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Introduction to Dietary Reference Intakes

Dietary Reference Intakes (DRIs) comprise a set of nutrient-based reference values, each of which has special uses. The development of DRIs expands on the periodic reports, *Recommended Dietary Allowances*, which have been published since 1941 by the National Academy of Sciences and the *Recommended Nutrient Intakes* of Canada. This comprehensive effort is being undertaken by the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes of the Food and Nutrition Board, Institute of Medicine, National Academies, with the active involvement of Health Canada. See Appendix A for a description of the overall process and its origins.

WHAT ARE DIETARY REFERENCE INTAKES?

The reference values, collectively called the Dietary Reference Intakes (DRIs), include the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), and Tolerable Upper Intake Level (UL).

A requirement is defined as the lowest continuing intake level of a nutrient that will maintain a defined level of nutriture in an individual. The chosen criterion of nutritional adequacy is identified in each chapter; note that the criterion may differ for individuals at different life stages. Hence, particular attention is given throughout this report to the choice and justification of the criterion used to establish requirement values.

This approach differs somewhat from that used by the World Health Organization, Food and Agriculture Organization, and Inter-

national Atomic Energy Agency (WHO/FAO/IAEA) Expert Consultation on *Trace Elements in Human Nutrition and Health* (WHO, 1996). That publication uses the term *basal requirement* to indicate the level of intake needed to prevent pathologically relevant and clinically detectable signs of a dietary inadequacy. The term *normative requirement* indicates the level of intake sufficient to maintain a desirable body store or reserve. In developing RDAs and AIs, emphasis is placed instead on the reasons underlying the choice of the criterion of nutritional adequacy used to establish the requirement. They have not been designated as basal or normative.

Unless otherwise stated, all values given for EARs, RDAs, and AIs represent the quantity of the nutrient or food component to be supplied by foods from a diet similar to those consumed in Canada and the United States. If the food source of a nutrient is very different (as in diets of some ethnic groups) or if the source is supplements, adjustments may have to be made for differences in nutrient bioavailability. When this is an issue, it is discussed for the specific nutrient in the section “Special Considerations”.

RDAs and AIs are levels of intake recommended for individuals. They should reduce the risk of developing a condition that is associated with the nutrient in question and that has a negative functional outcome. The DRIs apply to the apparently healthy general population. Meeting the recommended intakes for the nutrients would not necessarily provide enough for individuals who are already malnourished, nor would they be adequate for certain disease states marked by increased nutritional requirements. Qualified medical and nutrition personnel must tailor recommendations for individuals who are known to have diseases that greatly increase nutritional requirements or who are at risk for developing adverse effects associated with higher intakes. Although the RDA or AI may serve as the basis for such guidance, qualified personnel should make necessary adaptations for specific situations

CATEGORIES OF DIETARY REFERENCE INTAKES

Each type of Dietary Reference Intake (DRI) refers to average daily nutrient intake of individuals over time. In most cases, the amount taken from day to day may vary substantially without ill effect.

Recommended Dietary Allowance

The *Recommended Dietary Allowance* (RDA) is the average daily dietary intake level that is sufficient to meet the nutrient require-

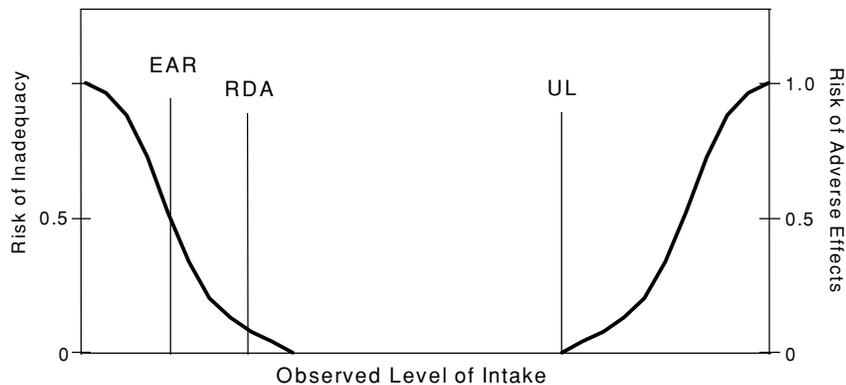


FIGURE 1-1 Dietary reference intakes. This figure shows that the Estimated Average Requirement (EAR) is the intake at which the risk of inadequacy is 0.5 (50 percent) to an individual. The Recommended Dietary Allowance (RDA) is the intake at which the risk of inadequacy is very small—only 0.02 to 0.03 (2 to 3 percent). The Adequate Intake (AI) does not bear a consistent relationship to the EAR or the RDA because it is set without being able to estimate the requirement. At intakes between the RDA and the Tolerable Upper Intake Level (UL), the risks of inadequacy and of excess are both close to 0. At intakes above the UL, the risk of adverse effects may increase.

