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EVALUATION OF INTERNAL DOSE, DUE TO THE INGESTION OF PRIMORDIAL RADIONUCLIDE 40K AROUND NARORA SITE, INDIA

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Two 220 MWe pressurized heavy water reactors are under operation at Narora in the state of Uttar Pradesh in India. Environmental radiological survey of the surrounding areas of the Narora site is carried out by the Bhabha Atomic Research Centre, Mumbai. The estimated dose to the members of the public due to ingestion of radioactive isotope of potassium, a natural radionuclide, in the surroundings of the Narora site is 163.5 µSv (16.3 mrem) per year. The value indicates that the dose to the public due to the operation of the nuclear reactors in Narora is insignificant in comparison with the dose due to unavoidable natural radioactivity.

Keywords: Nuclear Reactors, Radioactivity.

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INTRODUCTION

The sources of radioactivity in the environment are of natural, both terrestrial and extra terrestrial, and anthropogenic origins. Owing to geographical and geological factors, natural radionuclide concentrations in environmental samples can vary [(1)]. The various components of natural radioactivity are cosmic rays, cosmogenic radionuclides, primordial radionuclides and fall out radionuclides[(2 – 5)]. The primordial radionuclides found in the earth's crust are thorium, uranium and actinium series radionuclides and singly occurring radionuclides ^{40}K and ^{87}Rb[(6)]. Of these natural radioactive isotopes, ^{40}K, is the most important from the health physics point of view by virtue of the widespread distribution of potassium in the environment[(5)]. Potassium is an essential element in the body and its average mass concentration for an adult male is approximately 2 g per kg of body weight. Natural potassium is a mixture of three isotopes: ^{39}K, ^{40}K and ^{41}K with mass percentages of 93.08, 0.0118 and 6.91, respectively[(7)]. The isotopic ratio of ^{40}K is 1.18×10^{-4} and the average activity concentration of ^{40}K in the body is approximately 60 Bq kg^{-1}[(6)]. The half-life of ^{40}K is 1.27×10^9y and it decays to ^{40}Ca by emitting a beta particle (89 %) and the gas ^{40}Ar by electron capture accompanied by a 1.46-MeV gamma emission with an 11 % abundance[(8)]. The biological half-life of ^{40}K in the human body is reported as 30 d[(8)]. ^{40}K is the predominant radionuclide that contributes maximum share to the natural radioactivity of the environment[(9)]. Potassium is one of the most important nutrients and is an essential element in life processes. It occurs in plants, principally as soluble inorganic salts, although potassium salts of organic acids are also found in plant cells. It is an indispensable element and cannot be completely replaced even by such chemically similar elements as sodium or lithium. The young and actively growing regions of plants, especially buds, young leaves and root tips, are always rich in potassium while as a rule the proportion of potassium is relatively low in seeds and mature tissues[(10)]. When ingested or inhaled, naturally occurring radionuclides is distributed among body organs according to the metabolism of the element involved[(11)]. Through food chain, ^{40}K enters the human body and imparts radiation dose[(12)]. There are various reports on the level of ^{40}K in food stuffs and resultant annual ingestion radiation dose[(13, 14)]. It has been reported that ^{40}K contributes highest to the daily dose produced by the intake of composite diets[(15)]. Jibiri et al.[(16)] estimated the annual effective dose due to the ingestion of natural radioactive elements ^{40}K, ^{238}U, ^{232}Th in foodstuffs in Nigeria. Abbady calculated the annual dose due to daily intake of radium, thorium and potassium through wheat flour, lentils and beans consumed in Upper Egypt[(13)]. Ismail et al.[(17)]assessed the natural radioactivity levels in drinking water consumed in Jordan and calculated the committed effective dose. Fletcher evaluated the dose from 40K activity in tobacco leaves and cigarettes[(18)]. Martinez et al.[(19)] estimated ^{40}K activity in tobacco samples of Mexican cigarettes and calculated annual dose equivalents to the whole body due to inhalation and ingestion of 40K through cigarettes. It is mentioned that the potassium content of the body is under strict homeostatic control and is not influenced by variations in environmental levels, and hence, the dose of ^{40}K within the body is constant[(20)]. Environmental Survey Laboratory, Narora, carries out the monitoring of the environment around Narora, where four pressurised heavy water reactors (PHWRs) are operational. In this paper, the annual effective dose of a member of the public around the Narora site due to the ingestion of ^{40}K is estimated, using dietary survey data and average ^{40}K activity levels in dietary components.

