macromolecules	Inadequate data necessitate use of default assumptions
Structure-activity relationships support hazard potential	or
Comparable metabolism and toxicokinetics between species	Data show that animal findings are not relevant to humans
Toxicological and human clinical data support tumor findings	
Biomarker data support attribution of effects to agent	
Mode-of-action data support causal interpretation of human evidence or relevance of animal evidence	



**Figure 2-3. Factors for weighing other data.**

1  
2  
3  
4  
5

***Totality of Evidence***

In reaching a view of the entire weight of evidence, all data and inferences are merged. Figure 2-4 indicates the generalities. In fact, possible weights of evidence span a broad continuum that cannot be capsulized. Most of the time the data in various lines of evidence fall in the middle of the weights represented in the four figures in this section.

Increase Weight	Decrease Weight
Evidence of human causality	Data not available or do not show causality
Evidence of animal effects relevant to humans	Data not available or not relevant
Coherent inferences	Conflicting data
Comparable metabolism and toxicokinetics between species	Metabolism and toxicokinetics not comparable
Mode of action comparable across species	Mode of action not comparable across species

△

**Figure 2-4. Factors for weighing totality of evidence.**

1 The following section and the weight-of-evidence narrative discussed in Section 2.8  
2 provide a way to state a conclusion and capture this complexity in a consistent way.  
3

#### 4 **2.6.2. Descriptors for Summarizing Weight of Evidence**

5  
6 To express conclusions about the weight of evidence for human carcinogenic potential,  
7 standard descriptors are utilized as part of the narrative (see Section 2.7.2.). The descriptors are  
8 not meant to replace an explanation of the nuances of the biological evidence, but rather to  
9 summarize it. Applying a descriptor is a matter of judgment and cannot be reduced to a formula.  
10 Each standard descriptor may be applicable to a wide variety of potential data sets and weights of  
11 evidence. There will always be gray areas, gradations, and borderline cases. That is why the  
12 descriptors are presented only in the context of a weight of evidence narrative. Using them within  
13 a narrative preserves and presents the complexity that is an essential part of the hazard  
14 characterization. Risk managers should consider the entire range of information included in the  
15 narrative rather than focusing simply on the descriptor.

16 Different conclusions may be reached for a single agent when carcinogenicity is dose or  
17 route dependent. For instance, the agent is likely to be carcinogenic by one route of exposure but  
18 not by others (Section 2.3.3). In this instance, more than one descriptor is used, one for each  
19 route of exposure. Another example would be that an agent is likely carcinogenic above a certain  
20 dose range but not likely to be carcinogenic below that range.

21 The descriptors are standardized and are to be used consistently from case to case. They  
22 are part of the first sentence of the narrative. The discussions below explain descriptors which  
23 appear in italics, and along with Appendices A and C, illustrate their use, including by route of  
24 exposure.

#### 25 *"Carcinogenic To Humans"*

26  
27 This descriptor is appropriate when there is convincing epidemiologic evidence  
28 demonstrating causality between human exposure and cancer.  
29

30 This descriptor is also appropriate when there is an absence of conclusive epidemiologic  
31 evidence to clearly establish a cause and effect relationship between human exposure and cancer,  
32 but there is compelling evidence of carcinogenicity in animals and mechanistic information in  
33 animals and humans demonstrating similar mode(s) of carcinogenic action. It is used when all of  
34 the following conditions are met:



- There is evidence in a human population(s) of association of exposure to the agent with cancer, but not enough to show a causal association, and
- There is extensive evidence of carcinogenicity, and
- The mode(s) of carcinogenic action and associated key events have been identified in animals, and
- The keys events that precede the cancer response in animals have been observed in the human population(s) that also shows evidence of an association of exposure to the agent with cancer.

***“Likely To be Carcinogenic To Humans”***

This descriptor is appropriate when the available tumor effects and other key data are adequate to demonstrate carcinogenic potential to humans. Adequate data are within a spectrum. At one end is evidence for an association between human exposure to the agent and cancer and strong experimental evidence of carcinogenicity in animals; at the other, with no human data, the weight of experimental evidence shows animal carcinogenicity by a mode or modes of action that are relevant or assumed to be relevant to humans.

***“Suggestive Evidence of Carcinogenicity,  
but Not Sufficient to Assess Human Carcinogenic Potential”***

This descriptor is appropriate when the evidence from human or animal data is suggestive of carcinogenicity, which raises a concern for carcinogenic effects but is judged not sufficient for a conclusion as to human carcinogenic potential. Examples of such evidence may include: a marginal increase in tumors that may be exposure-related, or evidence is observed only in a single study, or the only evidence is limited to certain high background tumors in one sex of one species. Dose-response assessment is not indicated for these agents. Further studies would be needed to determine human carcinogenic potential.

***“Data Are Inadequate for An Assessment of Human Carcinogenic Potential”***

This descriptor is used when available data are judged inadequate to perform an assessment. This includes a case when there is a lack of pertinent or useful data or when existing evidence is conflicting, e.g., some evidence is suggestive of carcinogenic effects, but other equally

1 pertinent evidence does not confirm a concern.

2  
3 ***"Not likely To Be Carcinogenic To Humans"***  
4

5 This descriptor is used when the available data are considered robust for deciding that  
6 there is no basis for human hazard concern. The judgment may be based on—  
7

- 8 • Extensive human experience that demonstrates lack of carcinogenic effect (e.g.,  
9 phenobarbital).
- 10
- 11 • Animal evidence that demonstrates lack of carcinogenic effect in at least two well-  
12 designed and well-conducted studies in two appropriate animal species (in the absence  
13 of human data suggesting a potential for cancer effects).
- 14
- 15 • Extensive experimental evidence showing that the only carcinogenic effects observed  
16 in animals are not considered relevant to humans (e.g., showing only effects in the  
17 male rat kidney due to accumulation of  $\alpha$ 2u-globulin).
- 18
- 19 • Evidence that carcinogenic effects are not likely by a particular route of exposure  
20 (Section 2.3.3.)
- 21 • Evidence that carcinogenic effects are not anticipated below a defined dose range.  
22  
23

24 **2.7. TECHNICAL HAZARD CHARACTERIZATION**

25 The hazard characterization has two functions. First, it presents results of the hazard  
26 assessment and an explanation of how the weight-of-evidence conclusion was reached. It explains  
27 the potential for human hazard, anticipated attributes of its expression, and mode-of-action  
28 considerations for dose response. Second, it contains the information needed for eventual  
29 incorporation into a risk characterization consistent with EPA guidance on risk characterization  
30 (U.S. EPA, 1995).

31 The characterization summarizes the conclusions reached concerning the mode of action  
32 of the agent and devotes particular attention to a clear statement of the strengths and weaknesses  
33 of the inferences made and their relation to the framework for analyzing described in Chapter 2.  
34 The implications of the mode of action for the dose-response assessment are clearly stated, along

1 with the degree of confidence in those conclusions.

2 The characterization qualitatively describes the conditions under which the agent's effects  
3 may be expressed in human beings. These qualitative hazard conditions are ones that are  
4 observable in the tumor and other key data without having done either quantitative dose-response  
5 or exposure assessment. The description includes how expression is affected by route of  
6 exposure and dose levels and durations of exposure. Implications for disproportionate risks in  
7 particular subpopulations, including fetuses and children, are identified when such information  
8 exists.

9 The discussion of limitations of dose as a qualitative aspect of hazard addresses the  
10 question of whether reaching a certain dose range appears to be a precondition for a hazard to be  
11 expressed; for example, when carcinogenic effects are secondary to another toxic effect that  
12 appears only when a certain dose level is reached. The assumption is made that an agent that  
13 causes internal tumors by one route of exposure will be carcinogenic by another route, if it is  
14 absorbed by the second route to give an internal dose. Conversely, if there is a route of exposure  
15 by which the agent is not absorbed (does not cross an absorption barrier; e.g., the exchange  
16 boundaries of skin, lung, and digestive tract through uptake processes) to any significant degree,  
17 hazard is not anticipated by that route. An exception to the latter statement would be when the  
18 site of contact is also the target tissue of carcinogenicity. Duration of exposure may be a  
19 precondition for hazard if, for example, the mode of action requires cytotoxicity or a physiologic  
20 change, or is mitogenicity, for which exposure must be sustained for a period of time before  
21 effects occur. The characterization could note that one would not anticipate a hazard from  
22 isolated, acute exposures. The above conditions are qualitative ones regarding preconditions for  
23 effects, not issues of relative absorption or potency at different dose levels. The latter are dealt  
24 with under dose-response assessment (Section 3), and their implications can only be assessed after  
25 human exposure data are applied in the characterization of risk.

26 The characterization describes conclusions about mode-of-action information and its  
27 support for recommending dose-response approaches.

28 The hazard characterization routinely includes the following in support of risk  
29 characterization:

- 30
- 31 • a summary of results of the assessment;
  - 32 • identification of the kinds of data available to support conclusions and explanation of  
33 how the data fit together, highlighting the quality of the data in each line of evidence,  
34 e.g., tumor effects, short-term studies, structure-activity relationships), and

- 1 highlighting the coherence of inferences from the different kinds of data;
- 2 • strengths and limitations (uncertainties) of the data and assessment, including
  - 3 identification of default assumptions invoked in the face of missing or inadequate data;
  - 4 • identification of alternative interpretations of data that are considered equally
  - 5 plausible;
  - 6 • identification of any subpopulations believed to be more susceptible to the hazard than
  - 7 the general population, especially attending to fetuses, infants, and children;
  - 8 • conclusions about the agent's mode of action and recommended dose-response
  - 9 approaches; and
  - 10 • significant issues regarding interpretation of data that arose in the assessment. Typical
  - 11 ones may include:
    - 12 -- determining causality in human studies,
    - 13 -- dosing (MTD), background tumor rates, relevance of animal tumors to
    - 14 humans;
    - 15 -- weighing studies with positive and null results, considering the influence of
    - 16 other available kinds of evidence; and
    - 17 -- drawing conclusions based on mode-of-action data versus using a default
    - 18 assumption about the mode of action.

## 20 **2.8. WEIGHT-OF-EVIDENCE NARRATIVE**

21 The weight-of-evidence narrative summarizes the results of hazard assessment employing  
22 the descriptors defined in Section 2.6.1. The narrative (about two pages in length) explains an  
23 agent's human carcinogenic potential and the conditions of its expression. If data do not allow a  
24 conclusion as to carcinogenicity, the narrative explains the basis of this determination. An  
25 example narrative appears below. More examples appear in Appendix A.

26 The items regularly included in a narrative are:

- 27
- 28 • name of agent and Chemical Abstracts Services number, if available;
- 29 • conclusions (by route of exposure) about human carcinogenicity, using a standard
- 30 descriptor from Section 2.6.1;
- 31 • summary of human and animal tumor data on the agent or its structural analogues,
- 32 their relevance, and biological plausibility;
- 33 • other key data (e.g., structure-activity data, toxicokinetics and metabolism, short-term
- 34 studies, other relevant toxicity or clinical data);

- discussion of possible mode(s) of action and appropriate dose-response approach(es); and
- conditions of expression of carcinogenicity, including route, duration, and magnitude of exposure.

*Example Narrative*

**Aromatic Compound**

**CAS# XXX**

**CANCER HAZARD SUMMARY**

Aromatic compound (AR) is *carcinogenic to humans* by all routes of exposure.

The weight of evidence of human carcinogenicity is based on (a) consistent evidence of elevated leukemia incidence in studies of exposed workers and significant increases of genetic damage in bone marrow cells and blood lymphocytes of exposed workers; (b) significantly increased incidence of cancer in both sexes of several strains of rats and mice; (c) genetic damage in bone marrow cells of exposed rodents and effects on intracellular signals that control cell growth.

AR is readily absorbed by all routes of exposure and rapidly distributed throughout the body. The mode of action of AR is not understood. A dose-response assessment that assumes linearity of the relationship is recommended as a default.

**SUPPORTING INFORMATION**

Data include numerous human epidemiologic and biomonitoring studies, long-term bioassays, and other data on effects of AR on genetic material and cell growth processes. The key epidemiologic studies and animal studies are well conducted and reliable. The other data are generally of good quality also.

**Human Effects**

Numerous epidemiologic and case studies have reported an increased incidence or a causal relationship associating exposure to AR and leukemia. Among the studies are five for which the design and performance as well as follow-up are considered adequate to demonstrate the causal relationship. Biomonitoring studies of exposed workers have found dose-related increases in chromosomal aberrations in bone marrow cells and blood lymphocytes.

1           **Animal Effects**

2           AR caused increased incidence of tumors in various tissues in both sexes of several rat and  
3 mouse strains. AR also caused chromosomal aberrations in rabbits, mice, and rats--as it does in  
4 humans.

5  
6           **Other Key Data**

7           AR itself is not DNA reactive and is not mutagenic in an array of test systems both in vitro  
8 and in vivo. Metabolism of AR yields several metabolites that have been separately studied for  
9 effects on carcinogenic processes. Some have mutagenic activity in test systems and some have  
10 other effects on growth controls inside cells.

11  
12       **MODE OF ACTION**

13           No rodent tumor precisely matches human leukemia in pathology. The closest parallel is a  
14 mouse cancer of blood-forming tissue. Studies of the effects of AR at the cell level in this model  
15 system are ongoing. As yet, the mode of action of AR is unclear, but most likely the carcinogenic  
16 activity is associated with one or a combination of its metabolites. It is appropriate to apply a  
17 linear approach to the dose-response assessment pending a better understanding because: (a)  
18 genetic damage is a typical effect of AR exposure in mammals, and (b) metabolites of AR produce  
19 mutagenic effects in addition to their other effects on cell growth controls; AR is a multitissue  
20 carcinogen in mammals, suggesting that it is affecting a common controlling mechanism of cell  
21 growth.

### 3. DOSE-RESPONSE ASSESSMENT

Dose-response assessment evaluates potential risks to humans at exposure levels of interest. The approach to dose-response assessment for a particular agent is based on the conclusion reached as to its mode of action (Sections. 2.4 -2.5). The evaluation first covers the relationship of the dose<sup>6</sup> to the degree of response in the dose range of observation in experiments or human studies. This evaluation is then followed by extrapolation to estimate response at lower environmental exposure levels (ILSI, 1995). In general, three extrapolations may be made: from high to low doses, from animal to human responses, and from one route of exposure to another.

Cancer is a disease that develops through many cell and tissue changes over time. Traditional dose-response assessment procedures using tumor incidence as the response have seldom taken into account the effects of key events within the whole biological process, even though these events are the determinants of the overall dose-response. This has been due to lack of empirical data and understanding about these events. As more data become available and our understanding about how agents cause cancer improves, they can be used in dose-response assessment along with the traditional procedures. These guidelines encourage use of these new data as they become available to improve dose-response assessment.

In this discussion, “response” data include measures of key events<sup>7</sup> considered integral to the carcinogenic process, in addition to tumor incidence. These responses may include changes in DNA, chromosomes, or other key macromolecules; effects on growth signal transduction, including induction of hormonal changes; or physiological or toxic effects that affect cell proliferation. Key events are precursors to cancer pathology; they may include proliferative events diagnosed as precancerous, but not pathology that is judged to be cancer. Analysis of such responses may be done along with those of tumor incidence to enhance the tumor dose-response analysis. If dose-response analysis of non tumor key events is more informative about the carcinogenic process for an agent, it is used in lieu of, or in conjunction with, tumor incidence

---

1. For this discussion, “exposure” means contact of an agent with the outer boundary of an organism. “Applied dose” means the amount of an agent presented to an absorption barrier and available for absorption. “Internal dose” means the amount crossing an absorption barrier (e.g., the exchange boundaries of skin, lung, and digestive tract) through uptake processes. “Delivered dose” for an organ or cell means the amount available for interaction with that organ or cell (U.S. EPA, 1992a).

2. A “key event” is an empirically observed precursor consistent with a mode of action.

1 analysis for the overall dose-response assessment.

2 “Dose” means the “human equivalent dose” as discussed in Section 3.3, unless otherwise  
3 noted. When animal responses are used in the assessment, the animal dose is adjusted to human  
4 equivalence. The preferred approach for this is to use toxicokinetic modeling to compare species.  
5 If this is not possible given the data available, a default factor for allometric scaling of oral dose is  
6 provided. For adjustment of inhalation dose, the EPA’s Reference Concentration (RfC)  
7 methodology is used.

### 8 9 10 *Coverage of the Chapter*

11 This chapter covers: 1) consideration of mode of action in selecting dose-response  
12 assessment approaches, 2) assessment of observed data and extrapolation procedures, 3)  
13 analyses of response data and 4) analyses of dose data. The final section discusses dose-response  
14 characterization.

### 15 16 **3.1 HUMAN STUDIES**

17 Analysis of human studies in the observed range is determined according to the type of  
18 study and how dose and response are measured in the study. In some cases the agent may have  
19 discernible interactive effects with another agent (e.g., asbestos and smoking), making possible  
20 estimation of contribution of the agent and others as risk factors. Also, in some cases, estimation  
21 of population risk in addition to, or in lieu of, individual risk may be appropriate. The following  
22 discussions are addressed mainly to animal data. Nevertheless, if human data permit, the  
23 principles or approaches below apply for performing dose-response assessment in two parts--  
24 range of observation and range of extrapolation, for deriving a point of departure, and for linear  
25 or margin of exposure analysis according to mode of action (NRC, 1999; Teta, 1999). The  
26 approach is tailored to the nature of the human data and the mode of action data available, if any.

### 27 28 29 **3.2. MODE OF ACTION AND DOSE-RESPONSE APPROACH**

30  
31 The cancer dose-response relationship(s) for a chemical is considered in a two step  
32 process. First is the determination of the mode of action and dose response for each tumor type  
33 that results in a significant increase in tumor incidence. Second is an analysis of the information  
34 bearing on all tumor types that are increased in incidence by the chemical. The overall synthesis



1 includes consideration of the number of sites, their consistency across sexes, strains and species,  
2 the strength of the mode of action information for each tumor type, the anticipated relevance of  
3 each tumor type to humans, and the consistency of the means of estimating risks across tumor  
4 types.

5 For each tumor the mode of action and other information may support one of the  
6 following dose response extrapolations: 1) linear, 2) nonlinear using a margin of exposure  
7 (MOE) analysis, or 3) both linear and nonlinear (MOE) analyses. In rare cases, detailed mode of  
8 action information may be available which allow the formulation of a biologically based model.  
9 Examples include the following:

### 10 *Factors Supporting a Linear Approach*

11 Any of the following conclusions leads to selection of a linear dose-response assessment  
12 approach:  
13

- 14 • There is an absence of sufficient tumor mode of action information.
- 15 • The chemical has direct DNA mutagenic activity or other indications of DNA effects  
16 that are consistent with linearity.
- 17 • Human exposure or body burden is high and near doses associated with key events in  
18 the carcinogenic process (e.g., 2,3,7,8-tetrachlorodibenzo-p-dioxin)
- 19 • Mode of action analysis does not support direct DNA effects, but the dose-response  
20 relationship is expected to be linear (e.g., certain receptor-mediated effects)

### 21 *Factors Supporting a Nonlinear Approach*

22 Any of the following conclusions leads to selection of a nonlinear (margin of exposure)  
23 approach to dose-response assessment:  
24

- 25 • A tumor mode of action supporting nonlinearity applies (e.g., some cytotoxic and  
26 hormonal agents such as disruptors of hormone homeostasis), *and* the chemical does  
27 not demonstrate mutagenic effects consistent with linearity.
- 28 • A mode of action supporting nonlinearity has been demonstrated, *and* the chemical has  
29 some indication of mutagenic activity, but it is judged not to play a significant role in  
30 tumor causation.

### 31 *Factors Supporting Both Linear And Nonlinear Approaches*

32 Any of the following conclusions leads to selection of both a linear and nonlinear approach  
33 to dose-response assessment. Relative support for each dose response method and advice on the  
34

1 use of that information needs to be presented. In some cases, evidence for one mode of action is  
2 stronger than for the other, allowing emphasis to be placed on that dose-response approach. In  
3 other cases, both modes of action are equally possible, and both dose-response approaches should  
4 be emphasized.

- 5
- 6 • Modes of action for a single tumor type support both linear and nonlinear dose  
7 response in different parts of the dose-response (e.g., 4,4' methylene chloride).
- 8 • A tumor mode of action supports different approaches at high and low dose; e.g., at  
9 high dose, nonlinearity, but, at low dose, linearity (e.g., formaldehyde).
- 10 • The agent is not DNA-reactive and all plausible modes of action are consistent with  
11 nonlinearity, but not fully established (arsenic).
- 12 • Modes of action for different tumor types support differing approaches, e.g., nonlinear  
13 for one and linear due to lack of mode of action for the other (e.g., trichloroethylene).
- 14

15 The use of biologically based models is covered below.

### 17 **3.3. DOSE-RESPONSE ANALYSIS**

#### 18 **3.3.1. Modeling the Overall Process--Biologically-based Models**

19 Generally applicable biologically-based models may be applied such as the two-stage  
20 models of initiation plus clonal expansion and progression developed by Moolgavkar and  
21 Knudson (1981), Chen and Farland (1991) and others. These models of the carcinogenic process  
22 continue to be improved, but are not yet standard methods. No model of this kind is available for  
23 standard application.

24 If data are extensive and sufficient to quantitatively relate specific key events in the cancer  
25 process to neoplasia, and the purpose of the assessment is such as to justify investing the  
26 necessary resources, a biologically-based model may be developed on an agent-specific basis.  
27 Before developing such a model, extensive data are needed to build its form as well as to estimate  
28 how well it conforms with the observed data to support confidence in results. Theoretical  
29 estimates of critical parameters, such as cell proliferation rates, are not used to enable application  
30 of such a model in the absence of data (Portier, 1987). It is possible that different models will  
31 provide equivalent fits to the observed data but differ substantially in their projections below the  
32 observed range. This is often the case when a model is over-parameterized (that is, there are  
33 more parameters to be estimated than data points to be fitted), so that different combinations of  
34 parameter estimates can yield similar results in the observed range. For this reason, critical

1 parameters of a biologically based model, such as mutation and proliferation rates, are measured  
2 in the laboratory and not estimated by curve-fitting to tumor incidence data. This approach helps  
3 reduce model uncertainty (i.e., uncertainty due to choice of models or model structure) and  
4 ensures that the models do not give answers that are biologically unrealistic. This approach also  
5 provides a robustness of results (i.e., results are not likely to change substantially when fitted to a  
6 slightly different data set), if the mode of action is sufficiently understood so that model  
7 parameters represent rates and other quantities associated with known key events in tumor  
8 development.

9 Such models are to be distinguished from toxicokinetic models (i.e., physiologically based  
10 pharmacokinetic” models) which address dose issues, as discussed in Section 3.3.2. Effects on  
11 dose such as saturation of metabolic pathways may introduce nonlinearities in the dose-response  
12 relationship, but are not modes of action, and are dealt within arriving at an appropriate dose  
13 metric.  
14

### 15 **3.3.2. Analysis in the Range of Observation**

16 This section covers use of information about key events which may be in the context of  
17 either human or animal data. It then discusses curve-fitting and selecting a point of departure  
18 with regard to animal data. Last, it discusses human data.  
19

#### 20 **3.3.2.1. Applying Information About Key Events**

21 Even though a biologically-based model may not be feasible, information about key events  
22 in the process can be used in the assessment. The principle underlying these Guidelines is to use  
23 approaches that include as much information about these events as possible. When such  
24 information is available, it may be used in a variety of ways:

25 1) If an event(s) is quantitatively described and considered key to cancer development, its  
26 dose-response assessment in the range of observation can be used in conjunction with, or in lieu  
27 of, the dose-response for tumor incidence to establish the point of departure for extrapolation.  
28 [Caution must be used in using rates of molecular events such as mutation or cell proliferation or  
29 of signal transduction. Such rates may be difficult to relate to cell or tissue changes overall. The  
30 timing of observations of these phenomena, as well as the cell type involved, need to be linked to  
31 other precursor events to ensure the measurement is truly a “key”event (see Section 2.5). In  
32 many cases such rates are more appropriately used as in "2)" or "3)" below.]

33 2) Quantitative description of a key event(s) can be used to test whether the dose-  
34 response for tumor incidence can be confidently extended to support a lower point of departure

1 for linear extrapolation than the tumor data alone would support (e.g., to an LED<sub>01</sub> from an  
2 LED<sub>10</sub>).

3 3) Quantitative information on a key event(s) can be used to address the question of how  
4 quickly risk decreases as dose decreases in a margin of exposure analysis.  
5

### 6 ***3.3.2.2. Procedures for Analysis in the Range of Observation of Animal Studies***

#### 7 **Curve-fitting**

8  
9 A curve-fitting procedure is used that is appropriate to the kind of response data in the  
10 range of observation. This may be tumor incidence or data on a key event(s). For incidence  
11 information, the Agency applies a standard curve-fitting procedure to provide consistency among  
12 assessments. This procedure models incidence, adjusted for background, as an increasing function  
13 of dose; it is available to the public on the Agency's World Wide Web site for immediate use or  
14 for downloading (reference to be provided). The procedure identifies situations in which the  
15 standard algorithm fails to yield a reliable point of departure, signaling the need for additional  
16 judgment and an alternative analysis.

17 For tumor incidence studies that provide time-to-tumor information, more elaborate  
18 models would be appropriate. The Agency intends to provide a time-to-tumor version of its  
19 standard procedure in the future.

20 For non tumor data, curve-fitting procedures are used that are appropriate to the kind of  
21 response data in the observed range, and are explained in each case (reference to benchmark  
22 models to be provided).

#### 23 ***NOAEL/LOAEL***

24 As discussed below, the observed range of data may be represented by a  
25 NOAEL/LOAEL procedure when a margin of exposure analysis is chosen as the default  
26 procedure for nonlinear dose-response extrapolation.  
27

### 28 ***3.3.2.3. Point of Departure for Extrapolation from Observed Animal Data***

29 A point of departure from observed data--for tumor incidence, or for key event(s)--is  
30 estimated to mark the beginning of extrapolation. This is a point that is either a data point or an  
31 estimated point that can be considered to be in the range of observation, without significant  
32 extrapolation. Depending on the kind of data available and the purpose of the analysis, there are  
33 differing procedures for estimating the point of departure. The point of departure employs the  
34 human equivalent dose.

1 Incidence data are most amenable to curve-fitting procedures. For example, tumor data  
2 from a rodent bioassay are traditionally modeled with curve-fitting procedures. Some key event  
3 data may also be in the form of incidence data (e.g., hyperplasia), but more likely will be  
4 continuous data for which currently there are not standard and consistent modeling procedures.  
5 Continuous data include, for instance, tissue weight changes or blood levels of a hormone.  
6 NOAEL/LOAEL procedures are available for continuous and other data as needed.

### 7 8 *Point of Departure Using Data Suitable for Curve-fitting*

9 When a curve-fitting procedure is applied to tumor data (see Figure 3-1) or to incidence  
10 data on a key event, the point of departure used in most cases is the LED<sub>10</sub>--the 95% lower  
11 confidence limit on a dose associated with 10% extra risk adjusted for background. For tumor  
12 data, it is used as a matter of science policy to provide consistency among assessments. It is also  
13 useful in comparing results with assessment of noncancer endpoints (U.S. EPA, 1991d). The 10%  
14 level is selected because a 10% response is at or just below the limit of sensitivity for discerning a  
15 statistically significant tumor increase in most long-term rodent studies (Haseman, 1983), and is  
16 within the observed range for many other kinds of toxicity studies. Use of the lower limit takes  
17 experimental variability and sample size into account. If a tumor incidence study has greater than  
18 usual sensitivity and an observed response is below LED<sub>10</sub>, then a lower point for linear  
19 extrapolation can be used to improve the assessment. [The ED<sub>10</sub> (central estimate) is appropriate  
20 for use in relative hazard/potency ranking among agents for priority setting because it is a more  
21 confident comparison point among many assessments than an extrapolated point. Because of its  
22 convenience for comparison uses, the ED<sub>10</sub> is always presented for reference with its upper and  
23 lower 95% confidence limits.]

24 The LED<sub>10</sub> is adopted as the standard point of departure for non tumor key event or  
25 toxicity incidence data in order to harmonize curve-fitting procedures between cancer and  
26 noncancer toxicity assessments. Because the NOAEL in study protocols for non tumor toxicity  
27 can range from about a 5% to a 30% effect level (Faustman et al., 1994), adopting the 10%  
28 effect level as the standard point of departure will accommodate most of these data sets without  
29 departing the range of observation. The LED<sub>10</sub> can be regarded as an improved and harmonized  
30 estimate of the NOAEL.

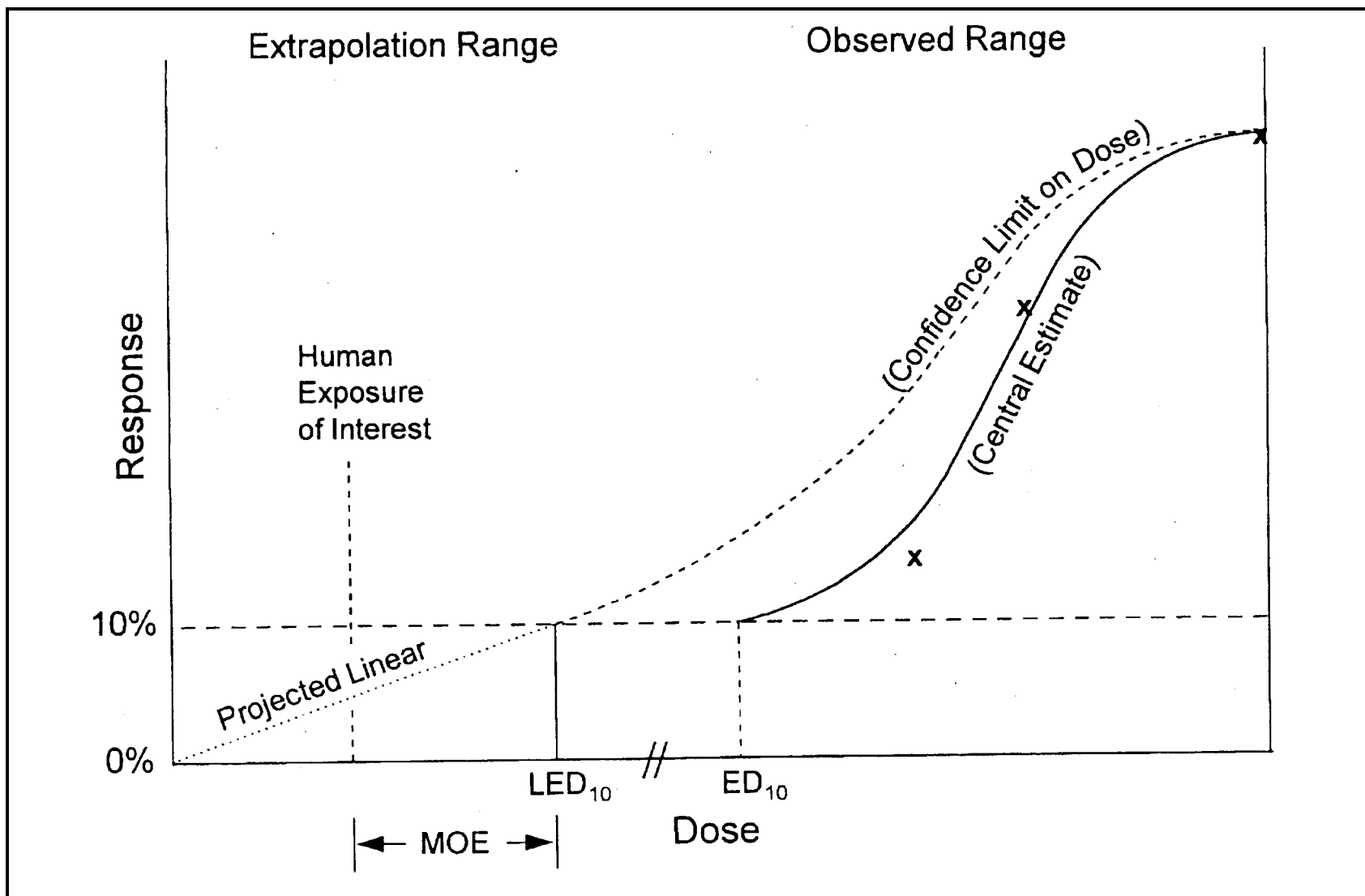


Figure 3-1. Graphical presentation of data and extrapolation.

1                    ***Point of Departure Using Data Suitable for a NOAEL/LOAEL Procedure***

2                    The point of departure may be a NOAEL when a margin of exposure analysis is the  
3 nonlinear dose-response approach. The kinds of data available and the circumstances of the  
4 assessment both contribute to deciding to estimate a NOAEL or LOAEL which is not as rigorous  
5 or as ideal as curve-fitting, but can be appropriate. The NOAEL/LOAEL procedure is used to  
6 maintain consistency among assessments while still encouraging quantitative analyses of the data  
7 by modeling to explore underlying phenomena.

8                    The circumstances of an assessment can also lead to choosing a NOAEL/LOAEL  
9 approach. If several data sets for key events and tumor response are available for an agent, and  
10 they are a mixture of continuous and incidence data, the most practicable way to assess them  
11 together is through a NOAEL/LOAEL approach. The purpose of the assessment also may lead to  
12 a decision to use the NOAEL/LOAEL approach. A preliminary or screening assessment to decide  
13 whether risk concern is high or low or to decide on additional data requirements is one example.  
14 Similarly, the nature of the regulatory decision may be served well by this approach to assessment.

15  
16                    **3.3.3. Analysis in the Range of Extrapolation--Default Procedures**

17                    Extrapolation from the point of departure to lower doses is usually necessary, and in the  
18 absence of a data set rich enough to support a biologically based model, is conducted using one of  
19 the two default procedures described below. The Agency has adopted these procedures as a  
20 matter of science policy based on current hypotheses of the potential shapes of dose-response  
21 curves for differing modes of action at low doses. The choice of the procedure to be used in an  
22 individual case is a judgment based on the agent's mode of action (See Section 3.2).

23  
24                    **3.3.3.1. Linear Procedure**

25                    For linear extrapolation, a straight line is drawn from the point of departure expressed as a  
26 human equivalent dose (Section 3.3.2) to the origin--zero incremental dose, zero incremental  
27 response to give a probability of extra risk. The slope of the line expresses extra risk per dose  
28 unit (Flamm and Winbush, 1984; Gaylor and Kodell, 1980; Krewski et al., 1984). Risk is the  
29 product of the slope and anticipated exposure. This approach to assessing risk is considered  
30 generally conservative of public health, including sensitive subpopulations, in the absence of  
31 specific information about the extent of human variability in sensitivity to effects. When a linear  
32 extrapolation procedure is used, the risk characterization summary also displays the degree of  
33 extrapolation from empirical data by showing the margin of exposure associated with exposure  
34 scenarios of interest as below.

1 **3.3.3.2. *Nonlinear Extrapolation***

2 A default assumption of nonlinearity is appropriate when there is no evidence for linearity  
3 and sufficient evidence to support an assumption of nonlinearity. The mode of action may lead to  
4 a dose-response relationship that is nonlinear, with response falling much more quickly than  
5 linearly with dose, or being most influenced by individual differences in sensitivity. Alternatively,  
6 the mode of action may theoretically have a threshold, e.g., the carcinogenicity may be a  
7 secondary effect of toxicity or of an induced physiological change that is itself a threshold  
8 phenomenon (see Appendix C, example 5, or Appendix D, example 2 ). The EPA does not  
9 generally try to distinguish between modes of action that might imply a "true threshold" from  
10 others with a nonlinear dose-response relationship. Except in unusual cases where extensive  
11 information is available, it is not possible to distinguish between these empirically.

12 As a matter of science policy under this analysis, nonlinear probability functions are not  
13 fitted to the response data to extrapolate quantitative low-dose risk estimates because different  
14 models can lead to a very wide range of results, and there is currently no basis, generally, to  
15 choose among them. Thus, the default procedure for nonlinear extrapolation is to conduct a  
16 margin of exposure analysis, as described below, to evaluate concern for levels of exposure.

17  
18 **3.3.3.2.1. *Margin of Exposure Analysis***

19 A margin of exposure is defined as the point of departure divided by the environmental  
20 exposure of interest. The environmental exposures of interest, for which margins of exposure are  
21 estimated, may be actual or projected exposure levels. A risk manager decides whether a given  
22 margin of exposure is acceptable under applicable management policy criteria. The risk  
23 assessment provides supporting information to assist the decisionmaker in this determination.

24 A margin of exposure analysis is applicable if data are sufficient to presume a non-linear  
25 dose-response function containing a significant change in slope. If, in a particular case, the  
26 evidence indicates a biological threshold, as in the case of carcinogenicity being secondary to  
27 another toxicity that has a threshold, an RfD<sup>8</sup> or RfC like approach may be estimated and  
28 considered in cancer assessment. In this case, the RfD or RfC is an estimate with uncertainty

---

3. A reference dose (RfD) or reference concentration (RfC) for noncancer toxicity is an estimate with uncertainty spanning perhaps an order of magnitude of daily exposure to the human population (including sensitive subgroups) that is anticipated to be without appreciable deleterious effects during a lifetime. It is arrived at by dividing empirical data on effects by uncertainty factors that consider inter- and intraspecies variability, extent of data on all important chronic exposure toxicity endpoints, and availability of chronic as opposed to subchronic data.