ment of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group (see Figure 1-1). The RDA is intended to be used as a goal for daily intake by individuals. The process for setting the RDA is described below; it usually depends on being able to set an Estimated Average Requirement (EAR). That is, if an EAR cannot be set, no RDA will be set.

Estimated Average Requirement¹

The *Estimated Average Requirement* (EAR) is the daily intake value that is estimated to meet the requirement, as defined by the specified indicator or criterion of adequacy, in half of the apparently healthy individuals in a life stage or gender group (see Figure 1-1). A normal or symmetrical distribution (median and mean are simi-

¹ The definition of EAR implies a median as opposed to a mean, or average. The median and average would be the same if the distribution of requirements followed a symmetrical distribution and would diverge as a distribution became skewed.

lar) is usually assumed for nutrient requirements. At this level of intake, the other half of a specified group would not have its nutritional needs met. The general method used to set the EAR is the same for all the nutrients. The specific approaches, which are provided in Chapters 4 through 12, differ because of the different types of data available. For many of the nutrients, there are few direct data on the requirements of children. Thus, EARs and RDAs for children are based on extrapolations from adult values. The method is described in Chapter 2.

Method for Setting the RDA when Nutrient Requirements Are Normally Distributed

If the requirement for the nutrient is normally distributed, and the standard deviation (SD) of the EAR is available, the RDA is defined as equal to the EAR plus 2 SDs of the EAR:

$$\text{RDA} = \text{EAR} + 2 \text{SD}_{\text{EAR}}$$

If data about variability in requirements are insufficient to calculate an SD, a coefficient of variation (CV_{EAR}) of 10 percent will be ordinarily assumed and used to estimate the SD:

$$\text{CV}_{\text{EAR}} = \text{SD}_{\text{EAR}} / \text{EAR}$$

and

$$\text{SD} = (\text{EAR} \times \text{CV}_{\text{EAR}});$$

the resulting equation for the RDA is

$$\text{RDA} = \text{EAR} + 2 (0.1 \times \text{EAR})$$

or

$$\text{RDA} = 1.2 \times \text{EAR}.$$

The assumption of a 10 percent CV is based on extensive data on the variation in basal metabolic rate (FAO/WHO/UNA, 1985; Garby and Lammert, 1984), which contributes about two-thirds of the daily energy needs of many individuals residing in Canada and the United States (Elia, 1992) and on the similar CV of 12.5 percent estimated for the protein requirements in adults (FAO/WHO/

UNA, 1985). If data are not available for estimation of a standard deviation, then a CV of 10 percent is assumed depending on the information that is available.

Method for Setting the RDA when Nutrient Requirements Are Not Normally Distributed

When factorial modeling is used to estimate the distribution of requirements from the distributions of the individual components of requirement (e.g., losses, accretion), it is necessary to add the individual distributions. For normal component distributions, this is straightforward since the resultant distribution is also normal, with a mean that is the sum of component means and a variance (the square of the SD) that is the sum of the individual variances. The ninety-seven and one-half percentile is then estimated as the mean value plus two SDs.

If the requirement of a nutrient is not normally distributed but can be transformed to normality, its EAR and RDA can be estimated by transforming the data, calculating a fiftieth and a ninety-seventh and one-half percentile, and transforming these percentiles back into the original units. In this case, the difference between the EAR and the RDA cannot be used to obtain an estimate of the CV because skewing is usually present.

If normality cannot be assumed for all of the components of requirement, then Monte Carlo simulation is used for the summation of the components. This approach involves simulation of a large population of individuals (e.g., 100,000) each with his or her own requirement for a particular nutrient. To accomplish this, the component parts of nutrient needs (the factorial components) are treated as coming from independent random distributions.