MATERIALS AND METHODS

Site description

NAPS site is on the right bank of the Lower Ganga Canal (LGC) and Parallel Lower Ganga Canal (PLGC) at a distance of 3.5 km from Narora Barrage. The nearest broad gauge railway station is Rajghat Narora at about 11.5 km from the site on Aligarh – Bareilly section of Northern Railway.

The area of the plant site is fairly flat terrain, gently sloping towards LGC & PLGC. The site lies in Indo-Gangetic alluvium, bordered on the north by the Shivalic foothills. The land around the site is predominantly agricultural. The main crop is wheat followed by other cereals. There are guava, mango groves and vegetable farms around the site. The region gets an average rainfall of 600 mm extended over a period of 4 months (June to September). The relative humidity at Narora varies from 8 to 99.9 % and the ambient temperature from 0.1 to

45.3^{0}C[21]).The location of the Narora site is given in Figure 1.

Sample collection and analysis Samples of dietary components such as rice, leafy vegetables, non-leafy vegetables, fish, milk and meat commonly consumed by the population in villages around Narora were collected. The samples were weighed, washed with water and dried; after the dry weight was noted, they were charred to ash in a muffle furnace at a temperature of 450^{o}C and the ash weight was recorded. ^{40}K activity in plant matrices was determined by gamma spectrometric analysis of ash samples. A high-purity germanium detector of coaxial type having a 15 % relative efficiency coupled to 16K multi channel analyzer was used for analysis. The system was calibrated for energy and efficiency, using a plastic container containing ash sample spiked with ^{137}Cs, ^{60}Co, ^{133}Ba and ^{40}K. The correctness of the sample counting was checked by the analysis of certified reference materials IAEA-414 provided by IAEA. Dietary survey

RESULTS AND DISCUSSION

Dietary intake

The per capita daily consumption of dietary items by the adult population around Narora site is given in Table 1. The major dietary items of the people in this area are wheat, rice, fish, meat, milk, leafy vegetables and non-leafy vegetables. The average daily intake of wheat by an adult varied from 150 to 230 g per day from village to village. The average consumption rate of fish and meat in these villages varied from 6 to 11 g per day. The average consumption of leafy vegetables by village adults varied from 32 to 46 g per day. The consumption of non-leafy vegetables varied from 85 to 108 g per day. The average daily intake of milk by village adults varied from 90 to 150 ml per day. From the data of the daily consumption, the annual average consumption of dietary components was calculated, which is presented in Table 2.

The daily consumption of cereals, fish, meat and milk by adult population living around the Narora site was found to be lower than that of Kaiga and the vegetable consumption was higher than that of Kaiga[9]. Consumption of all the major items except meat& fish was higher among the Narora population compared with the Tarapur population[22]. The annual intake of vegetables by the Narora population was found to be higher than that by Kakrapar, whereas fish consumption was found to be less than that of Kakrapar[23]. The values of annual average consumption of dietary items among the Narora population were compared with the national average and it was observed that the values of consumption of Wheat and vegetables are higher than the national average values[22]. The average consumption of milk for Iranians has been reported as 75 kg y^{-1}[8]. The annual consumption of vegetables in Egypt has been reported to be 139.3 kg y^{-1}[1]. ^{40}K activity in dietary components Table 3 presents the range of ^{40}K activity in major dietary components of populations around the Narora site during the period 2009–13. The average values show that ^{40}K activity varies in the order Cereals>Wheat>leafy vegetables>Root Vegetable>Fish>Fruit>Non-Leafy vegetable>Milk>Rice. The average of 6-y data show that the values of ^{40}K activity in dietary components are comparable to that of samples from the Kaiga environment in India[9] within statistical variations. ^{40}K activity in unwashed rice samples in Nigerea has been reported as 74.46+5.54 Bq kg^{-1}[24]. ^{40}K activity in wheat grain samples from different parts of India has been found to vary from 79.1 to 130 Bq kg^{-1}[25]. ^{40}K activity in wheat grain samples from Belgium has been found to vary from 76 to 157 Bq kg^{-1} dry weight[26]. ^{40}K activity in cereal flours in South Brazil has been reported to vary in soy 474+3 Bq kg^{-1}, corn 30+0.3 Bq kg^{-1}, rye 94+1 Bq kg^{-1}, manioc 67+1 Bq kg^{-1}, oat 76+1 Bq kg^{-1} and wheat 36.2+0.4 Bq kg^{-1}(27). ^{40}K activity in vegetable samples from Egypt was varying from 55 to 328 Bq kg^{-1} fresh weight[1]. ^{40}K activity in edible plants in Bulgaria has been reported to vary from 30 to 322 Bq kg^{-1}[28]. The average ^{40}K activity in mostly consumed fresh vegetables, parsley and leek, in the Tehran Province, Iran, has been reported to be 187.4 and 174.6 Bq kg^{-1}, respectively[29]. ^{40}K activity in milk samples in Narora has been found to be higher than that of Iran, where it has been reported to vary from 11.4 to 42.8 Bq kg^{-1} with an average activity concentration of 31.0+6.1 Bq kg^{-1}[8]. The average annual levels of ^{40}K in milk samples from Bombay during the period 1965–90 have been reported to vary from 33 to 66 Bq l^{-1}[30]

