ANALYSIS OF FOOD BY NUCLEAR AND RELATED ANALYTICAL TECHNIQUES (INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS)

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ANALYSIS OF FOOD BY NUCLEAR AND RELATED ANALYTICAL TECHNIQUES (INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS)

By

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ABSTRACT

The purpose of this study was to evaluate the sensitivity of INAA for multi-element analysis of some 23 foodstuffs most commonly consumed by the South African population. The minimum detectable concentration of the essential and/or toxic elements, as determinable by the routine Instrumental Neutron Activation Analysis (INAA) protocol at Necsa, has been evaluated in terms of the recommended daily intake and/or tolerable intake. The information regarding the commonly consumed food types, the quantity of intake and the dietary recommendations of essential and toxic elements were obtained from world literature as no South African regulations or guidelines were available up to this point in time(49). The foodstuffs used in this study were purchased around Pretoria and may probably be regarded to provide a suitable first order database to compare element concentrations of foodstuffs expected to be contaminated by natural geological phenomena, agricultural practices (e.g. use of fertilizers, irrigation from contaminated water sources) and by mining and mineral processing activities in South Africa.

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Declaration of authenticity

I, the undersigned Disang Macdonald Sennanye, hereby certify that the work presented in this dissertation except where otherwise indicated, is my own original work and has not been submitted to any university for the purpose of obtaining a degree.

Disang Sennanye

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GENERAL ABBREVIATIONS and SYMBOLS

AI	Adequate Intake
DRI	Dietary Reference Intake
EAR	Estimated Average Requirement
ESADDI	Estimated Safe and Adequate Daily Dietary Intake
FAO	Food and Agriculture Organization of the United Nations
FWHM	Full Width at Half Maximum of the photo peak
IAEA	International Atomic Energy Agency
IDC	Irradiation, Delay and Counting
INAA	Instrumental Neutron Activation Analysis
MDC	Minimum Detectable Concentration
Necsa	South African Nuclear Energy Corporation Pty Ltd.
ppm	Parts per million (10^{-6})
ppb	Parts per billion (10^{-9})
PTI	Provisional Tolerable Intake
RDA	Recommended Dietary Allowance
SAFARI-1	South African Fundamental Atomic Reactor Installation
$T_{1/2}$	Half-life
Unc	Uncertainty
WHO	World Health Organisation
Yrs	Years
μ	Micro (10^{-6})
μg	Microgram
φ	Neutron flux

TABLE OF CONTENTS **Page**

1 INTRODUCTION, OBJECTIVES AND SIGNIFICANCE OF THE STUDY

1.1 Introduction

There has been a growing interest in the determination of concentration levels of inorganic elements in foodstuffs over the last few years. Investigating the concentration of elements in foodstuffs is of eminent importance, since deficiency or toxicity of these elements can cause disease in humans. Nuclear techniques like Instrumental Neutron Activation Analysis (INAA) are commonly used at Necsa to determine macro, micro and trace amounts of various elements in a wide variety of matrices.

In this study INAA will be evaluated to which extent it is capable to determine relevant quantities of elements in foodstuffs, taking the nutritive value (essential and/or toxic elements) of foodstuffs and the rate of consumption into consideration. Or in other words, is INAA, as routinely applied at Necsa, sensitive enough to evaluate the nutritive value of foodstuffs based on element concentrations? It should be emphasized that this study only evaluates the sensitivity of the routine protocols applied at Necsa for short-, intermediate- and long-lived isotopes. Optimization of the protocols, if required, will be dealt with in a follow-up study.

Commonly consumed foodstuffs, which were considered in this study, include fish, beef, pork, pumpkin, beetroot, green beans, porridge, sugar, coffee, tea, milk, spinach, potatoes, white bread, brown bread, rice, cabbage, tomatoes, margarine, onions and chicken meat, livers and eggs.

A database has been built, from which some examples will be provided to show the potential to evaluate foodstuffs for essential and/or toxic elements.

1.2 Objectives

The main objective of the study is to evaluate the sensitivity of INAA for its capability of multi-element determinations in foodstuffs. The following information will be gathered to fulfill the objectives.

- Information on type of foodstuffs produced in South Africa, which are generally consumed by its multi-ethnic population.
- Tabulation of essential and/or toxic inorganic elements with regard to their required daily intake and/or toxic levels.
- Evaluation of element concentration ranges in foodstuffs from national and international literature.

- Evaluation of concentrations and lower limits of determination for elements in foodstuffs by routine INAA as applied by Necsa.

1.3 Significance of the study

Since a deficiency or sufficiency can cause abnormalities or diseases in humans, the knowledge of element concentrations in foodstuffs is important. However, scattered information on concentration of biological important and toxic elements in food in South Africa is available, which needs to be compiled. The study includes the dietary intake as a function of age, as well as the nutritive value (essential and/or toxic elements) of foodstuffs as obtained from literature. From this the capability of routine INAA in food analysis, to contribute to nutrition and health related issues for South Africa, is evaluated.

2 THEORETICAL BACKGROUND OF FOOD ANALYSIS

2.1 Identified foodstuff and the consumption rate in South Africa.

South Africa is a multicultural population country, which leads to large differences in foodstuff consumption. According to the report on South African food consumption studies undertaken amongst different population groups [32], a few main food groups are common for the South African population at large. They are cereals, stimulants, sugar and honey. Three age groups (1-5 years, 6-9 years and 10+ years) are differentiated between (the persons of ten years and above are regarded as adults since the average consumption of adolescents did not differ significantly from that of adults). Pregnant women, infants (0-1 year) and the elderly people could not be included in the study since no or little data are available for these groups.

The summary of food items commonly consumed by children and adults in South Africa, compiled from all databases reviewed [32], is provided in Table 1. These foodstuffs are also used to evaluate the element sensitivity of routine INAA as applied at Necsa.

Table 1: Summary of food items commonly consumed by children and adults in South Africa, together with the estimated daily intake

Foodstuff	Quantity of intake (g/d) for 1- 5 years		Quantity of intake (g/d) for 6 - 9 years		Quantity of intake (g/d) for 10+ years	
	Wet	Dry	Wet	Dry	Wet	Dry
Maize porridge	1140	218	1251	240	2055	395
Coffee	540	10	540	12	1367	24
Tea	500	10	520	10	1283	20
Milk	700	112	500	80	778	124
Spinach	420	30	421	30	501	35
Potatoes	300	48	480	76	481	76
White bread	270	169	360	225	481	300
Rice	460	460	500	500	423	423
Brown bread	240	137	360	205	408	233
Cabbage	220	20	241	22	344	32
Tomatoes & onion stew	210	10	300	15	300	15
Chicken meat	159	50	250	79	265	84
Chicken eggs	156	39	200	50	206	51
Sugar	60	60	61	61	99	99
Margarine	35	35	47	47	64	64

The consumption rates are originally given in gram per kilogram of body weight per day. For further data evaluation these were converted to gram per day (g/d) by multiplying the intake value by the estimated average bodyweights of the groups concerned. They were thereafter converted to dry weight by multiplying the intake value with the dry/wet mass ratio as determined for the individual foodstuffs (see Annexure 3) . As stated above, the information in Table 1 has been obtained from the report on South African food consumption studies undertaken amongst different population groups [32]. ***However, this needs to be investigated further and updated where required, since the estimated total food intake seems to be high for the individual age groups. Preferably data should be gathered for more differentiated age groups than those given in Table 1***.

Estimated values for food intake used to evaluate the element sensitivity by INAA were obtained from the South African estimated values for intake via ingestion[7]. However, these values have been adapted to make provision for the respective age categories for which dietary element intake recommendations were available (see 2.4.1). Intake values for coffee, tea, sugar and bread, as shown in Table 2, were obtained as a common factor from a food survey amongst Necsa personnel (15 persons: Building P1600) for an age group between 20-40 years, which included mostly women. The overall compiled data is provided in Table 3. This survey also showed that there are more foodstuffs commonly consumed than those provided in Table 1 and used in this study, which shows that specific food consumption habits may be required for specific target groups.

Table 2: Average intake of some foodstuffs by Necsa personnel (Building P 1600)

Coffee	12 g/d
Bread	140 g/d
Tea	10 g/d
Sugar	20 g/d

Table 3: Other foodstuffs consumed by Necsa personnel (P1600)

Foodstuff	Response (%)	Indicated approximate intake
Carrots	33	2 table spoons a week
Corn flakes	20	2 cups twice a week
Fish fingers	6	8 twice a week
Apple	40	1 apple per day
Orange	26	1 orange per day
Marrows	6	2 in a week
Cucumber	6	1 twice a week
Garlic (crushed)	6	1 table spoon in a week
Olive oil	6	10ml per day
Sweet pepper	6	50g in a week
Beef (mince)	33	2 table spoon in a week
Peas	6	2 table spoon in a week
Mushroom	6	1 table spoon in a week
Juice	6	250ml per day
Polony	20	3slices thrice a week
Tuna	6	3 table spoon in a week
Cheese	33	3 table spoons in a week
Spaghetti	6	2 table spoons in a week
Fish	13	200g in a week
Red meat	40	200g thrice a week
Eggs	26	2 eggs twice a week
Porridge	40	2 ladles per day
Pear	6	1 pear twice a week
Avocado	20	1 in a week
Sweet potato	20	2 table spoon in a week
Spinach	20	2 table spoon in a week
Banana	13	1 banana in twice a week
Rice	40	2 ladles twice a week
Milk (powder)	33	2 tea spoon per day
Milk	13	250ml per day
Chicken	26	200g twice a week
Chicken liver	33	100g per week
Soft drink	20	340ml thrice a week
Cabbage	26	2 table spoon in a week
Margarine	20	2 tea spoon per day
Beetroot	26	1 table spoon in a week
Fatcakes	20	2 in a week

2.2 Classification of elements

Minerals and trace elements enter the human body through ingestion of food, inhalation of air and absorption through the skin. The chemical elements can be categorized, depending on their biological functions in the human body, as essential, non-essential and toxic [40].

Some elements are commonly observed in various foodstuffs at high concentrations like e.g. calcium, potassium, magnesium and sodium, whereas other elements are found at low concentration and even trace amounts like e.g. iron and iodine. Trace elements normally occur in concentrations ranging from around 10 ppm down to sub-ppb levels [18,22].

2.3 Essential and toxic elements

The human 's body is supplied with elements mostly through the dietary intake. Every element has its specific function in the body. Some of these elements play an important role in the human body as they are building and maintaining the optimum health, and accordingly they are regarded as essential. Others may cause sicknesses or even death and are therefore regarded as toxic. Different authors [3,4,40,43,46] describe the biological role of the various elements and the potential food sources where these elements can be obtained.

Although classification of elements is a difficult task, some authors have classified the elements into essential, probably essential and toxic as shown in Table 3 [22,28,33,34,35]. Parr R.M et al. and Reilly C classified nickel, silicon and vanadium as essential for the human diet, whereas international organizations like the IAEA, FAO and WHO [40] classified them as probably essential.

Table 4: Classification of essential and/or toxic elements

Essential macro-nutrients and essential trace elements	Ba, Br, Ca, Cl, Co, Cr, Cs, Cu, Fe, I, K, Mg, Mn, Mo, Na, Rb, Se, Sc, Zn
Trace elements that are probably essential	B, Ni, Si, V
Toxic elements	F, Pb, Cd, Hg, Al, As, Li, Sn

Zinc is one of the most important essential trace elements, which forms part of many enzymes. It plays an important role in the synthesis and decomposition of carbohydrates, proteins, lipids and nucleic acids [2]. Essential elements can be toxic to the body when large amounts are taken in [30]. For this purpose Dietary Reference Intake values (Recommended Dietary Allowance [RDA], Provisional Tolerable intake [PTI], Adequate Intake [AI], etc) are recommended by amongst others the FAO, WHO and the United States National Research Council [22,40].

The concentration of elements in the body may vary and is affected by a number of factors like nutrition, sex, age, chemical form of the element and physiological conditions (e.g. pregnancy).

Toxic elements cause harm to the body through skin contact, ingestion and inhalation [19]. Since the human body is supplied with elements mostly through the dietary intake, the information concerning the naturally occurring levels of toxic elements in food is necessary for regulatory purposes. Toxic elements have traditionally been considered as a subgroup of nonessential elements, but this classification is misleading because many, if not all, essential elements are toxic when they are ingested at high levels for long periods [17].

2.4 Dietary recommendations

The human body needs balanced levels of elements from the diet to avoid too high intake (toxicity) or too low intake (deficiency). Nutritional deficiency of essential elements is affecting hundreds of millions of people worldwide, especially in the developing countries [24]. For that reason, international organizations like the IAEA, WHO and independent countries like the USA and Australia have made recommendations on daily and/or weekly element intake.

The National Academy of Sciences describes dietary reference intake values as "the reference values that are quantitative estimates of nutrient intake to be used to planning and assessing diets for healthy people". They include the recommended dietary allowance [RDA] but also the adequate intake [AI], the uptake intake level [UL], and the estimated average requirement [EAR] [30].
In this study the adequate intake and estimated average requirement were used where data was not sufficient to provide RDA values for essential elements. Furthermore, the provisional tolerable intake [PTI] data was used for toxic elements.

One of the observations from this study is that there are no dietary reference intake values available for South Africa. Furthermore, the dietary recommendations of nutrients differ depending on the source reviewed. The recommendations differ from one source to another and not all cover the same nutrients. The United State's adult RDA for iodine is e.g. 150 μg/d, the Australian RDI is 150 μg/d and the WHO/FAO value is 160 μg/d, while values between 150-200 μg/d are common in European and other countries. As a further example the selenium values regarded essential for human health between various countries is given in Table 4 [18,21,22,36,40,,45].

2.4.1 Derived values for application in South Africa

Most of the values used for the purpose of this study are obtained from different sources [30,31,40,41]. These data are compiled in Table 5, from which it is observed also that analytical techniques with a large dynamic range are required since the dietary recommendations differ largely for various elements; up to six orders of magnitude (e.g. 0.2 micrograms of chromium to 0,6 grams of potassium). In this regard the use of INAA may also proof a good choice. The elements chlorine and vanadium, which could not be obtained from these sources were taken from other specific publications [47, 48], to allow a first order of estimate on the sensitivity for these element by routine INAA. Uranium and thorium were also evaluated in the study. However, here both the radiological toxicity and chemical toxicity were taken as criteria to evaluate the INAA-sensitivity against[7].

The Provisional Tolerable intake values for toxic elements as set by WHO for all six age/sex groups starting from a young child of 1-3 years [40] , are shown in Table 6. According to the joint FAO/WHO Expert Committee on Food Additives these values are said to be provisional because new information would initiate a review of intake. Tolerable signifies permissibility rather than acceptability, where intake of contaminant is unavoidably associated with the consumption of otherwise regarded nutritious food or with the inhalation of air. Weekly data are given when a compound has a bio-accumulative chronic toxic effect and daily fluctuations in intake are acceptable if the average longer term does not exceed a certain limit [45].

Table 5: Selenium recommendations in human diet in different countries

Age (months/ years)	Body Weight (kg)	UK RNI (μg/d)	USA RDA (μg/d)	Australia RDI (μg/d)	FAO/WHO (μg/d)	Average (μg/d)
Infants						
0-6 m	6	10	10	10	6	8
7-12 m	9	10	15	15	10	13
1-3 yrs	13	15	20	25	17	19
4-6 yrs	20	20	20	30	22	23
7-10 yrs	28	30	30	50	21	33
Men						
11-14 yrs	45	45	40	85	32	50
15-18 yrs	66	70	50	85	32	59
19-50 yrs	79	75	70	85	34	66
51+ yrs	77	75	70	85	33	66
Women						
11-14 yrs	46	45	40	70	26	45
15-18 yrs	55	60	50	70	26	52
19-50 yrs	63	60	55	70	29	54
51+ yrs	65	60	55	70	25	53
Pregnant	62		65	80	30	58
Lactating						
0-6 m	62	75	75	85	35	68
7-12 m	62	75	75	85	42	69

Although the elements barium, bromine, cesium, nickel, rubidium and scandium are also indicated in the literature [10,11,36] as (probably) essential, no recommended or indicative intake values could be obtained. However, these elements were implemented in the study for future estimate of sensitivity of INAA, once reference intake values become available.

Table 6: Dietary recommendations of essential elements

Age (months/ years)	Body weight kg	Ca AI mg/d	Cl RDA mg/d	Co RDA μg/d	Cr AI μg/d	Cu RDA μg/d	F ESADDI mg/d	Fe RDA mg/d	I RDA μg/d	K RDI mg/d	Mg RDA mg/d	Mn AI mg/d	Mo RDA μg/d	Na RDI mg/d	P RDA mg/d	Se* RDA μg/d	Th PTI μg/d	U PTI μg/d	V RDA μg/d	Zn RDA mg/d
Infants																				
0-0.5 yrs	6	210			0.2	200[AI]	0.1-0.5	0.27[AI]	40	580	30[AI]	0.003	2 [AI]	280	100	8	36.2	24.7	50	2 [AI]
0.5-1 yrs	9	270			5.5	200[AI]	0.2-1.0	11	50	1370	75[AI]	0.6	3 [AI]	580	275	13	36.2	24.7	50	3
1-3 yrs	13	500			11	340	0.5-1.5	7	90	2730	80	1.2	17	1150	460	19	370	35.6	50	3
4-8 yrs	20	800			15	440	1.0-2.5	10	90	3900	130	1.5	22	1730	500	23	476	41.1	50	5
Men																				
9-13 yrs	45	1300			25	700	1.5-2.5	8	120	5460	240	1.9	34	2300	1250	50	653	65.1	50	11
14-18 yrs	55	1300	750	3	35	890	1.5-4.0	11	150	5460	410	2.2	43	2300	1250	59	653	65.1	50	11
19-30 yrs	66	1000	750	3	35	900	1.5-4.0	8	150	5460	400	2.3	45	2300	700	59	724	100	50	11
31-50 yrs	79	1000	750	3	35	900	1.5-4.0	8	150	5460	420	2.3	45	2300	700	66	724	100	50	11
51-70 yrs	77	1200	750	3	30	900	1.5-4.0	8	150	5460	420	2.3	45	2300	700	66	724	100	50	11
Women																				
9-13 yrs	46	1300	750		21	700	1.5-4.0	8	120	5460	240	1.6	34	2300	1250	40	653	65.1	50	8
14-18 yrs	55	1300	750	3	24	890	1.5-4.0	15	150	5460	360	1.6	43	2300	1250	45	653	65.1	50	9
19-30 yrs	58	1000	750	3	25	900	1.5-4.0	18	150	5460	310	1.8	45	2300	700	52	724	100	50	8
31-50 yrs	63	1000	750	3	25	900	1.5-4.0	18	150	5460	320	1.8	45	2300	700	54	724	100	50	8
51-70 yrs	65	1200	750	3	20	900	1.5-4.0	8	150	5460	320	1.8	45	2300	700	53	724	100	50	8
Pregnant																				
≤18 yrs	62	1300	750		29	1000	1.5-4.0	27	220	5460	400	2	50	2300	1250	58	724	100	50	13
19-50 yrs	62	1000	750		30	1000	1.5-4.0	27	220	5460	360	2	50	2300	700	58	724	100	50	11
Lactation																				
≤18 yrs	62	1300	750		44	1300	1.5-4.0	10	290	5460	360	2.6	50	2300	1250	68	724	100	50	14
19-30 yrs	62	1000	750		44	1300	1.5-4.0	9	290	5460	310	2.6	50	2300	700	68	724	100	50	12
31-50 yrs	62	1000	750		45	1300		9	290	5460	320	2.6	50	2300	700	69	724	100	50	12

RDA: Recommended Dietary Allowance. The intake that meets the nutrient need of almost all (97-98 percent) of individuals of the group

AI: Adequate Intake is used if sufficient scientific evidence is not available to derive an EAR (Estimated Average Requirement).

* Average values obtained from Table 3

ESADDI Estimated Safe and Adequate Daily Dietary Intake

Table 7: Provisional Tolerable intake of Toxic Elements

Elements	PTWI (μg/kg per bodyweight/week)
As	15
Cd	7
Pb	25
Hg	5
Sn	14000

2.5 Concentration of elements in food

Background information concerning the naturally occurring levels of essential and toxic elements in food is necessary for both nutritional and regulatory purposes. The element concentration in soil is the primary determinant of the element content of plant foods and in animals that feed on them. Soil element concentration will vary according to the geology of the food producing regions. Accordingly, we may expect the element content in food to vary worldwide. An example is the distribution of Keshan disease and Kaschin-Beck disease in China that reflects the distribution of soils from which selenium is poorly available to rice, maize, wheat and pasture grasses (12,40).

Data are now available on some essential trace elements in foods commonly consumed in most of the developed countries and many of the developing countries. Among the countries, for which food composition data have been published in recent years, are USA(21,34), Brazil(28) and China(26). Table 7 gives an example of the selenium concentration range in various foodstuffs (36).

Table 8: Selenium content in different food groups

Food group	Selenium (μg/g, fresh weight)
Cereal, cereal products	0.01-0.55
Meat, eggs	0.01-0.36
Fish	0.11-0.97
Milk, dairy products	0.001-0.17
Vegetables, Fruit	0.001-0.02

Some of the richest sources of zinc are beef, pork and lamb (31,22) as can be seen from Table 8, although this may vary strongly between regions.

Table 9: Zinc content in different food groups

Food group	Zinc (μg/g, fresh weight)
Beef, pork and lamb	20-60
Milk	3-5
Fish and sea foods	15
Legumes	15-50
Green leafy vegetables	< 10

Magnesium is widely distributed in plant and animal foods. Most green vegetables, beans and nuts are rich in magnesium, all of which contain more than 500 μg/g fresh weight [22]. The green leafy vegetables, especially spinach, are rich in cobalt (≈ 0.5 μg/g)[43]. Typical concentration values for molybdenum [12] are 6 μg/g for potatoes, 2.8 μg/g for cabbage, 2 μg/g for carrots and 0.1 -1.1 μg/g for cereal grains.

2.6 Food Analysis

There are many methods, which have been used for general food analysis of micro-nutrients and trace elements. The methods include molecular techniques like High Performance Liquid Chromatography (HPLC), Gas Chromatography (GC), Fourier Transform Infra-Red (FTIR) and Mass Spectroscopy (MS), as well as elemental techniques like Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), Proton Induced X-Ray Emission (PIXE) and Neutron Activation Analysis (NAA).

Instrumental neutron activation analysis has certain definite advantages such as high potential sensitivity and a minimum of sample preparation [1]. The present study was undertaken to assess a standard regime of instrumental neutron activation analysis as a method to investigate the trace element contents of foodstuffs.

There are many studies that compare the different analytical methods to INAA regarding the determination of elements in various matrices. They include comparison with PIXE [35], ICP-MS [9,37] and electroanalytical and x-ray methods [38]. The principles and methodology of INAA will be discussed in Chapter 3.

3 PRINCIPLES OF INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS

3.1 Introduction

The basic principle of this technique is that a sample of a material of interest is irradiated with neutrons, which are normally produced in a nuclear research reactor. In this process various isotopes can undergo nuclear transformation, whereby stable isotopes are converted into radioactive isotopes. These isotopes are unstable and decay with half-lives varying from microseconds to thousands of years. Upon decay, they emit different kind of particles and electromagnetic radiation. The electromagnetic (gamma) radiation, measured through semi-conductor gamma-ray spectrometers, is to a large extent specific for individual radionuclides. Accordingly, a peak in a gamma-spectrum at a certain energy provides information on the isotope it corresponds to as well as the relative amount of the element present in the sample.

