Iranian Journal of Science & Technology, Transaction A, Vol. 34, No. A3
Printed in the Islamic Republic of Iran, 2010

INTAKES OF RADIOLOGICALLY IMPORTANT TRACE AND MINOR ELEMENTS FROM IRANIAN DAILY DIETS*

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Abstract – Cesium content and some other more radiologically important mineral elements were measured by nuclear and non-nuclear analytical methods in Iranian daily diets.This study was extended to a few more similar functioning elements such as Sr, Rb, I, K, Mg and Ca as well. Though the ^{137}Cs and other radionuclieds were not measured in these diets under planned regular investigation in this work, but in comparison with some other backgrounds, the contribution and the impact/effective amount of ^{137}Cs in the daily diet/total mixed diet may be estimated either by its own part concentrations or by the amount of intakes per person per day, if any of those, is in sufficient quantity of normal range. Nevertheless, the protective role of these minerals in human organs is the main issue of this assessment. The amount of ^{137}Cs and other radionulides in the foodstuff depends upon direct contamination/exposure or via the mineral and organic content of the radionuclides in the soil and environment to be transferred to nutritive species. This effect is also considered.

Keywords – Iranian, radiological protection, radionuclides, daily dietary

1. INTRODUCTION

The role of some trace and minor elements in human health is now rather well-established and quite understandable for many countries as well as for the public [1-4]. Today, people are faced with a rather new problem which comes from the modernized world and is mainly due to the demand for energy from nuclear sources. Nuclear contaminants and radiation hazards may be induced from natural or artificial sources. It is now known that the level of some certain trace/minor elements and likely some similar radionuclides in human is inevitable and this knowledge can be quite helpful for their essentiality and to avoid their radiation impacts. Daily dietary intakes of trace elements such as Cs, Sr, Rb or other alkaline elements are important in the case of food contamination when internal intakes/absorption happen by their counterpart radionuclides. Also, there are some trace and minor elements such as I, Ca, K and Mg that are not only nutritionally important, but from a radiological point of view, play an adversely important role as well. The reason for the elements mentioned above is the similarity of their chemical behavior in radionuclide and non-radionuclide forms. Therefore, if the natural intakes of these elements are quite enough, then similar or relevant radionuclides cannot remain in the body for a longer time or substitute the natural ones. This is especially true for ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{131}I, ^{129}I, and to some extent for ^{40}K and ^{78}Rb whose half lives (of most of them) are quite long and dangerous for man, and are very much susceptible to go to the bones and even perhaps to remove very useful structural elements such as Ca and Mg. The latter incident happens since Cs and Sr are in the alkali and earth alkaline group, and again chemically are acting

*Received by the editor May 12, 2009 and in final revised form March 13, 2011
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the same way as K, Ca and Mg do. It means that the radionulides of ^{137}Cs, ^{134}Cs, and ^{90}Sr may be absorbed in the absence of the above -mentioned natural nuclides and/or to immigrate to the bones and muscles when structural elements (Ca, Mg) are inadequate.

Moreover, even adequate essential trace elements (e. g. Fe, Zn, Cr, Mn, Se…) in man may be protective against radiation hazard, either because of their antioxidative role or as the result of their local effectiveness in individual organs [5-8].

It should be remembered that cesium is the most of electropositive and least abundant of the naturally alkali metals and strontium is an alkaline earth metal. They chemically resemble their own group IA (e. g. Rb and K) and IIA (e. g. Ca and Mg) in the periodic table respectively, but they are abundant in the earth's crust too.

This is expected to make a data base for future work to accumulate and enhance quite enough data, especially for occupational personnel or those residing near nuclear facilities, in order to protect workers and the public from the nutritional and radiological impact.

The present study is part of a previous coordinated research work to measure the 24 trace and minor elements [9-13]. Therefore, a comparable basis is provided, since the proposed diets have been prepared almost simultanously by many investigators from various countries for their own use in different parts of the world in the above-mentioned coordinated research work. The subject must be taken into consideration, since the overall and local radioactive substances are unlikely/likely discharged to the environment, contaminating foodstuffs produced in the vicinity of nuclear establishments or facilities [7-8].