^{40}K activity in milk powder samples consumed in Mexico imported from Europe has been reported as 59+0.02 Bq/100 g powder milk[31]).

Evaluation of ingestion dose due to ^{40}K

The dietary survey indicates that the consumption pattern of dietary components vary from village to village and hence, the average 40K ingestion dose may also vary. Using the annual consumption data (Table 2) and the average activity levels of ^{40}K in dietary components for the period 2009–13 (Table 3), the average ^{40}K ingestion dose to the population for the period 2009–13 was calculated using the following equation.

Ingestion dose = Concentration of radionuclide (Bq kg^{-1}) x Intake per year (kg y^{-1}) x Dose conversion factor (Sv Bq^{-1})[32].

The dose conversion factor of ^{40}K is 6.2E-09 Sv Bq^{-1}[33]. It is observed that the annual effective dose of an adult member of the public around the Narora site due to the ingestion of ^{40}K through dietary components vary from 149 µSv (14.9 mrem) to 178 µSv (17.8 mrem) with minimum at Rasulpur and maximum at Ramghat. The detailed results are given in Table 4. The average annual effective dose of an adult member of the public around the Narora site due to ^{40}K ingestion was calculated as 163.5 µSv (16.3 mrem). B.Dube et al[21] et al reported that the mean dose received by members of the public at Narora due to the operation of nuclear power stations during 2009-2013 ranged from 0.31 to 0.48 µSv a^{-1}. It has been reported that an Indian adult receives a radiation dose of 189 µSv per year from potassium present in the body[30] and Bangladeshi adults receive a mean effective dose of 100±25 µSv per year from ^{40}K present in the body[35]. Sugiyama et al. reported that the daily intake of ^{40}K for Japanese adults vary from 68.5 to 94.2 Bq d^{-1} with a mean of 81.5+8.5 Bq d^{-1} and committed effective dose varies from 0.16 to 0.21 with a mean of 0.18+0.02 mSv[36]. Frissel et al.[37] reported that people receive approximately 180 µSv per year from ^{40}K through diet. The annual effective dose from ^{40}K due to ingestion of total daily diet for the members of the public in 13 cities in Japan during the period 2003–05 has been reported to vary from 130 to 217 µSv[38]. It has been reported that coastal inhabitants around Kudankulam in Tamil Nadu, India, receive a dose of 143 µSv per year from the ingestion of ^{40}K[39]. It has been reported that the total effective dose intake from the most common foodstuffs is about 0.122 mSv y^{-1} in Mexico's urban zones[40]. The estimated effective doses from ^{40}K in drinking water were found to be 0.5 mSv y^{-1} in Beni Suef Governate, Middle Egypt[41]. The annual effective dose due to ^{40}K resulting from the consumption of parsley leek vegetables in the Tehran province has been reported to be 5.24 mSv y^{-1}[29]. Makon et al.[12] reported the annual effective dose resulting from the consumption of edible vernonia cultivated in Cameroon to be 0.15 mSv y-1.