3.1.1 Properties of neutron activation analysis

To apply neutron activation analysis, to determine the qualitative and quantitative elemental composition of a material, the following properties need to be satisfied as described by Lenihan [14] :

(a) Elements present in the material must have a favorable neutron interaction cross-section.

(b) Each element to be analyzed must produce one or more gamma-ray emitting isotopes upon neutron activation.

(c) The gamma-ray emitting isotopes formed as a result of the neutron bombardment must have half-lives that are suitably situated between certain upper and lower limits.

(d) The elements to be analyzed must be present in sufficient quantities.

(e) The nuclear characteristics of the non-radioactive element and its activation products must be known.

After all these conditions are met the sample may be bombarded with neutrons for a predetermined time. Specific hard- and software is needed for spectrum accumulation and data analysis.

3.1.2 Neutron activation analysis

Neutron activation analysis is a method for quantitative and qualitative determination of elements based on the measurement of radiation from radionuclides formed by neutron irradiation of an element in a matrix of interest. The technique is particularly sensitive and accurate for a wide variety of elements, which cannot be determined by other methods. This technique is capable to determine 30-40 elements in different matrices and is applied in many fields of research, e.g.:

- Geology and geochemistry [rocks, soil]
- Archaeology [ceramics, glasses]
- Nutrition [composite diets, food]
- Environmental sciences [dust, plants and tree-leaves]
- Industrial products [fertilizers, coatings]
- Forensic [hair, gun-powder]
- Certification of standards reference materials

Thermal and epi-thermal neutrons from a nuclear research reactor (20) are commonly used for element determinations by NAA. Neutrons are produced in a nuclear reactor through a process called nuclear fission.

Nuclear reactors are capable of producing high neutron fluxes (φ = neutron flux, is the number of neutrons passing per unit area per unit time, i.e. neutrons/cm^2/sec) (39). Besides neutrons, one also requires equipment to measure and analyze the energy and intensity of gamma rays emitted from the irradiated samples and element standards (comparative method).

3.1.3 Advantages and disadvantages of INAA

Advantages

The principal advantages of INAA are considered to be:

- Little sample preparation, thereby minimizing the possibility for contamination.
- The method is useful for materials, which are hard to dissolve.
- It is inherently sensitive for some elements and it has good accuracy.
- The results are reliable because errors due to contamination and element losses can be easily avoided.

- Rapid analyses with turnaround times of only a few days are possible.
- INAA is capable of analyzing samples varying from milligrams to kilograms.

Disadvantages

- Most reactors used for INAA in the world are expensive equipment and require highly skilled operators.
- It is sometimes difficult to gain access for non-nuclear scientists.
- It can be time consuming when long-lived isotopes are involved and the technique is relatively expensive.
- Not all elements can be determined (e.g. Li, Be, B, P, Tl and Pb cannot be determined while S and Ni are troublesome as well).

3.2 Theory of Neutron Activation Analysis

3.2.1 Introduction

This chapter describes the experimental procedure of instrumental neutron activation analysis and how the analysis is performed. The analysis can be divided into three steps:

- Preparation and neutron irradiation of samples
- Measurement of radioactivity
- Interpretation, data reduction and presentation of the results

The flow-diagram of neutron activation is presented in Figure 3 in chapter 4.

3.2.2 Sample preparation

From the schematic view of neutron activation (Figure 3) it can be seen that firstly the sample needs to be prepared for neutron irradiation (e.g. dried if necessary, pulverized and be transferred in small polyethylene vials, which are suitable for a manual or pneumatic transfer system). Sample preparation of powders is clearly explained in the literature. It is necessary to press the powder into a pellet or to compact the powder uniformly with a levered pestle in a suitable container, to obtain a reproducible irradiation geometry. Loosely packed samples and partly filled vials may give considerably different results, which also holds for the element standards [6].

3.2.3 Analytical quality assurance

Standard reference materials are used to assure the quality of the results since its element composition is known from literature and suppliers. Good standards must fulfill the requirement that after irradiation its measured specific activity equals that of the element to be determined in a given sample. For that reason, samples and standards are irradiated at the same time and measured in the same geometry with the same radiation detection system, etc. [(25)]

3.2.4 Sample irradiation

Samples are irradiated at the Safari-1 nuclear research reactor using pneumatic rabbit transfer systems to transport the samples and standards to the desired position in or close to the reactor core, to be irradiated for a predetermined time.

3.3 Neutron reactions

Neutrons produced in a reactor can be divided into fast neutrons with energies larger than 1 MeV, resonance neutrons with energies between 0.5 eV and 1 MeV and thermal neutrons with energies less than 0.5 eV. The type of nuclear reaction and its cross-section differ greatly with the energy of the neutrons. The wide energy region between 0.5 eV and 1 MeV is referred to as the resonance region because many isotopes show high cross section in this region. Neutron interactions with the target sample nucleus can take place via inelastic scattering or by neutron absorption. The most common modes are:

3.3.1 Transmutation

This activation reaction is the absorption of a neutron with the subsequent release of a charged particle, most often a proton. The reactions most often observed in INAA are the displacement of a proton by a neutron (e.g. $^{27}Al(n,p)^{27}Mg$) and of an alpha-particle by a neutron (e.g. $^{27}Al(n,\alpha)^{24}Na$). In a research reactor the neutrons are normally highly thermalized and accordingly the (n,α) reaction occurs less frequent compared to the (n,p) reaction as more energy is required to remove an alpha particle from a nucleus. The (n,p) and (n,α) reactions are more common for lighter elements [(39)].

3.3.2 Inelastic scattering

When the energy of the incident neutron exceeds that required for the excitation of the lowest level of the target nucleus, it becomes possible for the nucleus to be left in an excited state. The scattered neutron has reduced energy and the nucleus de-excites promptly (in about 10^{-12} second) with the emission of a gamma ray. This process is called inelastic scattering and is expressed by (n,n'); e.g.$^{103}Rh(n,n')^{103m}Rh$. The (n,2n) reaction may occur when the scattered neutron imparts enough energy to exceed the binding energy of the least bound neutron in the target nucleus. The net result is the removal of one neutron from the target nucleus e.g. $^{23}Na(n,2n)^{22}Na$ [27,39]

3.3.3 Radiative capture

The most common activation reaction is neutron capture in which a low-energy neutron is absorbed by a nucleus with the prompt emission of a gamma-ray, e.g.$^{113}Cd(n,\gamma)^{114}Cd$. The (n,$\gamma$) reaction is normally called the thermal neutron reaction. Most of the research reactors around the world use thermal neutrons (i.e. neutrons in thermal equilibrium with their environment). Thermal neutrons are said to be the most useful neutrons produced in a nuclear reactor. They are produced in large quantities (i.e. a large thermal-neutron flux) in the reactors and generally have large neutron cross sections for most elements [27]. Figure 1 presents an illustration of this process.

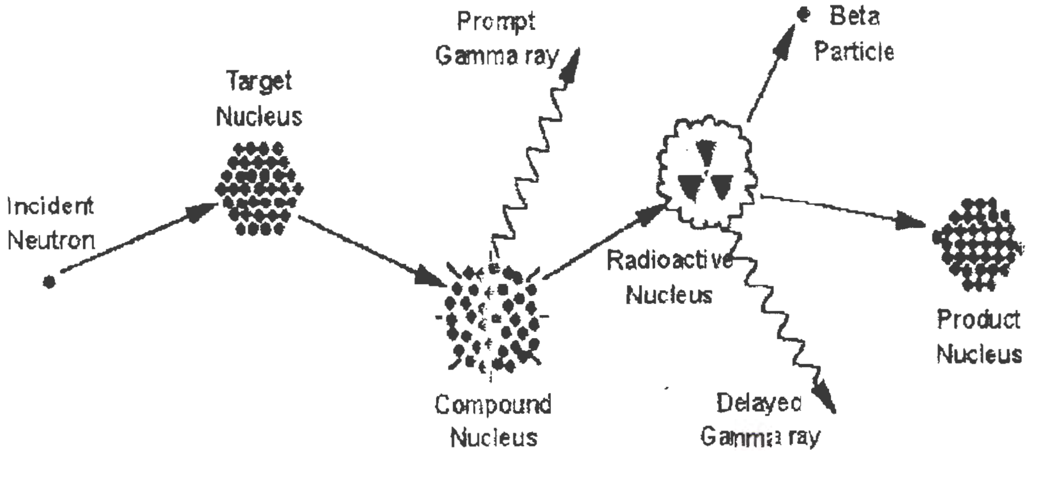


Figure 1: Diagram illustrating the process of neutron capture by a target nucleus followed by emission of gamma rays.

3.4 Production of radioactivity

Radioactivity is the property of certain unstable nuclei to emit energy in the form of particles and/or photons. Radioactivity depends on the state of the nucleus and not on the chemical or physical state of the material.

A radioactive nucleus formed as the result of neutron absorption undergoes transformation by α-decay, β-decay (β^- or β^+), electron capture or neutron emission. Nuclei below the curve of stability have a Z/N ratio that is too low for stability (i.e. they have too many neutrons for the number of protons), and will decay by β^- decay (i.e. transformation of a neutron in a proton and an electron). Nuclei above the narrow valley of stability have Z/N ratio that is too high for stability (i.e. they contain few neutrons relative to the number of protons), and will decay by β^+ (i.e. transforming a proton into a neutron and a positron), electron capture (i.e. transforming a proton and a shell-electron into a neutron) or by α (i.e. loosing 2 protons and 2 neutrons).

When the sample is exposed to neutrons, a nuclear reaction occurs resulting in the formation of radionuclides, which (if radioactive) decay to (eventually) stable isotopes. A daughter nuclide is left in an excited state (high energy) that decays quickly to the ground state (low energy) by emission of one or more gamma rays (photons) or neutrons [8,44]. The reactions may be represented as follows,

$$\begin{array}{ccccc} \text{Nuclide 1} & \xrightarrow{\text{Activation}} & \text{Nuclide 2} & \xrightarrow{T_{1/2}} & \text{Nuclide 3} \\ E_0 & & E_1 & & E_2 \end{array}$$

where $E_1 > E_2 > E_0$(normally).

Assume that a stable isotope is bombarded with neutrons and is transformed into a radionuclide, which decays with it's characteristic disintegration constant ($\lambda = \ln 2 \;/\; T_{1/2}$). The rate of formation of this radionuclide depends on the neutron flux (ϕ), which is the number of neutrons passing through a square centimeter of area (e.g. of the sample) per second ($n.cm^{-2}.s^{-1}$), the number of atoms of the element (N) being bombarded, the tendency to capture the neutrons, also called the cross section (σ), and on the decay of the formed radionuclide during the time-span of the bombardment. Accordingly, the production of the number of radioactive atoms is given by the rate of its formation $N\phi\sigma$, minus the rate of disintegration λN, which can be described by:

$$dN/dt = N \, . \, \phi \, . \, \sigma \; - \; \lambda \, . \, N \qquad \ldots\ldots (1)$$

By the integration of equation (1) we will obtain the number of radioactive atoms present at the end of bombardment:

$$N_t = N_0 \, . \, \phi \, . \, \sigma \, . \, 1/\lambda \, . \, (1 - e^{-\lambda t}) \qquad \ldots\ldots (2)$$

where:

N_t the number of radionuclides formed

N_0 the number of stable nuclides

t the irradiation time in seconds

σ the cross section usually expressed in barns (1 barn = 10^{-24} cm^2)

ϕ the neutron flux ($n.cm^{-2}.sec^{-1}$)

λ the decay constant (s^{-1}), which is equal to $\ln 2/T½$

$T½$ the half-life of the radionuclide (s)

The activity of a specific source is directly related to the number of atoms available and the rate at which they decay, which again is a function of the half-life of the radionuclide concerned. The relation is given by:

$$A_t = \lambda \, . \, N_t \qquad \ldots\ldots (3)$$

Substitution of (2) into (3) gives the activity formed after a neutron bombardment that last for time t:

$$A_t = N_0 \, . \, \phi \, . \, \sigma \, . \, (1 - e^{-\lambda t}) \qquad \ldots\ldots (4)$$

The number of atoms available can be calculated from the mass of the element in the sample, the atomic mass, the isotopic abundance and Avogadro's number:

$$N = (W \cdot \Phi \cdot N_{Av}) / M \qquad \ldots\ldots (5)$$

where :

N	the number of atoms
W	the element mass
Φ	the isotopic abundance
N_{Av}	Avogadro 's number
M	the atomic mass of the element

Substitution of (5) into (4) leads to:

$$A_t = (W \cdot \Phi \cdot N_{Av}) / M \cdot \phi \cdot \sigma \cdot (1 - e^{-\lambda t}) \qquad \ldots\ldots (6)$$

From equation (6) it is clear that the mass of the element (W) can be determined if all the other quantities are known. However, the neutron flux and the isotopic neutron cross section are usually not known with sufficient accuracy [19,34,42]. Accordingly, element standards are normally irradiated along with samples to allow for comparative measurements.

3.5 Measurements of Gamma-ray Spectra

3.5.1 Counting with a detector

After irradiation the detection of radioactivity should be performed. All nuclear radiation detection is based on the interaction of the radiation with matter. The detection methods are in general based on the process of excitation or of ionization of atoms in the detector by the passage of energy rich particles or photons. Detectors may be employed in various ways,

- as detectors recording all the radiation passing through the sensitive detection volume,
- as rate meters recording the neutron flux,
- as spectrometers yielding the information about the energies and the intensities of the gamma radiation.

Gamma radiation can be detected and analyzed by gamma-ray spectroscopic techniques. Gamma-ray spectrometry is in most cases based on two classes of detector materials, scintillation (NaI) and semiconductors (Ge) detectors [5].

3.5.2 Scintillation detectors

The relevant scintillation detector materials that can be used for gamma-ray measurements are sodium iodide [NaI(Tl)], cesium iodide [CsI(Tl), CsI(Na)], barium fluoride [BaF_2] and cesium fluoride [CsF]. The most commonly used scintillation detector is sodium iodide NaI(Tl). The iodide atom of the NaI(Tl) provides a high gamma-ray absorption coefficient and accordingly has a high intrinsic efficiency [15].

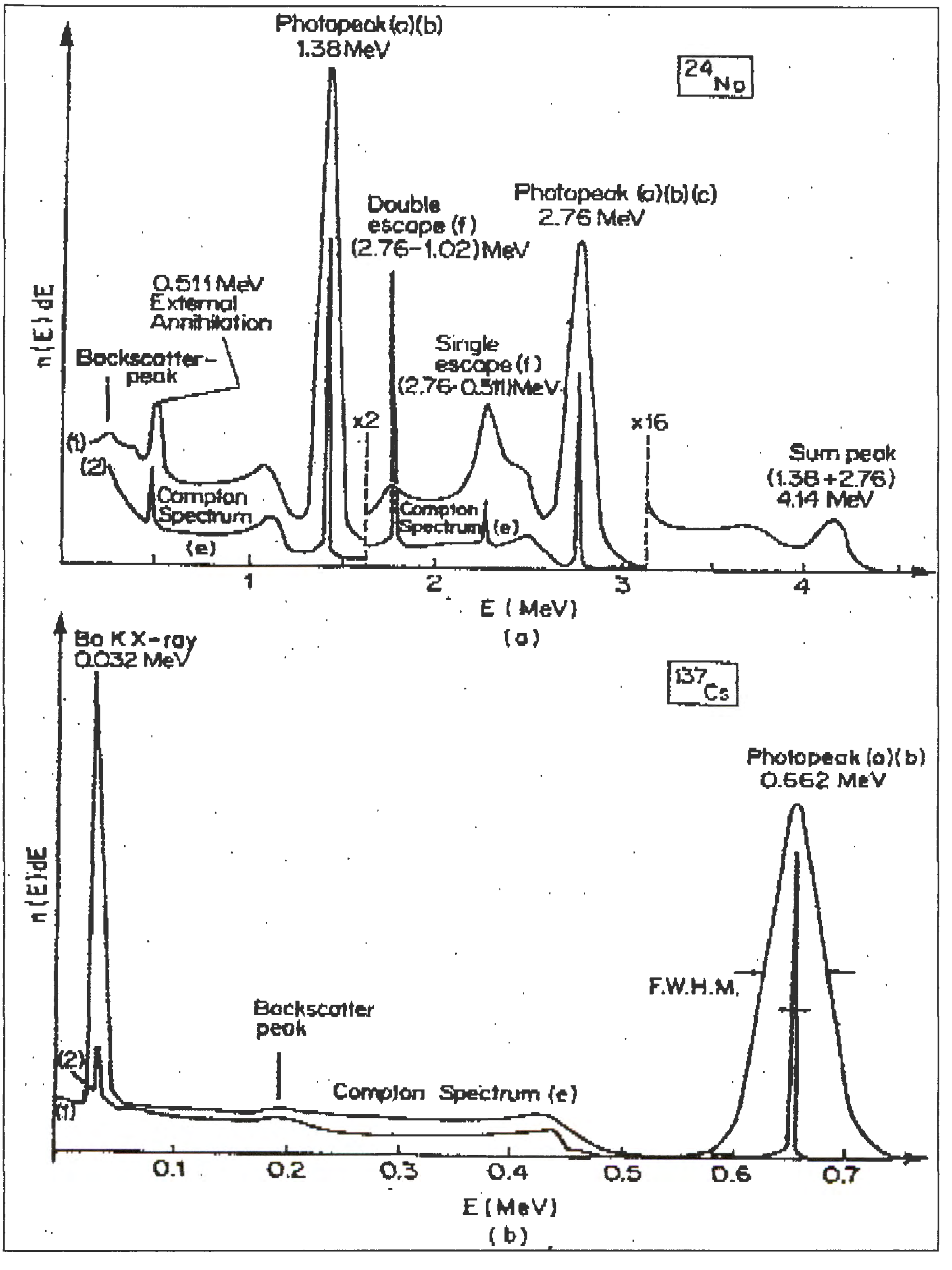
3.5.3 Semiconductor detectors.

Carbon, silicon and germanium in certain forms can all be used as semiconductor radiation detectors. The semiconductor detectors are preferred for the detection of gamma-rays because of the improved energy resolution compared to scintillation detectors. The detector provides an output pulse, which is directly proportional to the energy of the particle (or photon) detected. It is then possible to use a pulse-amplitude analyzer with a channel setting appropriate to the energy of the radiation (which is specific for the element to be detected [27,5]). A typical pulse height spectrum of ^{24}Na collected with a NaI(Tl) and a Ge(Li) detector is illustrated in Figure 2.

3.6 Qualitative analysis

In qualitative analysis one needs to determine the energy of all the gamma rays being emitted from the sample, through examination and comparison with tables of gamma-ray energies, to evaluate which radioisotopes may be present. Once the possible radioisotopes have been found, a check is made on each isotope to see if other gamma rays resulting from the identified nuclide are also found [13]. As an example, the amount of sodium in a sample can be measured by the 2.78 MeV and/or the 1.38 MeV gamma-emission of ^{24}Na formed by the nuclear reaction $^{23}Na(n,\gamma)^{24}Na$ (see Figure 2).

Figure 2: Gamma spectrum of ^{24}Na and ^{137}Cs measured with NaI(Tl) [1] and with a Ge(Li) [2] detector.



3.7 Sensitivity of NAA

Neutron activation analysis is considered as an inherently sensitive technique in elemental analysis. When one considers using an analytical technique, it is important to have a good understanding of the sensitivity of the technique for a given element or chemical specie. Sensitivity in this study is expressed in terms of the smallest amount of a certain element, which can be detected in a specific sample of interest (in e.g. foodstuffs).

Due to the inherently sensitivity of NAA for most elements, it is worthwhile to discuss several factors (i.e. theoretical and practical), which influence the sensitivity of the technique. Some are variable within limits while others are fixed. From equation (6) [repeated hereunder] the theoretical sensitivity of an element, expressed in terms of the induced activity of the nuclide formed from a specific element of interest (e.g. Se in rice) can be evaluated.

$$A_t = (W \,.\, \Phi \,.\, N_{Av}) \,/\, M \,.\, \phi \,.\, \sigma \,.\, (1 - e^{-\lambda t}) \qquad \ldots\ldots. (6)$$

Following this equation it can be seen that the sensitivity depends on:

- The mass of the element in the sample. This is evident: the more element the better it will be detectable.
- The isotopic abundance, which is fixed (one can evaluate different isotopes of the same element).
- Avogadro's number, which is fixed.
- The atomic mass of the element, which is fixed.
- The neutron flux induced on the sample. The neutrons flux expresses the number of the bombarding neutrons per square centimeter per second. The higher the neutrons flux the higher the sensitivity.
- The cross-section of the target element-nuclide. The cross section of the target element-nuclide expresses the probability that the nuclide will undergo a reaction with the bombarding neutrons. If the activation cross-section is high there will be increased sensitivity. However, the cross-section is not a constant and depends on the energy of the bombarding neutrons. Many isotopes have high cross-sections at neutron energies between 0.1 eV and 1 MeV (i.e. the so-called thermal and epi-thermal part of the neutron spectrum). Accordingly, one may influence the sensitivity by

exposing the sample to a specific part of the neutron spectrum. The most commonly used technique is to filter away the thermal neutrons and expose the samples and standards to the epi-thermal neutrons only, which in most cases will enhance the sensitivity for the heavier elements by suppression of the thermal-neutron reactions of the lighter elements. Common thermal neutron filters are made from cadmium or boron.

- Decay constant and irradiation time. Due to the large variations in the decay constants (i.e. half-lives) of the radioisotopes produced, different irradiation times have to be applied to obtain the highest sensitivity of each element present in the sample. This can clearly be seen from the last part of equation (6). The induced radioactivity is a logarithmic function of the irradiation time t and the half-life $T_{½}$ (i.e. $\lambda = \ln 2/T_{½}$). From this equation it is easily observed that if the irradiation time is equal to the half-life of the nuclide of interest the induced activity will be 50% of the maximum achievable activity. After two half-lives, 75%-maximum level will be reached, three half-lives will give 87,5% of the maximum level, etc, etc. It will thus be clear that irradiating the sample for more than 5-times the half-live of a particular nuclide of interest does not improve anymore on the obtainable sensitivity. Longer irradiation will actually be counter-productive as it will only increase the activity of the longer-lived nuclides, which also contribute to the gamma-spectrum and accordingly decreases sensitivity due to the larger underground at the site of the energy peak of the nuclide of interest.
- Other factors that also contribute to the detection sensitivity are the allowed time between irradiation and detection, the nature and amount of radiation emitted by the radionuclide and the detection efficiency of the detector [16,23,27 and 42].

