ISSN: 2633-4828 Vol. 5 No.4, December, 2023

International Journal of Applied Engineering & Technology

HEALTH IMPLICATIONS OF URANIUM CONTAMINATION IN DRINKING WATER

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ABSTRACT

This study aimed to assess the presence of uranium and its associated toxicity in the drinking water of Fazilka district, Punjab, India. Water samples were collected from 30 villages during the monsoon season. The concentration of uranium was analyzed using LED Flourimeter at the Radiation Physics Laboratory of the National Institute of Technology, Jalandhar. The results revealed a wide range of uranium concentration, spanning from 2.33µg/l to 217.23µg/l. In certain areas, these levels exceeded the WHO-recommended drinking water guideline value of30 µg/l. The potential health impacts of uranium exposure through drinking water are concerningdue to both its radiological and chemical toxicities. Uranium intake has been linked to severe illnesses such as stomach cancer, kidney disease, bone deformities, and liver ailments. The absorption of uranium from the gastrointestinal tract is crucial, influenced by factors like the solubility of the ingested uranium compound, food intake, and concurrent use of oxidizingagents. Once in the bloodstream, the uranyl ion forms complexes with bicarbonate, citrate anions, and proteins, dispersing into body tissues. Uranium may subsequently be reabsorbedfrom various organs like soft tissues, liver, skeleton, and kidneys, and either re-deposited or excreted through urine, feces, and hair. The study estimated an average daily ingestion rate of

104.86 µg over a 60-year exposure period, considering uranium retention in different body organs. Furthermore, the research explored into the timely assessment of uranium excretion through urine, faeces, and hair, employing the ICRP bio-kinetic model for evaluation.

Keywords: Ingestion, Uranium, Water, Exposure, Toxicity

1. INTRODUCTION

Uranium, often perceived as a rare element, is, in fact, a plentiful metal that occurs more frequently in nature than other trace elements like cadmium, selenium, and other less common elements.[1]. Uranium is found in notable amounts in water sources, including seawater, with reported concentrations approximately around 3.0µg/l [2]. The concentration of uranium ingroundwater is depend upon the lithological, geo morphological, and other geological conditions of the region. [3]. The geological characteristics of the area in concerned and various environmental factors can influence the concentration of uranium in groundwater. Groundwater and drinking water typically contain low levels of uranium. Uranium can enter the human and animal bodies through three main pathways: ingestion, skin contact, and inhalation. The oral route accounts for the majority, with approximately 15% of the uranium present in the human body originating from food consumption, while the remaining 85% is derived from the intake of drinking water [4]. High concentrations of uranium exposure pose a risk of kidney failure [5-6]. In several states of India, over 90% of the population relies on groundwater for drinking and other purposes. [7-8]. The current study aims to assess the uranium levels in groundwater sources within the Fazilka region of Punjab, India.

2. GEOLOGY OF THE STUDY AREA AND SAMPLING LOCATIONS

The State of Punjab spans from approximately 28° 17' to 32° 17' North latitudes and 74° 04' to 77° 06' East longitudes, situated in the northwest region of India. Fazilka district, the focus of this study, covers a total geographical area of 3113 sq. km, positioned between approximately 30° 24' N latitude and 74° 02' E longitude. The district comprises primarily two types of soils: chestnut brown (Alluvial) covering 69% and desert soil covering 31% (DC-Fazilka). [9].

The Fazilka District is situated within the Punjab plain, characterized by vast, flat expanses largely formed by Pleistocene and Sub-recent alluvial deposits of the Indo-Gangetic system. The district's landscape has been influenced by wind activity, particularly due to its proximity to the Rajasthan Desert, resulting in the presence of sand dunes in certain areas. The district's total area is divided into 30 sample locations, selected based on the availability of water sources at each site and the consumption patterns of the residents. This sampling grid formation is shown in Fig1

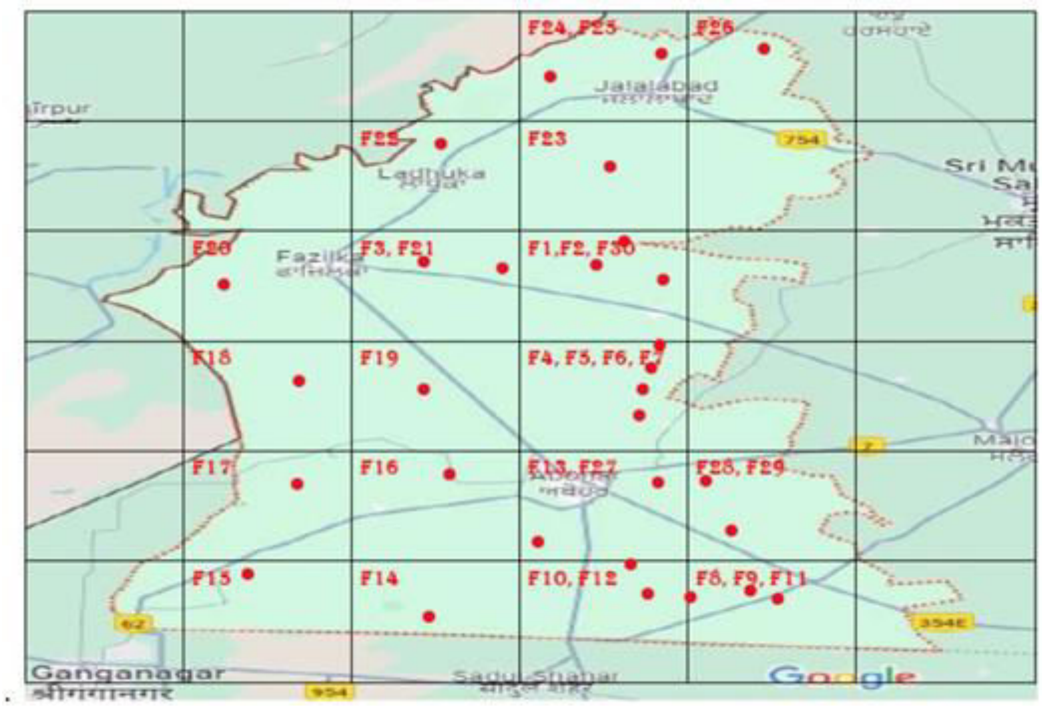


Figure 1: Grid map showing sampling sites in Fazilka district.

Table 1 presents the location data for the 30 sample sites. This information includes the latitude and longitude coordinates obtained from the Global Positioning System (GPS). Groundwater borehole samples were gathered from 30 villages across the Fazilka district, covering the entire district in a grid pattern. The sample locations were coded as sample numbers F1 to F30, marked at various positions on the grid map.