Using iron as an example (see Chapter 9), for basal iron loss, a distribution of expected losses was generated. For each individual in the simulated population, a randomly selected iron loss value was drawn from that distribution of iron losses. This is done for each component of iron need and then these components were summed for each individual yielding the simulated iron needs. The total requirement is then calculated for each individual and the median and the ninety-seven and one-half percentile calculated directly.

Information about the distribution of values for the requirement components is modeled on the basis of known physiology. Monte Carlo approaches may be used in the simulation of the distribution of components; or, where large data sets exist for similar populations (such as growth rates in infants), estimates of relative variability

may be transferred to the component in the simulated population (Gentle, 1998). At each step, the goal is to achieve distribution values for the component that not only reflect known physiology or known direct observations, but also values that can be transformed into a distribution that can be modeled and used in selecting random members to contribute to the final requirement distribution. When the final distribution representing the convolution of components has been derived, then the median and ninety-seven and one-half percentile of the distribution can be directly estimated. It is recognized that in its simplest form, the Monte Carlo approach ignores possible correlation among components. In the case of iron, however, expected correlation is built into the modeling of the requirement where components are linked to a common variable, such as growth rate, so that not all sources of correlation are neglected.

Other Uses of the EAR

The EAR may also be used in the assessment of the intake of groups (IOM, 2000) or, together with an estimate of the variance of intake, be used in planning for the intake of groups (Beaton, 1994) (see Chapter 14).

Adequate Intake

If sufficient scientific evidence is not available to calculate an EAR, a reference intake called an *Adequate Intake* (AI) is provided instead of an RDA. The AI is a value based on experimentally derived intake levels or approximations of observed mean nutrient intakes by a group (or groups) of healthy people. In the judgment of the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, the AI for children and adults is expected to meet or exceed the amount needed to maintain a defined nutritional state or criterion of adequacy in essentially all members of a specific healthy population. Examples of defined nutritional states include normal growth, maintenance of normal circulating nutrient values, or other aspects of nutritional well-being or general health.

The AI is set when data are considered to be insufficient or inadequate to establish an EAR on which an RDA would be based. For example, for young infants for whom human milk is the recommended sole source of food for most nutrients for the first 4 to 6 months, the AI is based on the daily mean nutrient intake supplied by human milk for healthy, full-term infants who are exclusively fed human milk. For adults, the AI may be based on data from a single

experiment, on estimated dietary intakes in apparently healthy population groups (e.g., vitamin K, chromium, or manganese), or on a review of data from different approaches that considered alone do not permit a reasonably confident estimate of an EAR.

Similarities Between the AI and the RDA

Both the AI and RDA are to be used as a goal for individual intake. In general, the values are intended to cover the needs of nearly all persons in a life stage group. (For infants, the AI is the mean intake when infants in the age group are consuming human milk. Larger infants may have greater needs, which they meet by consuming more milk.) As with RDAs, AIs for children and adolescents may be extrapolated from adult values if no other usable data are available.

Differences Between the AI and the RDA

There is much less certainty about the AI value than about the RDA value. Because AIs depend on a greater degree of judgment than is applied in estimating the EAR and subsequently the RDA, the AI may deviate significantly from and be numerically higher than the RDA. For this reason, AIs must be used with greater care than is the case for RDAs. Also, the RDA is usually calculated from the EAR by using a formula that takes into account the expected variation in the requirement for the nutrient (see previous section, “Estimated Average Requirement”).

Tolerable Upper Intake Level

The *Tolerable Upper Intake Level* (UL) is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects for almost all individuals in the specified life stage group (see Figure 1-1). As intake increases above the UL, the potential risk of adverse effects may increase. The term *tolerable intake* was chosen to avoid implying a possible beneficial effect. Instead, the term is intended to connote a level of intake that can, with high probability, be tolerated biologically. The UL is not intended to be a recommended level of intake, and there is no established benefit for healthy individuals if they consume a nutrient in amounts exceeding the recommended intake (the RDA or AI).

The UL is based on an evaluation conducted by using the methodology for risk assessment of nutrients (see Chapter 3). The need

for setting ULs grew out of the increased fortification of foods with nutrients and the use of dietary supplements by more people and in larger doses. The UL applies to chronic daily use. As in the case of applying AIs, professionals should avoid very rigid application of ULs and first assess the characteristics of the individual and group of concern, such as source of nutrient, physiological state of the individual, length of sustained high intakes, and so forth.