1 spanning perhaps an order of magnitude of daily exposure to the human population (including  
2 sensitive subgroups) that is anticipated to be without a cancer hazard despite a lifetime of  
3 exposure. In many cases, data may be insufficient to determine an RfD and/or an RfC for the  
4 cancer endpoint. In that case, a margin of exposure analysis provides useful input to the decision-  
5 maker regarding the distance between an exposure of interest and the range of observation where  
6 cancer risk is inferred to be sub-linear.

7  
8 To support a risk manager's consideration of the margin of exposure, all of the pertinent  
9 hazard, dose-response, and human exposure information is characterized so as to provide insights  
10 about the scientific community's current understanding of the phenomena that may be occurring  
11 as dose (exposure) decreases substantially below the observed data. The goal is to provide as  
12 much information as possible about the risk reduction that accompanies lowering of exposure and  
13 the adequacy of a margin of exposure based on scientific input, recognizing that, in some cases,  
14 legislative, sociological, and/or technological issues may also impact on the decision regarding the  
15 acceptability of a given margin of exposure. The discussion below describes the general principles  
16 and major elements to be considered in a margin of exposure analysis. The Agency will develop  
17 more specific guidance on the margin of exposure approach, as recommended (SAB, 1999). The  
18 guidance will be peer reviewed and published separately as part of the Agency's implementation  
19 activity of these guidelines.

20  
21 For a margin of exposure analysis, the point of departure would ideally be the dose where  
22 the key events in tumor development would not occur in a heterogenous human population, thus  
23 representing an actual "no effect level." Therefore, it is recommended that margin of exposure  
24 analyses be based on precursor responses rather than tumor incidences, since precursor events  
25 can often be detected with greater sensitivity( i.e. both earlier and at lower doses), providing  
26 further input to the decision regarding acceptability of the margin of exposure. An analysis of an  
27 actual point of departure derived from available data, however, would often contain residual  
28 uncertainty regarding its designation as an actual no effect level for cancer in the population. The  
29 earlier the precursor event in the carcinogenic process and the larger the margin of exposure the  
30 more likely the exposure of interest will be without appreciable risk of cancer. To this end, some  
31 important points to address in the analysis of the point of departure and the margin of exposure  
32 include the following:

- 33  
34
- *Nature of the response.* Is the point of departure based on tumors or on a *key event*

1 that is a precursor to tumors? A mode of action can be represented by a sequence of  
2 dose-response curves, where an early key event arises at a low dose, subsequent key  
3 events at higher doses, and tumors at a still higher dose. For example, a mode of  
4 action that begins with bladder stones and progresses through epithelial irritation and  
5 hyperplasia before producing tumors can be represented by a sequence of dose-  
6 response curves for stones, irritation, hyperplasia, and tumors, each curve higher on  
7 the dose scale than its immediate precursor. A nonlinear dose-response assessment  
8 considers more than tumors as it identifies a dose where events that can lead to tumor  
9 development would not occur. Identification of a key event does not imply that it is  
10 adverse in itself, only that it is an observable step preceding tumor development.  
11 Basing a dose-response assessment on key events is intended to protect against not  
12 only the observation of adverse effects, but also earlier damage that can lead to later  
13 tumor development.

14  
15 Thus, it is most desirable to estimate a dose-response curve for the key event precipitating  
16 tumor development, and use this curve to estimate the point of departure. However, lack  
17 of quantitative information on the key event may make it necessary to use tumor data  
18 instead of key event data. In this case, the analysis of the margin of exposure must  
19 contain an estimate of the dose-response curve for tumors plus have sufficient discussion  
20 of the difference (on the dose scale) between no effect levels and effect levels for key  
21 events and for tumors. A larger margin of exposure may be needed to account for  
22 possible differences between the dose-response curves for the key events and for tumors,  
23 and to assure decision-makers that cancer risk for the heterogeneous population  
24 (including sensitive subgroups) is not appreciable.

- 25
- 26 • *Slope of the observed dose-response curve.* Have we reached a dose where tumors  
27 or (preferably) the key precursor events *would not occur*? A 10-percent incidence is  
28 typically used as a point of departure because it reflects the lowest incidence that  
29 experimental studies can typically detect. This does not, however, mean that a 10-  
30 percent incidence represents a level where tumors or the key precursor events would  
31 not occur. To account for this limitation, one needs to consider the slope of the dose-  
32 response curve, which describes how sharply the incidence declines below the point of  
33 departure. If the dose-response curve at the point of departure is relatively steep, the  
34 point of departure represents a point on the dose-response curve where occurrence of

1 the key event(s) declines rapidly with decreasing dose. On the other hand, if the dose-  
2 response curve is relatively shallow, then the point where the effect virtually  
3 disappears may lie far below the point of departure. In short, the margin of exposure  
4 needs to be larger if the analysis is based on a response(s) that has a shallow dose-  
5 response curve compared to an analysis based on a response with a steep dose-  
6 response curve. More guidance needs to be developed to define quantitatively what  
7 constitutes a steep versus a shallow dose-response curve.  
8

- 9 • *Human sensitivity compared with experimental animals.* How sensitive is the *human*  
10 *population* compared with the tested animals? For this comparison, all doses should  
11 have already been converted to equivalent human doses, using either a physiologically  
12 based toxicokinetic model, a cross-species dosimetry model, or the default cross-  
13 species scaling factor. These dose conversions reflect interspecies differences in  
14 toxicokinetics, not toxicodynamics. When information is not sufficient to quantify  
15 human sensitivity with regard to the toxicodynamics compared with the tested animals,  
16 this uncertainty needs to be taken into account in the discussion of an adequate margin  
17 of exposure. As with noncancer assessment, the default assumption is that the most  
18 sensitive humans are more sensitive than the test animals. Depending on the data  
19 available on the sensitivity of the test species to the agent and the endpoint of concern  
20 as compared to humans, the margin of exposure decision may need to incorporate  
21 more or less conservatism.  
22
- 23 • *Nature and extent of human variability in sensitivity.* Is there information on *sensitive*  
24 *individuals* that would be part of a heterogeneous human population? Pertinent  
25 information would come from human studies, since animal studies, particularly those  
26 using homogeneous animal strains, do not provide information about human  
27 variability. When information is not sufficient to quantify the extent of human  
28 variability in sensitivity, this uncertainty should be reflected in the discussion of an  
29 adequate margin of exposure (also see discussion below on human exposure).  
30
- 31 • *Human Exposure.* The evaluation of margin of exposure also takes into account the  
32 expected pattern of human exposure to an agent including the magnitude, frequency,  
33 and duration of exposure. Some modes of action involve significant duration of  
34 exposure before tumorigenicity results. For example, stimulus of cell growth through

1 hormonal or other signal disruption or as a result of damage from toxicity is reversible  
2 if the exposure is for a short time, since homeostasis brings a return to normal levels  
3 after cessation of exposure. Thus, for a specialized population that is occasionally and  
4 briefly exposed to an agent with such a mode of action, an adequate margin of  
5 exposure would be smaller than for chronic exposure. As the duration of exposure or  
6 frequency of exposure increases, an adequate margin of exposure would increase  
7 accordingly.

8  
9 Furthermore, if the population exposed in a particular scenario is wholly or largely  
10 composed of a subpopulation of special concern (e.g. children) for whom evidence  
11 indicates a special sensitivity to the agent's mode of action, an adequate margin of  
12 exposure would be larger than for general population exposure.

13  
14 To provide input regarding scientific considerations regarding the acceptability of a margin of  
15 exposure by the risk manager, the risk assessment along with risk characterization explicitly  
16 considers all of the hazard and dose-response and human exposure factors together. This input on  
17 the margin of exposure is not solely a composite of individual adjustment factors to account for  
18 missing data or knowledge gaps as discussed above. Rather, each case calls for individual  
19 judgment, taking all of these points as a whole. It is appropriate to provide a graphical  
20 representation of the data and dose-response modeling in the observed range, also showing  
21 exposure levels of interest to the decision-maker (See figure 3-1.). In order to provide a frame of  
22 reference, by way of comparison, a straight line extrapolation may be displayed to show what risk  
23 levels would be associated with decreasing dose, if the dose-response were linear.

#### 24 25 **3.3.3.3. *Linear and Nonlinear Extrapolations***

26 Both linear and nonlinear procedures may be used in particular cases. If a mode of action  
27 analysis finds substantial support for differing modes of action for different tumor sites, an  
28 appropriate procedure is used for each. Both procedures may also be appropriate to discuss  
29 implications of complex dose-response relationships. For example, if it is apparent that an agent  
30 is both DNA reactive and is highly active as a promotor at high doses, and there are insufficient  
31 data for modeling, both linear and nonlinear default procedures may be needed to decouple and  
32 consider the contribution of both phenomena.

#### 33 34 **3.3.3.4. *Use of Toxicity Equivalence Factors and Relative Potency Estimates***

1 A toxicity equivalence factor (TEF) procedure is one used to derive quantitative dose-  
2 response estimates for agents that are members of a category or class of agents. TEFs are based  
3 on shared characteristics that can be used to order the class members by carcinogenic potency  
4 when cancer bioassay data are inadequate for this purpose (U.S. EPA, 1991c). The ordering is by  
5 reference to the characteristics and potency of a well-studied member or members of the class.  
6 Other class members are indexed to the reference agent(s) by one or more shared characteristics  
7 to generate their TEFs. The TEFs are usually indexed at increments of a factor of 10. Very good  
8 data may permit a smaller increment to be used. Shared characteristics that may be used are, for  
9 example, receptor-binding characteristics, results of assays of biological activity related to  
10 carcinogenicity, or structure-activity relationships.

11 TEFs are generated and used for the limited purpose of assessment of agents or mixtures  
12 of agents in environmental media when better data are not available. When better data become  
13 available for an agent, its TEF should be replaced or revised. Criteria for constructing TEFs are  
14 given in U.S. EPA (1991b). The criteria call for data that are adequate to support summing doses  
15 of the agents in mixtures. To date, adequate data to support use of TEF's has been found in only  
16 one class of compounds (dioxins) (U.S. EPA, 1989a).

17 Relative potencies can be similarly derived and used for agents with carcinogenicity or  
18 other supporting data. These are conceptually similar to TEFs, but they are less firmly based in  
19 science and do not have the same level of data to support them. They are used only when there is  
20 no better alternative.

21 The uncertainties associated with both TEFs and relative potencies are explained  
22 whenever they are used.

### 23 24 **3.4. RESPONSE DATA**

25 Response data for analysis include tumor incidence data from human or animal studies as  
26 well as data on other responses as they relate to an agent's carcinogenicity, such as effects on  
27 growth control processes or cell macromolecules or other toxic effects. Tumor incidence data are  
28 ordinarily the basis of dose-response assessment, but other response data can augment such  
29 assessment or provide separate assessments of carcinogenicity or other important effects.

30 Data on carcinogenic processes underlying tumor effects may be used to support  
31 biologically based or case-specific models. Other options for such data exist. If confidence is  
32 high in the linkage of a precursor effect and the tumor effect, the assessment of tumor incidence  
33 may be extended to lower dose levels by linking it to the assessment of the precursor effect  
34 (Swenberg et al., 1987). Even if a quantitative link is not appropriate, the assessment for a

1 precursor effect may provide a view of the likely shape of the dose-response curve for tumor  
2 incidence below the range of tumor observation (Cohen and Ellwein, 1990; Choy, 1993). If  
3 responses other than tumor incidence are regarded as better representations of the carcinogenicity  
4 of the agent, they may be used in lieu of tumor responses. For example, if it is concluded that the  
5 carcinogenic effect is secondary to another toxic effect, the dose-response for the other effect will  
6 likely be more pertinent for risk assessment. As another example, if disruption of hormone  
7 activity is the key mode of action of an agent, data on hormone activity may be used in lieu of  
8 tumor incidence data.

9       If adequate positive human epidemiologic response data are available, they provide an  
10 advantageous basis for analysis since concerns about interspecies extrapolation do not arise.  
11 Adequacy of human exposure data for quantification is an important consideration in deciding  
12 whether epidemiologic data are the best basis for analysis in a particular case. If adequate  
13 exposure data exist in a well-designed and well-conducted epidemiologic study that detects no  
14 effects, it may be possible to obtain an upper-bound estimate of the potential human risk to  
15 provide a check on plausibility of available estimates based on animal tumor or other responses,  
16 e.g., do confidence limits on one overlap the point estimate of the other?

17       When animal studies are used, response data from a species that responds most like  
18 humans should be used if information to this effect exists. If this is unknown and an agent has  
19 been tested in several experiments involving different animal species, strains, and sexes at several  
20 doses and different routes of exposure, all of the data sets are considered and compared, and a  
21 judgment is made as to the data to be used to best represent the observed data and important  
22 biological features such as mode of action. Appropriate options for presenting results include:

- 23       ● use of a single data set,
- 24       ● combining data from different experiments (Stiteler et al., 1993; Vater et al., 1993),
- 25       ● showing a range of results from more than one data set,
- 26       ● showing results from analysis of more than one statistically significant tumor response  
27       based on differing modes of action,
- 28       ● representing total response in a single experiment by combining animals with  
29       statistically significant tumors at more than one site, or
- 30       ● a combination of these options.

31 The approach judged to best represent the data is presented with the rationale for the judgment,  
32 including the biological and statistical considerations involved. The following are some points to  
33 consider:

- 34       ● quality of study protocol and execution,

- 1 ● proportion of malignant neoplasms,
- 2 ● latency of onset of neoplasia,
- 3 ● number of data points to define the relationship of dose and response,
- 4 ● background incidence in test animal,
- 5 ● differences in range of response among species, sexes, strains,
- 6 ● most sensitive responding species, and
- 7 ● availability of data on related precursor events to tumor development.

8 Analyses of carcinogenic effects other than tumor incidence are similarly presented and evaluated  
9 for their contribution to a best judgment on how to represent the biological data for dose-  
10 response assessment.

### 11 12 **3.5. DOSE DATA**

13 Whether animal experiments or epidemiologic studies are the sources of data, questions  
14 need to be addressed in arriving at an appropriate measure of dose for the anticipated  
15 environmental exposure. Among these are:

- 16 ● whether the dose is expressed as an environmental concentration, applied dose, or  
17 delivered dose to the target organ,
- 18 ● whether the dose is expressed in terms of a parent compound, one or more  
19 metabolites, or both,
- 20 ● the impact of dose patterns and timing where significant,
- 21 ● conversion from animal to human doses, where animal data are used, and
- 22 ● the conversion metric between routes of exposure where necessary and appropriate.

23 In practice, there may be little or no information on the concentration or identity of the active  
24 form at a target; being able to compare the applied and delivered doses between routes and  
25 species is the ideal, but is rarely attained. Even so, the objective is to use available data to obtain  
26 as close to a measure of internal or delivered dose as possible.

27 The following discussion assumes that the analyst will have data of varying detail in  
28 different cases about toxicokinetics and metabolism. Discussed below are approaches to basic  
29 data that are most frequently available, as well as approaches and judgments for improving the  
30 analysis based on additional data. The estimation of dose in human studies is tailored to the form  
31 of dose data available.

1 **3.5.1. Interspecies Adjustment of Dose--Adult Human**

2 When adequate data are available, the doses used in animal studies can be adjusted to  
3 equivalent human doses using toxicokinetic information on the particular agent. The methods  
4 used should be tailored to the nature of the data on a case-by-case basis. In rare cases, it may also  
5 be possible to make adjustments based on toxicodynamic considerations. In most cases, however,  
6 there are insufficient data available to compare dose between species. In these cases, the estimate  
7 of human equivalent dose is based on science policy default assumptions. The defaults described  
8 below are modified or replaced whenever better comparative data on toxicokinetic or metabolic  
9 relationships are available. The availability and discussion of the latter also may permit reduction  
10 or discussion of uncertainty in the analysis.

11 For oral exposure, the default assumption is that delivered doses are related to applied  
12 dose by a power of body weight. This assumption rests on the similarities of mammalian  
13 anatomy, physiology, and biochemistry generally observed across species. This assumption is  
14 more appropriate at low applied dose concentrations where sources of nonlinearity, such as  
15 saturation or induction of enzyme activity, are less likely to occur. To derive an equivalent human  
16 oral dose from animal data, the default procedure is to scale daily applied doses experienced for a  
17 lifetime in proportion to body weight raised to the 0.75 power ( $W^{0.75}$ ). Equating exposure  
18 concentrations in parts per million units for food or water is an alternative version of the same  
19 default procedure because daily intakes of these are in proportion to  $W^{0.75}$ . The rationale for this  
20 factor rests on the empirical observation that rates of physiological processes consistently tend to  
21 maintain proportionality with  $W^{0.75}$ . A more extensive discussion of the rationale and data  
22 supporting the Agency's adoption of this scaling factor is in U.S. EPA, 1992b. Information such  
23 as blood levels or exposure biomarkers or other data that are available for interspecies comparison  
24 are used to improve the analysis when possible.

25 The default procedure to derive an human equivalent concentration of inhaled particles  
26 and gases is described in U.S. EPA (1994) and Jarabek (1995a,b). The methodology estimates  
27 respiratory deposition of inhaled particles and gases and provides methods for estimating internal  
28 doses of gases with different absorption characteristics. The method is able to incorporate  
29 additional toxicokinetics and metabolism to improve the analysis if such data are available.  
30

31 **3.5.2. Adjustment of Dose from Adults to Children**

32 Slope factors and unit risk estimates for lifetime exposure incorporate exposure factors  
33 that are based on adults (specifically, body weight, breathing rate, and drinking water ingestion  
34 rate). When these unit risk estimates are used to assess risks from less-than-lifetime exposure that



1 occurs during childhood, adjustments for differences between adults and children may be  
2 appropriate.

3 *Inhalation unit risk estimates:* Section 3.5.1 specifies that the inhalation methodology  
4 (U.S. EPA, 1994) be used for inhaled concentrations when agent-specific data are insufficient to  
5 develop a case-specific dosimetry model. The methodology incorporates exposure factors based  
6 on a 70-kg adult who breathes at a plausibly high rate of 20 m<sup>3</sup>/d. Because children breathe more  
7 air per unit of body weight (U.S. EPA, 1998), use of adult exposure factors may not be  
8 appropriate. Consequently, inhalation unit risk estimates are adjusted to reflect a child's body  
9 weight and breathing rate. For example, the following calculation adjusts an (adult) unit risk  
10 estimate of 1x10<sup>-4</sup> per ug/m<sup>3</sup> so that it applies to a 9-kg infant who breathes 4.5 m<sup>3</sup>/d:

$$(1 \times 10^{-4} \text{ per ug/m}^3) \times (4.5 \text{ m}^3/\text{d} / 20 \text{ m}^3/\text{d}) / (9 \text{ kg} / 70 \text{ kg}) = 1.75 \times 10^{-4} \text{ per ug/m}^3.$$

12 For inhaled gases and aerosols, this adjustment is intended to provide the same degree of  
13 health-conservatism for children and adults. For inhaled particles, the adjustment does not take  
14 into account the different size and spacing of airways of children and adults; this difference could  
15 result in children and adults retaining particles with a different size distribution and different  
16 toxicologic properties. To reduce this uncertainty, EPA is developing a default dosimetry model  
17 for children that is based on children's inhalation parameters.

18 *Drinking water unit risk estimates:* Similarly, drinking water unit risk estimates  
19 incorporate exposure factors based on a 70-kg adult who drinks water at a plausibly high rate of  
20 2 L/d. Because children drink more water per unit of body weight (U.S. EPA, 1997c), use of  
21 adult exposure factors may not be appropriate. Consequently, drinking water unit risk estimates  
22 will be adjusted to reflect a child's body weight and drinking water ingestion rate.

23 *Oral slope factors:* Oral slope factors incorporate a cross-species scaling factor based on  
24 equivalence of mg/kg<sup>3/4</sup>-d (U.S. EPA, 1992b). This cross-species factor is intended to achieve  
25 equivalence in lifetime cancer risk in different mammalian species. When risks from childhood  
26 exposure are being assessed, the child's weight is not substituted for an adult weight in the cross-  
27 species scaling factor. There are several reasons why using the child's weight in the cross-species  
28 factor may not be appropriate:

- 29 • Using the child's weight instead of an adult weight assumes that children have faster  
30 metabolism, leading to faster clearance, smaller body burdens, and smaller risks.  
31 Although children generally metabolize and eliminate many chemicals faster than  
32 adults, this is not true in all cases (Renwick, 1998).
- 33 • The data supporting the 3/4-power factor pertain to cross-species equivalence, a  
34 fundamentally different question from determining equivalence across different life

1 stages of a single species.

- 2 • Although exposure may begin during childhood, subsequent events that complete the  
3 carcinogenesis process may continue into adulthood.

4 Using an adult body weight is also a science policy choice that provides some degree of  
5 health-conservatism for children in view of the uncertainties in extrapolating risks to children.  
6 Quantitatively, the effect of this choice is rather modest; for example, basing the scaling factor on  
7 a 70-kg adult instead of a 10-kg child results in risk estimates that are 1.6 times higher  
8 ( $[(70/10)^{1-3/4}] = 1.6$ ).

9 *Dermal exposure:* The risk of distal-site cancers from the fraction of a dermal exposure  
10 that is systemically absorbed is sometimes assessed by reducing the oral slope factor by a dermal  
11 absorption factor that reflects the ratio of absorption by the dermal route to absorption by the oral  
12 route. Use of a dermal absorption factor based on adults could increase the uncertainty in a risk  
13 assessment of childhood exposure. Neonates, especially premature infants, have much greater  
14 skin absorption than older children or adults (Schilter et al., 1996).

15 The risk of skin cancer from dermal exposure, in particular, from the fraction that remains  
16 on the skin and is not systemically absorbed, has generally not been addressed because methods to  
17 do so have not been developed. In order to assess children's risks from this important pathway,  
18 methodological research is needed in this area.

### 19 20 **3.5.3. Toxicokinetic Analyses**

21 Physiologically based mathematical models are potentially the most comprehensive way to  
22 account for toxicokinetic processes affecting dose. Models build on physiological compartmental  
23 modeling and attempt to incorporate the dynamics of tissue perfusion and the kinetics of enzymes  
24 involved in metabolism of an administered compound.

25 A comprehensive model requires the availability of empirical data on the carcinogenic  
26 activity contributed by parent compound and metabolite or metabolites and data by which to  
27 compare kinetics of metabolism and elimination between species. A discussion of issues of  
28 confidence accompanies presentation of model results (Monro, 1992). This includes  
29 considerations of model validation and sensitivity analysis that stress the predictive performance  
30 of the model. When a delivered dose measure is used in animal to human extrapolation of dose-  
31 response data, the assessment should discuss the confidence in the assumption that the  
32 toxicodynamics of the target tissue(s) will be the same in both species. Toxicokinetic data can  
33 improve dose-response assessment by accounting for sources of change in proportionality of  
34 applied to internal or delivered dose at various levels of applied dose. Many of the sources of

1 potential nonlinearity involve saturation or induction of enzymatic processes at high doses. An  
2 analysis that accounts for nonlinearity (for instance, due to enzyme saturation kinetics) can assist  
3 in avoiding overestimation or underestimation of low dose-response otherwise resulting from  
4 extrapolation from a sublinear or supralinear part of the experimental dose-response curve  
5 (Gillette, 1983). Toxicokinetic processes tend to become linear at low doses, an expectation that  
6 is more robust than low-dose linearity of response (Hattis, 1990). Accounting for toxicokinetic  
7 nonlinearities allows better description of the shape of the curve at relatively high levels of dose in  
8 the range of observation, but cannot determine linearity or nonlinearity of response at low dose  
9 levels (Lutz, 1990a; Swenberg et al., 1987).

10 Toxicokinetic modeling results may be presented as the preferred method of estimating  
11 human equivalent dose or in parallel discussion with default assumptions depending on relative  
12 confidence in the modeling.

#### 13 14 **3.5.4. Route-to-Route Extrapolation**

15 Judgments frequently need to be made about the carcinogenicity of an agent through a  
16 route of exposure different than the one in the underlying studies. For example, exposures of  
17 interest may be through inhalation of an agent tested primarily through animal feeding studies or  
18 through ingestion of an agent that showed positive results in human occupational studies from  
19 inhalation exposure.

20 Route-to-route extrapolation has both qualitative and quantitative aspects. For the  
21 qualitative aspect, the assessor weighs the degree to which positive results through one route of  
22 exposure in human or animal studies support a judgment that similar results would have been  
23 observed in appropriate studies using the route of exposure of interest. In general, confidence in  
24 making such a judgment is strengthened when the tumor effects are observed at a site distant from  
25 the portal of entry and when absorption through the route of exposure of interest is similar to  
26 absorption via the tested routes. In the absence of contrary data, the qualitative default  
27 assumption is that, if the agent is absorbed by a route to give an internal dose, it may be  
28 carcinogenic by that route. (See section 2.7.1.)

29 When a qualitative extrapolation can be supported, quantitative extrapolation may still be  
30 problematic in the absence of adequate data. The differences in biological processes among  
31 routes of exposure (oral, inhalation, dermal) can be great because of, for example, first-pass  
32 effects and differing results from different exposure patterns. There is no generally applicable  
33 method for accounting for these differences in uptake processes in quantitative route-to-route  
34 extrapolation of dose-response data in the absence of good data on the agent of interest.

1 Therefore, route-to-route extrapolation of dose data relies on a case-by-case analysis of available  
2 data. When good data on the agent itself are limited, an extrapolation analysis can be based on  
3 expectations from physical and chemical properties of the agent, properties and route-specific  
4 data on structurally analogous compounds, or in vitro or in vivo uptake data on the agent. Route-  
5 to-route uptake models may be applied if model parameters are suitable for the compound of  
6 interest. Such models are currently considered interim methods; further model development and  
7 validation is awaiting the development of more extensive data (see generally, Gerrity and Henry,  
8 1990). For screening or hazard ranking, route-to-route extrapolation may be based on assumed  
9 quantitative comparability as a default, as long as it is reasonable to assume absorption by  
10 compared routes. When route-to-route extrapolation is used, the assessor's degree of confidence  
11 in both the qualitative and quantitative extrapolation should be discussed in the assessment and  
12 highlighted in the dose-response characterization.

### 13 14 **3.5.5. Dose Averaging**

15 The cumulative dose received over a lifetime, expressed as lifetime average daily dose, is  
16 generally considered an appropriate default measure of exposure to a carcinogen (Monro, 1992).  
17 The assumption is made that a high dose of a carcinogen received over a short period of time is  
18 equivalent to a corresponding low dose spread over a lifetime. While this is a reasonable default  
19 assumption based on theoretical considerations, departures from it are expected. Another  
20 approach is needed in some cases, such as when dose-rate effects are noted (e.g., formaldehyde).  
21 Cumulative dose may be replaced, as appropriate and justified by the data, with other dose  
22 measures. In such cases, modifications to the default assumption are made to take account of  
23 these effects; the rationale for the selected approach is explained.

24 In cases where a mode of action or other feature of the biology has been identified that has  
25 special dose implications for sensitive subpopulations (e.g., differential effects by sex or  
26 disproportionate impacts of early-life exposure), these are explained and are recorded to guide  
27 exposure assessment and risk characterization. Special problems arise when the human exposure  
28 situation of concern suggests exposure regimens (e.g., route and dosing schedule) that are  
29 substantially different from those used in the relevant animal studies. These issues are explored  
30 and pointed out for attention in the exposure assessment and risk characterization.

## 31 32 **3.6. DISCUSSION OF UNCERTAINTIES**

33 The exploration of significant uncertainties in data for dose and response and in  
34 extrapolation procedures is part of the assessment. The presentation distinguishes between model

1 uncertainty and parameter uncertainty. Model uncertainty is an uncertainty about a basic  
2 biological question. For example, a default, linear dose-response extrapolation may have been  
3 made based on tumor and other key evidence supporting the view that the model for an agent's  
4 mode of action is a DNA-reactive process. Discussion of the confidence in the extrapolation is  
5 appropriately done qualitatively or by showing results for alternatives that are equally plausible. It  
6 is not useful, for example, to conduct quantitative uncertainty analysis running multiple forms of  
7 linear models. This would obviate the function of the policy default.

8 Parameter uncertainties deal with numbers representing statistical or analytical measures  
9 of variance or error in data or estimates. Uncertainties in parameters are described quantitatively,  
10 if practicable, through sensitivity analysis and statistical uncertainty analysis. With the recent  
11 expansion of readily available computing capacity, computer methods are being adapted to create  
12 simulated biological data that are comparable with observed information. These simulations can  
13 be used for sensitivity analysis, for example, to analyze how small, plausible variations in the  
14 observed data could affect dose-response estimates. These simulations can also provide  
15 information about experimental uncertainty in dose-response estimates, including a distribution of  
16 estimates that are compatible with the observed data. Because these simulations are based on the  
17 observed data, they cannot assist in evaluating the extent to which the observed data as a whole  
18 are idiosyncratic rather than typical of the true situation. If quantitative analysis is not possible,  
19 significant parameter uncertainties are described qualitatively. In either case, the discussion  
20 highlights uncertainties that are specific to the agent being assessed, as distinct from those that are  
21 generic to most assessments.

22 Estimation of the applied dose in a human study has numerous uncertainties such as the  
23 exposure fluctuations that humans experience compared with the controlled exposures received  
24 by animals on test. In a prospective cohort study, there is opportunity to monitor exposure and  
25 human activity patterns for a period of time that supports estimation of applied dose (U.S. EPA,  
26 1992a). In a retrospective study, exposure may be based on monitoring data but is often based on  
27 human activity patterns and levels reconstructed from historical data, contemporary data, or a  
28 combination of the two. Such reconstruction is accompanied by analysis of uncertainties  
29 considered with sensitivity analysis in the estimation of dose (Wyzga, 1988; U.S. EPA, 1986a).  
30 These uncertainties can also be assessed for any confounding factor for which a quantitative  
31 adjustment of dose-response data is made (U.S. EPA, 1984).  
32

### 3.7. TECHNICAL Dose-response CHARACTERIZATION

As with hazard characterization, the dose-response characterization serves the dual purposes of presenting a technical characterization of the assessment results and supporting the risk characterization.

The characterization presents the results of analyses of dose data, of response data, and of dose-response. When alternative approaches are plausible and persuasive in selecting dose data, response data, or extrapolation procedures, the characterization follows the alternative paths of analysis and presents the results. The discussion covers the question of whether any should be preferred over others because it (or they) better represents the available data or corresponds to the view of the mechanism of action developed in the hazard assessment. The results for different tumor types by sex and species are provided along with the one(s) preferred. Similarly, results for responses other than tumor incidence are shown if appropriate.

Numerical dose-response estimates are presented to one significant figure to prevent an inappropriate sense of high precision. However, since rounding can introduce significant errors in a calculation, the rounding should be performed explicitly in the presentation of results; the actual calculations are not done with intermediate rounding. Numbers are qualified as to whether they represent central tendency or upper bounds and whether the method used is inherently more likely to overestimate or underestimate (Krewski et al., 1984).

In cases where a mode of action or other feature of the biology has been identified that has special implications for early-life exposure, differential effects by sex, or other concerns for sensitive subpopulations, these are explained. Similarly, any expectations that high dose-rate exposures may alter the risk picture for some portion of the population are described. These and other perspectives are recorded to guide exposure assessment and risk characterization. Whether the lifetime average daily dose or another measure of dose should be considered for differing exposure scenarios is discussed.

Uncertainty analyses, qualitative or quantitative if possible, are highlighted in the characterization.

The dose-response characterization routinely includes the following, as appropriate for the data available:

- identification of the kinds of data available for analysis of dose and response and for dose-response assessment,
- results of assessment as above,
- explanation of analyses in terms of quality of data available,
- selection of study/response and dose metric for assessment,

- 1 ● discussion of implications of variability in human susceptibility, including for
- 2 susceptible subpopulation,
- 3 ● applicability of results to varying exposure scenarios--issues of route of exposure, dose
- 4 rate, frequency, and duration,
- 5 ● discussion of strengths and limitations (uncertainties) of the data and analyses that are
- 6 quantitative as well as qualitative, and
- 7 ● special issues of interpretation of data, such as:
- 8 -- selecting dose data, response data, and dose-response approach(es),
- 9 -- use of meta-analysis,
- 10 -- uncertainty and quantitative uncertainty analysis.

#### 4. TECHNICAL EXPOSURE CHARACTERIZATION

1 Exposure assessment is the determination (qualitative and quantitative) of the magnitude,  
2 frequency, and duration of exposure (EPA, 1992). The following section provides a brief  
3 overview of exposure assessment principles with an emphasis on issues related to carcinogenic  
4 risk assessment. The information presented here should be used in conjunction with other  
5 guidances including: the 1992 Guidelines for Exposure Assessment, the 1995 Policy and  
6 Guidance for Risk Characterization, the 1997 Exposure Factors Handbook, the 1997 Policy for  
7 Use of Probabilistic Analysis in Risk Assessments, and the 1997 Guiding Principles for Monte  
8 Carlo Analysis. In addition, program specific guidelines for exposure assessment should be  
9 consulted.

10 Exposure assessment generally consists of four major steps: defining the assessment  
11 questions, selecting or developing the conceptual and mathematical models, collecting data or  
12 selecting and evaluating available data, and exposure characterization. Each of these steps is  
13 briefly described below.

##### 14 **Defining the Assessment Questions**

15 In providing a clear and unambiguous statement of the purpose and scope of the exposure  
16 assessment (EPA, 1997a), consider the following.

- 17 ▶ The management objectives of the assessment will determine whether deterministic  
18 screening level analyses are adequate or whether full probabilistic exposure  
19 characterization is needed.
- 20 ▶ Identify and include all important sources (e.g., pesticide applications), pathways (e.g.,  
21 food or water), and routes (e.g., ingestion, inhalation, and dermal) of exposure in the  
22 assessment. If a particular source, pathway, or route is omitted, a clear and  
23 transparent explanation should be provided.
- 24 ▶ Separate analyses should be conducted for each definable subgroup within the  
25 population of interest. In particular, subgroups that are believed to be highly exposed  
26 or susceptible to a particular health effect should be studied. This includes people with



1 certain diseases or genetic susceptibilities, and others whose behavior or physiology  
2 may lead to higher exposure or susceptibility. Consider the following examples.

- 3 ▶ Physiological differences between men and women (e.g., body weight and  
4 inhalation rate) may lead to important differences in exposures. See, for example,  
5 the discussion in the Exposure Factors Handbook, Appendix 1A (EPA, 1997c).
- 6 ▶ Pregnant and lactating women may have exposures that differ from the general  
7 population (e.g., slightly higher water consumption) (EPA, 1997c). Further,  
8 exposure to pregnant women may result in exposure to the developing fetus.  
9 (NAS, 1993).
- 10 ▶ Children consume more food per body weight than adults while consuming fewer  
11 types of foods (ILSI, 1992, NAS, 1993 and EPA, 1997c). In addition, children  
12 engage in crawling and mouthing (i.e., putting hands and objects in the mouth)  
13 behaviors which can increase their exposures.
- 14 ▶ The elderly and disabled may have important differences in their exposures due to  
15 a more sedentary lifestyle (EPA, 1997c). In addition, the health status of this  
16 group may affect their susceptibility to the detrimental effects of exposure.

17 For further guidance, see the Guidelines for Exposure Assessment, § 3 (EPA, 1992).

## 18 **Selecting or Developing the Conceptual and Mathematical Models**

19 Carcinogen risk assessment models are generally based on the premise that risk is  
20 proportional to total lifetime dose. Therefore, the exposure metric used for carcinogenic risk  
21 assessment is the Lifetime Average Daily Dose (LADD). The LADD is typically used in  
22 conjunction with the Cancer Slope Factor (CSF) to calculate individual excess cancer risk. It is  
23 an estimate of the daily intake of a carcinogenic agent throughout the entire life of an individual.  
24 Depending on the objectives of the assessment, the LADD may be calculated deterministically  
25 (using point estimates for each factor to derive a point estimate of the exposure) or stochastically  
26 (using probability distributions to represent each factor and such techniques as Monte Carlo  
27 analysis to derive a distribution of the LADD) (EPA, 1997b). Stochastic analyses may help to

1 identify certain population segments that are highly exposed and may need to be assessed as a  
2 special subgroup. For further guidance, see the Guidelines for Exposure Assessment, § 5.3.5.2  
3 (EPA, 1992).

4 When the route of exposure is inhalation or dermal contact, derivation of the LADD will  
5 often require an approach to “route-to-route extrapolation.” The CSF and other measures of  
6 toxicity are typically derived from oral administered doses in animal studies. Therefore, for  
7 ingestion exposures in a human population it is not usually necessary to make adjustments to  
8 account for route specific differences in absorption and uptake. However, for inhalation and  
9 dermal exposures, such adjustments may be necessary. For further guidance, see the Guidelines  
10 for Exposure Assessment, § 2.1.4 (EPA, 1992).

