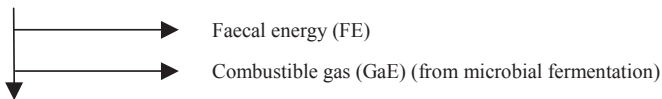# Food energy – methods of analysis and conversion factors
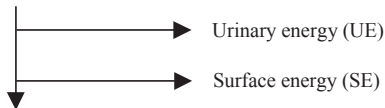
Ingested energy (IE) = gross energy (GE)

→ Faecal energy (FE)

→ Combustible gas (GaE) (from microbial fermentation)

Digestible energy (DE)

→ Urinary energy (UE)

→ Surface energy (SE)

Metabolizable energy (ME)

→ Heat of microbial fermentation

→ Obligatory thermogenesis, i.e. excess heat relative to glucose during ATP synthesis

Net (metabolizable) energy (NME)

→ Non-obligatory dietary thermogenesis

→ Thermogenesis due to effects of cold, drugs, hormones, bioactive compounds or other stimulants

Net energy for maintenance (NE)

→ Basal metabolism

→ Physical activity
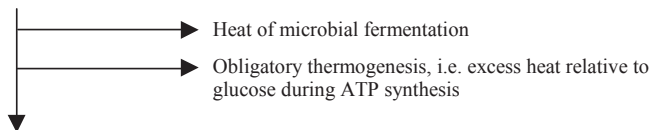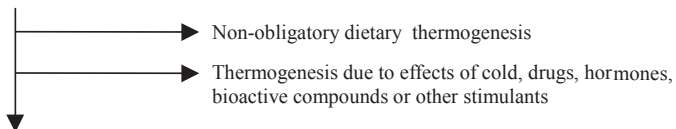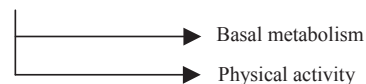
Food energy – methods of analysis and conversion factors

Report of a technical workshop
Rome, 3–6 December 2002

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FOREWORD

Ever since its inception, one of FAO's primary objectives has been to assure an adequate, nutritionally sound and safe food supply. This has required periodic assessments of the food supply and its comparison with the needs of the population. To enable this, knowledge of human food requirements, both qualitative and quantitative, is required. Thus, one of the earliest and ongoing activities of FAO's Food and Nutrition Division has been to determine the energy and nutrient requirements of humans. FAO's first review of energy ("calorie") requirements was made in 1949. This was followed by four subsequent reviews, the most recent being in 2001.

However, recommendations for optimal energy requirement become practical only when they are related to foods, which provide the energy to meet those requirements. This linking of energy requirements with energy intake depends on knowledge of the amounts of energy-providing components in foods and the use of a valid expression of the energy values of those components. At first glance, this may seem simple but, with the increasing number of available methods of analysis and the enhanced sophistication of the analytical methods used to determine food components, there are myriad possible options for expressing the energy value of foods. An obvious conclusion is that the standardization and harmonization of energy conversion factors is urgently needed. This conclusion is not new, and was noted more than 55 years ago by the Expert Committee on Calorie Conversion Factors and Food Composition Tables (FAO, 1947).

Expert reviews of energy requirements have not examined closely the possible implications and effects that using different expressions of energy values of foods may have on the recommendations for requirements. Hence, no expert review has yet provided guidelines on the most appropriate methodology and expression to adopt. This technical workshop was convened to examine – in depth and for the first time – the issue of the energy content of foods and how it relates to energy requirements. In organizing it, FAO adopted the long-standing philosophy of past reviews, beginning in 1949, that any conclusions and recommendations are provisional and subject to later review. However,

the fact that they are provisional or tentative does not detract from their immediate practical value. The Technical Workshop on Food Energy: Methods of Analysis and Conversion Factors met in Rome from 3 to 6 December 2002 and examined a number of topics related to the various methods of analysis of macronutrients in food and the energy conversion factors used, including close consideration of various options, as well as the implications on the food and nutrition sector of any changes that may be proposed. The objectives and framework of the workshop are described in Chapter 1. The working papers from this technical workshop will be published in a special issue of the *Journal of Food Composition and Analysis*, to be published in 2004 (*Journal of Food Composition and Analysis*, in press), thus allowing a more detailed peer-reviewed literature source for many of the arguments on the various topics debated in Rome.

The recommendations of this report are tentative. Although consensus emerged regarding the need to adopt changes as new scientific evidence emerges, the workshop participants also recognized that due consideration needs to be given to the practical aspects of implementing changes that would have an impact on a wide range of stakeholders in the food and nutrition sector. FAO expects to review this topic periodically as new scientific information becomes available and the need to change the manner in which we use the new information in everyday life emerges.

I would personally like to thank the participants (listed in Annex I) for their dedication and openness in addressing the various issues in a spirit of compromise and scientific rigour. In particular, I want to thank Bill MacLean, not only for serving as Chairperson at the bequest of FAO, but also for preparing the early versions of the draft report and resolving many of the more contentious issues. Thanks are also due to Dr Penny Warwick in her role as rapporteur and for her copious and accurate notes of the discussion. She was also active in reviewing the various drafts of the report. Finally I would like to express special thanks to the FAO staff who constituted the Secretariat and carried out much of the post-workshop follow-up, which culminated in this report.

Kraisid Tontisirin
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CHAPTER 1: INTRODUCTION

1.1 HISTORICAL BACKGROUND

In 1948, three years after the founding of FAO, the newly established Standing Advisory Committee noted that "the problem of assessing the calorie[1] and nutrient requirements of human beings, with the greatest possible degree of accuracy, is of basic importance to FAO" (FAO, 1950). As a result, a gathering of experts was convened in September 1949 to address the issue of calorie needs. The foreword of the report of this meeting stated that "even tentative recommendations would be of immediate practical value to FAO but also to its member countries" and that the recommendations would also be of value to "nutrition workers and others concerned with the problems of food requirements" (FAO, 1950).

This Expert Committee meeting was the first of what was to become a recurrent activity within FAO, to begin with on its own, but later in collaboration with other United Nations organizations, most notably the World Health Organization (WHO). Since the 1949 meeting, energy requirements were reviewed again in 1956 (FAO, 1957a); protein was investigated in 1955 (FAO, 1957b) and 1963 (FAO, 1964), and energy and protein were reviewed together in 1971 (FAO, 1973) and 1981 (WHO, 1985). More recently, energy was reviewed in 2001 (FAO, 2004), and protein in 2002 (WHO, forthcoming).

Over the years, energy requirement recommendations have been used for many purposes by scientists, planners, policy-makers, regulators, etc. Among these uses are: 1) assessment of the energy needs of countries, populations and subgroups of populations living under different circumstances; 2) assessment of food availability within regions and countries; 3) assessment of the potential ability of available food supplies to meet a country's or a population's needs, during normal circumstances or acute shortages; 4) assessment of individuals' diets

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[1] During the early years of FAO, within the general scientific community energy was referred to in terms of "calories", the unit then applied to expressing energy. In fact, the correct unit is "kilocalorie" (kcal), and increasingly the convention is to use kilojoules (kJ), with 1 kilocalorie equal to 4.184 kJ.

(although the recommendations are not meant for this purpose, they are commonly used for it as there is no other broadly applicable international standard); and 5) as a basis for food labelling, with implications for consumer information/education about specific foods, regulatory compliance regarding nutrient content and claims, and trade. All these uses relate to one of the issues recognized by the first committee – that whereas the recommended requirement values were determined at the physiological level, a country's food supply is estimated at the production or retail level, and therefore some adjustment is required when comparing the two levels (FAO, 1950).

Experience over the years has revealed that practical application of the requirement recommendations continues to be both elusive and complex. The 1949 group called on food economists to assist in the assessment of energy needs, but this collaboration has never been fully realized. Initially, the reviewing experts assigned to the Secretariat the mandate of preparing a chapter or section of the report to address the practical applications of the requirements, but this aspect was found to be increasingly problematic and requires more attention.

1.2 BACKGROUND TO THE TECHNICAL WORKSHOP

In 2001, FAO, WHO and the United Nations University (UNU) convened an Expert Consultation on Energy in Human Nutrition, which provided the most recent review of requirements and other energy-related topics (FAO, 2004). As part of the preparatory process for both the Joint FAO/WHO/UNU Expert Consultation on Energy and that on Protein and Amino Acids in Human Nutrition five working groups were created and convened in June 2001 to deal with various topics that required a more thorough review than the others. Working Group 5 was devoted to Analytical Issues in Food Energy and Composition: Energy in Food Labelling, including Regulatory and Trade Issues (see Annex II), and was created partially in anticipation of possible changes in the energy requirements that may have resulted from the new requirements being based totally on energy expenditure data.[2] In addition to discussing the preferred methods of protein, fat, carbohydrate and dietary fibre

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[2] In fact, the resulting recommendations for younger age groups were significantly different from those made in the 1985 report.

analysis, Working Group 5 also considered the following in its deliberations: 1) the routes of energy loss from the body such that the lost energy cannot contribute to maintaining energy balance; 2) the size of the energy loss for each of the energy-providing substrates, including fermentable carbohydrate; 3) variations in the energy losses reported in different studies of food components; 4) energy losses from normally consumed foods that have not previously been taken into account; and 5) factors external to food energy availability that modulate energy needs and the ability to maintain energy balance. Taking all of these into consideration, possible approaches to energy evaluation, including ways to account for diet-induced thermogenesis, were discussed. At about this time, the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) requested FAO's assistance in harmonizing energy conversion factors, and thus enabling uniformity in labelling and in the information provided to consumers (CCNFSDU, 2001a; 2002). This request was reinforced by the introduction of the information paper by the Australian delegation at the 23rd CCNGSDU session in 2001 (CCNFSDU, 2001b).

As alluded to in the previous paragraph, the expected adoption of new energy requirement values based on energy expenditure raised the issue of how best to match requirements with food intakes. This topic was briefly introduced and discussed at the 2001 Expert Consultation on Energy in Human Nutrition, but the experts present at that meeting were primarily physiologists and felt that the subject was outside their area of competence. Thus, a Technical Workshop on Food Energy: Methods of Analysis and Conversion Factors took place in Rome from 3 to 6 December 2002 to review the subject further (see Annex 1 for the list of participants at that workshop). To provide continuity between Working Group 5 and this technical workshop, the chairperson and one other member of Working Group 5 also participated in the technical workshop. The background papers and conclusions from Working Group 5 were considered extensively and were integrated, in some cases with modifications, into the present recommendations on methods of analysis and food energy factors. The goal of the technical workshop participants was to make recommendations on both methods of analysis and food energy conversion factors that would: 1) be analytically accurate; 2) if possible, tie conceptually to the physiological underpinning of the

methods used to estimate energy requirements; 3) be acceptable worldwide, in terms of cost, complexity and compatibility with currently used approaches; 4) be acceptable to a broad variety of stakeholders – e.g. nutrition scientists, public health professionals, consumers, policy-makers, regulators and industry; and 5) based on these, foster harmonization.

The following sections of this report deal with several important and related issues. Chapter 2 describes the various methods of food analysis, reviews the current status of the analytical methods for proteins, fats and carbohydrates and makes preferred recommendations for use in food analysis based on the current state of the art and the available technology. Chapter 3 looks at the energy flow in the body and provides a theoretical framework for the use of appropriate energy conversion factors to estimate the energy content of foods. It describes the various energy conversion factors in current use and distinguishes the differences among them. It also highlights the need to standardize the energy conversion factors and reviews the implications of changes in current practices for the wide range of stakeholders in the food and nutrition sector. The final chapter (Chapter 4) summarizes the technical workshop's views on how it may be possible to integrate methods and factors into a coherent approach to estimation of the energy contents of the macronutrient components of foods and diets.

1.3 RATIONALE FOR THE TECHNICAL WORKSHOP

Energy requirement recommendations remain "theoretical" and of little practical value until they can be related to foods, which provide the energy to meet requirements, and food intakes. Two pieces of information are needed in order to translate individual foods, and ultimately diets, into energy intakes that can be compared with the requirement recommendations. First, the composition of foods for those components that provide energy – i.e. the amounts of protein, fat, carbohydrate, etc. – must be analysed using appropriate methods. Second, these amounts of components must be converted into energy content using an agreed set of physiology-related factors that correspond to the energy-producing potential of the components in the human body. Thus, in order to make accurate estimates of energy intake, it is essential

to have energy conversion factors for each component that denote the energy per gram for that component. However, it has long been recognized that the energy contents of protein, fat and carbohydrate differ, both inherently in the compounds themselves and owing to their different digestion, absorption and metabolism. Understanding of foods and nutrition has become increasingly sophisticated over recent decades, particularly regarding enhanced understanding of the relationship between diet and health. Much of the work of the first part of the twentieth century was directed towards understanding the roles of specific nutrients in intermediary metabolism: the goal of an adequate and healthy diet was to prevent energy and nutrient deficiencies. There is now increasing awareness of the key role that diet plays in the induction or prevention of specific diseases, such as heart disease, strokes, cancer and diabetes mellitus (WHO, 2003). Inadequate energy intake still limits the potential of individuals in many developing countries, while excess energy intakes are increasingly leading to very high prevalence of obesity (with its attendant complications) across all socio-economic strata in both developing and developed countries.

As understanding of foods and nutrition grows, the analytical methods used to determine food components become increasingly sophisticated. Newer methods allow more precise separation of the various macro- and micronutrients in foods. In the case of energy, each of the energy-providing constituents can now be broken down into a variety of subfractions or components. Carbohydrates, for example, can now be analysed to provide the amounts of specific mono-, di-, oligo- and polysaccharides, the latter comprising both starch and non-starch polysaccharides. Dietary fibre, which includes non-starch polysaccharides and has both a physiological and an analytical connotation, can be analysed directly. The ability to carry out these more complex and precise analyses has, in turn, facilitated a more sophisticated understanding of the nutritional, physiological and metabolic effects of these components and their relationship to health.

The interplay between analytical and physiological advances has made the field of nutrition increasingly rewarding, but also increasingly complex. In the case of the macronutrients that provide energy, there are now a number of different methods of analysis and different energy conversion factors. Each of the energy-providing components of foods is

associated with its own variety of analytical methods, each of which may arrive at a slightly or very different value for the actual content of protein, fat, carbohydrate or dietary fibre. Each of the components also has its own energy value (or in some cases, values) – which in the case of "subfractions" may or may not differ from the value generally assigned to the macronutrient itself. This issue is complicated further by the fact that the energy conversion factor chosen is not necessarily tied to the specific analytical method used. The possibility of using any one of several analytical results with any one of several conversion factors results in myriad possibilities for expressing the energy content of individual foods, with consequent effects on estimation of the overall energy content of diets. Although this situation has become more complex over time, it is not new, and FAO has been recognizing and addressing it since as long ago as 1947.[3]

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[3] In 1947, an Expert Committee on Calorie Conversion Factors and Food Composition Tables stated: "FAO should ... develop the principles on which average food composition figures ... should be based, ... whereby comparability of data for international use can be attained, ... at the earliest possible time ... including, if necessary, the revision of tables at present used." (FAO, 1947).

CHAPTER 2: METHODS OF FOOD ANALYSIS

Despite efforts over the past half-century, there is still a need for internationally harmonized methods and data. In fact, as described in Chapter 1, the development of new methods for analysing specific components of the energy-yielding macronutrients has increased the complexity and made this need greater than ever.

This chapter discusses the commonly used analytical methods for protein, fat and carbohydrate, and makes recommendations regarding the preferred methods for the current state of the art and available technology. Methods that continue to be acceptable when the preferred methods cannot be used are also noted. Analytical methods for alcohol, which can be a significant source of energy in some diets, polyols and organic acids were not discussed, and hence no recommendations for methods are made.

2.1 ANALYTICAL METHODS FOR PROTEINS IN FOODS

2.1.1 Current status

For many years, the protein content of foods has been determined on the basis of total nitrogen content, while the Kjeldahl (or similar) method has been almost universally applied to determine nitrogen content (AOAC, 2000). Nitrogen content is then multiplied by a factor to arrive at protein content. This approach is based on two assumptions: that dietary carbohydrates and fats do not contain nitrogen, and that nearly all of the nitrogen in the diet is present as amino acids in proteins. On the basis of early determinations, the average nitrogen (N) content of proteins was found to be about 16 percent, which led to use of the calculation N x 6.25 (1/0.16 = 6.25) to convert nitrogen content into protein content.

This use of a single factor, 6.25, is confounded by two considerations. First, not all nitrogen in foods is found in proteins: it is also contained in variable quantities of other compounds, such as free amino acids, nucleotides, creatine and choline, where it is referred to as non-protein nitrogen (NPN). Only a small part of NPN is available for the synthesis

of (non-essential) amino acids. Second, the nitrogen content of specific amino acids (as a percentage of weight) varies according to the molecular weight of the amino acid and the number of nitrogen atoms it contains (from one to four, depending on the amino acid in question). Based on these facts, and the different amino acid compositions of various proteins, the nitrogen content of proteins actually varies from about 13 to 19 percent. This would equate to nitrogen conversion factors ranging from 5.26 (1/0.19) to 7.69 (1/0.13).