For some nutrients such as vitamin K, arsenic, chromium, and silicon, data are not sufficient for developing a UL. This indicates the need for caution in consuming amounts greater than the recommended intakes; it does not mean that high intakes pose no risk of adverse effects.

The safety of routine, long-term intake above the UL is not well documented. Although members of the general population should be advised not to routinely exceed the UL, intake above the UL may be appropriate for investigation within well-controlled clinical trials. Clinical trials of doses above the UL should not be discouraged as long as subjects participating in these trials have signed informed consent documents regarding possible toxicity and as long as these trials employ appropriate safe monitoring of trial subjects.

Determination of Adequacy

In the derivation of the EAR or AI, close attention has been paid to the determination of the most appropriate indicators of adequacy. A key question is, Adequate for what? In many cases, a continuum of benefits may be ascribed to various levels of intake of the same nutrient. One criterion may be deemed the most appropriate to determine the risk that an individual will become deficient in the nutrient whereas another may relate to reducing the risk of chronic degenerative disease, such as diabetes mellitus or osteoporosis.

Each EAR and AI is described in terms of the selected criterion. The potential role of the nutrient in the reduction of disease risk was considered in developing the EARs. With the acquisition of additional data relating intake to chronic disease or disability, the choice of the criterion for setting the EAR may change.

PARAMETERS FOR DIETARY REFERENCE INTAKES

Life Stage Groups

The life stage groups described below were chosen by keeping in mind all the nutrients to be reviewed, not only those included in

this report. Additional subdivisions within these groups may be added in later reports. If data are too sparse to distinguish differences in requirements by life stage or gender group, the analysis may be presented for a larger grouping.

Infancy

Infancy covers the period from birth through 12 months of age and is divided into two 6-month intervals. The first 6-month interval was not subdivided further because intake is relatively constant during this time. That is, as infants grow they ingest more food; however, on a body weight basis their intake remains the same. During the second 6 months of life, growth velocity slows, and thus total daily nutrient needs on a body weight basis may be less than those during the first 6 months of life.

For a particular nutrient, the average intake by full-term infants who are born to healthy, well-nourished mothers and exclusively fed human milk has been adopted as the primary basis for deriving the Adequate Intake (AI) for most nutrients during the first 6 months of life. The value used is thus not an Estimated Average Requirement (EAR); the extent to which intake of human milk may result in exceeding the actual requirements of the infant is not known, and ethics of experimentation preclude testing the levels known to be potentially inadequate. Therefore, the AI is not an EAR in which only half of the group would be expected to have their needs met.

Using the infant fed human milk as a model is in keeping with the basis for estimating nutrient allowances of infants developed in the last Recommended Dietary Allowances (RDA) (NRC, 1989) and Recommended Nutrient Intakes (RNI) (Health Canada, 1990) reports. It also supports the recommendation that exclusive human milk feeding is the preferred method of feeding for normal full-term infants for the first 4 to 6 months of life. This recommendation has also been made by the Canadian Paediatric Society (Health Canada, 1990), the American Academy of Pediatrics (AAP, 1997) and in the Food and Nutrition Board report *Nutrition During Lactation* (IOM, 1991).

In general, for this report special consideration was not given to possible variations in physiological need during the first month after birth or to the variations in intake of nutrients from human milk that result from differences in milk volume and nutrient concentration during early lactation. Specific Dietary Reference Intakes (DRIs) to meet the needs of formula-fed infants are not proposed in this report. The previously published RDAs and RNIs for infants

have led to much misinterpretation of the adequacy of human milk because of a lack of understanding about their derivation for young infants. Although they were based on human milk composition and volume of intake, the previous RDA and RNI values allowed for lower bioavailability of nutrients from nonhuman milk.

Ages 0 through 6 Months. To derive the AI value for infants ages 0 through 6 months, the mean intake of a nutrient was calculated on the basis of the average concentration of the nutrient from 2 through 6 months of lactation with use of consensus values from several reported studies (Atkinson et al., 1995), and an average volume of milk intake of 0.78 L/day as reported from studies of full-term infants by test weighing, a procedure in which the infant is weighed before and after each feeding (Butte et al., 1984; Chandra, 1984; Hofvander et al., 1982; Neville et al., 1988). Because there is variation in both of these measures, the computed value represents the mean. It is expected that infants will consume increased volumes of human milk as they grow.