3.8 Detection limit

Detection limit is a term used to express the detection capability of a measurement system under certain conditions like irradiation/decay/counting time, sample size, detector efficiency, sample-detector geometry, etc. An estimate for the lowest amount of activity of a specific gamma-emitting radionuclide that can be determined at the time of measurement can be calculated from different expressions. The generally accepted expression for the estimate of the detection limit, which is referred to as the lower limit of detection (LLD) at 95% degree of confidence to determine the presence of activity, is as follows:

$$LLD = 4{,}66 \,.\, S_b / (\epsilon \,.\, P_\gamma) \qquad \ldots\ldots (7)$$

where,

S_b the estimated standard error of the net count-rate

ϵ the counting efficiency of the specific nuclide's energy

P_γ the absolute transition probability of gamma decay at the selected energy (the same energy as for ϵ)

4.66 Constant to protect against statistical errors at the 5% confidence level.

The LLD of equation (7) provides a means of determining the capability of measuring system without the influence of the sample. When a sample is measured by gamma-spectroscopy, the term usually associated with detection limits is the minimum detectable concentration (MDC) which can be expressed by the lower limit of detection per unit mass (W in gram) :

$$MDC = 4{,}66 \,.\, S_b / (\epsilon \,.\, P_\gamma \,.\, W) \qquad \ldots\ldots (8)$$

From equation (8) it can be seen that factors, which can be influenced to optimize the detection limits, are counting efficiency, the quantity of the sample, the counting time and the background of the counting system (which will both influence the net count-rate and thus the associated S_b). To obtain low detection limits the efficiency should be high, the sample should be as large as practicable, the counting time should be as long as practicable, and the background should be as low as attainable. The efficiency is strongly influenced by the sample geometry and tends to decrease as the sample size increases. Therefore, optimum sample-size-geometry may be used to obtain low detection limits. Doubling the sample mass would improve the sensitivity by a factor of two, although this may prove to become problematic if too much activity is introduced, which may overload the counting system. One can also increase the sensitivity by increasing the counting time. However, in order to lower detection limits by a factor of two, the counting time would need to be four times as long (this as the uncertainty in the count-rate is a square root function of the count-rate itself). The background of measurement systems is usually kept as low as possible [19].

The literature on neutron activation analysis contains many tables of (sensitivities) limits of detection for various elements, for various conditions of thermal neutron flux, irradiation time, counting time, sample size, etc. However, all of these limits of detection are for situations where the levels of interference are negligible. But in normal day-to-day application there are three main types of potential interference in instrumental neutron activation analysis:

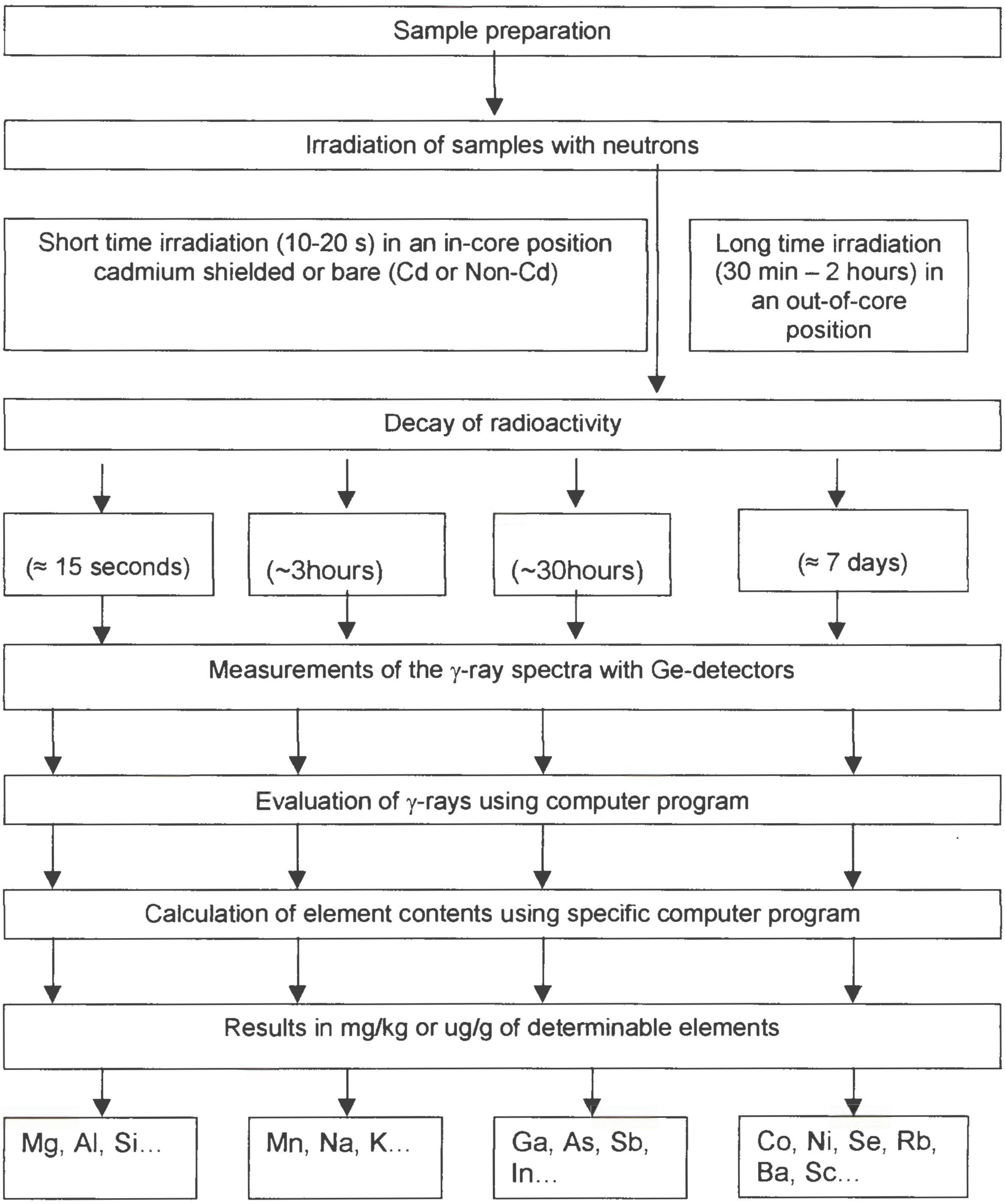
- Interference resulting from formation of the same radionuclide, from fast neutron (n,p) or (n,α) reactions on an element one or two units higher in Z than the element of interest that is formed by (n,γ) thermal neutron reaction on the element/isotope of interest.
- Interference resulting from the formation of one or more other radionuclides that emit gamma-rays of energies sufficiently close to the gamma-ray energy of the nuclide of interest (peak-overlap).
- Interference resulting from high Compton edges in the pulse-height spectra caused by interactions of gamma-rays of higher energy than the peak of interest upon which the peak of interest is superimposed [14,15].

Accordingly, the best practice is to evaluate the best possible way to provide an analytical service through evaluation of the elements of interest and the matrix of the sample concerned. This evaluation can be based on experience or alternatively to perform a "test-irradiation" from which the optimum irradiation and counting conditions can be estimated.

4 EXPERIMENTAL PROCEDURE

The overview of routine instrumental neutron activation analysis procedure applied at Necsa is represented in Figure 3 below.

Figure 3: Schematic view of INAA procedure



4.1 Preparation of samples and reference standards

Different institutes have slightly different methods of applying INAA. Here, the routine method applied at the RadioAnalysis group of Necsa using the SAFARI-1 research reactor is described.

- Foodstuffs were obtained and washed with distilled water with the exception of bread, rice, sugar, milk powder, coffee, tea, margarine, egg and maize. Empty metal drying pans lined with polyethylene sheeting, were weighed. Samples were put into drying pans and wet weights were determined. Samples were then dried in an oven at a temperature of 65 ^{0}C for 24 hours, except for margarine. Tomatoes, potatoes and onion were dried for another day since they were not completely dry after the first period. Samples were taken out of the oven, allowed to cool and weighed to obtain the dry weight of the foodstuffs. A plastic eggbeater was used in mixing the eggs before drying.
- Thereafter the samples were milled (except margarine) in an agate-vessel swing-mill and put into cleaned polyethylene bottles and capped. Portions of 200-mg of each sample were weighed into small plastic polyethylene vials (with a diameter of 1.0 cm and 0.9 cm high) using an analytical balance (with the resolution of 0.0001/0.00001 gram) and then capped and ultrasonically sealed. These vials were put into bigger vials (diameter 1.2 cm and a height of 2.0 cm), which were again capped and ultrasonically sealed. The double vial encapsulation was both to reduce sample contamination and to fulfil the research reactor safety requirements.

4.2 Analytical quality assurance

Standard reference materials are used to assure the quality of the results since its element composition data is known. The standard reference material used were Whey powder (IAEA-155), Lichen powder (IAEA-336), Rye flour (IAEA-V-8), Seaweed (IAEA-140), Milk powder (IAEA-A-11), Fish flesh homogenate (IAEA-MA-A-2/TM), Horse kidney (IAEA-H-8) and Lake sediment (IAEA-SL-1) purchased from the international Atomic Energy Agency, as well as Coal fly ash 1533a, Orchard leaves 1571 and Spinach 1570 purchased from USA National Institute of Standards and Technology, and SARM-7 and SARM-9 purchased from the South African Bureau of Standards. All these standards were prepared in the same manner as the foodstuff samples to be analyzed. Specific amounts of single element standard solutions were pipetted into small vials, air dried, capped to serve as comparative element standards. Certified solutions obtained from IAEA were used to prepare these element standards.

4.3 Irradiation facilities

The SAFARI-1 research reactor is located at Pelindaba, approximately 30 km west of Pretoria. The reactor was commissioned in 1965 and has a maximum power of 20 MW. The reactor, an Oak Ridge Reactor (ORR) design, is cooled and moderated by light water, with an 8 x 9 core lattice, which currently contains 28 fuel elements and 6 control elements. The reactor is used for many purposes like isotope production, neutron doping of silicon and research for (mostly) South African industries and academic institutions. The reactor is equipped with two pneumatic transfer systems (PRS and RINGAS), which were used for irradiation of the foodstuffs. These two facilities pneumatically transfer the samples between the laboratory and the reactor.

4.3.1 RINGAS (Routine Instrumental Neutron and Gamma-ray Analysis System)

The RINGAS-system is mainly used for short- and intermediate-lived nuclides with half-lives between about 10 seconds and 30 hours. The system is fitted with two irradiation channels located at the core of the reactor. One position is shielded with cadmium to absorb the thermal neutrons and accordingly expose the samples and standards to epi-thermal and fast neutrons only. In the other position samples and standards are exposed to the full neutron energy spectrum. Typical neutron fluxes, at 20 MW operational power, in the irradiation positions are:

Bare tube position:

$1.46 - 1.73 \cdot 10^{14}$ neutrons/cm^2/s of epi-thermal and fast neutrons
$1.20 - 1.27 \cdot 10^{14}$ neutrons/cm^2/s of thermal neutrons

Cadmium shielded position

$\approx 5 \cdot 10^{13}$ neutrons/cm^2/s of epi-thermal and fast neutrons

The system can be operated both to measure delayed neutrons and gamma-rays. Samples and standards are automatically transferred and irradiated one after the other. The system makes provision to monitor the neutron flux imposed on individual samples and standards, although the flux in practice appears to be stable enough and only every 10^{th} sample is monitored on average.

- For short-lived radionuclides (half-life between about 10 seconds and 30 minutes), samples, standards and blanks were put into individual polyethylene irradiation capsules and screw capped. They were then irradiated individually for 8 seconds, delayed for 30 seconds and counted for 120 seconds by gamma spectrometry.
- For intermediate-lived radionuclides (half-life between about 0,5 and 30 hours), samples, standards and blanks were put into individual polyethylene irradiation capsules and screw capped. They were then irradiated for eight seconds each under the cadmium-shielded part of the neutron energy spectrum (this to reduce the relative interference of elements with low Z-values like sodium). They were delayed for 3 hours and 30 hours respectively and counted for 15 minutes and 30 minutes respectively by gamma spectrometry.

4.3.2 PRS (Pneumatic Rabbit System)

This system is mainly used for analysis based on longer-lived radionuclides (half-life in excess of days). The system is manually operated and can irradiate batches of up to 10 samples at a time. Irradiation times of 0,5 – 1 hour are normally applied. Individual iron neutron flux monitors are used to cater for the spatial distribution of the samples and standards and accordingly for varying flux. The samples, standards and blanks are prepared the same as for the short- and intermediate-lived nuclide determinations and batches are packed in polyethylene irradiation vials and screw capped. They are then irradiated at a thermal neutron flux of about 3.9×10^{13} $n.cm^{-2}.s^{-1}$ (at 20 MW) under the full neutron energy spectrum. Thereafter the vials are unscrewed; samples, standards and blanks are manually removed and arranged numerically in racks. The outer containers are then cut open and the inner containers transferred into new polyethylene vials (diameter of 1.2 cm and a height of 2.0 cm). The flux monitors are transferred and packed in the same manner (bearing the same identification as the analytical samples, standards and blanks). Each vial is well capped and stored in lead-shielded vaults till counting.

4.4 Counting facilities

4.4.1 Short-lived nuclides

The RINGAS system is a PC-based gamma-ray spectroscopy system, used for irradiating and counting a wide variety of sample matrices. The spectrometry part of the system consists of a high purity germanium detector (HPGe) with a resolution of 1.8 keV (FWHM) for 1332 keV ^{60}Co gamma-ray energy and a relative efficiency of about 10%. The detector is partly shielded with lead to reduce influences of the background on the measurements. The RINGAS system pneumatically transports samples between the reactor core and the counting station using both vacuum and pressurized air. The samples are irradiated and counted individually and will finally be sent to a lead-shielded waste store. Each sample can be equipped with a flux-monitor to correct for possible neutron flux variations between individual irradiations. As the system makes provision for samples to be counted shortly after irradiation, it is mostly used for the analysis of short-lived nuclides. The summary of the detailed information about the irradiation and counting conditions, as well as an indication of possible nuclides analyzed for short-lived is given in Table 9. Element concentrations and/or minimum determinable concentrations are obtained through comparative calculations of sample, element, blank and flux-monitor signals. The system is operated fully automatically once a batch of samples has been loaded.

4.4.2 Intermediate- and long-lived nuclides

A PC-based gamma-ray spectroscopy system is used for counting the irradiated samples. It consists of a high purity well-type germanium detector (20% relative efficiency and a resolution of 2.3 keV at 1332 keV). Other auxiliary equipment are a cylindrical lead-shield around the detector with a hole on top to allow access to the detector-well. The system is fitted with an automatic sample changer to move the samples from the lead-shielded sample storage cassette to the counting position and back. Samples brought into the counting room after irradiation are transferred into glass tubes, about 15 mm diameter and 90 mm long. Samples are then arranged in a 50-hole carousel and placed in the cylindrical lead shield serving as a radiation shield to the operator. Two of the holes are blank to allow for background activity monitoring. Accordingly, unattended counting can be performed.

4.5 Data reduction

Element concentrations and/or minimum determinable concentrations are obtained through comparative calculations of sample, element, blank and flux-monitor signals.

4.6 Overview of routine applications at Necsa

Compiled information about the irradiation and counting conditions, as well as an indication of possible nuclides that can be analyzed is given in Table 9.

Table 10: Irradiation, counting conditions and analyzed nuclides

Irradiation facility	Irradiation time	Decay time	Counting time	Typical suite of nuclides that can be analyzed
RINGAS Short-lived	8 sec	30 sec	120 sec	^{38}Cl, ^{66}Cu, ^{20}F, ^{179m}Hf, ^{128}I, ^{27}Mg, ^{46m}Sc, ^{52}V,
	8 sec	10 min	10 min	^{80}Br, ^{38}Cl, ^{128}I, ^{27}Mg
RINGAS Intermediate-Lived	8 sec	3 hours & 30 hours	15 min & 30 min	^{42}K, ^{24}Na, ^{56}Mn, ^{99}Mo, ^{139}Ba, ^{82}Br, ^{115}Cd, ^{72}Ga, ^{159}Gd, ^{122}Sb, ^{76}As, ^{140}La, ^{116m}In, ^{198}Au
PRS Long-lived	30 min	5-7 days	1 hour*	^{47}Ca, ^{59}Fe, ^{65}Zn, ^{60}Co, ^{51}Cr, ^{58}Co(Ni), ^{75}Se, ^{131}Ba, ^{46}Sc, ^{86}Rb, ^{134}Cs, ^{203}Hg, ^{115m}Cd, ^{124}Sb, ^{140}La, ^{114m}In, ^{177}Lu, ^{110m}Ag, ^{198}Au, ^{232}Th, ^{238}U

* Flux-monitors are counted for five minutes each

4.7 Examples of foodstuff spectra

Sodium could be observed in most samples analyzed for the study. A gamma-spectrum of white bread is given in Figure 4. One can clearly distinguish the energy lines of ^{24}Na at 1368 keV and 1732 keV. Figure 5 shows the spectral data plot of a rice sample illustrating ^{76}As at 559 keV and ^{82}Br at 554 keV and 776 keV respectively. The 559 keV of arsenic is not clearly distinguishable in Figure 5 as it is small and close to 554 keV of ^{82}Br, but it can be clearly seen in the resolved peak area in Figure 6. Figure 7 provides a similar situation for a fish sample.

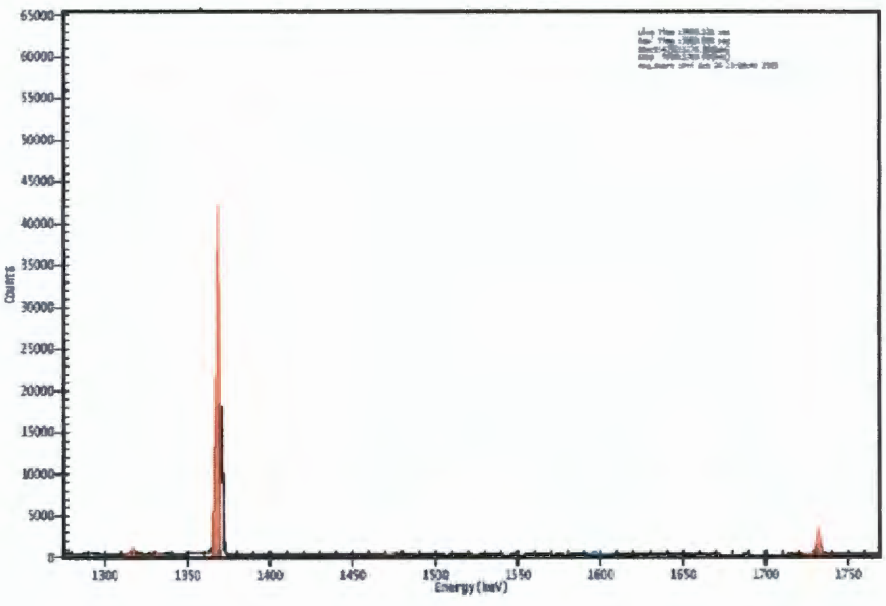


Figure 4: Gamma spectrum of a white bread sample.

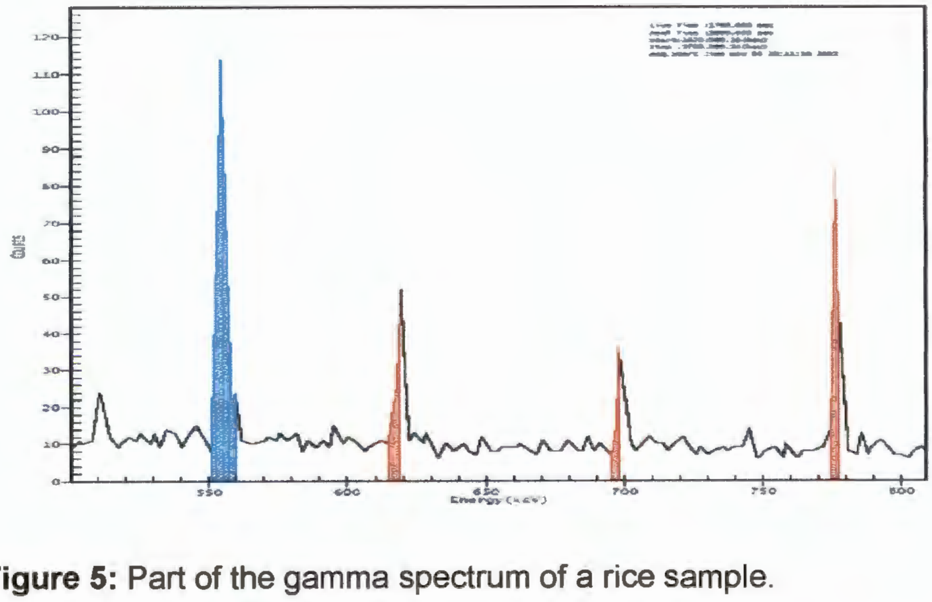


Figure 5: Part of the gamma spectrum of a rice sample.

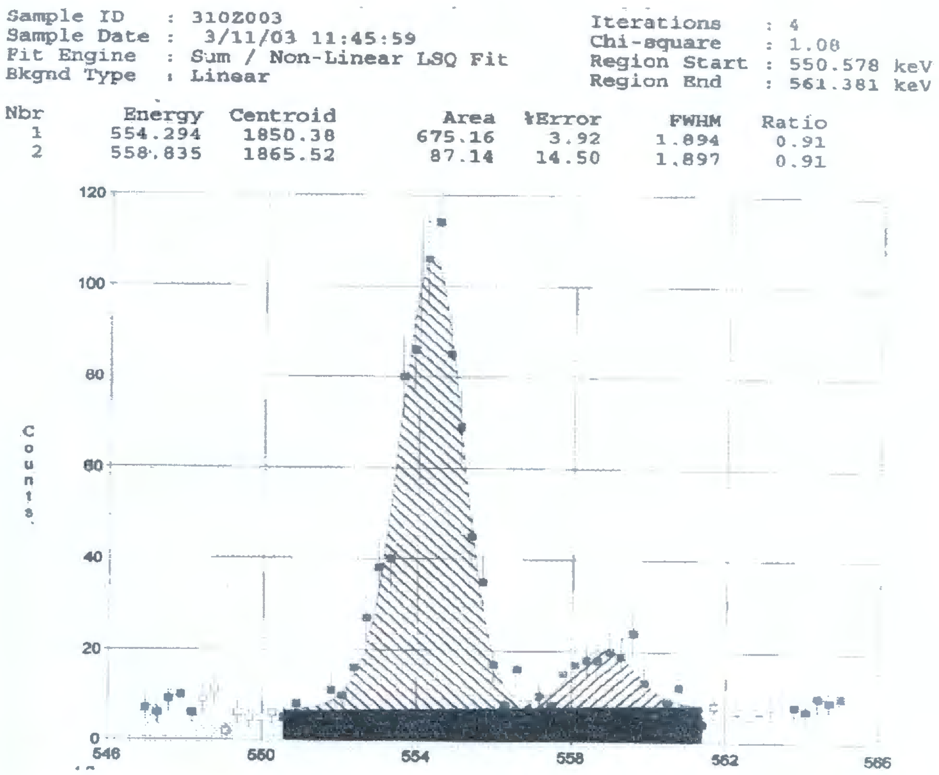


Figure 6: ^{76}As in a rice sample at 559 keV.