In response to these considerations, Jones (1941) suggested that N x 6.25 be abandoned and replaced by N x a factor specific for the food in question. These specific factors, now referred to as "Jones factors", have been widely adopted. Jones factors for the most commonly eaten foods range from 5.18 (nuts, seeds) to 6.38 (milk). It turns out, however, that most foods with a high proportion of nitrogen as NPN contain relatively small amounts of total N (Merrill and Watt, 1955; and 1973).[4] As a result, the range of Jones factors for major sources of protein in the diet is narrower. Jones factors for animal proteins such as meat, milk and eggs are between 6.25 and 6.38; those for the vegetable proteins that supply substantial quantities of protein in cereal-/legume-based diets are generally in the range of 5.7 to 6.25. Use of the high-end factor (6.38) relative to 6.25 increases apparent protein content by 2 percent. Use of a specific factor of 5.7 (Sosulski and Imafidon, 1990) rather than the general factor of 6.25 decreases the apparent protein content by 9 percent for specific foods. In practical terms, the range of differences between the general factor of 6.25 and Jones factors is narrower than it at first appears (about 1 percent), especially for mixed diets. Table 2.1 gives examples of the Jones factors for a selection of foods.

Because proteins are made up of chains of amino acids joined by peptide bonds, they can be hydrolysed to their component amino acids, which can then be measured by ion-exchange, gas-liquid or high-

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[4] The first version of Merrill and Watt's *Energy value of foods: basis and derivation* was published in 1955. In 1973, a "slightly revised" version was published, but no details were provided as to what revisions had been made. Most likely, any citing of Merrill and Watt would hold true for both editions. For simplicity, unless otherwise stated or the reference is specifically to the 1955 edition, only the 1973 version will be cited throughout this document.

TABLE 2.1
**Specific (Jones) factors for the conversion of nitrogen content
to protein content (selected foods)**

Food	Factor
Animal origin	
Eggs	6.25
Meat	6.25
Milk	6.38
Vegetable origin	
Barley	5.83
Corn (maize)	6.25
Millets	5.83
Oats	5.83
Rice	5.95
Rye	5.83
Sorghums	6.25
Wheat: Whole kernel	5.83
Bran	6.31
Endosperm	5.70
Beans: Castor	5.30
Jack, lima, navy, mung	6.25
Soybean	5.71
Velvet beans	6.25
Peanuts	5.46

Source: Adapted and modified from Merrill and Watt (1973).

performance liquid chromatography. The sum of the amino acids then
represents the protein content (by weight) of the food. This is sometimes
referred to as a "true protein". The advantage of this approach is that it
requires no assumptions about, or knowledge of, either the NPN content
of the food or the relative proportions of specific amino acids – thus
removing the two problems with the use of total N x a conversion factor.
Its disadvantage is that it requires more sophisticated equipment than the
Kjeldahl method, and thus may be beyond the capacity of many
laboratories, especially those that carry out only intermittent analyses. In
addition, experience with the method is important; some amino acids

(e.g. the sulphur-containing amino acids and tryptophan) are more difficult to determine than others. Despite the complexities of amino acid analysis, in general there has been reasonably good agreement among laboratories and methods (King-Brink and Sebranek, 1993).

2.1.2 Recommendations

1)   It is recommended that protein in foods be measured as the sum of individual amino acid residues (the molecular weight of each amino acid less the molecular weight of water) plus free amino acids, whenever possible. This recommendation is made with the knowledge that there is no official Association of Analytical Communities (AOAC)[5] method for amino acid determination in foods. Clearly, a standardized method, support for collaborative research and scientific consensus are needed in order to bring this about.

2)   Related to the previous recommendation, food composition tables should reflect protein by sum of amino acids, whenever possible. Increasingly, amino acid determinations can be expected to become more widely available owing to greater capabilities within government laboratories and larger businesses in developed countries, and to the availability of external contract laboratories that are able to carry out amino acid analysis of foods at a reasonable cost for developing countries and smaller businesses.

3)   To facilitate the broader use of amino acid-based values for protein by developing countries and small businesses that may lack

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[5] AOAC was founded in 1884 as the Association of Official Agricultural Chemists. In 1965, in recognition of its expanded scope of interest beyond agricultural topics, its name was changed to the Association of Official Analytical Chemists. By 1991, AOAC had long ceased to be limited to regulatory ("Official") analytical chemists in the United States, and its name was changed to AOAC International. The new name retained the initials by which the association had been known for more than 100 years, while eliminating reference to a specific scientific discipline or profession and reflecting the expanding international membership and focus of AOAC as the Association of Analytical Communities. See the AOAC, 2000 entry in the Reference list (p. 61) for information about AOAC's *Official Methods of Analysis*.

resources, FAO and other agencies are urged to support food analysis and to disseminate updated food tables whose values for protein are based on amino acid analyses.

4)   When data on amino acids analyses are not available, determination of protein based on total N content by Kjeldahl (AOAC, 2000) or similar method x a factor is considered acceptable.

5)   A specific Jones factor for nitrogen content of the food being analysed should be used to convert nitrogen to protein when the specific factor is known. When the specific factor is not known, N x the general factor 6.25 should be used. Use of the general factor for individual foods that are major sources of protein in the diet introduces an error in protein content that is relative to the specific factors and ranges from -2 percent to +9 percent. Because protein contributes an average of about 15 percent of energy in most diets, the use of N x 6.25 should introduce errors of no more than about 1 percent in estimations of energy content from protein in most diets ([-2 to +9 percent] x 15).

6)   It is recommended that only amino acid analysis be used to determine protein in the following:

- foods used as the sole source of nourishment, such as infant formula;
- foods/formulas designed specifically for special dietary conditions;
- novel foods.

2.2 ANALYTICAL METHODS FOR FATS IN FOOD

2.2.1. Current status

There is perhaps more agreement on standardized methods of analysis for fat than for protein and carbohydrate. Most fat in the diet is in the form of triglyceride (three fatty acids esterified to a glycerol molecule backbone). There are also non-glyceride components such as sterols, e.g. cholesterol. While there is considerable interest in the roles that these non-glyceride components may play in metabolism, they are not important sources of energy in the diet (FAO, 1994).

There are accepted AOAC gravimetric methods for crude fat, which includes phospholipids and wax esters, as well as minor amounts of non-

fatty material (AOAC, 2000). Total fat can be expressed as triglyceride equivalents determined as the sum of individual fatty acids and expressed as triglycerides (FAO, 1994). This method is satisfactory for the determination of fat in a wide variety of foods.

2.2.2 Recommendations
1)   For energy purposes, it is recommended that fats be analysed as fatty acids and expressed as triglyceride equivalents, as this approach excludes waxes and the phosphate content of phospholipids, neither of which can be used for energy (James, Body and Smith, 1986).
2)   A gravimetric method, although less desirable, is acceptable for energy evaluation purposes (AOAC, 2000).

2.3 ANALYTICAL METHODS FOR CARBOHYDRATES IN FOODS

2.3.1 Current status
FAO/WHO held an expert consultation on carbohydrate in 1997. The report of this meeting (FAO, 1998) presents a detailed description of the various types of carbohydrates and a review of methods used for analysis, which is summarized conceptually in the following paragraphs. Other recommendations from the 1997 consultation, e.g. the nomenclature of carbohydrates, were considered by the current technical workshop participants.

Total carbohydrate content of foods has, for many years, been calculated by difference, rather than analysed directly. Under this approach, the other constituents in the food (protein, fat, water, alcohol, ash) are determined individually, summed and subtracted from the total weight of the food. This is referred to as *total carbohydrate by difference* and is calculated by the following formula:

100 – (weight in grams [protein + fat + water + ash + alcohol] in 100 g of food)

It should be clear that carbohydrate estimated in this fashion includes fibre, as well as some components that are not strictly speaking

carbohydrate, e.g. organic acids (Merrill and Watt, 1973). Total carbohydrate can also be calculated from the sum of the weights of individual carbohydrates and fibre after each has been directly analysed.

Available carbohydrate represents that fraction of carbohydrate that can be digested by human enzymes, is absorbed and enters into intermediary metabolism. (It does not include dietary fibre, which can be a source of energy only after fermentation – see the following subsections.) Available carbohydrate can be arrived at in two different ways: it can be estimated by difference, or analysed directly.[6] To calculate available carbohydrate by difference, the amount of dietary fibre is analysed and subtracted from total carbohydrate, thus:

100 – (weight in grams [protein + fat + water + ash + alcohol + dietary fibre] in 100 g of food)

This yields the estimated weight of available carbohydrate, but gives no indication of the composition of the various saccharides comprising available carbohydrate. Alternatively, available carbohydrate can be derived by summing the analysed weights of individual available carbohydrates. In either case, available carbohydrate can be expressed as the weight of the carbohydrate or as monosaccharide equivalents. For a summary of all these methods, see Table 2.2.

Dietary fibre is a physiological and nutritional concept relating to those carbohydrate components of foods that are not digested in the small intestine. Dietary fibre passes undigested from the small intestine into the colon, where it may be fermented by bacteria (the microflora), the end result being variable quantities of short-chain fatty acids and several gases such as carbon dioxide, hydrogen and methane. Short-chain fatty acids are an important direct source of energy for the colonic mucosa; they are also absorbed and enter into intermediary metabolism (Cummings, 1981).

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[6] Obtaining values by difference should be discouraged because these values include the cumulative errors from the analytical measures of each of the other non-carbohydrate compounds; these errors are not included in direct analyses.

TABLE 2.2
Total and available carbohydrate

Total carbohydrate:
By difference: 100 – (weight in grams [protein + fat + water + ash + alcohol] in 100 g of food)
By direct analysis: weight in grams (mono- + disaccharides + oligsaccharides + polysaccharides, including fibre)
Available carbohydrate:
By difference: 100 – (weight in grams [protein + fat + water + ash + alcohol + fibre] in 100 g of food)
By direct analysis: weight in grams (mono- + disaccharides + oligosaccharides + polysaccharides, excluding fibre)*

* May be expressed as weight (anhydrous form) or as the monosaccharide equivalents (hydrous form including water).

Chemically, dietary fibre can comprise: cellulose, hemicellulose, lignin and pectins from the walls of cells; resistant starch; and several other compounds (see Figure 2.1). As more has been learned about fibre, a variety of methods for analysis have been developed. Many of these measure different components of fibre, and thus yield different definitions of, and values for, it. Three methods have had sufficient collaborative testing to be generally accepted by such bodies as AOAC International and the Bureau Communautaire de Reference (BCR) of the European Community (EC) (FAO, 1998): the AOAC (2000) enzymatic, gravimetric method – Prosky (985.29); the enzymatic, chemical method of Englyst and Cummings (1988); and the enzymatic, chemical method of Theander and Aman (1982). Monro and Burlingame (1996) have pointed out, however, that at least 15 different methods are applied for determining the dietary fibre values used in food composition tables. Their publication, and the FAO/WHO report on carbohydrates in human nutrition (FAO, 1998), discuss these issues in more detail. The effect of having such a variety of methods for dietary fibre, each giving a somewhat different value, affects not only the values in food composition tables for dietary fibre *per se*, but also those for available carbohydrate by difference.

2.3.2 Recommendations

1)   Available carbohydrate is a useful concept in energy evaluation and should be retained. This recommendation is at odds with the view of the expert consultation in 1997, which endorsed the use of the term "glycaemic carbohydrate" to mean "providing carbohydrate for metabolism" (FAO, 1998). The current group expressed concerns that "glycaemic carbohydrate" might be confused or even equated with the concept of "glycaemic index", which is an index that describes the relative blood glucose response to different "available carbohydrates". The term "available" seems to convey adequately the concept of "providing carbohydrate for metabolism", while avoiding this confusion.

2)   Carbohydrate should be analysed by a method that allows determination of both available carbohydrate and dietary fibre. For energy evaluation purposes, standardized, direct analysis of available carbohydrate by summation of individual carbohydrates (Southgate, 1976; Hicks, 1988) is preferred to assessment of available carbohydrate by difference, i.e. total carbohydrate by difference minus dietary fibre. This allows the separation of mono- and disaccharides from starches, which is useful in determination of energy content, as discussed in Chapter 3.

3)   Determination of available carbohydrate by difference is considered acceptable for purposes of energy evaluation for most foods, but not for novel foods or food for which a reduced energy content claim is to be made. In these cases, a standardized, direct analysis of available carbohydrate should be carried out.

4)   "Dietary fibre" is a useful concept that is familiar to consumers and should be retained on food labelling and in food tables. Because the physical characteristic of solubility/insolubility does not strictly correlate with fermentability/non-fermentability, the distinction between soluble and insoluble fibre is not of value in energy evaluation, nor is it of value to the consumer.

5)   The AOAC (2000) analysis – Prosky (985.29) or similar method should be used for dietary fibre analysis.

FIGURE 2.1
Dietary fibre: constituents and associated polysaccharide fractions
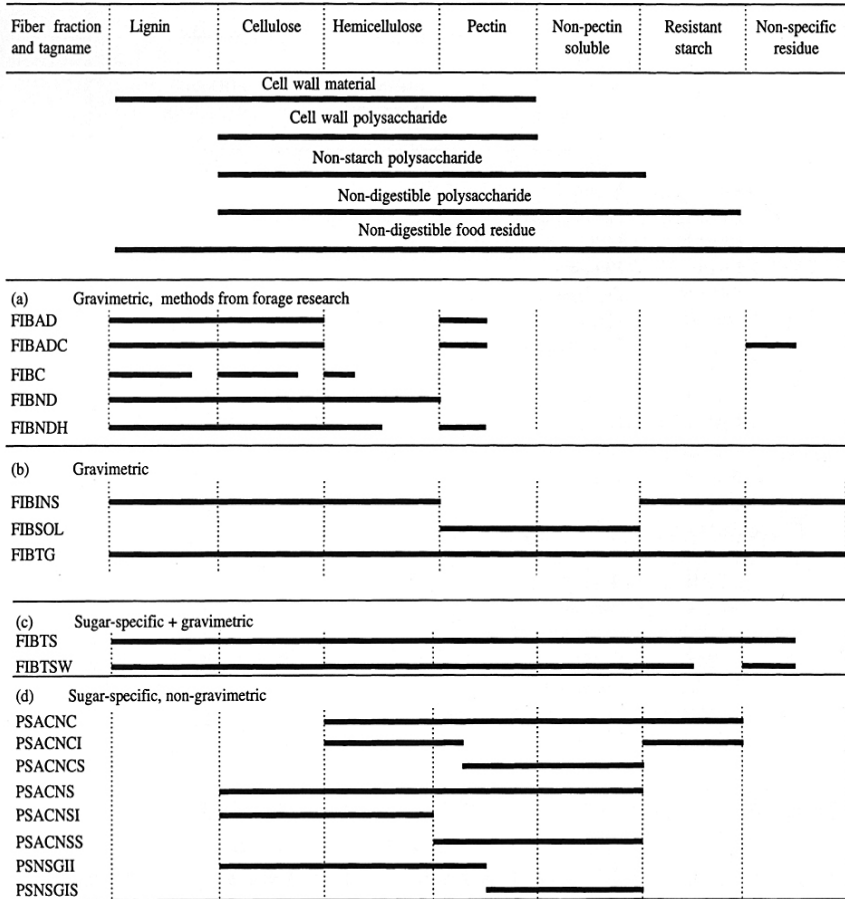
Source: Monro and Burlingame (1996).

6)   Because dietary fibre can be determined by a number of methods that yield different results, when the Prosky method is not used the method used should be stated and the value should be identified by INFOODS tagnames[7] (Klensin *et al*., 1989). In addition, the method should be identified with the tagname in food composition tables.

7)   Further research and scientific consensus are needed in order to develop standardized methods of analysis of resistant starch.

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[7] INFOODS tagnames provide standardized food component nomenclature for international nutrient data exchange. INFOODS sets out straightforward rules for identifying food components precisely and for constructing databases that are suitable for transfer among computers. The use of common names for food components, which are often applied to a variety of methods of analysis or combinations of chemicals, can result in different quantitative values for the same food (see: www.fao.org/infoods/index_en.stm).

CHAPTER 3: CALCULATION OF THE ENERGY CONTENT OF FOODS – ENERGY CONVERSION FACTORS

As stated in Chapter 1, the translation of human energy requirements into recommended intakes of food and the assessment of how well the available food supplies or diets of populations (or even of individuals) satisfy these requirements require knowledge of the amounts of available energy in individual foods. Determining the energy content of foods depends on the following: 1) the components of food that provide energy (protein, fat, carbohydrate, alcohol, polyols, organic acids and novel compounds) should be determined by appropriate analytical methods; 2) the quantity of each individual component must be converted to food energy using a generally accepted factor that expresses the amount of available energy per unit of weight; and 3) the food energies of all components must be added together to represent the nutritional energy value of the food for humans. The energy conversion factors and the models currently used assume that each component of a food has an energy factor that is fixed and that does not vary according to the proportions of other components in the food or diet.