Figure 2 presents the percentage contribution of dietary components to the ingestion dose due to ^{40}K activity in the Narora site environment. It is observed that consumption of cereals is the major contributor of ingestion dose due to the intake of ^{40}K. Ingestion dose due to ^{40}K through the consumption of vegetables was found to vary from 5.9 to 7.9 µSv per year with an average of 6.9 µSv per year. In Egypt, ingestion dose due to ^{40}K through the consumption of vegetables has been found to be 80 µSv per year[1]. The ^{40}K ingestion dose due to the consumption of milk has been found to vary from 18.7 to 29.8 µSv per year with an average of 24.1 µSv per year, which is higher than the reported 14 µSv per year for Iran[8].

Figure 1. Location of Narora.

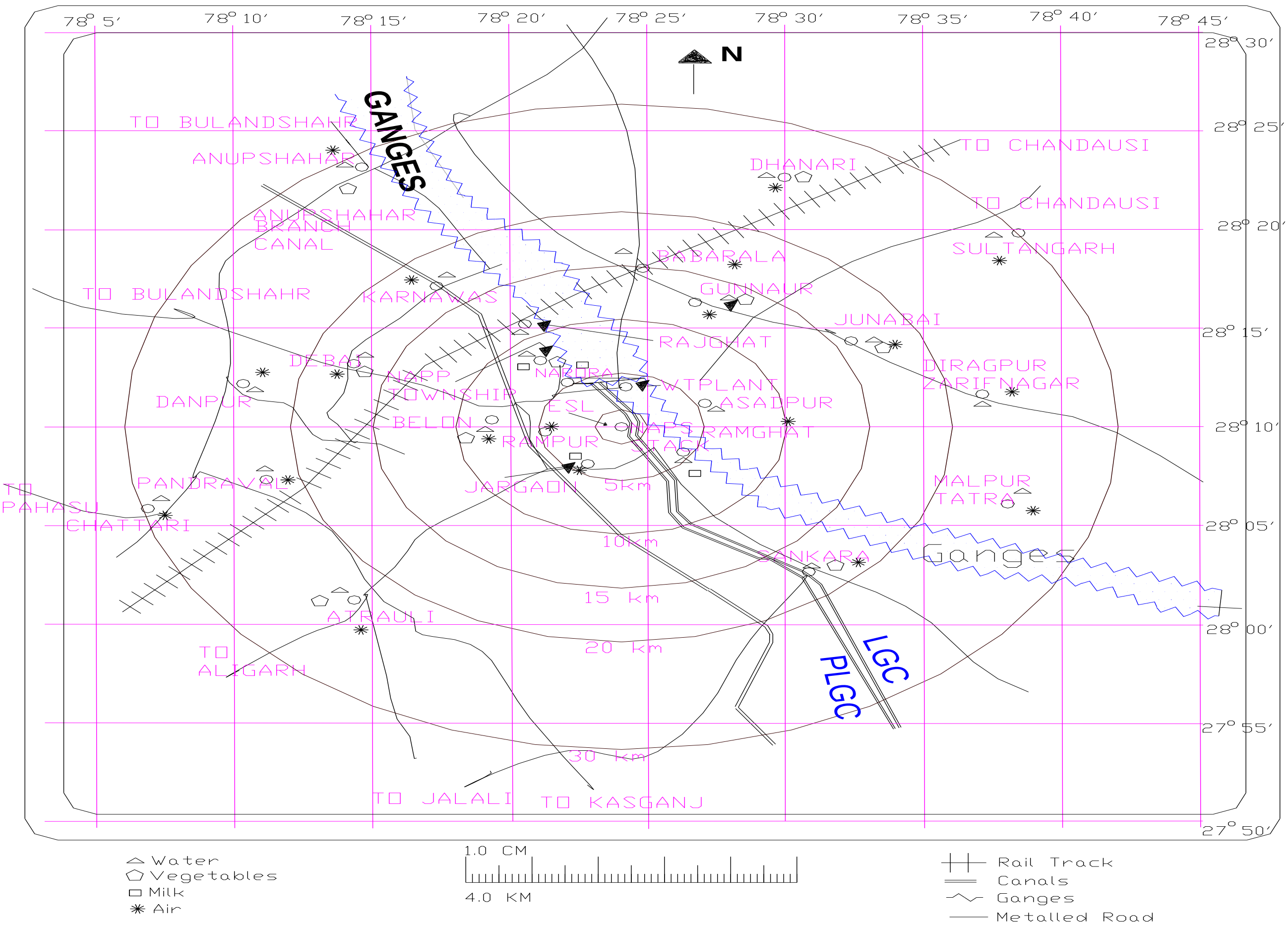


Fig.1 Environmental Sampling Locations Around NAPS, Narora

Table 1. Daily consumption of dietary components by adult population of villages in Narora

