HARMONIZATION OF APPROACHES TO THE ASSESSMENT OF RISK FROM EXPOSURE TO CHEMICALS

International Programme on Chemical Safety
Harmonization Project
Exposure Assessment Planning Workgroup
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EXPOSURE TERMINOLOGY

This glossary of exposure assessment terminology is intended to help facilitate communication and consistency of language used in the exposure sciences. The glossary was developed under the auspices of the International Programme on Chemical Safety (IPCS) as part of its Harmonization Project. The terminology project began in September 1999 as one of a series of planned projects to harmonize approaches and issues in risk assessment.

A terminology workgroup was assembled. Our goal has been to harmonize usage within a consistent exposure assessment framework. After an in-depth review of 57 glossaries of terms used in risk assessment, the terms presented here were selected because they describe fundamental concepts in exposure assessment and are, in most instances, in common use. In general, definitions are based on a review and refinement of the definitions in the 57 glossaries considered. Where fundamentally different definitions existed for a particular term, the definition most commonly used in exposure science was selected and, if necessary, refined. Although we recommend a single definition for each term, which is consistent with the goal of harmonizing usage, we recognize that other definitions have been used for some of these terms.

The glossary was submitted for review to the IPCS Harmonization Project Steering Committee, the Harmonization Project Exposure Planning Work Group, and to selected reviewers in the organizations of the terminology workgroup members (Tier 1 review). A revised glossary and a disposition of comments were completed on July 25, 2001. This version of the glossary was sent to selected outside experts for review (Tier 2 review). In addition, the glossary was presented in platform and poster sessions at the November 2001 annual meeting of the International Society of Exposure Analysis, and comments were solicited.

The framework of exposure and dose and related definitions presented in this glossary is based on those in Zartarian, VG, Ott, WR, Duan, N, 1997, “Feature article: A Quantitative Definition of Exposure and Related Concepts”, Journal of Exposure Analysis and Environmental Epidemiology, 7(4): 411-438 (Zartarian et al., 1997). Although definitions presented use the terms agent and target generally, the primary
focus of this glossary is the human as a target of exposure and a chemical as an agent of exposure. Some terms, such as stressor, are common to both human health and ecological assessment. Harmonizing terminology between human health and ecological assessment is important, but is outside the scope of this glossary. The intent of our definitions is that they would (1) build on previous definitions; (2) constitute a logically consistent framework (e.g., across routes of exposure); (3) be parsimonious; (4) be able to be expressed mathematically; (5) agree with common sense; and (6) be consistent with common usage (Zartarian et al., 1997).

Two of the fundamental terms in the exposure sciences that have caused confusion are exposure and dose. We define exposure as contact between an agent and a target, with contact taking place at an exposure surface over an exposure period. The existing environmental health literature contains many different definitions of exposure. Some are specific, some vague, or inconsistent with others. Our definitions build on a mathematical framework from the definition of exposure at a single point in space at a single instant in time. Exposure is commonly quantified as concentration integrated over time. In addition to this time-integrated exposure, we define time-averaged exposure, which can also be toxicologically important. The definitions allow us to mathematically describe spatially-integrated and spatially-averaged exposures (i.e. exposure mass and exposure loading, respectively) that are relevant to exposure measurement methods such as wipe samples. A dermal exposure measurement based on a skin wipe sample, expressed as a mass of residue per skin surface area, is an example of an exposure loading. The total mass on the wipe sample is the exposure mass.

Current methods aren’t always able to measure factors such as exposure concentration, exposure mass, and contact volume with complete accuracy. For example, the exposure concentration is calculated as the amount of agent collected in a personal air monitor (a surrogate for the exposure mass) divided by the volume of air sampled (a surrogate for the contact volume). In fact, the measured exposure concentration is not identical to the concentration inhaled. Variation in breathing rate throughout the monitoring period will affect the amount inhaled, and the personal air monitor may not retain 100% of the agent that is drawn into the air filter. Likewise for dermal exposure, the exposure mass and exposure loading that actually come into contact with the skin are usually only fractions of the amount removed from the skin by a wipe sample because only a thin layer of agent directly in contact with the skin is capable of being absorbed. However, wipe sampling methods remove all of the agent from the skin. These discrepancies reflect limitations in the measurement methods, rather than in the definitions, and should be noted as uncertainties in the exposure assessment.