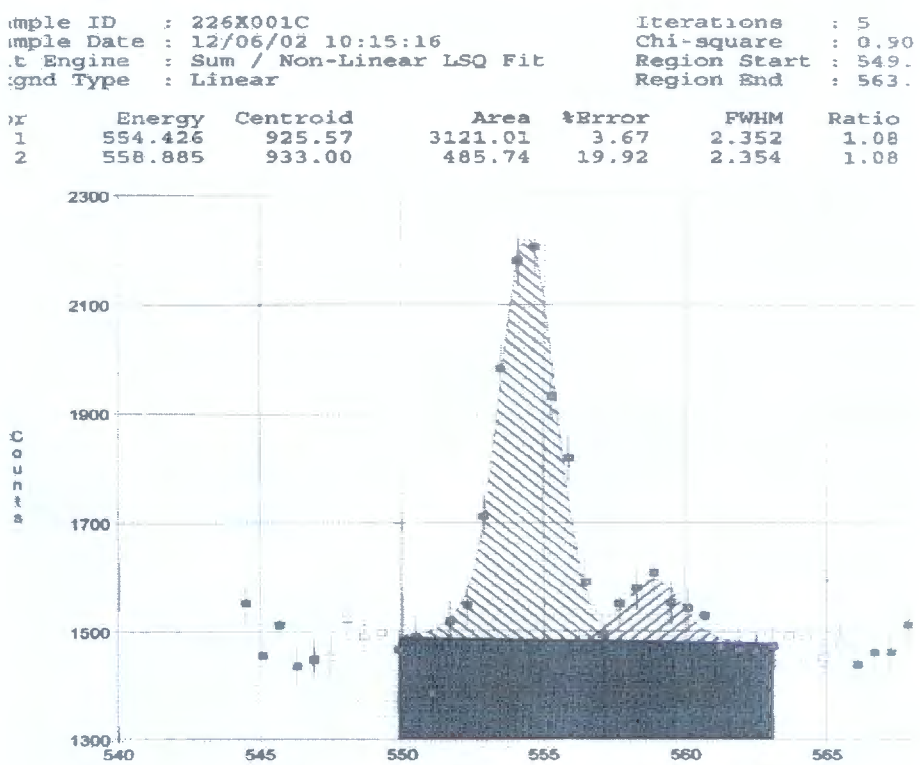


Figure 7: ^{76}As in a fish sample at 559 keV

5 RESULTS

- Table 11 presents the summary of all the elements analyzed i.e. their half-life, nuclear reactions and peak energies.
- Table12 present the results of arsenic in fish obtained for the example shown in Figure 7.
- The overall results for 28 elements determined in 23 foodstuffs investigated in this study, applying five different routine INAA-regimes in use at Necsa, are presented in Annexure 1.

It is also mentioned that the data for aluminum have been omitted from the database due to a relatively large variance observed between sub-samples of certain foodstuffs, which may have been caused by contamination of the samples from the aluminum conveyor tubes used in the irradiation systems.

5.1 Evaluation of sensitivity

In order to evaluate if the routine INAA-regimes as applied at Necsa provide adequate sensitivity one needs to compare the minimum detectable concentration (MDC) in microgram per gram (µg/g) of each element and foodstuff with both the estimated intake values (EIV) for South Africa of the foodstuffs concerned in gram per day (g/d) for the various age and sex categories, and the reference intake values (RIV) of the individual elements in microgram per day (µg/d).

One can than find whether the INAA-regimes applied will be adequately sensitive through the following comparison:

Adequate if:	MDC < RIV / EIV	or	MDC / (RIV / EIV) < 1
Inadequate if:	MDC > RIV / EIV	or	MDC / (RIV / EIV) > 1

As one is interested to have a general overview of the sensitivity of a specific element in the various foodstuffs and more specifically in to what extent one has to improve on the sensitivity, where necessary, it is meaningful to evaluate the magnitude of the required sensitivity improvement. One therefor can evaluate on the average as well as the maximum sensitivity improvement required and accordingly make suggestions on how this may be achieved in changing a variety of parameters influencing the sensitivity obtainable by INAA. These conclusions are summed up in Table 13. The following elaborations have lead to these final conclusions:

- The data of Annexure 1 were reworked to obtain an overview on the range of the minimum detectable concentration (MDC) for the individual elements over the suite of foodstuffs examined. These data are given in Annexure 2. From this it can be observed that the MDC-values per element vary on average about one order of magnitude, which actually means that the required sensitivity for each element will not be dramatically influenced by the sample matrix (i.e. the kind of foodstuff) and should be obtained by variations of sample mass and/or changes in the irradiation/decay/counting time-regime. It should also be mentioned that each of the foodstuffs was thoroughly homogenized and accordingly we may expect that the elements are homogeneously distributed and data may be regarded representative for all foodstuffs concerned. However, regional variations should be reckoned with for future applications.
- As INAA requires dry sample matrices one needs to evaluate the fresh/dry weight ratio, together with the estimated intake values for the foodstuffs concerned. Annexure 3 provides the data on fresh/dry weight ratios as well as the estimated intake values derived for South Africa for 23 foodstuffs and 9 different categories taking age, sex and special conditions into consideration.
- Furthermore one needs to evaluate the minimum detectable concentration of the individual elements against the recommended daily allowances and/or provisional tolerable intake values. Annexure 4 provides the data on the reference intake values for 28 elements regarded essential or toxic for the 9 different age and sex groups. As mentioned in paragraph 2.4 the elements barium, bromine, cesium, nickel, rubidium and scandium are also indicated in the literature as (probably) essential, but no recommended or indicative intake values could be obtained. Accordingly, these elements were implemented in the study to enable future estimate of sensitivity by INAA, once reference intake values become available. However, no data is reported in this study.
- Comparison of the minimum detectable concentration of the individual elements in the various foodstuffs against the reference element intake values provides a means to evaluate the sensitivity of INAA. In this survey

we chose to express the sensitivity in terms of the achievable sensitivity against the required sensitivity, which will allow us to see whether the routine INAA applications are adequate, and if not, by how much we need to improve the sensitivity. These results are shown in Annexure 5. It should be noted that the indicated "sensitivity factor" is introduced to evaluate the sensitivity against the following expressions:

Adequate if: MDC / (RIV / EIV) < 1

Inadequate if: MDC / (RIV / EIV) > 1

Accordingly, a "sensitivity factor" of e.g. 10 means that one needs to improve the sensitivity for a specific element by at least a factor of 10, while a "sensitivity factor" of less than one indicates that the applied routine INNA-regimes as applied by Necsa are adequate for the evaluation of the nutritive value of the element concerned over a wide range of foodstuffs.

Table 11: Properties of Elements analyzed

Radionuclide	Half-life	Nuclide & reaction	Energy(keV)
^{76}As	26.4 h	$^{75}As(n,\gamma)$	559
^{131}Ba	11.5 d	$^{130}Ba(n,\gamma)$	496
^{82}Br	35.3h	$^{81}Br(n,\gamma)$	776
^{47}Ca	4.54 d	$^{46}Ca(n,\gamma)$	1297
^{115m}Cd	44.8d	$^{114}Cd(n,\gamma)$	934, 1291
^{38}Cl	37.2m	$^{37}Cl(n,\gamma)$	1642
^{60}Co	5.27a	$^{59}Co(n,\gamma)$	1173, 1332
^{51}Cr	27.7d	$^{50}Cr(n,\gamma)$	320
^{134}Cs	2.06a	$^{133}Cs(n,\gamma)$	795
^{66}Cu	5.1m	$^{65}Cu(n,\gamma)$	1039
^{20}F	11s	$^{19}F(n,\gamma)$	1634
^{59}Fe	44.6d	$^{58}Fe(n,\gamma)$	1099
^{203}Hg	46.6d	$^{202}Hg(n,\gamma)$	279
^{128}I	25m	$^{127}I(n,\gamma)$	443
^{42}K	36 h	$^{41}K(n,\gamma)$	1525
^{27}Mg	9.46m	$^{26}Mg(n,\gamma)$	844, 1014
^{56}Mn	2.58h	$^{55}Mn(n,\gamma)$	846
^{99}Mo	66h	$^{98}Mo(n,\gamma)$	740, 181, 778, 140 (^{99m}Tc)
^{24}Na	15.03h	$^{23}Na(n,\gamma)$	1369
^{58}Co	70.78d	$^{58}Ni(n,p)$	811
^{86}Rb	18.7d	$^{85}Rb(n,\gamma)$	1077
^{46}Sc	84d	$^{45}Sc(n,\gamma)$	889
^{75}Se	120d	$^{74}Se(n,\gamma)$	265
^{125m}Sn	9.5m	$^{124}Sn(n,\gamma)$	332
^{233}Pa	27 d	$^{232}Th(n,\gamma)$ + β^--decay	312
^{239}Np	2.35 d	$^{238}U(n.\gamma)$ + β^--decay	228
^{52}V	3.75m	$^{51}V(n,\gamma)$	1434
^{65}Zn	244d	$^{64}Zn(n,\gamma)$	1115

Table 12: Concentration of ^{76}As in fish ($\mu g/g$) fresh weight

Element:	Arsenic		
Nuclide:	^{76}As		
Energy:	559.1 keV		
Half-life:	26.4 h		
IDC *:	10s/30h/30m		
Reaction:	$^{75}As(n,\gamma)$		
Results:	**Concentration**	**Uncertainty**	**MDC**
	2.18E-01	5.23E-02	4.07E-01

* IDC = Irradiation, delay and counting time-scheme.

Table 13 Overall evaluation of results

Element	Improvement	Suggested improvement
As	x10	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Ba	No RDA	
Br	No RDA	
Ca	x5	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Cd	x50	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Cl	Overall adequate	
Co	x15	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Cr	x15 *	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Cs	No RDA	
Cu	x500	Ashing, Isotope choice
F	x5	Semi-cyclic activation
Fe	x5*	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Hg	x10	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
I	Overall adequate	
K	Overall adequate	
Mg	Overall adequate	
Mn	Adequate *	
Mo	x20 *	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Na	Overall adequate	
Ni	No RDA	
Rb	No RDA	
Sc	No RDA	
Se	x20	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Sn	Overall adequate	
Th	Overall adequate	
U	x5	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
V	x5	$T_{irradiation}$ >, $T_{counting}$ >, M_{sample} >
Zn	Overall adequate	

* For infants: Sample ashing is advised to increase the sample mass

6 DISCUSSION AND CONCLUSION

- Some elements don't produce adequate isotopes upon neutron activation, i.e. Li, Be, B, C, N, P, Tl and Pb, and accordingly can not be analyzed by INAA (B and Pb are classified as "probably essential" and "toxic" respectively). Boron could be done by Prompt Gamma Neutron Activation Analysis (PGNAA), which is currently not available at Necsa. Other elements may be analyzed by Inductively Coupled Plasma Mass Spectrometry (ICPMS), Atomic Absorption Spectrometry (AAS) or X-ray Fluorescence spectrometry (XRF). However, the first two techniques require sample dissolution and according may be prone to contamination, especially at the trace concentration level.
- Aluminum is not included in the final results, as possible contamination from the sample conveyor tubes is suspected. This needs to be investigated for future applications.
- The element concentration in soils is the primary determinant of the element content of plant foods and in animals that feed on them. Soil element concentration will vary according to the geology of the food producing regions. However, some results obtained from this study compare with some of the data obtained from literature e.g.
  - The zinc content in pork of 31 ppm compares well with the zinc concentration given in Table 9 (Section 2.5).
  - The magnesium content of spinach compares with the 500 ppm content of green leafy vegetables from the literature[22]
- No recommended element intake values are available at this point in time for Ba, Br, Cs, Ni, Rb and Sc. However, the structure of the database allows easy update for the evaluation of the sensitivity by INAA, once values become available.
- The irradiation, decay and counting time-schemes as routinely applied at Necsa are chosen based on the half-life of a range of nuclides of interest. It will be clear that these general schemes can be optimized if targeted at one specific nuclide (element) of interest.
- Annexure 5 clearly indicates that in general INAA as routinely applied at Necsa, on average, has adequate sensitivity except for some foodstuffs like bread, beetroot and milk, which is mainly due to the relatively large

estimated daily consumption rates. Furthermore, it is observed that sensitivity may need to be improved for especially infants.

- Table 13 provides an overview of the suggested changes to the routine INAA applications to make the technique fully applicable in nutrition evaluation of foodstuffs. However, this should be investigated further to evaluate the validity of the recommended actions.

6.1 Recommendations for further investigations

- INAA seems to be an adequate choice for element analysis in foodstuffs.
- Some improvements can be easily obtained by increasing the irradiation and counting times as well as the sample volume.
- Copper needs more attention to evaluate the sensitivity of other copper isotopes generated upon neutron irradiation. Otherwise, ashing will be mandatory.
- One should develop a protocol to estimate actual and/or minimum determinable concentrations of individual elements from mixed diets. A first order evaluation of mixed diets can be performed by mathematical addition of appropriate fractions of the individual foodstuff-spectra according to a specific dietary habit under consideration. This will allow us to evaluate the advantage and/or disadvantage in analyzing individual foodstuffs against composite diets.
- One should also develop a database protocol to optimize INAA for sensitivity for a specific element and/or suite of elements, based on the available analysis parameters of foodstuffs and element standards. Typical parameters that are to be envisaged are irradiation time, decay time, counting time, sample mass and detector sensitivity.
- Further information has to be gathered on the dietary habits of the multiethnic South African population, including the vulnerable groups such as pregnant woman and infants.
- Other analytical techniques may be used for the analysis of foodstuff, especially for elements which can not be analyzed by INAA.

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8 List of Tables and Figures

8.1 List of figures

8.2 List of tables

9 GLOSSARY OF TERMS AND ANNEXURES

Abundance, isotopic

The relative number of atoms of a particular isotope in a mixture of the isotopes of an element, expressed as a fraction of all the atoms of the element.

Activation

Usually defined as the process of inducing radioactivity, and in the context in which the term is used in this study or thesis, the production of radionuclides by neutron bombardment.

Activity

Is the rate of decay of the radioactive nuclides in a sample. It is defined as the number of disintegration or nuclear transformations that will occur per second. The Becquerel is the SI unit used to express the activity of the sample. The older Curie-unit is still used, especially in isotope production for medical and industrial applications.

Activation Analysis

A method of analysis based on the detection of characteristic radionuclides formed by irradiation of a material with nuclear particles (e.g. neutrons, protons, gamma-rays).

Adequate Intake (AI)

The recommended average daily intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate. AI's are used when no Recommended Dietary Intake (RDA) values are available.

Cross-section

A measure of the probability of a specified interaction between an incident radiation and the target particle or system of particles.

Dead-time

Of a counter is the interval after the initiation of a voltage pulse during which a subsequent ionizing event does not provide a discharge.

Detector

A device which performs the function of identification and/or location of radiation (e.g. a radiation detector for location of gamma radiation).

Efficiency

A measure of the probability that a signal/count will be recorded when a particle or photon of ionizing radiation is incident on a detector.

Electromagnetic radiation

A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, infrared regions to radio waves of long wavelength. All electromagnetic radiations travel in a vacuum with the speed of light.

Fission

The splitting of a heavy nucleus into two approximately equal parts (which are radioactive nuclei of lighter elements) accompanied by the release of a relatively large amount of energy and generally one or more neutrons.

Half-life

The time in which the amount of a radioactive nuclide decays to half its initial value. Symbol is $T_{1/2}$

Irradiation

Exposure of a sample to nuclear radiation such as neutrons in a reactor core.

Isotope

Atoms having the same number of protons (which belong to the same element), but differing in the number of neutrons in the nuclei (e.g. ${}^{12}{}_{6}C_{6}$, ${}^{13}{}_{6}C_{7}$, ${}^{14}{}_{6}C_{8}$).

Matrix

Nature of sample material (e.g. Foodstuff, soil)

Neutrons

It is one of the types of ionizing radiation. The neutron is the neutral particle found in the atomic nucleus along with protons.

Nuclear reactor

A device in which a fission chain reaction can be initiated, maintained, and controlled.

Radiation

A term, which embraces electromagnetic waves (X-rays and gamma-rays) as well as streams of fast moving particles (electrons, protons etc.) and neutrons of all velocities.

Recommended Dietary Intake (RDI)

The average daily dietary nutrient intake level sufficient to meet the nutrient requirement of almost all (97 to 98 percent) healthy people in a particular life stage and gender group.

Provisional Tolerable Weekly Intake (PTWI)

This is the value set by the joint FAO/WHO Expert Committee on Food Additives. It is provisional because new information would initiate the review of intake. Tolerable signifies permissibility rather than acceptability, where intake of a contaminant is unavoidably associated with the consumption of nutritious food or with inhalation of air. Is set weekly because the compound has a bioaccumulative chronic toxic effect and daily fluctuations in intake are acceptable if the average longer-term intake does not exceed the limit.

Minimum Detectable Activity (MDA)

The minimum detectable activity is defined as the smallest amount of a specific radioactive nuclide that can be detected in a sample. The SI unit is Becquerel per gram (Bq/g).

Minimum Detectable Concentration (MDC)

The minimum detectable concentration is defined as the smallest concentration of an element that can be detected in a sample. The SI unit is gram per gram, often given in microgram per gram (μg/g) or parts per million (ppm).

Data in ug/g fresh weight

	As			Ba			Br			Ca			Cd			Cl			Co		
Foodstuff	Conc	Unc	MDC	Conc	Unc	MDC	Conc	Unc.	MDC	Conc.	Unc	MDC	Conc	Unc.	MDC	Conc.	Unc	MDC	Conc	Unc.	MDC
Beef			2.19E-01			1.84E+01	4.20E+00	5.12E-01	1.31E+00	3.56E+02	1.00E+02	5.94E+02			6.88E-01				9.21E-02	1.26E-02	3.47E-02
Beetroot			2.60E-01	8.74E+00	2.84E+00	1.20E+01	3.90E+00	5.66E-01	1.58E+00	3.91E+02	1.00E+02	5.99E+02			4.76E-01				1.75E-01	1.46E-02	3.19E-02
Brown bread			7.37E-01			4.80E+01	1.13E+01	7.63E-01	2.27E+00			3.27E+03			1.24E+00	7.39E+03	1.31E+03	2.08E+02	3.80E-01	2.75E-02	8.22E-02
Cabbage			1.77E-02			7.64E-01	2.67E+00	2.02E-01	4.74E-01	8.88E+01	5.84E+00	2.86E+01			2.47E-02	4.18E+02	7.56E+01	1.80E+01	8.30E-03	3.80E-04	9.32E-04
Chicken livers			2.16E-01			2.46E+01	2.40E+00	4.21E-01	1.24E+00			9.81E+02			9.97E-01				9.80E-02	1.24E-02	3.34E-02
Chicken meat			1.08E-01			4.79E+00	1.75E+00	1.27E-01	3.73E-01	2.63E+02	3.06E+01	1.56E+02			1.58E-01	6.75E+02	1.26E+02	4.22E+01	2.22E-02	1.85E-03	5.47E-03
Coffee			1.02E+00			5.12E+01	1.11E+01	1.23E+00	3.08E+00			3.34E+03			1.46E+00	1.37E+03	2.65E+02	1.52E+02	5.14E-01	2.87E-02	7.81E-02
Eggs			2.24E-01			1.31E+01	1.24E+01	6.92E-01	1.28E+00	3.75E+02	7.94E+01	4.61E+02			4.08E-01	1.61E+03	2.89E+02	6.83E+01	1.23E-01	6.72E-03	1.84E-02
Fish	2.18E-01	5.23E-02	4.07E-01			5.81E+01	7.37E+00	8.81E-01	2.34E+00	1.71E+04	3.14E+03	1.03E+03			2.25E+00				2.72E-01	3.09E-02	8.17E-02
Green Beans			6.18E-02			5.58E+00	4.20E-01	1.15E-01	3.63E-01	5.72E+02	1.11E+02	1.05E+02			2.49E-01				3.23E-02	3.42E-03	7.76E-03
Maize			3.11E-01			1.44E+01	1.51E+01	9.63E-01	1.59E+00			7.06E+02			4.69E-01	2.97E+02	6.40E+01	1.26E+01	1.33E-01	6.68E-03	1.62E-02
Margarine			1.15E+00			1.89E+01	4.49E+00	6.44E-01	2.69E+00			1.39E+03			5.56E-01	8.71E+03	1.55E+03	2.86E+02			4.47E-02
Milk			7.53E-02			4.17E+00			3.73E-01			2.52E+02			1.24E-01	1.41E+02	2.71E+01	1.33E+01	4.74E-03	1.62E-03	5.28E-03
Onions-002			6.09E-02			4.44E+00	1.74E+00	1.01E-01	2.75E-01	3.40E+02	7.14E+01	1.41E+02	1.30E-01	3.49E-02	2.73E-01	1.68E+02	3.23E+01	1.86E+01	4.58E-02	2.37E-03	6.08E-03
Pork			2.47E-01			2.05E+01	4.01E+00	5.28E-01	1.41E+00	6.19E+02	1.46E+02	4.92E+02			7.84E-01				7.79E-02	1.30E-02	3.78E-02
Potatoes-002			1.08E-01			7.09E+00	2.78E+00	1.59E-01	4.37E-01			4.93E+02			2.13E-01	8.23E+02	1.48E+02	2.78E+01	8.93E-02	3.93E-03	8.37E-03
Pumpkin			7.00E-02			6.23E+00	2.57E+00	2.25E-01	3.85E-01	4.08E+02	8.54E+01	2.00E+02			2.86E-01				4.46E-02	4.92E-03	1.24E-02
Rice	2.95E-01	4.27E-02	2.12E-01			3.11E+01	8.77E+00	5.03E-01	1.10E+00	1.38E+03	1.82E+02	9.50E+02			9.21E-01	1.37E+02	5.57E+01	1.48E+02	2.44E-01	1.33E-02	3.22E-02
Spinach			1.23E-02			5.71E-01	3.63E-01	1.57E-02	4.67E-02	4.09E+01	4.10E+00	2.38E+01			1.60E-02	7.26E+02	1.29E+02	3.00E+01	7.65E-03	3.51E-04	9.12E-04
Sugar-002			3.58E-02			8.54E+00			1.94E-01			5.93E+02			3.06E-01			1.11E+02	1.83E-02	3.15E-03	8.80E-03
Tea			3.22E-01	1.56E+01	1.99E+00	1.33E+01	1.47E+00	2.96E-01	9.21E-01	2.94E+03	1.64E+02	6.34E+02			6.64E-01	5.47E+02	1.11E+02	1.12E+02	3.63E-01	1.26E-02	2.03E-02
Tomatoes-002			4.25E-02			2.15E+00	6.63E-01	4.43E-02	1.24E-01	7.01E+01	1.76E+01	5.74E+01			6.36E-02	3.69E+02	6.60E+01	9.30E+00	2.01E-02	1.02E-03	2.57E-03
White bread			3.50E-01			2.03E+01	4.22E+00	4.37E-01	1.37E+00			1.39E+03			5.33E-01	7.39E+03	1.31E+03	2.19E+02	1.12E-01	1.19E-02	3.74E-02