Table 1: Location data of sample sites

S.No	SampleNo.	SamplingLocations	Longitude	Latitude
1	F1	JandwalaBhimeshah	74.2752	30.3987
2	F2	Ghattianwali	74.2114	30.415
3	F3	Tahliwala Bodla	74.1572	30.3807
4	F4	Arniwala	74.2572	30.3467
5	F5	Dhabwali Kalan	74.2473	30.3179
6	F6	Burj Hanumangarh	74.2424	30.3
7	F7	Muradwala DalSingh	74.2562	30.2671
8	F8	Sito Gunno	74.36	30.0286
9	F9	Dutarwali	74.2931	30.08
10	F10	Raja wali	74.2628	30.0705
11	F11	Sukhchain	74.3457	30.0396

12	F12	KalaTibba	74.2529	30.102
13	F13	Chanan Khera	74.3037	30.1722
14	F14	Waryamkhera	70.0833	30.0252
15	F15	Kallar Khera	73.9527	30.04
16	F16	Siyad wala	74.1004	30.1256
17	F17	Diwan Khera	74.0057	30.0906
18	F18	Shatirwala	74.0028	30.2698
19	F19	Nihal Khera	74.1382	30.2349
20	F20	Karnikhera	73.9824	30.3732
21	F21	Choharianwali	74.0883	30.3928
22	F22	Ghubhaya	74.1415	30.5621
23	F23	Chak Romwali	75.743	31.2461
24	F24	Mida	74.2305	30.6531
25	F25	Khere Ke Uttar	74.2795	30.6776
26	F26	Guru Har sehai	75.8749	30.9386
27	F27	Kikkar Khera	74.1721	30.0809
28	F28	Chanan Khera	74.3049	30.1875
29	F29	Dhani Sucha Singh	74.2502	30.1322
30	F30	Pind chiragdhani	74.2418	30.4055

3 Sampling Procedures and Methodology

SAMPLES COLLECTION

The sample locations cover both urban and rural areas. Groundwater samples (sourced from bore wells) were collected in one-liter polyethylene bottles from 30 locations across the Fazilka district during the monsoon season. Prior to use, the bottles were pre-processed with 5% Nitric acid and washed with doubly de-ionized water (DDW). The quantity of samples collected from each village varied based on the availability of water extraction sources. To ensure uniformity in temperature, conductivity, and pH, the water was allowed to run from the sources for approximately 10-15 minutes before collection. Temperature and total dissolved solids (TDS) at each sampling point were measured in the field using an HM digital TDS meter instrument.

An HM digital TDS meter is calibrated to measure in parts per million (ppm), with TDS representing the concentration of a solution as the total weight of dissolved solids (1 ppm = 1 milligram/liter). To prevent the entry of atmospheric carbon dioxide, the collected samples were tightly capped. Subsequently, all samples were transported to the Radiation Physics Laboratory of NIT Jalandhar, India, and analyzed within 6-12 hours of collection. Prior to uranium examination, the water samples were filtered using filter paper with a pore size of 0.45 microns (specifically Whatman nitrocellulose membrane filters, pore size 0.45 um). The uranium level in water was assessed using an LED Fluorimeter instrument.

INSTRUMENTATION

The Quantanase LED Fluorimeter/Uranium Analyzer is designed for the detection and measurement of trace amounts of uranium. It operates based on the principle of fluorescence measurement of uranium complexes. When uranium complexes are excited with UV light of an appropriate wavelength, they emit green fluorescence, which is then detected by a sensitive photomultiplier tube. By measuring fluorescence, the instrument provides information about the concentration of uranium in the samples. The LED Fluorimeter is capable of measuring uranium concentrations ranging from 0.5 parts per billion (ppb) to 1000 ppb, with a detection limit as low as 0.5 ppb, equivalent to five parts in ten billion

URANIUM BIO-KINETIC MODEL

Uranium is primarily bound in complex forms with carbonates, proteins, and red blood cells in the blood [11]. The ICRP's bio-kinetic model of uranium is utilized to simulate the distribution of uranium within various organs of the human body [10, 12] This model delineates several key processes: (1) the movement of uranium from blood to different compartments, (2) the transfer of uranium between organs, (3) the re-retention of uranium from various organs back into the blood, and (4) the excretion of uranium through urine and feces. Each day, transfer rates govern the partial exchange of uranium between compartments, facilitating its movement throughout the body. To account for these dynamics, the ICRP's bio-kinetic model is segmented into various compartments, with Table 2 detailing the transfer rates for each compartment

Table 2 The transfer rates between various compartments used for adults in the ICRP model [10]

Path	Transfer rate(d^{-1})
From plasma to Soft tissue, extracellular Fluid (ST0)	1.05*10
RBC	2.45* 10^{-1}
Urinary bladder	1.54 * 10
Kidneys (urinary path)	2.94
Kidneys (other kidney tissues)	1.22*10^{-2}
Upper large intestine	1.22* 10^{-1}
Liver 1	3.67*10^{-1}
Soft tissue, intermediate turnover	1.63
Soft tissue, slow turnover	7.35*10^{-2}
Skeleton, trabecular surfaces	2.04
Skeleton, cortical surfaces	1.63
To plasma	8.32
From Soft tissue, extracellular Fluid (ST0)	
RBC	3.47 *10^{-1}
Kidneys (other kidney tissues)	3.80 * 10^{-4}
Liver 1	9.20 * 10^{-2}
Liver 2	1.90 * 10^{-4}
Soft tissue, intermediate turnover (ST1)	3.47* 10^{-2}
Soft tissue, slow turnover (ST2)	1.90* 10^{-5}
Bone surfaces	6.93 * 10^{-2}
Non-exchangeable trabecular bone volume	4.93*10^{-4}
Non-exchangeable cortical bone volume	8.21 *10^{-5}
Other paths	
Urinary path to urinary bladder	9.90 * 10^{-2}
Liver 1 to liver 2	6.93* 10^{-3}
Bone surfaces to exchangeable bone volume	6.93* 10^{-2}
Exchangeable bone volume to bone surfaces	1.73* 10^{-2}
Exchangeable bone volume to non-exchangeable bonevolume	5.78 *10^{-3}

A fraction of the uranium deposited in soft tissues may be released back into the bloodstream, while some may migrate freely to other areas within the soft tissues. Uranium stored in the skeleton eventually redistributes to bone surfaces, whether trabecular or cortical. Over time, it undergoes exchange with bone volume or returns to the bloodstream. Uranium that does not participate in bone volume exchange may remain on the surface or become further embedded in the bone volume (non-exchangeable). The transportation pathways of uranium are aligning in the ICRP's bio-kinetic model, based on Laggett's studies [13, 14]. The radioactivity of uranium can lead to cancer-causing symptoms due to the extremely long half-lives of prevailing uranium isotopes [15].

4. RESULTS AND DISCUSSION

The investigation examined the uranium concentration in drinking water samples from the Fazilka District of Punjab, with the findings outlined in the Table 3. Among the sampled villages, the uranium levels in water from 12 villages fall below the WHO guideline value, ranging from 2.33 to 217.23µg/l. However, in 18 out of the 30 villages studied, the uranium concentration exceeds the WHO guideline value of 30µg/l [16]

Bio-kinetic-data The bio-kinetic model provides insights into the pathways of different radionuclides within the body, enabling the determination of their retention in various organs and tissues. Table 3 presents uranium retention data for various body organs, considering chronic intake, and offers information on the remaining uranium content after 60 years.

GI tract The primary route of exposure to common radio-nuclides in water for individuals is through ingestion. Upon ingestion, uranium enters the bloodstream via the Gastrointestinal (GI) tract, where retention primarily occurs in the small intestine, serving as the primary compartment. According to the ICRP's bio-kinetic model, the average concentration of uranium in the GI tract is estimated to be 13.39 µg with values ranging from 0 to 100.18 µg. Equilibrium is established between various body organs as uranium is transported from the blood. Higher concentrations of uranium in different body organs may lead to greater retention.

Blood. Following ingestion, uranium rapidly enters the bloodstream, with literature indicating that a significant portion of uranium is associated with red blood cells [11]. The average concentration of uranium in blood plasma is reported to be 0.0047µg. Within about one day, uranium binds to red blood cells (RBCs) from the plasma and then returns to the plasma once more [13].