With the definition of an exposure surface, the framework inherent in our glossary emphasizes the need for exposure assessors to specify where the contact between an agent and a target occurs, to help facilitate communication and clarify the difference between exposure and dose. We define dose as amount of agent that enters a target by crossing an exposure surface. If the exposure surface is an absorption barrier (e.g., exposure surface specified as a surface on the skin, lung, gut), the dose is an absorbed dose; otherwise (e.g., exposure surface specified as a conceptual surface over the nostrils
and open mouth), it is an intake dose. This concise definition simplifies and is consistent with the numerous dose-related terms used in exposure-related fields. Terms such as internal dose, bioavailable dose, delivered dose, applied dose, active dose, and biologically effective dose that refer to agent crossing an absorption barrier are consistent with our definition of an absorbed dose. Terms such as administered dose and potential dose, that refer to the amount of agent in contact with an exposure surface, are consistent with our definitions of either intake dose or exposure mass depending on where the exposure surface is specified. While it is recognized that the term dose is often used in a way that does not refer to the crossing of an exposure surface (e.g., fields of toxicology, pharmacology), it is being defined this way here to eliminate confusion between exposure mass and dose.

Another source of confusion, as noted in the comments, is use of the terms, acute exposure, chronic exposure, and subchronic exposure. One of the reasons for this confusion is that the terms themselves are not very precise. These modifiers are also used to refer to effects, and are used in more than one way. Some definitions of acute exposure refer only to the length of time of the exposure (e.g., less than 24 hours) while others also require an accompanying acute effect that is seen immediately or shortly after the exposure. Chronic and subchronic exposures are used to refer specifically to the number of days of exposure in standard laboratory toxicity studies. The terminology workgroup decided to retain the terms acute, chronic, and subchronic exposure, limiting the definitions to the timing of exposure without reference to effects, because the terms are still widely used and seem to be a source of some confusion. In an exposure assessment, more precise quantification of the exposure period is necessary.

After considering comments received during the Tier 1 and Tier 2 reviews, the workgroup identified four terms which were particularly difficult to define due to their relatively recent emergence as terms of art. These are aggregate exposure, aggregate dose, cumulative exposure, and cumulative dose. Although reviewers generally agreed that it would be useful to have these terms in the glossary, they were divided on the definitions. In studying the literature, the terminology workgroup found very few formal definitions of these terms. In most instances where the terms appear, “aggregate” and “cumulative” are used as adjectives to modify “exposure” or “dose” without further elaboration. Often, “aggregate” and “cumulative” seem to be used interchangeably, suggesting (1) exposures that are from multiple sources, received via multiple exposure pathways, or doses received through multiple routes; (2) exposures or doses which accumulate over time, often over a lifetime; or (3) exposures or doses from more than one chemical or stressor simultaneously or sequentially. The recent interest in "cumulative risk assessment” will soon demand that these terms be defined more precisely. The USEPA, in its Framework for Cumulative Risk Assessment (EPA/630/P-02/001A, 2002) uses “aggregate” as a term referring to the risks over time from multiple sources, pathways, and routes for a single chemical or stressor, reserving “cumulative” for assessments where (aggregate exposures or doses for) multiple chemicals or stressors are evaluated together. These definitions are based more on the contextual language of the 1996 Food Quality Protection Act than a study of how the terms are being used worldwide, so it remains to be seen whether these particular definitions will come into
general usage within the scientific community. At this time, we have chosen to postpone inclusion of these terms in the glossary, awaiting further developments in the field.