	Cr			Cs			Cu			F			Fe			Hg			I		
Foodstuff	Conc	Unc.	MDC	Conc.	Unc	MDC	Conc	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc	Unc.	MDC
Beef	1.72E+00	1.36E-01	2.12E-01			6.40E-02							2.63E+01	5.38E+00	1.70E+01			5.38E-01			
Beetroot	3.49E+00	2.19E-01	1.42E-01			4.76E-02							6.27E+01	6.64E+00	1.61E+01	8.25E-02	7.65E-02	3.02E-01			
Brown bread	3.74E+00	1.33E-01	4.70E-01			4.15E-01			4.81E+02	5.88E+00	8.83E-01	2.26E+00	3.69E+02	3.30E+01	1.02E+02			3.68E-01			2.83E-01
Cabbage	2.34E-02	1.58E-03	8.24E-03			5.31E-03			8.33E+01			4.73E-01	2.25E+00	3.31E-01	1.04E+00			6.38E-03			2.48E-02
Chicken livers	1.16E+00	1.66E-01	4.87E-01			6.84E-02							1.69E+02	1.38E+01	1.97E+01	2.73E-01	1.48E-01	6.13E-01			
Chicken meat	7.23E-02	9.45E-03	5.40E-02			3.31E-02			1.95E+02	2.76E-02	7.58E-03	2.27E-02			1.06E+01			4.26E-02			8.59E-02
Coffee	1.02E+01	3.14E-01	5.29E-01	4.28E-01	1.02E-01	3.30E-01			5.68E+02	2.49E+00	7.58E-01	2.25E+00	6.06E+02	3.40E+01	9.18E+01			4.02E-01			2.19E-01
Eggs	9.03E-01	9.34E-02	2.92E-01			9.73E-02			1.89E+02	2.41E+00	3.14E-01	6.90E-01	2.50E+01	3.89E+00	1.79E+01			1.08E-01			1.03E-01
Fish	2.84E+00	3.13E-01	8.07E-01			1.52E-01							1.69E+02	1.45E+01	3.37E+01	1.10E+00	4.48E-01	1.60E+00			
Green Beans	9.28E-02	2.03E-02	6.37E-02			1.56E-02							1.49E+01	1.48E+00	3.22E+00			1.65E-01			
Maize	3.18E-01	9.25E-02	2.97E-01			9.54E-02			2.11E+02			1.40E+00	9.74E+00	4.76E+00	1.55E+01			1.19E-01			6.26E-02
Margarine	3.70E-01	9.12E-02	2.63E-01			1.65E-01			6.01E+02	6.93E+00	1.19E+00	2.52E+00			6.16E+01			1.42E-01			4.26E-01
Milk	8.00E-01	2.54E-02	4.77E-02			3.09E-02			5.39E+01	3.56E-01	7.51E-02	2.04E-01	4.40E+00	2.56E+00	8.40E+00			3.74E-02			2.67E-02
Onions-002	5.25E-01	1.87E-02	4.76E-02			1.64E-02			7.96E+01			4.83E-01	1.05E+01	1.26E+00	4.00E+00			3.60E-02			1.90E-02
Pork	2.43E-01	8.45E-02	2.64E-01	3.73E-02	2.00E-02	6.50E-02							1.44E+01	2.97E+00	1.64E+01			5.98E-01			
Potatoes-002	1.88E+00	6.24E-02	7.75E-02			2.66E-02			9.11E+01			5.64E-01	5.58E+01	5.18E+00	8.79E+00			5.85E-02			3.02E-02
Pumpkin	3.06E-01	3.39E-02	8.27E-02			2.02E-02							9.04E+00	1.27E+00	5.29E+00			1.56E-01			
Rice	3.24E+00	1.29E-01	3.57E-01			2.17E-01			3.21E+02			1.08E+00	1.60E+02	1.70E+01	5.09E+01			2.75E-01			9.24E-02
Spinach	1.74E-01	4.90E-03	5.64E-03			4.71E-03			1.03E+02	2.14E+00	2.21E-01	4.31E-01	4.25E+00	3.54E-01	1.08E+00			4.20E-03			5.20E-02
Sugar-002	3.25E+00	1.24E-01	1.49E-01			3.08E-02			2.41E+02			1.27E+00	5.20E+01	5.52E+00	1.26E+01			4.48E-02			6.00E-02
Tea	6.69E+00	1.98E-01	2.31E-01	1.33E-01	2.87E-02	9.20E-02			6.07E+02	3.21E+00	9.06E-01	2.79E+00	3.63E+02	1.42E+01	2.79E+01			1.81E-01			1.76E-01
Tomatoes-002	5.49E-01	1.65E-02	2.29E-02			7.12E-03			4.90E+01			2.68E-01	3.72E+00	4.82E-01	1.54E+00			1.76E-02			1.39E-02
White bread	3.50E+00	1.08E-01	2.01E-01			1.75E-01			5.47E+02	2.33E+01	2.05E+00	2.65E+00	6.76E+01	1.62E+01	5.29E+01			1.55E-01			3.09E-01

Data in ug/g fresh weight

	K			Mg			Mn			Mo			Na			Ni			Rb		
Foodstuff	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC
Beef	2.52E+03	2.29E+02	5.90E+01						2.39E+00			4.83E-01	4.65E+02	3.80E+01	2.13E+00			1.18E+01	3.19E+00	2.73E-01	6.13E-01
Beetroot	3.44E+03	3.12E+02	7.79E+01				3.20E+01	1.27E+01	5.15E+00			2.64E-01	1.09E+03	8.82E+01	2.20E+00			9.02E+00	1.75E+00	1.91E-01	5.11E-01
Brown bread	1.87E+03	1.51E+02	4.67E+02	7.23E+02	8.38E+01	2.97E+02	2.08E+01	2.42E-01	5.82E-01			1.11E+01	3.92E+03	5.69E+01	1.35E+01			1.85E+02			6.20E+00
Cabbage	4.43E+02	8.82E+00	1.03E+01	2.14E+02	1.97E+01	5.01E+01	2.97E-01	9.16E-03	2.56E-02			1.53E-01	1.88E+01	2.80E-01	4.45E-01			2.33E+00	7.84E-02	1.33E-02	4.25E-02
Chicken livers	2.22E+03	2.02E+02	6.06E+01				3.43E+00	1.34E+00	3.31E+00			7.32E-01	5.44E+02	4.42E+01	2.03E+00			1.30E+01	5.59E+00	3.74E-01	6.13E-01
Chicken meat	9.72E+02	2.71E+01	5.89E+01	3.26E+02	3.86E+01	1.33E+02	8.97E-02	3.41E-02	1.11E-01			1.84E+00	2.38E+02	2.71E+00	2.82E+00			1.43E+01	8.82E-01	9.39E-02	2.87E-01
Coffee	1.32E+04	2.90E+02	5.66E+02	1.06E+03	1.29E+02	4.09E+02	1.42E+01	3.14E-01	7.64E-01			1.35E+01	1.63E+03	2.00E+01	2.34E+01			1.81E+02	3.65E+01	1.85E+00	4.81E+00
Eggs	1.31E+03	1.23E+02	9.61E+01	1.23E+02	2.46E+01	1.11E+02	7.34E-01	7.40E-02	2.33E-01			5.31E-01	1.44E+03	1.17E+02	2.81E+00			1.34E+01	2.73E+00	2.93E-01	7.84E-01
Fish	5.27E+03	4.77E+02	1.25E+02				6.00E+00	1.60E+00	5.05E+00			1.62E+00	1.26E+03	1.02E+02	4.09E+00	1.09E+01	3.63E+00	2.75E+01	1.98E+00	4.54E-01	1.42E+00
Green Beans	2.30E+03	2.07E+02	1.70E+01				3.66E+00	8.42E-01	8.79E-01			1.82E-01	1.20E+00	2.16E-01	6.60E-01	1.40E+00	6.65E-01	2.59E+00	1.84E+00	1.17E-01	1.37E-01
Maize	1.33E+03	4.98E+01	9.19E+01	3.73E+02	5.31E+01	1.53E+02	3.08E+00	1.13E-01	2.62E-01			4.99E+00	3.73E+00	1.02E+00	3.13E+00			4.12E+01	5.15E-01	2.03E-01	8.61E-01
Margarine	5.50E+02	1.95E+02	6.36E+02			5.82E+02			1.88E+00			4.50E+00	5.59E+03	9.20E+01	2.55E+01			7.30E+01			2.85E+00
Milk	8.51E+02	2.40E+01	5.42E+01			5.62E+01	8.74E-02	2.06E-02	6.71E-02			1.49E+00	2.18E+02	2.34E+00	2.26E+00			1.37E+01			4.71E-01
Onions-002	1.36E+03	1.21E+02	1.65E+01	1.67E+02	1.79E+01	5.42E+01	1.45E+00	3.44E-02	8.33E-02			1.82E-01	4.02E+01	3.25E+00	6.75E-01			3.20E+00	7.51E-01	7.10E-02	1.59E-01
Pork	2.77E+03	2.51E+02	8.79E+01						3.38E+00			5.35E-01	6.22E+02	5.04E+01	2.31E+00			1.21E+01	4.01E+00	3.11E-01	6.35E-01
Potatoes-002	3.64E+03	3.43E+02	2.98E+01	2.19E+02	2.29E+01	5.98E+01	1.31E+00	5.06E-02	1.40E-01			2.66E-01	2.85E+01	2.38E+00	1.11E+00	2.57E+00	1.23E+00	4.93E+00	8.02E-01	9.75E-02	2.56E-01
Pumpkin	2.06E+03	1.84E+02	1.74E+01				8.09E-01	1.70E-01	5.26E-01			1.59E-01	5.93E+00	5.58E-01	7.00E-01			3.83E+00	5.19E-01	7.15E-02	2.00E-01
Rice	1.99E+03	9.72E+01	2.05E+02	3.70E+02	8.50E+01	2.07E+02	1.40E+01	2.05E-01	2.83E-01			1.03E+01	1.30E+01	2.22E+00	6.25E+00			1.00E+02	6.08E+00	5.82E-01	1.69E+00
Spinach	1.50E+02	3.21E+00	7.93E+00	5.53E+02	4.00E+01	7.06E+01	1.27E+00	7.83E-03	1.59E-02			1.36E-01	8.08E+01	7.53E-01	2.29E-01			2.08E+00	2.12E-01	1.64E-02	4.97E-02
Sugar-002	2.37E+00	7.73E+00	1.48E+01			3.43E+02	7.77E-01	5.14E-02	8.38E-02			2.16E-01	3.51E+00	8.19E-01	1.77E+00			8.31E+00			3.38E-01
Tea	9.45E+03	2.30E+02	5.73E+02	2.25E+03	1.89E+02	4.45E+02	4.44E+02	1.48E+00	1.11E+00			7.57E+00	4.89E+01	3.52E+00	9.67E+00			8.56E+01	2.77E+01	9.23E-01	1.36E+00
Tomatoes-002	1.80E+03	1.61E+02	1.22E+01	1.67E+02	1.40E+01	3.14E+01	9.18E-01	1.93E-02	4.93E-02			9.91E-02	2.73E+01	2.22E+00	4.06E-01			1.33E+00	7.02E-01	4.77E-02	6.69E-02
White bread	6.73E+02	5.97E+01	1.83E+02	4.04E+02	7.58E+01	3.33E+02	4.28E+00	1.01E-01	2.85E-01			4.58E+00	2.02E+03	1.54E+01	9.58E+00			7.93E+01			2.65E+00

	Sc			Se			Sn			Th			U			V			Zn		
Foodstuff	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC	Conc.	Unc.	MDC
Beef			2.08E-03			7.94E-01			1.03E+01			1.89E-02			5.35E-01				3.94E+01	2.35E+00	1.38E+00
Beetroot	1.43E-02	9.56E-04	1.62E-03			4.62E-01			6.88E+00			1.19E-02			8.35E-01				5.69E+00	4.06E-01	9.35E-01
Brown bread	1.49E-01	8.10E-03	2.29E-02			1.83E+00										5.35E-01	1.59E-01	4.92E-01	1.34E+01	1.18E+00	7.38E+00
Cabbage	4.84E-04	4.50E-05	1.37E-04			3.13E-02			3.09E+00			5.45E-03			2.56E-01			1.46E-01	8.16E-01	2.27E-02	7.72E-02
Chicken livers	4.35E-03	7.40E-04	2.23E-03	6.92E-01	3.23E-01	1.06E+00			1.41E+01	9.92E-03	2.73E-03	2.46E-02			5.31E-01				4.59E+01	2.67E+00	1.05E+00
Chicken meat	9.69E-04	3.08E-04	1.00E-03			2.14E-01												3.16E-01	4.11E+00	2.47E-01	6.66E-01
Coffee	1.49E-01	5.74E-03	1.25E-02			1.97E+00										8.59E-01	2.29E-01	6.91E-01	6.27E+00	9.70E-01	5.67E+00
Eggs	2.50E-03	6.51E-04	2.11E-03			5.38E-01			1.23E+01			2.09E-02			8.38E-01			3.17E-01	8.18E+00	3.64E-01	1.46E+00
Fish	3.71E-03	1.53E-03	4.91E-03			2.72E+00			3.43E+01			6.32E-02			1.14E+00				9.38E+01	5.60E+00	3.81E+00
Green Beans	2.15E-03	2.02E-04	4.96E-04			2.44E-01			3.32E+00	1.90E-03	6.67E-04	5.41E-03			1.50E-01				3.63E+00	2.39E-01	2.41E-01
Maize	1.73E-03	7.19E-04	2.35E-03			5.65E-01												3.61E-01	7.51E+00	5.02E-01	1.37E+00
Margarine			6.58E-03			7.03E-01												8.27E-01			4.46E+00
Milk	1.17E-03	2.30E-04	7.35E-04			1.91E-01												9.34E-02			8.29E-01
Onions-002	1.17E-03	1.88E-04	5.41E-04			1.77E-01			3.32E+00			5.95E-03			1.44E-01	1.15E-01	3.39E-02	1.05E-01	2.67E+00	1.89E-01	2.70E-01
Pork			2.11E-03			8.81E-01			1.19E+01			2.07E-02			6.08E-01				3.13E+01	1.92E+00	1.48E+00
Potatoes-002	7.32E-04	2.51E-04	8.01E-04			2.89E-01			4.54E+00			9.24E-03			2.55E-01	1.44E-01	4.39E-02	1.37E-01	4.25E+00	3.10E-01	4.97E-01
Pumpkin	1.22E-03	2.08E-04	6.17E-04			2.25E-01			3.40E+00			5.67E-03			1.50E-01				1.29E+00	1.17E-01	3.48E-01
Rice	3.99E-02	2.23E-03	5.85E-03			1.35E+00												6.53E-01	1.51E+01	7.51E-01	2.60E+00
Spinach	1.66E-03	8.76E-05	1.62E-04			2.06E-02										3.53E-01	5.01E-02	1.43E-01	5.45E-01	1.98E-02	7.78E-02
Sugar-002			1.25E-03			3.32E-01			5.06E+00			9.91E-03			1.01E-01			4.72E-01	9.25E-01	2.15E-01	7.95E-01
Tea	1.07E-01	3.91E-03	8.17E-03			9.00E-01										6.12E-01	2.16E-01	6.90E-01	1.53E+01	5.83E-01	1.64E+00
Tomatoes-002	1.32E-04	5.83E-05	1.97E-04			8.76E-02			1.65E+00			2.94E-03			1.02E-01	5.95E-02	2.11E-02	6.75E-02	8.22E-01	7.59E-02	1.45E-01
White bread	4.30E-02	2.01E-03	5.16E-03	5.15E-01	2.22E-01	7.29E-01										8.49E-01	2.20E-01	6.79E-01	4.86E+00	4.95E-01	2.86E+00

Annexure 2 Evaluation of element concentrations and detection limits

Element:	As			Ba			Br			Ca			Cd			Cl			Co		
Foodstuff	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC
Beef	4	-	8.09E-01	5	-	6.79E+01	4	+	4.83E+00	5	+	2.19E+03	5	-	2.54E+00				5	+	1.28E-01
Beetroot	4	-	1.46E+00	5	+	6.76E+01	4	+	8.88E+00	5	+	3.37E+03	5	-	2.67E+00				5	+	1.79E-01
Brown bread	4	-	1.29E+00	5	-	8.41E+01	4	+	3.97E+00	5	-	5.72E+03	5	-	2.17E+00	2	+	3.64E+02	5	+	1.44E-01
Cabbage	4	-	1.90E-01	5	-	8.21E+01	4	+	4.91E-01	5	+	3.07E+02	5	-	2.66E-01	2	+	1.93E+02	5	+	1.00E-02
Chicken meat	4	-	3.40E-01	5	-	1.51E+01	4	+	1.18E+00	5	+	4.91E+02	5	-	4.97E-01	2	+	1.33E+02	5	+	1.73E-02
Chicken livers	4	-	8.59E-01	5	-	9.75E+01	4	+	4.92E+00	5	-	3.89E+03	5	-	3.96E+00				5	+	1.33E-01
Coffee	4	-	1.02E+00	5	-	5.12E+01	4	+	3.08E+00	5	-	3.34E+03	5	-	1.46E+00	2	+	1.52E+02	5	+	7.81E-02
Eggs	4	-	9.02E-01	5	-	5.30E+01	4	+	2.96E+00	5	+	1.86E+03	5	-	1.67E+00	2	+	2.75E+02	5	+	7.42E-02
Fish	4	+	8.47E-01	5	-	1.21E+02	4	+	4.87E+00	5	+	2.14E+03	5	-	4.69E+00				5	+	1.70E-01
Green Beans	4	-	6.00E-01	5	-	5.41E+01	4	+	3.52E+00	5	+	1.02E+03	5	-	2.42E+00				5	+	7.54E-02
Maize	4	-	5.34E-01	5	-	2.47E+01	4	+	9.96E-01	5	-	1.21E+03	5	-	8.05E-01	2	+	2.15E+01	5	+	2.78E-02
Margarine	4	-	1.15E+00	5	-	1.89E+01	4	+	2.69E+00	5	-	1.39E+03	5	-	5.56E-01	2	+	2.86E+02	5	-	4.47E-02
Milk	4	-	7.53E-01	5	-	4.17E+01	4	-	3.69E+00	5	-	2.52E+03	5	-	1.24E+00	2	+	1.33E+02	5	+	5.28E-02
Onion	4	-	8.45E-01	5	-	3.97E+01	4	+	2.46E+00	5	+	1.26E+03	5	+	1.16E+00	2	+	1.66E+02	5	+	5.43E-02
Pork	4	+	8.56E-01	5	-	7.10E+01	4	+	4.88E+00	5	+	1.70E+03	5	-	2.71E+00				5	+	1.31E-01
Potatoes	4	-	6.80E-01	5	-	4.46E+01	4	+	2.75E+00	5	-	2.66E+03	5	-	1.34E+00	2	+	1.75E+02	5	+	5.26E-02
Pumpkin	4	-	6.73E-01	5	-	5.99E+01	4	+	3.70E+00	5	+	1.92E+03	5	-	2.75E+00				5	+	1.19E-01
Rice	4	+	2.23E-01	5	-	3.27E+01	4	+	1.16E+00	5	+	1.00E+03	5	-	9.70E-01	2	+	1.56E+02	5	+	3.39E-02
Spinach	4	-	1.73E-01	5	-	8.04E+00	4	+	6.58E-01	5	+	3.35E+02	5	-	2.26E-01	2	+	4.23E+02	5	+	1.29E-02
Sugar	4	-	1.07E-01	5	-	8.54E+00	4	-	4.43E-01	5	-	5.93E+02	5	-	4.67E-01	2	-	1.11E+02	5	+	6.80E-03
Tea	4	-	6.43E-01	5	+	2.65E+01	4	+	1.84E+00	5	+	1.27E+03	5	-	1.33E+00	2	+	2.24E+02	5	+	4.05E-02
Tomatoes	4	-	9.47E-01	5	-	4.38E+01	4	+	2.53E+00	5	+	1.67E+03	5	-	1.30E+00	2	+	1.90E+02	5	+	5.24E-02
White bread	4	-	5.60E-01	5	-	3.25E+01	4	+	2.20E+00	5	-	2.22E+03	5	-	8.25E-01	2	+	3.50E+02	5	+	5.98E-02
MDC (ug/g) dry weight																					
Maximum observed detection limit			1.46E+00			1.21E+02			8.88E+00			5.72E+03			4.69E+00			4.23E+02			1.79E-01
Minimum observed detection limit			1.07E-01			8.04E+00			4.43E-01			3.07E+02			2.26E-01			2.15E+01			8.80E-03
Average observed detection limit			7.15E-01			4.98E+01			2.99E+00			1.92E+03			1.65E+00			2.10E+02			7.39E-02
Standard deviation on the average			3.45E-01			2.83E+01			1.89E+00			1.25E+03			1.14E+00			1.02E+02			5.10E-02
Ratio maximum/minimum			1.36E+01			1.50E+01			2.01E+01			1.86E+01			2.07E+01			1.97E+01			2.03E+01
Concentration (ug/g) dry weight																					
Maximum observed concentration		4.55E-01			4.91E+01			8.43E+01			3.56E+04			1.16E+00			1.29E+04			9.82E-01	
Minimum observed concentration		3.10E-01			3.12E+01			2.93E+00			5.76E+02			1.16E+00			1.44E+02			1.83E-02	
Average observed concentration		3.82E-01			4.01E+01			1.69E+01			4.43E+03			1.16E+00			5.04E+03			3.80E-01	
Standard deviation on the average		7.24E-02			8.98E+00			1.47E+01			7.78E+03			0.00E+00			4.20E+03			2.22E-01	

** Concentration (ug/g) dry weight

+ = Detected   - = Not detected

* IDC = Irrdiation, delay and couning scheme

1 = 10sec/10-30sec/30-120sec

2 = 10sec/10min/10min

3 = 10-20sec/3hrs/15-30min

4 = 10-20sec/30hrs/15-30min

5 = 30min/7days/30-60min

Annexure 2 Evaluation of element concentrations and detection limits (continued)