Skeleton. Uranyl in bones behaves similarly to calcium ions, exchanging with them at bone surfaces without participating in crystal formation or deep diffusion into bone mineral crystals. The average uranium concentration on cortical bone surfaces is 0.0248 µg and on trabecular bone surfaces is 0.0311 µg. In contrast, the uranium concentration in non- exchangeable cortical bone volume is 0.0012 µg and in trabecular bone volume is 0.0016 µg. Uranium elimination from non-exchangeable bone volume is expected to be exceptionally low in the ICRP's bio-kinetic model. Furthermore, it's evident that the uranium concentration in non- exchangeable cortical and trabecular bone volume is much higher compared to bone surfaces.

Liver. The liver compartment in the bio-kinetic model is divided into two sections: liver 1 and liver 2. Uranium is transferred from plasma to liver 1 and then subsequently to liver 2. The average uranium concentration in the liver compartment is 22.009µSv, with a range of minimumand maximum values between 0.685 and 63.8284µ

Kidney. The kidney compartment is further subdivided into two sections, kidney 1 and kidney 2, based on retention time. Uranium filtered by the glomerulus accumulates in kidney 1,and the separated substance proceeds to the urinary bladder and urine. Uranium from kidney 2 returns to the kidneys and is reintroduced into the bloodstream rather than being excreted in urine. The elimination half-time of other kidney tissues is approximately 45 years, resulting in ahigh concentration of uranium in the kidneys. On average, the retention of uranium in the kidneys is 58.3719 µSv.

Kidney retention and concentration The average retention and concentration of uraniumin the kidney are 0.0190 µg and 0.0001 µg, respectively.

Urinary bladder Following filtration in the kidney, uranium from the first kidney enters the urinary bladder. Moreover, uranium may directly enter the urinary bladder from the plasma. The average retention value of uranium in the urinary bladder is 0.0013µg.

Table 3: Bio-kinetic data for ingested uranium via the drinking water pathway

Sample Code	U conc.	U activity	Skeleton				Kidney		Kidneys	Blood	Liver(Lver1+Liver2)	GI tract from calculator				Urinary bladder	Excretion		
			Cortical bone surface	Cortical bone volume	Trabecular bone surface	Trabecular bone volume	Kidney retention	Kidney concentration				St Wall	SI wall	ULI wall	LLI wall		Faeces excretion	Urine excretion	Hair excretion
	ppb or ug/L	Bq L^{-1}	µg	µg	µg	µg	µg	µg	µSv	µg	µSv	µg	µg	µg	µg	µg	µg	µg	µg
Jandwala Bhimeshah	40.0870	1.0022	0.0133	0.0007	0.0166	0.0008	0.0102	0.0000	31.2388	0.0025	11.7786	0.0000	0.1320	10.0520	18.4878	0.0007	18.4878	0.0086	0.0104
Ghattianwali	15.8422	0.3961	0.0053	0.0003	0.0066	0.0003	0.0040	0.0000	12.3454	0.0010	4.6548	0.0000	0.0522	3.9725	7.3063	0.0003	7.3063	0.0034	0.0041
Tahliwala Bodla	4.0686	0.1017	0.0013	0.0001	0.0017	0.0001	0.0010	0.0000	3.1705	0.0003	1.1954	0.0000	0.0134	1.0202	1.8764	0.0001	1.8764	0.0009	0.0011
Arniwala	123.9465	3.0987	0.0411	0.0021	0.0515	0.0026	0.0314	0.0001	96.5884	0.0078	36.4186	0.0000	0.4082	31.0801	57.1632	0.0022	57.1632	0.0267	0.0320
Dhabwali Kalan	14.2189	0.3555	0.0047	0.0002	0.0059	0.0003	0.0036	0.0000	11.0804	0.0009	4.1779	0.0000	0.0468	3.5654	6.5576	0.0003	6.5576	0.0031	0.0037
Burj Hanumangarh	77.6200	1.9405	0.0257	0.0013	0.0322	0.0016	0.0197	0.0001	60.4873	0.0049	22.8067	0.0000	0.2556	19.4636	35.7977	0.0014	35.7977	0.0167	0.0201
Muradwala Dal Singh	21.8708	0.5468	0.0073	0.0004	0.0091	0.0005	0.0055	0.0000	17.0433	0.0014	6.4262	0.0000	0.0720	5.4842	10.0866	0.0004	10.0866	0.0047	0.0057
Sito Gunno	74.9101	1.8728	0.0248	0.0013	0.0311	0.0016	0.0190	0.0001	58.3756	0.0047	22.0105	0.0000	0.2467	18.7840	34.5480	0.0013	34.5480	0.0162	0.0194
Dutarwali	162.0856	4.0521	0.0538	0.0027	0.0673	0.0034	0.0411	0.0001	126.3093	0.0101	47.6248	0.0000	0.5338	40.6437	74.7526	0.0029	74.7526	0.0350	0.0419
Raja wali	177.1094	4.4277	0.0587	0.0030	0.0735	0.0037	0.0449	0.0001	138.0169	0.0111	52.0392	0.0000	0.5833	44.4109	81.6815	0.0032	81.6815	0.0382	0.0458
Sukhchain	55.2714	1.3818	0.0183	0.0009	0.0229	0.0012	0.0140	0.0000	43.0716	0.0035	16.2401	0.0000	0.1820	13.8595	25.4907	0.0010	25.4907	0.0119	0.0143
KalaTibba	54.5083	1.3627	0.0181	0.0009	0.0226	0.0011	0.0138	0.0000	42.4770	0.0034	16.0159	0.0000	0.1795	13.6682	25.1388	0.0010	25.1388	0.0118	0.0141
Chanan Khera	31.4260	0.7857	0.0104	0.0005	0.0130	0.0007	0.0080	0.0000	24.4895	0.0020	9.2337	0.0000	0.1035	7.8802	14.4934	0.0006	14.4934	0.0068	0.0081
Waryam khera	2.3344	0.0584	0.0008	0.0000	0.0010	0.0000	0.0006	0.0000	1.8191	0.0001	0.6859	0.0000	0.0077	0.5854	1.0766	0.0000	1.0766	0.0305	0.0006
Kallar Khera	19.6950	0.4924	0.0065	0.0003	0.0082	0.0004	0.0050	0.0000	15.3478	0.0012	5.7869	0.0000	0.0649	4.9386	9.0832	0.0004	9.0832	0.0042	0.0051
Siyad wala	24.3236	0.6081	0.0081	0.0004	0.0101	0.0005	0.0062	0.0000	18.9548	0.0015	7.1469	0.0000	0.0801	6.0992	11.2179	0.0004	11.2179	0.0052	0.0063
Diwan Khera	26.0733	0.6518	0.0086	0.0004	0.0108	0.0005	0.0066	0.0000	20.3183	0.0016	7.6610	0.0000	0.0859	6.5380	12.0248	0.0005	12.0248	0.0056	0.0067
Shatirwala	40.2230	1.0056	0.0133	0.0007	0.0167	0.0008	0.0102	0.0000	31.3448	0.0025	11.8185	0.0000	0.1325	10.0861	18.5505	0.0007	18.5505	0.0087	0.0104
Nihal Khera	25.2538	0.6313	0.0084	0.0004	0.0105	0.0005	0.0064	0.0000	19.6797	0.0016	7.4202	0.0000	0.0832	6.3325	11.6469	0.0005	11.6469	0.0054	0.0065
Karnikhera	125.0443	3.1261	0.0415	0.0021	0.0519	0.0026	0.0317	0.0001	97.4439	0.0078	36.7411	0.0000	0.4118	31.3554	57.6695	0.0022	57.6695	0.0270	0.0323
Chohorianwali	27.5848	0.6896	0.0092	0.0005	0.0115	0.0006	0.0070	0.0000	21.4961	0.0017	8.1051	0.0000	0.0908	6.9170	12.7219	0.0005	12.7219	0.0059	0.0071
Ghubhaya	177.2651	4.4316	0.0588	0.0030	0.0736	0.0037	0.0450	0.0001	138.1383	0.0111	52.0849	0.0000	0.5838	44.4500	81.7533	0.0032	81.7533	0.0382	0.0458
Chak Romwali	159.3476	3.9837	0.0529	0.0027	0.0661	0.0033	0.0404	0.0001	124.1756	0.0100	46.8203	0.0000	0.5248	39.9571	73.4899	0.0029	73.4899	0.0344	0.0412
Mida	135.4103	3.3853	0.0449	0.0023	0.0562	0.0028	0.0343	0.0001	105.5219	0.0085	39.7869	0.0000	0.4459	33.9547	62.4502	0.0024	62.4502	0.0292	0.0350
Khere Ke Uttar	141.7570	3.5439	0.0470	0.0024	0.0588	0.0030	0.0360	0.0001	110.4677	0.0089	41.6518	0.0000	0.4668	35.5462	65.3772	0.0025	65.3772	0.0306	0.0366
Guru Har sehai	217.2326	5.4308	0.0721	0.0036	0.0902	0.0045	0.0551	0.0002	169.2839	0.0136	63.8284	0.0000	0.7154	54.4720	100.1860	0.0039	100.1860	0.0468	0.0561
Kikkar Khera	2.8910	0.0723	0.0010	0.0000	0.0012	0.0001	0.0007	0.0000	2.2529	0.0002	0.8494	0.0000	0.0095	0.7249	1.3333	0.0001	1.3333	0.0006	0.0007
Chanan Khera	19.3000	0.4825	0.0064	0.0003	0.0080	0.0004	0.0049	0.0000	15.0400	0.0012	5.6708	0.0000	0.0636	4.8396	8.9010	0.0003	8.9010	0.0042	0.0050
Dhani Sucha Singh	191.3885	4.7847	0.0635	0.0032	0.0794	0.0040	0.0485	0.0002	149.1443	0.0120	56.2347	0.0000	0.6303	47.9915	88.2669	0.0034	88.2669	0.0413	0.0495
Pind chirag dhani	59.0736	1.4768	0.0196	0.0010	0.0245	0.0012	0.0150	0.0000	46.0346	0.0037	17.3573	0.0000	0.1945	14.8130	27.2443	0.0011	27.2443	0.0127	0.0153