3.1 JOULES AND CALORIES
The unit of energy in the International System of Units (SI)[8] is the joule (J). A joule is the energy expended when 1 kg is moved 1 m by a force of 1 Newton. This is the accepted standard unit of energy used in human

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[8] The SI (from the French *Système International d'Unités*) is the modern metric system of measurement. It was established in 1960 by the 11th General Conference on Weights and Measures (CGPM – *Conférence Générale des Poids et Mesures),* which is the international authority that ensures wide dissemination of the SI and modifies it, as necessary, to reflect the latest advances in science and technology. The SI is founded on seven *SI base units,* which are assumed to be mutually independent. There are 22 derived SI units defined in terms of the seven base quantities. The *SI derived unit* for energy, as work or quantity of heat, is the joule ($m^2 \cdot kg \cdot s^{-2}$), the symbol for which is J.

energetics and it should also be used for the expression of energy in foods. Because nutritionists and food scientists are concerned with large amounts of energy, they generally use kiloJoules (kJ = 10^3 J) or megaJoules (MJ = 10^6 J). For many decades, food energy has been expressed in calories, which is not a coherent unit of thermochemical energy. Despite the recommendation of more than 30 years ago to use only joules, many scientists, non-scientists and consumers still find it difficult to abandon the use of calories. This is evident in that both joules (kJ) and calories (kcal) are used side by side in most regulatory frameworks, e.g. Codex Alimentarius (1991). Thus, while the use of joules alone is recommended by international convention, values for food energy in the following sections are given in both joules and calories, with kilojoules given first and kilocalories second, within parenthesis and in a different font (Arial 9). In tables, values for kilocalories are given in italic type. The conversion factors for joules and calories are: 1 kJ = 0.239 kcal; and 1 kcal = 4.184 kJ.

3.2 THEORETICAL FRAMEWORK FOR AN UNDERSTANDING OF FOOD ENERGY CONVERSION FACTORS

As described in detail in the report of the most recent Expert Consultation on Energy in Human Nutrition (FAO, 2004), humans need food energy to cover the basal metabolic rate; the metabolic response to food; the energy cost of physical activities; and accretion of new tissue during growth and pregnancy, as well as the production of milk during lactation. "Energy balance is achieved when input (or dietary energy intake) is equal to output (or energy expenditure), plus the energy cost of growth in childhood and pregnancy, or the energy cost to produce milk during lactation" (FAO, 2004).

The total combustible energy content (or theoretical maximum energy content) of a food can be measured using bomb calorimetry. Not all combustible energy is available to the human for maintaining energy balance (constant weight) and meeting the needs of growth, pregnancy and lactation. First, foods are not completely digested and absorbed, and consequently food energy is lost in the faeces. The degree of incomplete absorption is a function of the food itself (its matrix and the amounts and types of protein, fat and carbohydrate), how the food has been prepared,

and – in some instances (e.g. infancy, illness) – the physiological state of the individual consuming the food. Second, compounds derived from incomplete catabolism of protein are lost in the urine. Third, the capture of energy (conversion to adenosine triphosphate [ATP]) from food is less than completely efficient in intermediary metabolism (Flatt and Tremblay, 1997). Conceptually, food energy conversion factors should reflect the amount of energy in food components (protein, fat, carbohydrate, alcohol, novel compounds, polyols and organic acids) that can ultimately be utilized by the human organism, thereby representing the input factor in the energy balance equation.

3.3 FLOW OF ENERGY THROUGH THE BODY – A BRIEF OVERVIEW

Food that is ingested contains energy – the maximum amount being reflected in the heat that is measured after complete combustion to carbon dioxide (CO_2) and water in a bomb calorimeter. This energy is referred to as ingested energy (IE) or gross energy (GE). Incomplete digestion of food in the small intestine, in some cases accompanied by fermentation of unabsorbed carbohydrate in the colon, results in losses of energy as faecal energy (FE) and so-called gaseous energy (GaE) in the form of combustible gases (e.g. hydrogen and methane). Short-chain (volatile) fatty acids are also formed in the process, some of which are absorbed and available as energy. Most of the energy that is absorbed is available to human metabolism, but some is lost as urinary energy (UE), mainly in the form of nitrogenous waste compounds derived from incomplete catabolism of protein. A small amount of energy is also lost from the body surface (surface energy [SE]). The energy that remains after accounting for the important losses is known as "metabolizable energy" (ME) (see Figure 3.1).

   Not all metabolizable energy is available for the production of ATP. Some energy is utilized during the metabolic processes associated with digestion, absorption and intermediary metabolism of food and can be measured as heat production; this is referred to as dietary-induced thermogenesis (DIT), or thermic effect of food, and varies with the type of food ingested. This can be considered an obligatory energy expenditure and, theoretically, it can be related to the energy factors

assigned to foods. When the energy lost to microbial fermentation and obligatory thermogenesis are subtracted from ME, the result is an expression of the energy content of food, which is referred to as net metabolizable energy (NME).

FIGURE 3.1
Overview of food energy flow through the body for maintenance of energy balance[1]

Ingested energy (IE) = gross energy (GE)

→ Faecal energy (FE)

→ Combustible gas (GaE) (from microbial fermentation)

Digestible energy (DE)

→ Urinary energy (UE)

→ Surface energy (SE)

Metabolizable energy (ME)

→ Heat of microbial fermentation

→ Obligatory thermogenesis, i.e. excess heat relative to glucose during ATP synthesis

Net (metabolizable) energy (NME)

→ Non-obligatory dietary thermogenesis

→ Thermogenesis due to effects of cold, drugs, hormones, bioactive compounds or other stimulants

Net energy for maintenance (NE)

→ Basal metabolism

→ Physical activity

[1] Additional energy is needed for gains of body tissue, any increase in energy stores, growth of the foetus during pregnancy, production of milk during lactation, and energy losses associated with synthesis/deposition of new tissue or milk.
Source: Adapted from Warwick and Baines (2000) and Livesey (in press [a]).

Some energy is also lost as the heat produced by metabolic processes associated with other forms of thermogenesis, such as the effects of cold, hormones, certain drugs, bioactive compounds and stimulants. In none of these cases is the amount of heat produced dependent on the type of food ingested alone; consequently, these energy losses have generally not been taken into consideration when assigning energy factors to foods. The energy that remains after subtracting these heat losses from NME is referred to as net energy for maintenance (NE), which is the energy that can be used by the human to support basal metabolism, physical activity and the energy needed for growth, pregnancy and lactation.

3.4 CONCEPTUAL DIFFERENCES BETWEEN METABOLIZABLE ENERGY AND NET METABOLIZABLE ENERGY

ME has traditionally been defined as "food energy available for heat production (= energy expenditure) and body gains" (Atwater and Bryant, 1900), and more recently as "the amount of energy available for total (whole body) heat production at nitrogen and energy balance" (Livesey, 2001). By contrast, net metabolizable energy (NME) is based on the ATP-producing capacity of foods and their components, rather than on the total heat-producing capacity of foods. It can be thought of as the "food energy available for body functions that require ATP". The theoretical appeal of NME for the derivation of energy conversion factors rests on the following: substrates are known to differ in the efficiency with which they are converted to ATP, and hence in their ability to fuel energy needs of the body. These differences in efficiency are reflected in the differences between heat production from each substrate and that from glucose; they can be determined stoichiometrically and can be measured. Furthermore, foods replace each other as energy sources in the diet and in intermediary metabolism on the basis of their ATP equivalence (which is reflected in NME), rather than on their ability to produce equal amounts of heat (which is reflected in ME). For more of the derivations of and differences between ME and NME see the detailed discussions of Warwick and Baines (2000) and Livesey (2001).

3.5 CURRENT STATUS OF FOOD ENERGY CONVERSION FACTORS

Just as a large number of analytical methods for food analysis have been developed since the late nineteenth century, so have a variety of different energy conversion factors for foods. In general, three systems are in use: the Atwater general factor system; a more extensive general factor system; and an Atwater specific factor system. It is important to note that all of these systems relate conceptually to (ME) as defined in the previous section. A general factor system based on NME has been proposed by Livesey (2001) as an alternative to these systems.

3.5.1 The Atwater general factor system

The Atwater general factor system was developed by W.O. Atwater and his colleagues at the United States Department of Agriculture (USDA) Agricultural Experiment Station in Storrs, Connecticut at the end of the nineteenth century (Atwater and Woods, 1896). The system is based on the heats of combustion of protein, fat and carbohydrate, which are corrected for losses in digestion, absorption and urinary excretion of urea. It uses a single factor for each of the energy-yielding substrates (protein, fat, carbohydrate), regardless of the food in which it is found. The energy values are 17 kJ/g (4.0 kcal/g) for protein, 37 kJ/g (9.0 kcal/g) for fat and 17 kJ/g (4.0 kcal/g) for carbohydrates.[9] The Atwater general system also includes alcohol with a rounded value of 29 kJ/g (7.0 kcal/g or an unrounded value of 6.9 kcal/g) (Atwater and Benedict, 1902). As originally described by Atwater, carbohydrate is determined by difference, and thus includes fibre. The Atwater system has been widely used, in part because of its obvious simplicity.

3.5.2 The extensive general factor system

A more extensive general factor system has been derived by modifying, refining and making additions to the Atwater general factor system. For

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[9] The figures given for kilojoules are the commonly used rounded values. The precise values for protein, fat, total carbohydrate and alcohol are, respectively, 16.7, 37.4, 16.7 and 28.9 kJ/g. The precise value for available carbohydrate as monosaccharide is 15.7 kJ/g.

example, separate factors were needed so that the division of total carbohydrate into available carbohydrate and fibre could be taken into account. In 1970, Southgate and Durnin (1970) added a factor for available carbohydrate expressed as monosaccharide (16 kJ/g [3.75 kcal/g]). This change recognized the fact that different weights for available carbohydrate are obtained depending on whether the carbohydrate is measured by difference or directly. In recent years, an energy factor for dietary fibre of 8.0 kJ/g (2.0 kcal/g) (FAO, 1998) has been recommended, but has not yet been implemented.

In arriving at this factor, fibre is assumed to be 70 percent fermentable. It should also be recognized that some of the energy generated by fermentation is lost as gas and some is incorporated into colonic bacteria and lost in the faeces. As already mentioned, there are also general factors in use for alcohol (29 kJ/g [7.0 kcal/g]), organic acids (13 kJ/g [3.0 kcal/g]) (Codex Alimentarius, 2001) and polyols (10k J/g (2.4 kcal/g]), as well as individual factors for specific polyols and for different organic acids (Livesey *et al*., 2000; for an example of a national specification, see Canada's at: www.inspection.gc.ca/english/bureau/labeti/guide/6-4e.shtml).

3.5.3 The Atwater specific factor system

The Atwater specific factor system, a refinement based on re-examination of the Atwater system, was introduced in 1955 by Merrill and Watt (1955). It integrates the results of 50 years of research and derives different factors for proteins, fats and carbohydrates, depending on the foods in which they are found. Whereas Atwater used average values of protein, fat and total carbohydrate, Merrill and Watt emphasized that there are ranges in the heats of combustion and in the coefficients of digestibility of different proteins, fats and carbohydrates, and these should be reflected in the energy values applied to them.[10] The following two examples help to make this clearer: 1) Because proteins differ in their amino acid composition, they also differ in their heats of combustion. Thus, the heat of combustion of protein in rice is approximately 20 percent higher than that of protein in potatoes, and

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[10] In addition, Merrill and Watt used Jones (1941) factors for nitrogen in determining protein content.

different energy factors should be used for each. 2) Digestibility (and fibre content) of a grain may be affected by how it is milled. Thus, the available energy from equal amounts (weight) of whole-wheat flour (100 percent extraction) and extensively milled wheat flour (70 percent extraction) will be different.

Based on these considerations, a system – or rather a set of tables – was created with substantial variability in the energy factors applied to various foods (see examples in Table 3.1). Among the foods that provide substantial amounts of energy as protein in the ordinary diet, energy conversion factors in the Atwater specific factor system vary, for example, from 10.2 kJ/g (2.44 kcal/g) for some vegetable proteins to 18.2 kJ/g (4.36 kcal/g) for eggs. Factors for fat vary from 35 kJ/g (8.37 kcal/g) to 37.7 kJ/g (9.02 kcal/g), and those for total carbohydrate from 11.3 kJ/g (2.70 kcal/g) in lemon and lime juices to 17.4 kJ/g (4.16 kcal/g) in polished rice. These ranges for protein, fat and carbohydrate are, respectively, 44, 7 and 35 percent. Merrill and Watt (1973) compared the energy values for different representative foods and food groups derived using these new specific factors with those derived using general Atwater factors (Table 3.2). Application of general factors to the mixed diet common in the United States resulted in values that were on average about 5 percent higher than those obtained with specific factors. There were several foods (for example, snap beans, cabbage and lemons) for which the differences ranged from 20 to 38 percent. When these foods were not included, the average difference between general and specific factor values was 2 percent.

The Atwater specific factor system appears to be superior to the original Atwater general system, which took only protein, fat, total carbohydrate and alcohol into account. However, it may not be vastly superior to the more extensive general factor system, which takes into account the differentiation between available carbohydrate and dietary fibre, and recognizes sources of energy other than protein, carbohydrates and fat.

TABLE 3.1
Atwater specific factors for selected foods

	Protein *kcal/g* (kJ/g)[§]	Fat *kcal/g* (kJ/g)[§]	Total carbohydrate *kcal/g* (kJ/g)[§]
Eggs, meat products, milk products:			
Eggs	4.36 (18.2)	9.02 (37.7)	3.68 (15.4)
Meat/fish	4.27 (17.9)	9.02 (37.7)	*
Milk/milk products	4.27 (17.9)	8.79 (36.8)	3.87 (16.2)
Fats – separated:			
Butter	4.27 (17.9)	8.79 (36.8)	3.87 (16.2)
Margarine, vegetable	4.27 (17.9)	8.84 (37.0)	3.87 (16.2)
Other vegetable fats and oils	--	8.84 (37.0)	--
Fruits :			
All, except lemons, limes	3.36 (14.1)	8.37 (35.0)	3.60 (15.1)
Fruit juice, except lemon, lime[#]	3.36 (14.1)	8.37 (35.0)	3.92 (15.1)
Lemon, limes	3.36 (14.1)	8.37 (35.0)	2.48 (10.4)
Lemon juice, lime juice[#]	3.36 (14.1)	8.37 (35.0)	2.70 (11.3)
Grain products:			
Barley, pearled	3.55 (14.9)	8.37 (35.0)	3.95 (16.5)
Cornmeal, whole ground	2.73 (11.4)	8.37 (35.0)	4.03 (16.9)
Macaroni, spaghetti	3.91 (16.4)	8.37 (35.0)	4.12 (17.2)
Oatmeal – rolled oats	3.46 (14.5)	8.37 (35.0)	4.12 (17.2)
Rice, brown	3.41 (14.3)	8.37 (35.0)	4.12 (17.2)
Rice, white or polished	3.82 (16.0)	8.37 (35.0)	4.16 (17.4)
Rye flour – whole grain	3.05 (12.8)	8.37 (35.0)	3.86 (16.2)
Rye flour – light	3.41 (14.3)	8.37 (35.0)	4.07 (17.0)
Sorghum – wholemeal	0.91 (3.8)	8.37 (35.0)	4.03 (16.9)
Wheat – 97–100% extraction	3.59 (14.0)	8.37 (35.0)	3.78 (15.8)
Wheat t – 70–74% extraction	4.05 (17.0)	8.37 (35.0)	4.12 (17.2)
Other cereals – refined	3.87 (16.2)	8.37 (35.0)	4.12 (17.2)
Legumes, nuts:			
Mature dry beans, peas, nuts	3.47 (14.5)	8.37 (35.0)	4.07 (17.0)
Soybeans	3.47 (14.5)	8.37 (35.0)	4.07 (17.0)

Table 3.1 continued	Protein kcal/g (kJ/g)[§]	Fat kcal/g (kJ/g)[§]	Total carbohydrate kcal/g (kJ/g)[§]
Vegetables:			
Potatoes, starchy roots	2.78 (11.6)	8.37 (35.0)	4.03 (16.9)
Other underground crops	2.78 (11.6)	8.37 (35.0)	3.84 (16.1)
Other vegetables	2.44 (10.2)	8.37 (35.0)	3.57 (14.9)

*Carbohydrate factor is 3.87 for brain, heart, kidney, liver; and 4.11 for tongue and shellfish.
Unsweetened.
[§] Original data were published in kcal/g; values for kJ/g have been calculated from calorie values. Hence, in this table, kcal values are given first, in italics, with kJ values following, in parenthesis.
Source: Modified from Merrill and Watt (1973).

3.5.4 Net metabolizable energy system

All three of the systems discussed in the previous sections are based on ME. On the basis of the theoretical discussion of energy flow through the body (see Section 3.1 and Figure 3.1), ME values can be modified further to account for energy that is lost as heat from different substrates via heat of fermentation and obligatory thermogenesis, i.e. energy that would not be available for the production of ATP to fuel metabolism. This results in the NME factors. The NME system retains a general factor approach, i.e. a single factor each for protein, fat, available carbohydrate, dietary fibre, alcohol, etc. that can be applied to all foods. This obviates the need for extensive tables.