Case studies illustrating the application of the IPCS glossary definitions to the inhalation, ingestion, and dermal routes of exposure are attached to the glossary. The glossary and the compilation of exposure terms from 57 glossaries IPCS web site: http://www.who.int/pcs/index.htm

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GLOSSARY OF EXPOSURE TERMINOLOGY

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1-ABSORPTION BARRIER
Any exposure surface that may retard the rate of penetration of an agent into a target. Examples of absorption barriers are the skin, respiratory tract lining and gastrointestinal tract wall (cf. exposure surface).

2-ACTIVITY PATTERN DATA
Information on human activities used in exposure assessments. These may include a description of the activity, frequency of activity, duration spent performing the activity, and the microenvironment in which the activity occurs.

3-ACUTE EXPOSURE
A contact between an agent and a target occurring over a short time, generally less than a day. (Other terms, such as “short-term exposure” and “single dose,” are also used.)

4-AGENT
A chemical, biological, or physical entity that contacts a target.

5-BACKGROUND LEVEL
The amount of an agent in a medium (e.g., water, soil) that is not attributed to the source(s) under investigation in an exposure assessment. Background level(s) can be naturally occurring or the result of human activities. (Note: natural background is the concentration of an agent in a medium that occurs naturally or is not the result of human activities).

6-BIOAVAILABILITY
The rate and extent to which an agent can be absorbed by an organism and is available for metabolism or interaction with biologically significant receptors. Bioavailability involves both release from a medium (if present) and absorption by an organism.

7-BIOMARKER/BIOLOGICAL MARKER
Indicator of changes or events in biological systems. Biological markers of exposure refer to cellular, biochemical, analytical, or molecular measures that are obtained from biological media such as tissues, cells, or fluids and are indicative of exposure to an agent.
8-BOUNDING ESTIMATE
An estimate of exposure, dose, or risk that is higher than that incurred by the person with the highest exposure, dose, or risk in the population being assessed. Bounding estimates are useful in developing statements that exposures, doses, or risks are "not greater than" the estimated value.

9-CHRONIC EXPOSURE
A continuous or intermittent long-term contact between an agent and a target. (Other terms, such as “long-term exposure,” are also used.)

10-CONTACT VOLUME
A volume containing the mass of agent that contacts the exposure surface.

11-DOSE
The amount of agent that enters a target after crossing an exposure surface. If the exposure surface is an absorption barrier, the dose is an absorbed dose/uptake dose (see uptake); otherwise it is an intake dose (see intake). (See introductory comments).

12-DOSE RATE
Dose per unit time.

13-EXPOSURE
Contact between an agent and a target. Contact takes place at an exposure surface over an exposure period.

14-EXPOSURE ASSESSMENT
The process of estimating or measuring the magnitude, frequency and duration of exposure to an agent, along with the number and characteristics of the population exposed. Ideally, it describes the sources, pathways, routes, and the uncertainties in the assessment.

15-EXPOSURE CONCENTRATION
The exposure mass divided by the contact volume or the exposure mass divided by the mass of contact volume depending on the medium.

16-EXPOSURE DURATION
The length of time over which continuous or intermittent contacts occur between an agent and a target. For example, if an individual is in contact with an agent for 10 minutes a day, for 300 days over a one year time period, the exposure duration is one year.

17-EXPOSURE EVENT
The occurrence of continuous contact between an agent and a target.
18- EXPOSURE FREQUENCY
The number of exposure events in an exposure duration.

19-EXPOSURE LOADING:
The exposure mass divided by the exposure surface area. For example, a dermal exposure measurement based on a skin wipe sample, expressed as a mass of residue per skin surface area, is an exposure loading.

20-EXPOSURE MASS
The amount of agent present in the contact volume. For example, the total mass of residue collected with a skin wipe sample over the entire exposure surface is an exposure mass.

21-EXPOSURE MODEL
A conceptual or mathematical representation of the exposure process.

22-EXPOSURE PATHWAY
The course an agent takes from the source to the target.

23-EXPOSURE PERIOD
The time of continuous contact between an agent and a target.