The other importance of this work was the coincidence of execution of the sampling of this study in 1986-1996 with the Chernobyl accident when the fallout of this nuclear accident enhanced the fission products on the earth, in particular in northern/eastern Europe and central Asia. This is while at the same time, the diets were under preparation by participants in different countries.

It is also somehow a complementary part of the original work to provide some experimental knowledge to those who desire public health and the environment to be effectively protected. As one knows, radioactivity in food is a source of exposure that could significantly contribute to an increased internal dose of the population in cases of radiological emergencies, like nuclear accidents or radioactive discharges.

2. EXPERIMENTAL

The procedure for diet preparation and the relevant study groups were described in previous papers [9-11]. Here, it is to be summarized briefly.

a) Study groups

The study groups were selected among common healthy people from five major regions of Iran in accordance with their various food habits in the Center, North, East, West and South indicated by C, N, E, W, and S respectively. Then, three classes of the population (study groups) were chosen: Literate, Illiterate and Rural indicated by numbers 1, 2 and 3 respectively. Since the central study groups have to be representative for a larger population, each study group (1-3) was formed from 6 sub-study groups composed of the families from 2, 3, 4, 5, 6 and 7 members and all were then put into one study group to be comparable with the others. However, in this study, the representative man out of each study group is an adult person aged 20-65 years and weight of 50-65 kg.

b) Sampling method

Total mixed diet was prepared on the basis of dietary recording method. This method was chosen since a) no statistic data were available on the food consumption at a national or regional level, b) no common understanding would allow one to apply a duplicate diet preparation in a large study group (regional level) and c) no marketing basket method could be implemented in the mid 1980's when this program was planned as a result of uneasiness/unpopular whole food marketing at that time. Therefore, this job was assigned by a few trained nutrition students. However, these volunteers, who were familiar with the region and food habits of the people, questioned the appropriate selected test subjects (study groups) and recorded what ever they had eaten (in accordance with their detailed food items and all forms of cooked or non cooked items) every day for 4-5 consecutive days. Also, the individual habit of eating, drinking and additives were questioned and recorded for the next stage of reformulating.

c) Diet reconstitution/Reformulating

The recording data of food consumption were processed and converted to the appropriate food composition, either cooked or raw in the laboratories of the National Nutrition Institute of Iran (Sh. Behshti Univ.). This composite was then transferred to a special blender with titanium blade, mixed, homogenized, freeze dried and powdered. This material was aliquoted to a few samples to be sent to different local and reference laboratories by the International Atomic Energy Agency (IAEA) to be taken up for analysis.

d) Measurement

As mentioned in earlier publications in more detail [9, 10], this was an international project and many countries participated as collection centers (for daily diet sampling) and reference analytical centers (for analytical purposes/measurements) or some for both.Therefore, the diets were to be analyzed in a few reference laboratories and back up laboratories along with the appropriate quality assurance criteria. For the elements concerning this paper, except for the Sr measurement which was carried out only by ICP-AES locally in AEOI's laboratories, the other elements measured both in local laboratories and reference back up laboratories. The results cited here are in good agreement with the criteria and checked with the Certified Reference Materials, CRM (s). Mg and Ca were measured by ICP-AES locally and in the IAEA laboratories of Seibersdorf by both ICP and INAA. Iodine was measured by Epithermal INAA, Canadian Trace Analysis Research Center in Halifax, and Wurenligen, the Swiss Federal Institute for Research Reactor. The main participant countries were all:

AU: Austrailia, BR: Brazil, CA: Canada, CH: China, IR: Iran, IT: Italy, JA: Japan, NO: Norway, PO: Portugal, SP: Spain, SU: Sudan, SW: Sweden, TH: Thailand, TU: Turkey and US: USA. These countries are namely collection centers, but some other countries participated as analytical centers or for both.

However, every analyte has been measured from the same aliquot under the same conditional preparation in replicate. Meanwhile, every individual measurement could be confirmed when enough assurance has been obtained regarding the method, analyst, analyte, CRM (s) as well as other parameters concerning sensitivity and accuracy were observed.