Ages 7 through 12 Months. Except for iron and zinc, which have relatively high requirements, there is no evidence for markedly different nutrient needs during the period of infants' growth acceleration and gradual weaning to a mixed diet of human milk and solid foods from ages 7 through 12 months. The basis of the AI values derived for this age category was the sum of the specific nutrient provided by 0.6 L/day of human milk, which is the average volume of milk reported from studies in this age category (Heinig et al., 1993), and that provided by the usual intakes of complementary weaning foods consumed by infants in this age category (Specker et al., 1997). This approach is in keeping with the current recommendations of the Canadian Paediatric Society (Health Canada, 1990), the American Academy of Pediatrics (AAP, 1997), and *Nutrition During Lactation* (IOM, 1991) for continued feeding of human milk to infants through 9 to 12 months of age with appropriate introduction of solid foods.

One problem encountered in trying to derive intake data in infants was the lack of available data on total nutrient intake from a combination of human milk and solid foods in the second 6 months of life. Most intake survey data do not identify the milk source, but the published values indicate that cow milk and cow milk formula were most likely consumed.

Toddlers: Ages 1 through 3 Years

The greater velocity of growth in height during ages 1 through 3 years compared with ages 4 through 5 years provides a biological basis for dividing this period of life. Because children in the United States and Canada from age 4 years onwards begin to enter the public school system, ending this life stage prior to age 4 years seemed appropriate. Data are sparse for indicators of nutrient adequacy on which to derive DRIs for these early years of life. In some cases, DRIs for this age group were derived from data extrapolated from studies of infants or of adults aged 19 years and older.

Early Childhood: Ages 4 through 8 Years

Because major biological changes in velocity of growth and changing endocrine status occur during ages 4 through 8 or 9 years (the latter depending on onset of puberty in each gender), the category of 4 through 8 years is appropriate. For many nutrients, a reasonable amount of data is available on nutrient intake and various criteria for adequacy (such as nutrient balance measured in young children ages 5 through 7 years) that can be used as the basis for the EARs and AIs for this life stage group.

Puberty/Adolescence: Ages 9 through 13 Years and 14 through 18 Years

Because current data support younger ages for pubertal development, it was determined that the adolescent age group should begin at 9 years. The mean age of onset of breast development (Tanner Stage 2) for white females in the United States is 10.0 ± 1.8 (standard deviation) years; this is a physical marker for the beginning of increased estrogen secretion (Herman-Giddens et al., 1997). In African-American females, onset of breast development is earlier (mean 8.9 years \pm 1.9). The reason for the observed racial differences in the age at which girls enter puberty is unknown. The onset of the growth spurt in girls begins before the onset of breast development (Tanner, 1990). The age group of 9 through 13 years allows for this early growth spurt of females.

For males, the mean age of initiation of testicular development is 10.5 to 11 years, and their growth spurt begins 2 years later (Tanner, 1990). Thus, to begin the second age category at 14 years and to have different EARs and AIs for females and males for some nutrients at this age seems biologically appropriate. All children continue

to grow to some extent until as late as age 20 years; therefore, having these two age categories span the period 9 through 18 years of age seems justified.

Young Adulthood and Middle Ages: Ages 19 through 30 Years and 31 through 50 Years

The recognition of the possible value of higher nutrient intakes during early adulthood on achieving optimal genetic potential for peak bone mass was the reason for dividing adulthood into ages 19 through 30 years and 31 through 50 years. Moreover, mean energy expenditure decreases during this 30-year period, and needs for nutrients related to energy metabolism may also decrease. For some nutrients, the DRIs may be the same for the two age groups. However, for other nutrients, especially those related to energy metabolism, EARs (and RDAs) are likely to differ for these two age groups.

Adulthood and Older Adults: Ages 51 through 70 Years and Over 70 Years

The age period of 51 through 70 years spans active work years for most adults. After age 70 years, people of the same age increasingly display variability in physiological functioning and physical activity. A comparison of people over age 70 years who are the same chronological age may demonstrate as much as a 15- to 20-year age-related difference in level of reserve capacity and functioning. This is demonstrated by age-related declines in nutrient absorption and renal function. Because of the high variability in functional capacity of older adults, the EARs and AIs for this age group may reflect a greater variability in requirements for the older age categories. This variability may be most applicable to nutrients for which requirements are related to energy expenditure.