Doses to organs

Uranium, like other heavy metals, can adversely affect the human body, especially the kidneys. Its long biological half-life makes even small doses harmful. While natural uranium has low specific radioactivity, its radiological effects may surpass its chemical toxicity, particularly wheninsoluble uranium compounds are inhaled and remain in the body for extended periods. Dose conversion factors, as determined by the International Commission on Radiological Protection (ICRP) [10, 12], quantify the doses resulting from a single uptake of uranium. These factors are not influenced by the distribution of uranium within organs (Table 4 and 5).

Bone Surfaces. Endo-steal refers to the radiosensitive cells found within the bone and the epithelial cells lining the bone surfaces, situated within distances of approximately 10 mm. Radiological effects on bones are generally less pronounced compared to other organs, as the primary impact of radiation on these cells is malignancy. The dose received by cells deep within the bone surface is notably higher compared to any other organ or tissue, varying between 5.069µSv and 471.77µSv, with an average value of 162.67µS

Table 4: Ingested uranium via drinking water doses to various organs and tissues of a human adult

Sample Code	Adrenals	Bladder Wall	Bone Surfaces	Brain	Breasts	GI tract				Kidneys	Liver(LIver1+Liver2)	Lungs
						Stomach wall(St Wall)	Small Intestine wall (SI wall)	Upper Large Intestine wall (ULI wall)	Lower Large Intestine (LLI wall)			
	µSv	µSv	µSv	µSv	µSv	µg	µg	µg	µg	µSv	µSv	µSv
Jandwala Bhimeshah	3.0215	3.0215	87.0589	3.0215	3.0215	0.0000	0.1320	10.0520	18.4878	31.2388	11.7786	3.0215
Ghattianwali	1.1941	1.1941	34.4052	1.1941	1.1941	0.0000	0.0522	3.9725	7.3063	12.3454	4.6548	1.1941
Tahliwala Bodla	0.3067	0.3067	8.8359	0.3067	0.3067	0.0000	0.0134	1.0202	1.8764	3.1705	1.1954	0.3067
Arniwala	9.3422	9.3422	269.1808	9.3422	9.3422	0.0000	0.4082	31.0801	57.1632	96.5884	36.4186	9.3422
Dhabwali Kalan	1.0717	1.0717	30.8798	1.0717	1.0717	0.0000	0.0468	3.5654	6.5576	11.0804	4.1779	1.0717
Burj Hanumangarh	5.8504	5.8504	168.5712	5.8504	5.8504	0.0000	0.2556	19.4636	35.7977	60.4873	22.8067	5.8504
Muradwala Dal Singh	1.6485	1.6485	47.4978	1.6485	1.6485	0.0000	0.0720	5.4842	10.0866	17.0433	6.4262	1.6485
Sito Gunno	5.6462	5.6462	162.6860	5.6462	5.6462	0.0000	0.2467	18.7840	34.5480	58.3756	22.0105	5.6462
Dutarwali	12.2168	12.2168	352.0094	12.2168	12.2168	0.0000	0.5338	40.6437	74.7526	126.3093	47.6248	12.2168
Raja wali	13.3492	13.3492	384.6373	13.3492	13.3492	0.0000	0.5833	44.4109	81.6815	138.0169	52.0392	13.3492
Sukhchain	4.1659	4.1659	120.0357	4.1659	4.1659	0.0000	0.1820	13.8595	25.4907	43.0716	16.2401	4.1659
KalaTibba	4.1084	4.1084	118.3785	4.1084	4.1084	0.0000	0.1795	13.6682	25.1388	42.4770	16.0159	4.1084
Chanan Khera	2.3687	2.3687	68.2494	2.3687	2.3687	0.0000	0.1035	7.8802	14.4934	24.4895	9.2337	2.3687
Waryam khera	0.1760	0.1760	5.0698	0.1760	0.1760	0.0000	0.0077	0.5854	1.0766	1.8191	0.6859	0.1760
Kallar Khera	1.4845	1.4845	42.7727	1.4845	1.4845	0.0000	0.0649	4.9386	9.0832	15.3478	5.7869	1.4845
Siyad wala	1.8333	1.8333	52.8248	1.8333	1.8333	0.0000	0.0801	6.0992	11.2179	18.9548	7.1469	1.8333
Diwan Khera	1.9652	1.9652	56.6247	1.9652	1.9652	0.0000	0.0859	6.5380	12.0248	20.3183	7.6610	1.9652
Shatirwala	3.0317	3.0317	87.3543	3.0317	3.0317	0.0000	0.1325	10.0861	18.5505	31.3448	11.8185	3.0317
Nihal Khera	1.9034	1.9034	54.8450	1.9034	1.9034	0.0000	0.0832	6.3325	11.6469	19.6797	7.4202	1.9034
Karnikhera	9.4249	9.4249	271.5650	9.4249	9.4249	0.0000	0.4118	31.3554	57.6695	97.4439	36.7411	9.4249
Choharianwali	2.0791	2.0791	59.9072	2.0791	2.0791	0.0000	0.0908	6.9170	12.7219	21.4961	8.1051	2.0791
Ghubhaya	13.3609	13.3609	384.9755	13.3609	13.3609	0.0000	0.5838	44.4500	81.7533	138.1383	52.0849	13.3609
Chak Romwali	12.0104	12.0104	346.0632	12.0104	12.0104	0.0000	0.5248	39.9571	73.4899	124.1756	46.8203	12.0104
Mida	10.2062	10.2062	294.0773	10.2062	10.2062	0.0000	0.4459	33.9547	62.4502	105.5219	39.7869	10.2062
Khere Ke Uttar	10.6846	10.6846	307.8608	10.6846	10.6846	0.0000	0.4668	35.5462	65.3772	110.4677	41.6518	10.6846
Guru Har sehai	16.3734	16.3734	471.7749	16.3734	16.3734	0.0000	0.7154	54.4720	100.1860	169.2839	63.8284	16.3734
Kikkar Khera	0.2179	0.2179	6.2785	0.2179	0.2179	0.0000	0.0095	0.7249	1.3333	2.2529	0.8494	0.2179
Chanan Khera	1.4547	1.4547	41.9149	1.4547	1.4547	0.0000	0.0636	4.8396	8.9010	15.0400	5.6708	1.4547
Dhani Sucha Singh	14.4254	14.4254	415.6480	14.4254	14.4254	0.0000	0.6303	47.9915	88.2669	149.1443	56.2347	14.4254
Pind chirag dhani	4.4525	4.4525	128.2931	4.4525	4.4525	0.0000	0.1945	14.8130	27.2443	46.0346	17.3573	4.4525