Therefore, the reference analytical laboratories/centers were required to validate the methods by at least three suitable CRMs such as Animal Muscle H-4, Mixed Human Diet IAEA H-9, Total Daily Diet Pool TDD-1D and NIST Reference Material 8431 [9, 12, 14-16]. Some further or comprehensive information data is given about QA/QC as well as detection limits for different elements, methods and standard deviations [9].

3. RESULTS AND DISCUSSION

A summary of dietary records on food categories and relevant items in all of the studied regions are given in Table1. Some further points are given later. The final result of analyses for radiological elements such as Cs, Sr, Rb, K and nutritional importance, as well as for radiation protection such as Ca, Mg, and in particular Iodine are summarized in Tables 2-3. In Table 4, the results for the central study groups are listed in more detail in differentiation of further study groups. The same results for various countries participating in this project, in comparison with Iran, is given in terms of elemental concentration of relevant diets in Table 5. The methods of measurements and Recommended Daily Allowances, RDA, as well as those suggested by the International Committee for Radiation Protection, ICRP, are shown in Table 6 [17, 18].

As mentioned previously, the validation of the analytical methods was made by at least three Certified Reference Materials. The inclusion of blind CRMs and/or duplicate sample in each batch was sent for analysis [9, 16]. A comparison of results between different laboratories was made [9, 14].

The Standard Deviation (SD) for all data in Tables 2, 3, 4 for 90% of the results by calculation are about 5-15%, only a few are about 20% [9-12].

At first glance, it is clear that the concentrations of Cs, Sr and Rb in adults in different regions are not so much, as they are quite higher in the diets of the other countries. However, except for ICRP [17], there is no specific data for these traces as an adequate or safe level. One may, of course, assume the reason for a higher level of cesium content in most of the other countries can be attributed partly to the ^{137}Cs and ^{134}Cs, which is absolutely undesirable (not significant in weight). In the case of Ca, K, Mg, as the minor essential and structural elements in the body, they seem to be rather normal in Iranian diets. Therefore, the deposition of radionuclides such as ^{137}Cs and ^{90}Sr is less likely to happen. The present status of Ca, K, Mg in accordance with the unpublished data is rather undesirable, since the dairy products of dietary consumption have decreased quite considerably among the Iranian people in the recent years.

One has to consider that the excess of some other traces such as Pb, Cd, Al via environmental impact would adversely affect the metabolic absorption of Ca and Mg. A similar violation may also happen to essential trace elements, and therefore a potential condition can be provided for ^{137}Cs, ^{134}Cs, ^{90}Sr deposition and more severe radiation hazards via internal or external exposure.

Concerning the intake of Iodine in the central and other regions are mostly lower than the recommended dietary allowances (RDA), most Iranians, in the case of the presence of relevant radioactive contaminants, are very much susceptible for deposition and accumulation of ^{131}I and ^{129}I in their thyroid gland. As the matter of fact, apart from the previous hazard, this deficiency is also nutritionally more important since Iodine plays a significant role in the health of the people as well [1, 11, 17, 18]. Even as it is observed in Table 4, the Iodine content of the Iranian diet is the lowest among others except the diet from Thailand.

Table 1 is provides some further information about the items in each food category and the contribution of each category in diet preparation for different regions based on the dietary records performed in this project [19]. The data for very recent national food consumption is given for comparison as well [20].

Concerning the radioactivity of the food items, it is difficult to make a certain statement. First of all, as it was mentioned earlier no comprehensive work on this matter has been carried out by the author or apparently by others in Iran. There are only some natural radioactivity measurements which have been made on a few food items and are indicated in Table 1 [21-23]. There is also another report reflecting many measurements for every food item imported to Iran. The average content of ^{137}Cs in meat and dairy product is given in Table 1 [21]. This part of the food items consumed in the period of 1985-1990 is approximately equal to 40-50%. There is no indication whether the local Iranian food products inside of the country were contaminated, and many attempts were made to measure the radioactivity concerning ^{137}Cs and ^{90}Sr, but no detectable amount could be measured in various items by existing and regular instruments. In fact, this is partly evidenced by the fact that Iranian diets are not associated with any significant radioactivity.