11 As discussed elsewhere in these guidelines, there may be cases where the mode of action  
12 indicates that dose rates are important in the carcinogenic process. In these cases, short term,  
13 less-than-lifetime exposure estimates may be more appropriate for risk assessment than the  
14 LADD. Such estimates could be used to calculate the margin (MOE) that exists between  
15 exposure and the point of departure derived in the dose-response assessment.

## 16 **Collecting Data or Selecting and Evaluating Available Data**

17 After the assessment questions have been defined and the conceptual and mathematical  
18 models have been developed, it is necessary to compile and evaluate existing data or, if necessary,  
19 to collect new data. Depending on the exposure scenario under consideration, data on a wide  
20 variety of exposure factors may be needed. The U.S. EPA Exposure Factors Handbook (EPA,  
21 1997c) contains a large compilation of exposure data with some analysis and recommendations.  
22 Some of these data are organized by age groups to assist with assessing such subgroups as  
23 children. See, for example, the Exposure Factors Handbook, Volume 1, Chapter 3 (EPA, 1997c).  
24 When using these existing data, it is important to evaluate the quality of the data and the extent to  
25 which the data are representative of the population under consideration. The U.S. EPA Guidance  
26 for Data Quality Assessment (EPA, 1996) and program specific guidances can provide further  
27 assistance for evaluating existing data.

28 When existing data fail to provide an adequate surrogate for the needs of a particular

1 assessment, it will be necessary to collect new data. Such data collection efforts should be guided  
2 by the references listed above (e.g., the Guidance for Data Quality Assessment and program  
3 specific guidance). Once again, subgroups of concern are an important consideration in any data  
4 collection effort.

## 5 **Exposure Characterization**

6 The exposure characterization is a technical characterization that presents the assessment  
7 results and supports the risk characterization. It provides a statement of the purpose, scope, and  
8 approach used in the assessment, identifying the exposure scenarios and population subgroups  
9 covered. It provides estimates of the magnitude, frequency, duration, and distribution of  
10 exposures among members of the exposed population as the data permit. It identifies and  
11 compares the contribution of different sources, pathways, and routes of exposure. In particular, a  
12 qualitative discussion of the strengths and limitations (uncertainties) of the data and models are  
13 presented.

14 The discussion of uncertainties is a critical component of the exposure characterization.  
15 Uncertainties can arise out of problems with the conceptual and mathematical models.  
16 Uncertainties can also arise from poor data quality and data that are not quite representative of  
17 the population or scenario of interest. Consider the following examples of uncertainties.

- 18 ▶ National data (i.e., data collected to represent the entire U.S. population) may not be  
19 representative of exposures occurring within a regional or local population.
- 20 ▶ Use of short term data to infer chronic, lifetime exposures must be done with caution.  
21 Using short term data to estimate long term exposures has the tendency to  
22 underestimate the number of people exposed, while overestimating the exposure levels  
23 experienced by those in the upper end (i.e., above the 90<sup>th</sup> percentile) of the exposure  
24 distribution. For further guidance, refer to the Guidelines for Exposure Assessment, §  
25 5.3.1 (EPA, 1992).
- 26 ▶ Children’s behavior may lead to relatively high but intermittent exposures (EPA,  
27 1998). This pattern of exposure, “one that gradually declines over the developmental  
28 period and which remains relatively constant thereafter” is not accounted for in the  
29 LADD model (ILSI, 1992). Further the physiological characteristics of children may

1           lead to important differences in exposure. Some of these differences can be accounted  
2           for in the LADD model. For further guidance, see the Guidelines for Exposure  
3           Assessment, § 5.3.5.2 (EPA, 1992).

4           Overall, the exposure characterization should provide a full description of the sources,  
5           pathways, and routes of exposure. The characterization also should include a full description of  
6           the populations assessed. In particular highly exposed or susceptible subgroups should be  
7           discussed. For further guidance on the exposure characterization, consult the 1992 Guidelines for  
8           Exposure Assessment (EPA, 1992), the 1995 Policy and Guidance for Risk Characterization  
9           (EPA, 1995b and a) and EPA's Rule Writer's Guide to Executive Order 13045 (especially  
10          Attachment C: Technical Support for Risk Assessors--Suggestions for Characterizing Risks to  
11          Children) (EPA, 1999).

## 5. RISK CHARACTERIZATION

### 5.1. PURPOSE

EPA has developed general guidance on risk characterization for use in all of its risk assessment activities. Administrator Carol Browner has issued a policy statement on risk characterization, the core of which is the following mandate:

Each risk assessment prepared in support of decision making at EPA should include a risk characterization that follows the principles and reflects the values outlined in this policy. A risk characterization should be prepared in a manner that is clear, transparent, reasonable, and consistent with other risk characterizations of similar scope prepared across programs in the Agency. Further, discussion of risk in all EPA reports, presentations, decision packages, and other documents should be substantively consistent with the risk characterization. The nature of the risk characterization will depend upon the information available, the regulatory application of the risk information, and the resources (including time) available. In all cases, however, the assessment should identify and discuss all the major issues associated with determining the nature and extent of the risk and provide commentary on any constraints limiting fuller exposition. (U.S. EPA, 1995)

EPA is also developing a Risk Characterization Handbook (draft available as publication number EPA/600/R-99/025, dated March 1999), which provides detailed guidance to Agency staff. The discussion below does not attempt to duplicate this material but summarizes its applicability to carcinogen risk assessment.

The risk characterization process includes an integrative analysis of the major results of the risk assessment which is summarized for the risk manager in a nontechnical discussion that minimizes the use of technical terms. It is an appraisal of the science that informs the risk manager in his/her public health decisions, as do other decision-making analyses of economic, social, or technology issues. It also serves the needs of other interested readers. The summary is an information resource for preparation of risk communication information, but being somewhat technical, is not itself the usual vehicle for communication with every audience.

The integrative analysis brings together the assessments of hazard, dose response, and exposure to make risk estimates for the exposure scenarios of interest. This analysis is generally much more extensive than the Risk Characterization Summary. It may be peer-reviewed or subject to public comment along with the summary in preparation for an Agency decision. The integrative analysis may be titled differently by different EPA programs (e.g., "Staff Paper" for

1 criteria air pollutants), but it typically will identify exposure scenarios of interest in decision  
2 making and present risk analyses associated with them. Some of the analyses may concern  
3 scenarios in several media; others may examine, for example, only drinking water risks. The  
4 integrative analysis also may be the document that contains quantitative analyses of uncertainty.

5 The values supported by a risk characterization throughout the process are *transparency*  
6 in environmental decision making, *clarity* in communication, *consistency* in core assumptions and  
7 science policies from case to case, and *reasonableness*. While it is appropriate to err on the side  
8 of protection of health and the environment in the face of scientific uncertainty, common sense  
9 and reasonable application of assumptions and policies are essential to avoid unrealistic estimates  
10 of risk (U.S. EPA, 1995). Both integrative analyses and the Risk Characterization Summary  
11 present an integrated and balanced picture of the analysis of the hazard, dose response, and  
12 exposure. The risk analyst should provide summaries of the evidence and results and describe the  
13 quality of available data and the degree of confidence to be placed in the risk estimates.  
14 Important features include the constraints of available data and the state of knowledge, significant  
15 scientific issues, and significant science and science policy choices that were made when  
16 alternative interpretations of data existed (U.S. EPA, 1995). Choices made about using default  
17 assumptions or data in the assessment are explicitly discussed in the course of analysis, and if a  
18 choice is a significant issue, it is highlighted in the summary.

## 20 **5.2. APPLICATION**

21 Risk characterization is a necessary part of generating any Agency report on risk, whether  
22 the report is preliminary, to support allocation of resources toward further study, or  
23 comprehensive, to support regulatory decisions. In the former case, the detail and sophistication  
24 of the characterization are appropriately small in scale; in the latter case, appropriately extensive.  
25 Even if a document covers only parts of a risk assessment (hazard and dose-response analyses, for  
26 instance), the results of these are characterized.

27 Risk assessment is an iterative process that grows in depth and scope in stages from  
28 screening for priority making, to preliminary estimation, to fuller examination in support of  
29 complex regulatory decision making. Default assumptions are used at every stage because no  
30 database is ever complete, but they are predominant at screening stages and are used less as more  
31 data are gathered and incorporated at later stages. Various provisions in EPA-administered  
32 statutes require decisions based on findings that represent all stages of iteration. There are close  
33 to 30 provisions within the major statutes that require decisions based on risk, hazard, or  
34 exposure assessment. For example, Agency review of pre-manufacture notices under Section 5 of

1 the Toxic Substances Control Act relies on screening analyses, while requirements for industry  
2 testing under Section 4 of that act rely on preliminary analyses of risk or simply of exposure. At  
3 the other extreme, air quality criteria under the Clean Air Act rest on a rich data collection  
4 required by statute to undergo reassessment every few years. There are provisions that require  
5 ranking of hazards of numerous pollutants--by its nature a screening level of analysis--and other  
6 provisions that require a full assessment of risk. Given this range in the scope and depth of  
7 analyses, not all risk characterizations can or should be equal in coverage or depth. The risk  
8 assessor must carefully decide which issues in a particular assessment are important to present,  
9 choosing those that are noteworthy in their impact on results. For example, health effect  
10 assessments typically rely on animal data since human data are rarely available. The objective of  
11 characterization of the use of animal data is not to recount generic issues about interpreting and  
12 using animal data. Agency guidance documents cover these. Instead, the objective is to call out  
13 any significant issues that arose within the particular assessment being characterized and inform  
14 the reader about significant uncertainties that affect conclusions.

### 15 16 **5.3. PRESENTATION OF RISK CHARACTERIZATION SUMMARY**

17 The presentation is a nontechnical discussion of important conclusions, issues, and  
18 uncertainties that uses the hazard, dose-response, exposure, and integrative analyses for technical  
19 support. The primary technical supports within the risk assessment are the hazard  
20 characterization, dose-response characterization, and exposure characterization described in this  
21 guideline. The risk characterization is derived from these. The presentation should fulfill the aims  
22 outlined in the purpose section above.

### 23 24 **5.4. CONTENT OF RISK CHARACTERIZATION SUMMARY**

25 Specific guidance on hazard, dose response, and exposure characterization appears in  
26 previous sections. Overall, the risk characterization routinely includes the following, capturing  
27 the important items covered in hazard, dose response, and exposure characterization:

- 28
- 29 • primary conclusions about hazard, dose response, and exposure, including equally  
30 plausible alternatives;
- 31 • nature of key supporting information and analytic methods;
- 32 • risk estimates and their attendant uncertainties, including key uses of default  
33 assumptions when data are missing or uncertain;
- 34 • statement of the extent of extrapolation of risk estimates from observed data to

- 1 exposure levels of interest (i.e., margin of exposure) and its implications for certainty  
2 or uncertainty in quantifying risk;
- 3 • significant strengths and limitations of the data and analyses, including any major peer  
4 reviewers' issues;
  - 5 • appropriate comparison with similar EPA risk analyses or common risks with which  
6 people may be familiar; and
  - 7 • comparison with assessment of the same problem by another organization.



## 6. REFERENCES

- 1 Alison, R.H., Capen, C.C., Prentice, D.E. (1994) Neoplastic lesions of questionable significance to humans.  
2 Toxicol. Pathol. 22:179-186.
- 3 Allen, B.C., Crump, K.S., Shipp, A.M. (1988) Correlation between carcinogenic potency of chemicals in animals  
4 and humans. Risk Anal. 8:531-544.
- 5 Ames, B.N., Gold, L.S. (1990) Too many rodent carcinogens: mitogenesis increases mutagenesis. Science  
6 249:970-971.
- 7 Anderson, E., Deisler, P.F., McCallum, D., St. Helaire, C., Spitzer, H.L., Strauss, H., Wilson, J.D., Zimmerman,  
8 R. (1993) Key Issues in Carcinogen Risk Assessment Guidelines. Society for Risk Analysis.
- 9 Ashby, J., Tennant, R.W. (1991) Definitive relationships among chemical structure, carcinogenicity and  
10 mutagenicity for 301 chemicals tested by the U.S. NTP. Mutat. Res. 257:229-306.
- 11 Ashby, J., Tennant, R.W. (1994) Prediction of rodent carcinogenicity for 44 chemicals: results. Mutagenesis 9:7-  
12 15.
- 13 Ashby, J., Doerrer, N.G., Flamm, F.G., Harris, J.E., Hughes, D.H., Johannsen, F.R., Lewis, S.C., Krivanek, N.D.,  
14 McCarthy, J.F., Moolenaar, R.J., Raabe, G.K., Reynolds, R.C., Smith, J.M., Stevens, J.T., Teta, M.J., Wilson, J.D.  
15 (1990) A scheme for classifying carcinogens. Regul. Toxicol. Pharmacol. 12:270-295.
- 16 Ashby, J., Brady, A., Elcombe, C.R., Elliott, B.M., Ishmael, J., Odum, J., Tugwood, D., Kettle, S., Purchase, I.F.H.  
17 (1994) Mechanistically based human hazard assessment of peroxisome proliferator-induced hepatocarcinogenesis.  
18 Hum. Exper. Toxicol. 13:1-117.
- 19 Auger, K.R., Carpenter, C.L., Cantley, L.C., Varticovski, L. (1989a) Phosphatidylinositol 3-kinase and its novel  
20 product, phosphatidylinositol 3-phosphate, are present in *Saccharomyces cerevisiae*. J. Biol. Chem. 264:20181-  
21 20184.
- 22 Auger, K.R., Sarunian, L.A., Soltoff, S.P., Libby, P., Cantley, L.C. (1989b) PDGF-dependent tyrosine  
23 phosphorylation stimulates production of novel polyphosphoinositides in intact cells. Cell 57:167-175.
- 24 Ayers, K.M., Torrey, C.E. and Reynolds, D.J. (1997) A transplacental carcinogenicity bioassay in CD-1 mice  
25 with zidovudine. Fundam. Appl. Toxicol. 38: 195-198.
- 26 Barnes, D.G., Daston, G.P, Evans, J.S., Jarabek, A.M., Kavlock, R.J., Kimmel, C.A., Park, C., Spitzer, H.L.

- 1 (1995) Benchmark dose workshop: criteria for use of a benchmark dose to estimate a reference dose. Regul.  
2 Toxicol. Pharmacol. 21:296-306.
- 3 Barrett, J.C. (1992) Mechanisms of Action of Known Human Carcinogens. In: Mechanisms of Carcinogenesis in  
4 Risk Identification. IARC Sci. Pubs. No. 116, Lyon, France: International Agency for Research on Cancer; 115-  
5 134.
- 6 Barrett, J.C. (1993) Mechanisms of multistep carcinogenesis and carcinogen risk assessment. Environ. Health  
7 Perspect. 100:9-20.
- 8 Barrett, J.C. (1995) Role of mutagenesis and mitogenesis in carcinogenesis. Environ. Mutagen., in press.
- 9 Barrett, J. C., Lee, T. C. (1992) Mechanisms of arsenic-induced gene amplification. In: Gene amplification in  
10 mammalian cells: A comprehensive guide (ed. R. E. Kellems), Marcel Dekker, New York: 441-446.
- 11 Bayly, A.C., Roberts, R.A., Dive, C. (1994) Suppression of liver cell apoptosis in vitro by the nongenotoxic  
12 hepatocarcinogen and peroxisome proliferator nafenopin. J. Cell. Biol. 125:197-203.
- 13 Bellamy, C.O.C., Malcomson, R.D.G., Harrison, D.J., Wyllie, A.H. (1995) Cell death in health and disease: The  
14 biology and regulation of apoptosis. Seminars in Cancer Biology, Apoptosis in Oncogenesis and Chemotherapy  
15 6:3-16.
- 16 Bianchi, A.B., Navone, N.M., Alda, C.M., Conti, C.J. (1991) Overlapping loss of heterozygosity by mitotic  
17 recombination on more chromosome 7F1-ter in skin carcinogenesis. Proc. Nat. Acad. Sci. 88:7590-7594.
- 18 Biggs, P.J., Warren, W., Venitt, S., Stratton, M.R. (1993) Does a genotoxic carcinogen contribute to human breast  
19 cancer? The value of mutational spectra in unraveling the etiology of cancer. Mutagenesis 8:275-283.
- 20 Birner, G., Albrecht, W., Neumann, H.G. (1990) Biomonitoring of aromatic amines. III: Hemoglobin binding and  
21 benzidine and some benzidine congeners. Arch. Toxicol. 64(2):97-102.
- 22 Blair, A., Burg, J., Foran, J., Gibb, H., Greenland, S., Morris, R., Raabe, G., Savitz, D., Teta, J., Wartenberg, D.,  
23 Wong, O., Zimmerman, R. (1995) Guidelines for application of meta-analysis in environmental epidemiology.  
24 Regul. Toxicol. Pharmacol. 22:189-197.
- 25 Bois, F.Y., Krowech, G., Zeise, L. (1995) Modeling human interindividual variability in metabolism and risk: the  
26 example of 4-aminobiphenyl. Risk Anal. 15:205-213.
- 27 Bottaro, D.P., Rubin, J.S., Faletto, D.L., Chan, A.M.L., Kmieck, T.E., Vande Woude, G.F., Aaronson, S.A. (1991)  
28 Identification of the hepatocyte growth factor receptor as the *c-met* proto-oncogene product. Science 251:802-804.

- 1 Bouck, N. (1990) Tumor angiogenesis: the role of oncogenes and tumor suppressor genes. *Cancer Cells* 2:179-183.
- 2 Burek, J.D., Patrick, D.H., Gerson, R.J. (1988) Weight-of-biological evidence approach for assessing  
3 carcinogenicity. In: Grice, H.C., Cimina, J.L., eds. *Carcinogenicity*. New York: Springer Verlag; pp. 83-95.
- 4 Burin, G.J., Gibb, H.J. and Hill, R.N. 1995 Human bladder cancer: evidence for a potential irritation-induced  
5 mechanism. *Fd. Chem. Toxicol.* 33: 785-795.
- 6 Bus, J.S., Popp, J.A. (1987) Perspectives on the mechanism of action of the splenic toxicity of aniline and  
7 structurally related compounds. *Fundam. Chem. Toxicol.* 25:619-626.
- 8 Callemen, C.J., Ehrenberg, L., Jansson, B., Osterman-Golkar, S., Segerback, D., Svensson, K, Wachtmeister, C.A.  
9 (1978) Monitoring and risk assessment by means of alkyl groups in hemoglobin in persons occupationally exposed  
10 to ethylene oxide. *J. Environ. Pathol. Toxicol.* 2:427-442.
- 11 Cantley, L.C., Auger, K.R., Carpenter, C., Duckworth, B., Graziani, A., Kapeller, R., Soltoff, S. (1991) Oncogenes  
12 and signal transduction. *Cell* 64:281-302.
- 13 Caporaso, N., Hayes, R.B., Dosemeci, M., Hoover, R., Ayesh, R., Hetzel, M., Idle, J. (1989) Lung cancer risk,  
14 occupational exposure, and the debrisoquine metabolic phenotype. *Cancer Res.* 49:3675-3679.
- 15 Cavenee, W. K., Koufos, A., Hansen, M. F. (1986) Recessive mutant genes predisposing to human cancer. *Mutat.*  
16 *Res.* 168:3-14.
- 17 Chang, C. C., Jone, C., Trosko, J. E., Peterson, A. R., Sevanian, A. (1988) Effect of cholesterol epoxides on the  
18 inhibition of intercellular communication and on mutation induction in Chinese hamster V79 cells. *Mutat. Res.*  
19 206:471-478.
- 20 Chen, C., Farland, W. (1991) Incorporating cell proliferation in quantitative cancer risk assessment: approaches,  
21 issues, and uncertainties. In: Butterworth, B., Slaga, T., Farland, W., McClain, M., eds. *Chemical Induced Cell*  
22 *Proliferation: Implications for Risk Assessment*. New York: Wiley-Liss, pp. 481-499.
- 23 Choy, W.N. (1993) A review of the dose-response induction of DNA adducts by aflatoxin B<sub>2</sub> and its implications to  
24 quantitative cancer-risk assessment. *Mutat. Res.* 296:181-198.
- 25 Clayson, D.B. (1989) Can a mechanistic rationale be provided for non-genotoxic carcinogens identified in rodent  
26 bioassays? *Mutat. Res.* 221:53-67.
- 27 Clayson, D.B., Mehta, R., Iverson, F. (1994) Oxidative DNA damage--The effects of certain genotoxic and  
28 operationally non-genotoxic carcinogens. *Mutat. Res.* 317:25-42.

- 1 Cogliano, V.J. (1986) The U.S. EPA's methodology for adjusting the reportable quantities of potential carcinogens.  
2 Proceedings of the 7th National Conference on Management of Uncontrollable Hazardous Wastes (Superfund '86).  
3 Washington, DC: Hazardous Wastes Control Institute, 182-185.
- 4 Cohen, S.W., Ellwein, L.B. (1990) Cell proliferation in carcinogenesis. *Science* 249:1007-1011.
- 5 Cohen, S.M., Ellwein, L.B. (1991) Genetic errors, cell proliferation and carcinogenesis. *Cancer Res.* 51:6493-  
6 6505.
- 7 Cohen, S.M. and Ellwein, L.B. (1991) Genetic errors, cell proliferation, and carcinogenesis. *Cancer Res.* 51:  
8 6493-6505.
- 9 Cohen, S.M., Purtilo, D.T., Ellwein, L.B. (1991) Pivotal role of increased cell proliferation in human  
10 carcinogenesis. *Mod. Pathol.* 4:371-375.
- 11 Cohen, S.M. (1995) Role of urinary physiology and chemistry in bladder carcinogenesis. *Fd. Chem. Toxicol.* 33:  
12 715-30.
- 13 Collum, R.G., Alt, F.W. (1990) Are *myc* proteins transcription factors? *Cancer Cells* 2:69-73.
- 14 Connolly, R.B., Andersen, M.E. (1991) Biologically based pharmacodynamic models: tools for toxicological  
15 research and risk assessment. *Ann. Rev. Pharmacol. Toxicol.* 31:503-523.
- 16 Cresteil, T., (1998) Onset of xenobiotic metabolism in children: toxicological implications. *Food Addit. and*  
17 *Contam.* 15, Supplement 45-51.
- 18 Cross, M., Dexter, T. (1991) Growth factors in development, transformation, and tumorigenesis. *Cell* 64:271-280.
- 19 D'Souza, R.W., Francis, W.R., Bruce, R.D., Andersen, M.E. (1987) Physiologically based pharmacokinetic model  
20 for ethylene chloride and its application in risk assessment. In: *Pharmacokinetics in risk assessment. Drinking*  
21 *Water and Health. Vol. 8.* Washington, DC: National Academy Press.
- 22 deThe, H., Lavau, C., Marchio, A., Chomienne, C., Degos, L., Dejean, A. (1991) The PML-RAR $\alpha$  fusion mRNA  
23 generated by the t (15;17) translocation in acute promyelocytic leukemia encodes a functionally altered RAR. *Cell*  
24 66:675-684.
- 25 DiGeorge, A.M. (1992) The endocrine system. In *Nelson Textbook of Pediatrics.* Behrman, R.E., Kliegman,  
26 R.M., Nelson, W.E., et al. eds. 14<sup>th</sup> ed. W.B. Saunders, Philadelphia PA, 1397-1472.
- 27 Dourson, M.L., Stara, J.F. (1983) Regulatory history and experimental support of uncertainty (safety) factors.

- 1 Regul. Toxicol. Pharmacol. 3:224-238
- 2 Enterline, P.E., Henderson, V.L., Marsh, G.M. (1987) Exposure to arsenic. *Amer. J. Epidemiol.* 125:929-938.
- 3 European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC). (1991) Early indicators of non-  
4 genotoxic carcinogenesis. ECETOC Monograph No. 16. Brussels: ECETOC. Printed in *Mutat. Res.* 248:211-374.
- 5 Faustman, E. et al. (1997) Experimental approaches to evaluate mechanisms of developmental toxicity. In Hood,  
6 R.D., ed. *Handbook of Developmental Biology*. Boca Raton, LA: CRC Press. pp. 13-41.
- 7 Faustman, E.M., Allen, B.C., Kavlock, R.J., Kimmel, C.A. (1994) Dose-response assessment for developmental  
8 toxicity. *Fundam. Appl. Toxicol.* 23:478-486.
- 9 Fearon, E., Vogelstein, B. (1990) A genetic model for colorectal tumorigenesis. *Cell* 61:959-967.
- 10 Federated Association of Societies of Experimental Biology (FASEB) (1994) Evaluation of evidence for the  
11 carcinogenicity of butylated hydroxyanisole (BHA). Life Sciences Research Office, Bethesda, MD. Letter from  
12 Hamilton Brown (FDA) to John Rice (FASEB), July 28, 1994. Letter from John Rice (FASEB) to Ed Arnold  
13 (FDA), August 4, 1994.
- 14 Fidler, I.J., Radinsky, R. (1990) Genetic control of cancer metastasis. *J. Natl. Cancer Inst.* 82:166-168.
- 15 Fisher, D.A. , Klein, A.H. (1981) Thyroid development and disorders of thyroid function in the new born. *N.*  
16 *Engl. J. Med.* 304:702-712.
- 17 Fisher, R.A. (1950) *Statistical Methods for Research Workers*. Edinburgh, Scotland: Oliver and Boyd.
- 18 Flamm, W.G., Winbush, J.S. (1984) Role of mathematical models in assessment of risk and in attempts to define  
19 management strategy. *Fundam. Appl. Toxicol.* 4:S395-S401.
- 20 Flammang, T.J., Von Tungeln, L.S., Kadlubar, F.F. and Fu, P.P. (1997) Neonatal mouse assay for tumorigenicity:  
21 alternative to the chronic rodent bioassay. *Regul. Toxicol. Pharmacol.* 26: 230-240.
- 22 Flynn, G.L. (1990) Physicochemical determinants of skin absorption. In: Gerrity, T.R., Henry, C.J., eds. *Principles*  
23 *of Route to Route Extrapolation for Risk Assessment*. New York: Elsevier Science Publishing Co.; pp. 93-127.
- 24 Forsburg, S.L., Nurse, P. (1991) Identification of a G1-type cyclin *pug1+* in the fission yeast *Schizosaccharomyces*  
25 *pombe*. *Nature* 351:245-248.
- 26 Garfinkel, L., Silverberg, E. (1991) Lung cancer and smoking trends in the United States over the past 25 years.

- 1 Cancer 41:137-145.
- 2 Gaylor, D.W., Kodell, R.L. (1980) Linear interpolation algorithm for low-dose risk assessment of toxic substances.  
3 J. Environ. Pathol. Toxicol. 4:305-312.
- 4 Gearhart, J.P., Herzberg, G.Z. and Jeffs, R.D. (1991) Childhood urolithiasis: experiences and advances.  
5 Pediatrics. 87: 445-450.
- 6 Gerrity, T.R., Henry, C., eds. (1990) Principles of Route to Route Extrapolation for Risk Assessment. New York:  
7 Elsevier Science Publishing Co.
- 8 Gibson, D.P., Aardema, M.J., Kerckaert, G.A., Carr, G.J., Brauninger, R.M., LeBoeuf, R.A. (1995) Detection of  
9 aneuploidy-inducing carcinogens in the Syrian hamster embryo (SHE) cell transformation assay. Mutat. Res.;  
10 Genet. Toxicol. 343:7-24.
- 11 Gillette, J.R. (1983) The use of pharmacokinetics in safety testing. In: Homburger, ed. Safety Evaluation and  
12 Regulation of Chemicals 2. 2nd Int. Conf., Cambridge, MA: Karger, Basel; pp. 125-133.
- 13 Gloeckler Ries, L.A., Hankey, B.F., Harras, A. and Devesa, S.S. 1996 Cancer incidence, mortality, and patient  
14 survival in the United States. In Schottenfeld, D. and Fraumeni, J.F., Jr., eds. Cancer epidemiology and  
15 prevention. 2nd ed. New York: Oxford University. pp. 168-191
- 16 Goldey, E.S., Kehn, L.S., Lau, C. et al. (1995) Developmental exposure to polychlorinated biphenyls (Aroclor  
17 1254) reduces circulating thyroid hormone concentrations and causes hearing deficits in rats. Toxicol. Appl.  
18 Pharmacol. 135:77-88
- 19 Goldman, L.R. (1998) Chemicals and childrens environment: what we don't know about risks. Environ Health  
20 Perspect 106 Suppl 3:875-880.
- 21 Goldsworthy, T.L., Hanigan, M.H., and Pitot, H.C. (1986) Models of hepatocarcinogenesis in the rat--contrasts and  
22 comparisons. CRC Crit. Rev. Toxicol. 17:61-89.
- 23 Goodman, G., Wilson, R. (1991) Predicting the carcinogenicity of chemicals in humans from rodent bioassay data.  
24 Environ. Health Perspect. 94:195-218.
- 25 Goodman, J.I., Counts, J.L. (1993) Hypomethylation of DNA: A possible nongenotoxic mechanism underlying the  
26 role of cell proliferation in carcinogenesis. Environ. Health Perspect. 101 Supp. 5:169-172.
- 27 Goodman, J.I., Ward, J.M., Popp, J.A., Klaunig, J.E., Fox, T.R. (1991) Mouse liver carcinogenesis: Mechanisms  
28 and relevance. Fundam. Appl. Toxicol. 17:651-665.

1 Grasso, P., Hinton, R.H. (1991) Evidence for and possible mechanisms of non-genotoxic carcinogenesis in rodent  
2 liver. *Mutat. Res.* 248:271-290.

3 Greenland, S. (1987) Quantitative methods in the review of epidemiologic literature. *Epidemiol. Rev.* 9:1-29.

4 Greenspan, F.S., Stewler, G.J. (1997) *Basic and clinical endocrinology*. Appleton & Lange, Stamford, CT.

5 Hale, G.A., Marina, N.M., Johnes-Wallace, D., Greenwarld, C.A., Jenkins, J.J., Rao, B.N., Luo, X., and Hudson,  
6 M.M. (1999) Late effects of treatment for germ cell tumors during childhood and adolescence. *J. Pediatr.*  
7 *Hematol. Oncol.* 21: 115-122.

8 Hammand, E.C. (1966) Smoking in relation to the death rates of one million men and women. In: Haenzel, W.,  
9 ed. *Epidemiological approaches to the study of cancer and other chronic diseases*. National Cancer Institute  
10 Monograph No. 19. Washington, DC.

11 Hankey, B.F., Silverman, D.T. and Kaplan, R. (1993) Urinary bladder. In Miller, B.A., Ries, L.A.G., Hankey,  
12 B.F. et al., eds. *SEER cancer statistics review: 1973-1990*. NIH Pub. No. 93-789. Bethesda, MD: National  
13 Cancer Institute. pp. XXXVI.1-17.

14 Harris, C.C. (1989) Interindividual variation among humans in carcinogen metabolism, DNA adduct formation  
15 and DNA repair. *Carcinogenesis* 10:1563-1566.

16 Harris, C.C., Hollstein, M. (1993) Clinical implications of the p53 tumor suppressor gene. *N. Engl. J. Med.*  
17 329:1318-1327.

18 Harris, H. (1990) The role of differentiation in the suppression of malignancy. *J. Cell Sci.* 97:5-10.

19 Hartwell, L.H., Kastan, M.B. (1994) Cell cycle control and cancer. *Science* 266:1821-1828.

20 Haseman, J.K. (1983) Issues: a reexamination of false-positive rates for carcinogenesis studies. *Fundam. Appl.*  
21 *Toxicol.* 3:334-339.

22 Haseman, J.K. (1984) Statistical issues in the design, analysis and interpretation of animal carcinogenicity studies.  
23 *Environ. Health Perspect.* 58:385-392.

24 Haseman, J.K. (1985) Issues in carcinogenicity testing: dose selection. *Fundam. Appl. Toxicol.* 5:66-78.

25 Haseman, J.K. (1990) Use of statistical decision rules for evaluating laboratory animal carcinogenicity studies.  
26 *Fundam. Appl. Toxicol.* 14:637-648.

1 Haseman, J.K. (1995) Data analysis: Statistical analysis and use of historical control data. Regul. Toxicol.  
2 Pharmacol. 21:52-59.

3 Haseman, J.K., Huff, J., Boorman, G.A. (1984) Use of historical control data in carcinogenicity studies in rodents.  
4 Toxicol. Pathol. 12:126-135.

5 Hatch, E.E., Palmer, J.R., Titus-Ernstoff, L., Noller, K.L., Kaufman, R.H., Mittendorf, R., Robboy, S.J., Hyer, M.,  
6 Cowan, C.M., Adam, E., Colton, T., Hartge, P., Hoover, R.N. (1998) J. Am. Med. Assoc. 280:630-634.

7 Hatch, E.E., Palmer, J.R., Titus-Ernstoff, L., Noller., K.L. et al. (1998) Cancer risk in women exposed to  
8 diethylstilbestrol in utero. JAMA 280: 630-634.

9 Hattis, D. (1990) Pharmacokinetic principles for dose-rate extrapolation of carcinogenic risk from genetically  
10 active agents. Risk Anal. 10:303-316.

11 Havu, N., Mattsson, H., Ekman, L., Carlsson, E. (1990) Enterochromaffin-like cell carcinoids in the rat gastric  
12 mucosa following long-term administration of ranitidine. Digestion 45:189-195.

13 Hayward, N.K., Walker, G.J., Graham, W., Cooksley, E. (1991) Hepatocellular carcinoma mutation. Nature  
14 352:764.

15 Hayward, J.J., Shane, B.S., Tindall, K.R., Cunningham, M.L. (1995) Differential in vivo mutagenicity of the  
16 carcinogen-noncarcinogen pair 2,4- and 2,6-diaminotoluene. Carcinogenesis 10:2429-2433.

17 Herschman, H.R. (1991) Primary response genes induced by growth factors or promoters. Ann. Rev. Biochem.  
18 60:281-319.

19 Herbst, A.L., Ulfelder, H., Poskanzer, D.C. (1971) Adenocarcinoma of the vagina: association of maternal  
20 stilbestrol therapy with tumor appearance in young women. N Engl. J. Med. 284:878-881.

21 Hiatt, R.A., Dales, L.G., Friedman, G.D. and Hunkeler, E.M. (1982) Frequency of nephrolithiasis in a prepaid  
22 medical care program. Am. J. Epidemiol. 115:225-265

23 Hill, A.B. (1965) The environment and disease: Association or causation? Proc. R. Soc. Med. 58:295-300;  
24 Department of Health and Human Services (1982) The health consequences of smoking--cancer, a report of the  
25 Surgeon General. Washington. pp.17-20, 29 et seq.

26 Hill, R.N., Erdreich, L.S., Paynter, O.E., Roberts, P.A., Rosenthal, S.L., Wilkinson, C.F. (1989) Thyroid follicular  
27 cell carcinogenesis. Fundam. Appl. Toxicol. 12:629-697.



1 Hoel, D.G., Portier, C.J. (1994) Nonlinearity of dose-response functions for carcinogenicity. *Environ. Health*  
2 *Perspect.* 102 Suppl 1:109-113.

3 Hoel, D.G., Haseman, J.K., Hogam, M.D., Huff, J., McConnell, E.E. (1988) The impact of toxicity on  
4 carcinogenicity studies: Implications for risk assessment. *Carcinogenesis* 9:2045-2052.

5 Holliday, R. (1987) DNA methylation and epigenetic defects in carcinogenesis. *Mutat. Res.* 181:215-217.

6 Hollstein, M., Sidransky, D., Vogelstein, B., Harris, C.C. (1991) p53 mutations in human cancers. *Science* 253:49-  
7 53.

8 Hotz, K.J., Wilson, A.G.E., Thake, D.C., Roloff, M.V., Capen, C.C., Kronenberg, J.M., Brewster, D.W. (1997)  
9 Mechanism of thiazopyr-induced effects on thyroid hormone homeostasis in male Sprague-Dawley rats. *Toxicol.*  
10 *Appl. Pharmacol.* 142, 133-142.

11 Hsu, I.C., Metcaff, R.A., Sun, T., Welsh, J.A., Wang, N.J., Harris, C.C. (1991) Mutational hotspot in human  
12 hepatocellular carcinomas. *Nature* 350:427-428.

13 Huff, J.E. (1993) Chemicals and cancer in humans: first evidence in experimental animals. *Environ. Health*  
14 *Perspect.* 100:201-210.

15 Huff, J.E. (1994) Chemicals causally associated with cancers in humans and laboratory animals. A perfect  
16 concordance. In: *Carcinogenesis*. Waalkes, M.P., Ward, J.M., eds., New York: Raven Press; pp. 25-37.

17 Hulka, B.S., Margolin, B.H. (1992) Methodological issues in epidemiologic studies using biological markers. *Am.*  
18 *J. Epidemiol.* 135:122-129.

19 Hunter, T. (1991) Cooperation between oncogenes. *Cell* 64:249-270.

20 IARC. (1994) IARC monographs on the evaluation of carcinogenic risks to humans. Vol. 60, Some Industrial  
21 Chemicals. Lyon, France: IARC; pp. 13-33.

22 ICRP, (1991). Recommendations of the International Commission on Radiation Protection. *Ann ICRP* 1991; 21  
23 (Publication 60): 1-20.