24-EXPOSURE ROUTE
The way an agent enters a target after contact (e.g., by ingestion, inhalation, or dermal absorption).

25-EXPOSURE SCENARIO
A combination of facts, assumptions, and inferences that define a discrete situation where potential exposures may occur. These may include the source, the exposed population, the time frame of exposure, microenvironment(s), and activities. Scenarios are often created to aid exposure assessors in estimating exposure.

26-EXPOSURE SURFACE
A surface on a target where an agent is present. Examples of outer exposure surfaces include the exterior of an eyeball, the skin surface, and a conceptual surface over the nose and open mouth. Examples of inner exposure surfaces include the gastro-intestinal tract, the respiratory tract and the urinary tract lining. As an exposure surface gets smaller, the limit is an exposure point.
27-INTAKE
The process by which an agent crosses an outer exposure surface of a target without passing an absorption barrier, i.e. through ingestion or inhalation (see dose).

28-MEDIUM
Material (e.g., air, water, soil, food, consumer products) surrounding or containing an agent.

29-MEDIUM INTAKE RATE
The rate at which the medium crosses the outer exposure surface of a target, during ingestion or inhalation.

30-MICROENVIRONMENT
Surroundings that can be treated as homogeneous or well characterized in the concentrations of an agent (e.g., home, office, automobile, kitchen, store). This term is generally used for estimating inhalation exposures.

31-PICA
A behaviour characterized by deliberate ingestion of non-nutritive substances such as soil.

32-SOURCE
The origin of an agent for the purposes of an exposure assessment.

33-STRESSOR
Any entity, stimulus, or condition that can modulate normal functions of the organism or induce an adverse response (e.g., agent, lack of food, drought).

34-SUBCHRONIC EXPOSURE
A contact between an agent and a target of intermediate duration between acute and chronic. (Other terms, such as “less-than-lifetime exposure” are also used.)

35-TARGET
Any biological entity that receives an exposure or a dose (e.g., a human, human population or a human organ).

36-TIME-AVERAGED EXPOSURE
The time-integrated exposure divided by the exposure duration. An example is the daily average exposure of an individual to carbon monoxide. (Also called time-weighted average exposure.)
37-TIME-INTEGRATED EXPOSURE
The integral of instantaneous exposures over the exposure duration. An example is the area under a daily time profile of personal air monitor readings, with units of concentration multiplied by time.

38-TIME PROFILE
A continuous record of instantaneous values over a time period (e.g., exposure, dose, medium intake rate).

39-UPTAKE (ABSORPTION)
The process by which an agent crosses an absorption barrier (see dose).
EXPOSURE ROUTE-SPECIFIC CASE STUDIES ILLUSTRATING THE DEFINITIONS IN THE IPCS EXPOSURE TERMINOLOGY GLOSSARY

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The following examples are intended to illustrate the application of the IPCS glossary definitions and to show that these definitions are self-consistent across agents, targets, and exposure routes. This discussion is intended to clarify important concepts that previously have been treated inconsistently in the literature. The three case studies below are based on those published in Zartarian et al., 1997; however, they have been modified and expanded to reflect the IPCS glossary definitions. IPCS glossary terms are italicized when first used.

INHALATION EXPOSURE OF A PERSON TO CARBON MONOXIDE

Because most studies in the exposure assessment field to date have focused on human exposure to air pollutants, our first example looks at carbon monoxide (CO) exposure. In this example, inhalation exposure refers to contact between an air pollutant and a human prior to inhalation. The exposure route is inhalation; the agent (also a stressor) of interest is carbon monoxide; the target is a man; the medium is air; and the exposure surface is specified as a locus of points over the entrance to the mouth and nose, (shown as S1 in Figure 1). Theoretically, the exposure concentration is the average of the air concentration at the entrance to the mouth and nose.
concentrations at each point on the exposure surface. Practical necessity dictates that in actual field studies, the air in the vicinity of a person’s nose is implicitly assumed to be well-mixed, and a measured exposure concentration (e.g., 20 ppm) is assumed to be the exposure at the person’s nose (assuming that the measurement was in close proximity to the person). The contact volume is the theoretical volume of air available for inhalation in the exposure period of interest. The volume of air inhaled during the exposure period is a surrogate for the contact volume. Often a personal air monitor is used to estimate the exposure concentration of the agent in the contact volume.