The differences of importance between ME and NME factors are found primarily in estimating the energy content of protein, fermentable, unavailable carbohydrate, and alcohol (Table 3.3). The NME factor for protein is 13 kJ/g (3.2 kcal/g) versus the Atwater general factor of 17 kJ/g (4.0 kcal/g). Use of the NME rather than the Atwater general factor results in a 24 percent decrease in energy from protein. The recommended ME factor for dietary fibre in ordinary diets is 8 kJ/g (2.0 kcal/g); the corresponding NME value is 6 kJ/g (1.4 kcal/g) – a decrease of 25 percent. Values for fermentable fibre are believed to vary by 27 percent, i.e. ME 11 kJ/g (2.6 kcal/g) and NME 8 kJ/g (2.0 kcal/g). Finally, the

TABLE 3.2
Average percentage differences in energy values for selected foods, derived using general and specific Atwater factors

Food group	Ratio of general to specific factor values
Animal foods:	
Beef	98%
Salmon, canned	97%
Eggs	98%
Milk	101%
Fats:	
Butter	102%
Vegetable fats, oils	102%
Cereals:	
Cornmeal – whole, ground	103%
Cornmeal – degermed	98%
Oatmeal	102%
Rice, brown	99%
Rice, white or milled	97%
Whole wheat flour	107%
Wheat flour, patent	98%
Legumes:	
Beans, dry seeds	102%
Peas, dry seeds	103%
Vegetables:	
Beans, snap	120%
Cabbage	120%
Carrots	107%
Potatoes	102%
Turnips	109%
Fruits:	
Apples, raw	110%
Lemons, raw	138%
Peaches, canned	110%
Sugar – cane or beet	103%

Source: Adapted from Merrill and Watt (1973).

values for alcohol are 29 kJ/g (7.0 kcal/g) for ME, and 26 kJ/g (6.3 kcal/g) for NME – a difference of 10 percent. The lower NME values for dietary fibre are due to a higher assumed loss of energy through heat of fermentation, while those for alcohol seem to be due to thermogenesis following alcohol consumption. The discrepancy between energy values calculated using ME and those using NME conversion factors will be greatest for diets that are high in protein and dietary fibre, as well as for some novel food components.

TABLE 3.3
Comparison of ME general factors and NME factors for the major energy-producing constituents of foods

	ME as general Atwater factors kJ/g (kcal/g)	Modified ME factors# kJ/g (kcal/g)	NME factors* [1] kJ/g (kcal/g)
Protein	17 (4.0)	17 (4.0)	13 (3.2)
Fat	37 (9.0)	37 (9.0)	37 (9.0)
Carbohydrate			
Available – monosaccharides	16 (3.75)[2]	16 (3.75)	16 (3.8)
Available – by difference, sum	17 (4.0)	17 (4.0)	17 (4.0)
Total	17 (4.0)	17 (4.0)	
Dietary fibre			
Fermentable		11 (2.6)*** [1]	8 (1.9)
Non-fermentable		0 (0.0)*** [1]	0 (0.0)
In conventional foods**		8 (2)*** [3]	6 (1.4)
Alcohol	29 (7)*	29 (6.9)[4]	26 (6.3)
Total polyols		10 (2.4)[5]	
Organic acids[+]		13 (3)[6]	9 (2.1)

* Rounded values are used.
\# Based on general Atwater factors.
** Assumes that 70 percent of the fibre in traditional foods is fermentable.
*** Proposed factors.
Sources: [1] Livesey (in press [b]); [2] Southgate and Durnin (1970); [3] FAO (1998); [4] Merrill and Watt (1973); [5] EC (1990); [6] Codex Alimentarius (2001).

3.5.5 Hybrid systems
Although ME factors are generally in use, there is a lack of uniformity in their application within and among countries. For example, Codex (Codex Alimentarius, 1991) uses Atwater general factors with additional factors for alcohol and organic acids. United Kingdom food regulations require that carbohydrates must be expressed as the weight of carbohydrate, thus corresponding to Codex. There is often a discrepancy between a country's food composition databases and its regulations for food labelling. The United States Nutrition Labeling and Education Act (NLEA, see: www.cfsan.fda.gov/~lrd/CFR101-9.HTML) of 1990, for example, allows five different methods, which include both general and specific factors. Depending on the available data, the energy content of different foods may be calculated in different ways within a single database. In addition, some countries use energy values for novel food ingredients such as polyols and polydextrose.

3.5.6 Resulting confusion
This array of conversion factors, coupled with the multiplicity of analytical methods discussed in Chapter 2, results in considerable confusion. The application of different specific Atwater conversion factors for the energy content of protein results in values for an individual food that differ from those obtained using the general factor by between -2 and +9 percent. For diets in which protein provides about 15 percent of energy, the resulting error for total dietary energy is small, at about 1 percent. In the case of fat, the Atwater general factor of 37 kJ/g (9.0 kcal/g) is commonly used. Specific factors range from 35 kJ/g (8.37 kcal/g) to 37.7 kJ/g (9.02 kcal/g), a range of -5 to +2 percent relative to the general factor. In a diet in which 40 percent of energy is derived from fat, the effect of using specific factors on total energy content would range from -2 to +0.8 percent.

   The conversion factors related to carbohydrate present the greatest problems. The confusion stems from three main issues: The same weight of different carbohydrates (monosaccharides, disaccharides and starch) yields different amounts of hydrous glucose (expressed as monosaccharide), and thus different amounts of energy. In other words, the amount (weight) of carbohydrate to yield a specific amount of energy

differs depending on the molecular form of the carbohydrate. This is owing to the water of hydration in different molecules. For example, if expressed as monosaccharide equivalent, 100 g of glucose, 105 g of most disaccharides and 110 g of starch each contain 100 g of anhydrous glucose. Thus, different energy conversion factors have to be used to convert carbohydrate expressed as weight (16.7 kJ/g, usually rounded to 17 kJ/g) and available carbohydrate expressed as monosaccharide equivalents (15.7 kJ/g, rounded to 16 kJ/g) in order to account for the weight difference between the values of these two expressions of carbohydrate (Table 3.4). The calculated energy values for carbohydrates are similar in most cases because the difference in energy conversion factors balances with the difference in carbohydrate values.

1) The use of specific rather than general factors can introduce major differences, which are more than threefold for certain foods. The value for carbohydrate energy in chocolate is an extreme example – the factors range from 5.56 kJ/g (1.33 kcal/g) to 17 kJ/g (4.0 kcal/g). For most individual foods that are major sources of energy in the diet, use of a specific rather than a general factor results in differences that range from -6 to +3 percent. Assuming a diet in which carbohydrate provides 50 percent of energy, the effect on total dietary energy would be between -3 and +1.5 percent. This range is narrower when mixed diets rather than specific foods are being assessed.

2) Factors for dietary fibre vary widely and are not dependent on method. Energy values for dietary fibre are: 0 kJ/g (0 kcal/g) for non-fermentable fibre; 0 to 17 kJ/g (0 to 4.0 kcal/g) for fermentable fibre; and 0 to 8 kJ/g (0 to 1.9 kcal/g) for commonly eaten foods that contain a mixture of fermentable (assumed to be on average 70 percent of the total) and non-fermentable fibre (FAO, 1998).

TABLE 3.4
ME and proposed rounded NME factors for available carbohydrates, as monosaccharide equivalent or by weight

	Available carbohydrate as monosaccharide equivalent		Available carbohydrate by weight		
	ME-general* kJ/g (*kcal/g*)	NME kJ/g (*kcal/g*)	ME-general kJ/g (*kcal/g*)	ME-specific kJ/g (*kcal/g*)	NME kJ/g (*kcal/g*)
Glucose monohydrate		16 (*3.8*)	17 (*4.0*)		14 (*3.4*)
Glucose	16 (*3. 75*)	16 (*3.8*)	17 (*4.0*)	15 (*3.68*) [#]	16 (*3.8*)
Fructose	16 (*3. 75*)	15 (*3.6*)	17 (*4.0*)		15 (*3.6*)
Lactose	16 (*3. 75*)	16 (*3.7*)	17 (*4.0*)	16 (*3.87*) [#]	16 (*3.9*)
Sucrose	16 (*3. 75*)	16 (*3.7?*)	17 (*4.0*)	16 (*3.87*) [#]	16 (*3.9*)
Starch	16 (*3. 75*)	16 (*3.8*)	17 (*4.0*)	17 (*4.16*) [#]	18 (*4.2*)

* According to Southgate and Durnin (1970).
[#] Merrill and Watt (1973).
All kJ values are rounded.
Source: Livesey (in press [b]).

In theory, there are 975 combinations for the major energy-containing components in food (13 definitions for protein, times three for fat, times five for carbohydrates, times five for fibre), each leading to different nutrient values (Charrondière *et al*., in press). The application of "accepted" energy conversion factors increases the number of different energy values. Clearly, a more uniform system is needed.

3.6 STANDARDIZATION OF FOOD ENERGY CONVERSION FACTORS

The previous section documented the need for harmonization and standardization of the definitions, analytical methods and energy conversion factors used to determine the energy content of foods. One approach would be to work towards the uniform application of one of the currently used ME systems. Alternatively, if changes are to be made, a move to an NME factor system could be considered. (However, as NME factors are derived from ME factors, the standardization of ME factors

would still seem to be a logical first step to such a change.) The ultimate recommendation must take into account the scientific differences between metabolizable and net metabolizable systems, the need to provide useful information to consumers, and the practical implications of either staying with and standardizing one of the systems currently in use or moving to the other system.

In considering the alternatives, there was general agreement on the following principles:

1) NME represents the biological ATP-generating potential and, as such, the maximum potential of individual food components and foods to meet energy requirements that require ATP; thus, NME represents a potential improvement in the description of food energy, especially when individual foods are to be compared.

2) The 2001 human energy requirement recommendations are based on data derived from energy expenditure measurements, and hence equate conceptually to ME (FAO, 2004).

3) The difference between ME and NME values is greater for certain foods than for most of the habitual diets that are commonly consumed.

3.6.1 Recommendation

With the above in mind, the participants at the FAO technical workshop reached consensus that the continued use of ME rather than NME factors is recommended for the present. The reasons for this are discussed in detail in the following sections.

3.7 THE RELATIONSHIP BETWEEN FOOD ENERGY CONVERSION FACTORS AND RECOMMENDATIONS FOR ENERGY REQUIREMENTS

Because energy factors are used to assess how well foods and diets meet the recommended energy requirements, it is desirable that values for requirements and those for food energy be expressed in comparable terms. An overriding consideration to endorse the continued use of energy conversion factors based on ME is related to the way in which estimations of energy requirement recommendations are currently derived. Requirements *for all ages* are now based on measurements of

energy expenditure, plus the energy needs for normal growth, pregnancy and lactation (FAO, 2004). Energy expenditure data have been obtained by a variety of techniques, including the use of doubly labelled water, heart rate monitoring and standard Basal Metabolic Rate (BMR) measurements. Regardless of the technique used, the energy values obtained are related to oxygen consumption or CO_2 production and (through indirect calorimetry calculations) heat production. In the non-fasting state, this includes the heat of microbial fermentation and obligatory thermogenesis, which are the defining differences between ME and NME. Thus, the current estimates of energy requirements and dietary energy recommendations relate more closely to ME, and the use of ME conversion factors allows a direct comparison between the values for food intakes and the values for energy requirements. This was perceived as desirable for both professionals and consumers alike.

As part of the process for this recommendation, the magnitude of the effect of using NME instead of ME factors was examined in relation to individual foods and mixed diets. In the case of individual foods, the difference between the use of NME and ME factors for the estimated energy content is minimal for foods with low protein and fibre contents, but can be quite large for foods that are high in protein and/or fibre. (The maximum differences for protein and fibre supplements would be 24 and 27 percent, respectively.) The use of NME rather than ME factors has less effect on the estimation of energy content for most mixed diets than it has for individual foods, because about 75 percent of the energy in mixed diets derives from fat and available carbohydrate, which have the same NME and ME factors (Table 3.3). Estimates of the energy provided by "representative" mixed diets[11] showed that the use of NME instead of the Atwater general factors resulted in a decrease in estimated energy content of between 4 and 6 percent. As previously discussed, however, these differences can be greater in some diets (Table 3.5). The use of ME food conversion factors conceals the fact that energy expenditure derived from assessments of heat production varies with the composition of the diet that is being metabolized. For this reason, it may be necessary to make corrections to the estimates of food energy requirements in

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[11] This is assuming that the diet derives about 15 percent of energy from protein and contains a modest amount (~20 g) of fibre.

circumstances where the diet has substantial amounts of protein or fibre. The factors outlined in Box III.1 of Annex III may be used to facilitate these corrections.

If NME factors were adopted, a decrease in energy requirement estimates would be needed in order to keep requirement and intake values compatible and comparable, i.e. to have both expressed in the same (NME) system. Failure to make such an adjustment to energy requirements could lead to erroneous dietary energy recommendations. This is because NME factors reduce the energy content of a food or diet, so the application of such factors to foods but not to energy requirements would imply that an *increased* food intake is needed to meet those requirements. It would be both inaccurate and undesirable to convey such a message. In fact, if the NME system were used, the energy requirements would be lowered approximately by the same percentage as food energy. Thus, the comparison between energy intake and requirements would provide similar results within both the ME and the NME systems.

There are clearly circumstances in which it is desirable to know with greater precision which specific foods will ultimately contribute to maintaining energy balance – for example: in the management of obesity through weight-loss diets that are high in protein or fibre, which will not be completely metabolized to yield energy; in diabetes mellitus with concomitant renal disease, when protein intake may be low, and therefore makes only a small contribution to total energy intake; or when using novel foods that may or may not be fully metabolized. It should be noted that in situations where NME conversion factors for food energy are used, guidance on "reduced" energy requirements based on NME factors must be provided so that requirements and intakes are expressed in the same fashion. Nevertheless, in most cases the error incurred will be about 5 percent, which is within the usually accepted limits of measurement error or biological variation.

TABLE 3.5
Differences in energy content of selected diets calculated using either modified ME or NME factors

	Difference using modified ME factors (%)	Additional difference using NME factors (%)	Total difference (%)	Source of dietary composition
Conventional/ representative diets				
Required protein + energy, children 4–6 years old*	1.0	1.1	**2.1**	WHO, 1985
Required protein + energy, women 50+ years old[#]	2.0	2.4	**4.4**	WHO, 1985
Tanzania, rural Ilala women 65+ years old	1.3	2.6	**3.9**	Mazengo et al., 1997
South Africa, rural Vendor people	2.6	4.1	**6.7**	Walker, 1996
Mexico, rural people	5.9	4.3	**10.5**	Rosado et al., 1992
United Kingdom, urban people	2.8	4.5	**7.4**	Gregory et al., 1990
Guatemala, rural people	8.7	4.7	**13.8**	Calloway and Kretsch, 1978
Inuit, traditional	1.1	11.4	**12.7**	Krogh and Krogh, 1913
Australia, Aborigine	4.6	13.3	**18.5**	Brand-Miller and Holt, 1998
Therapeutic diets – diabetes, weight loss				
Early diet – type II diabetes mellitus	11.4	6.5	**18.6**	Jenkins et al., 2001
Higher % protein replacing fat	2.9	7.9	**11.0**	Summerbell et al., 1998[§]
High % protein (90 g), fibre	5.4	12.5	**18.5**	Willi et al., 1998
United Kingdom, women slimming[§]	2.9	5.4	**8.4**	Gregory et al., 1990

Notes to Table 3.5:
Baseline values were obtained using Atwater general factors of 16.7 kJ/g protein, 37.4 kJ/g fat and 16.7 kJ/g carbohydrate. Modified general factors used were 16.7 kJ/g protein, 37.5 kJ/g fat, 16.7 kJ/g carbohydrate (or 15.7 kJ/g carbohydrate as monosaccharide equivalents) and 7.8 kJ/g dietary fiber. NME factors used were 13.3 kJ/g protein, 36.6 kJ/g fat, 16.7 kJ/g carbohydrate (or 15.7 kJ/g as monosaccharide equivalents) and 6.2 kJ/g dietary fibre.
* Dietary fibre assumed to be 10 g.
# Dietary fibre assumed to be 20 g.
§ Concept diet 1: United Kingdom women's slimming diet (as tabulated), with further replacement of fat by protein.
Source: Adapted from Livesey (in press [b]).

3.8 OTHER PRACTICAL IMPLICATIONS RELATED TO THE USE OF FOOD ENERGY CONVERSION FACTORS

The participants at the technical workshop discussed a number of additional topics related to the interplay between different analytical methods and food energy conversion factors. These were: 1) the effect of using NME factors rather than Atwater general factors on the determination of energy content and the labelling of infant formulas and foods for infants and young children; 2) the issues related to standardizing nutrient databases on a single set of food energy conversion factors; 3) the effects that using various analytical methods with different energy conversion factors have on the conclusions drawn from food consumption survey data; 4) the effects of using different food energy conversion factors on data in food balance sheets; 5) regulatory perspectives; 6) effects on industry; 7) consumer interests; and 8) effects on health care professionals, educators and government staff. Each of these areas is discussed briefly in the following subsections.