24 ILSI, International Life Sciences Institute. (1990) Similarities and Differences Between Children and Adults:  
25 Implications for Risk Assessment. Foran, J.A., Ed. ILSI Press: Washington, DC.

26 ILSI (1992). "Similarities & Differences Between Children & Adults; Implications for Risk Assessment." ILSI  
27 Press. Washington, DC.

- 1 ILSI, International Life Science Institute. (1995) The use of biological data in cancer risk assessment. In: Olin, S.,  
2 Farland, W., Park, C., Rhomberg, L., Scheuplein, R., Starr, T., Wilson, J., eds. Low-Dose Extrapolation of Cancer  
3 Risks: Issues and Perspectives. Washington, DC: ILSI Press; pp. 45-60.
- 4 ILSI, International Life Sciences Institute. (1997) Principles for the Selection of Doses in Chronic Rodent  
5 Bioassays. Foran, J.A., Ed. ILSI Press: Washington, DC.
- 6 Ingbar, S.H., Woeber, K.A. (1981) the thyroid gland. In: Textbook of endocrinology. Williams R.H., ed. W.B.  
7 Saunders, Philadelphia PA, 117-247.
- 8 Ingram, A.J., Grasso, P. (1991) Evidence for and possible mechanisms of non-genotoxic carcinogenesis in mouse  
9 skin. *Mutat. Res.* 248:333-340.
- 10 International Agency for Research on Cancer (IARC). (1990) Ciclosporin. IARC Monographs on the Evaluation of  
11 Carcinogenic Risks to Humans. Vol. 50. Lyon, France: IARC; pp. 77-114.
- 12 Israel, M.A. (1995) Molecular biology of childhood neoplasms. In Mendelsohn, J., Howley, P. M., Israel, M.A.  
13 and Liotta, L.A., eds. The molecular basis of cancer. Philadelphia: Saunders. pp. 294-316.
- 14 Ito, N., Shirai, T., and Hasegawa, R. (1992) Medium-term bioassays for carcinogens. In Mechanisms of  
15 Carcinogenesis in Risk Identifications (Vainio, H., Magee, P.N., McGregor, D.B., and McMichael, A.J., eds.),  
16 Lyon, International Agency for Research on Cancer, pp. 353-388.
- 17 Jack, D., Poynter, D., Spurling, N.W. (1983) Beta-adrenoreceptor stimulants and mesoovarian leiomyomas in the  
18 rat. *Toxicology* 2:315-320.
- 19 Jarabek, A.M. (1995a) The application of dosimetry models to identify key processes and parameters for default  
20 dose-response assessment approaches. *Toxicol. Lett.* 79:171-184.
- 21 Jarabek, A.M. (1995b) Interspecies extrapolation based on mechanistic determinants of chemical disposition.  
22 *Human Eco. Risk Assess.* 1(5):641-662.
- 23 Johnson, C.M., Wilson, D.M., O'Fallon, W.M., Malek, R.S. and Kurland, L.T. (1979) Renal stone epidemiology:  
24 a 25-year study in Rochester, Minnesota. *Kid. Internat.* 16: 624-631.
- 25 Jones, P.A. (1986) DNA methylation and cancer. *Cancer Res.* 46:461-466.
- 26 Kehrer, J.P. (1993) Free radicals as mediators of tissue injury and disease. *Crit. Rev. Toxicol.* 23:21-48.

1 Kelsey, J.L., Thompson, W.D., Evans, A.S. (1986) *Methods in Observational Epidemiology*. New York: Oxford  
2 University Press.

3 Khoory, B.J., Pedrolli, A., Vecchini, S., Benini, D. and Fanos, V. (1998) Renal calculosis in pediatrics. *Pediatr.*  
4 *Med. Chir.* 20: 367-76.

5 Kinzler, K.W., Nilbert, M.C., Su, L.-K., Vogelstein, B., Bryan, T.M., Levy, D.B., Smith, K.J., Preisinger, A.C.,  
6 Hedge, P., McKechnie, D., Finniear, R., Markham, A., Groffen, J., Boguski, M.S., Altschul, S.J., Horii, A., Ando,  
7 H., Miyoshi, Y., Miki, Y., Nishisho, I., Nakamura, Y. (1991) Identification of FAP locus genes from chromosome  
8 5q21. *Science* 253:661-665.

9 Kodell, R.L., Park, C.N. (1995) *Linear Extrapolation in Cancer Risk Assessment*. ILSI Risk Science Institute:  
10 Washington, D.C. In press.

11 Kraus, A.L., Munro, I.C., Orr, J.C., Binder, R.L., LeBoeuf, R.A., Williams, G.M. (1995) Benzoyl peroxide: an  
12 integrated human safety assessment for carcinogenicity. *Regul. Toxicol. Pharmacol.* 21:87-107.

13 Krewski, D., Brown, C., Murdoch, D. (1984) Determining "safe" levels of exposure: Safety factors of mathematical  
14 models. *Fundam. Appl. Toxicol.* 4:S383-S394.

15 Krewski, D., Murdoch, D.J., Withey, J.R. (1987) The application of pharmacokinetic data in carcinogenic risk  
16 assessment. In: *Pharmacokinetics in Risk Assessment. Drinking water and health*. Vol. 8. Washington, DC:  
17 National Academy Press, pp. 441-468.

18 Kripke, M.L. (1988) Immunoregulation of carcinogenesis: Past, present, and future. *J. Natl. Cancer Inst.* 80:722-  
19 727.

20 Kumar, R., Sukumar, S., Barbacid, M. (1990) Activation of *ras* oncogenes preceding the onset of neoplasia.  
21 *Science* 248:1101-1104.

22 Kushner, B.H., Heller, G., Cheung, N.K., Wollner, N., Kramer, K., Bajorin, D., Polyak, T., and Meyers, P.A.  
23 (1998) High risk of leukemia after short-term dose-intensive chemotherapy in young patients with solid tumors. *J.*  
24 *Clin. Oncol.* 16: 3016-3020.

25 Larsen, P.R. (1982) The thyroid. In *Cecil textbook of medicine*. 16<sup>th</sup> ed. Wyngaarden, J.B, Smith, L.H., eds. W.B.  
26 Saunders, Philadelphia PA, 1201-1225.

27 Larson, R.A., LeBeau, M.M., Vardiman, J.W. and Rowley, J.D. (1996) Myeloid leukemia after hematotoxins.  
28 *Environ. Health Perspect.* 104: 1303-1307.

- 1 Larson, J.L., Wolf, D.C., Butterworth, B.E. (1994) Induced cytotoxicity and cell proliferation in the  
2 hepatocarcinogenicity of chloroform in female B6C3F1 mice: comparison of administration by gavage in corn oil  
3 vs. ad libitum in drinking water. *Fundam. Appl. Toxicol.* 22:90-102.
- 4 Levine, A.M. (1993) AIDS-related malignancies: The emerging epidemic. *J. Natl. Cancer Inst.* 85:1382-1397.
- 5 Levine, P.H., Hoover, R.N., eds. (1992) The emerging epidemic of non-Hodgkin's lymphoma: current knowledge  
6 regarding etiological factors. *Cancer Res.* 52:5426s-5574s.
- 7 Levine, A. J., Momand, J., Finlay, C. A. (1991) The p53 tumour suppressor gene. *Nature* 351:453-456.
- 8 Levine, A.J., Perry, M.E., Chang, A., et al. (1994) The 1993 Walter Hubert Lecture: The role of the p53 tumor-  
9 suppressor gene in tumorigenesis. *Br. J. Cancer* 69:409-416.
- 10 Li, J.L., Okada, S., Hamazaki, S., Ebina, Y., Midorikawa, O. (1987) Subacute nephrotoxicity and induction of  
11 renal cell carcinoma in mice treated with ferric nitrilotriacetate. *Cancer Res.* 47:1867-1869.
- 12 Lijinsky, W. (1993) Species differences in carcinogenesis. *In Vivo* 7:65-72.
- 13 Lilienfeld, A.M., Lilienfeld, D. (1979) *Foundations of Epidemiology*, 2nd ed. New York: Oxford University Press.
- 14 Lindahl, T., Klein, G. Reedman, B.M., et al. (1974) Relationship between Epstein-Barr virus (EBV) DNA and  
15 the EBV-determined nuclear antigen (EBNA) in Burkitt lymphoma biopsies and other lymphoproliferative  
16 malignancies. *Int. J. Cancer.* 13: 764-772.
- 17 Loeb, L.A. (1991) Mutator phenotype may be required for multistage carcinogenesis. *Cancer Res.* 51:3075-3079.
- 18 Logothetopoulos, J.H. (1963) Growth and function of the thyroid gland in rats injected with L-thyroxine from birth  
19 to maturity. *Endocrinology* 73:349-352.
- 20 Lutz, W.K. (1990a) Endogenous genotoxic agents and processes as a basis of spontaneous carcinogenesis. *Mutat.*  
21 *Res.* 238:287-295.
- 22 Lutz, W.K. (1990b) Dose-response relationship and low dose extrapolation in chemical carcinogenesis.  
23 *Carcinogenesis* 11:1243-1247.
- 24 MacDonald, J.S., Lankas, G.R., Morrissey, R.E. (1994) Toxicokinetic and mechanistic considerations in the  
25 interpretaion of the rodent bioassay. *Toxicol. Pathol.* 22:124-140.

- 1 Maller, J.L. (1991) Mitotic control. *Curr. Opin. Cell Biol.* 3:269-275.
- 2 Maronpot, R.R., Shimkin, M.B., Witschi, H.P., Smith, L.H., and Cline, J.M. (1986) Strain A mouse pulmonary  
3 tumor test results for chemicals previously tested in National Cancer Institute carcinogenicity test. *J. Natl. Cancer*  
4 *Inst.* 76:1101-1112.
- 5 Marsman, D.S., Popp, J.A. (1994) Biological potential of basophilic hepatocellular foci and hepatic adenoma  
6 induced by the peroxisome proliferator, Wy-14,643. *Carcinogenesis* 15:111-117.
- 7 Mausner, J.S., Kramer, S. (1985) *Epidemiology*, 2nd ed. Philadelphia: W.B. Saunders Company.
- 8 McClain, R.M. (1994) Mechanistic considerations in the regulation and classification of chemical carcinogens. In:  
9 Kotsonis, F.N., Mackey, M., Hjelle, J., eds. *Nutritional Toxicology*. New York: Raven Press, pp. 273-304.
- 10 McConnell, E.E. (1992) Comparative response in carcinogenesis bioassay as a function of age at first exposure. In:  
11 Guzelian, P., Henry, C.J., and Olin, S.S. (eds). *Similarities and difference between children and adults:*  
12 *implications for risk assessment*. Washington, DC: ILSI Press, pp. 66-78.
- 13 McConnell, E.E., Solleveld, H.A., Swenberg, J.A., Boorman, G.A. (1986) Guidelines for combining neoplasms for  
14 evaluation of rodent carcinogenesis studies. *J. Natl. Cancer Inst.* 76:283-289.
- 15 McMichael, A.J. (1976) Standardized mortality ratios and the "healthy worker effect": scratching beneath the  
16 surface. *J. Occup. Med.* 18:165-168.
- 17 Melnick, R.L., Huff, J.E., Barrett, J.C., Maronpot, R.R., Lucier, G., Portier, C.J. (1993a) Cell proliferation and  
18 chemical carcinogenesis: A symposium overview. *Mol. Carcinog.* 7:135-138.
- 19 Melnick, R.L., Huff, J.E., Barrett, J.C., Maronpot, R.R., Lucier, G., Portier, C.J. (1993b) Cell proliferation and  
20 chemical carcinogenesis. *Mol. Carcinog.* 7:135-138.
- 21 Meyn, M.S. (1993) High spontaneous intrachromosomal recombination rates in ataxia-telangiectasia. *Science*  
22 260:1327-1330.
- 23 Modrich, P. (1994) Mismatch repair, genetic stability, and cancer. *Science* 266:1959-1960.
- 24 Monro, A. (1992) What is an appropriate measure of exposure when testing drugs for carcinogenicity in rodents?  
25 *Toxicol. Appl. Pharmacol.* 112:171-181.
- 26 Moolgavkar, S.H., Knudson, A.G. (1981) Mutation and cancer: a model for human carcinogenesis. *J. Natl. Cancer*  
27 *Inst.* 66:1037-1052.

1 Morrison, V., Ashby, J. (1994) A preliminary evaluation of the performance of the muta<sup>TM</sup> mouse (lacZ) and Big  
2 Blue<sup>TM</sup> (lacI) transgenic mouse mutation assays. *Mutagenesis* 9:367-375.

3 Naeve, G.S., Sharma, A., Lee, A.S. (1991) Temporal events regulating the early phases of the mammalian cell  
4 cycle. *Curr. Opin. Cell Biol.* 3:261-268.

5 National Academy of Science. (1993). "Pesticides in the Diets of Infants and Children." National Academy Press.  
6 Washington, DC.

7 National Research Council (NRC). (1983) Risk Assessment in the Federal Government: Managing the Process.  
8 Committee on the Institutional Means for Assessment of Risks to Public Health, Commission on Life Sciences,  
9 NRC. Washington, DC: National Academy Press.

10 NRC, (1990) Health effects of exposure to low levels of ionizing radiation. National Research Council. BEIR V.  
11 Washington: National Academy Press.

12 NRC. (1993) Pesticides in the diets of infants and children. Washington: National Academy Press.

13 NRC. (1993a) Pesticides in the Diets of Infants and Children. Committee on Pesticides in the Diets of Infants and  
14 Children, Commission on Life Sciences, NRC. Washington, DC: National Academy Press.

15 NRC. (1993b) Issues in Risk Assessment. Committee on Risk Assessment Methodology, Commission on Life  
16 Sciences, NRC. Washington, DC: National Academy Press.

17 NRC. (1994) Science and Judgment in Risk Assessment. Committee on Risk Assessment of Hazardous Air  
18 Pollutants, Commission on Life Sciences, NRC. Washington, DC: National Academy Press.

19 National Toxicology Program (NTP). (1984) Report of the Ad Hoc Panel on Chemical Carcinogenesis Testing and  
20 Evaluation of the National Toxicology Program, Board of Scientific Counselors. Washington, DC: U.S.  
21 Government Printing Office. 1984-421-132:4726.

22 Nebreda, A.R., Martin-Zanca, D., Kaplan, D.R., Parada, L.F., Santos, E. (1991) Induction by NGF of meiotic  
23 maturation of *xenopus* oocytes expressing the *trk* proto-oncogene product. *Science* 252:558-561.

24 Newbold, R.R., Jefferson, W.N., Padilla-Burgos, E., and Bullock, B.C. (1997) Uterine carcinoma in mice treated  
25 neonatally with tamoxifen. *Carcinogenesis*. 18: 2293-2298.

26 Nicholson, J.F., Pesce, M.A. (1992) Laboratory testing and reference values (Tabel 27-2) in infants and children.  
27 In Nelson Textbook of Pediatrics. Behrman, R.E., Kliegman, R.M., Nelson, W.E., et al. eds. 14<sup>th</sup> ed. W.B.  
28 Saunders, Philadelphia PA, 1797-1826.

- 1 Nowell, P. (1976) The clonal evolution of tumor cell populations. *Science* 194:23-28.
- 2 Nunez, G., Hockenberry, D., McDonnell, J., Sorenson, C.M., Korsmeyer, S.J. (1991) Bcl-2 maintains B cell  
3 memory. *Nature* 353:71-72.
- 4 Nyandoto, P., Muhonen, T., and Joensuu, H. (1998) Second cancer among long-term survivors from Hodgkin's  
5 disease. *Int. J. Radiat. Oncol. Biol. Phys.* 42: 373-378.
- 6 Office of Science and Technology Policy (OSTP). (1985) Chemical carcinogens: Review of the science and its  
7 associated principles. *Federal Register* 50:10372-10442.
- 8 Organization for Economic Cooperation and Development (OECD). (1981) Guidelines for testing of chemicals.  
9 Carcinogenicity studies. No. 451. Paris, France.
- 10 Parkin, D.M., Stiller, C.A., Draper, G.J., et al. (1988) International incidence of childhood cancer. IARC Sci.  
11 Pub. No. 87. Lyon: International Agency for Research on Cancer.
- 12 Peltomäki, P., Aaltonen, L.A., Sisonen, P., Pylkkänen, L., Mecklin, J.-P., Järvinen, H., Green, J.S., Jass, J.R.,  
13 Weber, J.L., Leach, F.S., Petersen, G.M., Hamilton, S.R., de la Chapelle, A., Vogelstein, B. (1993) Genetic  
14 mapping of a locus predisposing human colorectal cancer. *Science* 260:810-812.
- 15 Peto, J. (1992) Meta-analysis of epidemiological studies of carcinogenesis. In: *Mechanisms of Carcinogenesis in*  
16 *Risk Assessment*. IARC Sci. Pubs. No. 116, Lyon, France: IARC, pp. 571-577.
- 17 Peto, J., Darby, S. (1994) Radon risk reassessed. *Nature* 368:97-98.
- 18 Pitot, H., Dragan, Y.P. (1991) Facts and theories concerning the mechanisms of carcinogenesis. *FASEB J.* 5:2280-  
19 2286.
- 20 Portier, C. (1987) Statistical properties of a two-stage model of carcinogenesis. *Environ. Health Perspect.* 76:125-  
21 131.
- 22 Poskanzer, D. and Herbst, A. (1977) Epidemiology of vaginal adenosis and adenocarcinoma associated with  
23 exposure to stilbestrol in utero. *Cancer.* 39: 1892-1895.
- 24 Prahalada, S., Majka, J.A., Soper, K.A., Nett, T.M., Bagdon, W.J., Peter, C.P., Burek, J.D., MacDonald, J.S., van  
25 Zwieten, M.J. (1994) Leydig cell hyperplasia and adenomas in mice treated with finasteride, a 5 $\alpha$ -reductase  
26 inhibitor: A possible mechanism. *Fundam. Appl. Toxicol.* 22:211-219.
- 27 Raff, M.C. (1992) Social controls on cell survival and cell death. *Nature* 356:397-400.

1 Rall, D.P. (1991) Carcinogens and human health: Part 2. *Science* 251:10-11.

2 Regulatory Toxicology and Pharmacology. (1996) 24:126-140

3 Renwick, A.G., (1993) Data-derived safety factors for the evaluation of food additives and environmental  
4 contaminants. *Food Addit. And Contam.* 10, 275-305.

5

6 Renwick, A.G., (1998) Toxicokinetics in infants and children in relation to the ADI and TDI. *Food Addit.*  
7 *Contam.* 15, Supplement, 17-35.

8 Renwick, A.G., Lazarus, N.R. (1998) Human variability and noncancer risk assessment--an analysis of the default  
9 uncertainty factor. *Regul. Toxicol. Pharmacol.* 27:3-20.

10 Rice, JM. (1979) Problems and perspective in perinatal carcinogenesis: a summary of the conference. *NCI Moogr.*  
11 51:271-278.

12 Ries, L.A.G., Kosary, C.L., Hanky, B.F., Miller, B.A., Clegg, L., Edwards, B.K., eds. (1999) SEER cancer  
13 statistics review 1993-1998. National Cancer Institute, Bethesda, MD

14 Robboy, S.J. et al. (1984) Increased incidence of cervical and vaginal dysplasia in 3,980 diethylstilbestrol-exposed  
15 young women. *JAMA.* 252: 2979-2983.

16 Rothman, K.T. (1986) *Modern Epidemiology*. Boston: Little, Brown and Company.

17 Salomon, D.S., Kim, N., Saeki, T., Ciardiello, F. (1990) Transforming growth factor  $\alpha$ --an oncodevelopmental  
18 growth factor. *Cancer Cells* 2:389-397.

19 Santos-Victoriano, M., Brouhard, B.H., and Cunningham, R.J., III. 1998. Renal Stone Disease in Children. *Clin.*  
20 *Pediat.* 37:583-599.

21 Schottenfeld, D., Fraumeni, J.F. Jr, (1996) *Cancer epidemiology and prevention*. Oxford University Press N.Y.,  
22 Oxford.

23

24 Schneider, C., Gustincich, S., DelSal, G. (1991) The complexity of cell proliferation control in mammalian cells.  
25 *Curr. Opin. Cell Biol.* 3:276-281.

26 Schuller, H.M. (1991) Receptor-mediated mitogenic signals and lung cancer. *Cancer Cells* 3:496-503.

27 Schulte-Hermann, R., Bursch, W., Kraupp-Grasl, B., Oberhammer, F., Wagner, A., Jirtle, R. (1993) *Cell*



- 1 proliferation and apoptosis in normal liver and preneoplastic foci. Environ. Health Perspect. 101 (Supp. 5):87-90.
- 2 Science Advisory Board (1997) An SAB report: Guidelines for Cancer Risk Assessment. Washington, DC, EPA-  
3 SAB-EHC-97-010.
- 4 Shelby, M.D., Zeiger, E. (1990) Activity of human carcinogens in the *Salmonella* and rodent bone-marrow  
5 cytogenetics tests. Mutat. Res. 234:257-261.
- 6 Shelby, M.D. (1994) Human germ cell mutations. Environ. Mol. Mutagen. 23 (Supp. 24):30-34.
- 7 Sidransky, D., Von Eschenbach, A., Tsai, Y.C., Jones, P., Summerhayes, I., Marshall, F., Paul, M., Green, P.,  
8 Hamilton, P.F., Vogelstein, B. (1991) Identification of p53 gene mutations in bladder cancers and urine samples.  
9 Science 252:706-710.
- 10 Sidransky, D., Mikkelsen, T., Schwechheimer, K., Rosenblum, M.L., Cavanee, W., Vogelstein, B. (1992) Clonal  
11 expansion of p53 mutant cells is associated with brain tumor progression. Nature 355:846-847.
- 12 Sisk, S.C., Pluta, L.J., Bond, J.A., Recio, L. (1994) Molecular analysis of lacI mutants from bone marrow of  
13 B6C3F1 transgenic mice following inhalation exposure to 1,3-butadiene. Carcinogenesis 15(3):471-477.
- 14 Snedecor, G.W., Cochran, W.G. (1978) Statistical methods, Sixth ed. Ames, Iowa: Iowa State University Press,  
15 593 pp.
- 16 Snodgrass, W.R. (1992) Physiological and biochemical differences between children and adults as determinants  
17 of toxic response to environmental pollutants. In Guzelian, P.S., Henry, C.J. and Olin, S.S. Similarities and  
18 differences between children and adults. Washington: ILSI Press. pp. 35-42.  
19
- 20 Srivastava, S., Zou, Z., Pirollo, K., Blattner, W., Chang, E. (1990) Germ-line transmission of a mutated p53 gene  
21 in a cancer-prone family with Li-Fraumeni syndrome. Nature 348(6303):747-749.
- 22 Stapleton, F.B. (1996) Clinical approach to children with urolithiasis. Semin. Nephrol. 16: 389-97.
- 23 Stewart, B.W. (1994) Mechanisms of apoptosis: Integration of genetic, biochemical, and cellular indicators. J.  
24 Natl. Cancer Inst. 86:1286-1296.
- 25 Stiteler, W.H., Knauf, L.A., Hertzberg, R.C., Schoeny, R.S. (1993) A statistical test of compatibility of data sets to  
26 a common dose-response model. Regul. Toxicol. Pharmacol. 18:392-402.
- 27 Stitzel, K.A., McConnell, R.F., Dierckman, T.A. (1989) Effects of nitrofurantoin on the primary and secondary

1 reproductive organs of female B6C3F1 mice. Toxicol. Pathol. 17:774-781.

2 Strausfeld, U., Labbe, J.C., Fesquet, D., Cavadore, J.C., Dicard, A., Sadhu, K., Russell, P., Dor'ee, M. (1991)  
3 Identification of a G1-type cyclin puc1+ in the fission yeast *Schizosaccharomyces pombe*. Nature 351:242-245.

4 Sukumar, S. (1989) *ras* oncogenes in chemical carcinogenesis. Curr. Top. Microbiol. Immunol. 148:93-114.

5 Sukumar, S. (1990) An experimental analysis of cancer: Role of *ras* oncogenes in multistep carcinogenesis. Cancer  
6 Cells 2:199-204.

7 Surks, M.I., Chopra, I.J., Maiash, C.N. et al. (1990) American Thyroid Association guidelines for use of laboratory  
8 tests in thyroid disorders. JAMA 263:1529-1532.

9 Swenberg, J.A., Richardson, F.C., Boucheron, J.A., Deal, F.H., Belinsky, S.A., Charbonneau, M., Short, B.G.  
10 (1987) High to low dose extrapolation: Critical determinants involved in the dose-response of carcinogenic  
11 substances. Environ. Health Perspect. 76:57-63.

12 Swierenga, S.H.H., Yamasaki, H. (1992) Performance of tests for cell transformation and gap junction intercellular  
13 communication for detecting nongenotoxic carcinogenic activity. In: Mechanisms of Carcinogenesis in Risk  
14 Identification. IARC Sci. Pubs. No. 116, Lyon, France: International Agency for Research on Cancer, pp. 165-193.

15 Tanaka, K., Oshimura, M., Kikiuchi, R., Seki, M., Hayashi, T, Miyaki, M. (1991) Suppression of tumorigenicity in  
16 human colon carcinoma cells by introduction of normal chromosome 5 or 18. Nature 349:340-342.

17 Tarone, R.E. (1982) The use of historical control information in testing for a trend in proportions. Biometrics  
18 38:215-220.

19 Taylor, J.H., Watson, M.A., Devereux, T.R., Michels, R.Y., Saccomanno, G., Anderson, M. (1994) Lancet 343:86-  
20 87.

21 Tennant, R.W. (1993) Stratification of rodent carcinogenicity bioassay results to reflect relative human hazard.  
22 Mutat. Res. 286:111-118.

23 Tennant, R.W., Ashby, J. (1991) Classification according to chemical structure, mutagenicity to *Salmonella* and  
24 level of carcinogenicity of a further 39 chemicals tested for carcinogenicity by the U.S. National Toxicology  
25 Program. Mutat. Res. 257:209-277.

26 Tennant, R.W., Elwell, M.R., Spalding, J.W., Griesemer, R.A. (1991) Evidence that toxic injury is not always  
27 associated with induction of chemical carcinogenesis. Mol. Carcinog. 4:420-440.

- 1 Tennant, R.W., French, J.E., Spalding, J.W. (1995) Identifying chemical carcinogens and assessing potential risk  
2 in short-term bioassays using transgenic mouse models. *Environ. Health Perspect.* 103:942-950.
- 3 Teta, M.J. (1999) Ethylene oxide cancer risk assessment based on epidemiological data: application of revised  
4 regulatory guidelines. *Risk Anal.* In press.
- 5 Thompson, T.C., Southgate, J., Kitchener, G., Land, H. (1989) Multistage carcinogenesis induced by *ras* and *myc*  
6 oncogenes in a reconstituted organ. *Cell* 56:917-3183.
- 7 Tinwell, H., Ashby, J. (1991) Activity of the human carcinogen MeCCNU in the mouse bone marrow micronucleus  
8 test. *Environ. Molec. Mutagen.* 17:152-154.
- 9 Tischler, A.S., McClain, R.M., Childers, H., Downing, J. (1991) Neurogenic signals regulate chromaffin cell  
10 proliferation and mediate the mitogenic effect of reserpine in the adult rat adrenal medulla. *Lab. Invest.* 65:374-  
11 376.
- 12 Tobey, R.A. (1975) Different drugs arrest cells at a number of distinct stages in G2. *Nature* 254:245-247.
- 13 Todd, G.C. (1986) Induction of reversibility of thyroid proliferative changes in rats given an antithyroid  
14 compound. *Vet. Pathol.* 23:110-117.
- 15 Tomatis, L., Aitio, A., Wilbourn, J., Shuker, L. (1989) Human carcinogens so far identified. *Jpn. J. Cancer Res.*  
16 80:795-807.
- 17 Travis, C.C., McClain, T.W., Birkner, P.D. (1991) Diethylnitrosamine-induced hepatocarcinogenesis in rats: A  
18 theoretical study. *Toxicol. Appl. Pharmacol.* 109:289-309.
- 19 Trinchieri, A. 1996 Epidemiology of urolithiasis. *Arch. Ital. Urol. Androl.* 68: 203-249.
- 20 U.S. Environmental Protection Agency. (1983a) Good Laboratory Practices Standards–Toxicology Testing. Federal  
21 Register 48:53922.
- 22 U.S. Environmental Protection Agency. (1983b) Hazard Evaluations: Humans and Domestic Animals. Subdivision  
23 F. Available from: NTIS, Springfield, VA, PB 83-153916.
- 24 U.S. Environmental Protection Agency. (1983c) Health Effects Test Guidelines. Available from: NTIS,  
25 Springfield, VA, PB 83-232984.
- 26 U.S. Environmental Protection Agency. (1984) Estimation of the Public Health Risk from Exposure to Gasoline  
27 Vapor Via the Gasoline Marketing System. Office of Health and Environmental Assessment, Washington, DC.

- 1 U.S. Environmental Protection Agency. (1986a) Health Assessment Document for Beryllium. Office of Health and  
2 Environmental Assessment, Washington, DC.
- 3 U.S. Environmental Protection Agency. (1986b) Guidelines for Carcinogen risk assessment. Federal Register  
4 51(185):33992-34003.
- 5 U.S. Environmental Protection Agency. (1989a) Interim Procedures for Estimating Risks Associated with  
6 Exposures to Mixtures of Chlorinated Dibenzo-*p*-Dioxins and -Dibenzofurans (CDDs and CDFs) and 1989 Update.  
7 Risk Assessment Forum, Washington, DC. EPA/625/3-89/016.
- 8 U.S. Environmental Protection Agency. (1989b) Workshop on EPA Guidelines for Carcinogen Risk Assessment.  
9 Risk Assessment Forum, Washington, DC. EPA/625/3-89/015.
- 10 U.S. Environmental Protection Agency. (1989c) Workshop on EPA Guidelines for Carcinogen Risk Assessment:  
11 Use of Human Evidence. Risk Assessment Forum, Washington, DC. EPA/625/3-90/017.
- 12 U.S. Environmental Protection Agency. (1989d) Summary of the Second Workshop Carcinogenesis Bioassay with  
13 the Dermal Route. May 18-19, 1988, Research Triangle Park, NC. EPA 560/6-89-003, available from NTIS, 5284  
14 Port Royal Road, Springfield, VA 22161 (703-487-4650).
- 15 U.S. Environmental Protection Agency. (1991a) Pesticide Assessment Guidelines: Subdivision F, Hazard  
16 Evaluation, Human and Domestic Animals. Series 84, Mutagenicity, Addendum 9. Office of Pesticide Programs,  
17 Washington, DC. PB91-158394, 540/09-91-122.
- 18 U.S. Environmental Protection Agency. (1991b)  $\alpha$ 2u-globulin: Association With Chemically Induced Renal  
19 Toxicity and Neoplasia in the Male Rat. Risk Assessment Forum, Washington, DC. EPA/625/3-91/019F.
- 20 U.S. Environmental Protection Agency. (1991c) Workshop Report on Toxicity Equivalency Factors for  
21 Polychlorinated Biphenyl Congeners. Risk Assessment Forum, Washington, DC. EPA/625/3-91/020.
- 22 U.S. Environmental Protection Agency. (1991d) Guidelines for Developmental Toxicity Risk Assessment. Federal  
23 Register 56(234):63798-63826.
- 24 U.S. Environmental Protection Agency. (1992a) Guidelines for Exposure Assessment. Federal Register  
25 57(104):22888-22938.
- 26 U.S. Environmental Protection Agency. (1992b) Draft report: A Cross-Species Scaling Factor for Carcinogen Risk  
27 Assessment Based on Equivalence of  $\text{mg}/\text{kg}^{3/4}/\text{day}$ . Federal Register 57(109):24152-24173.
- 28 U.S. Environmental Protection Agency. (1992c) Health Assessment for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin

1 (TCDD) and Related Compounds (Chapters 1 through 8). Workshop Review Drafts. EPA/600/AP-92/001a through  
2 001h.

3 U.S. Environmental Protection Agency. (1994a) Estimating Exposure to Dioxin-like Compounds. Office of Health  
4 and Environmental Assessment, Office of Research and Development, Washington, DC. External Review Draft, 3  
5 vol. EPA/600/6-88/005Ca, Cb, Cc.

6 U.S. Environmental Protection Agency. (1994b) Report on the Workshop on Cancer Risk Assessment Guidelines  
7 Issues. Office of Research and Development, Risk Assessment Forum, Washington, DC. EPA/630/R-94/005a.

8 U.S. Environmental Protection Agency. (1994c) Methods for Derivation of Inhalation Reference Concentrations  
9 and Application of Inhalation Dosimetry. Office of Health and Environmental Assessment, Environmental Criteria  
10 and Assessment Office, Research Triangle Park, NC. EPA/600/8-90/066F.

11 U.S. Environmental Protection Agency. (1995) Policy for Risk Characterization. Memorandum of Carol M.  
12 Browner, Administrator, March 21, 1995, Washington, DC.

13 U.S. Environmental Protection Agency. (1996a) Comparison of the effects of chemicals with combined perinatal  
14 and adult exposure vs. adult only exposure in carcinogenesis bioassays.  
15 <http://www.epa.gov/pesticides/SAP/1996/index.htm>

16 U.S. Environmental Protection Agency. (1996b) Comparison of the Effects of Chemicals With Combined Perinatal  
17 and Adult Exposure vs. Adult Only Exposure in Carcinogenesis Studies. Office of Pesticide Programs, October  
18 1996.

19 U.S. Environmental Protection Agency. (1997a) A proposed OPP Policy on Determining the Need for Perinatal  
20 Carcinogenicity Testing on a Pesticide. Office of Pesticide Programs, 14 August 1997.

21 U.S. Environmental Protection Agency. (1997b) A Set of Scientific Issues Being Considered by the Agency in  
22 Connection With the Criteria for Requiring In-utero Cancer Studies. Office of Pesticide Programs. FIFRA  
23 Scientific Advisory Panel. September 1997 meeting report  
24 ([www.epa.gov/pesticides/SAP/archive/september/finalsep.htm](http://www.epa.gov/pesticides/SAP/archive/september/finalsep.htm)).

25 U.S. Environmental Protection Agency. (1997c) Exposure factors handbook. EPA/600/P-95/002F.

26 U.S. Environmental Protection Agency. (1998a) Assessment of Thyroid Follicular Cell Tumors. Office of  
27 Research and Development, Risk Assessment Forum, Washington, DC. EPA/630/R-97/002.

28 U.S. Environmental Protection Agency. (1998b) Peer Review Handbook. Office of Research and Development,  
29 Office of Science Policy, Washington, DC. EPA 100-B-98-001

- 1 U.S. Food and Drug Administration (1987) Sponsored Compounds in Food-producing Animals, Criteria and  
2 Procedures for Evaluating the Safety of Carcinogenic Residues. Final Rule. 21 CFR Parts 70, 500, 514 and 571.
- 3 Vahakangas, K.H., Samet, J.M., Metcalf, R.A., Welsh, J.A., Bennett, W.P., Lane, D.P., Harris, C.C. (1992)  
4 Mutation of p53 and *ras* Genes in Radon-associated Lung Cancer from Uranium Miners. *Lancet* 339:576-578.
- 5 Vainio, H., Magee, P., McGregor, D., McMichael, A.J. (1992) Mechanisms of Carcinogenesis in Risk  
6 Identification. IARC Sci. Pubs. No. 116. Lyon, France: IARC.
- 7 Van Sittert, N.J., De Jong, G., Clare, M.G., Davies, R., Dean, B.J., Wren, L.R., Wright, A.S. (1985) Cytogenetic,  
8 immunological, and hematological effects in workers in an ethylene oxide manufacturing plant. *Br. J. Indust. Med.*  
9 42:19-26.
- 10 Vater, S.T., McGinnis, P.M., Schoeny, R.S., Velazquez, S. (1993) Biological considerations for combining  
11 carcinogenicity data for quantitative risk assessment. *Regul. Toxicol. Pharmacol.* 18:403-418.
- 12 Vesselinovich, S.D., Rao, K.V.N., Mihailovich, N. (1979) Neoplastic response of mouse tissues during perinatal  
13 age periods and its significance in chemical carcinogenesis. *NCI Monogr* 51:239.
- 14 Vogelstein, B., Fearon, E. R., Hamilton, S. R., Kern, S. E., Presinger, A. C., Leppert, M., Nakamura, Y., White,  
15 R., Smits, A. M. M., Bos, J. L. (1988) Genetic alterations during colorectal-tumor development. *N Eng J Med*  
16 319:525-532.
- 17 Weinberg, R.A. (1989) Oncogenes, antioncogenes, and the molecular bases of multistep carcinogenesis. *Cancer*  
18 *Res.* 49:3713-3721.
- 19 Wellstein, A., Lupu, R., Zugmaier, G., Flamm, S.L., Cheville, A.L., Bovi, P.D., Basicico, C., Lippman, M.E.,  
20 Kern, F.G. (1990) Autocrine growth stimulation by secreted Kaposi fibroblast growth factor but not by endogenous  
21 basic fibroblast growth factor. *Cell Growth Differ.* 1:63-71.
- 22 West, G.B., Brown, J.H., Enquist, B.J. (1997) A General Model for the Origin of Allometric Scaling Laws in  
23 Biology. *Science* 276:122-126. Technical Comments and Responses: [www. sciencemag.org/cgi/content/  
24 full/s281/5378/751a](http://www.sciencemag.org/cgi/content/full/s281/5378/751a)
- 25 Woo, Y.T., Arcos, J.C. (1989) Role of structure-activity relationship analysis in evaluation of pesticides for  
26 potential carcinogenicity. In: Ragsdale, N.N., Menzer, R.E., eds. *Carcinogenicity and pesticides: Principles, issues,  
27 and relationship.* ACS Symposium Series No. 414. San Diego: Academic Press, pp. 175-200.
- 28 Wyzga, R.E. (1988) The role of epidemiology in risk assessments of carcinogens. *Adv. Mod. Environ. Toxicol.*  
29 15:189-208.