Figure 2 illustrates an actual diurnal carbon monoxide profile of a 58 year-old man who worked in a public garage within 30 yards (~27 meters) of a street (see Zartarian et al., 1997). This exposure time profile was plotted for one of the 450 Denver participants in the 1982-1983 Denver-Washington, DC, carbon monoxide personal exposure monitoring field study. Each point on the exposure time profile represents the instantaneous inhalation exposure to carbon monoxide and is measured by a personal exposure monitor. The man’s peak exposure on the study day can be seen as approximately 34 ppm CO. The exposure period that contains the peak exposure appears to be approximately 20 minutes. This high exposure is probably due to his proximity to emissions from motor vehicle tailpipes on repeated occasions during the day. The tailpipes in this exposure scenario are the sources. The physical course the CO moves from the tailpipe to the man’s exposure surface is the exposure pathway. However, the man could also be exposed to a background level of CO. The time profile in Figure 2 depicts the man’s acute exposure, since the exposure duration is one day. Each spike on the profile
represents an exposure event, and the exposure frequency appears to be 20 events per day. This exposure profile could have been estimated with an exposure model that combines the man’s activity pattern data with measured or predicted concentrations in the microenvironments in which he spent time. If longer exposure durations are of interest, such a study could be repeated for several days (subchronic exposure) or several years (chronic exposure).

The area under the profile shown in Figure 2 is the time-integrated exposure. The time-averaged exposure over the entire day can be found by dividing the area under the curve by the total time the monitor was worn, i.e., a 24 hour exposure duration. Also shown in the figure is the “moving average” 8-hour exposure, which is computed from the CO exposure profile by taking the average of the measured concentration over the previous 8 hours every hour and every time a new activity begins. The numbers at the top of the exposure profile are activity codes describing the person’s microenvironments in his activity pattern data based on the diary that each person maintained. Finally, the biomarker, blood carboxyhemoglobin (COHb), may be computed from the measured CO exposure profile using a pharmacokinetic model that provides an estimate of the absorbed dose of CO, which agrees fairly well with a blood-breath measurement of this respondent later in the day (see small dot marked “Observed COHb” on figure, which was derived from a breath measurement). A dose rate could be computed from this profile by computing the dose per unit time.

A dose can be calculated for this exposure scenario as the product of the time-averaged exposure, the exposure duration, and the average medium intake rate over the exposure duration. The medium intake rate is equivalent to the man’s inhalation rate, i.e., the volume of air breathed per unit time. This dose is the mass of carbon monoxide that crosses the theoretical surface at the entrance to the mouth and nose during the exposure duration. This exposure scenario is an example of intake, because it only estimates the amount of agent crossing the exposure surface and does not consider the amount that crosses an absorption barrier and is absorbed into the systemic circulation. An intake dose time profile could be obtained by multiplying each point on the exposure profile by the inhalation rate to obtain the various time formulations of inhalation dose (i.e., peak, maximum, temporally-integrated, temporally-averaged).

If we had defined an internal exposure surface such as the epithelial lining of the lung (S2 in Figure 1) and had defined the target to be the lung, then the definitions are still self-consistent; the dose process in this case would be uptake (absorption) rather than intake, because the agent would pass through an absorption barrier before entering the target. The specification of the exposure surface depends on the question to be answered.
DERMAL EXPOSURE TO DDT

This second example focuses on a dermal exposure scenario; the exposure route is dermal absorption. Figure 3 illustrates a dermal exposure time profile, with the person’s relevant activity pattern data indicated (including information about contacts with different media and surfaces). One can compute the time-integrated exposure and time-averaged exposure using Figure 3 in a way similar to that described in the inhalation example. However, it is often helpful in the case illustrated in Figure 3 to plot the exposure loading, rather than the exposure concentration, on the y-axis, since concentrations at different points on the skin surface are for different media and therefore have different units.