Element:	Cr			Cs			Cu			F			Fe			Hg			I		
Foodstuff	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC
Beef	5	+	7.81E-01	5	-	2.36E-01							5	+	6.29E+01	5	-	3.97E-01			
Beetroot	5	+	7.98E-01	5	-	2.69E-01							5	+	9.07E+01	5	+	3.40E-01			
Brown bread	5	+	8.23E-01	5	-	7.26E-01	1	-	8.42E+02	1	+	3.96E+00	5	+	1.78E+02	5	-	6.44E-01	2	-	4.96E-01
Cabbage	5	+	8.86E-02	5	-	5.72E-02	1	-	8.95E+02	1	-	5.08E+00	5	+	1.12E+01	5	-	6.86E-02	2	-	2.67E-01
Chicken meat	5	+	1.70E-01	5	-	1.04E-01	1	-	6.14E+02	1	+	7.16E-01	5	-	3.35E+01	5	-	1.34E-01	2	-	2.71E-01
Chicken livers	5	+	1.93E+00	5	-	2.72E-01							5	+	7.80E+01	5	+	4.87E-01			
Coffee	5	+	5.29E-01	5	+	3.30E-01	1	-	5.68E+02	1	+	2.25E+00	5	+	9.18E+01	5	-	4.02E-01	2	-	2.19E-01
Eggs	5	+	1.02E+00	5	-	2.90E-01	1	-	7.61E+02	1	+	2.78E+00	5	+	7.20E+01	5	-	4.34E-01	2	-	4.15E-01
Fish	5	+	1.68E+00	5	-	3.18E-01							5	+	7.01E+01	5	+	6.69E-01			
Green Beans	5	+	6.19E-01	5	-	1.52E-01							5	+	3.12E+01	5	-	3.21E-01			
Maize	5	+	5.10E-01	5	-	1.64E-01	1	-	3.62E+02	1	-	2.41E+00	5	+	2.65E+01	5	-	2.03E-01	2	-	1.07E-01
Margarine	5	+	2.63E-01	5	-	1.65E-01	1	-	6.01E+02	1	+	2.52E+00	5	-	6.16E+01	5	-	1.42E-01	2	-	4.28E-01
Milk	5	+	4.77E-01	5	-	3.09E-01	1	-	5.39E+02	1	+	2.04E+00	5	+	8.40E+01	5	-	3.74E-01	2	-	2.67E-01
Onion	5	+	4.25E-01	5	-	1.46E-01	1	-	7.11E+02	1	-	4.31E+00	5	+	3.57E+01	5	-	3.22E-01	2	-	1.69E-01
Pork	5	+	9.14E-01	5	+	2.25E-01							5	+	5.68E+01	5	-	4.14E-01			
Potatoes	5	+	4.88E-01	5	-	1.67E-01	1	-	5.73E+02	1	-	3.55E+00	5	+	5.53E+01	5	-	3.68E-01	2	-	1.90E-01
Pumpkin	5	+	7.95E-01	5	-	1.94E-01							5	+	5.09E+01	5	-	3.00E-01			
Rice	5	+	3.76E-01	5	-	2.28E-01	1	-	3.38E+02	1	-	1.13E+00	5	+	5.36E+01	5	-	2.89E-01	2	-	9.73E-02
Spinach	5	+	7.94E-02	5	-	6.64E-02	1	-	1.44E+03	1	+	6.07E+00	5	+	1.53E+01	5	-	5.91E-02	2	-	7.32E-01
Sugar	5	+	1.49E-01	5	-	3.08E-02	1	-	2.41E+02	1	-	1.27E+00	5	+	1.26E+01	5	-	4.48E-02	2	-	6.00E-02
Tea	5	+	4.62E-01	5	+	1.84E-01	1	-	1.21E+03	1	+	5.59E+00	5	+	5.58E+01	5	-	3.63E-01	2	-	3.53E-01
Tomatoes	5	+	4.68E-01	5	-	1.45E-01	1	-	1.00E+03	1	-	5.46E+00	5	+	3.15E+01	5	-	3.60E-01	2	-	2.84E-01
White bread	5	+	3.22E-01	5	-	2.81E-01	1	-	8.76E+02	1	+	4.23E+00	5	+	8.46E+01	5	-	2.47E-01	2	-	4.95E-01
MDC (ug/g) dry weight																					
Maximum observed detection limit			1.93E+00			7.26E-01			1.44E+03			6.07E+00			1.78E+02			6.69E-01			7.32E-01
Minimum observed detection limit			7.94E-02			3.08E-02			2.41E+02			7.16E-01			1.12E+01			4.48E-02			6.00E-02
Average observed detection limit			6.16E-01			2.20E-01			7.23E+02			3.34E+00			5.84E+01			3.21E-01			3.03E-01
Standard deviation on the average			4.49E-01			1.36E-01			3.08E+02			1.64E+00			3.52E+01			1.60E-01			1.71E-01
Ratio maximum/minimum			2.43E+01			2.36E+01			5.98E+00			8.48E+00			1.59E+01			1.49E+01			1.22E+01
Concentration (ug/g) dry weight																					
Maximum observed concentration		1.96E+01			4.28E-01						3.73E+01			7.26E+02			2.29E+00				
Minimum observed concentration		2.16E-01			1.29E-01						8.71E-02			1.67E+01			4.63E-01				
Average observed concentration		5.30E+00			2.74E-01						1.21E+01			2.15E+02			1.17E+00				
Standard deviation on the average		4.63E+00			1.22E-01						1.21E+01			2.14E+02			6.81E-01				

** Concentration (ug/g) dry weight

+ = Detected - = Not detected

* IDC = Irrdiation, delay and couning scheme

1 = 10sec/10-30sec/30-120sec

2 = 10sec/10min/10min

3 = 10-20sec/3hrs/15-30min

4 = 10-20sec/30hrs/15-30min

5 = 30min/7days/30-60min

Annexure 2 Evaluation of element concentrations and detection limits (continued)

Element:	K			Mg			Mn			Mo			Na			Ni			Rb		
Foodstuff	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC
Beef	4	+	2.18E+02				3	-	1.26E+00	3	-	1.78E+00	4	+	7.86E+00	5	-	4.37E+01	5	+	2.26E+00
Beetroot	4	+	4.37E+02				3	+	4.14E+00	3	-	1.48E+00	4	+	1.24E+01	5	-	5.07E+01	5	+	2.87E+00
Brown bread	4	+	2.72E+02	2	+	5.21E+02	3	+	1.02E+00	3	-	2.59E+00	4	+	2.36E+01	5	-	6.80E+01	5	-	1.09E+01
Cabbage	4	+	3.67E+01	2	+	5.38E+02	3	+	2.76E-01	3	-	1.64E+00	4	+	4.79E+00	5	-	5.26E+00	5	+	4.57E-01
Chicken meat	4	+	6.20E+01	2	+	4.20E+02	3	+	3.51E-01	3	-	7.73E-01	4	+	8.90E+00	5	-	9.44E+00	5	+	9.06E-01
Chicken livers	4	+	2.40E+02				3	+	1.88E+00	3	-	2.90E+00	4	+	8.08E+00	5	-	5.16E+01	5	+	2.43E+00
Coffee	4	+	1.89E+02	2	+	4.09E+02	3	+	7.64E-01	3	-	1.80E+00	4	+	2.34E+01	5	-	3.80E+01	5	+	4.81E+00
Eggs	4	+	1.29E+02	2	+	4.46E+02	3	+	9.40E-01	3	-	2.14E+00	4	+	1.13E+01	5	-	5.41E+01	5	+	3.16E+00
Fish	4	+	2.60E+02				3	+	1.50E+00	3	-	3.38E+00	4	+	8.52E+00	5	+	5.74E+01	5	+	2.95E+00
Green Beans	4	+	1.65E+02				3	+	1.22E+00	3	-	1.77E+00	4	+	6.41E+00	5	+	2.52E+01	5	+	1.33E+00
Maize	4	+	5.27E+01	2	+	2.63E+02	3	+	4.49E-01	3	-	1.14E+00	4	+	5.37E+00	5	-	1.48E+01	5	+	1.13E+00
Margarine	4	+	2.12E+02	2	-	5.82E+02	3	-	1.88E+00	3	-	6.00E-01	4	+	2.55E+01	5	-	1.53E+01	5	-	2.65E+00
Milk	4	+	1.81E+02	2	-	5.62E+02	3	+	6.71E-01	3	-	1.99E+00	4	+	2.26E+01	5	-	2.87E+01	5	-	4.71E+00
Onion	4	+	1.48E+02	2	+	4.84E+02	3	+	7.44E-01	3	-	1.63E+00	4	+	6.03E+00	5	-	2.86E+01	5	+	1.42E+00
Pork	4	+	2.35E+02				3	-	1.67E+00	3	-	1.85E+00	4	+	8.01E+00	5	-	4.18E+01	5	+	2.20E+00
Potatoes	4	+	1.87E+02	2	+	3.76E+02	3	+	8.82E-01	3	-	1.67E+00	4	+	6.99E+00	5	+	3.10E+01	5	+	1.61E+00
Pumpkin	4	+	1.68E+02				3	+	7.22E-01	3	-	1.53E+00	4	+	6.73E+00	5	-	3.68E+01	5	+	1.92E+00
Rice	4	+	7.17E+01	2	+	2.18E+02	3	+	2.97E-01	3	-	1.45E+00	4	+	6.57E+00	5	-	2.21E+01	5	+	1.78E+00
Spinach	4	+	3.73E+01	2	+	9.94E+02	3	+	2.24E-01	3	-	2.56E-01	4	+	3.23E+00	5	-	6.16E+00	5	+	7.00E-01
Sugar	4	+	1.48E+01	2	-	3.43E+02	3	+	8.38E-02	3	-	2.16E-01	4	+	1.77E+00	5	-	6.31E+00	5	-	3.38E-01
Tea	4	+	7.41E+02	2	+	8.90E+02	3	+	2.23E+00	3	-	2.01E+00	4	+	1.93E+01	5	-	2.75E+01	5	+	2.71E+00
Tomatoes	4	+	2.49E+02	2	+	6.41E+02	3	+	1.01E+00	3	-	2.02E+00	4	+	8.29E+00	5	-	2.72E+01	5	+	1.37E+00
White bread	4	+	9.77E+01	2	+	5.32E+02	3	+	4.75E-01	3	-	9.77E-01	4	+	1.53E+01	5	-	2.66E+01	5	-	4.24E+00
MDC (ug/g) dry weight																					
Maximum observed detection limit			7.41E+02			9.94E+02			4.14E+00			3.38E+00			2.55E+01			6.80E+01			1.09E+01
Minimum observed detection limit			1.48E+01			2.18E+02			8.38E-02			2.16E-01			1.77E+00			5.26E+00			3.38E-01
Average observed detection limit			1.91E+02			5.14E+02			1.07E+00			1.63E+00			1.09E+01			3.11E+01			2.56E+00
Standard deviation on the average			1.51E+02			1.97E+02			8.69E-01			7.46E-01			6.95E+00			1.72E+01			2.15E+00
Ratio maximum/minimum			5.00E+01			4.56E+00			4.94E+01			1.56E+01			1.44E+01			1.29E+01			3.22E+01
Concentration (ug/g) dry weight																					
Maximum observed concentration		3.73E+04			7.79E+03			8.89E+02						6.86E+03			2.28E+01			5.83E+01	
Minimum observed concentration		2.37E+00			3.89E+02			2.83E-01						3.51E+00			1.36E+01			8.21E-01	
Average observed concentration		1.14E+04			2.03E+03			5.61E+01						1.80E+03			1.75E+01			1.39E+01	
Standard deviation on the average		1.03E+04			2.02E+03			1.77E+02						2.02E+03			3.85E+00			1.55E+01	

** Concentration (ug/g) dry weight
+ = Detected - = Not detected
* IDC = Irrdiation, delay and couning scheme
1 = 10sec/10-30sec/30-120sec
2 = 10sec/10min/10min
3 = 10-20sec/3hrs/15-30min
4 = 10-20sec/30hrs/15-30min
5 = 30min/7days/30-60min

Annexure 2 Evaluation of element concentrations and detection limits (continued)

Element:	Sc			Se			Sn			Th			U			V			Zn		
Foodstuff	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC	IDC*	Conc **	MDC
Beef	5	-	7.68E-03	5	-	2.93E+00	5	-	3.81E+01	5	-	6.97E-02	5	-	1.97E+00				5	+	5.10E+00
Beetroot	5	+	9.08E-03	5	-	2.59E+00	5	-	3.87E+01	5	-	6.68E-02	5	-	3.57E+00				5	+	5.25E+00
Brown bread	5	+	1.66E-02	5	-	3.20E+00										1	+	8.62E-01	5	+	1.29E+01
Cabbage	5	+	1.47E-03	5	-	3.37E-01				5	-	5.86E-02	5	-	2.75E+00	1	-	1.57E+00	5	+	8.31E-01
Chicken meat	5	+	2.06E-03	5	-	6.74E-01										1	-	1.00E+00	5	+	2.17E+00
Chicken livers	5	+	8.87E-03	5	+	4.20E+00	5	-	5.60E+01	5	+	9.75E-02	5	-	2.11E+00				5	+	4.16E+00
Coffee	5	+	1.25E-02	5	-	1.97E+00										1	+	6.91E-01	5	+	5.87E+00
Eggs	5	+	8.52E-03	5	-	2.17E+00				5	-	8.44E-02	5	-	3.38E+00	1	-	1.28E+00	5	+	5.87E+00
Fish	5	+	1.02E-02	5	-	5.66E+00	5	-	7.15E+01	5	-	1.32E-01	5	-	2.39E+00				5	+	7.95E+00
Green Beans	5	+	4.82E-03	5	-	2.37E+00	5	-	3.22E+01	5	+	5.25E-02	5	-	1.46E+00				5	+	2.34E+00
Maize	5	+	4.03E-03	5	-	1.00E+00										1	-	6.19E-01	5	+	2.35E+00
Margarine	5	-	6.58E-03	5	-	7.03E-01										1	-	8.72E-01	5	-	4.46E+00
Milk	5	+	7.35E-03	5	-	1.91E+00										1	-	9.34E-01	5	-	8.29E+00
Onion	5	+	4.83E-03	5	-	1.58E+00				5	-	5.31E-02	5	-	1.28E+00	1	+	9.41E-01	5	+	2.41E+00
Pork	5	-	7.31E-03	5	-	3.05E+00	5	-	4.12E+01	5	-	7.18E-02	5	-	2.11E+00				5	+	5.14E+00
Potatoes	5	+	5.04E-03	5	-	1.82E+00				5	-	5.81E-02	5	-	1.60E+00	1	+	8.59E-01	5	+	3.12E+00
Pumpkin	5	+	5.93E-03	5	-	2.16E+00	5	-	3.27E+01	5	-	5.45E-02	5	-	1.44E+00				5	+	3.34E+00
Rice	5	+	5.02E-03	5	-	1.43E+00										1	-	6.88E-01	5	+	2.74E+00
Spinach	5	+	2.29E-03	5	-	2.91E-01										1	+	2.02E+00	5	+	1.10E+00
Sugar	5	+	1.25E-03	5	-	3.32E-01				5	-	9.91E-03	5	-	1.01E-01	1	-	4.27E-01	5	+	7.95E-01
Tea	5	+	1.63E-02	5	-	1.80E+00										1	+	1.38E+00	5	+	3.29E+00
Tomatoes	5	+	4.01E-03	5	-	1.79E+00				5	-	5.99E-02	5	-	2.08E+00	1	+	1.38E+00	5	+	2.96E+00
White bread	5	+	8.26E-03	5	+	1.17E+00										1	+	1.09E+00	5	+	4.58E+00

MDC (ug/g) dry weight	Sc	Se	Sn	Th	U	V	Zn
Maximum observed detection limit	1.66E-02	5.66E+00	7.15E+01	1.32E-01	3.57E+00	2.02E+00	1.29E+01
Minimum observed detection limit	1.25E-03	2.91E-01	3.22E+01	9.91E-03	1.01E-01	4.27E-01	7.95E-01
Average observed detection limit	6.96E-03	1.96E+00	4.43E+01	6.68E-02	2.02E+00	1.04E+00	4.22E+00
Standard deviation on the average	4.06E-03	1.26E+00	1.33E+01	2.70E-02	8.77E-01	3.91E-01	2.70E+00
Ratio maximum/minimum	1.33E+01	1.95E+01	2.22E+00	1.33E+01	3.53E+01	4.73E+00	1.62E+01

Concentration (ug/g) dry weight	Sc	Se	Sn	Th	U	V	Zn
Maximum observed concentration	2.61E-01	2.75E+00		3.94E-02		4.97E+00	1.95E+02
Minimum observed concentration	2.69E-03	8.25E-01		1.84E-02		8.59E-01	9.25E-01
Average observed concentration	4.21E-02	1.79E+00		2.89E-02		1.56E+00	4.10E+01
Standard deviation on the average	6.14E-02	9.61E-01		1.05E-02		1.30E+00	5.28E+01

** Concentration (ug/g) dry weight

+ = Detected - = Not detected

* IDC = Irrdiation, delay and couning scheme

1 = 10sec/10-30sec/30-120sec

2 = 10sec/10min/10min

3 = 10-20sec/3hrs/15-30min

4 = 10-20sec/30hrs/15-30min

5 = 30min/7days/30-60min

Annexure 3 Estimated Intake Values derived for South Africa

Foodstuff	Dry/wet mass ratio	0 - 0.5 yrs Intake (g/d)	0.5-1 yrs Intake (g/d)	1- 3yrs Intake (g/d)	4-8yrs Intake (g/d)	9-18yrs Intake (g/d)	+19yrs Male Intake (g/d)	+19yrs Female Intake (g/d)	Pregnant Intake (g/d)	Lactating Intake (g/d)
Beef	0.271	27	54	137	205	274	274	274	274	274
Beetroot	0.178	140	186	178	279	397	397	397	397	397
Brown bread	0.571	123	164	205	247	411	411	411	411	411
Cabbage	0.093	107	142	178	214	304	304	304	304	304
Chicken meat	0.317	21	41	99	164	205	205	205	205	205
Chicken livers	0.252	21	41	99	164	205	205	205	205	205
Coffee	1	1	1	1	10	11.5	11.5	11.5	11.5	11.5
Eggs	0.248	8	16	41	68	82	82	82	82	82
Fish	0.48	1	2	14	27	27	27	27	27	27
Green Beans	0.103	107	142	178	214	304	304	304	304	304
Maize	0.583	123	164	205	247	411	411	411	411	411
Margarine	1	1	1	1	30	30	30	30	30	30
Milk	0.16	820	820	820	820	685	685	685	685	685
Onion	0.112	107	107	178	214	304	304	304	304	304
Pork	0.289	27	54	137	205	274	274	274	274	274
Potatoes	0.159	140	186	233	279	397	397	397	397	397
Pumpkin	0.104	107	142	178	214	304	304	304	304	304
Rice	0.95	123	164	205	247	351	351	351	351	351
Spinach	0.071	107	142	178	214	304	304	304	304	304
Sugar	1	1	1	1	40	20	20	20	20	20
Tea	0.5	1	1	1	10	10	10	10	10	10
Tomatoes	0.049	107	142	178	214	304	304	304	304	304
White bread	0.625	123	164	205	247	411	411	411	411	411

Annexure 4 Reference intake values in µg/d

Element	Classification	0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant	Lactating
As	PTI	1.29E+01	1.93E+01	2.79E+01	4.29E+01	1.07E+02	1.61E+02	1.34E+02	1.33E+02	1.33E+02
Ba										
Br										
Ca	AI	2.10E+05	2.70E+05	5.00E+05	8.00E+05	1.30E+06	1.08E+06	1.08E+06	1.00E+06	1.00E+06
Cd	PTI	6.00E+00	9.00E+00	1.30E+01	2.00E+01	5.00E+01	7.52E+01	6.26E+01	6.20E+01	6.20E+01
Cl	RDA	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05
Co	RDA	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00
Cr	AI	2.00E-01	5.50E+00	1.10E+01	1.50E+01	2.50E+01	3.50E+01	2.35E+01	3.00E+01	4.45E+01
Cs										
Cu	RDA	2.00E+02	2.00E+02	3.40E+02	4.40E+02	8.00E+02	9.00E+02	9.00E+02	1.00E+03	1.30E+03
F	ESADDI	1.00E+02	2.00E+02	5.00E+02	1.00E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Fe	RDA	2.70E+02	1.10E+04	7.00E+03	1.00E+04	1.05E+04	8.00E+03	1.42E+04	2.70E+04	9.00E+03
Hg	PTI	4.29E+00	6.43E+00	9.29E+00	1.43E+01	3.57E+01	5.37E+01	4.47E+01	4.43E+01	4.43E+01
I	RDA	4.00E+01	5.00E+01	9.00E+01	9.00E+01	1.35E+02	1.50E+02	1.50E+02	2.20E+02	2.90E+02
K	RDI	5.80E+05	1.37E+06	2.73E+06	3.90E+06	5.46E+06	5.46E+06	5.46E+06	5.46E+06	5.46E+06
Mg	RDA	3.00E+04	7.50E+04	8.00E+04	1.30E+05	3.10E+05	4.20E+05	3.20E+05	3.60E+05	3.15E+05
Mn	AI	3.00E+00	6.00E+02	1.20E+03	1.50E+03	1.90E+03	2.30E+03	1.80E+03	2.00E+03	2.60E+03
Mo	RDA	2.00E+00	3.00E+00	1.70E+01	2.20E+01	3.85E+01	4.50E+01	4.50E+01	5.00E+01	5.00E+01
Na	RDI	2.80E+05	5.80E+05	1.15E+06	1.73E+06	2.30E+06	2.30E+06	2.30E+06	2.30E+06	2.30E+06
Ni										
Rb										
Sc										
Se	RDA	8.00E+00	1.30E+01	1.90E+01	2.80E+01	4.70E+01	6.60E+01	5.40E+01	5.80E+01	6.85E+01
Sn	PTI	1.20E+04	1.80E+04	2.60E+04	4.00E+04	1.00E+05	1.50E+05	1.25E+05	1.24E+05	1.24E+05
Th	PTI	3.62E+01	3.62E+01	3.70E+02	4.76E+02	6.53E+02	7.24E+02	7.24E+02	7.24E+02	7.24E+02
U	PTI	2.74E+01	2.74E+01	3.56E+01	4.11E+01	6.51E+01	1.00E+02	1.00E+02	1.00E+02	1.00E+02
V	RDA	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
Zn	RDA	2.00E+03	3.00E+03	3.00E+03	5.00E+03	1.00E+04	1.10E+04	8.00E+03	1.10E+04	1.20E+04

AI

AI Adequate Intake
PTI Provisional Tolerable Intake
RDA Recommended Dietary Allowance
ESADDI Estimated Safe and Adequate Daily Dietary Intake

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value

Element	As	INAA method	4	IDC scheme	10-20s/30h/15-30m					
	PTI (ug/d)	1.29E+01	1.93E+01	2.79E+01	4.29E+01	1.07E+02	1.61E+02	1.34E+02	1.33E+02	1.33E+02
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	8.09E-01	0.5	0.6	1.1	1.0	0.6	0.4	0.4	0.5	0.5
Beetroot	1.46E+00	2.8	2.5	1.7	1.7	1.0	0.6	0.8	0.8	0.8
Brown bread	1.29E+00	7.0	6.3	5.4	4.2	2.8	1.9	2.3	2.3	2.3
Cabbage	1.90E-01	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Chicken meat	3.40E-01	0.2	0.2	0.4	0.4	0.2	0.1	0.2	0.2	0.2
Chicken livers	8.59E-01	0.4	0.5	0.8	0.8	0.4	0.3	0.3	0.3	0.3
Coffee	1.02E+00	0.1	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.1
Eggs	9.02E-01	0.1	0.2	0.3	0.4	0.2	0.1	0.1	0.1	0.1
Fish	8.47E-01	0.0	0.0	0.2	0.3	0.1	0.1	0.1	0.1	0.1
Green Beans	6.00E-01	0.5	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1
Maize	5.34E-01	3.0	2.6	2.3	1.8	1.2	0.8	1.0	1.0	1.0
Margarine	1.15E+00	0.1	0.1	0.0	0.8	0.3	0.2	0.3	0.3	0.3
Milk	7.53E-01	7.7	5.1	3.5	2.3	0.8	0.5	0.6	0.6	0.6
Onion	8.45E-01	0.8	0.5	0.6	0.5	0.3	0.2	0.2	0.2	0.2
Pork	8.56E-01	0.5	0.7	1.2	1.2	0.6	0.4	0.5	0.5	0.5
Potatoes	6.80E-01	1.2	1.0	0.9	0.7	0.4	0.3	0.3	0.3	0.3
Pumpkin	6.73E-01	0.6	0.5	0.4	0.3	0.2	0.1	0.2	0.2	0.2
Rice	2.23E-01	2.0	1.8	1.6	1.2	0.7	0.5	0.6	0.6	0.6
Spinach	1.73E-01	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Sugar	1.07E-01	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Tea	6.43E-01	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Tomatoes	9.47E-01	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1
White bread	5.60E-01	3.3	3.0	2.6	2.0	1.3	0.9	1.1	1.1	1.1
Max improvement required		7.7	6.3	5.4	4.2	2.8	1.9	2.3	2.3	2.3
Average improvement required		1.4	1.2	1.0	0.9	0.5	0.3	0.4	0.4	0.4