- 1 Yamada, T., Nakamura, J., Murakami, M., Okuno, Y., Hosokawa, S., Matsuo, M., Yamada, H. (1994) The  
2 correlation of serum luteinizing hormone levels with the induction of Leydig cell tumors in rats by oxolinic acid.  
3 *Toxicol. Appl. Pharmacol.* 129:146-154.
- 4 Yamasaki, H. (1990) Gap junctional intercellular communication and carcinogenesis. *Carcinogenesis* 11:1051-  
5 1058.
- 6 Yamasaki, H. (1995) Non-genotoxic mechanisms of carcinogenesis: Studies of cell transformation and gap  
7 junctional intercellular communication. *Toxicol. Lett.* 77:55-61.
- 8 Zhang, K., Papageorge, A.G., Lowry, D.R. (1992) Mechanistic aspects of signaling through ras in NIH 3T3 cells.  
9 *Science* 257:671-674.

## APPENDIX A. WEIGHT-OF-EVIDENCE NARRATIVES

1 This appendix contains several general illustrations of weight-of-evidence narratives.

### 2 3 NARRATIVE #1

4 Substance #1

5 CAS# XXX

#### 6 CANCER HAZARD SUMMARY

7 Substance 1 is *likely to be carcinogenic to humans by all routes of exposure*. The weight  
8 of evidence of human carcinogenicity of Substance 1 is based on (a) findings of carcinogenicity in  
9 rats and mice of both sexes by oral and inhalation exposures; (b) its similarity in structure to other  
10 chlorinated organics that are known to cause liver and kidney damage, and liver and kidney  
11 tumors in rats and mice; (c) suggestive evidence of a possible association between Substance 1  
12 exposure of workers in the laundry and dry cleaning industries and increased cancer risk in a  
13 number of organ systems; and (d) human and animal data indicating that Substance 1 is absorbed  
14 by all routes of exposure.

15 In comparison with other agents designated as likely carcinogens, the overall weight of  
16 evidence for Substance 1 places it at the *low end* of the grouping. This is because one cannot  
17 attribute observed excess cancer risk in exposed workers solely to Substance 1. Moreover, there  
18 is considerable scientific uncertainty about the human significance and relevance of certain rodent  
19 tumors associated with exposure to Substance 1 and other chlorinated organics, but insufficient  
20 evidence about mode of action. Hence, the human relevance of the animal evidence of  
21 carcinogenicity relies on a default assumption.

22 There is no clear evidence about the mode of action for each tumor type induced in rats  
23 and mice. Available evidence suggests that Substance 1 induces cancer mainly by promoting cell  
24 growth rather than via direct mutagenic action, although a mutagenic mode of action for rat  
25 kidney tumors cannot be ruled out. The dos-response assessment should, therefore, adopt *both*  
26 *default approaches, nonlinear and linear*. It is recognized that the latter approach likely  
27 overestimates risk at low doses if the mode of action is primarily growth promoting. This  
28 approach, however, may be useful for screening analyses.



1 **SUPPORTING INFORMATION**

2 **Human Data**

3 A number of epidemiologic studies of dry cleaning and laundry workers have reported  
4 elevated incidences of lung, cervix, esophagus, kidney, blood, and lymphoid cancers. Many of  
5 these studies are confounded by coexposure to other petroleum solvents, making them limited for  
6 determining whether the observed increased cancer risks are causally related to Substance 1. The  
7 only investigation of dry cleaning workers with no known exposure to other chemicals did not  
8 evaluate other confounding factors such as smoking, alcohol consumption, and low  
9 socioeconomic status to exclude the possible contribution of these factors to cancer risks.

10  
11 **Animal Data**

12 The carcinogenic potential of Substance 1 has been adequately investigated in two chronic  
13 studies in two rodent species, the first study by gavage and the second study by inhalation.  
14 Substance 1 is carcinogenic in the liver in both sexes of mice when tested by either route of  
15 exposure. It causes marginally increased incidences of mononuclear cell leukemia (MCL) in both  
16 sexes of rats and low incidences of a rare kidney tumor in male rats by inhalation. No increases in  
17 tumor incidence were found in rats treated with Substance 1 by gavage. This rat study was  
18 considered limited because of high mortality of the animals.

19 Although Substance 1 causes increased incidences of tumors at multiple sites in two  
20 rodent species, controversy surrounds each of the tumor endpoints concerning their relevance  
21 and/or significance to humans (see discussion under Mode of Action).

22  
23 **Other Key Data**

24 Substance 1 is a member of a class of chlorinated organics that often cause liver and  
25 kidney toxicity and carcinogenesis in rodents. Like many chlorinated hydrocarbons, Substance 1  
26 itself has tested negative in a battery of standard genotoxicity tests using bacterial and mammalian  
27 cell systems, including human lymphocytes and fibroblast cells. There is evidence, however, that a  
28 minor metabolite generated by an enzyme found in rat kidney tissue is mutagenic. This kidney  
29 metabolite has been hypothesized to be related to the development of kidney tumors in the male  
30 rat. This metabolic pathway appears to be operative in the human kidney.

31 Human data indicate that Substance 1 is readily absorbed via inhalation, but to a much  
32 lesser extent by skin contact. Animal data show that Substance 1 is absorbed well by the oral  
33 route.

1 **MODE OF ACTION**

2 The mechanisms of Substance 1-induced mouse liver tumors are not completely  
3 understood. One mechanism has been hypothesized to be mediated by a genotoxic epoxide  
4 metabolite generated by enzymes found in the mouse liver, but there is a lack of direct evidence in  
5 support of this mechanism. A more plausible mechanism that still needs to be further defined is  
6 related to liver peroxisomal proliferation and toxicity by TCA (trichloroacetic acid), a major  
7 metabolite of Substance 1. However, there are no definitive data indicating that TCA induces  
8 peroxisomal proliferation in humans.

9 The mechanisms by which Substance 1 induces kidney tumors in male rats are even less  
10 well understood. The rat kidney response may be related to either kidney toxicity or the activity  
11 of a mutagenic metabolite of the parent compound.

12 The human relevance of Substance 1-induced MCL in rats is unclear. The biological  
13 significance of marginally increased incidences of MCL has been questioned by some, since this  
14 tumor occurs spontaneously in the tested rat strain at very high background rates. On the other  
15 hand, it has been considered by others to be a true finding because there was a decreased time to  
16 onset of the disease and the disease was more severe in treated as compared with untreated  
17 control animals. The exact mechanism by which Substance 1 increases incidence of MCL in rats  
18 is not known.

19 Overall, there is not enough evidence to justify high confidence in a conclusion about any  
20 single mode of action; it would appear that more than a single mode operates in different rodent  
21 tissues. The apparent lack of mutagenicity of Substance 1 itself and its general growth-promoting  
22 effect on high-background tumors, as well as its toxicity toward mouse liver and rat kidney tissue,  
23 support the view that its predominant mode of action is cell growth promoting rather than  
24 mutagenic. A mutagenic contribution to the renal carcinogenicity due to a metabolite cannot be  
25 entirely ruled out.

26  
27 **NARRATIVE #2**

28 **Substance #2**

29 **CAS# XXX**

30 **CANCER HAZARD SUMMARY**

31 There is *suggestive* evidence for carcinogenicity of Substance 2, but it is not sufficient for  
32 assessment of human carcinogenic potential.

33 The evidence on carcinogenicity consists of (a) data from an oral animal study showing a  
34 response only at the highest dose in female rats, with no response in males, and (b) the fact that

1 other low-molecular-weight chemicals in this class have shown tumorigenicity in the respiratory  
2 tract after inhalation. The one study of Substance 2 effects by the inhalation route was not  
3 adequately performed. The available evidence is too limited to describe human carcinogenicity  
4 potential or support dose-response assessment.

## 6 **SUPPORTING INFORMATION**

### 7 **Human Data**

8 An elevated incidence of cancer was reported in a cohort of workers in a chemical plant  
9 who were exposed to a mixture of chemicals, including Substance 2 as a minor component. The  
10 study is considered inadequate because of the small size of the cohort studied and the lack of  
11 adequate exposure data.

### 13 **Animal Data**

14 In a long-term drinking water study in rats, an increased incidence of adrenal cortical  
15 adenomas was found in the highest dosed females. No other significant finding was made. The  
16 oral rat study was well conducted by a standard protocol. In a 1-year study in hamsters at one  
17 inhalation dose, no tumors were seen. This study was inadequate because of high mortality and  
18 consequent short duration. The chemical is very irritating and is a respiratory toxicant in  
19 mammals. The animal data are too limited for conclusions to be drawn.

### 21 **Structural Analogue Data**

22 Substance 2's structural analogues, formaldehyde and acetaldehyde, both have  
23 carcinogenic effects on the rat respiratory tract.

### 25 **Other Key Data**

26 The weight of results of mutagenicity tests in bacteria, fungi, fruit flies, and mice leads to  
27 an overall conclusion of not mutagenic; Substance 2 is lethal to bacteria to a degree that makes  
28 testing difficult and test results difficult to interpret. The chemical is readily absorbed by all  
29 routes.

## 31 **MODE OF ACTION**

32 Data are not sufficient to judge whether there is a carcinogenic mode of action.  
33  
34

1 **NARRATIVE #3**

2 **Substance #3**

3 **CAS# XXX**

4 **CANCER HAZARD SUMMARY**

5 Substance 3 is *carcinogenic to humans by all routes of exposure*. Although several  
6 studies in workers fall short of establishing causality, when considered together, suggest an  
7 elevated risk of lung cancer after long-term exposure to Substance 3. More importantly, animal  
8 cancer bioassay studies and mechanistic studies in both animals and exposed humans have  
9 provided strong consistent results that support a level of concern equal to having conclusive  
10 epidemiologic evidence. The weight of evidence of human carcinogenicity of Substance 3 is based  
11 on (a) consistent evidence of carcinogenicity at multiple sites in both sexes of rats and mice by  
12 oral and inhalation exposure; (b) epidemiologic evidence suggestive of a possible association  
13 between exposure of industrial workers to Substance 3 and elevated risk of lung cancer, which is  
14 the tumor type consistently found in different test species and with different routes of  
15 administration; (c) mutagenic effects in numerous *in vivo* and *in vitro* test systems, which are  
16 similar to those found in humans; (d) a similar profile of p53 mutations in transgenic rodent and  
17 human lung tumor tissue; (e) membership in a class of DNA-reactive compounds that are  
18 regularly observed to cause carcinogenic and mutagenic effects in animals. Due to its ready  
19 absorption by all routes of exposure and rapid distribution throughout the body, Substance 3 is  
20 expected to pose a risk by all routes of exposure. The strong evidence of a mutagenic mode of  
21 action supports dose-response assessment that assumes *linearity* of the relationship.

22  
23 **SUPPORTING INFORMATION**

24 **Human Data**

25 Elevated risks of lung cancer different than that associated with smoking have been  
26 reported in exposed workers in several studies. The interpretation of the studies separately is  
27 complicated by the lack of consistency in dose-response, latency period, and average age of  
28 appearance exposures, as well as by exposure to other agents. So, there is no single study that  
29 demonstrates that Substance 3 caused the effects. Nevertheless, several of the studies together  
30 are considered suggestive of Substance 3 carcinogenicity because they consistently show cancer  
31 elevation in the same tissue. Biomonitoring studies of exposed workers find DNA damage in  
32 blood lymphocytes and the degree of DNA damage correlates with the level and duration of  
33 Substance 3 exposure. More importantly, a mechanistic linkage is found for humans by  
34 observation of a similar profile of mutation in the p53 gene from the lung tumor tissue of the p53

1 transgenic mouse and exposed workers. This mutation spectra is consistent with the type of  
2 predominant DNA adducts induced by Substance 3. This evidence provides strong support to the  
3 positive suggestion from the worker cancer studies.

#### 4 **Animal Data**

5 Substance 3 causes cancer in multiple tissue sites in rats and mice of both sexes by oral  
6 and inhalation exposure. In particular, there is a consistent trend of a similar tumor site found in  
7 the human studies, namely, an elevated incidence of lung tumor in different species/sexes and by  
8 different routes of exposure. The database is more extensive than usual and the studies are of  
9 good quality. The observation of multisite, multispecies carcinogenic activity by an agent is  
10 considered to be very strong evidence and is often the case with highly mutagenic agents. There  
11 are also strong evidence in many studies showing that Substance 3 is mutagenic across different  
12 phylogenetic levels including rodents, as well as in peripheral cells of exposed humans--a property  
13 that is very highly correlated with carcinogenicity. Further strengthening the concern for human  
14 cancer risk is a similar p53 mutation spectra observed in lung tumor tissue from the p53  
15 transgenic mouse and human cancer biopsies. In humans, a large number of the cases had a  
16 mutation in p53 with a predominance of GC to AT transitions. The mutation spectra of  
17 Substance 3 associated lung tumors differed from patterns reported for sporadic and smoking  
18 related tumors.

#### 19 **Structural Analogue Data**

20 SAR analysis indicates that Substance 3 is a highly DNA-reactive agent. Structurally  
21 related chemicals, also exhibit mutagenic and carcinogenic effects in laboratory animals.  
22

#### 23 **Other Key Data**

24 The structure and DNA reactivity of Substance 3 support potential carcinogenicity. Both  
25 properties are highly correlated with carcinogenicity. Numerous positive mutagenicity tests *in*  
26 *vitro* and *in vivo* add to this support and are reinforced by observation of similar genetic damage  
27 in exposed workers.  
28

29 Substance 3 is experimentally observed to be readily absorbed by all routes and rapidly  
30 distributed through the body.  
31

#### 32 **MODE OF ACTION**

33 All of the available data in both humans and animals, strongly indicate a mutagenic mode  
34 of action, with a particular human target in lung tissue. A mechanistic linkage is found for rodents

1 and humans by observations of a similar profile of mutations in the p53 gene from the lung tumor  
2 tissue of the p53 transgenic mouse and exposed workers. This mutation spectra is consistent with  
3 the type of predominant DNA adducts induced by Substance 3. The tumor suppressor gene, p53,  
4 is a frequently mutated gene in human tumors, including lung. The consistent finding of  
5 mutagenicity in experimental assays and human biomonitoring studies, the finding of p53  
6 mutations in transgenic animal and human lung tumor tissue, all points to a mutagenic mode of  
7 action and supports assuming linearity of the dose-response relationship.

8  
9 **NARRATIVE #4**

10 **Substance #4**

11 **CAS# XXX**

12 **CANCER HAZARD SUMMARY**

13 This chemical is *likely* to be carcinogenic to humans by *all routes* of exposure. Its  
14 carcinogenic potential is indicated by (a) tumor and toxicity studies on structural analogues, which  
15 demonstrate the ability of the chemical to produce thyroid follicular cell tumors in rats and  
16 hepatocellular tumors in mice following ingestion, and (b) metabolism and hormonal information  
17 on the chemical and its analogues, which contributes to a working mode of action and associates  
18 findings in animals with those in exposed humans. In comparison with other agents designated as  
19 likely carcinogens, the overall weight of evidence for this chemical places it at the *lower end* of  
20 the grouping. This is because there is a lack of tumor response data on this agent itself.

21 Biological information on the compound is contradictory in terms of how to quantitate  
22 potential cancer risks. The information on disruption on thyroid-pituitary status argues for using  
23 a margin of exposure evaluation. However, the chemical is an aromatic amine, a class of agents  
24 that are DNA-reactive and induce gene mutation and chromosome aberrations, which argues for  
25 low-dose linearity. Additionally, there is a lack of mode-of-action information on the mouse liver  
26 tumors produced by the structural analogues, also pointing toward a low-dose linear default  
27 approach. In recognition of these uncertainties, it is recommended to quantitate tumors using  
28 *both nonlinear* (to place a lower bound on the risks) *and linear* (to place an upper bound on the  
29 risks) *default approaches*. Given the absence of tumor response data on the chemical per se, it is  
30 recommended that tumor data on close analogues be used to possibly develop toxicity equivalent  
31 factors or relative potencies.

32 Overall, this chemical is an inferential case for potential human carcinogenicity. The  
33 uncertainties associated with this assessment include (1) the lack of carcinogenicity studies on the  
34 chemical, (2) the use of tumor data on structural analogues, (3) the lack of definitive information

1 on the relevance of thyroid-pituitary imbalance for human carcinogenicity, and (4) the different  
2 potential mechanisms that may influence tumor development and potential risks.

## 3 4 **SUPPORTING INFORMATION**

### 5 **Human Data**

6 Worker exposure has not been well characterized or quantified, but recent medical  
7 monitoring of workers exposed over a period of several years has uncovered alterations in  
8 thyroid-pituitary hormones (a decrease in T3 and T4 and an increase in TSH) and symptoms of  
9 hypothyroidism. A urinary metabolite of the chemical has been monitored in workers, with  
10 changes in thyroid and pituitary hormones noted, and the changes were similar to those seen in an  
11 animal study.

### 12 13 **Animal Data**

14 The concentration of the urinary metabolite in rats receiving the chemical for 28 days was  
15 within twofold of that in exposed workers, a finding associated with comparable changes in  
16 thyroid hormones and TSH levels. In addition, the dose of the chemical given to rats in this study  
17 was essentially the same as that of an analogue that had produced thyroid and pituitary tumors in  
18 rats. The human thyroid responds in the same way as the rodent thyroid following short-term,  
19 limited exposure. Although it is not well established that thyroid-pituitary imbalance leads to  
20 cancer in humans as it does in rodents, information in animals and in exposed humans suggests  
21 similar mechanisms of disrupting thyroid-pituitary function and the potential role of altered TSH  
22 levels in leading to thyroid carcinogenesis.

### 23 24 **Structural Analogue Data**

25 This chemical is an aromatic amine, a member of a class of chemicals that has regularly  
26 produced carcinogenic effects in rodents and gene and structural chromosome aberrations in  
27 short-term tests. Some aromatic amines have produced cancer in humans.

28 Close structural analogues produce thyroid follicular cell tumors in rats and hepatocellular  
29 tumors in mice following ingestion. The thyroid tumors are associated with known perturbations  
30 in thyroid-pituitary functioning. These compounds inhibit the use of iodide by the thyroid gland,  
31 apparently due to inhibition of the enzyme that synthesizes the thyroid hormones (T3, T4).  
32 Accordingly, blood levels of thyroid hormones decrease, which induces the pituitary gland to  
33 produce more TSH, a hormone that stimulates the thyroid to produce more of its hormones. The  
34 thyroid gland becomes larger because of increases in the size of individual cells and their

1 proliferation, and upon chronic administration of the chemical, tumors develop. Thus, thyroid  
2 tumor development is significantly influenced by disruption in the thyroid-pituitary axis.

3  
4 **Other Key Data**

5 The chemical can be absorbed by the oral, inhalation, and dermal routes of exposure.  
6

7 **MODE OF ACTION**

8 Data on the chemical and on structural analogues indicate the potential association of  
9 carcinogenesis with perturbation of thyroid-pituitary homeostasis. Structural analogues are  
10 genotoxic, thus raising the possibility of different mechanisms by which this chemical may  
11 influence tumor development.  
12

13 **NARRATIVE #5**

14 **Substance #5**

15 **CAS# XXX**

16 **CANCER HAZARD SUMMARY**

17 Substance 5 is *likely* to be a human carcinogen by *all routes* of exposure. Findings are  
18 based on very extensive and significant experimental findings that include (a) tumors at multiple  
19 sites in both sexes of two rodent species via three routes of administration relevant to human  
20 exposure; (b) close structural analogues that produce a spectrum of tumors like those from  
21 Substance 5; (c) significant evidence for the production of reactive Substance 5 metabolites that  
22 readily bind to DNA and produce gene mutations in many systems, including cultured mammalian  
23 and human cells; and (d) two null studies and one positive epidemiologic study; in the positive  
24 study, there may have been exposure to Substance 5. These findings support a decision that  
25 Substance 5 might produce cancer in exposed humans. In comparison to other agents considered  
26 likely human carcinogens, the overall weight of evidence for Substance 5 puts it near the top of  
27 the grouping. Given the agent's mutagenicity, which can influence the carcinogenic process, a  
28 linear dose-response extrapolation is recommended.

29 Uncertainties include the lack of adequate information on the mutagenicity of Substance 5  
30 in mammals or humans in vivo, although such effects would be expected.  
31



1 **SUPPORTING INFORMATION**

2 **Human Data**

3 The information on the carcinogenicity of Substance 5 from human studies is inadequate.  
4 Two studies of production workers have not shown significant increases in cancer from exposure  
5 to Substance 5 and other chemicals. An increase in lymphatic cancer was reported in a mortality  
6 study of grain elevator workers who may have been exposed to Substance 5 (and other  
7 chemicals).

8  
9 **Animal Data**

10 Substance 5 produced tumors in four chronic rodent studies. Tumor increases were  
11 noted in males and females of rats and mice following oral dermal and inhalation exposure (rat--  
12 oral and two inhalation, mouse--oral and dermal). It produces tumors both at the site of  
13 application (e.g., skin with dermal exposure) and at sites distal to the portal of entry into the body  
14 (e.g., mammary gland) following exposure from each route. Tumors at the same site were noted  
15 in both sexes of a species (blood vessel), both species (forestomach) and via different routes of  
16 administration (lung). Some tumors developed after very short latency, metastasized extensively,  
17 and produced death, an uncommon findings in rodents. The rodent studies were well designed  
18 and conducted except for the oral studies, in which the doses employed caused excessive toxicity  
19 and mortality. However, given the other rodent findings, lower doses would also be anticipated  
20 to be carcinogenic.

21  
22 **Structural Analogue Data**

23 Several chemicals structurally related to Substance 5 are also carcinogenic in rodents.  
24 Among four that are closest in structure, tumors like those seen for Substance 5 were often noted  
25 (e.g., forestomach, mammary, lung), which helps to confirm the findings for Substance 5 itself. In  
26 sum, all of the tumor findings help to establish animal carcinogenicity and support potential human  
27 carcinogenicity for Substance 5.

28  
29 **Other Key Data**

30 Substance 5 itself is not reactive, but from its structure it was expected to be metabolized  
31 to reactive forms. Extensive metabolism studies have confirmed this presumption and have  
32 demonstrated metabolites that bind to DNA and cause breaks in the DNA chain. These lesions  
33 are readily converted to gene mutations in bacteria, fungi, higher plants, insects, and mammalian  
34 and human cells in culture. There are only a limited number of reports on the induction of

1 chromosome aberrations in mammals and humans; thus far they are negative.

2

3 **MODE OF ACTION**

4 Human carcinogens often produce cancer in multiple sites of multiple animal species and  
5 both sexes and are mutagenic in multiple test systems. Substance 5 satisfies these findings. It  
6 produces cancer in males and females of rats and mice. It produces gene mutations in cells across  
7 all life forms--plants, bacteria, and animals--including mammals and humans. Given the  
8 mutagenicity of Substance 5 exposure and the multiplicity and short latency of Substance 5 tumor  
9 induction, it is reasonable to use a linear approach for cancer dose-response extrapolation.

**APPENDIX B. RESPONSES TO THE NATIONAL ACADEMY OF SCIENCES  
NATIONAL RESEARCH COUNCIL REPORT *SCIENCE AND JUDGMENT IN RISK  
ASSESSMENT* (NRC, 1994)**

**Recommendations of the National Academy of Sciences National Research Council**

In 1994, the National Academy of Sciences published a report, *Science and Judgment in Risk Assessment*. The report was written by a Committee on Risk Assessment of Hazardous Air Pollutants formed under the Academy's Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council. The report was called for under Section 112(o)(1)(A,B) of the Clean Air Act Amendments of 1990, which provided for the EPA to arrange for the Academy to review:

- risk assessment methodology used by EPA to determine the carcinogenic risk associated with exposure to hazardous air pollutants from source categories and subcategories subject to the requirements of this section, and
- improvements in such methodology.

Under Section 112(o)(2)(A,B), the Academy was to consider the following in its review:

- the techniques used for estimating and describing the carcinogenic potency to humans of hazardous air pollutants, and
- the techniques used for estimating exposure to hazardous air pollutants (for hypothetical and actual maximally exposed individuals as well as other exposed individuals).

To the extent practicable, the Academy was also to review methods of assessing adverse human health effects other than cancer for which safe thresholds of exposure may not exist [Section 112(o)(3)]. The Congress further provided that the EPA Administrator should consider, but need not adopt, the recommendations in the report and the views of the EPA Science Advisory Board with respect to the report. Prior to the promulgation of any standards under Section 112(f), the Administrator is to publish revised guidelines for carcinogenic risk assessment or a detailed explanation of the reasons that any recommendations contained in the report will not be implemented [Section 112(o)(6)].

The following discussion addresses the recommendations of the 1994 report that are pertinent to the EPA cancer risk assessment guidelines. Guidelines for assessment of exposure, of mixtures, and of other health effects are separate EPA publications. Many of the recommendations were related to practices specific to the exposure assessment of hazardous air

1 pollutants, which are not covered in cancer assessment guidelines. Recommendations about these  
2 other guidelines or practices are not addressed here.

#### 3 4 **Hazard Classification**

5 The 1994 report contains the following recommendation about classifying cancer hazard:

- 6 • The EPA should develop a two-part scheme for classifying evidence on  
7 carcinogenicity that would incorporate both a simple classification and a narrative  
8 evaluation. At a minimum, both parts should include the strength (quality) of the  
9 evidence, the relevance of the animal model and results to humans, and the relevance  
10 of the experimental exposures (route, dose, timing, and duration) to those likely to be  
11 encountered by humans.

12 The report also presented a possible matrix of 24 boxes that would array weights of evidence  
13 against low, medium, or high relevance, resulting in 24 codes for expressing the weight and  
14 relevance.

15 These guidelines adopt five standard hazard descriptors and a narrative for presentation of  
16 the weight-of-evidence findings. The descriptors are used within the narrative. There is no  
17 matrix of alphanumeric weight-of-evidence boxes.

18 The issue of an animal model that is not relevant to humans has been dealt with by not  
19 including an irrelevant response in the weighing of evidence, rather than by creating a weight of  
20 evidence and then appending a discounting factor as the NRC scheme would do. The issue of  
21 relevance is more complex than the NRC matrix makes apparent. Often the question of relevance  
22 of the animal model applies to a single tumor response, but one encounters situations in which  
23 there are more tumor responses in animals than the questioned one. Dealing with this complexity  
24 is more straightforward if it is done during the weighing of evidence rather than after as in the  
25 NRC scheme. Moreover, the same experimental data are involved in deciding on the weight of  
26 evidence and the relevance of a response. It would be awkward to go over the same data twice.

27 In recommending that the relevance of circumstances of human exposure be taken into  
28 account, the NRC appears to assume that all of the actual conditions of human exposure will be  
29 known when the classification is done. This is not the case. More often than not, the hazard  
30 assessment is applied to risks associated with exposure to different media or environments at  
31 different times. In some cases, there is no priority to obtaining exposure data until the hazard  
32 assessment has been done. The approach of these guidelines is to characterize hazards as to  
33 whether their expression is intrinsically limited by route of exposure or by reaching a particular  
34 dose range based strictly on toxicological and other biological features of the agent. Both the use

1 of descriptors and the narrative specifically capture this information. Other aspects of appropriate  
2 application of the hazard and dose-response assessment to particular human exposure scenarios  
3 are dealt with in the characterization of the dose-response assessment, e.g., the applicability of the  
4 dose-response assessment to scenarios with differing frequencies and durations.

5 The NRC scheme apparently intended that the evidence would be weighed, then given a  
6 low, medium, or high code for some combination of relevance of the animal response, route of  
7 exposure, timing, duration, or frequency. The 24 codes contain none of this specific information,  
8 and, in fact, do not communicate what the conclusion is about. To make the codes communicate  
9 the information apparently intended would require some multiple of the 24 in the NRC scheme.  
10 As the number of codes increases, their utility for communication decreases.

11 Another reason for declining to use codes is that they tend to become outdated as research  
12 reveals new information that was not contemplated when they were adopted. This has been the  
13 case with the classification system under the 1986 EPA guidelines.

14 Even though these guidelines do not adopt a matrix of codes, their method of using  
15 descriptors and narratives captures the information the NRC recommended as the most important,  
16 and in the EPA's view, in a more transparent manner.

## 17 18 **Dose-Response**

19 The 1994 report contains the following recommendations about dose-response issues:

- 20 • EPA should continue to explore, and when scientifically appropriate, incorporate  
21 toxicokinetic models of the link between exposure and biologically effective dose (i.e.,  
22 dose reaching the target tissue).
- 23 • Despite the advantages of developing consistent risk assessments between agencies by  
24 using common assumptions (e.g., replacing surface area with body weight to the 0.75  
25 power), EPA should indicate other methods, if any, that would be more accurate.
- 26 • EPA should continue to use the linearized multistage model as a default option but  
27 should develop criteria for determining when information is sufficient to use an  
28 alternative extrapolation model.
- 29 • EPA should continue to use as one of its risk characterization metrics upper-bound  
30 potency estimates of the probability of developing cancer due to lifetime exposure.  
31 Whenever possible, this metric should be supplemented with other descriptions of  
32 cancer potency that might more adequately reflect the uncertainty associated with the  
33 estimates.

- 1 • EPA should adopt a default assumption for differences in susceptibility among humans  
2 in estimating individual risks.
- 3 • In the analysis of animal bioassay data on the occurrence of multiple tumor types, the  
4 cancer potencies should be estimated for each relevant tumor type that is related to  
5 exposure, and the individual potencies should be summed for those tumors.

6 Toxicokinetic models are encouraged in these guidelines, with discussion of appropriate  
7 considerations for their use. When there are questions as to whether such a model is more  
8 accurate in a particular case than the default method for estimating the human equivalent dose,  
9 both alternatives may be used. It should be noted that the default method for inhalation exposure  
10 is a toxicokinetic model.

11 The rationale for adopting the oral scaling factor of body weight to the 0.75 power has  
12 been discussed above in the explanation of major defaults. The empirical basis is further explored  
13 in U.S. EPA (1992b). The more accurate approach is to use a toxicokinetic model when data  
14 become available, or to modify the default when data are available, as encouraged under these  
15 guidelines. As the U.S. EPA (1992b) discussion explores in depth, data on the differences among  
16 animals in response to toxic agents are basically consistent with using a power of 1.0, 0.75, or  
17 0.66. The Federal agencies chose the power of 0.75 for the scientific reasons given in the  
18 previous discussion of major defaults; these were not addressed specifically in the NRC report. It  
19 was also considered appropriate, as a matter of policy, for the agencies to agree on one factor.  
20 Again, the default for inhalation exposure is a model that is constructed to become better as more  
21 agent-specific data become available.

22 EPA proposes not to use a computer model such as the linearized multistage model as a  
23 default for extrapolation below the observed range. The reason is that the basis for default  
24 extrapolation is a theoretical projection of the likely shape of the curve, considering mode of  
25 action. For this purpose, a computer model looks more sophisticated than a straight-line  
26 extrapolation, but is not. The extrapolation will be by straight line as explained in the explanation  
27 of major defaults. This was also recommended by workshop reviewers of a previous draft of  
28 these guidelines (U.S. EPA, 1994b). In addition, a margin-of-exposure analysis is proposed in  
29 cases in which the curve is thought to be nonlinear, based on mode of action. In both cases, the  
30 observed range of data will be modeled by curve fitting in the absence of supporting data for a  
31 biologically based or case-specific model.

32 The result of using straight-line extrapolation is thought to be an upper bound on low-  
33 dose potency to the human population in most cases, but as discussed in the major defaults  
34 section, it may not always be. Exploration and discussion of uncertainty of parameters in curve-

1 fitting a model of the observed data or in using a biologically based or case-specific model is  
2 called for in the dose-response assessment and characterization sections of these guidelines.

3 The issue of a default assumption for human differences in susceptibility has been  
4 addressed under the major defaults discussion in Section 1.3 with respect to margin-of-exposure  
5 analysis. EPA has considered but decided not to adopt a quantitative default factor for human  
6 differences in susceptibility when a linear extrapolation is used. In general, EPA believes that  
7 linear extrapolation is sufficiently conservative to protect public health. Linear approaches (both  
8 LMS and straight-line extrapolation) from animal data are consistent with linear extrapolation on  
9 the same agents from human data (Goodman and Wilson, 1991; Hoel and Portier, 1994). If  
10 actual data on human variability in sensitivity are available they will, of course, be used.

11 In analyzing animal bioassay data on the occurrence of multiple tumor types, these  
12 guidelines outline a number of biological and other factors to consider. The objective is to use  
13 these factors to select response data (including nontumor data as appropriate) that best represent  
14 the biology observed. As stated in Section 3 of the guidelines, appropriate options include use of  
15 a single data set, combining data from different experiments, showing a range of results from  
16 more than one data set, showing results from analysis of more than one tumor response based on  
17 differing modes of action, representing total response in a single experiment by combining animals  
18 with tumors, or a combination of these options. The approach judged to best represent the data is  
19 presented with the rationale for the judgment, including the biological and statistical  
20 considerations involved. EPA has considered the approach of summing tumor incidences and  
21 decided not to adopt it. While multiple tumors may be independent, in the sense of not arising  
22 from metastases of a single malignancy, it is not clear that they can be assumed to represent  
23 different effects of the agent on cancer processes. In this connection, it is not clear that summing  
24 incidences provides a better representation of the underlying mode(s) of action of the agent than  
25 combining animals with tumors or using another of the several options noted above. Summing  
26 incidences would result in a higher risk estimate, a step that appears unnecessary without more  
27 reason.

### 28 29 **Risk Characterization**

- 30 • When EPA reports estimates of risk to decisionmakers and the public, it should  
31 present not only point estimates of risk, but also the sources and magnitudes of  
32 uncertainty associated with these estimates.
- 33 • Risk managers should be given characterizations of risk that are both qualitative and  
34 quantitative, i.e., both descriptive and mathematical.

- 1           • EPA should consider in its risk assessments the limits of scientific knowledge, the  
2           remaining uncertainties, and the desire to identify errors of either overestimation or  
3           underestimation.

4           In part as a response to these recommendations, the Administrator of EPA issued  
5           guidelines for risk characterization and required implementation plans from all programs in EPA  
6           (U.S. EPA, 1995). The Administrator's guidance is followed in these cancer guidelines. The  
7           assessments of hazard, dose-response, and exposure will all have accompanying technical  
8           characterizations covering issues of strengths and limitations of data and current scientific  
9           understanding, identification of defaults utilized in the face of gaps in the former, discussions of  
10          controversial issues, and discussions of uncertainties in both their qualitative and, as practicable,  
11          their quantitative aspects.



## APPENDIX C. CASE STUDY EXAMPLES FOR HAZARD EVALUATION

1 This section provides examples of substances that fit the descriptors above. These  
2 examples are based on available information about real substances and are selected to illustrate the  
3 principles for weight-of-evidence evaluation and the application of the classification scheme.

4 These case studies show the interplay of differing lines of evidence in making a conclusion.  
5 Some particularly illustrate the role that “other key data” can play in conclusions.  
6

### 7 *Example 1: “Carcinogenic to Humans”--Route-Dependent/Linear Extrapolation*

#### 8 Human Data

9 Substance 1 is an aluminosilicate mineral that exists in nature with a fibrous habit. Several  
10 descriptive epidemiologic studies have demonstrated very high mortality from malignant  
11 mesothelioma, mainly of the pleura, in three Turkish villages where there was a contamination of  
12 this mineral and where exposure had occurred from birth. Both sexes were equally affected and  
13 at an unusually young age.  
14

#### 15 Animal Data

16 Substance 1 has been studied in a single long-term inhalation study in rats at one exposure  
17 concentration that showed an extremely high incidence of pleural mesothelioma (98% in treated  
18 animals versus 0% in concurrent controls). This is a rare malignant tumor in the rat and the onset  
19 of tumors occurred at a very early age (as early as 1 year). Several studies involving injection into  
20 the body cavities of rats or mice (i.e., pleural or peritoneal cavities) also produced high incidences  
21 of pleural or peritoneal mesotheliomas. No information is available on the carcinogenic potential  
22 of substance 1 in laboratory animals via oral and dermal exposures.  
23

#### 24 Other Key Data

25 Information on the physical and chemical properties of substance 1 indicates that it is  
26 highly respirable to humans and laboratory rodents. It is highly insoluble and is not likely to be  
27 readily degraded in biological fluid.