Type of diet	Average Daily consumption of dietary components in villages			
	Niwari	Ramghat	Rasulpur	Belon
Wheat (g)	158 ± 45	147 ± 43	162 ± 47	156 ± 42
Rice (g)	165 ± 52	178 ± 49	161 ± 48	188 ± 62
Cereals/Millet (g)	128 ± 55	187± 61	130 ± 47	158 ± 55
Milk (ml)	86 ± 28	108 ± 36	76 ± 23	121 ± 39
Fruit (g)	28 ± 13	18 ± 8.7	16 ± 6.8	23 ± 7.9
Leafy Vegetables (g)	29 ± 15	38 ± 18	31 ± 21	39 ± 20
Non-leafy Vegetable (g)	88 ± 27	106 ± 32	77 ± 22	116 ± 29
Root Vegetable (g)	29 ± 12	18 ± 11	26 ± 12	31 ± 12
Meat(g)	13 ± 05	09 ± 3.5	16 ± 06	11 ± 4.2

Fish (g)	09 ± 3.5	17 ± 06	12 ± 4.2	11 ± 05

Table 2. Average annual consumption of dietary components by adult population in Narora

Type of diet	Average Annual consumption of dietary components in villages			
	Niwari	Ramghat	Rasulpur	Belon
Wheat (Kg)	57. 7± 16.4	53.6± 15.7	59.1 ± 17.2	56.9 ± 15.3
Rice (Kg)	60.2± 18.9	64.9± 17.8	58.8± 17.5	68.6 ± 22.6
Cereals/Millet (Kg)	46.7± 20.1	68.3± 22.3	47.5± 17.2	57.7± 20.1
Milk (l)	31.4+/-10.2	39.4+/-13.1	27.7+/-8.4	44.2+/-14.2
Fruit (Kg)	10.2 ± 4.7	6.6 ± 3.2	5.8 ± 2.5	8.4 ± 2.8
Leafy Vegetables (Kg)	10.6 ± 5.5	13.9 ± 6.6	11.3 ± 7.7	14.2 ± 7.3
Non-leafy Vegetable (Kg)	32.1 ± 9.8	38.7 ± 11.68	28.1 ± 8.0	42.3 ± 10.6
Root Vegetable (Kg)	10.6 ± 4.4	6.6 ± 4.0	9.5 ± 4.4	11.3 ± 4.4
Meat(Kg)	4.7 ± 1.8	3.3 ± 1.3	5.8 ± 2.2	4.0 ± 1.5
Fish (Kg)	3.3 ± 1.3	6.2 ± 2.2	4.4 ± 1.5	4.0 ± 1.8

Table 3 ^{40}K activity in dietary components of Narora population during the period 2009–13.

Year	^{40}K (Bq/Kg or Bq/l) activity in dietary components									
	2009		2010		2011		2012		2013	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Wheat	115.2 – 141.8	126.9	105.7- 129.6	114.2	98.3 – 139.2	116.5	128.6-146.8	132.8	109.9 – 139.8	122.7
Rice	15.8 - 32.9	24.8	21.7 – 41.8	29.6	19.8 – 38.5	31.2	21.8 – 41.8	33.8	31.7 – 42.8	33.8
Cereals	158.2 – 206.8	183.9	185.2 -198.6	194.3	148.3 – 216.8	177.2	128.8 -168.9	139.6	139.8-201.8	189.3
Leafy Vegetable	92.8 – 115.7	102.6	112.8 -135.2	123.6	86.3 – 118.4	99.6	109.5 – 124.2	112.4	102.8 – 116.8	107.2
Non Leafy vegetables	56.3 – 101.8	81.8	48.9 – 94.2	64.5	38.7 – 71.2	56.2	47.2 – 72.9	63.4	58.3 – 74.2	67.8
Root Vegetables	78.9 – 102.6	91.2	69.8 -115.6	84.3	81.8 – 109.6	89.9	76.3 – 102.9	97.5	59.6 – 119.8	87.3
Milk	15.7 – 28.6	22.8	18.6 – 31.2	26.2	20.8 – 41.8	27.9	17.9 – 31.8	24.7	18.9- 38.5	23.7
Fruit	54.8 – 82.1	68.9	41.8 – 92.8	72.7	58.9 – 91.7	76.2	48.9 -76.2	66.9	46.3 – 77.8	62.8