Dermal exposure is the contact between an agent and the external skin surface (the exposure surface) of a target (e.g., a human) (Figure 4). A point on the skin surface is considered to be exposed if chemical mass is present in the contact volume containing the point. Dermal exposure can occur via skin contact with a chemical in different media. Figure 4 illustrates the exposure of an area of a hand, during one exposure event, to the pesticide DDT (the agent or stressor) carried in air, water, and soil media. Some points are exposed to DDT on aerosols, some to aqueous phase DDT, and some to DDT molecules in a soil matrix. The exposure surface was selected here for the purpose of illustration as a rectangular region on the stratum corneum surface, as shown. Instantaneous exposures at points on the exposure surface in Figure 4 vary spatially because different media are in contact with the skin surface. Current dermal exposure measurement devices, including skin patches, fluorescent tracers, and skin wipes, measure dermal exposure as exposure loading.

The contact volume for the dermal route is the volume above the skin surface in which the chemical is considered to be in contact with the skin. The thickness of the contact
volume ($\Delta z$ in Figure 4), can be estimated as the height above the skin within which any molecule has a high probability of intersecting the exposure surface during the exposure period. This height will vary as a function of the exposure period since the probability of a far-away molecule intersecting the exposure surface will increase with time if diffusion is in the direction toward the skin. Zartarian et al., 1997 presents an approach for estimating the thickness of the contact volume using several well-established theories of mass transfer and a range of contact times. The results yield estimates of contact volume thickness in air, water, and soil that agree reasonably well with typical measured film thicknesses. The contact volume concept, based on sound engineering models, allows us to discuss the theory behind what we measure in practice.

When the skin is immersed in a fluid medium such as water or air containing the agent (Figure 5), uptake (absorption) is usually estimated as a function of the exposure concentration, the area of the exposure surface (i.e., the immersed skin surface area, shown as S1 and S2 in Figure 5), and the exposure period using an empirical, chemical-specific permeability coefficient. The agent in the medium is assumed to be an infinite, well-mixed source. While a contact volume could be defined for this exposure scenario in the same way that it is defined for the dermal residue deposition scenario (i.e., the
volume above the skin surface in which any molecule has a high probability of contacting the skin surface), the contact volume is not needed to estimate uptake for this scenario.

Chemicals in media contacting the skin surface partition to the stratum corneum, the outermost layer of the skin, and then diffuse through the stratum corneum into the viable epidermis and dermis, then into general circulation in the body. Because the agent diffuses through an absorption barrier, the dose process is uptake (absorption) and dermal dose is classified as an absorbed dose. The stratum corneum provides the major barrier to chemical absorption in the skin, and thus is the dermal absorption barrier. Dermal dose is complex not only because there can be multiple carrier media on a given exposure boundary, but also because the dose membrane is composed of different media. Because chemicals migrate through the stratum corneum via diffusion, the absorbed dose rate under steady state conditions can be calculated using basic principles of diffusion.

**INGESTION EXPOSURE TO MANGANESE IN A VITAMIN PILL AND TO LYCOPENE IN TOMATOES**

One also can speak of exposure and dose to chemicals consumed in food and drinking water. In these types of exposure scenarios, the exposure route is ingestion. Although ingestion dose may be of greater interest than ingestion exposure, we provide the following unusual examples to illustrate that the definition of exposure is consistent across all exposure routes.