28 No information is available on the deposition, translocation, retention, lung clearance, and  
29 excretion of the substance after inhalation exposure or ingestion. Lung burden studies have  
30 shown the presence of elevated levels of the substance in lung tissue samples of human cases of  
31 pleural mesotheliomas from contaminated villages compared with control villages.

1 No data are available on genetic or related effects in humans. The substance has been  
2 shown to induce unscheduled DNA synthesis in human cells in vitro and transformation and  
3 unscheduled DNA synthesis in mouse cells.

4 The mechanisms by which this substance causes cancer in humans and animals are not  
5 understood, but appear to be related to its unique physical, chemical, and surface properties. Its  
6 fiber morphology is similar to a known group of naturally occurring silicate minerals that have  
7 been known to cause respiratory cancers in humans(including pleural mesothelioma) from  
8 inhalation exposure and genetic changes.

#### 9 10 Evaluation

11 Human evidence is judged to establish a causal link between exposure to substance 1 and  
12 human cancer. Even though the human evidence does not satisfy all criteria for causality, this  
13 judgment is based on a number of unusual observations: large magnitude of the association,  
14 specificity of the association, demonstration of environmental exposure, biological plausibility,  
15 and coherence based on the entire body of knowledge of the etiology of mesothelioma.

16 Animal evidence demonstrates a causal relationship between exposure and cancer in  
17 laboratory animals. Although available data are not optimal in terms of design (e.g., the use of  
18 single dose, one sex only), the judgment is based on the unusual findings from the only inhalation  
19 experiment in rats (i.e., induction of an uncommon tumor, an extremely high incidence of  
20 malignant neoplasms, and onset of tumors at an early age). Additional evidence is provided by  
21 consistent results from several injection studies showing an induction of the same tumors by  
22 different modes of administration in more than one species.

23 Other key data, while limited, support the human and animal evidence of carcinogenicity.  
24 It can be inferred from human and animal data that this substance is readily deposited in the  
25 respiratory airways and deep lung and is retained for extended periods of time after first exposure.  
26 Information on related fibrous substances indicates that the modes of action are likely mediated by  
27 the physical and chemical characteristics of the substance (e.g., fiber shape, high aspect ratio, a  
28 high degree of insolubility in lung tissues).

29 Insufficient data are available to evaluate the human carcinogenic potential of substance 1  
30 by oral exposure. Even though there is no information on its carcinogenic potential via dermal  
31 uptake, it is not expected to pose a carcinogenic hazard to humans by that route because it is very  
32 insoluble and is not likely to penetrate the skin.

1           Conclusion

2           It is concluded that substance 1 is *carcinogenic to humans by inhalation exposure*. The  
3 weight of evidence of human carcinogenicity is based on (a) exceptionally increased incidence of  
4 malignant mesothelioma in epidemiologic studies of environmentally exposed human populations;  
5 (b) significantly increased incidence of malignant mesothelioma in a single inhalation study in rats  
6 and in several injection studies in rats and mice; and (c) supporting information on related fibrous  
7 substances that are known to cause cancer via inhalation and genetic damage in exposed  
8 mammalian and human mesothelial cells. The human carcinogenic potential of substance 1 via  
9 oral exposure cannot be determined on the basis of insufficient data. It is not likely to pose a  
10 carcinogenic hazard to humans via dermal uptake because it is not anticipated to penetrate the  
11 skin.

12           The mode of action of this substance is not understood. In addition to this uncertainty,  
13 dose-response information is lacking for both human and animal data. Epidemiologic studies  
14 contain observations of significant excess cancer risks at relatively low levels of environmental  
15 exposure. The use of *linear* extrapolation in a dose-response relationship assessment is  
16 appropriate as a default since mode-of-action data are not available.

17  
18           ***Example 2: "Carcinogenic to Humans"-- Any Exposure Conditions/Linear Extrapolation***

19           Human Data

20           Substance 2 is an alkylating agent that is used extensively as a chemical intermediate in  
21 organic synthesis, particularly in the synthesis of plastics and resins. Several cohort studies of  
22 workers using substance 2 have been conducted. Four studies of chemical workers exposed to  
23 substance 2 (as well as other agents) found an increased mortality rate from lung cancer. The  
24 excess was primarily found in small subgroups with high-level exposure. Although smoking was a  
25 confounding factor, the predominant lung tumor found was small-cell carcinoma, which is distinct  
26 from the squamous cell carcinomas usually found in smokers. Although the type of lung cancer  
27 was consistent among the four studies, the dose-response, latency period, and average age of  
28 appearance was not consistent. Furthermore, there are confounding exposures to other  
29 chemicals. No increase in mortality rate was observed in two studies, one of which had exposures  
30 higher than the studies reporting an increased incidence of lung cancer.

1           Animal Data

2           A multisite tumor response in rats and mice of both sexes is found in 2-year rodent  
3 bioassay studies when substance 2 is administered by various routes. In particular, the induction  
4 of lung tumors is consistently found across different studies, species, and routes of administration.  
5 For example, when administered by inhalation, substance 2 induced a dose-related increase in the  
6 incidences of lung tumors in female and male mice (B6C3F1); and squamous cell carcinomas of  
7 the lung and nasal tumors in male rats (F344). When administered by subcutaneous injection,  
8 substance 2 induced a statistically significant response for pulmonary tumors and local  
9 fibrosarcomas in mice of both sexes. An oral gavage 2-year study resulted in an elevated  
10 incidence of lung tumors in male rats and both sexes of mice, forestomach tumors in both sexes of  
11 rats and mice, liver tumors in both sexes of rats, and urinary bladder tumors in both sexes of mice.  
12 Substance 2 produced lung and forestomach tumors in the p53 mouse cancer transgenic assay  
13 when administered via gavage. It is an initiator of skin tumors in mice.  
14

15           Other Key Data

16           Substance 2 is a liquid but can exist as a vapor at room temperature given its high vapor  
17 pressure. It is readily absorbed dermally. Studies in rats indicate that, once absorbed, substance  
18 2 is uniformly distributed throughout the body. It is metabolized by hydrolysis and by conjugation  
19 with glutathione. The ability to form glutathione conjugate varies across animal species, with the  
20 rat being most active, followed by mice.  
21

22           Substance 2 induces cell transformation in the Syrian Hamster Embryo assay. It is a  
23 direct-acting alkylating agent and is consistently mutagenic when tested in a variety of  
24 nonmammalian and mammalian assays, including in vivo rodent tests. It has been shown to form  
25 DNA adducts and to produce predominantly GC to AT transitions. Substance 2 produces similar  
26 genetic lesions in rodents and humans. It was found to cause dose-related increases, HPRT  
27 mutations, and chromosome aberrations in peripheral blood lymphocytes of exposed workers. A  
28 similar p53 mutation spectra has been found in lung tumor tissue from the p53 transgenic mouse  
29 and human cancer biopsies. In humans, a large number of the cases had a mutation in p53, with a  
30 predominance of GC to AT transitions. The mutation spectra of substance-2-associated lung  
31 tumors differed from patterns reported for sporadic and smoking-related tumors.

32           SAR analysis indicates that substance 2 is a highly DNA-reactive agent. Structurally  
33 related chemicals also exhibit mutagenic and carcinogenic effects in laboratory animals.  
34

1           Evaluation

2           Available epidemiologic studies, taken together, suggest that a causal association between  
3 exposure to substance 2 and elevated risk of cancer is plausible. This judgment is based on small  
4 but consistent excesses of lung tumors that are distinct from smoking-related lung cancer in the  
5 studies of highly exposed workers. The evidence is close and indicates that causal interpretation  
6 is credible, but not conclusively demonstrated because of certain inconsistencies in the available  
7 studies, possible bias, and confounding factors that could not be adequately excluded.

8           Extensive evidence indicates that substance 2 is carcinogenic to laboratory animals in  
9 multiple species and at multiple tissue sites with multiple routes of exposure. There is an  
10 induction of malignant tumors to an unusual degree with regard to incidence. In particular, there  
11 is a consistent dose-related induction of lung tumors across different species and routes of  
12 administration in well-designed and conducted studies. This tumor response is similar to that  
13 reported in exposed humans.

14           The potential human carcinogenicity of substance 2 is reinforced by observations of similar  
15 genetic damage (DNA adducts, HPRT mutations, chromosomal aberrations) in experimental tests  
16 and exposed workers. The genetic effects induced in experimental animals are dose related and  
17 observed at exposures lower than those that produce lung tumors in rodent bioassays. A  
18 mechanistic linkage is found for rodents and humans by observations of a similar profile of  
19 mutations in the p53 gene from the lung tumor tissue of the p53 transgenic mouse and exposed  
20 workers. This mutation spectra is consistent with the type of predominant DNA adducts induced  
21 by substance 2.

22           Substance 2 belongs to a well-defined, structurally related class of substances whose  
23 members are carcinogenic in rodents and are likely to be human carcinogens.

24  
25           Conclusion

26           It is concluded that substance 2 is ***“carcinogenic to humans”*** by *all routes of exposure*.  
27 The weight of evidence of human carcinogenicity is based on (a) consistent evidence of  
28 carcinogenicity in rats and mice by oral and inhalation exposure; (b) epidemiologic evidence  
29 suggestive of a causal association between exposure and elevated risk of lung cancer, which is the  
30 tumor type consistently induced in different test species and with different routes of  
31 administration; (c) evidence of genetic damage in blood lymphocytes of exposed workers; (d)  
32 mutagenic effects in numerous in vivo and in vitro test systems, which are similar to those found  
33 in humans; (e) similar profile of p53 mutations in rodent and human lung tumor tissue; (f)  
34 membership in a class of DNA-reactive compounds that have been shown to cause carcinogenic

1 and mutagenic effects in animals; and (g) ability to be absorbed by all routes of exposure,  
2 followed by rapid distribution throughout the body.

3 The evidence is compelling that the mutagenic properties of substance 2 in experimental  
4 animals and humans are an important influence on the carcinogenic process. Thus, substance 2  
5 acts through a mode of action that is operative in humans and would therefore reasonably be  
6 anticipated to cause cancer in humans. A linear extrapolation should be assumed in dose-response  
7 assessment.

8  
9 ***Example 3: "Likely Human Carcinogen"--Any Exposure Conditions/Linear Extrapolation***

10 Human Data

11 Substance 3 is a brominated alkane. Three studies have investigated the cancer mortality  
12 of workers exposed to this substance. No statistically significant increase in cancer at any site was  
13 found in a study of production workers exposed to substance 3 and several other chemicals.  
14 Elevated cancer mortality was reported in a much smaller study of production workers. An  
15 excess of lymphoma was reported in grain workers who may have had exposure to substance 3  
16 and other chemical compounds. These studies are considered inadequate due to their small  
17 cohort size; lack of or poorly characterized exposure concentrations; or concurrent exposure of  
18 the cohort to other potential or known carcinogens.

19  
20 Animal Data

21 The potential carcinogenicity of substance 3 has been extensively studied in an oral gavage  
22 study in rats and mice of both sexes, two inhalation studies of rats of different strains of both  
23 sexes, an inhalation study in mice of both sexes, and a skin painting study in female mice.

24 In the oral study, increased incidences of squamous-cell carcinoma of the forestomach  
25 were found in rats and mice of both sexes. Additionally, there were increased incidences of liver  
26 carcinomas in female rats, hemangiosarcomas in male rats, and alveolar/bronchiolar adenoma of  
27 the lung of male and female mice. Excessive toxicity and mortality were observed in the rat study,  
28 especially in the high-dose groups, which resulted in early termination of the study, and similar  
29 time-weighted average doses for the high- and low-treatment groups.

30 In the first inhalation study in rats and mice, increased incidences of carcinomas and  
31 adenocarcinomas of the nasal cavity and hemangiosarcoma of the spleen were found in exposed  
32 animals of each species of both sexes. Treated female rats also showed increased incidences of  
33 alveolar/bronchiolar carcinoma of the lung and mammary gland fibroadenomas. Treated male rats  
34 showed an increased incidence of peritoneal mesothelioma. In the second inhalation study in rats

1 (single exposure only), significantly increased incidences of hemangiosarcoma of the spleen and  
2 adrenal gland tumors were seen in exposed animals of both sexes. Additionally, increased  
3 incidences of subcutaneous mesenchymal tumors and mammary gland tumors were induced in  
4 exposed male and female rats, respectively.

5 Lifetime dermal application of substance 3 to female mice resulted in significantly  
6 increased incidences of skin papillomas and lung tumors.

7 Several chemicals structurally related to substance 3 are also carcinogenic in rodents. The  
8 spectrum of tumor responses induced by related substances was similar to those seen with  
9 substance 3 (e.g., forestomach, mammary gland, and lung tumors).

#### 10 11 Other Key Data

12 Substance 3 exists as a liquid at room temperature and is readily absorbed by ingestion,  
13 inhalation, and dermal contact. It is widely distributed in the body and is eliminated in the urine  
14 mainly as metabolites (e.g., glutathione conjugate).

15 Substance 3 is not itself DNA-reactive, but is biotransformed to reactive metabolites, as  
16 inferred by findings of its covalent binding to DNA and induction of DNA strand breaks, both in  
17 vivo and in vitro. Substance 3 has been shown to induce sister chromatid exchanges, mutations,  
18 and unscheduled DNA synthesis in human and rodent cells in vitro. Reverse and forward  
19 mutations have been consistently produced in bacterial assays and in vitro assays using eukaryotic  
20 cells. Substance 3, however, did not induce dominant lethal mutations in mice or rats, or  
21 chromosomal aberrations or micronuclei in bone marrow cells of mice treated in vivo.

#### 22 23 Evaluation

24 Available epidemiologic data are considered inadequate for an evaluation of a causal  
25 association of exposure to the substance and excess of cancer mortality due to major study  
26 limitations.

27 There is extensive evidence that substance 3 is carcinogenic in laboratory animals.  
28 Increased incidences of tumors at multiple sites have been observed in multiple studies in two  
29 species of both sexes with different routes of exposure. It induces tumors both at the site of entry  
30 (e.g., nasal tumors via inhalation, forestomach tumors by ingestion, skin tumors with dermal  
31 exposure) and at distal sites (e.g., mammary gland tumors). Additionally, it induced tumors at the  
32 same sites in both species and sexes via different routes of exposure (e.g., lung tumors). With the  
33 exception of the oral study in which the employed doses caused excessive toxicity and mortality,  
34 the other studies are considered adequately designed and well conducted. Overall, given the

1 magnitude and extent of animal carcinogenic responses to substance 3, coupled with similar  
2 responses to structurally related substances, these animal findings are judged to be highly relevant  
3 and predictive of human responses.

4 Other key data, while not very extensive, are judged to be supportive of carcinogenic  
5 potential. Substance 3 has consistently been shown to be mutagenic in mammalian cells, including  
6 human cells, and in nonmammalian cells; thus, mutation is likely a mode of action for its  
7 carcinogenic activity. However, the possible involvement of other modes of action has not been  
8 fully investigated. Furthermore, induction of genetic changes from in vivo exposure to substance  
9 3 has not been demonstrated.

#### 10 Conclusion

11 Substance 3 is *likely to be carcinogenic to humans*. In comparison with other agents  
12 designated as likely human carcinogens, the overall weight of evidence for substance 3 puts it at  
13 the *high end* of the grouping.

14 The weight of evidence of human carcinogenicity is based on animal evidence and other  
15 key evidence. Human data are inadequate for an evaluation of human carcinogenicity. The  
16 overall weight of evidence is based on (a) extensive animal evidence showing induction of  
17 increases of tumors at multiple sites in both sexes of two rodent species via three routes of  
18 administration relevant to human exposure; (b) tumor data of structural analogues exhibiting  
19 similar patterns of tumors in treated rodents; (c) in vitro evidence for mutagenic effects in  
20 mammalian cells and nonmammalian systems; and (d) its ability to be absorbed by all routes of  
21 exposure followed by rapid distribution throughout the body.

22 Some uncertainties are associated with the mechanisms of carcinogenicity of substance 3.  
23 Although there is considerable evidence indicating that mutagenic events could account for  
24 carcinogenic effects, there is still a lack of adequate information on the mutagenicity of substance  
25 3 in vivo in animals or humans. Moreover, alternative modes of action have not been explored.  
26 Nonetheless, available data indicate a likely mutagenic mode of action. Linear extrapolation  
27 should be assumed in dose-response assessment.

#### 28 ***Example 4: "Likely Human Carcinogen"--All Routes/Linear and Nonlinear Extrapolation***

##### 29 Human Data

30 Substance 4 is a chlorinated alkene solvent. Several cohort studies of dry cleaning and  
31 laundry workers exposed to substance 4 and other solvents reported significant excesses of  
32 mortality due to cancers of the lung, cervix, esophagus, kidney, bladder, lymphatic and  
33  
34



1 hematopoietic system, colon, or skin. No significant cancer risks were observed in a subcohort of  
2 one of these investigations of dry cleaning workers exposed mainly to substance 4. Possible  
3 confounding factors such as smoking, alcohol consumption, or low socioeconomic status were  
4 not considered in the analyses of these studies.

5 A large case-control study of bladder cancer did not show any clear association with dry  
6 cleaning. Several case-control studies of liver cancer identified an increased risk of liver cancer  
7 with occupational exposure to organic solvents. The specific solvents to which workers were  
8 exposed and exposure levels were not identified.

#### 9 10 Animal Data

11 The potential carcinogenicity of substance 4 has been investigated in two long-term  
12 studies in rats and mice of both sexes by oral administration and inhalation.

13 Significant increases in hepatocellular carcinomas were induced in mice of both sexes  
14 treated with substance 4 by oral gavage. No increases in tumor incidence were observed in  
15 treated rats. Limitations in both experiments included control groups smaller than treated groups,  
16 numerous dose adjustments during the study, and early mortality due to treatment-related  
17 nephropathy.

18 In the inhalation study, there were significantly increased incidences of hepatocellular  
19 adenoma and carcinoma in exposed mice of both sexes. In rats of both sexes, there were  
20 marginally significant increased incidences of mononuclear cell leukemia (MCL) when compared  
21 with concurrent controls. The incidences of MCL in control animals, however, were higher than  
22 historical controls from the conducting laboratory. The tumor finding was also judged to be  
23 biologically significant because the time to onset of tumor was decreased and the disease was  
24 more severe in treated than in control animals. Low incidences of renal tubular cell adenomas or  
25 adenocarcinomas were also observed in exposed male rats. The tumor incidences were not  
26 statistically significant, but there was a significant trend.

#### 27 28 Other Key Data

29 Substance 4 has been shown to be readily and rapidly absorbed by inhalation and ingestion  
30 in humans and laboratory animals. Absorption by dermal exposure is slow and limited. Once  
31 absorbed, substance 4 is primarily distributed to and accumulated in adipose tissue and the brain,  
32 kidney, and liver. A large percentage of substance 4 is eliminated unchanged in exhaled air, with  
33 urinary excretion of metabolites comprising a much smaller percentage. The absorption and  
34 distribution profiles of substance 4 are similar across species including humans.

1 Two major metabolites (trichloroacetic acid [TCA] and trichloroethanol), which are  
2 formed by a P-450-dependent mixed-function oxidase enzyme system, have been identified in all  
3 studied species, including humans. There is suggestive evidence for the formation of an epoxide  
4 intermediate based on the detection of two other metabolites (oxalic acid and trichloroacetyl  
5 amide). In addition to oxidative metabolism, substance 4 also undergoes conjugation with  
6 glutathione. Further metabolism by renal beta-lyases could lead to two minor active metabolites  
7 (trichlorovinyl thiol and dichlorothiokente).

8 Toxicokinetic studies have shown that the enzymes responsible for the metabolism of  
9 substance 4 can be saturated at high exposures. The glutathione pathway was found to be a  
10 minor pathway at low doses, but more prevalent following saturation of the cytochrome P-450  
11 pathway. Comparative in vitro studies indicate that mice have a greater capacity to metabolize to  
12 TCA than rats and humans. Inhalation studies also indicate saturation of oxidative metabolism of  
13 substance 4, which occurs at higher dose levels in mice than in rats and humans. Based on these  
14 findings, it has been postulated that the species differences in the carcinogenicity of substance 4  
15 between rats and mice may be related to the differences in the metabolism to TCA and glutathione  
16 conjugates.

17 Substance 4 is a member of the class of chlorinated organics that often cause liver and  
18 kidney toxicity and carcinogenesis in rodents. Like many chlorinated organics, substance 4 itself  
19 does not appear to be mutagenic. Substance 4 was generally negative in in vitro bacterial systems  
20 and in vivo mammalian systems. However, a minor metabolite formed in the kidney by the  
21 glutathione conjugation pathway has been found to be a strong mutagen.

22 The mechanisms of induced carcinogenic effects of substance 4 in rats and mice are not  
23 completely understood. It has been postulated that mouse liver carcinogenesis is related to liver  
24 peroxisomal proliferation and toxicity of the metabolite TCA. Information on whether or not  
25 TCA induces peroxisomal proliferation in humans is not definitive. The induced renal tumors in  
26 male rats may be related either to kidney toxicity or the activity of a mutagenic metabolite. The  
27 mechanisms of increases in MCL in rats are not known.

### 28 29 Evaluation

30 Available epidemiologic studies, taken together, provide suggestive evidence of a possible  
31 causal association between exposure to substance 4 and cancer incidence in the laundry and dry  
32 cleaning industries. This is based on consistent findings of elevated cancer risks in several studies  
33 of different populations of dry cleaning and laundry workers. However, each individual study is  
34 compromised by a number of study deficiencies including small numbers of cancers, confounding

1 exposure to other solvents, and poor exposure characterization. Others may interpret these  
2 findings collectively as inconclusive.

3 There is considerable evidence that substance 4 is carcinogenic to laboratory animals. It  
4 induces tumors in mice of both sexes by oral and inhalation exposure and in rats of both sexes via  
5 inhalation. However, owing to incomplete understanding of the mode of action, the predictivity  
6 of animal responses to humans is uncertain.

7 Animal data of structurally related compounds showing common target organs of toxicity  
8 and carcinogenic effects (but lack of mutagenic effects) provide additional support for the  
9 carcinogenicity of substance 4. Comparative toxicokinetic and metabolism information indicates  
10 that the mouse may be more susceptible to liver carcinogenesis than rats and humans. This may  
11 indicate differences of the degree and extent of carcinogenic responses, but does not detract from  
12 the qualitative weight of evidence of human carcinogenicity. The toxicokinetic information also  
13 indicates that oral and inhalation are the major routes of human exposure.

#### 14 Conclusion

15 Substance 4 is *likely to be carcinogenic to humans by all routes of exposure*. The weight  
16 of evidence of human carcinogenicity is based on: (a) demonstrated evidence of carcinogenicity in  
17 two rodent species of both sexes via two relevant routes of human exposure; (b) the substance's  
18 similarity in structure to other chlorinated organics that are known to cause liver and kidney  
19 toxicity and carcinogenesis in rodents; (c) suggestive evidence of a possible association between  
20 exposure to the substance in the laundry and dry cleaning industries and increased cancer  
21 incidence; and (d) human and animal data indicating that the substance is absorbed by all routes of  
22 exposure.

23 There is considerable scientific uncertainty about the human significance of certain rodent  
24 tumors associated with substance 4 and related compounds. In this case, the human relevance of  
25 the animal evidence of carcinogenicity relies on the default assumption.

26 Overall, there is not enough evidence to give high confidence in a conclusion about any  
27 single mode of action; it appears that more than one is plausible in different rodent tissues.  
28 Nevertheless, the lack of mutagenicity of substance 4 and its general growth-promoting effect on  
29 high background tumors, as well as its toxicity toward mouse liver and rat kidney tissue, support  
30 the view that the predominant mode is growth-promoting rather than mutagenic. A mutagenic  
31 contribution to carcinogenicity due to a metabolite cannot be ruled out. The dose-response  
32 assessment should, therefore, adopt both default approaches, nonlinear and linear extrapolations.  
33

1 The latter approach is very conservative since it likely overestimates risk at low doses in this case,  
2 and is primarily useful for screening analyses.

3  
4 ***Example 5: “Likely/Not Likely Human Carcinogen”--Range of Dose Limited, Margin-of-  
5 Exposure Extrapolation***

6 Human Data

7 Substance 5 is a metal-conjugated phosphonate. No human tumor or toxicity data exist  
8 on this chemical.

9  
10 Animal Data

11 Substance 5 caused a statistically significant increase in the incidence of urinary bladder  
12 tumors in male, but not female, rats at 30,000 ppm (3%) in the diet in a long-term study. Some of  
13 these animals had accompanying urinary tract stones and toxicity. No bladder tumors or adverse  
14 urinary tract effects were seen in two lower dose groups (2,000 and 8,000 ppm) in the same  
15 study. A chronic dietary study in mice at doses comparable to those in the rat study showed no  
16 tumor response or urinary tract effects. A 2-year study in dogs at doses up to 40,000 ppm  
17 showed no adverse urinary tract effects.

18  
19 Other Key Data

20 Subchronic dosing of rats confirmed that there was profound development of stones in the  
21 male bladder at doses comparable to those causing cancer in the chronic study, but not at lower  
22 doses. Sloughing of the epithelium of the urinary tract accompanied the stones.

23 There was a lack of mutagenicity relevant to carcinogenicity. In addition, there is nothing  
24 about the chemical structure of substance 5 to indicate DNA reactivity or carcinogenicity.

25 Substance 5 is composed of a metal, an ethanol, and a simple phosphorus-oxygen-  
26 containing component. The metal is not absorbed from the gut, whereas the other two  
27 components are absorbed. At high doses, ethanol is metabolized to carbon dioxide, which makes  
28 the urine more acidic; the phosphorus level in the blood and calcium in the urine are increased.  
29 Chronic testing of the phosphorus-oxygen-containing component alone in rats did not show any  
30 tumors or adverse effects on the urinary tract.

31 Because substance 5 is a metal complex, it is not likely to be readily absorbed from the  
32 skin.

33  
34 Evaluation

1 Substance 5 produced cancer of the bladder and urinary tract toxicity in male, but not  
2 female rats and mice, and dogs failed to show the toxicity noted in male rats. The mode of action  
3 developed from the other key data to account for the toxicity and tumors in the male rats is the  
4 production of bladder stones. At high but not lower subchronic doses in the male rat, substance 5  
5 leads to elevated blood phosphorus levels; the body responds by releasing excess calcium into the  
6 urine. The calcium and phosphorus combine in the urine and precipitate into multiple stones in  
7 the bladder. The stones are very irritating to the bladder; the bladder lining is eroded and cell  
8 proliferation occurs to compensate for the loss of the lining. Cell layers pile up, and finally,  
9 tumors develop. Stone formation does not involve the chemical per se but is secondary to the  
10 effects of its constituents on the blood and, ultimately, the urine. Bladder stones, regardless of  
11 their cause, commonly produce bladder tumors in rodents, especially the male rat.

### 12 13 Conclusion

14 Substance 5, a metal aliphatic phosphonate, is *likely to be carcinogenic to humans* only  
15 under high-exposure conditions following *oral and inhalation exposure* that lead to bladder stone  
16 formation, but is *not likely* to be carcinogenic under low-exposure conditions. It is *not likely to*  
17 *be a human carcinogen* via the *dermal* route, given that the compound is a metal conjugate that is  
18 readily ionized and its dermal absorption is not anticipated. The weight of evidence is based on  
19 (a) bladder tumors only in male rats; (b) the absence of tumors at any other site in rats or mice; (c)  
20 the formation of calcium-phosphorus-containing bladder stones in male rats at high, but not low,  
21 exposures that erode bladder epithelium and result in profound increases in cell proliferation and  
22 cancer; and (d) the absence of structural alerts or mutagenic activity.

23 There is a strong mode-of-action basis for the requirements of (a) high doses of substance  
24 5, (b) which lead to excess calcium and increased acidity in the urine, (c) which result in the  
25 precipitation of stones, and (d) the necessity of stones for toxic effects and tumor hazard  
26 potential. Lower doses fail to perturb urinary constituents, lead to stones, produce toxicity, or  
27 give rise to tumors. Therefore, dose-response assessment should assume nonlinearity.

28 A major uncertainty is whether the profound effects of substance 5 may be unique to the  
29 rat. Even if substance 5 produced stones in humans, there is only limited evidence that humans  
30 with bladder stones develop cancer. Most often human bladder stones are either passed in the  
31 urine or lead to symptoms resulting in their removal. However, since one cannot totally dismiss  
32 the male rat findings, some hazard potential may exist in humans following intense exposures.  
33 Only fundamental research could illuminate this uncertainty.

1 ***Example 6: “Suggestive” Evidence***

2 Human Data

3 Substance 6 is an unsaturated aldehyde. In a cohort study of workers in a chemical plant  
4 exposed to a mixture of chemicals with substance 6 as a minor component, a greater risk of  
5 cancer was reported than was expected. This study is considered inadequate because of multiple  
6 exposures, small cohort, and poor exposure characterization.

7  
8 Animal Data

9 Substance 6 was tested for potential carcinogenicity in a drinking water study in rats, an  
10 inhalation study in hamsters, and a skin painting study in mice. No significant increases in tumors  
11 were observed in male rats treated with substance 6 at three dose levels in drinking water.  
12 However, a significant increase of adrenal cortical adenomas was found in the only treated female  
13 dose group administered a dose equivalent to the high dose of males. This study used a small  
14 number of animals (20 per dose group).

15 No significant finding was detected in the inhalation study in hamsters. This study is  
16 inadequate due to the use of too few animals, short duration of exposure, and inappropriate dose  
17 selection (use of a single exposure that was excessively toxic as reflected by high mortality).

18 No increase in tumors was induced in the skin painting study in mice. This study is of  
19 inadequate design for carcinogenicity evaluation because of several deficiencies: small number of  
20 animals, short duration of exposure, lack of reporting about the sex and age of animals, and purity  
21 of test material.

22 Substance 6 is structurally related to low-molecular-weight aldehydes that generally  
23 exhibit carcinogenic effects in the respiratory tracts of laboratory animals via inhalation exposure.  
24 Three skin painting studies in mice and two subcutaneous injection studies of rats and mice were  
25 conducted to evaluate the carcinogenic potential of a possible metabolite of substance 6  
26 (identified in vitro). Increased incidences of either benign or combined benign and malignant skin  
27 tumors were found in the dermal studies. In the injection studies of rats and mice, increased  
28 incidences of local sarcomas or squamous cell carcinoma were found at the sites of injection. All  
29 of these studies are limited by the small number of test animals, the lack of characterization of test  
30 material, and the use of single doses.

31  
32 Other Key Data

33 Substance 6 is a flammable liquid at room temperature. Limited information on its  
34 toxicokinetics indicates that it can be absorbed by all routes of exposure. It is eliminated in the

1 urine mainly as glutathione conjugates. Substance 6 is metabolized in vitro by rat liver and lung  
2 microsomal preparations to a dihydroxylated aldehyde.

3 No data were available on the genetic and related effects of substance 6 in humans. It did  
4 not induce dominant lethal mutations in mice. It induced sister chromatid exchanges in rodent  
5 cells in vitro. The mutagenicity of substance 6 is equivocal in bacteria. It did not induce DNA  
6 damage or mutations in fungi.

### 7 8 Evaluation

9 Available human data are judged *suggestive, but not sufficient* for an evaluation of any  
10 causal relationship between exposure to substance 6 and human cancer.

11 The carcinogenic potential of substance 6 has not been adequately studied in laboratory  
12 animals due to serious deficiencies in study design, especially the inhalation and dermal studies.  
13 There is suggestive evidence of carcinogenicity in the drinking water study in female rats.  
14 However, the significance of that study to a potential for human response is uncertain since the  
15 finding is limited to occurrence of benign tumors in one sex, and at the high dose only. Additional  
16 suggestion for animal carcinogenicity comes from observation that a possible metabolite is  
17 carcinogenic at the site of administration. This metabolite, however, has not been studied in vivo.  
18 Overall, the animal evidence is judged to be suggestive for human carcinogenicity.

19 Other key data, taken together, do not add significantly to the overall weight of evidence  
20 of carcinogenicity. SAR analysis indicates that substance 6 would be DNA-reactive. However,  
21 mutagenicity data are inconclusive. Limited in vivo data do not support a mutagenic effect.  
22 While there is some evidence of DNA damage in rodent cells in vitro, there is either equivocal or  
23 no evidence of mutagenicity in nonmammalian systems.

### 24 25 Conclusion

26 While there is a suggestion of animal carcinogenicity, the data are inadequate for a  
27 judgment about the human carcinogenicity potential of substance 6. Both human and animal data  
28 are judged inadequate for an evaluation. There is evidence suggestive of potential carcinogenicity  
29 on the basis of limited animal findings and SAR considerations. Data are not sufficient to judge  
30 whether there is a mode of carcinogenic action. Additional studies are needed for a full evaluation  
31 of the potential carcinogenicity of substance 6. Hence, dose-response assessment is not  
32 appropriate.

1 ***Example 7: “Not Likely to be a Human Carcinogen”--Appropriately Studied Chemical in***  
2 ***Animals Without Tumor Effects***

3 Human Data

4 Substance 7, a plant extract, has not been studied for its toxic or carcinogenic potential in  
5 humans.

6  
7 Animal Data

8 Substance 7 has been studied in four chronic studies in three rodent species. In a feeding  
9 study in rats, males showed a nonsignificant increase in benign tumors of the parathyroid gland in  
10 the high-dose group, where the incidence in concurrent controls greatly exceeded the historical  
11 control range. Females demonstrated a significant increase in various subcutaneous tumors in the  
12 low-dose group, but findings were not confirmed in the high-dose group, and there was no dose-  
13 response relationship. These effects were considered as not adding to the evidence of  
14 carcinogenicity. No tumor increases were noted in a second adequate feeding study in male and  
15 female rats. In a mouse feeding study, no tumor increases were noted in dosed animals. There  
16 was some question as to the adequacy of the dosing; however, it was noted that in the mouse 90-  
17 day subchronic study that a dose of twice the high dose in the chronic study led to significant  
18 decrements in body weight. In a hamster study there were no significant increases in tumors at  
19 any site. No structural analogues of substance 7 have been tested for cancer.

20  
21 Other Key Data

22 There are no structural alerts that would suggest that substance 7 is a DNA-reactive  
23 compound. It is negative for gene mutations in bacteria and yeast, but positive in cultured mouse  
24 cells. Tests for structural chromosome aberrations in cultured mammalian cells and in rats are  
25 negative; however, the animals were not tested at sufficiently high doses. Substance 7 binds to  
26 proteins of the cell division spindle; therefore, there is some likelihood for producing numerical  
27 chromosome aberrations, an endpoint that is sometimes noted in cancers. In sum, there is limited  
28 and conflicting information concerning the mutagenic potential of the agent.

29 The compound is absorbed via oral and inhalation exposure but only poorly via the skin.

30  
31 Evaluation

32 The only indication of a carcinogenic effect comes from the finding of benign tumors in  
33 male rats in a single study. There is no confirmation of a carcinogenic potential from dosed



1 females in that study, in males and females in a second rat study, or from mouse and hamster  
2 studies.

3           There is no structural indication that substance 7 is DNA-reactive, there is inconsistent  
4 evidence of gene mutations, and chromosome aberration testing is negative. The agent binds to  
5 cell division spindle proteins and may have the capacity to induce numerical chromosome  
6 anomalies. Further information on gene mutations and in vivo structural and numerical  
7 chromosome aberrations may be warranted.

8

9           Conclusion

10           Substance 7 is *not likely to be carcinogenic to humans* via all relevant routes of exposure.  
11 This weight-of-evidence judgment is largely based on the absence of significant tumor increases in  
12 chronic rodent studies. Adequate cancer studies in rats, mice, and hamsters fail to show any  
13 carcinogenic effect; a second rat study showed an increase in benign tumors at a site in dosed  
14 males, but not females.

## APPENDIX D. CASE STUDY EXAMPLES FOR MODE-OF-ACTION EVALUATION

1            *This appendix contains case examples to illustrate the application of the framework for*  
2 *mode-of-action analysis. Evaluations of mode-of-action information will ordinarily appear*  
3 *before or within the hazard characterization section of a risk assessment. Since these examples*  
4 *are given outside of a risk assessment, the basic data that underlie the evaluation are*  
5 *summarized first for reference, followed by the mode-of-action analysis.*

### 6 7            **D.1.0. EXAMPLE 1: CHEMICAL T (THYROID DISRUPTION)**

#### 8 9            **D.1.1. HAZARD DATA SUMMARY**

##### 10           **D.1.1.1. Data Availability**

11            Data include a rat chronic/carcinogenicity feeding study, an 18-month CD-1 mouse  
12 carcinogenicity study, a 1-year dog feeding study, a subchronic feeding study in the rat, a 4-week  
13 and 1-year subchronic feeding study in the dog, a 21-day dermal study in the rat, developmental  
14 toxicity studies in the rat and rabbit, a two-generation reproduction study in the rat, mutagenicity  
15 studies, metabolism studies, and special subchronic mechanistic studies.