Table 5: Ingested uranium via drinking water

Sample Code	U conc.	U activity	Muscle	Ovaries	Pancreas	Red Marrow	Skin	Spleen	Testes	Thymus	Thyroid	Uterus	Remainder	Effect do
	ppb or ug/L	Bq L^{-1}	µSv	µSv	µSv	µSv	µSv	µSv	µSv	µSv	µSv	µSv	µSv	µ
Jandwala Bhimeshah	40.0870	1.0022	3.0215	3.0215	3.0215	9.2180	3.0215	3.0215	2.9702	3.0215	3.0215	3.0215	3.3287	6.493
Ghattianwali	15.8422	0.3961	1.1941	1.1941	1.1941	3.6429	1.1941	1.1941	1.1738	1.1941	1.1941	1.1941	1.3155	2.566
Tahliwala Bodla	4.0686	0.1017	0.3067	0.3067	0.3067	0.9356	0.3067	0.3067	0.3015	0.3067	0.3067	0.3067	0.3378	0.659
Arniwala	123.9465	3.0987	9.3422	9.3422	9.3422	28.5015	9.3422	9.3422	9.1838	9.3422	9.3422	9.3422	10.2922	20.07
Dhabwali Kalan	14.2189	0.3555	1.0717	1.0717	1.0717	3.2696	1.0717	1.0717	1.0535	1.0717	1.0717	1.0717	1.1807	2.303
Burj Hanumangarh	77.6200	1.9405	5.8504	5.8504	5.8504	17.8487	5.8504	5.8504	5.7513	5.8504	5.8504	5.8504	6.4454	12.57
Muradwala Dal Singh	21.8708	0.5468	1.6485	1.6485	1.6485	5.0292	1.6485	1.6485	1.6205	1.6485	1.6485	1.6485	1.8161	3.542
Sito Gunno	74.9101	1.8728	5.6462	5.6462	5.6462	17.2256	5.6462	5.6462	5.5505	5.6462	5.6462	5.6462	6.2203	12.13
Dutarwali	162.0856	4.0521	12.2168	12.2168	12.2168	37.2716	12.2168	12.2168	12.0097	12.2168	12.2168	12.2168	13.4592	26.25
Raja wali	177.1094	4.4277	13.3492	13.3492	13.3492	40.7263	13.3492	13.3492	13.1229	13.3492	13.3492	13.3492	14.7067	28.68
Sukhchain	55.2714	1.3818	4.1659	4.1659	4.1659	12.7097	4.1659	4.1659	4.0953	4.1659	4.1659	4.1659	4.5896	8.952
KalaTibba	54.5083	1.3627	4.1084	4.1084	4.1084	12.5342	4.1084	4.1084	4.0388	4.1084	4.1084	4.1084	4.5262	8.829
Chanan Khera	31.4260	0.7857	2.3687	2.3687	2.3687	7.2264	2.3687	2.3687	2.3285	2.3687	2.3687	2.3687	2.6095	5.090
Waryam khera	2.3344	0.0584	0.1760	0.1760	0.1760	0.5368	0.1760	0.1760	0.1730	0.1760	0.1760	0.1760	0.1938	0.378
Kallar Khera	19.6950	0.4924	1.4845	1.4845	1.4845	4.5289	1.4845	1.4845	1.4593	1.4845	1.4845	1.4845	1.6354	3.190
Siyad wala	24.3236	0.6081	1.8333	1.8333	1.8333	5.5932	1.8333	1.8333	1.8023	1.8333	1.8333	1.8333	2.0198	3.939
Diwan Khera	26.0733	0.6518	1.9652	1.9652	1.9652	5.9956	1.9652	1.9652	1.9319	1.9652	1.9652	1.9652	2.1651	4.223
Shatirwala	40.2230	1.0056	3.0317	3.0317	3.0317	9.2493	3.0317	3.0317	2.9803	3.0317	3.0317	3.0317	3.3400	6.515
Nihal Khera	25.2538	0.6313	1.9034	1.9034	1.9034	5.8071	1.9034	1.9034	1.8712	1.9034	1.9034	1.9034	2.0970	4.090
Karnikhera	125.0443	3.1261	9.4249	9.4249	9.4249	28.7539	9.4249	9.4249	9.2652	9.4249	9.4249	9.4249	10.3834	20.25
Chohariannwali	27.5848	0.6896	2.0791	2.0791	2.0791	6.3431	2.0791	2.0791	2.0439	2.0791	2.0791	2.0791	2.2906	4.468
Ghubhaya	177.2651	4.4316	13.3609	13.3609	13.3609	40.7621	13.3609	13.3609	13.1345	13.3609	13.3609	13.3609	14.7197	28.71
Chak Romwali	159.3476	3.9837	12.0104	12.0104	12.0104	36.6420	12.0104	12.0104	11.8069	12.0104	12.0104	12.0104	13.2318	25.81
Mida	135.4103	3.3853	10.2062	10.2062	10.2062	31.1376	10.2062	10.2062	10.0332	10.2062	10.2062	10.2062	11.2441	21.93
Khere Ke Uttar	141.7570	3.5439	10.6846	10.6846	10.6846	32.5970	10.6846	10.6846	10.5035	10.6846	10.6846	10.6846	11.7711	22.96
Guru Har sehai	217.2326	5.4308	16.3734	16.3734	16.3734	49.9526	16.3734	16.3734	16.0958	16.3734	16.3734	16.3734	18.0385	35.18
Kikkar Khera	2.8910	0.0723	0.2179	0.2179	0.2179	0.6648	0.2179	0.2179	0.2142	0.2179	0.2179	0.2179	0.2401	0.4683
Chanan Khera	19.3000	0.4825	1.4547	1.4547	1.4547	4.4380	1.4547	1.4547	1.4300	1.4547	1.4547	1.4547	1.6026	3.1262
Dhani Sucha Singh	191.3885	4.7847	14.4254	14.4254	14.4254	44.0098	14.4254	14.4254	14.1809	14.4254	14.4254	14.4254	15.8924	31.0011
Pind chirag dhani	59.0736	1.4768	4.4525	4.4525	4.4525	13.5840	4.4525	4.4525	4.3771	4.4525	4.4525	4.4525	4.9053	9.5687

Red bone marrow. Due to concerns regarding radiation protection, special consideration should be directed towards the red bone marrow, as its exposure to radiation is strongly linked to the development of leukemia. Red bone marrow receives a higher dose compared to other organs. The average dose value for red bone marrow is 17.2245 µSv.