Table 1. Daily dietary intakes of various food items in major food categories in terms of gr/day/person and relevant radioactivity of a few food items

Food categories and relevant items	National consumption data / Market basket	Duplicate diet	Dietary recording during 1985 - 1990						Artificial and Natural radionuclides, Bq/kg [21-23]		
			Center	North	East	West	South	Repve. Iranian diet	^{137}Cs	^{40}K	^{226}Ra
Cereals: bread, macaroni, rice	484	-	473	685	417	650	410	527	-	80,14	-
Pulses: lentil, peas, beans, split peas, chick peas	21	-	23	102	21	26	34	41	-	-	-
Meat: lamb, poultry, beef, fish, eggs	111	-	155	212	139	89	148	148	up to 230*	100	-
Dairy products: milk, cheese, yogurt	167	-	140	138	167	102	190	147	up to 250*	150-300	-
Fruits and Vegetables: leafy, rooty, tubers vegetables, onion and etc., all fruits	469	-	965	1052	668	399	371	691	-	-	-
Sweets: sugar, jam, honey, candies, sweets	70	-	77	78	46	61	41	61	-	20	50 D.Wt. 5 W.Wt.
Oil and Fats	39	-	43	43	28	30	31	35	-	25	-
Beverages: soft drinks, juices, tea, coffee	10	-	19	52	22	24	105	44	-	420-1200	-
Seeds and Nuts	3	-	8	21	13	13	7	12	-	-	-
Spices	-	-	31	51	32	9	8	24	-	#600	-
Wet weight, gr	1374	1546	1934	2434	1553	1403	1345	1734	-	-	-
Added water, gr	500+…	1300	1420	1830	1640	1300	2600	1758	-	-	7.7 **
Total wet weight, gr	-	2846	3354	4264	3193	2703	3945	3492	-	-	-
Dry weight, gr	-	711	877	1322	775	979	698	935	-	-	-
Total water content after cooking,%	-	75	74	69	76	64	82	73	-	-	-

*imported items # 50% total relevant food group, ** mBq/kg

Table 2. Intakes of mineral elements of importance in radiation protection and nutrition in different regions of Iranian daily diets (mg/day/person)

Study Group	Cs	Sr	Rb	Ca	K	Mg	I	Sc
IR-C-1	0.0068	9.3	3.53	1335	6522	547	0.127	0.0054
IR-C-2	0.0060	8.4	2.88	1024	6634	611	0.090	0.0079
IR-C-3	0.0052	9.2	2.68	1020	5802	618	0.075	0.0042
IR-C	**0.0060**	**9.0**	**3.03**	**1126**	**6319**	**592**	**0.097**	**0.0058**
IR-N-1	-	7.6	-	1681	6909	747	-	-
IR-N-2	-	14.6	7.20	2350	10718	1073	-	-
IR-N-3	-	-	-	1934	8740	921	0.208	-
IR-N	**-**	**11.1**	**7.20**	**1988**	**8789**	**914**	**0.208**	**-**
IR-E-1	-	-	-	1057	3684	485	-	-
IR-E-2	-	-	-	943	3763	515	-	-
IR-E-3	-	-	-	1774	4858	788	-	-
IR-E	**-**	**-**	**-**	**1258**	**4102**	**596**	**-**	**-**
IR-W-1	-	-	-	1256	4683	592	-	-
IR-W-2	-	-	-	1216	5162	732	-	-
IR-W-3	-	-	-	738	3492	580	-	-
IR-W	**-**	**-**	**-**	**1070**	**4446**	**635**	**-**	**-**
IR-S-1	-	-	0.70	1092	4035	519	-	
IR-S-2	-	-	2.95	1118	4257	667	-	
IR-S-3	-	-	-	1477	5626	1071	-	
IR-S	**-**	**-**	**1.83**	**1229**	**4639**	**752**	**-**	

Another report indicating that various industrial minerals imported to Iran including phosphate fertilizer contain a rather considerable amount of ^{232}Th, ^{226}Ra and ^{40}K [24]. The radioactivity of the mentioned mineral for the above nuclides are 4, 657 and 412 Bq/kg respectively, which finally enter into the food chain and daily diets of the people.