The effect of using NME factors rather than Atwater general factors on energy content and the labelling of infant formulas and foods for infants and young children. Infant formulas and foods for infants and young children present a special situation, and in most regulatory frameworks are handled separately from foods in general. The effect of using NME conversion factors for formulas and foods destined for infants needed to be examined for several reasons.

First, there is a need to consider whether the NME values applied to foods for infants and small children differ from those for adults owing to differences in developmental physiology, such as the maturation of many

enzyme systems and processes, and growth. Infants differ from adults in particular in their ability to digest and absorb nutrients, although absorption of protein, fat and carbohydrate is at or near adult levels after six months of age (Fomon, 1993). They also differ in heat loss and maintenance of body temperature owing to their greater body surface area relative to weight and their lower heat-producing capacity (LeBlanc, 2002). And they differ in growth. Whereas the normal state of the adult is "zero balance" – no net retention of energy or other nutrients – the normal state of infants and children is growth, which implies the retention of large amounts of energy and other nutrients as new tissue, although the energy cost of weight gain of tissue of similar composition does not differ appreciably from that of adults (Roberts and Young, 1988). Of the two principal differences between ME and NME factors (i.e. heat of fermentation and thermogenesis), heat of fermentation is a more significant factor in infants because of both the presence of non-digestible carbohydrates, such as oligosaccharides, in the infant's diet (breastmilk) and the inability to digest fully carbohydrates that are normally fully assimilated by the older child and adult (Aggett *et al.*, 2003). Differences in thermogenesis are due to differences in size compared with adults, and are not due to the foods themselves. ME factors appear to be reasonably valid for infants and small children; furthermore, neither ME nor NME factors have been specifically investigated in infants or young children.

Second, a single food usually represents the entire diet for infants in the first six months of life, and the differences between energy contents estimated by the ME and by the NME systems may be greater when single foods, rather than mixed diets, are involved. Since infant formulas are patterned on human milk, it was important to understand how the application of NME factors to the contents of protein, fat and carbohydrate in human milk alters its apparent energy content relative to current values in the literature. The use of Atwater general and specific factors was compared with the use of NME factors. The value per 100 g of human milk is 253 kJ (61 kcal) using Atwater specific factors (USDA, 2003), 259 kJ (63 kcal) using Atwater general factors, and 248 kJ (60 kcal) using NME factors (Table 3.6). These differences are not considered significant, as the composition of human milk reported in the literature

and using a variety of methods differs by more than this percentage (Fomon, 1993).[12]

TABLE 3.6
Energy values of human milk

	Composition[1] g/litre	ME-ATW[2] kJ/ml (kcal/ml)	ME-specific[3] kJ/ml (kcal/ml)	NME-1[4, 6] kJ/ml (kcal/ml)	NME-2[5,6] kJ/ml (kcal/ml)
Protein – total [7]	8.9	0.15 (0.04)	0.17 (0.04)	0.12 (0.03)	0.10 (0.03)
Immunoglobulins	1.1				
Fat	32	1.18 (0.29)	1.17 (0.28)	1.18 (0.29)	1.18 (0.28)
CHO-lactose/ glucose	74	1.26 (0.30)	1.21 (0.29)	1.18 (0.28)	1.18 (0.28)
Oligosaccharides	13				0.08 (0.02)
Energy		2.59 (0.63)	2.55 (0.61)	2.48 (0.60)	2.54 (0.61)

[1] Values for all but oligosaccharides from Fomon (1993) pp. 124, 125, 410. Values for oligosaccharides from McVeagh and Miller (1997) and Coppa *et al.* (1997).
[2] ME using the Atwater conversion factors: protein 17 kJ/g (*4 kcal/g*), fat 37 kJ/g (*9 kcal/g*), carbohydrate 17 kJ/g (*4 kcal/g*).
[3] Values calculated using specific Atwater factors: *4.27 kcal/g* for protein, *8.79 kcal/g* for fat and *3.87 kcal/g* for carbohydrates.
[4] NME-1: applying values to total protein, fat and lactose/glucose. Protein 13 kJ/g (*3.2 kcal/g*), fat 37 kJ/g (*9 kcal/g*) and lactose/glucose 16 kJ/g (*3.8 kcal/g*). Energy value for carbohydrate assumes weight of carbohydrate reflects weight of mono- and disaccharides.
[5] NME-2: assumes 10 percent of protein is unavailable, leaving 8.01 g/litre of available protein. Also assumes presence of oligosaccharides, which are calculated as unavailable carbohydrate. The same factors listed in footnote 3 were used, plus a factor for oligosacccharides of 6 kJ/g (*1.5 kcal/g*).
[6] NME-1 and NME-2 in this table are not the same variables that appear in Figure 3.2 and Table 3.7
[7] does not include the free amino acids normally present in human milk.
Source: MacLean (in press).

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[12] Annex IV gives a more detailed discussion of this topic.

Third, Codex (Codex Alimentarius, 1994) and many other regulatory codes specify minimum and maximum nutrient levels in infant formulas based on energy content. As a result, any change in the way energy content is calculated would change the *apparent* content of product formulation for all other nutrients. Specifically, in the same infant formula, a change in the calculated energy content resulting from the use of NME conversion factors would lead to a corresponding change in the amounts of all other nutrients expressed per 100 kJ or 100 kcal. Although nutrient composition is generally expressed per 100 g of the formula on the label, those values will be derived from, and will reflect the changes per, 100 kJ or 100 kcal. On the label however, nutrient composition is generally expressed per 100 g of the formula, even though manufacturers are permitted to express it per 100 kJ or 100 kcal. This may result in apparent differences in the nutrient composition of infant formulas, especially when compared with human milk, for which nutrient content is always expressed per 100 g or 100 ml. It was important for at least two reasons to ask how the application of NME factors would affect the declared energy contents and relative amounts of other nutrients (i.e. per 100 kJ or 100 kcal) of currently available formulas: first, most health care professionals and consumers who use infant formula have a concept of the energy content (per 100 ml or per ounce); and second, regulatory frameworks (e.g. Codex Alimentarius, 1994) for infant formula specify the content of minimum and maximum nutrient levels per 100 available kilojoules or kilocalories. Hence, if a change in energy content is made by adapting NME factors, appropriate changes in minimum and maximum nutrient levels may be necessary. The use of NME will result in a decrease in energy content (expressed per millilitre, decilitre or litre) of 3 to 5 percent in milk-based formulas, and of about 0 to 2 percent in soy protein-based formulas, using either specific or general Atwater factors. Thus, while resorting to the use of different energy conversion factors increases the nutrient declarations per 100 kJ or 100 kcal on the label, there should be no need to reformulate existing standard formulas to meet current regulations.

The effect of using NME factors rather than Atwater general factors (ME) on the labelling of "baby foods" (food designed to be fed specifically to infants and small children) was also examined. Application of NME factors resulted in expected variable decreases in

the energy content of baby foods that ranged in the examples examined from a low of 2 percent, for apple sauce, to a high of 9 percent, for chicken with gravy. The issues raised for these foods do not differ specifically from those concerning food for adults, and it is therefore recommended that the same energy conversion factors used for foods in general be applied to baby foods. Although use of NME conversion factors does not present insurmountable problems, and could therefore be acceptable from an operational point of view, the fact that energy requirements for this age group have been estimated from measurements reflecting ME (as is also the case for adults) makes it seem logical to continue using the ME conversion factors for foods and formulas for infants and young children. Furthermore, it was considered not pragmatic to recommend the use of NME for infant formulas only.

Issues related to standardizing nutrient databases on a single set of food energy conversion factors. Government organizations, universities and the food industry organize and maintain databases of the nutrient composition of foods. These databases are used in a number of areas, including: 1) epidemiological and clinical studies; 2) formulation of menus, diets and food products; 3) food entitlement programmes; 4) nutrient labelling of food products; 5) regulation of international trade; and 6) generation of derivative, second-generation databases for special purposes. As discussed in Chapter 2, the food composition data in these databases are based on a variety of analytical methods and, as discussed earlier in this chapter, the energy content of different foods may be calculated in different ways (using different conversion factors) within the same database, depending on the analytical data available. The interaction of these two "terms in the equation" results in an unacceptably large number of possible values for energy of any food. Standardization of specific methods of analysis and use of energy conversion factors may improve this situation.

The USDA Nutrient Database for Standard Reference (USDA, 2003) was examined in order to look at the variations that result from the use of different methods and energy conversion factors. Although all energy values in the database are derived using ME factors, it has not been possible to calculate the energy values for all foods using the same set of factors (i.e. specific or general). Different factors are used for different

foods depending on the availability of either analytical information on the composition of protein, fat and carbohydrate, or specific information on the ingredients and their amounts. The following approach is used by USDA (Harnly *et al.,* in press): For food commodities, specific Atwater factors are preferred. If these are not known, Atwater general factors are used. For commercial, multi-ingredient foods, the database generally relies on manufacturers' data for composition. Specific energy conversion factors are used when all ingredients have a known specific factor *and* the exact proportion of ingredients is also known. The Atwater general factors are used when specific factors are not known for all ingredients, or when the formulation is proprietary, and thus the amounts and proportions of ingredients are not known by the database compiler. Most other food composition databases do not face this problem as they use only the general Atwater factors for all foods.

Energy values in centrally maintained databases are likely to be modifiable, some with less effort and cost than others. Depending on the source and quality of the analytical data, standardizing on a single set of ME factors is likely to be no easier than adopting NME factors. Neither modification may be possible, depending on the source of the analytical data. The primary database can be modified by changing factors in an algorithm in the system and using the new factors to recalculate the database. Thus, changing energy conversion factors in the primary database is relatively easy from a purely mechanical point of view, and it need not be problematic for a database to hold and disseminate a variety of energy values for food. Any derivative database would need to be modified accordingly. The ease or difficulty of that task will depend on how the secondary database was constructed.

The effects of using various analytical methods with different energy conversion factors on the conclusions drawn from food consumption survey data. Household food consumption surveys are an important tool used to estimate dietary adequacy of individuals and population groups. In these surveys, estimates of food intake, either by recall or weighing, are converted to the corresponding energy (and other nutrient values) to determine adequacy of intakes. It is common to estimate the prevalence or numbers of individuals in a population who are not achieving energy (or nutrient) adequacy based on the ratio of actual intake to the optimum

requirement. Clearly, the availability of data derived from different analytical methods, and the choice of energy conversion factors used to calculate energy content of the diet will affect the calculated intakes, and in turn the estimates of these numbers or the prevalence of inadequacy.

To improve understanding of these issues, a case study was undertaken using food intake data collected in a national food consumption and family budget survey in 1974–1975[13] (Vasconcellos, in press). Briefly described, this study was a household, probabilistic sample of 53 311 families including more than 267 000 individuals. Intake data were obtained by weighing the food items consumed and wasted in each household during a period of seven consecutive days. The weights of foods were expressed as nutrients using food composition tables compiled from 40 national and international sources.

In the original survey, protein content was calculated as N x the specific Jones factor, while the Atwater specific energy conversion factors (from Merrill and Watt, 1973) were used to calculate energy content of proteins, lipids, alcohol and total carbohydrates (as well as total energy content) of the edible portions of foods. For the current case study, as well as using these conversion factors, which also served as a baseline, additional variables were created. These included two additional methods for estimating protein content – N x 6.25 and the sum of amino acid values – and also total and available carbohydrate by difference. The energy content was also recalculated with Atwater general factors and NME conversion factors, applying them to the existing and the newly created variables. At least 12 possible combinations of useful ways of calculating energy content were found. These variables were subjected to a number of tests to see how their results compared with each other, and in some cases it was decided to merge some of the methods because the results were similar. These new estimates were then compared with the baseline values (derived from the specific ME conversion factors) to determine the effects of different systems on energy intake estimates.

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[13] The National Study of Family Expenditure (Estudo Nacional da Despesa Familiar [ENDEF]) was conducted by the Brazilian Institute of Geography and Statistics.

Estimates of energy intake per adult-day were calculated using these approaches and when compared with the baseline (based on specific ME factor values) revealed values ranging from -3 to +1 percent (Figure 3.2).[14] Recalculated intake data were also compared with the baseline "energy requirement standard" to assess the effect of energy conversion factor on estimates of the apparent percentage of individuals with low energy intake. Relative to the baseline values, use of the Atwater general factors with available or total carbohydrates resulted in an apparent decrease of 1.8 percent. Depending on the assumptions, use of the ME factors resulted in only modest changes (-0.6 to +0.2 percent). The use of NME factors resulted in an apparent increase in the prevalence of low energy intake of 3.3 to 4.1 percent compared with the use of specific ME factors (Table 3.7). The effect of any method of calculation was similar across all socio-economic groups (Figure 3.3).

It is clear from this that the analytical definition of energy-yielding components of the diet and the choice of energy conversion factors may have major effects on the analysis and interpretation of food consumption data. In large countries, such as Brazil, wide regional variations in the amounts and types of foods that comprise the diet may affect significantly the interpretation of the food intake, and may not be appreciated when mean values only are considered.

However, the following points, which were made previously, should be kept in mind when interpreting these findings. While the differences in energy intakes using different ME factors appear to be small (regardless of how the amounts of protein, fat, carbohydrate and fibre are calculated), the differences using NME factors appear to be relatively larger. The different results most likely reflect the fact that the standard for adequacy of intake – "the requirements" – against which intakes are judged is based on data that reflect ME and not NME. Thus, any shift to the use of NME conversion factors for the determination of energy intake in food consumption surveys would have to be accompanied by a simultaneous change in expressing energy requirements. In addition, when comparing such results with other studies in the same or another

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[14] These differences are small owing to the nutrient definition adopted for fibre, i.e. crude versus dietary: the fibre value of the former is much smaller than that of the latter owing to incomplete recovery from the analysis method.

country, a restatement of both intakes and the requirement standard using NME conversion factors would also be required. Finally, it may not be appropriate to extrapolate the magnitude of change induced by different food energy conversion systems in the Brazilian data to other countries with other diets, where different intakes of protein, fibre, carbohydrates and alcohol are likely.

TABLE 3.7
Per adult-day energy consumption and prevalence of low energy intake according to nine different methods for determining energy content of foods

Methods for determining energy content of foods				Per adult-day energy consumption		Difference in prevalence of low energy intake
Energy conversion factor	Description					
	Protein based on	Carbohydrates by difference	Energy from fibre	Kcal	%	
Atwater	Jones	Total	#	2 739	101.2	-1.8
ME2	Jones	Available	Included	2 714	100.3	-0.6
Merrill and Watt*	Jones	Total	#	2 706	100.0	0.0
ME1	Jones	Available	Ignored	2 698	99.7	0.2
NME2[AA]	Total AA	Available	Included	2 634	97.3	3.3
NME2[Jones]	Jones	Available	Included	2 632	97.3	3.4
NME2[6.25]	6.25	Available	Included	2 631	97.2	3.5
NME1[AA]	Total AA	Available	Ignored	2 621	96.9	4.1
NME1[Jones]	Jones	Available	Ignored	2 619	96.8	4.0
NME1[6.25]	6.25	Available	Ignored	2 618	96.7	4.1

* The baseline values for the survey used the values from Merrill and Watt (1973). All intakes were judged against the same energy requirement.
[#] Fibre content included in total carbohydrates by difference.
Source: ENDEF study, 1974–1975. Analysis carried out by Vasconcellos (in press).

FIGURE 3.2
Percentage differences in estimates of Brazilian daily mean energy consumption, calculated as the difference between each method and the estimate based on Merrill and Watt method (1973), by reference adult
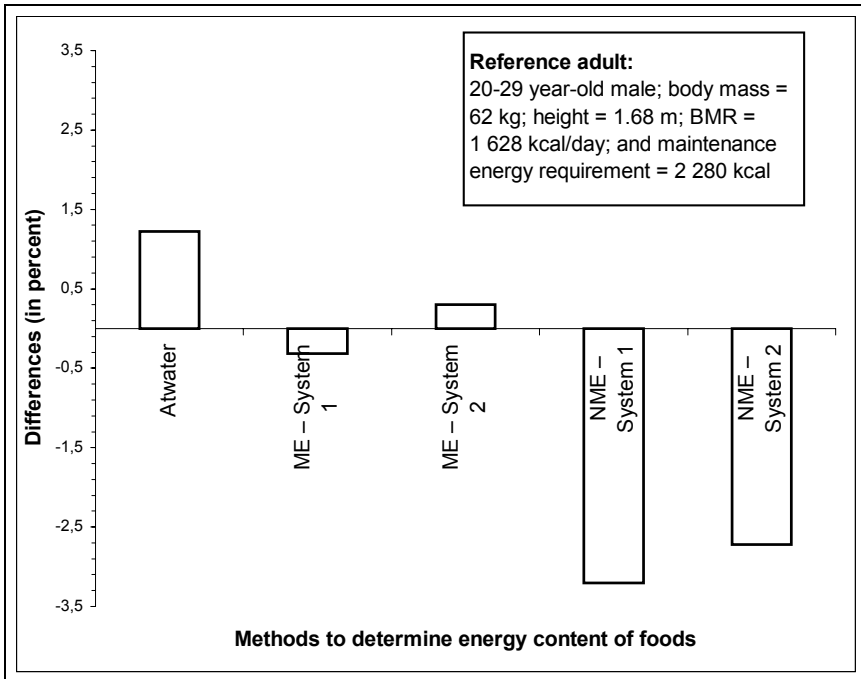
Notes for Figures 3.2 and 3.3:
Atwater = Atwater general conversion factors with total carbohydrate determined by difference, i.e. fibre is included.
ME-System 1 = Atwater specific conversion factors, *not* including energy from fibre.
ME-System 2 = Atwater specific conversion factors, including energy from fibre.
NME-System 1 = NME specific conversion factors (proposed), *not* including energy from fibre.
NME-System 2 = NME specific conversion factors (proposed), including energy from fibre.
NB: NME-Systems 1 and 2 in these figures are not the same variables, labelled as NME-1 and NME-2, that appear in Table 3.6 and in Annex IV.
For all ME and NME systems, protein content calculated from an average of the three primary methods: N x 6.25, Jones specific factors and AA analysis.