Thyroid Radiological effects can be notable, especially concerning thyroid exposure, given its high sensitivity to radiation and elevated risk of cancer development due to irradiation. The typical ingested uranium dose for the thyroid ranges between 0.176 and 16.373µSv, with an average value of 5.645µSv.

Breast: The breast is regarded as one of the most radio-sensitive organs in the human body. However, when it comes to exposure to ingested uranium, its sensitivity is nearly on par with that of the thyroid gland. In the investigated region, the typical adult exhibits doses ranging from 0.176µSv (minimum) to 16.3734µSv (maximum), with an average dose of 5.645µSv.

Skin: The primary effect of radiation exposure on the skin is erythema, commonly known as reddening or blushing. In the study region, the average skin dose resulting from exposure to uranium through drinking water for the adult population is measured at 5.645 µSv.

Brain, Lungs, Muscle, Pancreas, Adernals, Thymus, Uterus and Spleen The average exposure dose of uranium acquired by the brain, lungs, muscles, pancreas, adrenals, thymus, uterus, and spleen through drinking water is 5.645µSv for the adult population in the investigated region.

Gonads: There are three distinct types of effects resulting from radiation exposure on gonads. The primary impact on gonads is genetic effects. In the studied region, the gonads of females and males receive an average dose of 5.64 µSv and 5.55 µSv respectively.

Bladder wall. The detrusor muscle fibers form the wall of the human bladder, which acts as a reservoir for collecting urine expelled from the kidneys. In the investigated region, the average dose received by the bladder wall for the adult population is 5.64 µSv.

CONCENTRATION OF URANIUM WITH RESPECT TO TIME IN VARIOUS ORGANS AND TISSUES OF BODY

The concentration of uranium in various organs and tissues of the adult human body in the investigation region is determined using the ICRP's bio-kinetic model. The average concentration of uranium in drinking water samples in the investigation region is 74.9µg/l, resulting in an ingestion of 104.86 µg of uranium per day. The following results are observed when considering an ingestion rate of 104.86 µg of uranium per day over a period of 60 years of exposure.

(1) After approximately 60 years of continuous exposure, the non-exchangeable trabecular bone volume (TBV) reaches a uranium value of 0.000008 µg (Fig. 2). Similarly, the non-exchangeable cortical bone volume (CBV) reaches a uranium value of 0.001611 µg after the same duration of exposure. These results demonstrate the time-dependent saturation of uranium in the kidney and liver.

(2) One of the transient accumulation compartments is the blood plasma, which reaches an equilibrium saturation level of 0.000002 µg after 270 days of exposure.

(3) The majority of uranium intake is deposited on the bone surfaces of the human body. The cortical bone surfaces (CBS) and trabecular bone surfaces (TBS) reach stability after approximately 10 and 15 years of exposure, with values of 0.000002 µg and 0.000001 µg, respectively.

(4) In the gastrointestinal tract, uranium reaches an equilibrium value of approximately 0.000002µg after a 90-day exposure period.

(5) Uranium causes issues in the liver as it does not completely absorb, and the concentration of uranium in the kidneys saturates after 180 days of exposure.

(6) The non-exchangeable cortical bone volume (CBV) and non-exchangeable trabecular bonevolume (TBV) do not reach a stable uranium equilibrium value (Fig. 3)

(7) The amount of uranium excreted into the hair is similar to that in urine in an adult for 5 years

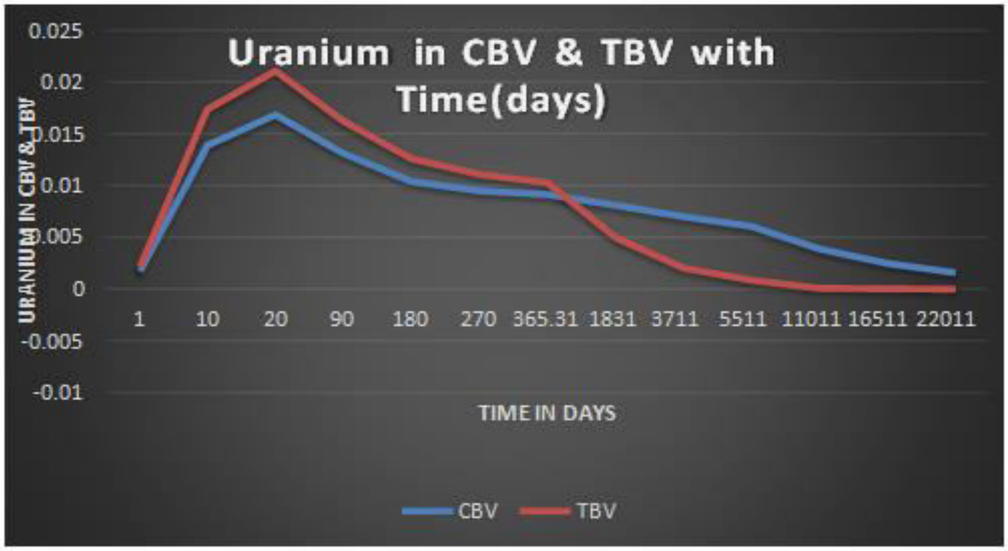
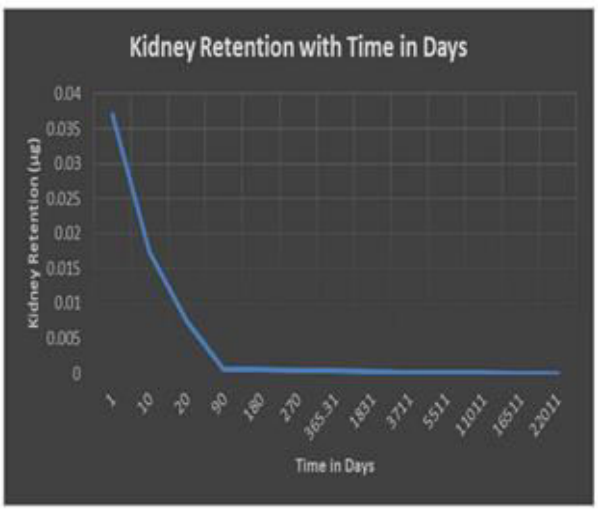


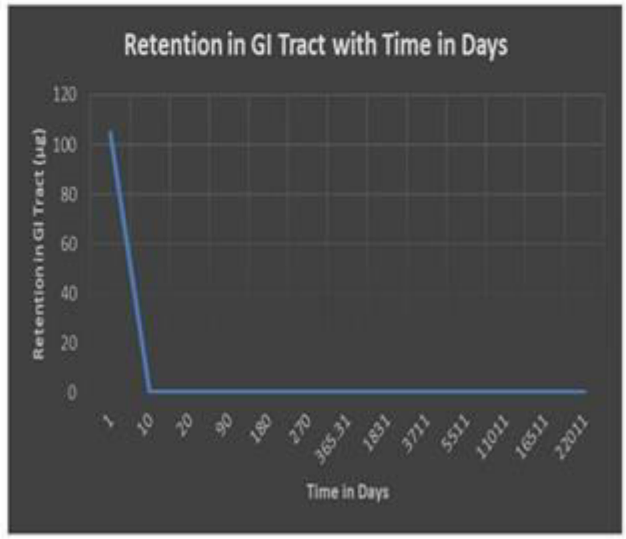
Fig 2: Time –dependent variation of uranium in CBV and TBV