Meat	68.9 – 88.2	73.2	59.8 – 96.2	77.8	48.3 -103.8	62.9	54.8 -112.3	69.8	56.7 -108.2	71.6
Fish	58.3 – 102.8	81.8	80.9 – 194.2	94.5	38.7 – 71.2	56.8	47.2 – 78.9	64.4	68.3 – 101.2	77.8

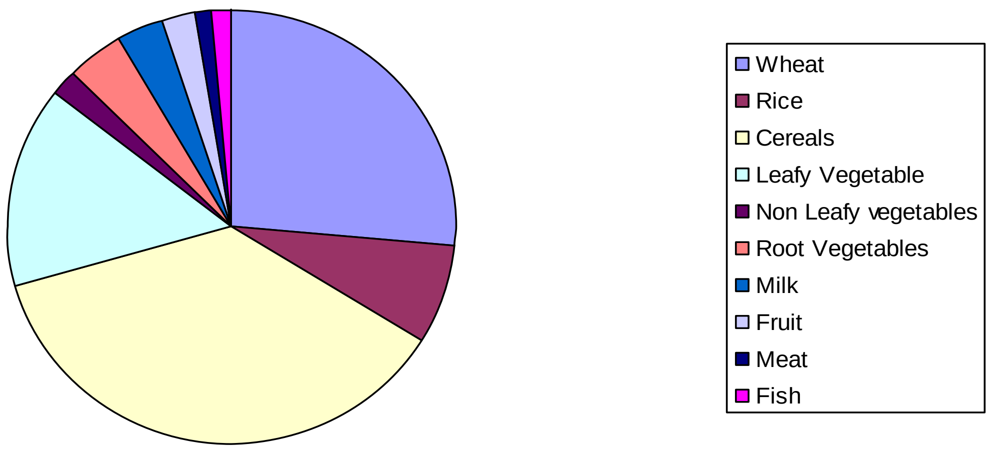
CONCLUSION

^{40}K activity in dietary components from the Narora environment varies in theorderCereals>Wheat>leafy>vegetables>RootVegetable>Fish>Fruit>Non-Leafyvegetable>Milk>Rice. The major dietary components of adult population around the Narora site are wheat > rice, fish, non-leafy vegetables, leafy vegetables, milk and meat. The consumption of wheat and cereals are the major contributor of ^{40}K ingestion dose for members of the public around the Narora site. The annual effective dose to an adult member of the public around the Narora site due to the ingestion of ^{40}K through dietary components varies from 149 µSv (14.9 mrem) to178 µSv (17.8 mrem) with an average of 163.5 µSv (16.3 mrem). In comparison with this value, the dose received by members of the public due to the operation of nuclear power stations at the Narora site is insignificant.

Table 4. Annual ingestion dose (µSv per year) due to ^{40}K activity in dietary components of Narora population.

Dietary Components	Niwari	Ramghat	Rasulpur	Belon	Average
Wheat	4.39E+01	4.07E+01	4.49E+01	4.33E+01	4.32E+01
Rice	1.14E+01	1.23E+01	1.12E+01	1.30E+01	1.20E+01
Cereals	5.12E+01	7.49E+01	5.21E+01	6.33E+01	6.04E+01
Leafy Vegetable	2.12E+01	2.66E+01	1.87E+01	2.99E+01	2.41E+01
Non Leafy vegetable	4.22E+00	2.73E+00	2.40E+00	3.48E+00	3.21E+00
Root Vegetables	5.92E+00	7.76E+00	6.31E+00	7.93E+00	6.98E+00
Milk	4.99E+00	6.01E+00	4.37E+00	6.57E+00	5.48E+00
Fruit	4.57E+00	2.84E+00	4.09E+00	4.87E+00	4.09E+00
Meat	2.07E+00	1.45E+00	2.56E+00	1.76E+00	1.96E+00
Fish	1.54E+00	2.89E+00	2.05E+00	1.86E+00	2.08E+00
Total (µSv per year)	**1.51E+02**	**1.78E+02**	**1.49E+02**	**1.76E+02**	**1.63E+02**

Figure:2 Contribution of various dietary items in total ingestion dose due to K-40



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