FIGURE 3.3
Differences in estimates of the prevalence of low energy intake based on each method in relation to Merrill and Watt method (1973), according to nine income expenditure categories
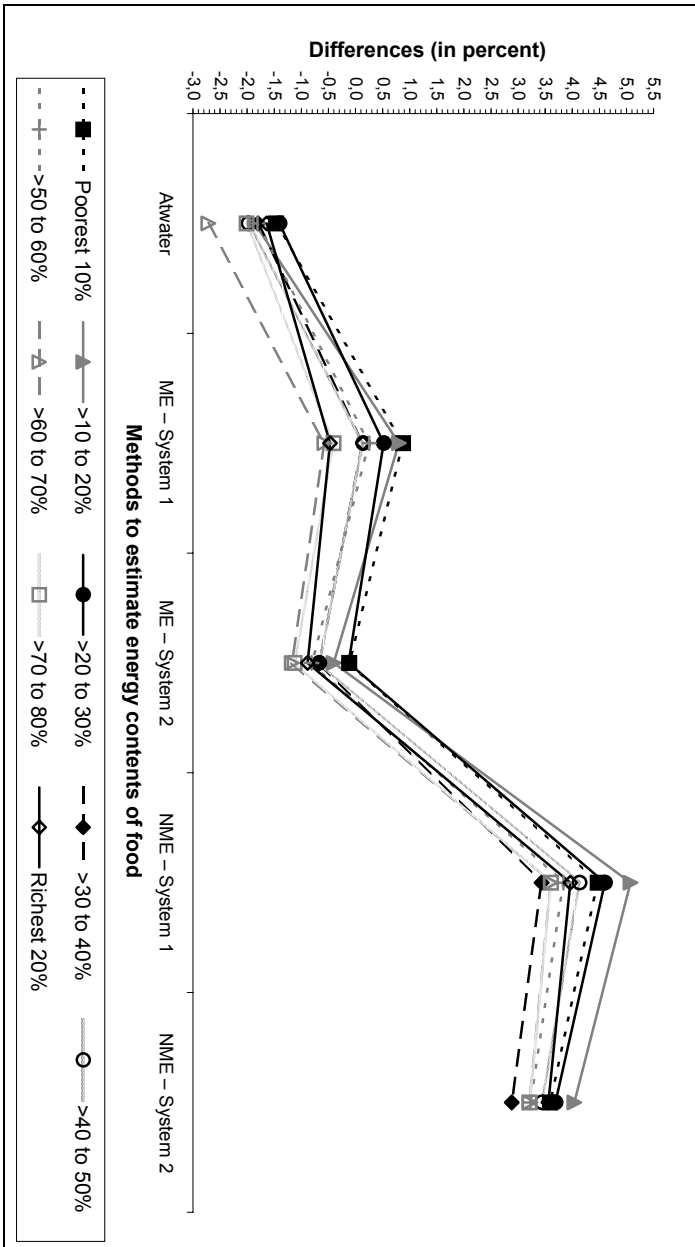
The effects of using different food energy conversion factors on data in food balance sheets. To address this last point – i.e. the inability to extrapolate conclusions based on data from one country to other countries – food balance sheets (FBS) data from different countries were examined relative to the different methods used to calculate food energy.

FAO has used FBS to estimate national food supplies for decades. Currently these comprise data from more than 180 countries/territories, plus various aggregation categories on overall food supply and food use. Among other applications, data in FBS are used to: 1) follow trends in food supplies; 2) compare available food supplies with estimated country requirements; 3) estimate shortages; and 4) evaluate the effectiveness of food and nutrition policies. FAO maintains the FAOSTAT statistical databases (http://apps.fao.org/default.htm), which contain data on protein, fat and energy for 506 food commodities and aggregations of foods. These are based on international values for most foods, although there are country-specific values in some instances. Energy values are drawn from what is judged to be the most appropriate regional or national food composition table. They may be derived from direct analysis of some individual components or by difference, and are mainly based on specific Atwater energy conversion factors. The dietary energy supply (DES) – average available kilocalories per person per day – can then be judged against requirements. A detailed description of the derivation and uses of FBS is beyond the scope of this document, and fuller information is available from the FAO/ESS Web site (at www.fao.org/ES/ESS/index_en.asp; http://faostat.fao.org/abcdq/docs/FBS_review.pdf; and www.fao.org/ES/ESS/menu3.asp).

For the workshop, FBS data from nine countries were examined using the USDA data set for calculating energy availability. The countries represented different regions of the world and different diets: Afghanistan, Bangladesh and the Islamic Republic of Iran are characterized by a high rice and wheat supply; in Guatemala, Guinea and Mozambique maize and tubers are important, and also sorghum in Mozambique; and Italy, Tunisia and the United States observe a mixed diet. The protein supply ranges from 35 g in Mozambique (or 7.2 percent of energy from protein) to 101 g in Italy and the United States (or 11.2 percent of energy from protein). Figure 3.4 clearly demonstrates that energy supply calculated through NME relates well with the application

of general Atwater factors. ME with general Atwater factors always generates higher values than NME and, as expected, the difference between the two calculations increases linearly, from 2 to 5 percent, as the percentage of energy from protein increases. The picture is very different for specific Atwater factors, where there is no linear relationship to NME. Depending on the diet, the difference in energy supply between the application of NME or specific Atwater factors varies from -1 to +5 percent. This can be explained by the different compositions of the diet – especially the contribution of cereals and vegetable foods against that of animal foods, and the differences in their specific energy factors (see Table 3.1) – but not by the increasing protein content in the diets, as is the case in the comparison between general Atwater and NME factors. It can therefore be concluded that ME is generating between 1 percent (or 80 kJ [20 kcal]) less and 5 percent (or 630 kJ [150 kcal]) more energy supply than NME. Differences between general and specific Atwater factors result in relatively small differences in energy supply, of only 80 to 200 kJ (20 to 50 kcal).

While dietary fibre content plays a role in determining the differences between ME and NME, its impact on energy supply depends on whether any energy is attributed to dietary fibre or not. The different calculation methods for protein (N x Jones factors, N x 6.25, or the sum of amino acids) have a minor impact on energy supply as they generate differences of less than 1 percent, or 4 to 80 kJ (1 to 20 kcal). The highest difference in energy supply calculations occurs as a result of different carbohydrate definitions (i.e. total or available carbohydrates) and ranges from 1 to 5 percent, or 80 to 500 kJ (20 to 120 kcal). This exercise clearly shows that the harmonization of nutrient definitions, especially of carbohydrates, is as important as the energy factors applied.

Regulatory perspectives. Different countries, communities and regions are in different states of development regarding food regulations and labelling. There are differences among countries depending on which regulatory framework predominates. Many countries follow Codex standards. These are not legally binding, and regulations must be developed and adopted at the national level in order to become binding.

FIGURE 3.4
Percentage differences in energy supply between ME and NME with increasing protein content in the diet
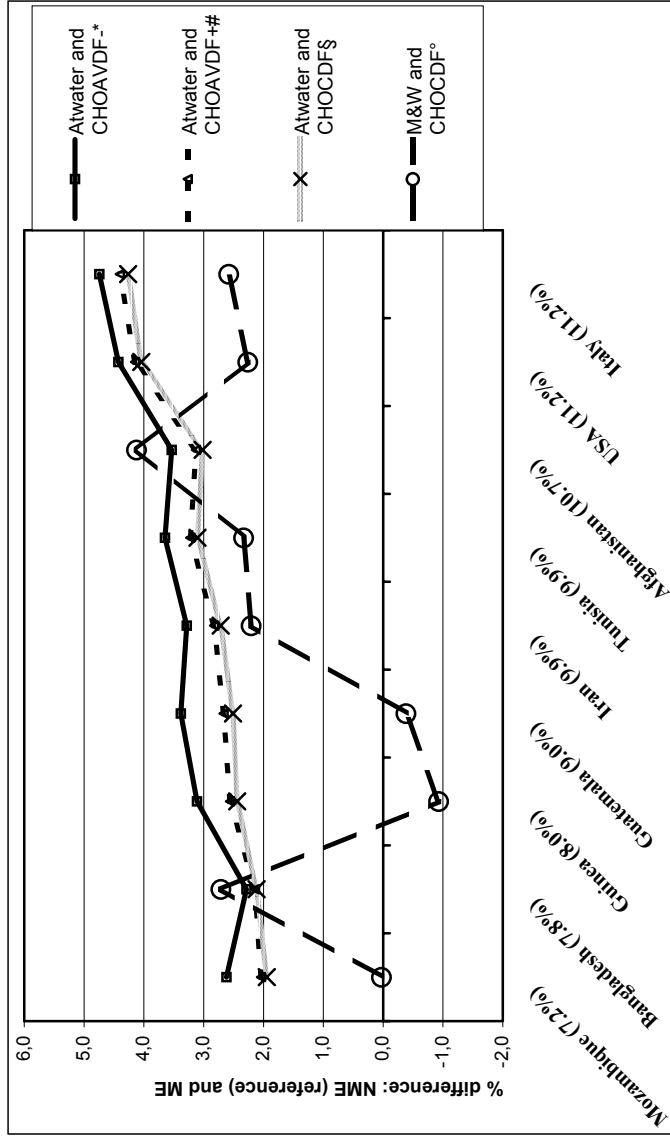
The figures in parenthesis after the country name indicate the percentage of energy from protein.

Notes for Figure 3.4
* The general Atwater factors were applied and values of available carbohydrates by difference (CHOAVDF-)** were used with protein calculated with Jones factors.
\# The general Atwater factors and 8 kJ/g fibre were applied and values of available carbohydrates by difference (CHOAVDF +)** were used with protein calculated with Jones factors.
§ The general Atwater factors were applied and values of total carbohydrates by difference (CHOCDF)** were used with protein calculated with Jones factors.
° The specific Atwater factors (Merrill and Watt, 1973) were applied and values of total carbohydrates by difference (CHOCDF)** were used with protein calculated with Jones factors.
** Tagnames – see footnote[7] on page 17 for an explanation.

This results in different regulations in different parts of the world (e.g. Australia and New Zealand, the EC, the United States, Taiwan Province of China), which may be at odds with each other in specific areas (e.g. allowable ingredients, labelling requirements, etc.). Because of the importance of food and the broad-reaching effects of food regulations within a country's borders, and beyond as they affect trade, it is fair to say that whatever system is in use in a given country is likely to be entrenched, and there will be a great deal of inertia and resistance to change.

The current disparities in the energy conversion factors specified in Codex (Codex Alimentarius, 1991) and in the United States Code of Federal Regulations (FDA, 1985) provide an example of this regulatory dissonance. Codex specifies the use of general factors for energy conversion: 17 kJ/g (4 kcal/g), 37 kJ/g (9 kcal/g) and 17 kJ/g (4 kcal/g), for protein, fat and carbohydrate, respectively. A factor of 29 kJ/g (7 kcal/g) is specified for alcohol, and one of 13 kJ/g (3 kcal/g) for organic acids. The EU (EC, 1990) mirrors Codex with the addition of a factor for polyols, 10 kJ/g (2.4 kcal/g).

In contrast, the United States Code of Federal Regulations allows any one of five ways to calculate energy content of foods. Energy content must include energy from protein, fat, carbohydrate and any ingredients for which specific food factors are known. With these stipulations, any of the following approaches can be used: 1) specific Atwater factors; 2) general factors that are identical to Codex standards for protein, fat and carbohydrate; 3) general factors in which carbohydrate is defined as total carbohydrate minus fibre; 4) specific food factors for particular foods or

ingredients that have been approved by the Food and Drug Administration (FDA); and 5) bomb calorimetry data, subtracting 1.25 kcal per gram of protein to correct for incomplete digestibility.

In a number of countries, labelling regulations are kept simple so that they can be implemented at a reasonable cost by all segments of the food industry. Simplicity would seem especially important for developing countries and smaller food companies. It would also encourage food labelling in those countries in which it is voluntary. Regulatory authorities benefit from a system that allows them to assure compliance with regulations at a reasonable cost. In this regard, uniformity is perhaps a greater consideration than the energy conversion factor or system that is adopted. Regulatory harmonization of both analytical methods and the energy conversion factors would be a great step forward, as regulations have major implications for international trade, and lack of harmonization represents a barrier to trade.

Effects on industry. The current energy values on labels for foods must meet the regulations in force, and thus reflect some form of ME. Any change from the status quo will affect a number of stakeholders: food producers (both large and small), ingredient manufacturers, institutional catering companies, hospitals, restaurants in some countries, and specific sectors such as the weight-loss industry, to name but a few. A change in the prescribed energy conversion factors is not likely to be viewed in the same way by all companies or segments. Many companies may view any change as an undue burden, while a few – e.g. those involved in weight-loss products – might see change as an opportunity, especially if the use of NME factors results in a label with a lower declared energy content.

Larger food companies generally have the capability to adapt readily to whichever system is adopted. Labels have life spans of their own and, given time, they can be modified to reflect changes in regulations; changes have been successfully implemented in some countries with an adequate period of transition. However, it must be recognized that the cost and complexity of a wholesale change to a new system would not be small. Any increased cost would almost certainly be passed on to the consumer and hence, to justify the increase in cost, the consumer should derive real benefit from the proposed change.

Smaller food companies have fewer and limited capabilities. They will often need to rely on values in food tables that are derived from the databases generated by government agencies, or on outside laboratories for food analysis, and they may have to rely on regulatory and other consultants to help them to understand and implement changes. It is likely that this segment will view any change as a burden.

Consumer interests. Consumers are highly variable in their desire for and understanding of nutrition information. In more developed, industrial societies, consumers are increasingly interested in the effects of nutrition on health and longevity. Food labels, and in particular nutrition labelling, can help consumers identify the nutrient content of foods, compare different foods and make informed choices suitable for their individual needs. The amount and type of nutrition information currently required on food labels vary from country to country. The degree to which labels are read and understood is not known with any certainty, and it is likely to be very variable. In many countries, the principal concern for the majority of the population is getting enough to eat at a reasonable cost, whereas in others it is to limit energy and fat intake in order to control body weight and conditions associated with obesity.

In more developed countries, consumers seem best served by a system that allows them to: 1) compare food and energy intakes with recommended energy requirements that are based on the same standard; and 2) compare individual products with each other when making purchase or menu decisions. Relative to the first goal, the consistent application of a uniform system to all foods is likely to be the first step in yielding the greatest benefits to the most consumers. Since recommended energy intakes are currently related to ME, consumers are best served in meeting this goal by food labels that reflect ME. Standardizing energy factors would be a substantial step forward because the flexible use of energy factors can lead to different energy values for the same food. Relative to the second goal, however, NME conversion factors would appear to be preferable in at least two situations: comparisons of individual foods or food products when it is desirable to know their relative potential to support gains of weight, especially gains in fat; and, related to this, counselling of individuals with specific dietary needs that

relate to weight control.[15] Currently, NME factors do not seem to be well understood or to have been widely adopted for these purposes, even by health care professionals. This argues against the benefits of a wholesale change in more developed countries at this time, given the conflicting goals.

In countries where the major nutritional problem is assuring adequate intakes, the vast majority of consumers would be best served by harmonization on factors that take into account the issues relative to energy requirements, how they are expressed, and how well food supplies meet these needs: food databases, food consumption surveys, and FBS. This is because the public health aspects of nutrition predominate for such countries, and these are the "tools of the trade" in the public health arena. Even in such countries, the primary concern of a steadily increasing percentage of individuals is overnutrition. For these individuals, use of NME factors in the clinical setting may be of value.

Effects on health care professionals, educators and government staff.
It is clear from this discussion that the lack of standards for measuring and expressing energy-yielding components is problematic for both ME and NME. Nevertheless, any change in the food energy conversion factors that are used, be it standardization within the ME factor system or a shift to the use of NME factors, would have major implications. Since the use of ME factors of one type or another represents the status quo, a change to NME at this time would seem to have larger implications. All food composition databases and tables, textbooks, planning guides, etc. would need to be changed, and an extensive (re-)education programme to bring professionals up to an acceptable level of understanding would be necessary.