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Ca	INAA method	4	IDC scheme	10-20s/30h/15-30m					
	RDA (ug/d)	2.10E+05	2.70E+05	5.00E+05	8.00E+05	1.30E+06	1.08E+06	1.08E+06	1.00E+06	1.00E+06
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	2.19E+03	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.2
Beetroot	3.37E+03	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Brown bread	5.72E+03	1.9	2.0	1.3	1.0	1.0	1.2	1.2	1.3	1.3
Cabbage	3.07E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chicken meat	4.91E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chicken livers	3.89E+03	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Coffee	3.34E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eggs	1.86E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	2.14E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Green Beans	1.02E+03	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maize	1.21E+03	0.4	0.4	0.3	0.2	0.2	0.3	0.3	0.3	0.3
Margarine	1.39E+03	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Milk	2.52E+03	1.6	1.2	0.7	0.4	0.2	0.3	0.3	0.3	0.3
Onion	1.26E+03	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pork	1.70E+03	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Potatoes	2.66E+03	0.3	0.3	0.2	0.1	0.1	0.2	0.2	0.2	0.2
Pumpkin	1.92E+03	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Rice	1.00E+03	0.6	0.6	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Spinach	3.35E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugar	5.93E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tea	1.27E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tomatoes	1.67E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White bread	2.22E+03	0.8	0.8	0.6	0.4	0.4	0.5	0.5	0.6	0.6
Max improvement required		1.9	2.0	1.3	1.0	1.0	1.2	1.2	1.3	1.3
Average improvement required		0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.2

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Cd	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	6.00E+00	9.00E+00	1.30E+01	2.00E+01	5.00E+01	7.52E+01	6.26E+01	6.20E+01	6.20E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	2.54E+00	3.1	4.1	7.3	7.1	3.8	2.5	3.0	3.0	3.0
Beetroot	2.67E+00	11.1	9.8	6.5	6.6	3.8	2.5	3.0	3.0	3.0
Brown bread	2.17E+00	25.4	22.6	19.5	15.3	10.2	6.8	8.1	8.2	8.2
Cabbage	2.66E-01	0.4	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1
Chicken meat	4.97E-01	0.6	0.7	1.2	1.3	0.6	0.4	0.5	0.5	0.5
Chicken livers	3.96E+00	3.5	4.5	7.6	8.2	4.1	2.7	3.3	3.3	3.3
Coffee	1.46E+00	0.2	0.2	0.1	0.7	0.3	0.2	0.3	0.3	0.3
Eggs	1.67E+00	0.6	0.7	1.3	1.4	0.7	0.5	0.5	0.5	0.5
Fish	4.69E+00	0.4	0.5	2.4	3.0	1.2	0.8	1.0	1.0	1.0
Green Beans	2.42E+00	4.4	3.9	3.4	2.7	1.5	1.0	1.2	1.2	1.2
Maize	8.05E-01	9.6	8.6	7.4	5.8	3.9	2.6	3.1	3.1	3.1
Margarine	5.56E-01	0.1	0.1	0.0	0.8	0.3	0.2	0.3	0.3	0.3
Milk	1.24E+00	27.1	18.1	12.5	8.1	2.7	1.8	2.2	2.2	2.2
Onion	1.16E+00	2.3	1.5	1.8	1.4	0.8	0.5	0.6	0.6	0.6
Pork	2.71E+00	3.5	4.7	8.3	8.0	4.3	2.9	3.4	3.5	3.5
Potatoes	1.34E+00	5.0	4.4	3.8	3.0	1.7	1.1	1.4	1.4	1.4
Pumpkin	2.75E+00	5.1	4.5	3.9	3.1	1.7	1.2	1.4	1.4	1.4
Rice	9.70E-01	18.9	16.8	14.5	11.4	6.5	4.3	5.2	5.2	5.2
Spinach	2.26E-01	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Sugar	4.67E-01	0.1	0.1	0.0	0.9	0.2	0.1	0.1	0.2	0.2
Tea	1.33E+00	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1
Tomatoes	1.30E+00	1.1	1.0	0.9	0.7	0.4	0.3	0.3	0.3	0.3
White bread	8.25E-01	10.6	9.4	8.1	6.4	4.2	2.8	3.4	3.4	3.4
Max improvement required		27.1	22.6	19.5	15.3	10.2	6.8	8.1	8.2	8.2
Average improvement required		5.8	5.1	4.8	4.2	2.3	1.5	1.9	1.9	1.9

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Cl	INAA method	2	IDC scheme	10s/10m/10m					
	RDA (ug/d)	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05	7.50E+05
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	3.64E+02	0.034	0.045	0.057	0.068	0.114	0.114	0.114	0.114	0.114
Cabbage	1.93E+02	0.003	0.003	0.004	0.005	0.007	0.007	0.007	0.007	0.007
Chicken meat	1.33E+02	0.001	0.002	0.006	0.009	0.012	0.012	0.012	0.012	0.012
Chicken livers										
Coffee	1.52E+02	0.000	0.000	0.000	0.002	0.002	0.002	0.002	0.002	0.002
Eggs	2.75E+02	0.001	0.001	0.004	0.006	0.007	0.007	0.007	0.007	0.007
Fish										
Green Beans										
Maize	2.15E+01	0.002	0.003	0.003	0.004	0.007	0.007	0.007	0.007	0.007
Margarine	2.86E+02	0.000	0.000	0.000	0.011	0.011	0.011	0.011	0.011	0.011
Milk	1.33E+02	0.023	0.023	0.023	0.023	0.019	0.019	0.019	0.019	0.019
Onion	1.66E+02	0.003	0.003	0.004	0.005	0.008	0.008	0.008	0.008	0.008
Pork										
Potatoes	1.75E+02	0.005	0.007	0.009	0.010	0.015	0.015	0.015	0.015	0.015
Pumpkin										
Rice	1.56E+02	0.024	0.032	0.041	0.049	0.069	0.069	0.069	0.069	0.069
Spinach	4.23E+02	0.004	0.006	0.007	0.009	0.012	0.012	0.012	0.012	0.012
Sugar	1.11E+02	0.000	0.000	0.000	0.006	0.003	0.003	0.003	0.003	0.003
Tea	2.24E+02	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
Tomatoes	1.90E+02	0.001	0.002	0.002	0.003	0.004	0.004	0.004	0.004	0.004
White bread	3.50E+02	0.036	0.048	0.060	0.072	0.120	0.120	0.120	0.120	0.120
Max improvement required		0.036	0.048	0.060	0.072	0.120	0.120	0.120	0.120	0.120
Average improvement required		0.006	0.008	0.010	0.012	0.018	0.018	0.018	0.018	0.018

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Co	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	1.28E-01	0.3	0.6	1.6	2.4	3.2	3.2	3.2	3.2	3.2
Beetroot	1.79E-01	1.5	2.0	1.9	3.0	4.2	4.2	4.2	4.2	4.2
Brown bread	1.44E-01	3.4	4.5	5.6	6.8	11.3	11.3	11.3	11.3	11.3
Cabbage	1.00E-02	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chicken meat	1.73E-02	0.0	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4
Chicken livers	1.33E-01	0.2	0.5	1.1	1.8	2.3	2.3	2.3	2.3	2.3
Coffee	7.81E-02	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3
Eggs	7.42E-02	0.0	0.1	0.3	0.4	0.5	0.5	0.5	0.5	0.5
Fish	1.70E-01	0.0	0.1	0.4	0.7	0.7	0.7	0.7	0.7	0.7
Green Beans	7.54E-02	0.3	0.4	0.5	0.6	0.8	0.8	0.8	0.8	0.8
Maize	2.78E-02	0.7	0.9	1.1	1.3	2.2	2.2	2.2	2.2	2.2
Margarine	4.47E-02	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4
Milk	5.28E-02	2.3	2.3	2.3	2.3	1.9	1.9	1.9	1.9	1.9
Onion	5.43E-02	0.2	0.2	0.4	0.4	0.6	0.6	0.6	0.6	0.6
Pork	1.31E-01	0.3	0.7	1.7	2.6	3.5	3.5	3.5	3.5	3.5
Potatoes	5.26E-02	0.4	0.5	0.6	0.8	1.1	1.1	1.1	1.1	1.1
Pumpkin	1.19E-01	0.4	0.6	0.7	0.9	1.3	1.3	1.3	1.3	1.3
Rice	3.39E-02	1.3	1.8	2.2	2.7	3.8	3.8	3.8	3.8	3.8
Spinach	1.29E-02	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sugar	8.80E-03	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Tea	4.05E-02	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Tomatoes	5.24E-02	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3
White bread	5.98E-02	1.5	2.0	2.6	3.1	5.1	5.1	5.1	5.1	5.1
Max improvement required		3.4	4.5	5.6	6.8	11.3	11.3	11.3	11.3	11.3
Average improvement required		0.6	0.8	1.0	1.4	1.9	1.9	1.9	1.9	1.9

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Cr	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	2.00E-01	5.50E+00	1.10E+01	1.50E+01	2.50E+01	3.50E+01	2.35E+01	3.00E+01	4.45E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	7.81E-01	28.6	2.1	2.6	2.9	2.3	1.7	2.5	1.9	1.3
Beetroot	7.98E-01	99.4	4.8	2.3	2.6	2.3	1.6	2.4	1.9	1.3
Brown bread	8.23E-01	289.0	14.0	8.8	7.7	7.7	5.5	8.2	6.4	4.3
Cabbage	8.86E-02	4.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chicken meat	1.70E-01	5.7	0.4	0.5	0.6	0.4	0.3	0.5	0.4	0.2
Chicken livers	1.93E+00	51.1	3.6	4.4	5.3	4.0	2.9	4.2	3.3	2.2
Coffee	5.29E-01	2.6	0.1	0.0	0.4	0.2	0.2	0.3	0.2	0.1
Eggs	1.02E+00	10.1	0.7	0.9	1.1	0.8	0.6	0.9	0.7	0.5
Fish	1.68E+00	4.0	0.3	1.0	1.5	0.9	0.6	0.9	0.7	0.5
Green Beans	6.19E-01	34.1	1.6	1.0	0.9	0.8	0.6	0.8	0.6	0.4
Maize	5.10E-01	182.9	8.9	5.5	4.9	4.9	3.5	5.2	4.1	2.7
Margarine	2.63E-01	1.3	0.0	0.0	0.5	0.3	0.2	0.3	0.3	0.2
Milk	4.77E-01	312.9	11.4	5.7	4.2	2.1	1.5	2.2	1.7	1.2
Onion	4.25E-01	25.5	0.9	0.8	0.7	0.6	0.4	0.6	0.5	0.3
Pork	9.14E-01	35.6	2.6	3.3	3.6	2.9	2.1	3.1	2.4	1.6
Potatoes	4.88E-01	54.3	2.6	1.6	1.4	1.2	0.9	1.3	1.0	0.7
Pumpkin	7.95E-01	44.2	2.1	1.3	1.2	1.0	0.7	1.1	0.8	0.6
Rice	3.76E-01	219.7	10.7	6.7	5.9	5.0	3.6	5.3	4.2	2.8
Spinach	7.94E-02	3.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0
Sugar	1.49E-01	0.7	0.0	0.0	0.4	0.1	0.1	0.1	0.1	0.1
Tea	4.62E-01	1.2	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.1
Tomatoes	4.68E-01	12.3	0.6	0.4	0.3	0.3	0.2	0.3	0.2	0.2
White bread	3.22E-01	123.8	6.0	3.8	3.3	3.3	2.4	3.5	2.8	1.9
Max improvement required		312.9	14.0	8.8	7.7	7.7	5.5	8.2	6.4	4.3
Average improvement required		67.2	3.2	2.2	2.2	1.8	1.3	1.9	1.5	1.0

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Cu	INAA method	2	IDC scheme	10s/10m/10m					
	RDA (ug/d)	2.00E+02	2.00E+02	3.40E+02	4.40E+02	8.00E+02	9.00E+02	9.00E+02	1.00E+03	1.30E+03
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	8.42E+02	295.7	394.2	289.9	269.9	247.0	219.6	219.6	197.6	152.0
Cabbage	8.95E+02	44.5	59.1	43.6	40.5	31.6	28.1	28.1	25.3	19.5
Chicken meat	6.14E+02	20.4	39.9	56.7	72.5	49.9	44.3	44.3	39.9	30.7
Chicken livers										
Coffee	5.68E+02	2.8	2.8	1.7	12.9	8.2	7.3	7.3	6.5	5.0
Eggs	7.61E+02	7.5	15.1	22.8	29.2	19.3	17.2	17.2	15.5	11.9
Fish										
Green Beans										
Maize	3.62E+02	129.8	173.1	127.2	118.5	108.4	96.4	96.4	86.7	66.7
Margarine	6.01E+02	3.0	3.0	1.8	41.0	22.5	20.0	20.0	18.0	13.9
Milk	5.39E+02	353.6	353.6	208.0	160.7	73.8	65.6	65.6	59.1	45.4
Onion	7.11E+02	42.6	42.6	41.7	38.7	30.3	26.9	26.9	24.2	18.6
Pork										
Potatoes	5.73E+02	63.8	84.7	62.4	57.8	45.2	40.2	40.2	36.2	27.8
Pumpkin										
Rice	3.38E+02	197.5	263.3	193.6	180.3	140.9	125.2	125.2	112.7	86.7
Spinach	1.44E+03	54.7	72.6	53.5	49.7	38.9	34.5	34.5	31.1	23.9
Sugar	2.41E+02	1.2	1.2	0.7	21.9	6.0	5.4	5.4	4.8	3.7
Tea	1.21E+03	3.0	3.0	1.8	13.8	7.6	6.7	6.7	6.1	4.7
Tomatoes	1.00E+03	26.2	34.8	25.7	23.8	18.6	16.6	16.6	14.9	11.5
White bread	8.76E+02	336.7	448.9	330.1	307.3	281.3	250.0	250.0	225.0	173.1
Max improvement required		353.6	448.9	330.1	307.3	281.3	250.0	250.0	225.0	173.1
Average improvement required		68.8	86.6	63.5	62.5	49.1	43.7	43.7	39.3	30.2

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	F	INAA method	1	IDC scheme	10s/10-30s/10-30s					
	RDA (ug/d)	1.00E+02	2.00E+02	5.00E+02	1.00E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	3.96E+00	2.78	1.85	0.93	0.56	0.62	0.62	0.62	0.62	0.62
Cabbage	5.08E+00	0.51	0.34	0.17	0.10	0.10	0.10	0.10	0.10	0.10
Chicken meat	7.16E-01	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03
Chicken livers										
Coffee	2.25E+00	0.02	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02
Eggs	2.78E+00	0.06	0.06	0.06	0.05	0.04	0.04	0.04	0.04	0.04
Fish										
Green Beans										
Maize	2.41E+00	1.73	1.15	0.58	0.35	0.38	0.38	0.38	0.38	0.38
Margarine	2.52E+00	0.03	0.01	0.01	0.08	0.05	0.05	0.05	0.05	0.05
Milk	2.04E+00	2.68	1.34	0.54	0.27	0.15	0.15	0.15	0.15	0.15
Onion	4.31E+00	0.52	0.26	0.17	0.10	0.10	0.10	0.10	0.10	0.10
Pork										
Potatoes	3.55E+00	0.79	0.52	0.26	0.16	0.15	0.15	0.15	0.15	0.15
Pumpkin										
Rice	1.13E+00	1.32	0.88	0.44	0.27	0.25	0.25	0.25	0.25	0.25
Spinach	6.07E+00	0.46	0.31	0.15	0.09	0.09	0.09	0.09	0.09	0.09
Sugar	1.27E+00	0.01	0.01	0.00	0.05	0.02	0.02	0.02	0.02	0.02
Tea	5.59E+00	0.03	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02
Tomatoes	5.46E+00	0.29	0.19	0.10	0.06	0.05	0.05	0.05	0.05	0.05
White bread	4.23E+00	3.25	2.17	1.08	0.65	0.72	0.72	0.72	0.72	0.72
Max improvement required		3.25	2.17	1.08	0.65	0.72	0.72	0.72	0.72	0.72
Average improvement required		0.63	0.40	0.20	0.12	0.12	0.12	0.12	0.12	0.12

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Fe	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	2.70E+02	1.10E+04	7.00E+03	1.00E+04	1.05E+04	8.00E+03	1.42E+04	2.70E+04	9.00E+03
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	6.29E+01	1.7	0.1	0.3	0.3	0.4	0.6	0.3	0.2	0.5
Beetroot	9.07E+01	8.4	0.3	0.4	0.5	0.6	0.8	0.5	0.2	0.7
Brown bread	1.78E+02	46.4	1.5	3.0	2.5	4.0	5.2	2.9	1.5	4.6
Cabbage	1.12E+01	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chicken meat	3.35E+01	0.8	0.0	0.2	0.2	0.2	0.3	0.2	0.1	0.2
Chicken livers	7.80E+01	1.5	0.1	0.3	0.3	0.4	0.5	0.3	0.1	0.4
Coffee	9.18E+01	0.3	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1
Eggs	7.20E+01	0.5	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.2
Fish	7.01E+01	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.1
Green Beans	3.12E+01	1.3	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.1
Maize	2.65E+01	7.0	0.2	0.5	0.4	0.6	0.8	0.4	0.2	0.7
Margarine	6.16E+01	0.2	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.2
Milk	8.40E+01	40.8	1.0	1.6	1.1	0.9	1.2	0.6	0.3	1.0
Onion	3.57E+01	1.6	0.0	0.1	0.1	0.1	0.2	0.1	0.0	0.1
Pork	5.68E+01	1.6	0.1	0.3	0.3	0.4	0.6	0.3	0.2	0.5
Potatoes	5.53E+01	4.6	0.1	0.3	0.2	0.3	0.4	0.2	0.1	0.4
Pumpkin	5.09E+01	2.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2
Rice	5.36E+01	23.2	0.8	1.5	1.3	1.7	2.2	1.3	0.7	2.0
Spinach	1.53E+01	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugar	1.26E+01	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Tea	5.58E+01	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tomatoes	3.15E+01	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
White bread	8.46E+01	24.1	0.8	1.5	1.3	2.1	2.7	1.5	0.8	2.4
Max improvement required		46.4	1.5	3.0	2.5	4.0	5.2	2.9	1.5	4.6
Average improvement required		7.3	0.2	0.5	0.4	0.6	0.7	0.4	0.2	0.6

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Hg	INAA method	4	IDC scheme	10-20sec/30hrs/15-30min					
	RDA (ug/d)	4.29E+00	6.43E+00	9.29E+00	1.43E+01	3.57E+01	5.37E+01	4.47E+01	4.43E+01	4.43E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	3.97E-01	0.7	0.9	1.6	1.5	0.8	0.5	0.7	0.7	0.7
Beetroot	3.40E-01	2.0	1.7	1.2	1.2	0.7	0.4	0.5	0.5	0.5
Brown bread	6.44E-01	10.5	9.4	8.1	6.4	4.2	2.8	3.4	3.4	3.4
Cabbage	6.86E-02	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Chicken meat	1.34E-01	0.2	0.3	0.5	0.5	0.2	0.2	0.2	0.2	0.2
Chicken livers	4.87E-01	0.6	0.8	1.3	1.4	0.7	0.5	0.6	0.6	0.6
Coffee	4.02E-01	0.1	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.1
Eggs	4.34E-01	0.2	0.3	0.5	0.5	0.2	0.2	0.2	0.2	0.2
Fish	6.69E-01	0.1	0.1	0.5	0.6	0.2	0.2	0.2	0.2	0.2
Green Beans	3.21E-01	0.8	0.7	0.6	0.5	0.3	0.2	0.2	0.2	0.2
Maize	2.03E-01	3.4	3.0	2.6	2.1	1.4	0.9	1.1	1.1	1.1
Margarine	1.42E-01	0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.1	0.1
Milk	3.74E-01	11.4	7.6	5.3	3.4	1.1	0.8	0.9	0.9	0.9
Onion	3.22E-01	0.9	0.6	0.7	0.5	0.3	0.2	0.2	0.2	0.2
Pork	4.14E-01	0.8	1.0	1.8	1.7	0.9	0.6	0.7	0.7	0.7
Potatoes	3.68E-01	1.9	1.7	1.5	1.1	0.7	0.4	0.5	0.5	0.5
Pumpkin	3.00E-01	0.8	0.7	0.6	0.5	0.3	0.2	0.2	0.2	0.2
Rice	2.89E-01	7.9	7.0	6.1	4.8	2.7	1.8	2.2	2.2	2.2
Spinach	5.91E-02	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Sugar	4.48E-02	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Tea	3.63E-01	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Tomatoes	3.60E-01	0.4	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1
White bread	2.47E-01	4.4	3.9	3.4	2.7	1.8	1.2	1.4	1.4	1.4
Max improvement required		11.4	9.4	8.1	6.4	4.2	2.8	3.4	3.4	3.4
Average improvement required		2.1	1.8	1.6	1.3	0.7	0.5	0.6	0.6	0.6

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	I	INAA method	2	IDC scheme	10s/10m/10m					
	RDA (ug/d)	4.00E+01	5.00E+01	9.00E+01	9.00E+01	1.35E+02	1.50E+02	1.50E+02	2.20E+02	2.90E+02
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	4.96E-01	0.87	0.93	0.65	0.78	0.86	0.78	0.78	0.53	0.40
Cabbage	2.67E-01	0.07	0.07	0.05	0.06	0.06	0.05	0.05	0.03	0.03
Chicken meat	2.71E-01	0.05	0.07	0.09	0.16	0.13	0.12	0.12	0.08	0.06
Chicken livers										
Coffee	2.19E-01	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.01	0.01
Eggs	4.15E-01	0.02	0.03	0.05	0.08	0.06	0.06	0.06	0.04	0.03
Fish										
Green Beans										
Maize	1.07E-01	0.19	0.20	0.14	0.17	0.19	0.17	0.17	0.12	0.09
Margarine	4.28E-01	0.01	0.01	0.00	0.14	0.10	0.09	0.09	0.06	0.04
Milk	2.67E-01	0.88	0.70	0.39	0.39	0.22	0.20	0.20	0.13	0.10
Onion	1.69E-01	0.05	0.04	0.04	0.05	0.04	0.04	0.04	0.03	0.02
Pork										
Potatoes	1.90E-01	0.11	0.11	0.08	0.09	0.09	0.08	0.08	0.05	0.04
Pumpkin										
Rice	9.73E-02	0.28	0.30	0.21	0.25	0.24	0.22	0.22	0.15	0.11
Spinach	7.32E-01	0.14	0.15	0.10	0.12	0.12	0.11	0.11	0.07	0.05
Sugar	6.00E-02	0.00	0.00	0.00	0.03	0.01	0.01	0.01	0.01	0.00
Tea	3.53E-01	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01
Tomatoes	2.84E-01	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.01
White bread	4.95E-01	0.95	1.01	0.70	0.85	0.94	0.85	0.85	0.58	0.44
Max improvement required		0.95	1.01	0.70	0.85	0.94	0.85	0.85	0.58	0.44
Average improvement required		0.16	0.16	0.11	0.14	0.14	0.12	0.12	0.08	0.06