4. CONCLUSION

This work provides adequate and vast reliable data for interested elements not only nationally, but almost globally. This may provide and go far beyond those discussions made here in this article by experts and specialists. However, since in the process of nuclear fission including nuclear accident and nuclear explosion, the radionuclides of cesium, strontium and iodine: a) can be produced as a relatively considerable amount, b) cesium may be spread over a very vast distance as the result of low melting point and also, c) because of the long half lives of these radionuclides, they are potentially very dangerous to humans if intaken through food items directly or indirectly. Though the present data for K, Ca and Mg is not undesirable, the regular survey of the elemental consumption in food dietary and their bioavailability is matter of great importance for K, Ca, Mg or for essential elements comprehensively. However, the intakes of Iodine in almost all Iranian diets is crucial and must be taken into consideration much more intensively than ever before from a nutritional and radiological point of view. The amount of these radionuclides released in the Chernobyl accident is reported as 37 P Bq for ^{137}Cs, 19 P Bq for ^{134}Cs, 8.1 P Bq for ^{90}Sr and 670 P Bq for ^{131}I. Something more or less than these radionuclides and many others including ^{129}I are released from reprocessing plants and other nuclear establishments as well [25, 26]. Therefore, a rather conclusive care is to be taken about what has happened in past as well as in future. This is, in particular, more important since AEOI is going to be active a few nuclear facilities in the imminent coming years for its energy production [6, 27]. The hazardous impact of the likely existence of radionuclides and their biological effects are explained in [14]. It is also recommended that the matters related to bioavailability and toxicity of trace elements written by the same authors be considered [28, 29].

Table 3. Intakes of mineral elements of importance in radiation protection and nutrition in daily diets of main Iranian study groups (mg/day/person)

Study Group	Cs	Sr	Rb	Ca	K	Mg	I	Sc
IR-C-1	0.0068	9.3	3.53	1335	6522	547	0.127	0.0054
IR-N-1	-	7.6	-	1681	6909	747	-	-
IR-E-1	-	-	-	1057	3684	485	-	-
IR-W-1	-	-	-	1256	4683	592	-	-
IR-S-1	-	-	0.70	1092	4035	519	-	-
IR1	**0.0068**	**8.5**	**2.12**	**1284**	**5167**	**578**	**0.127**	**0.0054**
IR-C-2	0.0060	8.4	2.88	1024	6634	611	0.090	0.0079
IR-N-2	-	14.6	7.20	2350	10718	1073	-	-
IR-E-2	-	-	-	943	3763	515	-	-
IR-W-2	-	-	-	1216	5162	732	-	-
IR-S-2	-	-	2.95	1118	4257	667	-	-
IR2	**0.0060**	**11.5**	**4.34**	**1330**	**6107**	**720**	**0.090**	**0.0079**
IR-C-3	0.0052	9.2	2.68	1020	5802	618	0.075	0.0042
IR-N-3	-	-	-	1934	8740	921	0.208	-
IR-E-3	-	-	-	1774	4858	788	-	-
IR-W-3	-	-	-	738	3492	580	-	-
IR-S-3	-	-	-	1477	5626	1071	-	-
IR3	**0.0052**	**9.2**	**2.68**	**1389**	**5704**	**796**	**0.142**	**0.0042**
IR av.	**0.0060**	**9.7**	**3.05**	**1334**	**5659**	**698**	**0.120**	**0.0058**

Table 4. Intakes of dietary mineral elements of importance in radiation protection and nutrition in central region of Iran (mg/day/person)