Pregnancy and Lactation

Recommendations for pregnancy and lactation may be subdivided because of the many physiological changes and changes in nutrient needs that occur during these life stages. In setting EARs and AIs for these life stages, however, consideration is given to adaptations to increased nutrient demand, such as increased absorption and greater conservation of many nutrients. Moreover, nutrients may undergo net losses due to physiological mechanisms regardless of the nutrient intake. Thus, for some nutrients, there may not be a

basis for EAR values that are different during these life stages than they are for other women of comparable age.

Reference Weights and Heights

The reference weights and heights selected for children and adults are shown in Table 1-1. The values are based on anthropometric data collected from 1988–1994 as part of the Third National Health and Nutrition Examination Survey (NHANES III) in the United States. When extrapolation to a different age group was conducted, these reference weights were used, except for iron which used weights with known coefficients of variation that were required for factorial modeling.

Using NHANES III data, the median heights for the life stage and gender groups through age 30 years were identified, and the median weights for these heights were based on reported median Body Mass Index (BMI) for the same individuals. Since there is no evidence that weight should change as adults age if activity is maintained, the reference weights for adults ages 19 through 30 years are applied to all adult age groups.

The most recent nationally representative data available for Canadians (from the 1970–1972 Nutrition Canada Survey [Demirjian, 1980]) were reviewed. In general, median heights of children from

TABLE 1-1 Reference Heights and Weights for Children and Adults in the United States^a

Gender	Age	Median Body Mass Index (kg/m ²)	Reference Height, cm (in)	Reference Weight ^b kg (lb)
Male, female	2–6 mo	–	64 (25)	7 (16)
	7–11 mo	–	72 (28)	9 (20)
	1–3 y	–	91 (36)	13 (29)
Male	4–8 y	15.8	118 (46)	22 (48)
	9–13 y	18.5	147 (58)	40 (88)
	14–18 y	21.3	174 (68)	64 (142)
	19–30 y	24.4	176 (69)	76 (166)
Female	9–13 y	18.3	148 (58)	40 (88)
	14–18 y	21.3	163 (64)	57 (125)
	19–30 y	22.8	163 (64)	61 (133)

^a Adapted from the Third National Health and Nutrition Examination Survey (NHANES III), 1988–1994.

^b Calculated from body mass index and height for ages 4 through 8 years and older.

1 year of age in the United States were greater by 3 to 8 cm (1 to 3 inches) than those of children of the same age in Canada measured two decades earlier (Demirjian, 1980). This difference could be partly explained by approximations necessary to compare the two data sets but more likely by a continuation of the secular trend of increased heights for age noted in the Nutrition Canada Survey when it compared data from that survey with an earlier (1953) national Canadian survey (Pett and Ogilvie, 1956).

Similarly, median weights beyond age 1 year derived from the recent survey in the United States (NHANES III) were also greater than those obtained from the older Canadian survey (Demirjian, 1980). Differences were greatest during adolescence, ranging from 10 to 17 percent higher. The differences probably reflect the secular trend of earlier onset of puberty (Herman-Giddens et al., 1997), rather than differences in populations. Calculations of BMI for young adults (e.g., a median of 22.6 for Canadian women compared with 22.8 for U.S. women) resulted in similar values, thus indicating greater concordance between the two surveys by adulthood.

The reference weights chosen for this report were based on the most recent data set available from either country, with recognition that earlier surveys in Canada indicated shorter stature and lower weights during adolescence than did surveys in the United States.

Reference weights are used primarily when setting the EAR or Tolerable Upper Intake Level for children or when relating the nutrient needs of adults to body weight. For the 4- to 8-year-old age group, a small 4-year-old child can be assumed to require less than the EAR and that a large 8-year-old child will require more than the EAR. However, the RDA or AI should meet the needs of both.

SUMMARY

Dietary Reference Intakes (DRIs) is a generic term for a set of nutrient reference values that includes the Estimated Average Requirement, Recommended Dietary Allowance, Adequate Intake, and Tolerable Upper Intake Level. These reference values are being developed for life stage and gender groups in a joint U.S. and Canadian activity. This report, which is one volume in a series, covers the DRIs for vitamins A and K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc.

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