Suppose someone were interested in the total amount of manganese (Mn), the agent, entering the body when a person, the target, takes a vitamin pill containing 5 mg of Mn, a typical formulation for nonprescription multi-vitamin products. The contact volume in this case is the volume of the pill, i.e., 400 mm$^3$. If the analyst selects an exposure
surface directly in front of the mouth (Figure 1), the same theoretical surface used earlier to illustrate inhalation exposure, the oral exposure to Mn will be zero up until the instant that the tablet first touches the exposure surface. Exposure occurs for the second that it takes for the tablet to cross the exposure surface, and then drops to zero again. The exposure mass in this example is 5 mg, and the exposure concentration is $1.25 \times 10^7$ mg/m$^3$ (5 mg divided by the 400 mm$^3$ volume of the tablet). The exposure period is the one second that it takes for the pill to cross the exposure surface. The vitamin pill container in this example is the source, and the exposure pathway is the course the pill takes from the container to the person’s mouth. The vitamin pill is the medium here, and the medium intake rate is 400 mm$^3$ per second. Because the pill crosses an exposure surface that is not an absorption barrier, this is an example of intake, and the dose is an intake dose. The person’s oral intake dose from the tablet will be 5 mg, even though other parts of the person’s body may receive a different exposure and dose later. The pill’s external exposure surface is the locus of points over the mouth (similar to the external exposure surface in the inhalation case). Alternatively, an internal exposure surface could be defined as the epithelial lining of the gastrointestinal tract, and the Mn from the vitamin pill that crossed this epithelial absorption barrier would be an uptake dose.

A person who has difficulty swallowing solid pills might grind up the tablet and dissolve it in a glass of water. If the liquid in the glass is 200 ml, then the concentration of the tablet when diluted in water will be 5 mg/200 ml = 25,000 mg/m$^3$. If the person drinks the entire contents, the values on the person’s time profile of exposure concentrations would be zero as the glass moves toward the lips, followed by 25,000 mg/m$^3$ for several seconds (as it crosses the exposure surface), followed again by zero. Regardless of whether the tablet is eaten or dissolved in water and drunk, the same amount of Mn crosses the oral exposure surface, and the dose is 5 mg in both cases.

We could plot an exposure time profile as in the inhalation example. If the person takes a vitamin pill once a day every day for a year, then the exposure frequency is one exposure event per day, and the exposure duration is 1 year. The time-integrated exposure would be 25000 mg/m$^3$ * 1 sec * 365 and the time-averaged exposure would be 25000 mg/m$^3$ * 1 sec * 365/525,600 sec. The daily time profile would illustrate the person’s acute exposure; the 1 year time profile would illustrate the person’s chronic exposure. The person’s behaviors regarding consumption of vitamin pills would be the relevant activity pattern data for this example.

Additives, nutrients, and chemical residues in food items can be treated in a similar way. Consider the ingestion exposure to lycopene from consumption of a tomato. In this case, lycopene is the agent. The contact volume is the volume of the tomatoes consumed. Exposure occurs when the tomatoes cross the exposure surface in front of the mouth in the same way as it does in the vitamin pill example. As lycopene would be absorbed from the GI tract, one could define the exposure surface of interest as the epithelium of the GI tract, an absorption barrier. The concentration of lycopene at the surface of the GI tract could be considered as a function of time (or the integrated concentration over time) at any given point. This exposure would be similar to that in the example of dermal
exposure, rising from zero to a maximum, followed by a decline back to zero as a result of absorption or passage with other materials out of the GI tract via excretion.

It is impractical to measure the concentration of lycopene as it passes through the body and is metabolized or eliminated. Typically, the concentration of lycopene in consumed foods would be measured, and the intake of those foods would be combined with the measured concentrations in each food type to estimate exposure.

There are a number of techniques for estimating exposure to ingredients such as lycopene in a tomato product, additives such as a high intensity sweetener in a beverage, or contaminants such as methylmercury in fish. Market basket studies, and duplicate diet studies provide information concerning the level of the substance in foods. In the duplicate diet approach, for example, a second helping of all the food items a person eats at a given meal is prepared and submitted for laboratory analysis. Then the pollutant concentration in each food item or composites of several food items is measured, and the person’s intake dose is estimated by multiplying the pollutant concentration by the quantity of each food item that the person eats. This practical method for estimating dose from ingestion is useful in many applications, and it is consistent with the Zartarian et al., 1997 conceptual framework inherent in the IPCS glossary.