Study Group	Cs	Sr	Rb	Ca	K	Mg	I	Sc
IR-C-12	0.0068	5.5	3.32	1140	5533	538	0.102	0.0059
IR-C-13	0.0061	6.2	2.99	1226	5292	441	0.093	0.0042
IR-C-14	0.0049	6.7	2.90	1075	5101	438	0.120	0.0059
IR-C-15	0.0059	11.3	3.32	996	5870	533	0.086	0.0048
IR-C-16	0.0068	9.7	4.11	2025	7054	592	0.229	0.0037
IR-C-17	0.0103	16.2	4.55	1547	10279	737	0.133	0.0079
IR-C-1 av.	**0.0068**	**9.3**	**3.53**	**1335**	**6522**	**547**	**0.127**	**0.0054**
IR-C-22	0.0076	9.5	3.70	1028	8071	685	0.076	0.0410
IR-C-23	0.0080	14.4	3.33	1046	6612	571	0.089	0.0069
IR-C-24	0.0056	5.8	3.00	1093	6881	682	0.080	0.0048
IR-C-25	0.0040	5.2	2.02	876	5340	488	0.074	0.0025

Table 4. (Continued)

IR-C-26	0.0048	10.1	2.50	1099	7326	661	0.140	0.0028
IR-C-27	0.0060	5.6	2.74	1000	5572	579	0.080	0.0041
IR-C-2 av.	**0.0060**	**8.4**	**2.88**	**1024**	**6634**	**611**	**0.090**	**0.0079**
IR-C-32	0.0069	14.6	3.00	1228	5549	753	0.109	0.0064
IR-C-33	0.0042	8.0	2.30	749	5045	520	0.069	0.0031
IR-C-34	0.0051	8.2	2.00	841	5151	508	0.038	0.0030
IR-C-35	0.0044	10.2	3.66	1452	8369	823	0.084	0.0034
IR-C-36	0.0044	5.8	2.53	842	4903	486	0.065	0.0026
IR-C-37	0.0060	8.2	2.59	1008	5793	619	0.086	0.0064
IR-C-3 av.	**0.0052**	**9.2**	**2.68**	**1020**	**5802**	**618**	**0.075**	**0.0042**
IR-C av.	**0.0060**	**9.0**	**3.03**	**1126**	**6319**	**592**	**0.097**	**0.0058**

Table 5. The concentration of a few important mineral elements in daily diets of various countries (ppm-mg/kg)

Countries	**Cs**	**Sr**	**Rb**	**Ca**	**K**	**Mg**	**I**
Australia	-	-	9.38	1693	6498	760	-
Brazil	0.03	-	12.54	1179	4242	-	0.480
Canada		-	5.92	-	6055	653	-
China	0.02	-	6.35	1311	3390	666	0.620
Iran	**0.01**	**9.7**	**3.49**	**1374**	**6600**	**713**	**0.110**
Italy	0.1	-	6.73	1898	5811	551	0.175
Japan	-	-	6.38	1630	5710	618	2.804
Norway	-	-	7.23	2175	7089	774	0.592
Portugal	-	-	-	2004	6863	645	-
Spain	0.05	-	6.54	2405	7234	637	0.398
Sudan	0.01	-	3.85	1179	4512	792	0.170
Sweden	-	-	-	3354	6734	708	-
Thailand	-	-	11.36	978	2851	410	0.095
Turkey	0.02	-	4.18	1424	5240	667	0.236
USA	0.01	-	5.36	1990	6323	617	0.510
Median	**0.02**	**-**	**6.38**	**1795**	**5933**	**656**	**0.398**
Recommeded values suggested by ICRP[17] for Cs, Sr and RDA[18] for other elements mg/day/person	0.01	2	-	800	1870-5620	300-350	0.15

ICRP: International Committee for Radiation Protection, RDA: Recommended Daily Allowances

Table 6. Further information for performance and comparative basis of the present work [1, 17, 18]

Elements	Cs *	Sr *	Rb	Ca	K	Mg	I	Sc
Analytical Method	INAA(A)	ICP(L)	INAA(A)	ICP(A,L)	INAA(A,L)	ICP(A,L)	EINAA(H,W)	INAA(A)
RDA & ICRP*, mg/day	0.01	2	-	800	1870-5620	300-350	0.15	-

A, L, H and W each represent: IAEA-Laboratories of Seibersdorf, AEOI's laboratories, Halifax-Trace Analysis Research Center and Wurnligen-Swiss Federal Institute for Research respectively.

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