(8) The age-dependent retentions of average uranium per day in kidney, liver, skeleton, GI tract,blood, and whole body are shown in **Fig. 3 a–f**

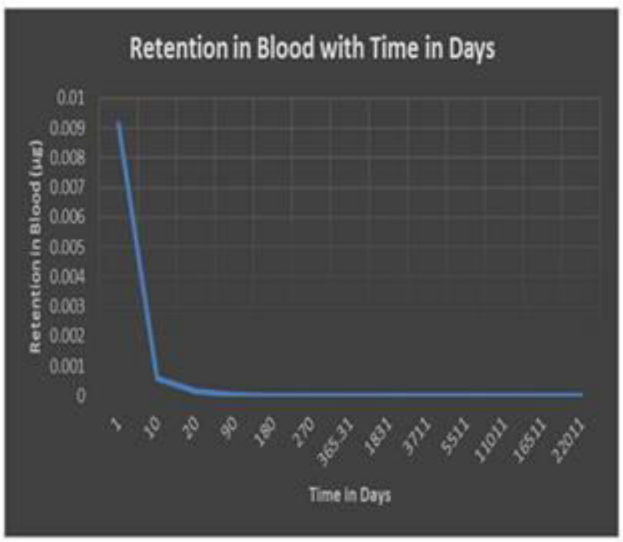


(a)

(B)



(C) **(D)**



(e) **(f)**

Fig. 3 a–f Age-dependent retentions of average uranium

(9) Retentions in main organs i.e Kidney, Liver and Skeleton for a period of 45 and 60 years afrom ingestion of a normal diet for an adult person is shown in **Fig. 4**

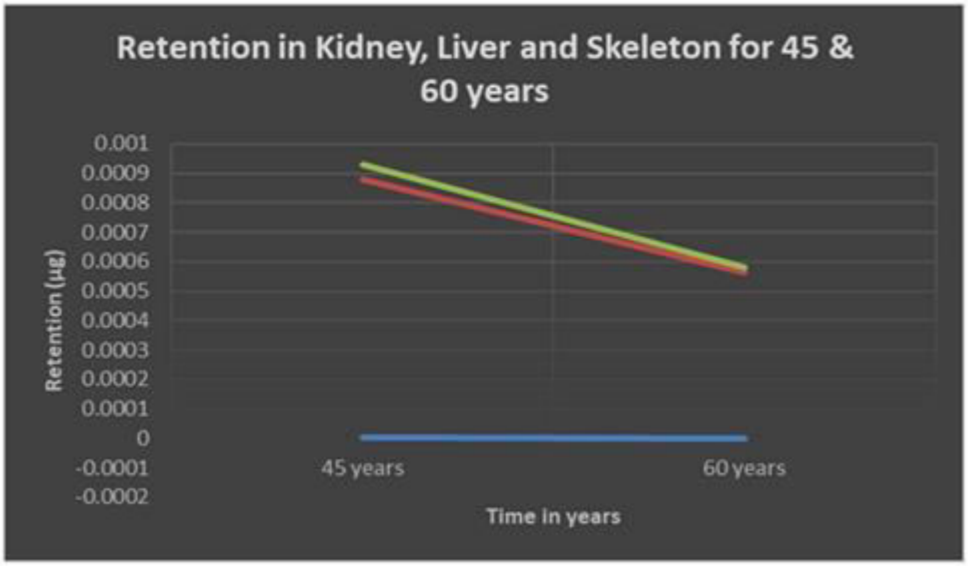


Fig.4 Retentions in main organs i. e Kidney, Liver and Skeleton for a period of 45 and 60 years

Rate Coefficients

The rate coefficient, also known as transfer coefficient "f," is calculated as the ratio of the uranium content in a specific organ to the amount of uranium consumed by the individual on a daily basis. In the current study, the rate coefficients for various organs and tissues for an average ingestion rate ofare compared with the findings from previous research, as presented in Table 6

Table 6: Transfer Coefficient of different organs for uranium

Previous research	Kidney	Liver	Skeleton	GI tract	Urinary bladder	Blood
Utah[17]	0.19	0.14	3.69			
Colorado[17]	0.08	0.13	4.86			
Pennsylvania[17]	0.09	0.15	5.34			
Rajasthan(India)[18]	0.07	0.15	4.61	0.01	0.002	
Mansaand	0.01	0.04	1.21	0.01	0.0002	0.005
Mukatsar(India)[19]						
Fazilka (India)	0.00026	0.000077	0.00019	.715	.000017	.000062

The transfer coefficient "f" exhibits the lowest value for the urinary bladder and the highest for the GI tract. The diversity in "f" values across various tissues and organs elucidates the variation in uranium's bio-kinetics as it transitions from one organ to another

EXCRETION OF URANIUM FROM BODY

The natural rates of uranium excretion through three distinct routes—hair, faeces, and urine—arecomputed. The excretion rate through faeces ranges from 1.07 to 100.18µg/day, with mean and median values of 34.545µg/day and 21.8µg/day, respectively. The average daily excreted uranium value by the body via urine is 0.0172 µg and via hair is 0.0194 µg. The variation in uranium excretion rates through different pathways is illustrated in Fig 5 and Fig 6. In summary, excretion rates are initially faster for longer periods of ingestion.

Fig 5: Time–dependent variation of uranium excretion rates through urine and hair

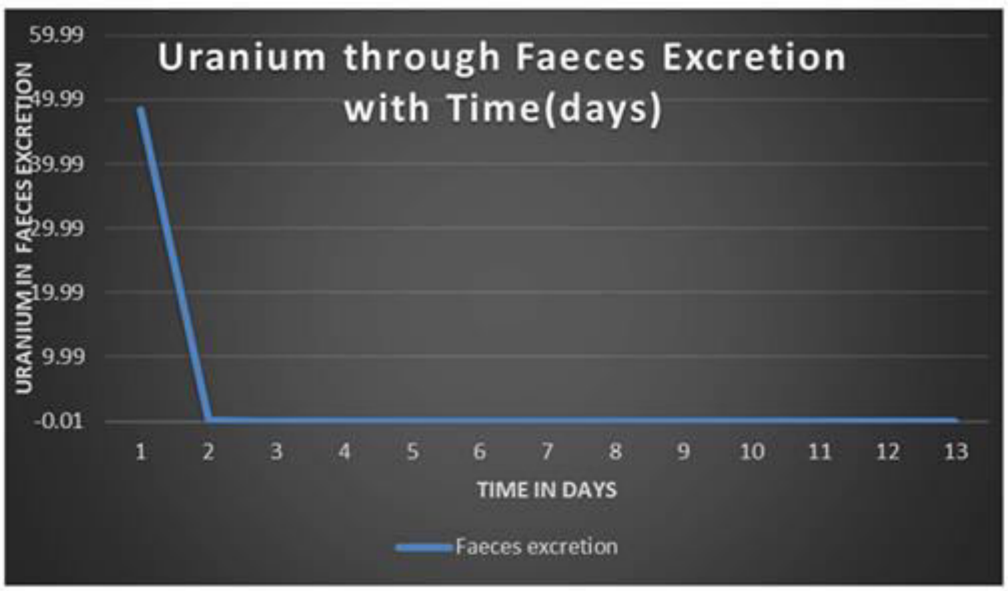


Fig 6: Time–dependent variation of uranium excretion rates through urine and hair

Urine and faeces serve as the primary routes for uranium excretion from the human body. On average, individuals in the studied region ingest uranium at a rate of 104.86 µg per day. The typical uranium excretion by residents via urine is 0.022611 µg per day, while via feces it is 48.36091 µg per day. This indicates a significant ingestion of uranium by the body. Over time, uranium is gradually excreted from the body through feces and urine. Additionally, the uranium content excreted via feces reaches a consistent balance value after 90 days, while the excreted uranium content saturates after approximately 5 years of exposure through urine. The standard measure of uranium in both compartments is 0.000001 µg after 90 days in feces and 0.000001 µgafter 5 years in urine. Furthermore, the study reveals that the excretion of uranium from hair reaches an equilibrium steady state value of 0.000001 µg after 10 years.