##### 16 17           **D.1.1.1.1. Rat**

18           **D.1.1.1.1.1. 24-month toxicity.** Male and female Sprague-Dawley rats received chemical T in the  
19 diet for 24 months. Thyroid follicular cell tumor incidence was increased in male but not female  
20 animals (see Table D-1). Tumor incidence in the two high-dose male groups was higher than in  
21 historical control studies. Thyroid and liver weights were increased in the two high-dose groups. A  
22 few renal tubular adenomas occurred in dosed male and female animals, but there was no statistical  
23 significance. SGPT was increased in high-dose animals; some other liver enzymes were increased at  
24 various times.

**Table D-1. Thyroid follicular cell tumor incidence in male rats**

<b>Tumor</b>	<b>Dose (ppm in diet)</b>					
	<b>0</b>	<b>1</b>	<b>10</b>	<b>100</b>	<b>1000</b>	<b>3000<sup>a</sup></b>
Benign	1/50 <sup>b</sup>	2/47	0/49	2/47	8/49	12/48 <sup>b</sup>
Malignant	1/50 <sup>b</sup>	1/47	0/49	0/47	1/49	4/48
Combined	2/50 <sup>b</sup>	3/47	0/49	2/47	9/49	14/48 <sup>b</sup>

<sup>a</sup>Two animals had both benign and malignant tumors.

<sup>b</sup>Statistically significant for trend noted at control; pairwise comparison noted at dose level.

1 **D.1.1.1.1.2. *Special subchronic studies.*** Groups of male Sprague-Dawley rats were fed  
2 chemical T at 3000 ppm in the diet for 7, 14, 28, 56, or 90 days. Starting at 7 days, TSH levels  
3 were significantly increased and T<sub>4</sub> values were significantly decreased. There were also  
4 significant increases in thyroid and liver weights and for follicular cell hypertrophy and  
5 hyperplasia. Hepatic UDPGT activity for T<sub>4</sub> was increased, while hepatic 5'-monodeiodinase  
6 activity was either unaffected or decreased. Radioiodine uptake into the thyroid gland was  
7 measured. The percent of the dose per gram of thyroid tissue was equivalent in 3000 ppm and  
8 control groups, as was protein-bound iodide per mg of thyroid protein. Activities of hepatic aryl  
9 hydrocarbon hydroxylase, ethoxycoumarin O-dehydrase, and cytochrome P-450 were significantly  
10 increased in chemical T dosed animals.

11 Groups of male Sprague-Dawley rats were fed chemical T (30, 100, 300, 1000, 3000  
12 ppm) for 56 days; some animals were taken off chemical T for another 56 or 112 days to evaluate  
13 reversibility of effects. Thyroid weights were significantly increased in the top two doses, while  
14 liver weights were increased in the top three doses. T<sub>4</sub> UDPGT activity was increased in the top  
15 two doses. T<sub>4</sub> was decreased and TSH increased at the top dose, along with increases in the  
16 incidence of follicular cell hypertrophy and hyperplasia. Upon stopping chemical T dosing, all  
17 parameters returned to normal except for thyroid weight. Elimination of radioiodine-labeled T<sub>4</sub>  
18 from the blood and into the bile was measured after 56 days of chemical T dosing. Blood  
19 clearance was twice as fast in dosed animals as in controls, while there was a 40% increase in the  
20 rate of excretion of the hormone into the bile of treated animals.

#### 21 **D.1.1.1.2. *Dog***

22 **D.1.1.1.2.1. *Subchronic toxicity.*** Subchronic feeding of chemical T (0, 10, 100, 1000, 5000  
23 ppm) produced an increase in thyroid weight and hyperplasia of the gland at 5000 ppm. There  
24 was hepatocellular hypertrophy at 1000 ppm and above.  
25

26  
27 **D.1.1.1.2.2. *12-month toxicity.*** One-year feeding of chemical T (1, 20, 200, 2000 ppm) led to  
28 hepatocellular hypertrophy/hyperplasia at 200 and 2000 ppm but not at 0 or 20 ppm. At 2000  
29 ppm, absolute and relative liver weights were increased. At 2000 ppm, there were increases in  
30 SGOT, SGPT, GGT, and ALK, and decreases in cholesterol, albumin, and total protein.  
31

#### 32 **D.1.1.1.3. *Mouse***

33 **D.1.1.1.3.1. *18-month toxicity.*** In an 18-month chemical T feeding study (0, 1, 10, 100, 400,  
34 800 ppm), there were no increases in tumor incidence at any site. Absolute and relative liver

1 weights were statistically significantly increased over controls at the highest dose level, as were  
2 kidney weights in the female. Increases in liver enzymes were noted at various intervals, including  
3 SGPT, SGOT, and ALK. Dose levels in the study were considered adequate.  
4

#### 5 **D.1.1.2. Mutagenicity**

6 Negative results were seen in four strains of Salmonella with or without metabolic  
7 activation; negative results in assay of forward mutation of HGPT locus of Chinese hamster ovary  
8 cells (dosing probably not sufficient); negative results in mouse bone marrow micronucleus assay;  
9 negative results in assay for unscheduled DNA synthesis in rat hepatocytes pretreated with  
10 chemical T. The compound does not have a structure that suggests electrophilicity.  
11

#### 12 **D.1.2. SUMMARY DESCRIPTION OF POSTULATED MODE OF ACTION**

13 Thyroid hormone production is regulated by actions of the hypothalamus, pituitary, and  
14 thyroid glands. Homeostasis of thyroid hormone is maintained by a feedback loop among the  
15 hypothalamus and pituitary and the thyroid gland. The hypothalamus produces thyrotrophin  
16 reducing hormone (TRH), which stimulates the pituitary to produce thyroid stimulating hormone  
17 (TSH) which, in turn, stimulates the thyroid to produce thyroid hormone. The hypothalamus and  
18 pituitary respond to a high level of circulating thyroid hormone by suppressing TRH and TSH  
19 production, and to a low level by increasing them. The mode of action considered is continuous  
20 elevation of TSH levels that stimulates the thyroid gland to deplete its stores of thyroid hormone  
21 and continues to push production, resulting in hypertrophy of the production cells (follicular cells)  
22 leading to hyperplasia, nodular hyperplasia and, eventually, tumors of these cells. In rats, the  
23 chain of events may be induced by direct effects on hormone synthesis or by metabolic removal of  
24 circulating hormone.  
25

#### 26 **D.1.3. KEY EVENTS**

27 The key events considered with respect to chemical T-induced tumorigenesis in male rats  
28 include hormone changes in TSH, T<sub>4</sub>, and T<sub>3</sub>, and changes in hepatic T<sub>4</sub>-UDPGT, indicators of  
29 liver microsomal enzyme induction, enhanced liver metabolism, increased biliary excretion of T<sub>4</sub>,  
30 increase in thyroid weight and liver weight, and thyroid follicular cell hypertrophy/hyperplasia.  
31 These events have been well defined and measured in male rats in subchronic studies, augmenting  
32 observations at interim and terminal sacrifice in a chronic study.

1 **D.1.4. STRENGTH, CONSISTENCY, SPECIFICITY OF ASSOCIATION OF TUMOR**  
2 **RESPONSE WITH KEY EVENTS**

3 The thyroid tumor response in the chronic study at the highest dose was associated with  
4 hypertrophy/hyperplasia in the thyroid and increase in weight of the thyroid. In subchronic  
5 studies, the organ weight and hypertrophy/hyperplasia were shown to appear and reverse in  
6 statistically significant degrees under the same conditions of dose and time as the appearance and  
7 reversal of changes in thyroid hormone levels and thyroid hormone metabolism. Stop/recovery  
8 studies showed that cessation of dosing was followed in turn by return of hormone levels to  
9 control levels, reduction in liver and thyroid weights, and reversal of hyperplasia in thyroid  
10 follicular cells. The only sign slow to reverse was thyroid weight after the longest dosing period.  
11 Strength, consistency, and specificity of association were well established in the studies.

12  
13 **D.1.5. DOSE-RESPONSE RELATIONSHIP**

14 Dose correlations exist for parameters in the chronic and subchronic studies for all of the  
15 relevant parameters. Thyroid follicular cell tumors, thyroid hypertrophy/hyperplasia, and  
16 increased thyroid and liver weight are noted at similar doses, usually at dietary levels of 1000 and  
17 3000 ppm chemical T. Correspondingly in the subchronic study, at 3000 ppm T<sub>4</sub> is depressed  
18 while TSH is elevated. At 1000 and 3000 ppm, hepatic T<sub>4</sub>-UDPGT activity is statistically  
19 significantly elevated, and there is an increase in biliary excretion of T<sub>4</sub> at 3000 ppm. The only  
20 parameter showing significant effect at a dose below 100 ppm chemical T was liver weight  
21 increase in a subchronic study at 300 ppm.

22  
23 **D.1.6. TEMPORAL ASSOCIATION**

24 The chronic study, together with the three subchronic studies of key events observing  
25 effects after different durations at one dose, at multiple doses, and after recovery, shows events  
26 occurring in the following sequence: (1) increase in hepatic glucuronidation, de-iodination and  
27 excretion of T<sub>4</sub>, as well as its elimination from the blood; (2) a rise in circulating TSH; (3) an  
28 increase in thyroid weight and thyroid follicular cell hypertrophy; (4) thyroid follicular cell  
29 hyperplasia; and (5) thyroid follicular cell tumors. The stop experiments indicate reversal of the  
30 thyroid and liver weight increases as well as reversal of hormone and other protein measures.  
31 While reversal of thyroid weight increase in the recovery study was less after a longer duration of  
32 treatment, hypertrophy/hyperplasia did reverse after the longer duration.

33  
34 **D.1.7. BIOLOGICAL PLAUSIBILITY AND COHERENCE OF THE DATABASE**

1 Under EPA science policy (U.S. EPA, 1998a), determination of the antithyroid activity of  
2 a chemical requires empirical demonstration of five items: (1) increases in thyroid growth, (2)  
3 changes in thyroid and pituitary hormones, (3) location of the site(s) of antithyroid action, (4)  
4 dose-response correlations among various key precursor events and tumor incidence, and (5)  
5 reversibility of effects following treatment cessation. The database on chemical T documents all  
6 such information.

7 Thyroid tumorigenesis, particularly in the male rat, has been observed to be associated  
8 with exposure to a number of industrial chemicals, pesticides, and pharmaceuticals. A significant  
9 number of these appear to work in a manner similar to chemical T, by enhancing thyroid hormone  
10 metabolism and excretion by the liver.

11 Thyroid tumors did not appear in the female rats in the 2-year study. Thyroid hypertrophy  
12 and hyperplasia were observed in the females 6 months after their appearance in males. As is  
13 noted with other chemicals, the female rat is less sensitive to the effect of antithyroid chemicals  
14 regarding key events and tumor development. Hepatic enlargement and effects are noted in the  
15 mouse and dog studies, as they are in the rat. In addition, dogs receiving high doses of chemical  
16 T show enlargement of the thyroid gland.

#### 18 **D.1.8. OTHER MODES OF ACTION**

19 Chemical T does not belong to a class of chemicals that is expected to generate reactive  
20 metabolites, and no related chemicals have been tested for carcinogenicity. Short-term studies  
21 demonstrate that the chemical does not increase gene mutations in Salmonella (Ames test) or  
22 cultured mammalian cells (maximal dosage may not have been reached), micronuclei in bone  
23 marrow cells, and unscheduled DNA synthesis in cultured cells. No other modes of action, apart  
24 from thyroid disruption, are described to account for the thyroid tumors.

25 Several sites of action were investigated as being the source of the antithyroid effects of  
26 chemical T. The chemical does not inhibit the entry of inorganic iodide into the thyroid (iodide  
27 pump) or block the organification and incorporation of iodide into thyroid hormone (thyroid  
28 peroxidase); likewise, it does not inhibit monodeiodinase, which blocks the conversion of T<sub>4</sub> to  
29 T<sub>3</sub>.

30 Chemical T administration leads to renal adenomas in male and female rats; the response  
31 lacked statistical significance. The mode of action for the thyroid tumors does not account for the  
32 renal tumors. Assessment of the significance and mode of action of the renal tumors requires  
33 separate analysis.

1 **D.1.9. CONCLUSION**

2 The weight of evidence supports a conclusion that chemical T acts by inducing hepatic  
3 metabolism and biliary elimination of thyroid hormone, prompting increased production of TSH,  
4 which ultimately results in thyroid follicular cell neoplasia as postulated.  
5

6 **D.1.10. RELEVANCE OF THE MODE OF ACTION TO HUMANS**

7  
8 *Relevance to humans*

9 Chemical T affects the liver of rats, mice, and dogs, and the thyroid of rats and dogs.  
10 Given the breadth of responses, it is possible that humans may respond similarly. The subject of  
11 the relevance of an antithyroid mode of action for thyroid tumors is extensively covered in the  
12 Agency's policy for the assessment of this mode of action (U.S. EPA, 1998a). In summary the  
13 policy states:  
14

15 The role of thyroid-pituitary disruption in cancer development in humans is much  
16 less convincing than in animals. Iodide deficiency is associated with increases in  
17 thyroid cancer in some studies but not others. Similarly, an association between  
18 either inborn errors of metabolism affecting thyroid hormone output or  
19 autoimmune-related Graves' disease and cancer is suggested but not proved. It  
20 seems that TSH may at least play some permissive role in carcinogenesis in  
21 humans. Accordingly, one cannot qualitatively reject the animal model; it seems  
22 reasonable that it may serve as an indicator of a potential human thyroid cancer  
23 hazard. However, to the extent that humans are susceptible to the tumor-inducing  
24 effects of thyroid-pituitary disruption, and given that definitive human data are not  
25 available, it would appear that quantitatively humans are less sensitive than rodents  
26 in regard to developing cancer from perturbations in thyroid-pituitary status.  
27

28 The measured key events and their effects, as well as effects of reversal of the events, are  
29 consistent with what is known about the regulation of thyroid hormone balance, and the  
30 postulated carcinogenic mode of action as summarized above.

31 Thyroid tumorigenesis, particularly in the male rat, has been observed to be associated  
32 with exposure to a number of pesticides and pharmaceuticals. A pattern of thyroid organ growth,  
33 frequently liver growth, thyroid hormone changes, or changes in hormone metabolism has been



1 seen with a large proportion of these compounds. Chemical T effects are parallel to these other  
2 cases.

3 Thyroid tumors did not appear in the female rats in the 2-year study. Thyrotrophy and  
4 hyperplasia were observed in the females with a 6-month lag after their appearance in the male.  
5 The female is apparently more tolerant of thyroid disruption; whether tumors would have been  
6 seen in the females if the 2-year study had been extended is uncertain.

### 7 **Relevance to subpopulations**

8 Thyroid hormones are regulated within rather narrow ranges, with normal adult human  
9 serum values often being given as T4--4 to 11 ug/dL and T3--80 to 180 ng/dL. TSH levels  
10 extend over a broader range--0.4 to 8 ug/ml, due to the incorporation in recent years of more  
11 sensitive laboratory methods that have extended the normal range to lower values (Ingbar &  
12 Woeber, 1981; Surks et al., 1990). The upper bound on normal TSH has not changed, and it is  
13 the one of import to considerations of antithyroid effects of chemicals. During development  
14 somewhat higher levels for each of the hormones are noted, with adult hormone values being  
15 reached beyond about 10 years of age (Nicholson and Pesce, 1992). Growth of the thyroid gland  
16 continues for the first 15 years of life, going from about 1 gram at birth to an adult size of about  
17 17 grams (Fisher and Klein, 1981; Larsen, 1982). Early developmental inability to synthesize  
18 adequate thyroid hormone leads to altered physical and mental development (cretinism)  
19 (DiGeorge, 1992; Goldey et al., 1995) and is treatable. The control of normal thyroid growth  
20 during development is not totally known, although the increase in gland size may be independent  
21 of TSH stimulation (Logothetopoulos, 1963). Extended deviations in human thyroid hormone  
22 levels either above or below the normal range are associated with hyperthyroidism and  
23 hypothyroidism, respectively and are treated in the U.S. to restore balance.

24 Thyroid cancer is a rare condition in the U.S., occurring with an incidence of about  
25 0.004% per year (Greenspan & Strewler, 1997). The incidence is predominantly in persons over  
26 30, and increases in older persons; in children the incidence is at the 1 per million rate. Mortality  
27 rates per 100,000 are above zero only for those older than 35 (Ries et al., 1999).

28 It is recognized that the human thyroid is susceptible to ionizing radiation, the only  
29 verified human thyroid carcinogen. Children are known to be more sensitive than adults to the  
30 carcinogenic effects of radiation (NRC, 1990; IAEA, 1996). The nature and consequences of  
31 radiation have differences from thyroid disruption by inborn deficits or possible chemical influence  
32 that is not mutagenic. The major effect of ionizing radiation on the thyroid is thought to be due to  
33 mutation. Antithyroid effects can also be induced at elevated radiation doses due to cytotoxicity  
34 of follicular cells with resulting reduction in thyroid hormone and elevation of TSH. Mutagenic

1 chemicals, however, do not act totally like radiation: (a) X rays penetrate the body and target  
2 organs without having to be absorbed. Chemicals must be absorbed and distributed to target  
3 organs. (b) Unlike most organic chemicals, radioiodine is actively transported and concentrated in  
4 the thyroid gland, and it becomes incorporated into nascent thyroglobulin. (c) Given that the size  
5 of the thyroid gland is smaller in children than in adults, for a given blood level of radioiodine, the  
6 internal dose to the thyroid of a child is greater than that for an adult. (d) Radioiodine in the  
7 Chernobyl accident was picked up by cattle and incorporated into milk. Due to differences in  
8 milk consumption, the external dose presented to children was greater than to adults.(e) Single  
9 quanta of radiation result in a series of ionizations within biological material, each of which can  
10 react with DNA to induce mutations and affect the carcinogenic process. Chemicals are much less  
11 efficient: they frequently need to be metabolized to active intermediates, with each molecule  
12 interacting singly with DNA, usually by forming adducts which can be converted to mutations. (f)  
13 The spectrum of mutagenic effects vary with the source. Ionizing radiation often results in  
14 deletions and other structural chromosomal aberrations, while chemicals not uncommonly  
15 produce more gene mutations. (g) The thyroid of children is more sensitive to carcinogenic effects  
16 of external radiation on a per unit dose basis than in adults, especially for children less than 5  
17 years of age. Sensitivity decreases with advancing age and seems to disappear in adulthood. It is  
18 estimated that, overall, children may be two or more times more sensitive to carcinogenic effects  
19 of external emitters than are adults (NRC, 1990).

20 The evidence supports the view that Chemical T's mode of action will not be different for  
21 children. Thyroid cancer is very rare in younger age groups and lower in incidence and mortality  
22 than for older adults. It does not appear that the young have any propensity for thyroid cancer  
23 from which one could infer some underlying cancer process that differs from adults (absent  
24 ionizing radiation treatment or incidents, discussed above). The basic elements of thyroid  
25 function and hormone homeostasis are the same in children and adults with a period of growth  
26 during which children reach lower adult balances. The chemical disruption mode of action of  
27 Chemical T in animals, to the extent that it is applicable to humans, appears equally applicable to  
28 human subpopulations. It is not expected to share the features of radiation.

1  
2 **D.2.0. EXAMPLE 2: CHEMICAL Z (BLADDER TUMOR)**

3  
4 **D.2.1. HAZARD DATA SUMMARY**

5 **D.2.1.1. Data Availability**

6 Data include a rat chronic/carcinogenicity feeding study, an 18 month CD-1 mouse  
7 carcinogenicity study, a three-generation reproduction study in the rat, and a 2-year feeding study  
8 in dogs. There are no data on the effects in humans of exposure to chemical Z.

9 A 13-week feeding study in rats included interim sacrifices at 2, 4, and 8 weeks and  
10 establishment of 16-week recovery groups at 8 weeks and a 21-week recovery group at 13  
11 weeks.

12 **D.2.1.2. Tumor Observations**

13 **D.2.1.2.1. Tumor Response**

14 **D.2.1.2.1.1. Rats.** Administration of chemical Z in the diet to male Sprague-Dawley rats at dose  
15 levels of 30,000 ppm or more for 2 years resulted in an increase in bladder urothelial tumors in  
16 male rats. Statistically significant increases ( $p < 0.05$ ) were noted at the high dose only  
17 (40,000/30,000 ppm) in the incidences of transitional cell papillomas, carcinomas, combined  
18 papillomas and carcinomas, and hyperplasia in the 2-year SD rat bioassay (Table D-2). Bladder  
19 calculi were observed in some animals but correlation between stones and tumors was not evident  
20 at final sacrifice.

**Table D-2. Incidence of transitional cell lesions and stones in the bladder of males from a 2-year SD rat study**

Parameter	Dose (ppm)			
	0	2000	8000	40,000/30,000
<i>N</i>	73	75	78	78
Lesion				
Papilloma	1	1	1	5
Carcinoma	2	2	1	16
Combined	3	3	2	21
Hyperplasia	5	7	5	29
Stones	0	0	0	5

1 **D.2.1.2.1.2. Mice.** No increase in tumor incidences was observed in an 18-month bioassay with  
2 mice.

3  
4 **D.2.1.3. Mutagenicity**

5 Chemical Z has not shown mutagenic activity based on results of *Salmonella sp.* or  
6 micronucleus assays. No evidence exists that the chemical produces effects on DNA synthesis nor  
7 does it appear to be clastogenic. There are no structural alerts suggesting mutagenic potential for  
8 the chemical.

9  
10 **D.2.1.4. Toxicity, Uroliths, and Hyperplasia**

11 There was a strong association among disruptions in urinary physiology, toxicity, uroliths,  
12 and hyperplasia in the 13-week study in mid-dose and high-dose animals (30,000 and 50,000 ppm  
13 respectively, [ $p < .05$ ]). In the control and 8,000 ppm group, no animals had stones and no animals  
14 had hyperplasia (see Table D-3).

**Table D-3. Incidence of bladder hyperplasia and stones in male SD rats treated up to 13 weeks**

<b>Parameter</b>	<b>2 weeks</b>				<b>8 weeks</b>				<b>13 weeks</b>			
Dose <sup>a</sup>	1	2	3	4	1	2	3	4	1	2	3	4
<i>N</i>	10	10	10	10	10	10	10	9	10	10	10	6
Papillary hyperplasia	0	0	7	8	0	0	9	7	0	0	5	6
Simple hyperplasia									0	0	2	0
Stones	0	0	3	4	0	0	9	8	0	0	7	6

<sup>a</sup>Dose (ppm): 1 = control, 2 = 8000, 3 = 30,000, 4 = 50,000.

1 **D.2.1.4.1. *Thirteen-Week Study***

2 Urothelial toxicity and disruptions in urinary physiology and urothelial toxicity appeared  
3 early in the study. Early changes in urinary physiology (decreased pH and increased cation  
4 concentration) were observed following 2 weeks of treatment and persisted throughout the  
5 duration of the study. Urothelial toxicity was expressed as edema, cystitis, and hyperplasia;  
6 hyperplasia (simple and papillary transitional cell combined) increased in overall incidence with  
7 continued treatment. It was present in 70% of mid-dose (30,000 ppm) animals and 80% of high-  
8 dose (50,000 ppm) animals following 2 weeks of exposure, and in 70% of the mid-dose group  
9 and 100% of the high-dose group at 13 weeks. There was some indication of a decrease in  
10 severity of hyperplasia at 13 weeks when compared to earlier time periods, as there was an  
11 apparent shift from the incidence of papillary hyperplasia to simple hyperplasia and a decrease in  
12 the combined incidence of hyperplasia in the 30,000 ppm group of animals.

13 Uroliths were found to be present as early as 2 weeks (0%, 0%, 30%, and 40%) and the  
14 incidence increased over the period of the study. The incidence of uroliths at termination of the  
15 13-week study was 0%, 0%, 70%, and 100%, but there was a decrease in size and number of  
16 stones per animal at 13 weeks.

17  
18 **D.2.1.4.2. *Three-Generation Reproduction Study in Rats***

19 High dose levels (>20,000 ppm in the diet) led to formation of lesions in the urinary tract of  
20 males and females of the F1, F2, and F3 generations. The lesions included hemorrhage of the  
21 bladder wall, increased pelvic dilation, and papillary necrosis. In the F3 generation, additional  
22 effects noted in renal tissue were hyperplasia of the transitional epithelium and desquamation of  
23 cells in the lumen of the urinary tract. The changes were associated with crystalline or calcareous  
24 deposits.

25  
26 **D.2.1.5. *Reversibility of Effects***

27 There was strong evidence of reversibility of bladder stones and bladder hyperplasia. When  
28 animals that had been treated for 8 weeks were returned to basal diet for 16 weeks, uroliths were  
29 found in 30% of 30,000 ppm animals and 25% of high-dose animals. Bladder hyperplasia  
30 (papillary and transitional cell combined) was reduced to 25% and 30% in each of these two dose  
31 groups (Table D-4). An analysis of individual animal data revealed a strong correlation between  
32 the incidence of uroliths and hyperplasia at the termination of the recovery period.

**Table D-4. Reversal of incidence of bladder hyperplasia and stones following 8 weeks treatment and 16 weeks recovery**

Parameter	Dose (ppm)			
	0	8000	30,000	50,000
<i>N</i>	10	10	10	8
Papillary hyperplasia	0	0	2	1
Simple hyperplasia	0	0	1	1
Stones	0	0	3	2



1 **D.2.1.6. Blood and Urine Chemistry**

2 Chemical Z administration resulted in increases in blood phosphorus and carbon dioxide  
3 (data not shown). Urinalyses (Table D-5) showed elevated calcium levels, reduced urinary  
4 phosphorus, and a profound lowering of urinary pH (5.0), which began at 2 weeks and persisted  
5 throughout the 13-week study in the 30,000 and 50,000 ppm group of rats. These changes  
6 occurred in the presence of bladder stones, which were reported to consist of 33% calcium and  
7 23% phosphorus.  
8

**Table D-5. Clinical chemistry values (urine) in male SD rats treated up to 13 weeks**

Parameter	2 weeks				8 weeks				13 weeks			
	1	2	3	4	1	2	3	4	1	2	3	4
Dose	1	2	3	4	1	2	3	4	1	2	3	4
N	10	10	10	10	10	10	10	9	10	10	10	6
Calcium - mg/dL	6	11	56 <sup>b</sup>	36 <sup>c</sup>	11	11	18	65 <sup>b</sup>	5	7	14 <sup>b</sup>	58 <sup>b</sup>
Phosphorus - mg/dL	90	62	2 <sup>b</sup>	13 <sup>c</sup>	109	90	19	1 <sup>b</sup>	57	67	26	1 <sup>b</sup>
pH	7	6.5	5 <sup>b</sup>	5 <sup>b</sup>	7.4	6.9	5.8 <sup>b</sup>	5.0 <sup>b</sup>	7.2	6.7	6.0 <sup>b</sup>	5.0 <sup>b</sup>
Stones	0	0	3	4	0	0	9	8	0	0	7	6

<sup>a</sup>Dose (ppm): 1 = control, 2 = 8000, 3 = 30,000, 4 = 50,000.

<sup>b</sup> $p < .01$ .

<sup>c</sup> $p < .05$

1 **D.2.1.7. Metabolism**

2       Upon ingestion by rats, the ethyl moiety of chemical Z is rapidly absorbed, hydrolyzed to a  
3 phosphite, and oxidized via acetaldehyde and acetate to carbon dioxide and water. Absorption of  
4 the phosphite moiety leads to increased blood phosphorus levels. There is also an increase in  
5 blood calcium load, which leads to increased excretion of calcium via the urine. Ethyl phosphite  
6 moieties and carbon dioxide are also eliminated via the urine. A marked depression of urinary pH  
7 (5.0) results from acidification of the urine by carbon dioxide. An aluminum moiety of the parent  
8 chemical is poorly absorbed, and most is eliminated in the feces. The phosphite metabolite, the  
9 major urinary metabolite, was not shown to express carcinogenic potential when administered to  
10 Sprague-Dawley rats at dose levels up to 32,000 ppm. It also does not express any mutagenic  
11 potential and does not have any structural alerts.  
12

13 **D.2.1.8. Structure-Activity Relationships**

14       There are no data on structurally related chemicals.  
15

16 **D.2.2. MODE-OF-ACTION ANALYSIS**

17 **D.2.2.1. Summary Description of Postulated Mode of Action**

18       Chemical Z produces transitional cell tumors in male Sprague-Dawley rats. The mode of  
19 action includes disruption in urinary physiology, including precipitation of calcium and  
20 phosphorus and formation of bladder calculi. The stones irritate the urothelium of the bladder,  
21 followed by transitional cell hyperplasia and bladder tumor formation. Disruption of urinary  
22 physiology is a consequence of a metabolic sequence involving (1) absorption and metabolism of  
23 the ethyl moiety to carbon dioxide, resulting in a reduction in urinary pH; and (2) absorption of  
24 the phosphite moiety, which leads to increased blood phosphorus levels and increased release of  
25 calcium into the urine. Increases in water consumption followed by increased urinary volume may  
26 contribute to bladder toxicity, but a precise role of increased urinary volume has not been  
27 established.

28       The mode of action for chemical Z is consistent with other data that demonstrate that solid  
29 masses in the rodent bladder, regardless of their origin--insertion of solid materials, including inert  
30 pellets, precipitation of administered chemicals (e.g., melamine) or disruption of urinary  
31 physiology (e.g., diethylene glycol)--lead to urothelial toxicity and the formation of tumors.  
32

33 **D.2.2.2. Key Events**

1 The key precursor events associated with bladder tumor formation following administration  
2 of chemical Z to rats include increased blood phosphorus and carbon dioxide, elevated urinary  
3 calcium and volume, decreased urinary pH and phosphorus, formation of bladder stones, and  
4 irritation and hyperplasia of the urothelium.

#### 5 6 **D.2.2.3. Strength, Consistency, and Specificity of Association of Tumor Response with Key** 7 **Events**

8 The only tumor response seen in animal studies is bladder tumors in male Sprague-Dawley  
9 rats. Studies in dogs and mice showed no effect on the bladder. The rat tumor response was seen  
10 only at high doses that lead to key precursor effects: altered urinary physiology (volume, calcium,  
11 pH) results in stones and produces toxicity and hyperplasia of the urothelium. The high-dose  
12 changes were noted in a rat chronic, a rat subchronic, and a three-generation reproduction study  
13 in rats. The key events, including hyperplasia, were observed to be reversible in subchronic  
14 stop/recovery studies. Administration of the major metabolite of chemical Z, monosodium  
15 phosphite, fails to reduce urinary pH, increase urinary volume, or produce nonneoplastic or  
16 neoplastic lesions of the bladder. The database on chemical Z is sufficient to evaluate the  
17 proposed mode of action despite the absence of more complete information on the composition of  
18 the stones and questions regarding the absence of toxicity following the administration of  
19 monosodium phosphite. There is a high degree of confidence that the findings accurately reflect  
20 the effects associated with administration of the chemical. No data gaps were identified that  
21 would substantially alter the evaluation of the proposed mode of action.

#### 22 23 **D.2.2.4. Dose-Response (D/R) Relationships**

24 The 2-year bioassay showed urothelial hyperplasia, transitional cell papillomas, and  
25 transitional cell carcinomas and a few bladder stones at 40,000/30,000 ppm. Of 78 high-dose  
26 animals, 37% showed bladder tumors. Tumors, hyperplasia, and stones were not increased at  
27 8000 ppm. A special 13-week feeding study demonstrated that key events--increased urinary  
28 calcium levels, decreased urinary phosphorus levels, decreased pH, bladder stones, irritation,  
29 edema, and hyperplasia--occurred consistently only at dose levels of 30,000 ppm or greater. A  
30 strong dose-response correlation was shown between calculus formation and hypercalciuria,  
31 acidic urine, and bladder hyperplasia. In a rat reproduction study, bladder effects were noted at  
32 24,000 ppm but not at 12,000 ppm.

#### 33 34 **D.2.2.5. Temporal Association**

1 A subchronic rat study with serial sacrifices at 2, 4, 8, and 13 weeks, including evaluation  
2 of 16-week recovery groups after 8 weeks and a 21-week recovery group after 13 weeks, was  
3 performed. By 2 weeks of administration, chemical Z produced stones that filled the bladder and  
4 resulted in advanced papillary hyperplasia. The number and size of stones was greatest at two  
5 weeks and there was a progressive decrease over the 13 week period. Early changes in urinary  
6 physiology (decreased urinary pH, increased calcium concentration, and decreased phosphorus  
7 concentration) were observed following 2 weeks of treatment and persisted throughout the  
8 duration of the study. Observation of the 8-week treatment/16-week recovery groups showed  
9 that incidence of both stones and hyperplasia significantly decreased as compared with incidence  
10 in animals sacrificed at 8 weeks. Also, upon cessation of dosing at 13 weeks, the incidence of  
11 animals with stones, the incidence of papillary hyperplasia, and the severity of hyperplasia  
12 decreased significantly by the end of a 21-week recovery period (data not shown). The changes  
13 noted within 2 weeks of dosing appear to have set in motion a series of events beginning with  
14 increased urinary calcium concentrations, followed or accompanied by stone formation, irritation  
15 of the bladder urothelium, hyperplasia and, eventually, neoplasia.

#### 16 17 **D.2.2.6. Biological Plausibility and Coherence of the Database**

18 Long-term and subchronic studies with chemical Z have demonstrated a dose correlation  
19 between development of stones and bladder tumor formation in male rats. Data from the 13-  
20 week study indicate a rapid onset of effects (changes in urinary parameters, formation of stones,  
21 and hyperplasia within 2 weeks of dosing) and adaptation of treated animals to chemical Z  
22 exposure by 13 weeks (decreased numbers and size of stones per animal, decreased severity of  
23 hyperplasia). Tumors were observed only at doses at which key events were observed.

24 Additional bioassay data provide support for the association of tumors in rats with the key  
25 events in rats and the absence of both tumors and similar key events in other species treated with  
26 chemical Z. Treatment of rats in a three-generation reproduction study at high dose levels  
27 (>20,000 ppm in the diet) led to formation of lesions in the urinary tract of males and females.  
28 When administered to dogs at dose levels up to 40,000 ppm in the diet for up to 2 years, the  
29 chemical produced minimal toxic effects overall, no effects on the urinary tract, and no tumors.  
30 Chemical Z produced no effects in mice when administered up to a dose level of 20,000/30,000  
31 ppm in the diet for 2 years.

32 Observations with chemical Z are in keeping with those observed in many other  
33 experimental settings. Stones, regardless of their chemical makeup, are irritating to the rodent  
34 bladder, causing irritation, hyperplasia, and eventually neoplasia.

1           There are some uncertainties regarding the role of certain findings following chemical Z  
2 administration. Generally, an increase in urinary pH is associated with the precipitation of calcium  
3 and phosphorus-containing stones in rats. However, stones are formed in the presence of a low  
4 urinary pH in rats administered chemical Z. It is also unclear whether or not the acidic  
5 environment of the urine (most likely a consequence of the conversion of the ethyl moiety to  
6 carbon dioxide in the blood) contributes to or enhances any effects noted in bladder tissue in rats.  
7 There was a paucity of stones in high-dose animals at termination of the 2-year study but a higher  
8 incidence of bladder tumors, which suggests that bladder stones may not be the causative factor  
9 involved in bladder tumor formation. Other considerations discount this presumption. First, a  
10 number of the high-dose animals showed hydronephrosis or dilation of the ureters, presumptive  
11 indications of past urinary tract obstruction. Second, the 13-week study provided evidence that  
12 bladder calculi develop rapidly (within 2 weeks), but then decreased in frequency and size. The  
13 decrease in size and number of bladder calculi was accompanied by a decrease in severity of  
14 bladder hyperplasia in animals treated with 30,000 ppm of chemical Z. Third, it is recognized that  
15 a constant ppm of an agent in the diet results in a reduction in dose per unit body weight as an  
16 animal grows. Finally, the increased urinary volume or decreased urinary pH may have led to a  
17 dissolution of stones over time.

18           The absence of bladder stones and urothelial toxicity following administration of the major  
19 metabolite, monosodium phosphite, is puzzling, as one might expect administration to rats would  
20 lead to similar bladder effects as with chemical Z. However, the metabolite when administered to  
21 rats, leads to an increase in blood levels of phosphorus but does not alter urinary volume or pH as  
22 would be expected with an increase in sodium consumption. Considering the high dose-level of  
23 metabolite administered to rats (32,000 ppm), it is unlikely an additional bioassay using higher  
24 dose-levels would provide useful information.

#### 25 26 **D.2.2.7. Other Modes of Action**

27           Chemical Z is not mutagenic in short-term tests and it does not have a structure  
28 suggesting biological reactivity. No other modes of action, apart from that postulated, are in  
29 evidence. The fact that bladder tumors were the sole tumors seen in rats and that no other species  
30 showed tumors or other toxicities like those in the rat make it less likely that the agent has another  
31 generalized mode of action.

#### 32 33 **D.2.2.8. Conclusion**

1           The available bioassay data on chemical Z are sufficient to support the postulated mode of  
2 action that the chemical, which lacks mutagenic potential, leads to bladder tumor formation in  
3 male rats through a sequence of key events involving perturbations in urinary physiology,  
4 especially increased calcium concentration, calculus formation, urothelial irritation, hyperplasia,  
5 and neoplasia.