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	K	INAA method	4	IDC scheme	10-20s/30h/15-30m					
	RDA (ug/d)	5.80E+05	1.37E+06	2.73E+06	3.90E+06	5.46E+06	5.46E+06	5.46E+06	5.46E+06	5.46E+06
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	2.18E+02	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Beetroot	4.37E+02	0.019	0.011	0.005	0.006	0.006	0.006	0.006	0.006	0.006
Brown bread	2.72E+02	0.033	0.019	0.012	0.010	0.012	0.012	0.012	0.012	0.012
Cabbage	3.67E+01	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chicken meat	6.20E+01	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chicken livers	2.40E+02	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002
Coffee	1.89E+02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eggs	1.29E+02	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Fish	2.60E+02	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Green Beans	1.65E+02	0.003	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Maize	5.27E+01	0.007	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Margarine	2.12E+02	0.000	0.000	0.000	0.002	0.001	0.001	0.001	0.001	0.001
Milk	1.81E+02	0.041	0.017	0.009	0.006	0.004	0.004	0.004	0.004	0.004
Onion	1.48E+02	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Pork	2.35E+02	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003
Potatoes	1.87E+02	0.007	0.004	0.003	0.002	0.002	0.002	0.002	0.002	0.002
Pumpkin	1.68E+02	0.003	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rice	7.17E+01	0.014	0.008	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Spinach	3.73E+01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sugar	1.48E+01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tea	7.41E+02	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
Tomatoes	2.49E+02	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
White bread	9.77E+01	0.013	0.007	0.005	0.004	0.005	0.005	0.005	0.005	0.005
Max improvement required		0.041	0.019	0.012	0.010	0.012	0.012	0.012	0.012	0.012
Average improvement required		0.007	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Mg	INAA method	2	IDC scheme	10s/10m/10m					
	RDA (ug/d)	3.00E+04	7.50E+04	8.00E+04	1.30E+05	3.10E+05	4.20E+05	3.20E+05	3.60E+05	3.15E+05
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	5.21E+02	1.22	0.65	0.76	0.57	0.39	0.29	0.38	0.34	0.39
Cabbage	5.38E+02	0.18	0.09	0.11	0.08	0.05	0.04	0.05	0.04	0.05
Chicken meat	4.20E+02	0.09	0.07	0.16	0.17	0.09	0.06	0.09	0.08	0.09
Chicken livers										
Coffee	4.09E+02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.01
Eggs	4.46E+02	0.03	0.02	0.06	0.06	0.03	0.02	0.03	0.03	0.03
Fish										
Green Beans										
Maize	2.63E+02	0.63	0.34	0.39	0.29	0.20	0.15	0.20	0.18	0.20
Margarine	5.82E+02	0.02	0.01	0.01	0.13	0.06	0.04	0.05	0.05	0.06
Milk	5.62E+02	2.46	0.98	0.92	0.57	0.20	0.15	0.19	0.17	0.20
Onion	4.84E+02	0.19	0.08	0.12	0.09	0.05	0.04	0.05	0.05	0.05
Pork										
Potatoes	3.76E+02	0.28	0.15	0.17	0.13	0.08	0.06	0.07	0.07	0.08
Pumpkin										
Rice	2.18E+02	0.85	0.45	0.53	0.39	0.23	0.17	0.23	0.20	0.23
Spinach	9.94E+02	0.25	0.13	0.16	0.12	0.07	0.05	0.07	0.06	0.07
Sugar	3.43E+02	0.01	0.00	0.00	0.11	0.02	0.02	0.02	0.02	0.02
Tea	8.90E+02	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01
Tomatoes	6.41E+02	0.11	0.06	0.07	0.05	0.03	0.02	0.03	0.03	0.03
White bread	5.32E+02	1.36	0.73	0.85	0.63	0.44	0.33	0.43	0.38	0.43
Max improvement required		2.46	0.98	0.92	0.63	0.44	0.33	0.43	0.38	0.43
Average improvement required		0.34	0.16	0.19	0.15	0.09	0.06	0.08	0.07	0.08

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Mn	INAA method	3	IDC scheme	10-20s/3h/15-30m					
	RDA (ug/d)	3.00E+00	6.00E+02	1.20E+03	1.50E+03	1.90E+03	2.30E+03	1.80E+03	2.00E+03	2.60E+03
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	1.26E+00	3.1	0.03	0.04	0.05	0.05	0.04	0.05	0.05	0.04
Beetroot	4.14E+00	34.4	0.23	0.11	0.14	0.15	0.13	0.16	0.15	0.11
Brown bread	1.02E+00	23.9	0.16	0.10	0.10	0.13	0.10	0.13	0.12	0.09
Cabbage	2.76E-01	0.9	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chicken meat	3.51E-01	0.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Chicken livers	1.88E+00	3.3	0.03	0.04	0.05	0.05	0.04	0.05	0.05	0.04
Coffee	7.64E-01	0.3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Eggs	9.40E-01	0.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fish	1.50E+00	0.2	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Green Beans	1.22E+00	4.5	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Maize	4.49E-01	10.7	0.07	0.04	0.04	0.06	0.05	0.06	0.05	0.04
Margarine	1.88E+00	0.6	0.00	0.00	0.04	0.03	0.02	0.03	0.03	0.02
Milk	6.71E-01	29.3	0.15	0.07	0.06	0.04	0.03	0.04	0.04	0.03
Onion	7.44E-01	3.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pork	1.67E+00	4.3	0.04	0.06	0.07	0.07	0.06	0.07	0.07	0.05
Potatoes	8.82E-01	6.5	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.02
Pumpkin	7.22E-01	2.7	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Rice	2.97E-01	11.6	0.08	0.05	0.05	0.05	0.04	0.06	0.05	0.04
Spinach	2.24E-01	0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	8.38E-02	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tea	2.23E+00	0.4	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00
Tomatoes	1.01E+00	1.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
White bread	4.75E-01	12.2	0.08	0.05	0.05	0.06	0.05	0.07	0.06	0.05
Max improvement required		34.4	0.23	0.11	0.14	0.15	0.13	0.16	0.15	0.11
Average improvement required		6.8	0.04	0.03	0.03	0.04	0.03	0.04	0.03	0.03

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Mo	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	2.00E+00	3.00E+00	1.70E+01	2.20E+01	3.85E+01	4.50E+01	4.50E+01	5.00E+01	5.00E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	1.78E+00	6.5	8.7	3.9	4.5	3.4	2.9	2.9	2.6	2.6
Beetroot	1.48E+00	18.5	16.4	2.8	3.4	2.7	2.3	2.3	2.1	2.1
Brown bread	2.59E+00	90.8	80.7	17.8	16.6	15.8	13.5	13.5	12.1	12.1
Cabbage	1.64E+00	8.2	7.2	1.6	1.5	1.2	1.0	1.0	0.9	0.9
Chicken meat	7.73E-01	2.6	3.4	1.4	1.8	1.3	1.1	1.1	1.0	1.0
Chicken livers	2.90E+00	7.7	10.0	4.3	5.5	3.9	3.3	3.3	3.0	3.0
Coffee	1.80E+00	0.9	0.6	0.1	0.8	0.5	0.5	0.5	0.4	0.4
Eggs	2.14E+00	2.1	2.8	1.3	1.6	1.1	1.0	1.0	0.9	0.9
Fish	3.38E+00	0.8	1.1	1.3	2.0	1.1	1.0	1.0	0.9	0.9
Green Beans	1.77E+00	9.8	8.6	1.9	1.8	1.4	1.2	1.2	1.1	1.1
Maize	1.14E+00	40.9	36.4	8.0	7.5	7.1	6.1	6.1	5.5	5.5
Margarine	6.00E-01	0.3	0.2	0.0	0.8	0.5	0.4	0.4	0.4	0.4
Milk	1.99E+00	130.3	86.9	15.3	11.8	5.7	4.8	4.8	4.4	4.4
Onion	1.63E+00	9.8	6.5	1.9	1.8	1.4	1.2	1.2	1.1	1.1
Pork	1.85E+00	7.2	9.6	4.3	5.0	3.8	3.3	3.3	2.9	2.9
Potatoes	1.67E+00	18.6	16.5	3.6	3.4	2.7	2.3	2.3	2.1	2.1
Pumpkin	1.53E+00	8.5	7.5	1.7	1.5	1.3	1.1	1.1	1.0	1.0
Rice	1.45E+00	84.9	75.5	16.6	15.5	12.6	10.8	10.8	9.7	9.7
Spinach	2.56E-01	1.0	0.9	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Sugar	2.16E-01	0.1	0.1	0.0	0.4	0.1	0.1	0.1	0.1	0.1
Tea	2.01E+00	0.5	0.3	0.1	0.5	0.3	0.2	0.2	0.2	0.2
Tomatoes	2.02E+00	5.3	4.7	1.0	1.0	0.8	0.7	0.7	0.6	0.6
White bread	9.77E-01	37.6	33.4	7.4	6.9	6.5	5.6	5.6	5.0	5.0
Max improvement required		130.3	86.9	17.8	16.6	15.8	13.5	13.5	12.1	12.1
Average improvement required		21.4	18.2	4.2	4.2	3.3	2.8	2.8	2.5	2.5

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Na	INAA method	4	IDC scheme	10-20s/30h/15-30m					
	RDA (ug/d)	2.80E+05	5.80E+05	1.15E+06	1.73E+06	2.30E+06	2.30E+06	2.30E+06	2.30E+06	2.30E+06
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	7.86E+00	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Beetroot	1.24E+01	0.0011	0.0007	0.0003	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Brown bread	2.36E+01	0.0059	0.0038	0.0024	0.0019	0.0024	0.0024	0.0024	0.0024	0.0024
Cabbage	4.79E+00	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Chicken meat	8.90E+00	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Chicken livers	8.08E+00	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Coffee	2.34E+01	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Eggs	1.13E+01	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Fish	8.52E+00	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Green Beans	6.41E+00	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Maize	5.37E+00	0.0014	0.0009	0.0006	0.0004	0.0006	0.0006	0.0006	0.0006	0.0006
Margarine	2.55E+01	0.0001	0.0000	0.0000	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003
Milk	2.26E+01	0.0106	0.0051	0.0026	0.0017	0.0011	0.0011	0.0011	0.0011	0.0011
Onion	6.03E+00	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Pork	8.01E+00	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Potatoes	6.99E+00	0.0006	0.0004	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Pumpkin	6.73E+00	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Rice	6.57E+00	0.0027	0.0018	0.0011	0.0009	0.0010	0.0010	0.0010	0.0010	0.0010
Spinach	3.23E+00	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sugar	1.77E+00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tea	1.93E+01	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Tomatoes	8.29E+00	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
White bread	1.53E+01	0.0042	0.0027	0.0017	0.0014	0.0017	0.0017	0.0017	0.0017	0.0017
Max improvement required		0.0106	0.0051	0.0026	0.0019	0.0024	0.0024	0.0024	0.0024	0.0024
Average improvement required		0.0013	0.0007	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Se	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	8.00E+00	1.30E+01	1.90E+01	2.80E+01	4.70E+01	6.60E+01	5.40E+01	5.80E+01	6.85E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	2.93E+00	2.7	3.3	5.7	5.8	4.6	3.3	4.0	3.8	3.2
Beetroot	2.59E+00	8.1	6.6	4.3	4.6	3.9	2.8	3.4	3.2	2.7
Brown bread	3.20E+00	28.1	23.1	19.7	16.1	16.0	11.4	13.9	12.9	11.0
Cabbage	3.37E-01	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.1
Chicken meat	6.74E-01	0.6	0.7	1.1	1.3	0.9	0.7	0.8	0.8	0.6
Chicken livers	4.20E+00	2.8	3.3	5.5	6.2	4.6	3.3	4.0	3.7	3.2
Coffee	1.97E+00	0.2	0.2	0.1	0.7	0.5	0.3	0.4	0.4	0.3
Eggs	2.17E+00	0.5	0.7	1.2	1.3	0.9	0.7	0.8	0.8	0.6
Fish	5.66E+00	0.3	0.4	2.0	2.6	1.6	1.1	1.4	1.3	1.1
Green Beans	2.37E+00	3.3	2.7	2.3	1.9	1.6	1.1	1.4	1.3	1.1
Maize	1.00E+00	9.0	7.4	6.3	5.1	5.1	3.6	4.4	4.1	3.5
Margarine	7.03E-01	0.1	0.1	0.0	0.8	0.4	0.3	0.4	0.4	0.3
Milk	1.91E+00	31.3	19.3	13.2	8.9	4.5	3.2	3.9	3.6	3.1
Onion	1.58E+00	2.4	1.5	1.7	1.4	1.1	0.8	1.0	0.9	0.8
Pork	3.05E+00	3.0	3.7	6.4	6.5	5.1	3.7	4.5	4.2	3.5
Potatoes	1.82E+00	5.1	4.1	3.5	2.9	2.4	1.7	2.1	2.0	1.7
Pumpkin	2.16E+00	3.0	2.5	2.1	1.7	1.5	1.0	1.3	1.2	1.0
Rice	1.43E+00	20.9	17.1	14.7	12.0	10.1	7.2	8.8	8.2	7.0
Spinach	2.91E-01	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Sugar	3.32E-01	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.1	0.1
Tea	1.80E+00	0.1	0.1	0.0	0.3	0.2	0.1	0.2	0.2	0.1
Tomatoes	1.79E+00	1.2	1.0	0.8	0.7	0.6	0.4	0.5	0.5	0.4
White bread	1.17E+00	11.2	9.2	7.9	6.5	6.4	4.6	5.6	5.2	4.4
Max improvement required		31.3	23.1	19.7	16.1	16.0	11.4	13.9	12.9	11.0
Average improvement required		5.8	4.7	4.3	3.8	3.2	2.2	2.7	2.6	2.2

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Sn	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	1.20E+04	1.80E+04	2.60E+04	4.00E+04	1.00E+05	1.50E+05	1.25E+05	1.24E+05	1.24E+05
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	3.81E+01	0.02	0.03	0.05	0.05	0.03	0.02	0.02	0.02	0.02
Beetroot	3.87E+01	0.08	0.07	0.05	0.05	0.03	0.02	0.02	0.02	0.02
Brown bread										
Cabbage										
Chicken meat										
Chicken livers	5.60E+01	0.02	0.03	0.05	0.06	0.03	0.02	0.02	0.02	0.02
Coffee										
Eggs										
Fish	7.15E+01	0.00	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Green Beans	3.22E+01	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Maize										
Margarine										
Milk										
Onion										
Pork	4.12E+01	0.03	0.04	0.06	0.06	0.03	0.02	0.03	0.03	0.03
Potatoes										
Pumpkin	3.27E+01	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Rice										
Spinach										
Sugar										
Tea										
Tomatoes										
White bread										
Max improvement required		0.08	0.07	0.06	0.06	0.03	0.02	0.03	0.03	0.03
Average improvement required		0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Th	INAA method	5	IDC scheme	30m/7d/30m					
	PTI (ug/d)	3.62E+01	3.62E+01	3.70E+02	4.76E+02	6.53E+02	7.24E+02	7.24E+02	7.24E+02	7.24E+02
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	6.97E-02	0.014	0.028	0.007	0.008	0.008	0.007	0.007	0.007	0.007
Beetroot	6.68E-02	0.046	0.061	0.006	0.007	0.007	0.007	0.007	0.007	0.007
Brown bread										
Cabbage	5.86E-02	0.016	0.021	0.003	0.002	0.003	0.002	0.002	0.002	0.002
Chicken meat										
Chicken livers	9.75E-02	0.014	0.028	0.007	0.008	0.008	0.007	0.007	0.007	0.007
Coffee										
Eggs	8.44E-02	0.005	0.009	0.002	0.003	0.003	0.002	0.002	0.002	0.002
Fish	1.32E-01	0.002	0.004	0.002	0.004	0.003	0.002	0.002	0.002	0.002
Green Beans	5.25E-02	0.016	0.021	0.003	0.002	0.003	0.002	0.002	0.002	0.002
Maize										
Margarine										
Milk										
Onion	5.31E-02	0.018	0.018	0.003	0.003	0.003	0.002	0.002	0.002	0.002
Pork	7.18E-02	0.015	0.031	0.008	0.009	0.009	0.008	0.008	0.008	0.008
Potatoes	5.81E-02	0.036	0.047	0.006	0.005	0.006	0.005	0.005	0.005	0.005
Pumpkin	5.45E-02	0.017	0.022	0.003	0.003	0.003	0.002	0.002	0.002	0.002
Rice										
Spinach										
Sugar	9.91E-03	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Tea										
Tomatoes	5.99E-02	0.009	0.012	0.001	0.001	0.001	0.001	0.001	0.001	0.001
White bread										
Max improvement required		0.046	0.061	0.008	0.009	0.009	0.008	0.008	0.008	0.008
Average improvement required		0.009	0.013	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	U	INAA method	5	IDC scheme	30m/7d/30m					
	PTI (ug/d)	2.74E+01	2.74E+01	3.56E+01	4.11E+01	6.51E+01	1.00E+02	1.00E+02	1.00E+02	1.00E+02
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	1.97E+00	0.5	1.1	2.1	2.7	2.2	1.5	1.5	1.5	1.5
Beetroot	3.57E+00	3.2	4.3	3.2	4.3	3.9	2.5	2.5	2.5	2.5
Brown bread										
Cabbage	2.75E+00	1.0	1.3	1.3	1.3	1.2	0.8	0.8	0.8	0.8
Chicken meat										
Chicken livers	2.11E+00	0.4	0.8	1.5	2.1	1.7	1.1	1.1	1.1	1.1
Coffee										
Eggs	3.38E+00	0.2	0.5	1.0	1.4	1.1	0.7	0.7	0.7	0.7
Fish	2.39E+00	0.0	0.1	0.5	0.8	0.5	0.3	0.3	0.3	0.3
Green Beans	1.46E+00	0.6	0.8	0.8	0.8	0.7	0.5	0.5	0.5	0.5
Maize										
Margarine										
Milk										
Onion	1.28E+00	0.6	0.6	0.7	0.7	0.7	0.4	0.4	0.4	0.4
Pork	2.11E+00	0.6	1.2	2.3	3.0	2.6	1.7	1.7	1.7	1.7
Potatoes	1.60E+00	1.3	1.7	1.7	1.7	1.6	1.0	1.0	1.0	1.0
Pumpkin	1.44E+00	0.6	0.8	0.7	0.8	0.7	0.5	0.5	0.5	0.5
Rice										
Spinach										
Sugar	1.01E-01	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Tea										
Tomatoes	2.08E+00	0.4	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
White bread										
Max improvement required		3.2	4.3	3.2	4.3	3.9	2.5	2.5	2.5	2.5
Average improvement required		0.4	0.6	0.7	0.9	0.7	0.5	0.5	0.5	0.5

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	V	INAA method	2	IDC scheme	10s/10m/10m					
	RDA (ug/d)	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef										
Beetroot										
Brown bread	8.62E-01	1.2	1.6	2.0	2.4	4.0	4.0	4.0	4.0	4.0
Cabbage	1.57E+00	0.3	0.4	0.5	0.6	0.9	0.9	0.9	0.9	0.9
Chicken meat	1.00E+00	0.1	0.3	0.6	1.0	1.3	1.3	1.3	1.3	1.3
Chicken livers										
Coffee	6.91E-01	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2
Eggs	1.28E+00	0.1	0.1	0.3	0.4	0.5	0.5	0.5	0.5	0.5
Fish										
Green Beans										
Maize	6.19E-01	0.9	1.2	1.5	1.8	3.0	3.0	3.0	3.0	3.0
Margarine	8.72E-01	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5
Milk	9.34E-01	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
Onion	9.41E-01	0.2	0.2	0.4	0.5	0.6	0.6	0.6	0.6	0.6
Pork										
Potatoes	8.59E-01	0.4	0.5	0.6	0.8	1.1	1.1	1.1	1.1	1.1
Pumpkin										
Rice	6.88E-01	1.6	2.1	2.7	3.2	4.6	4.6	4.6	4.6	4.6
Spinach	2.02E+00	0.3	0.4	0.5	0.6	0.9	0.9	0.9	0.9	0.9
Sugar	4.27E-01	0.0	0.0	0.0	0.3	0.2	0.2	0.2	0.2	0.2
Tea	1.38E+00	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Tomatoes	1.38E+00	0.1	0.2	0.2	0.3	0.4	0.4	0.4	0.4	0.4
White bread	1.09E+00	1.7	2.2	2.8	3.4	5.6	5.6	5.6	5.6	5.6
Max improvement required		2.5	2.5	2.8	3.4	5.6	5.6	5.6	5.6	5.6
Average improvement required		0.4	0.5	0.6	0.8	1.1	1.1	1.1	1.1	1.1

Annexure 5: Element specific sensitivity in foodstuffs as a function of age and nutritive value (continued)

Element	Zn	INAA method	5	IDC scheme	30m/7d/30m					
	RDA (ug/d)	2.00E+03	3.00E+03	3.00E+03	5.00E+03	1.00E+04	1.10E+04	8.00E+03	1.10E+04	1.20E+04
		0 - 0.5 yrs	0.5-1 yrs	1- 3yrs	4-8yrs	9-18yrs	+19yrs Male	+19yrs Female	Pregnant Women	Lactating Woman
Foodstuff	MDC (ug/g) dry	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor	Sensitivity factor
Beef	5.10E+00	0.02	0.02	0.06	0.06	0.04	0.03	0.05	0.03	0.03
Beetroot	5.25E+00	0.07	0.06	0.06	0.05	0.04	0.03	0.05	0.03	0.03
Brown bread	1.29E+01	0.45	0.40	0.50	0.36	0.30	0.28	0.38	0.28	0.25
Cabbage	8.31E-01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chicken meat	2.17E+00	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.01
Chicken livers	4.16E+00	0.01	0.01	0.03	0.03	0.02	0.02	0.03	0.02	0.02
Coffee	5.87E+00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Eggs	5.87E+00	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Fish	7.95E+00	0.00	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Green Beans	2.34E+00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Maize	2.35E+00	0.08	0.07	0.09	0.07	0.06	0.05	0.07	0.05	0.05
Margarine	4.46E+00	0.00	0.00	0.00	0.03	0.01	0.01	0.02	0.01	0.01
Milk	8.29E+00	0.54	0.36	0.36	0.22	0.09	0.08	0.11	0.08	0.08
Onion	2.41E+00	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Pork	5.14E+00	0.02	0.03	0.07	0.06	0.04	0.04	0.05	0.04	0.03
Potatoes	3.12E+00	0.03	0.03	0.04	0.03	0.02	0.02	0.02	0.02	0.02
Pumpkin	3.34E+00	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Rice	2.74E+00	0.16	0.14	0.18	0.13	0.09	0.08	0.11	0.08	0.08
Spinach	1.10E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	7.95E-01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Tea	3.29E+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tomatoes	2.96E+00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00
White bread	4.58E+00	0.18	0.16	0.20	0.14	0.12	0.11	0.15	0.11	0.10
Max improvement required		0.54	0.40	0.50	0.36	0.30	0.28	0.38	0.28	0.25
Average improvement required		0.07	0.06	0.08	0.06	0.04	0.04	0.05	0.04	0.03