DOSES TO INTERNAL ORGANS/TISSUES

The dose level of uranium in different organs and tissues of an adult is influenced by various factors: (i) the level of intake (acute or chronic), (ii) the source of intake (injection, inhalation, ingestion, or wound), (iii) the time elapsed from exposure to measurement, (iv) the size of particles, and (v) the chemical characteristics of impurities. The annual effective uranium ingestion dose through drinking water ranges from 0.0378 to 35.187 µSv, with an average of

12.1332 µSv. This average value falls well below the acceptable limit of 100 µSv (WHO, 2004). The effective dose intake in various organs and tissues is illustrated in Fig 7 Bone surfaces bear the maximum share of dose (35%) due to uranium and its daughters followed by kidneys (12%), large intestine (4%), liver (5%) and small intestinal wall (2%).The adrenal, bladder wall, brain, breast, lungs, muscle, ovaries, pancreas, skin, spleen, thymus, thyroid and uterus all take up 1 % of the total dose. The hair model has lower value for dose coefficients than those determined by utilizing the ICRP's bio-kinetic model.

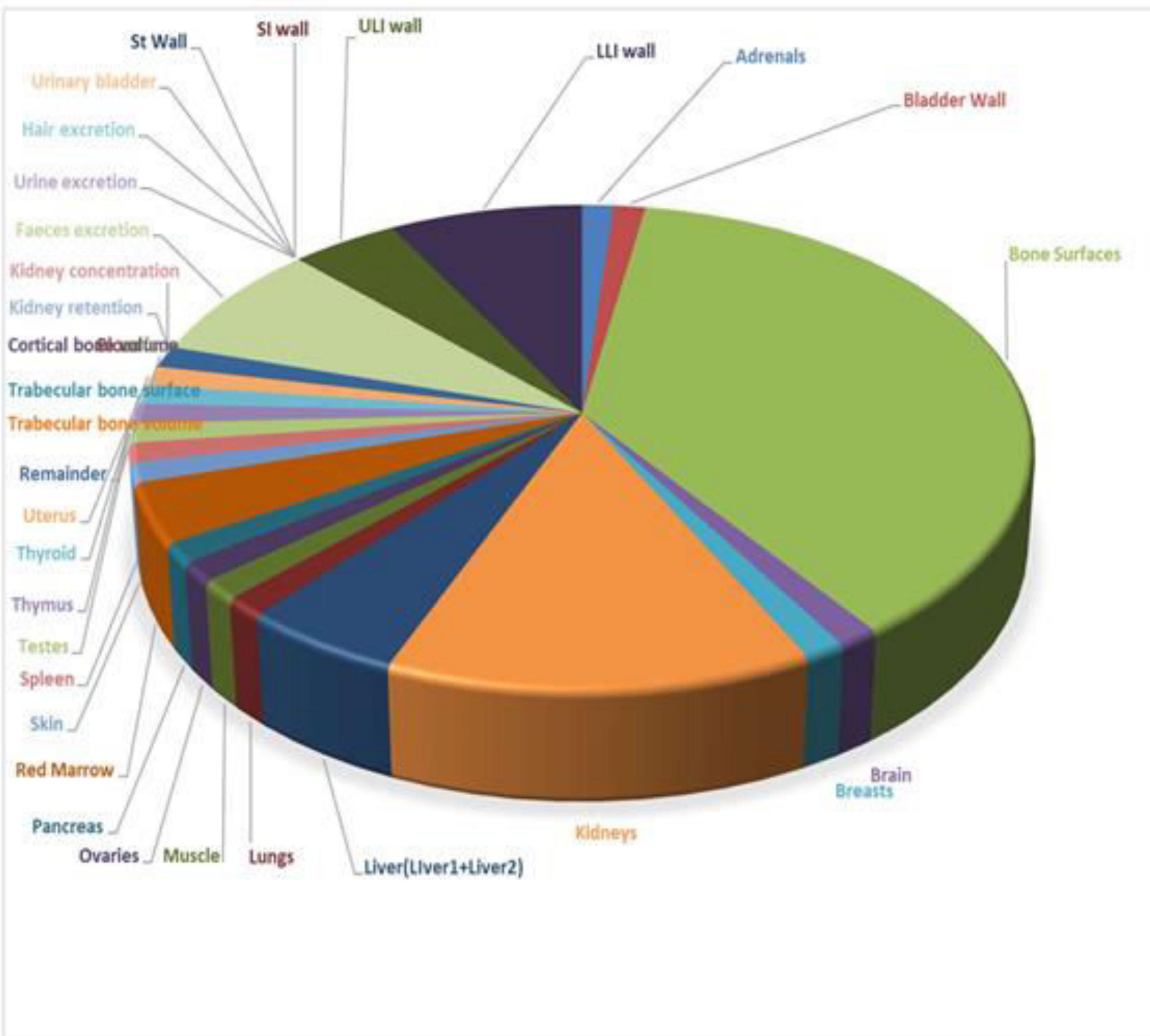


Fig 7: Effective dose intake in various organs and tissues via Pie-chart

5. CONCLUSION

The drinking water samples from the Fazilka region of Punjab, contaminated with uranium, havebeen examined, and the results are presented in Table 3. Upon analysis, it is found that the uranium levels in water samples from the investigation region are below the recommended limit set by WHO [16] of 30 µg/l, ranging between 2.33 and 217.23 µg/l. The current investigation reveals high uranium content in the groundwater of the Fazilka area, with uranium concentration varying significantly from one location to another throughout the region. This wide variation in uranium concentrations is attributed to the heterogeneous distribution of uranium in the earth's crust. Approximately 60% of the groundwater samples exceeded the uranium concentration limit(30µg/l) set by USEPA [15] and WHO for drinking purposes. Given the high uranium concentrations observed in the analyzed samples, further clinical and comprehensive investigations are warranted in this region.

The findings of the current study reveal that bones (CBV and TBV), kidneys, and liver are the major organs affected by uranium concentration in individuals due to the water they consume. Human analysis and estimation form the basis of Bio-kinetic models, which predict excretion, absorption, and retention by the body. The case study of groundwater in the Fazilka district of Punjab, India raises concerns over the elevated uranium content and its potential health impacts on the public. Based on the hair compartment model, we can conclude that:

(a) The primary recipients of the dose are CBV and TBV, kidneys, and liver due to uraniumingestion.

(b) The excretion rate is initially faster in the first few days and then slows down over the yearsthrough urine.

(c) The amount of uranium excreted into the hair is similar to that in urine in an adult is same asreported in literature [20]

ACKNOWLEDGMENT

The authors express their gratitude to Dr. B R Ambedkar NIT Jalandhar for overseeing this investigation at the Radiation Physics Research Laboratory. Additionally, heartfelt thanks are extended to the residents of the study area who provided the water samples and relevant essentialdata.

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