### 7 **D.2.3. RELEVANCE OF THE MODE OF ACTION TO HUMANS**

8  
9           Bacterial infection, urinary stones or a combination of the two may be risk factors for  
10 human urinary tract cancer (Burin et al., 1995; Davis et al., 1984; Gonzalez et al., 1991; Kawai et  
11 al., 1994; Hiatt et al., 1982). Infection of the bladder with *Schistosoma haematobium* leads to  
12 bladder tumors, and part of its action may be associated with stone formation (IARC, 1995). A  
13 significant relationship has also been shown between spinal cord injury and bladder cancer;  
14 chronic infection and stones are found in individuals so affected (Bickel et al., 1991; Broecker et  
15 al., 1981; Dolin et al., 1994; El-Marsi and Fellows, 1981; Stonehill et al., 1996). Case control  
16 epidemiologic studies (relative risks less than three) suggest associations between bladder cancer  
17 and urinary tract stones (Burin et al., 1995; Gonzalez et al. 1991). A large cohort study supports  
18 the association shown between bladder stones and bladder cancer (Chow et al., 1991). Taken as a  
19 whole, stones may play some role (particularly, along with infection) in bladder cancer formation.  
20 Bladder cancer is a disease of advancing age, with about 2/3 of all cases occurring among persons  
21 aged 65 years or older (Hankey et al., 1993).

22  
23           Stones occur much more frequently in the upper urinary tract than in the bladder of  
24 humans (about 10% of urinary stones are found in the bladder), presumably because the upright  
25 posture of humans predisposes them to expelling stones through the urethra once a stone passes  
26 from the kidney to the bladder (Hiatt et al., 1982; Johnson et al. 1979; DeSesso, 1995). This  
27 characteristic, as well as the pain which accompanies such stones and leads to their surgical  
28 removal. Stones in the rodent bladder tend to be retained, because of their horizontal position.  
29 These findings suggest suggest that there may be a lower susceptibility of humans compared to  
30 rodents to the development of urinary tract tumors associated with stones.

31  
32           Precipitation of chemicals in the urinary tract with the formation of stones is a common  
33 finding, with about 12% of males and 5% of females having a history over a lifetime of at least  
34 one stone (Johnson et al., 1979). Compared to adults, urinary stone formation in children is an

1 uncommon occurrence except in individuals with a predisposing condition, such as, various inborn  
2 errors of metabolism (e.g., cystinuria) and congenital malformations (Gearhart et al., 1991). The  
3 prevalence of urinary stones in children is about 1 case per 20,000 per year (0.005%) (Khoory et  
4 al., 1998). Only about 5% of stones are initially manifest during the first 20 years of life (Johnson  
5 et al., 1979). Causes of urinary stones in children are remarkably similar to those of adults  
6 (Khoory et al., 1998; Stapleton, 1996). Like with adults, the urine of children varies in pH and  
7 osmolality, particularly in response to diet and physiologic stressors (e.g., exercise, heat). Urinary  
8 excretion of chemicals occurs throughout life, although there may be quantitative differences  
9 associated with a number of factors including disease states and nutritional status. Stones used to  
10 be more common in children in developed countries than they are now, largely due to  
11 malnutrition, which is still a problem in developing nations today (Trinchieri, 1996).

12  
13 Chemical Z is converted to metabolic derivatives through simple hydrolysis, a chemical  
14 conversion that does not depend on enzymatic activity. It is not plausible that differences in levels  
15 of enzymatic activity, such as detoxification via hepatic metabolism or metabolism in other tissues  
16 will alter, qualitatively, responses in population subgroups such as the aged, the infirm, or infants  
17 and children who may be exposed to Chemical Z.

18  
19 In summary, the potential human carcinogenic hazard of the chemical cannot be dismissed  
20 for Chemical Z. Chemical Z poses a carcinogenic hazard to humans only under conditions that  
21 would lead to the formation of bladder stones. It is reasonable to conclude that the mode of  
22 action involving stone formation for Chemical Z that has been developed for adult animals may be  
23 applicable to young animals and to children. Information suggests that effects in the young may  
24 not be any greater than in adults and, in fact, the young may be less susceptible unless there are  
25 rare extenuating factors.

### 26 27 28 29 **3.0. EXAMPLE 3: CHEMICAL D**

#### 30 31 **D.3.1. HAZARD DATA SUMMARY**

##### 32 **D.3.1.1. Data Availability**

33 Human data are inadequate to establish a basis for carcinogenicity. Experimental data  
34 include:



- 1 • Three chronic toxicity and carcinogenicity studies in rats and mice: an inhalation study,  
2 an oral dietary study, and an oral gavage study;
- 3 • Subchronic studies by the oral and inhalation routes in rats and mice;
- 4 • Inhalation developmental toxicity studies in rats and rabbits;
- 5 • An inhalation two-generation reproductive toxicity study in the rat;
- 6 • In vitro and in vivo genotoxicity studies;
- 7 • Toxicokinetic and metabolism studies; and
- 8 • Protein binding studies.

9

10 **D.3.1.2. Carcinogenicity/Chronic Toxicity**

11 Chemical D has been shown to cause increased tumor incidences in rats and mice. The  
12 tumor responses seem to be dependent on the tested animal species, sex, dose, and route of  
13 administration. Results of available chronic bioassays are summarized in Table D-6.

14

**Table D-6. Summary results of chronic bioassays**

Study/dose	F344 rats	B6C3F1 mice
<p><b>Oral gavage</b></p> <p><i>Rat study:</i> 0, 25, 50 mg/kg (5 d/wk for 2 yr)</p> <p><i>Mouse study:</i> 0, 50, 100 mg/kg (5 d/wk for 2 yr)</p>	<p><b>Forestomach:</b> Papillomas (males: 1/50, 2/50, 8/50; females: 0/50, 2/50, 3/50) Carcinomas (males only- 0/50, 0,50, 4/50) Basal cell and epithelial hyperplasia (dose-related; males and females)</p> <p><b>Liver:</b> Adenomas (males:1/50, 6/50, 7/50) Carcinomas (males: 0/50, 1/50, 3/50)</p>	<p><b>Forestomach:</b> Papillomas (males: 0/50, 1/50, 5/49; females: 0/50, 2/50, 7/50) Carcinomas (females only: 0/50,1/50, 4/50) Basal cell and epithelial hyperplasia (dose-related; males and females)</p> <p><b>Lung:</b> Adenomas (males: 2/50, 4/50, 8/49; females: 2/50, 4/50, 7/50) Carcinomas (males only: 0/52, 2/52, 4/49)</p>
<p><b>Oral dietary</b></p> <p><i>Rat study:</i> 0, 2.5, 12.5, 25 mg/kg/day for 2 yr</p> <p><i>Mouse study:</i> 0, 2.5. 25, 50 mg/kg/day for 2 yr</p>	<p><b>Forestomach:</b> Basal cell and epithelial hyperplasia (dose-related; males and females)</p> <p><b>Liver:</b> Adenomas (significant in males only: 2/50, 1/50, 6/50, 9/50)</p>	<p>No histopathologic changes</p>
<p><b>Inhalation</b></p> <p><i>Rat study:</i> 0, 5, 20, 60 ppm (6 hr/d 5 d/wk for 2yr)</p> <p><i>Mouse study:</i> 0, 5, 20, 60 ppm (6 hr/d 5 d/wk for 2yr)</p>	<p><b>Nasal cavity:</b> Epithelial hyperplasia (dose-related; males and females)</p>	<p><b>Nasal cavity:</b> Epithelial hyperplasia (dose-related; males and females)</p> <p><b>Lung:</b> Adenomas (males only: 2/50, 3/50, 6/50)</p>

- 1 • In rats, chemical D caused dose-related increases in liver tumors (males only) and  
2 forestomach tumors (both sexes) via oral gavage, but only liver tumors (males high  
3 dose only) by ingestion. No tumors were found in an inhalation study.
- 4 • In mice, chemical D caused dose-related increases in forestomach and lung tumors  
5 (both sexes) by oral gavage, but no tumors were observed in the oral dietary study.  
6 Chemical D only induced an increased incidence of lung tumors in male mice exposed  
7 to the high dose by inhalation.
- 8 • Nonneoplastic changes were observed in the forestomach of treated rats (gavage and  
9 dietary studies) and mice (gavage only) of both sexes. Chemical D also induced  
10 nonneoplastic changes in the nasal mucosa of rats and mice of both sexes via  
11 inhalation.

### 12 13 **D.3.1.3. Subchronic Toxicity**

14 Subchronic toxicity studies have been conducted in rats and mice by the oral and  
15 inhalation routes. The primary organs affected were the forestomach (rats) and the liver (mice) via  
16 oral exposure, and the nasal cavity and respiratory tract of both rodent species via inhalation.

#### 17 18 **D.3.1.3.1. Oral Studies**

19 Groups of F344 rats (10 animals of each sex per dose group) were administered 0, 5, 15,  
20 50, or 100 mg/kg/day of chemical D via their diets for 13 weeks. Dose-related decreases in body  
21 weight gain were observed in treated males and females. Basal cell hyperplasia and hyperkeratosis  
22 of the forestomach was found in males and females rats treated with chemical D at the three  
23 highest doses.

24 B6C3F1 mice (10 animals of each sex per dose group) were administered 0, 25, 50, 100,  
25 or 175 mg/kg/day via their diets for 13 weeks. Body weight gains of treated males and females  
26 were depressed in a dose-related manner compared to controls. Histologic changes were noted in  
27 the liver and were characterized as decreased hepatocyte size in all treatment groups. This  
28 observation was consistent with decreased hepatocellular cytoplasmic glycogen.

#### 29 30 **D.3.1.3.2. Inhalation Studies**

31 F344 rats (10 animals of each sex per dose group) were exposed to 0, 10, 30, 90, or 150  
32 ppm of chemical D for 6 hr/day, 5 days/week for 13 weeks. Treatment-related effects included  
33 depressed body weight gain (at 30 ppm and greater), degenerative changes in nasal olfactory

1 epithelium, and hyperplasia of respiratory epithelium in both males and females (at 90 and 150  
2 ppm).

3 B6C3F1 mice (10 animals of each sex per dose group) were exposed to 0, 10, 30, 90, or  
4 150 ppm of chemical D for 6 hr/day, 5 days/week for 13 weeks. Treatment-related effects  
5 included depressed body weight gain (at 30 ppm and greater), and histopathologic changes in the  
6 respiratory and olfactory epithelium of the nasal mucosa of both sexes exposed to 30, 90, and 150  
7 ppm).

#### 8 9 **D.3.1.4. Developmental and Reproductive Toxicity**

10 Pregnant F344 rats and New Zealand White rabbits were exposed to 0, 20, 60, or 120  
11 ppm of chemical D during gestation days 6-15 (rats) and 6-18 (rabbits). Maternal effects  
12 (decrease body weight gain) were observed in rabbits and rats, in all treatment groups. A slight  
13 but statistically significant increase in the incidence of delayed ossification of the vertebral centra  
14 was observed in rats exposed to the high dose level. No developmental effects were observed in  
15 the rabbit study.

16 Exposure of F344 rats to 0, 10, 30, or 90 ppm of chemical D for up to two generations  
17 did not induce any effects on reproductive parameters or neonatal growth and survival in any of  
18 the generations. Parental effects were limited to epithelial degeneration of the nasal mucosa of the  
19 adults rats exposed to 90 ppm.

#### 20 21 **D.3.1.5. Mutagenicity**

22 Chemical D was tested in many assays for gene mutation and chromosomal aberrations, as  
23 well as assays indicative of DNA damage, DNA strand breaks, and DNA alkylation. A  
24 heterogeneous database is found (a few in vitro positive responses and several negative results).  
25 It has been suggested that this heterogeneity is due to different studies that have used different  
26 test materials containing varying levels of impurities.

27 A few studies demonstrated that chemical D was weakly positive in the Ames bacterial  
28 assays in the presence of liver microsomes. Addition of cytosolic enzymes, presumably containing  
29 the detoxification enzyme glutathione transferase (GST), abolished mutagenic activity. Studies  
30 for chromosomal aberrations in vitro assays using mammalian cells have tended to be negative.  
31 There are a few positive results reported, but these are inconsistent with negative studies  
32 conducted in the same assay.

33 There are very few in vivo genotoxicity studies on chemical D. Chemical D has been  
34 found to be negative in a mouse micronucleus assay when tested up to oral doses of 175 mg/kg.

1 Chemical D has been reported to produce sister chromatid exchanges (SCEs) in mice. It should  
2 be noted that this assay has a low specificity for predicting carcinogenesis (i.e., a high rate of false  
3 positives compared to results of the rodent cancer bioassay). No dominant lethal effects (i.e.,  
4 germ cell genetic damage) were found in rats exposed to chemical D by inhalation up to 150 ppm.  
5

6 In vivo DNA binding studies were conducted in rats and mice. Rats were exposed acutely  
7 to chemical D at doses of 0, 10, 25, or 100 mg/kg. Mice were exposed acutely by inhalation to  
8 chemical D at 0, 30, and 60 ppm. No significant DNA binding (as measured by <sup>32</sup>P postlabeling  
9 assay) was seen in liver tissue from treated rats and lung tissue from exposed mice. In the mouse,  
10 DNA strand breakage was also studied by alkaline elution. Negative results were reported.  
11

#### 12 **D.3.1.6. Toxicokinetic and Metabolism Studies**

13 Toxicokinetic and metabolism studies in rats and mice have demonstrated that chemical D  
14 was rapidly absorbed by the oral and inhalation route. Blood half-lives were less than 10 minutes.  
15 Mercapturic acid conjugate of chemical D was the only major metabolite detected in the urine of  
16 treated rats and mice (about 80-90% of administered dose). Conjugated metabolites of chemical  
17 D epoxide were not detected in the urine of treated rats and mice.

18 Significant dose-related decreases in hepatic and lung tissues of GSH were observed in  
19 rats treated acutely with chemical D at oral doses of 0, 5, 20, 50, or 100 mg/kg, and in mice  
20 exposed acutely by inhalation to 0, 30, 60, or 150 ppm, respectively.  
21

#### 22 **D.3.1.7. Protein Binding Studies**

23 Chemical D was found to bind with tissue proteins in the forestomach and liver of rats  
24 treated acutely with oral doses 10, 50, and 100 mg/kg. Chemical D binding to tissue proteins was  
25 also found in the lung of mice exposed via acute inhalation at 30, 60, or 100 ppm.  
26

### 27 **D.3.2. MODE-OF-ACTION ANALYSIS**

#### 28 **D.3.2.1. Summary Description of Postulated Mode of Action**

29 It is postulated that chemical D causes tumors in rats and mice only when it is  
30 administered at high doses and/or by bolus administration that overwhelms the detoxifying  
31 mechanisms. The tumorigenic responses also appear to be closely associated with tissue toxicity  
32 (e.g., rat and mouse forestomach) and high background spontaneous tumors (e.g., mouse lung, rat  
33 liver). These observations, coupled with the lack of significant in vivo mutagenic activity, lead to  
34 the postulation that chemical D-induced tumorigenicity is likely to be operated by a nonmutagenic

1 mode of action, and appears to be secondary to toxicity and reparative cell proliferation. At high  
2 doses, a mutagenic mode of action may also be involved.

3  
4 It is postulated that once absorbed, chemical D is biotransformed spontaneously or by  
5 microsomal mixed functional oxidases (MFO) to an epoxide derivative that can react directly with  
6 DNA. Both parent chemical D and the epoxide derivative are rapidly conjugated with glutathione  
7 (GSH), which then can be excreted in the urine, mainly as the mercapturic acid conjugate of  
8 chemical D. Under normal physiologic conditions, i.e., at nonsaturating doses, chemical D is  
9 effectively detoxified as glutathione conjugate, and epoxidation does not take place in any great  
10 extent. At high doses, chemical D is expected to react chemically with thiols in proteins, causing  
11 tissue toxicity (forestomach), depleting tissue GSH, and causing proliferation of high background  
12 spontaneous foci of altered cells (rat liver and mouse lung) leading to tumorigenesis. As less GSH  
13 is available for detoxifying chemical D, more chemical D is metabolized to the mutagenic epoxide  
14 derivative, which may play a role in the carcinogenic process.

#### 15 16 **D.3.2.2. Key Events**

##### 17 **D.3.2.2.1. *Metabolism***

18 It is hypothesized that epoxidation of chemical D does not take place to any great extent  
19 since conjugated metabolite(s) of chemical D epoxide have not been detected in the urine of  
20 treated rats and mice. This finding was based only on acute exposure to chemical D. The  
21 metabolic profile of chemical D might differ under repeated exposures, particularly because  
22 chemical D has been found to deplete tissue GSH. Additional in vitro and in vivo metabolism  
23 studies are needed to further elucidate the potential role of MFO and epoxidation of chemical D.

##### 24 25 **D.3.2.2.2. *Tissue Toxicity***

26 It is postulated that chemical D-induced tumorigenicity is secondary to toxicity. The only  
27 target organ that exhibits both toxicity and tumorigenicity is the forestomach of rats and mice.  
28 Liver and lung toxicities have not been observed in chronic studies, although they have been  
29 reported in subchronic studies at higher doses. On the other hand, nasal toxicity was observed in  
30 exposed rats and mice, but no tumors were found.

31 Furthermore, the data supporting the postulated mechanism(s) of chemical D-induced  
32 toxicity are limited. It is hypothesized to be mediated by chemical D binding to tissue proteins.  
33 The only available information is the finding from acute oral and inhalation studies showing dose-  
34 related chemical D binding to proteins of the liver and forestomach of rats, and lung of mice,

1 respectively. Additional studies are needed to investigate the potential toxicity of chemical D at  
2 the biochemical, molecular, cellular, and tissue levels.

#### 3 4 **D.3.2.2.3. Depletion of GSH**

5 The ability of chemical D to deplete tissue GSH has been demonstrated to take place only  
6 in the liver and forestomach of rats following acute ingestion and in the lung of mice via acute  
7 inhalation. Additional data are needed to examine the effects of chemical D on GSH levels in  
8 target organs as well as unaffected organs after repeated exposure.

#### 9 10 **D.3.2.2.4. Proliferation Activity**

11 There is no information to substantiate the postulate that chemical D promotes highly  
12 spontaneous rat liver or mouse lung altered cells. Cell proliferation and mutation spectra studies  
13 are needed to examine the proliferative potential of chemical D.

#### 14 15 16 **D.3.2.3. Strength, Consistency, Specificity of Association of Tumor Response With Key** 17 **Events**

18 As discussed above, the postulated key events have not been clearly established. Thus, it is  
19 difficult to determine how well these key events relate to the observed tumorigenic responses. In  
20 general, the relationship between toxic and carcinogenic effects of chemical D on the forestomach  
21 of rats and mice is relatively stronger and more consistent than its effects on the rat liver and the  
22 mouse lung.

#### 23 24 **D.3.2.3.1. Forestomach Tumors**

25 Subchronic studies and chronic studies in rats and mice demonstrate that the forestomach  
26 is the primary target by oral exposure to chemical D. The rat appears to be more susceptible to  
27 chemical D-induced forestomach toxicity than the mouse.

28 Dose-related neoplastic and nonneoplastic lesions of the forestomach were observed in  
29 treated rats and mice of both sexes when chemical D was administered by gavage. In contrast,  
30 only hyperplastic lesions of the forestomach were found in male and female rats following  
31 subchronic and chronic dietary exposures to chemical D. No histopathologic changes were  
32 observed in the forestomach of treated mice in the subchronic and chronic dietary studies.

#### 33 34 **D.3.2.3.2. Liver Tumors**

1           Chronic exposure of chemical D caused increased incidences of hepatic adenomas in male  
2 rats when administered in the diet and by gavage. However, nonneoplastic changes in the liver  
3 were not observed in male rats after chronic or subchronic oral exposure to chemical D.  
4

#### 5 **D.3.2.3.3. Lung Tumors**

6           Chemical D induced increased incidences of lung adenomas in exposed mice via chronic  
7 inhalation (males only) and oral gavage. Nonneoplastic changes in the lung of exposed mice were  
8 not reported in the chronic study.  
9

#### 10 **D.3.2.4. Dose-Response Relationships**

11           As discussed above, dose correlations were demonstrated for chemical D-induced toxicity  
12 and/or carcinogenicity in the various target tissues of treated rats and mice. Dose-related  
13 depletion of tissue GSH was demonstrated with chemical D. However, no dose-related data are  
14 available for other toxicokinetic and metabolic parameters (absorption, uptake, distribution,  
15 metabolism, clearance and excretion of chemical D and metabolites), in vivo DNA binding, and  
16 other key events (e.g., cytotoxicity, cell proliferation) that are postulated to be involved in the  
17 tumorigenic process.  
18

#### 19 **D.3.2.5. Temporal Association**

20           While there are limited data indicating an association between chemical D-induced  
21 carcinogenicity and related toxicity (mostly for the forestomach), there are no data to discern the  
22 temporal association of these effects. Moreover, no data are available to establish the sequence of  
23 key events at the biochemical, molecular, or cellular levels that might mediate the tumorigenic  
24 responses.  
25

#### 26 **D.3.2.6. Biological Plausibility and Coherence of the Database**

27           The postulated mode of action for chemical D-induced forestomach tumors in rats and  
28 mice appears plausible and coherent with current knowledge. Many chemicals that are strong  
29 irritants have been shown to cause forestomach tumors via bolus administration. Similarly, the  
30 mouse lung appears to be more susceptible to the carcinogenic actions of many toxicants by  
31 inhalation. On the other hand, the observation that chemical D induces liver tumors only in the rat  
32 is not consistent with the general observation that the mouse is more susceptible than the rat to  
33 the carcinogenic effects of many halogenated hydrocarbons.  
34



1 **D.3.2.7. Other Modes of Action**

2 Chemical D bears a structural resemblance to several short-chain halogenated  
3 hydrocarbons that are also animal carcinogens. Chemical D is expected to generate a mutagenic  
4 epoxide. Chemical D has been shown to exhibit weak mutagenic responses in a number of in vitro  
5 bacterial assays in the presence of liver microsomes, although addition of cytosolic enzymes,  
6 presumably containing GST, has been shown to abolish the mutagenic activity. Several  
7 cytogenetic assays demonstrated that chemical D can cause chromosomal damage in mammalian  
8 cells. Thus, a mutagenic mode of action cannot be entirely ruled out for chemical D.  
9

10 **D.3.2.8. Conclusion**

11 There is little evidence to support a conclusion that chemical D-induced tumorigenicity in  
12 rats and mice is mediated by a nonlinear mode of action. The key events responsible for the  
13 tumorigenic responses are not well defined and a temporal association of these key events has not  
14 been fully investigated. Furthermore, it is still not possible to rule out a mutagenic mode of action  
15 by chemical D. Additional data on the chemical interactions of chemical D with macromolecules,  
16 and the nature of cytotoxic insults in target tissues and their relationship to tumor formation are  
17 needed.

**APPENDIX E. NONLINEAR DOSE-RESPONSE:  
MARGIN OF EXPOSURE ANALYSIS**

1

[To Be Developed]

1           **APPENDIX F. DOSE-RESPONSE ASSESSMENT FOR A CARCINOGEN POSING**  
2                           **HIGHER RISKS AFTER CHILDHOOD EXPOSURE**

3  
4  
5  
6   **a. Introduction**

7           Compound K is a carcinogenic to humans by all exposure routes. This conclusion is based  
8 on: (1) consistent epidemiologic evidence of a causal association between occupational exposure  
9 and the development of angiosarcoma, an extremely rare tumor; (2) suggestive epidemiological  
10 evidence that cancers of the brain, lung, and lymphopoietic system are associated with exposure;  
11 (3) consistent evidence of carcinogenicity in rats, mice, and hamsters via the oral and inhalation  
12 routes; (4) mutagenicity and DNA adduct formation by compound K and its metabolites in  
13 numerous *in vivo* and *in vitro* test systems; and (5) efficient absorption via all routes of exposure  
14 tested, followed by rapid distribution throughout the body.

15           Carcinogenicity involves genetic toxicity and is understood in some detail. Compound K  
16 is metabolized to a reactive metabolite, probably an epoxide, which is believed to be the ultimate  
17 carcinogenic metabolite. The reactive metabolite then binds to DNA, forming DNA adducts that,  
18 if not repaired, ultimately lead to mutations and tumor formation. Therefore, a linear  
19 extrapolation was used in the dose-response assessment. Because of uncertainty regarding  
20 exposure levels in the occupationally exposed cohorts, an inhalation unit risk of  $2 \times 10^{-6}$  per  $\mu\text{g}/\text{m}^3$   
21 was based on chronic inhalation studies in rats (not presented here).

22           Evidence has also been reported indicating increased sensitivity to early-life exposure.  
23 This case study shows how to use such evidence in a quantitative risk assessment. To focus on  
24 early-life exposures, the hazard assessment and dose-response assessment for chronic exposure  
25 (including derivation of the inhalation unit risk of  $2 \times 10^{-6}$  per  $\mu\text{g}/\text{m}^3$ ) are not presented here.  
26

27   **b. Dose-response data for early-life exposure**

28           A dose-rate study compared responses to different dosing regimens, in which rats inhaled  
29 compound K for 100 hours, starting at 13 weeks of age or 1 day of age (see table F-1). No effect  
30 was observed for 100-hr exposures starting at 13 weeks, but 100-hr exposure starting at 1 day  
31 had a clear carcinogenic effect, causing both angiosarcomas and hepatomas.

32           Tumor incidences in the newborn rats were also compared with rats inhaling compound K  
33 for 52 weeks starting later in life (at 13 weeks) (see table F-2). Angiosarcoma incidence was  
34 comparable from 52-week exposure starting at 13 weeks and 5-week exposure starting at 1 day.

1 Hepatoma incidence, however, was high after newborn exposure but virtually absent after chronic  
2 exposure starting later in life.

3 These data illustrate two phenomena that indicate higher cancer risks from childhood  
4 exposure: (1) high incidence of a tumor (angiosarcomas) also caused by adult exposure, and  
5 (2) occurrence of another tumor (hepatomas) not associated with adult exposure. The data  
6 suggest that risks from short-term, early-life exposure may not be reversible even in the absence  
7 of further exposure. The data do not, however, help us understand why early-life exposure poses  
8 greater risks. It could be that the metabolized dose is higher in newborns than in adults (either  
9 through more efficient metabolism, slower elimination, or a higher saturation point), alternatively,  
10 metabolized doses could be comparable in newborns and adults, but newborns could be  
11 biologically more sensitive to the same dose. Without understanding the mode of action early in  
12 life, we can nonetheless use these data to estimate the higher cancer risks caused by early-life  
13 exposure.

### 14 **c. Dose conversion**

15 Extensive pharmacokinetic studies show that the carcinogenic effects are caused by a  
16 metabolite and that metabolism becomes saturated below the tested doses. A PBPK model was  
17 fitted and validated (using independent data) to convert the experimental inhaled concentrations  
18 to equivalent human concentrations (see table F-3). This involved two steps: (1) convert  
19 experimental concentrations in air (ppm) to tissue concentrations in rat liver (mg metabolite per  
20 L liver), and (2) convert these tissue concentrations to equivalent human concentrations in air  
21 (ppm or mg/m<sup>3</sup>). The inhalation unit risk for chronic adult exposure was derived using doses  
22 from this model.

23 Although the PBPK model was fitted using data on mature rats and adult human males,  
24 dose estimates from this model were also used for dose-response modeling of tumors from early-  
25 life exposure. Similarly, although liver tissue concentrations were used as the dose metric in the  
26 PBPK model, this model was also used for angiosarcomas and angiomas at all sites (NTP  
27 guidance indicates that these tumors should be combined). Although the ideal would be to have  
28 pharmacokinetic information on various tissue concentrations in children, these studies have not  
29 been conducted. The lack of this information introduces some uncertainty into the results. Use of  
30 the PBPK model reflects a conscious decision that a credible dose-response model would be  
31 based on saturable metabolism and not on administered concentrations alone.

32 Although it is standard practice to calculate lifetime average daily doses for carcinogens  
33 (U.S. EPA, 1992), a different approach may be appropriate when considering effects of childhood  
34

1 exposures if children are more sensitive than adults. Specifically, it may not be appropriate to  
2 average childhood exposures over a full lifetime, since that implies that childhood exposure is  
3 equivalent to full-life exposure at a lower rate. Consequently, the dose estimates from the PBPK  
4 model are not averaged over a lifetime. Instead, the average dose during the early-life period (in  
5 this experiment, 5 weeks) is used. That is, the administered concentration is reduced to reflect  
6 intermittent exposure of 4 hr/d, 5 d/wk, but there is no further reduction by the ratio of the early-  
7 life period (5 wk) to a lifetime. This childhood exposure estimate is applied to the childhood-  
8 specific unit risk estimate calculated below. (If a unit risk estimate could not be calculated from  
9 the early-life experiments and the adult unit risk estimate were used instead, the adult unit risk  
10 would be adjusted for children as discussed in section 3.5.2.)

#### 11 12 **d. Analysis in the range of observation**

13 In the range of observation, incidences of angiosarcomas or hepatomas (from table F-1)  
14 are modeled separately as functions of equivalent human concentration based on metabolized dose  
15 (from table F-3) using a quantal polynomial model of the form

$$16 \quad p(d) = 1 - \exp(-q_1d - \dots - q_kd^k), \quad q_1, \dots, q_k \geq 0$$

17 The resulting *points of departure* are  $LEC_{10} = 36$  ppm for angiosarcomas and  $LEC_{10} = 33$  ppm for  
18 hepatomas. Converting these to units of  $\mu\text{g}/\text{m}^3$  (for this compound,  $1 \text{ ppm} = 2600 \mu\text{g}/\text{m}^3$ ) yields  
19  $LEC_{10} = 9.4 \times 10^4 \mu\text{g}/\text{m}^3$  for angiosarcomas and  $LEC_{10} = 8.6 \times 10^4 \mu\text{g}/\text{m}^3$  for hepatomas.

#### 20 21 **e. Extrapolation to lower doses**

22 The available mechanistic information, which indicates a reactive metabolite that binds to  
23 DNA and forms DNA adducts that ultimately lead to mutations and tumor formation, supports  
24 linear extrapolation to lower doses. Linear extrapolation follows the line from the point of  
25 departure to the origin (zero dose, zero excess risk). The slope of this line is  $0.10/LEC_{10}$ .  
26 Accordingly, the unit risk estimates are  $1.1 \times 10^{-6}$  per  $\mu\text{g}/\text{m}^3$  for angiosarcomas and  $1.2 \times 10^{-6}$  per  
27  $\mu\text{g}/\text{m}^3$  for hepatomas.

#### 28 29 **f. Combining unit risk estimates for multiple tumor types**

30 To obtain an estimate of overall cancer risk, the unit risks for the induced tumor types are  
31 combined. In the absence of individual animal pathology data, a neutral assumption is that the  
32 tumor types are independent. In this case, the induction of angiosarcomas but not hepatomas by  
33 later-life exposure suggests that these tumor types are caused by different modes of action and  
34 may be independent. Under an assumption of independence, the combined unit risk is

1 
$$1.1 \times 10^{-6} + 1.2 \times 10^{-6} - (1.1 \times 10^{-6} \times 1.2 \times 10^{-6}) = 2.3 \times 10^{-6} \text{ per } \mu\text{g}/\text{m}^3$$

2  
3 **g. Strengths and limitations of the data**

4 Although the data on newborn animals come from one rat strain over a limited range of  
5 inhalation concentrations and there are no epidemiologic studies of children exposed to this  
6 compound, the animal results indicate a potential for an increased susceptibility to tumors if  
7 children are exposed. Another limitation is that individual animal data are not available to  
8 determine whether animals with angiosarcomas are more likely to have hepatomas. Without these  
9 data, an assumption of independence was made when combining unit risks across multiple tumor  
10 sites.

11 The conversion used in this assessment to obtain the human continuous exposure  
12 concentrations in ppm from the corresponding human dose metric in mg/L was a linear one. This  
13 conversion methods seems simplistic given the complexity of the human body. This conversion  
14 may be not be unreasonable, however, because this compound is rapidly and efficiently absorbed,  
15 converted to water-soluble metabolites, and excreted.

16  
17 **h. Application to less-than-lifetime exposure scenarios**

18 Two observations about the early-life studies have implications for how this assessment  
19 would be applied to less-than-lifetime exposure scenarios, particularly during childhood.

- 20 1. The exposure period in the early-life experiment (weeks 1-5) does not overlap that of  
21 the chronic experiments (weeks 14-65) used to estimate the inhalation unit risk for  
22 chronic adult exposure. Therefore, the full lifetime cancer risk can be approximated by  
23 adding risks from these nonoverlapping exposure periods.
- 24 2. Because the effects of early-life exposure are different from effects of later exposures, it  
25 would not be appropriate to prorate childhood exposures as if they were received at a  
26 proportionately lower rate over a full lifetime.

27 These observations imply that the potential for increased sensitivity to childhood exposure  
28 is not reflected in the unit risk estimated from later-life exposures. The following examples  
29 illustrate how to combine early-life and later-life unit risk estimates.

30  
31 **Example 1. Full lifetime exposure (birth through death) to 1  $\mu\text{g}/\text{m}^3$**

32 The total risk is made up of two components, an early-life risk and a later-life risk.

33 Risk from early-life exposure:  $(2.3 \times 10^{-6} \text{ per } \mu\text{g}/\text{m}^3) \times (1 \mu\text{g}/\text{m}^3) = 2.3 \times 10^{-6}$

34 Risk from later-life exposure:  $(2 \times 10^{-6} \text{ per } \mu\text{g}/\text{m}^3) \times (1 \mu\text{g}/\text{m}^3) = 2 \times 10^{-6}$

1 Total risk:  $4.3 \times 10^{-6}$

2

3 **Example 2. Exposure to  $2 \text{ ug/m}^3$  from ages 30-60**

4 Because exposure begins at age 30, there is no early-life component. The later-life  
5 component is prorated as a duration of 30 years over an assumed lifespan of 70 years.

6 Risk from early-life exposure: Not applicable

7 Risk from later-life exposure:  $(2 \times 10^{-6} \text{ per ug/m}^3) \times (2 \text{ ug/m}^3) \times (30/70) = 1.7 \times 10^{-6}$

8 Total risk:  $1.7 \times 10^{-6}$

9

10 **Example 3. Exposure to  $5 \text{ ug/m}^3$  from ages 0-10**

11 Here there is an early-life component that is not prorated. The later-life component is,  
12 however, prorated as 10 out of 70 years.

13 Risk from early-life exposure:  $(2.3 \times 10^{-6} \text{ per ug/m}^3) \times (5 \text{ ug/m}^3) = 1.2 \times 10^{-5}$

14 Risk from later-life exposure:  $(2 \times 10^{-6} \text{ per ug/m}^3) \times (5 \text{ ug/m}^3) \times (10/70) = 1.4 \times 10^{-6}$

15 Total risk:  $1.3 \times 10^{-5}$

1 Table F-1. Comparison of tumor incidences in male and female Sprague-Dawley rats from 100-hr inhalation  
 2 exposures to newborn and mature rats

Inhaled concentration (ppm)	Angiosarcomas and angiomas (all sites)			Liver hepatomas		
	Control <sup>a</sup>	6000 ppm	10,000 ppm	Control <sup>a</sup>	6000 ppm	10,000 ppm
4 hr/d, 5 d/wk, 5 wk, starting at age 13 wk	1/277	3/120	2/118	0/277	0/120	1/118
1 hr/d, 4 d/wk, 25 wk, starting at age 13 wk	1/277	5/118	4/119	0/277	0/118	0/119
4 hr/d, 1 d/wk, 25 wk, starting at age 13 wk	1/277	4/120	4/119	0/277	2/120	0/119
4 hr/d, 5 d/wk, 5 wk, starting at age 1 day	1/277	20/42	18/44	0/277	20/42	20/44
<sup>a</sup> One control group served for all exposure patterns						



1 Table F-2. Comparison of tumor incidences in male and female Sprague-Dawley rats from 5-wk newborn  
 2 exposure and 52-wk later-life exposure

Inhaled concentration (ppm)	Angiosarcomas and angiomas (all sites)			Liver hepatomas		
	Control	6000 ppm	10,000 ppm	Control	6000 ppm	10,000 ppm
4 hr/d, 5 d/wk, 52 wk, starting at age 13 wk	2/58	22/59	13/60	0/58	1/59	1/60
4 hr/d, 5 d/wk, 5 wk, starting at age 1 day <sup>a</sup>	1/277	20/42	18/44	0/277	20/42	20/44
<sup>a</sup> Repeated from table F-1						

1  
2  
3  
4  
5

Table F-3. Results of PBPK modeling			
Inhaled concentration (ppm)	Control	6000 ppm	10,000 ppm
Internal dose of metabolite (mg metabolite / L liver)	0	395	404
Equivalent continuous human inhaled concentration (ppm)	0	251	257

**APPENDIX G. RESPONSE TO COMMENTS ON  
OTHER SCIENCE ISSUES**

1

[To Be Developed]