One example serves to illustrate these issues. The convention of expressing data and recommendations for protein, fat and carbohydrate as percentages of energy in the diet is deeply entrenched and widely used by health professionals. Current recommendations for a healthy diet suggest a distribution of protein, fat and carbohydrate in the range of 15,

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[15] As ME factors overestimate the ATP-producing potential of some foods, their continued use in these situations will not induce overconsumption; in fact, they will suggest an individual is eating more than he or she actually is.

30 and 55 percent of energy, respectively (based on ME factors). Expressing these same recommendations in NME terms, energy from protein becomes 12 percent, and from fat 31 percent (see Table 3.8). However, it is likely that, because some of the changes to the important recommendations such as energy from fat in the diet are relatively minor, they may simply be ignored.

TABLE 3.8
Effect of using ME or proposed NME factors on apparent percentages of protein, fat and carbohydrate in the diet

	Factor ME-general Atwater kJ/g (kcal/g)	Energy factor NME kJ/g (kcal/g)	In diet g	Energy ME-general Atwater kJ (kcal)	Energy NME kJ (kcal)	Energy ME-general Atwater %	Energy NME %
Protein	17 (4)	13 (3.2)	90	1 530 (360)	1 170 (288)	15	12
Fat	37 (9)	37 (9)	80	2 960 (720)	2 960 (720)	29	30
Available carbohydrates as weight	17 (4)	17 (4)	330	5 610 (1 320)	5 610 (1 320)	55	56
Dietary fibre	8 (2)*	6 (1.4)	25	200 (50)	150 (35)	2	2
Total energy without fibre energy				10 100 (2 400)	9 740 (2 328)		
Total energy with fibre energy				10 300 (2 450)	9 890 (2 363)		

* Proposed new value from FAO, 1998.

Conclusion. Pragmatic consideration of the practical implications of standardizing on one set of energy conversion factors, including a critical evaluation of the possible change from the use of ME factors, leads to several conclusions. First, in none of the areas examined is such a change infeasible – it is more difficult in some than others, but it is feasible in all. Second, such a change would have broad-reaching implications for a

wide range of interests, most of which have been considered only briefly here and some of which may not yet have been recognized. Third, if changes are to made, they will need to be made "simultaneously" across a number of different sectors. Thus, the complexity and costs of making changes must be clearly justified by the benefits to be derived from those changes.

The technical workshop participants addressed the specific issue of whether energy conversion factors should shift from their current system based on ME to one based on NME. On balance, the participants did not endorse changing at this time, because the problems and burdens ensuing from such a change would appear to outweigh by far the benefits. There was uniform agreement, however, that the issue should continue to be discussed in the future, and that it could profitably be revisited during workshops and expert consultations involving recommendations, assessment of adequacy, public health policy, etc. surrounding food and dietary energy. This would assure that scientists in a variety of disciplines, regulators, and policy-makers have an opportunity to explore more thoroughly the merits and implications of making such a change when it is deemed appropriate.

CHAPTER 4: SUMMARY – INTEGRATION OF ANALYTICAL METHODS AND FOOD ENERGY CONVERSION FACTORS

The discussions in the two previous chapters document the major need for rationalization and harmonization of methods of food analysis and energy conversion factors. The participants at the workshop recognized that this is no small task, but believe it is a task that can be accomplished gradually over a number of years, if scientists and regulatory authorities have the will and the willingness to work together to that end. The goal of this chapter is to start that process by summarizing and integrating the recommendations from the previous two chapters. For methods of food analysis, the recommendations are listed in order, from the most desirable approach based on current science to those approaches considered acceptable given current realities. For food energy conversion factors, the preferred factors are integrated into the recommendations, based on the analytical methods used. These factors are based on ME.

4.1 PROTEIN

Preferred. Protein is best measured as the sum of individual amino acid residues (the molecular weight of each amino acid less the molecular weight of water). Amino acid analysis to determine protein should be mandatory in the following situations: 1) food used as the sole source of nourishment, such as infant formula; 2) foods and formulas designed specifically for special dietary conditions; and 3) foods that contain novel proteins. When protein is expressed as the sum of amino acids, an energy conversion factor of 17 kJ/g (4 kcal/g) should be used.

Acceptable. Until values for protein based on amino acid analyses are generally available, protein based on total nitrogen (N) by Kjeldahl (or comparable method) x a factor (AOAC, 2000) is acceptable. When protein is determined in this way, the general factor - 17 kJ (4 kcal/g) should be applied, unless the complete package of analyses specified by Merrill and Watt (1973) are used, in which case the specific factor is preferable.

4.2 FAT

Preferred. For energy purposes, fats should be analysed as fatty acids and expressed as triglycerides (FAO, 1998), as this approach excludes wax esters and the phosphate content of phospholipids, neither of which can be used for energy. For normal dietary fats, a factor of 37 kJ/g (9 kcal/g) should be used. With novel fats (such as salatrims and Olestra®), the content of non-digestible fat should not be included in the energy content of the food. In these instances, the conversion factor for the digestible portion of the fat is 37 kJ/g (9 kcal/g). This requires that a specific energy conversion factor be determined and used for these fats. For example, salatrims:[16] general family 22 kJ/g (5.2 kcal/g), Olestra® 0 kJ/g (0 kcal/g).

Acceptable. Although less desirable, a gravimetric method (AOAC, 2000), is acceptable for the measurement of normal dietary fats. When a gravimetric method is used, an energy conversion factor of 37 kJ/g (9 kcal/g) should be applied, unless the complete package of analyses specified by Merrill and Watt (1973) are used, in which case the specific factor is preferable.

4.3 CARBOHYDRATE

Carbohydrate should be analysed in a way that allows determination of both available carbohydrate and dietary fibre.

Preferred – available carbohydrate. For purposes of energy evaluation, a standardized, direct analysis of available carbohydrate (by summation of individual carbohydrates) (FAO, 1998; Southgate, 1976) is preferable to an assessment of available carbohydrate by difference (total carbohydrate by difference minus dietary fibre). Direct analysis allows separation of individual mono- and disaccharides and starch, which is useful in determination of energy values. Direct analysis is considered the only acceptable method for analysis of carbohydrate in novel foods or in foods for which a reduced energy content claim is to be made. When carbohydrate is determined by direct analysis, it is expressed as the weight of the carbohydrate with a conversion factor of 17 kJ/g (4.0

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[16] Salatrims: random **s**hort- **a**nd **l**ong-chain **tri**acylglycerol **m**olecule**s**.

kcal/g). When expressed as monosaccharide equivalents, a conversion factor of 16 kJ/g (3.75 kcal/g) should be used.

Acceptable – available carbohydrate. Assessment of available carbohydrate by difference (total carbohydrate by difference minus dietary fibre by Prosky or comparable method) is considered acceptable for purposes of energy evaluation of conventional foods. In these instances, an energy factor of 17 kJ/g (4 kcal/g) should be used.

Preferred – dietary fibre. The AOAC (2000) analysis – Prosky (985.29) or similar total dietary fibre method is preferred for analysis of dietary fibre in conventional foods, and an energy conversion factor of 8 kJ/g (2 kcal/g) should be used. When dealing with fibres or oligosaccharides that are specifically added to a food, an analytical method (Prosky or other) and an energy conversion factor specific for the fibre or oligosaccharide in questions should be used. For example, energy conversion factors range from 1.3 kJ/g (0.3 kcal/g) for maize bran fibre to 11 kJ/g (2.6 kcal/g) for fructo-oligosaccharides.

Acceptable – dietary fibre. At present, dietary fibre is determined by a number of methods yielding different results. The method used should be stated and the results of each method should be identified by INFOODS tagnames (Klensin *et al.*, 1989). In food composition tables, the result should similarly be identified with the tagname. The energy factor to be applied to these results should be appropriate for the faction analysed. In the absence of a specific factor associated with the method, a value of 8 kJ/g (2 kcal/g) should be used.

A note about food labelling of carbohydrates. Having different energy conversion factors for carbohydrate determined by different methods is not ideal. Currently there is no way to label carbohydrate with a single value that describes the energy content accurately. As pointed out in Chapter 3, the same weight of different carbohydrates (monosaccharides, disaccharides and starch) yields different amounts of hydrous glucose, and thus different amounts of energy. Stated conversely, the amount (weight) of carbohydrate to yield a specific amount of energy differs

depending on the form, owing to the water of hydration in different molecules.

4.4 ALCOHOL, POLYOLS, ORGANIC ACIDS AND OTHER FOOD ENERGY PRODUCING SUBSTRATES

Analytical methods for organic acids and polyols were not discussed, nor were recommendations made. The following general energy conversion factors are recommended for these substances: alcohol – 29 kJ/g (7 kcal/g), organic acids – 13 kJ/g (3 kcal/g), and polyols – 10 kJ/g (2.4 kcal/g). The recommendations reflect the EC directive (EC, 1990). Where one organic acid or polyol represents a substantial source of energy in a product, use of a more specific factor for that compound may be desirable.

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ANNEXES

I. PARTICIPANTS – TECHNICAL WORKSHOP ON FOOD ENERGY: METHODS OF ANALYSIS AND CONVERSION FACTORS

II. MEMBERS OF WORKING GROUP 5, THEIR RECOMMENDATIONS AND THE MODIFICATIONS TO THOSE RECOMMENDATIONS MADE BY THE CURRENT TECHNICAL WORKSHOP PARTICIPANTS

III. CORRECTIONS TO THE DIET AND/OR STANDARD ENERGY REQUIREMENTS WHEN USING METABOLIZABLE ENERGY (ME) OR NET METABOLIZABLE ENERGY (NME) FACTORS

IV. COMPARISONS OF ENERGY CONTENTS OF BREASTMILK, INFANT FORMULA AND SELECTED FOODS FOR INFANTS AND YOUNG CHILDREN USING ME AND NME ENERGY CONVERSION FACTORS

ANNEX I: PARTICIPANTS – TECHNICAL WORKSHOP ON FOOD ENERGY: METHODS OF ANALYSIS AND CONVERSION FACTORS

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ANNEX II: MEMBERS OF WORKING GROUP 5, THEIR RECOMMENDATIONS AND THE MODIFICATIONS TO THOSE RECOMMENDATIONS MADE BY THE CURRENT TECHNICAL WORKSHOP PARTICIPANTS

As part of the Expert Consultation on Protein in Human Nutrition that took place in July 2001, a working group – Working Group 5 – met for two days to address Analytical Issues in Food Energy and Composition: Energy in Food Labelling, including Regulatory and Trade Issues. This annex gives their recommendations, which were extensively considered and modified to some degree by the current technical workshop participants. These modifications are also given.

1. Members of Working Group 5

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* Also participated at the current technical workshop.

2. Recommendations of Working Group 5 – Analytical Issues in Food Energy and Composition: Energy in Food Labelling, including Regulatory and Trade Issues

Summary
The Working Group met to review and consider the literature on this topic, with special reference to: a) the routes of energy loss from the body such that they could not normally be used to maintain energy balance; b) the size of each energy loss for the energy-providing substrates, including fermentable carbohydrates; c) variation in energy losses among studies of food components; d) the fact that traditional foods have associated energy losses that are not taken into account at present; and e) the factors that modulate energy requirements. Various possible approaches to energy evaluation were examined against a set of criteria suggested in the working paper for the selection of energy values. These included approaches that would account for substrate-associated thermogenesis. The Working Group was aware of difficulties that could arise in the use of various terms that have been used to describe food components to which food energy factors are applicable, and sought to make clarifications. The following recommendations were made.

Energy conversion factors

Recommendation 1
Consideration should be given to the use of the net metabolizable energy (NME) system of factors for food labelling, for food tables and when calculating practical food needs from energy requirements.

Recommendation 2
Circumstances external to food energy availability should be considered to vary energy requirements and not to vary energy availability. Environmental temperature, drugs, exogenous hormones and bioactive compounds should be considered to act on the utilization of NME.

Recommendation 3
The SI unit of energy is the Joule, which should be used for the expression of energy in nutrition (J, kJ, MJ, etc.), without needing to be accompanied by the calorie equivalent.

Terminology

Recommendation 4
To avoid confusion with the National Research Council's definition (NRC, 1981) of net energy, the contraction of "net metabolizable energy" to "net energy" is not advised.

Recommendation 5
INFOODS Tagnames (Klensin *et al.,* 1989) should be used for the unambiguous identification of food components in food databases and for other purposes as appropriate.

Recommendation 6
- Available carbohydrate is a useful concept in energy evaluation and requires to be retained.

- For energy evaluation purposes, an assured direct analysis of available carbohydrate is considered preferable to an assessment of total carbohydrate by difference less dietary fibre.
- Nevertheless, assessment of total carbohydrate by difference less dietary fibre is considered acceptable for energy evaluation purposes with traditional foods, but not with clinical formulations or novel foods, or with foods when reduced or low-energy claims are made.
- In energy evaluation, it is preferable to express available carbohydrate as monosaccharide equivalents.
- The term "glycaemic carbohydrate" may be confused with glycaemic index and has no use in energy evaluation. The term "glycaemic index" should inform the consumer about the quality, and not the quantity, of carbohydrate in foods.

Recommendation 7
- The term "dietary fibre" is familiar to consumers and ought to be retained in food labelling, and therefore in food tables.
- The concept of soluble versus insoluble dietary fibre should not be used in energy evaluation.
- For the present, the AOAC (2000) – Prosky (985.29) method of dietary fibre analysis or similar method should be used in food analysis for the purpose of calculating food energy.
- Fermentability of dietary fibre should be adopted in energy evaluation.
- In determining the energy factor for dietary fibre in traditional foods, a general fermentability value of 70 percent has been assumed when deriving the energy factors of 8 kJ ME/g and 6 kJ NME/g. However, when a nutritional claim for energy is made, the fermentability of the dietary fibre should be determined.
- When unavailable carbohydrate in a product or ingredient is quantifiable as non-starch polysaccharide, fermentability determinations can use Englyst (AOAC, 2000) or similar methodology.
- Isolates of dietary fibre or foods that are artificially enriched in any components of dietary fibre (e.g. resistant starch) should have their specific energy factors determined.

- At present, dietary fibre terminology confuses a number of analytical methods. The results of each method should appear in separate columns in food tables, identified by INFOODS tagnames, allowing energy factors to be applied as appropriate.

Recommendation 8
- For energy evaluation purposes it is recommended that fats are analysed as fatty acids and expressed as triglycerides.
- Poorly or non-available fats and fat-like substances (e.g. artificial fats and natural waxes) and fats that are unusually high in selected fatty acids (e.g. when compared with traditional foods) should have specific energy values if the values differ significantly from the general energy value of fats.
- The non-digestible fat content of poorly or non-digestible fats should not contribute to the nutrient fat content of a food.

Recommendation 9
The term "sugar alcohol" should be phased out of food labelling and replaced with "polyol". Polyols should be recognized as carbohydrates, but not sugars.

Recommendation 10
Individual energy factors for the most abundant organic acids should be required in energy evaluation, although a general factor can usually be applied in food labelling.

3. The current technical workshop's modifications to the recommendations of Working Group 5

Among bullets in Recommendation 6
- For energy evaluation purposes, a standardized direct analysis of available carbohydrate is considered preferable to an assessment of total carbohydrate by difference less dietary fibre.

Among bullets in Recommendation 7

- In determining the energy factor for dietary fibre in traditional foods, a general fermentability value of 70 percent was adopted (Livesey, 1990) when deriving the energy factors of 8 kJ ME/g and 6 kJ NME/g. Specific energy factors should apply to added and novel (EC, 1997) or functional (FNBIM, 2002) fibre (e.g. resistant starches, inulin, polydextrose).
- At present, dietary fibre is determined by a number of methods yielding different results. Therefore, the results of each method should appear in separate columns of food tables, identified by INFOODS tagnames, allowing energy factors to be applied appropriately.

Among bullets in Recommendation 8

- Determination of total lipid by standardized gravimetric methods is acceptable for most energy evaluation purposes. However, it is preferred that fats are analysed as fatty acids and expressed as triglycerides because this excludes waxes and the phosphate content of phospholipids.
- The non-digestible triglyceride or fat content of energy-reduced fats should not contribute to the nutrient fat content of a food.

Note: Modifications were also suggested regarding labelling of the nutrient content of carbohydrate.

ANNEX III: CORRECTIONS TO THE DIET AND/OR STANDARD ENERGY REQUIREMENTS WHEN USING METABOLIZABLE ENERGY (ME) OR NET METABOLIZABLE ENERGY (NME) FACTORS

Energy requirement estimates for all ages are currently based on representative energy expenditures plus additional needs for growth, pregnancy and lactation. Once the energy requirement has been estimated, the food energy intakes needed to match this requirement must be determined. Current estimates of energy requirements are based on methods that reflect the measurement of metabolizable energy (ME) expenditure and hence are expressed in ME terms (FAO, 2004). However, energy expenditure varies with the composition of the diet, particularly with protein, alcohol, fibre and other fermentable compounds and short- to medium-chain fats. Because current estimates of requirements were derived from healthy people consuming representative diets, a correction may be desirable in circumstances in which the composition of the diet departs from "average". In addition, there are some clinical situations in which such a correction may prove useful.

Methods of applying corrections when matching intakes with requirements were previously given for variations in dietary fibre content (WHO, 1985). A revised method to correct for the composition of the diet using ME is shown in Box III.1, while an alternative method using net metabolizable energy (NME) is shown in Box III.2. The basis for the corrections is outlined in the current report. For some purposes, corrections may not be necessary. For regular diets, i.e. those consumed by 95 out of every 100 people in an adult group – male, female, of any age, healthy, non-slimming – and with no more than average alcohol consumption, the correction will usually be less than 2.5 percent (Livesey, 2002). For practical purposes, diets containing 10 to 20 percent of energy (ME) from protein, 1 to 3 percent of energy (ME) from fibre and 0 to 6 percent of energy (ME) from alcohol result in errors of less than 2.5 percent.

An alternative approach uses revised food energy factors (NME values) and a single adjustment of energy requirement to the same scale.

This method overcomes the problem of regular diets with similar ME contents differing from one another by up to 5 percent in their capacity to match energy requirements, and by up to 11 percent in the protein intakes that fall within the range from adequate to tolerable upper intakes (Livesey, 2002). The method also overcomes the problem of some traditional foods and novel ingredients with similar ME contents differing by up to 30 percent in their capacity to contribute to the standard energy requirement estimate (Livesey, 2001).

BOX III.1

Correction for the composition of the diet when ME intakes are being matched with requirements

General conversion factors used to obtain the ME of the diet

Protein	17 kJ (*4 kcal*) per gram
Fat	37 kJ (*9 kcal*) per gram
Available carbohydrate (expressed as monosaccharide equivalent) *or*	16 kJ (*3.75 kcal*) per gram
Available carbohydrate (by difference or by weight) or total carbohydrate	17 kJ (*4 kcal*) per gram
Dietary fibre (in mixed diets)	8 kJ (*2 kcal*) per gram
Alcohol	29 kJ (*7 kcal*) per gram

Separation of carbohydrate into available carbohydrate and dietary fibre is preferred. If only the value for total carbohydrate is known, a conversion factor of 16.7 kJ/g, or rounded to 17 kJ/g (*4 kcal/g*), should be used. Refer also to Table 3.3 on p. 29.

For diets that are very high or low in protein, or high in dietary fibre (or high in alcohol or other components not used traditionally in foods) the following corrections can be applied (background outlined in current report):

- For every 1 percent of ME from **protein** consumed above the amount that provides 15 percent of ME in the diet, increase the requirement by 0.2 percent (or add 3.4 kJ [0.8 kcal] for each gram of protein consumed above the amount that provides 15 percent of energy). Decrease by (or deduct) this amount when protein intake is less than 15 percent of ME.
- For every 1 percent of ME from **alcohol** consumed, increase the requirement by 0.1 percent (or add 3 kJ [0.7 kcal] per gram of alcohol to the energy requirement).

Box III.1 continued

- For every 1 percent of ME from **dietary fibre** (natural and intact in plant foods) consumed above the amount that provides 2 percent of ME in the diet, increase the requirement by 0.25 percent (or add 2 kJ [0.5 kcal] for each gram of fibre above the amount that provides 2 percent of energy). Decrease by (or deduct) this amount when dietary fibre intake is less than 2 percent of ME.
- For **other components** when present in foods or diets, including those not traditionally added (e.g. non-digestible and fermentable carbohydrates, medium- and short-chain triglycerides, lactic acid, etc.) add the difference between the ME and NME values (kJ [or kcal] per gram), for which sets of both values are given in the current report.

Example

For an estimated energy requirement of 8 000 kJ/day and a diet containing 30 percent of ME from protein, 5 percent of ME from fibre and no alcohol. For the extra protein (15 percent of ME above 15 percent of ME for a total of 30 percent), increase the requirement by 3 percent (15 × 0.2 percent). For the extra fibre (3 percent ME above 2 percent of ME for a total of 5 percent), increase the requirement by 0.75 percent (3 × 0.25 percent). In total, increase the energy requirement of this diet by 3.75 percent (3 percent for extra protein, 0.75 percent for extra fibre) to a total of 8 300 kJ/day (8 000 × 1.0375).

BOX III.2

Expression of food needs as the "food NME requirement" when food energy value is expressed in the mode of NME

General conversion factors used to obtain the NME of the diet (see current report)

Protein	13.3 kJ (*3.2 kcal*) per gram
Fat	36.6 kJ (*8.7 kcal*) per gram
Available carbohydrate (expressed as monosaccharide) *or*	15.7 kJ (*3.75 kcal*) per gram
Available carbohydrate (by difference less weight of dietary fibre)	16.7 kJ (*4 kcal*) per gram
Total dietary fibre (in mixed diets)	6 kJ (*1.5 kcal*) per gram
Alcohol	26 kJ (*6.2 kcal*) per gram

The FAO/WHO/UNU standard energy requirement is multiplied by the factor 0.96 to obtain the practical food needs in terms of NME (food NME requirement).

Notes:
a) The 0.96 factor is the ratio of NME to ME for the average diet consumed during determination of the FAO/WHO/UNU requirement recommendations (FAO, 2004). As in Box III.1, this is deemed to be 15 percent of ME (13 percent of NME) from protein, 2 percent of ME (1.5 percent of NME) from dietary fibre, and no alcohol.
b) When a requirement recommendation derives from experimental studies during which a diet consumed has a different composition from that described in the previous paragraph (i.e. for which the average NME:ME ratio is not 0.96 *during the experimental determination*), the more specific NME:ME factor for the diet consumed during the determination should be used in preference to 0.96.
c) It is not possible to ascribe an NME value for total carbohydrate as the proportion of fibre is not known. In these cases, it must be assumed that ME and NME values for total carbohydrates are the same.

ANNEX IV: COMPARISONS OF ENERGY CONTENTS OF BREASTMILK, INFANT FORMULA AND SELECTED FOODS FOR INFANTS AND YOUNG CHILDREN USING ME AND NME ENERGY CONVERSION FACTORS[1]

The energy content of breastmilk is calculated in four different ways in Table 3.6 (see Section 3.8 on p 37) using representative values for protein (8.9 g/litre), fat (32 g/litre) and carbohydrate (74 g/litre) (Fomon, 1993). ME-ATW represents an estimation of the energy content using standard Atwater general factors. ME-specific is calculated using the Atwater specific factors published by Merrill and Watt (1973). NME-1 and NME-2 values are calculated using NME factors with two different sets of assumptions. The NME-1 value was calculated using the same figures for protein, fat and carbohydrate as were used to calculate ME-ATW, and does not take into account the different digestibilities of immunoglobulins and oligosaccharides in human milk. Immunoglobulins comprise about 12 percent of the protein in human milk – about 1.1 g/liter (Fomon, 1993) – mostly (95 percent) IgA which, along with some other proteins in human milk such as lactoferrin, is not completely digestible. Up to 10 percent of the protein in human milk may not be nutritionally available to the infant (Davidson and Lonnerdal, 1987). Oligosaccharides comprise about 15 percent of carbohydrate in breastmilk (13 g/litre) (McVeagh and Miller, 1997; Coppa *et al*., 1997). These carbohydrates are not digestible, but are fermentable in the colon. NME-2 in Table IV.1 is a recalculation of the energy content of human milk assuming that 10 percent of the protein is unavailable and applying the NME factor for unavailable carbohydrate to oligosaccharides. The energy value calculated with the Atwater specific factor value is about 22 percent higher than that calculated using Atwater general factors. NME results in a decrease of an additional 4 percent, regardless of the assumptions made.

Table IV.1 examines the effects of using NME conversion factors rather than Atwater general or specific factors on the energy contents of

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[1] Annex IV is based on MacLean (in press). The tables come from that publication.

a standard milk-based formula[2] containing 14 g/litre protein (non-fat milk and whey protein concentrate), 36.5 g/litre fat (a mixture of three vegetable oils) and 73 g/litre carbohydrate (lactose). Heat processing of lactose-containing formulas converts some of the lactose to lactulose (Beach and Menzies, 1986; Hendrickse, Wooldridge and Russell, 1977). Lactulose is indigestible in the small intestine, but fermentable in the colon. Levels greater than 3 g/litre are uncommon. NME-2 shows the recalculated energy content of the formula assuming a level of lactulose of 3 g/litre and a corresponding decrease of lactose content. Using NME rather than ME (Atwater general factors) results in a decrease of between 5 and 6 percent.

A representative soy protein-based infant formula[3] is also shown in Table IV.1. Protein (16.6 g/litre) is provided by soy protein isolate and l-methionine, fat (36.9 g/litre) by a mixture of vegetable oils, and carbohydrate (69.6 g/litre) by a mixture of corn syrup solids and sucrose. The energy contents using Atwater general and specific factors and NME factors are shown. Soy protein-based formulas have an inherent content of fibre – soy polysaccharide – that derives from the soy protein isolate ingredient used in their manufacture. This fibre, which would not normally exceed 3 g/litre, is fermentable to some degree. NME-3 in the table assumes this level of soy polysaccharide and applies the NME value for unavailable carbohydrate. Use of NME factors results in a decrease of between 4 and 5 percent compared with ME general factors.

Tables IV.2A and IV.2B show the composition and declared values for energy for four representative baby foods from a single manufacturer[4] and compare these values with those calculated using Atwater general and, where possible, specific factors and NME factors. Using NME rather than ME general factors results in variable decreases in energy content from as low as 2 percent for rice cereal to as high as 9 percent for chicken with gravy.

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[2] Similac® with Iron, Abbott Laboratories, United States Formulation.
[3] Isomil® with Iron, Abbott Laboratories, United States Formulation.
[4] Gerber Products Company, Freemont, Michigan. 1999 nutrient values.

TABLE IV.1

Energy values of standard infant formulas

	Composition g/litre	ME-Atwater[5] kJ/ml (kcal/ml)	ME-specific[6] kJ/ml (kcal/ml)	NME-1[7] kJ/ml (kcal/ml)	NME-2[8] kJ/ml (kcal/ml)
Milk-based[1]					
Protein	14.0	0.24 (0.06)	0.25 (0.06)	0.18 (0.04)	0.18 (0.04)
Fat	36.5	1.35 (0.32)	1.35 (0.32)	1.35 (0.32)	1.35 (0.32)
Carbohydrate	73	1.24 (0.30)	1.18 (0.28)	1.17 (0.28)	1.12 (0.27)
Lactulose[3]	3.0	--		--	0.02 (0.00)
Fibre[4]	--	--	--	--	-- --
Energy		2.83 (0.68)	2.78 (0.67)	2.70 (0.64)	2.67 (0.63)
Soy protein-based[2]					
Protein	16.6	0.28 (0.07)	0.24 (0.06)	0.22 (0.05)	0.22 (0.05)
Fat	36.9	1.37 (0.33)	1.36 (0.33)	1.37 (0.33)	1.37 (0.33)
Carbohydrate	69.6	1.18 (0.28)	1.16 (0.28)	1.18 (0.28)	1.13 (0.27)
Lactulose[3]	--	--	--	--	--
Fibre[4]	3.0	--	--	--	0.02 (0.00)
Energy		2.83 (0.68)	2.77 (0.66)	2.77 (0.66)	2.74 (0.65)

[1] Similac® with Iron (Abbott Laboratories): composition shown is United States formulation, label claim values.

[2] Isomil® with Iron (Abbott Laboratories): composition shown is United States formulation, label claim values.

[3] Variable, low (negligible) in powders, higher in liquids (see Beach and Menzies, 1986; Hendrickse, Wooldridge and Russell, 1977).

[4] Maximum inherent level from soy protein isolate ingredient.

[5] Metabolizable energy using the Atwater conversion factors: protein 17 kJ/g (*4 kcal/g*), fat 37 kJ/g (*9 kcal/g*), carbohydrate 17 kJ/g (*4 kcal/g*).

[6] Calculated using specific factors from Merrill and Watt (1973: Tables 1 and 8). Carbohydrate in soy protein-based formulas uses a blended figure assuming a mixture of corn syrups and sucrose.

[7] NME-1: applying NME values to protein, fat and carbohydrate without regard to lactulose or fibre: protein 13 kJ/g (*3.2 kcal/g*), fat 37 kJ/g (*9 kcal/g*), carbohydrate 17 kJ/g (*4.0 kcal/g*).

[8] NME-2: applying NME values to protein, fat and carbohydrate, but assuming amount of lactose is reduced by a corresponding increase in lactulose, which is calculated as unavailable carbohydrate; energy factor for available carbohydrate assumes present as disaccharides: protein 13 kJ/g (*3.2 kcal/g*), fat 37 kJ/g (*9 kcal/g*), lactose 16 kJ/g (*3.8 kcal/g*).

Note: NME-1 and NME-2 in this table are not the same variables that appear in Figure 3.2 and Table 3.7.

TABLE IV.2A

Effect of using rounded ME and NME conversion values on label claim values for energy of selected baby foods[1]

	Current label[2, 3, 4]	Calculated ME[7] kJ/100g (*kcal/100g*)	ME specific	Calculated NME[8] kJ/100g (*kcal/100g*)
Rice cereal (dry)				
Protein-g	8.2	139 (*33*)		107 (*26*)
Fat-g	3.2	118 (*29*)		118 (*29*)
Total carbohydrate-g[5]	79.4	1 336 (*315*)[6]		1 333 (*314*)[6]
Fibre-g	1.5			
Sugars-g	3.8			
Energy kJ (*kcal*)	1 590 (*380*)	1 593 (*377*)	1 602[9] (*383*)	1 558 (*369*)
Apple sauce[10]				
Protein-g	--	--		--
Fat-g	--	--		--
Total carbohydrate-g[5]	13.4	211 (*49*)[6]		207 (*49*)[6]
Fibre-g	1.9			
Sugars-g	11.3			
Energy kJ (*kcal*)	234 (*56*)	211 (*49*)	176 (*41*)	207 (*49*)

[1] Gerber Products Company, Fremont, Michigan. United States nutrient label claim values (1999).
[2] Macronutrients for all products are g per 100 g.
[3] Label energy values in this column for all products are kJ (kcal) per 100 g declared by the manufacturer.
[4] Values for kJ for all products are calculated from manufacturer's values for kcal.
[5] Total carbohydrate includes values for fibre and sugars.
[6] Calculated as available carbohydrate (total less fibre) x a factor + fibre x a factor.
[7] Calculated using the following factors: protein 17 kJ/g (*4 kcal/g*), fat 37kJ/g (*9 kcal/g*), available carbohydrate 17 kJ/g (*4 kcal/g*), fibre 8 kJ/g (*1.8 kcal/g*).

[8] Calculated using the following factors: protein 13 kJ/g (*3.2 kcal/g*), fat 37 kJ/g (*9 kcal/g*), available carbohydrate 17 kJ/g (*4 kcal/g*), fibre 6 kJ/g (*1.5 kcal/g*).

[9] Taken from rice, dry – granulated for breakfast cereal (item 1882, Table 1) from Merrill and Watt (1973).

[10] Taken from apple sauce, ingredient apples (item 28, Table 1) from Merrill and Watt (1973).

TABLE IV.2B
Effect of using rounded ME and NME conversion values on label claim values for energy of selected baby foods[1]

	Squash			Chicken and chicken gravy		
	Current label[2, 3, 4]	**Calculated ME**[7] kJ/100g (*kcal/100g*)	**Calculated NME**[8] kJ/100g (*kcal/100g*)	**Current label**[2, 3, 4]	**Calculated ME**[7] kJ/100g (*kcal/100g*)	**Calculated NME**[8] kJ/100g (*kcal/100g*)
Protein-g	0.8	14 (*3*)	10 (*3*)	10.9	185 (*44*)	142 (*35*)
Fat-g	0.2	7 (*2*)	7 (*2*)	6.4	237 (*58*)	237 (*58*)
Total carbohydrate-g[5]	7.1	106 (*25*)[6]	102 (*25*)[6]	3.1	48 (*11*)[6]	47 (*11*)[6]
Fibre-g	1.7			0.6		
Sugars-g	3.8					
Energy-kJ (*kcal*)	142 (*34*)	127 (*30*)	119 (*30*)	477 (*114*)	470 (*113*)	426 (*104*)

[1] Gerber Products Company, Fremont, Michigan. United States nutrient label claim values (1999).

[2] Macronutrients for all products are g per 100 g.

[3] Label energy values in this column for all products are kJ (kcal) per 100 g declared by the manufacturer.

[4] Values for kJ for all products are calculated from manufacturer's values for kcal.

[5] Total carbohydrate includes values for fibre and sugars.

[6] Calculated as available carbohydrate (total less fibre) x a factor + fibre x a factor.

[7] Calculated using the following factors: protein 17 kJ/g (*4 kcal/g*), fat 37 kJ/g (*9 kcal/g*), available carbohydrate 17 kJ/g (*4 kcal/g*), fibre 8 kJ/g (*2.0 kcal/g*). Atwater specific values for energy are not included because the type of squash used and the proportions of ingredients in the chicken and chicken gravy are not known.

[8] Calculated using the following factors: protein 13 kJ/g (*3.2 kcal/g*), fat 37 kJ/g (*9 kcal/g*), available carbohydrate 17 kJ/g (*4 kcal/g*), fibre 6 kJ/g (*1.5 kcal/g*).