Review Article

Uranium: A Dentist's perspective

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Abstract

Uranium is a naturally occurring radionuclide found in granite and other mineral deposits. In its natural state, it consists of three isotopes (U-234, U-235 and U-238). On an average, 1% – 2% of ingested uranium is absorbed in the gastrointestinal tract in adults. The absorbed uranium rapidly enters the bloodstream and forms a diffusible ionic uranyl hydrogen carbonate complex (UO2HCO3+) which is in equilibrium with a nondiffusible uranyl albumin complex. In the skeleton, the uranyl ion replaces calcium in the hydroxyapatite complex of the bone crystal. Although in North India, there is a risk of radiological toxicity from orally ingested natural uranium, the principal health effects are chemical toxicity. The skeleton and kidney are the primary sites of uranium accumulation. Acute high dose of uranyl nitrate delays tooth eruption, and mandibular growth and development, probably due to its effect on target cells. Based on all previous research and recommendations, the role of a dentist is to educate the masses about the adverse effects of uranium on the overall as well as the dental health. The authors recommended that apart from the discontinuation of the addition of uranium to porcelain, the Public community water supplies must also comply with the Environmental Protection Agency (EPA) standards of uranium levels being not more than 30 ppb (parts per billion).

Key words: *Community water supplies, environmental protection agency standards, uranium*

INTRODUCTION

Uranium (chemical symbol U) is a naturally occurring radionuclide found in granite and other mineral deposits. It enters local water, air and food supplies in varying concentrations through leaching from natural deposits [Table 1] and is also found in mill tailings, emissions from nuclear industry, phosphate fertilizers and during combustion of coal and other fuels. In its pure form it is a silver-coloured heavy metal. In its natural state, it consists of three isotopes (U-234, U-235 and U-238). Natural uranium exist in rocks in the form of uranium ore which after mining forms a yellow cake (U_3O_8), and gets converted into uranium hexafluoride (UF_6). Uranium hexafluoride further acts as a source of uranium Enriched UF_6 and Depleted UF_6. Enriched uranium can be used for production of fuel and power plants while Depleted uranium is mainly used in military purposes, e.g., counterweights and radiation shielding.

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Depleted uranium

Depleted uranium (DU) is a metal made from uranium hexaflouride and is the by-product of the uranium enrichment process. Depleted uranium is actually

Table 1: Naturally occurring uranium ores

Ore	Composition
Uraninite	UO2 +UO3
Pitchblende	UO2 +UO3
Carnotite	K2O 2U2O3 V2O5 3H2O (uranium potassium vanadate)
Autunite	Ca(UO2)2(PO4)2 10H2O
Torbernite	Cu(UO2)2(PO4)2 10H2O
Coffinite	U(SiO4)1-x(OH)4x (uranium silicate)
Tyuyamunite	Ca(UO2)2(VO4)2.5–8H2O (uranium calcium vanadate)

Adapted from: Agency of Toxic Substances and Diseases Registry (1999)

the uranium 238 isotope. Natural uranium contains 99.2% by weight U-238 while DU contains 99.8% by weight U-238. In addition, daughter products emit beta particles and gamma rays that may cause further radiological damage.

Physical properties

Depleted uranium or U-238 has an atomic mass of 238. Its half-life is 4.468 billion years. Its natural occurrence is 2.1 parts per million. Uranium is silver white, lustrous, malleable, ductile, and pyrophoric. This makes DU an ideal metal for use as kinetic energy penetrators, counterweights, and shielding or armor. The most exhaustive studies on natural uranium in the diet and of levels in man for specific geographical locations were carried out in the United States of America by Welford and Baird and by Fisenne *et al.,* who reported a daily uranium intake of 30.3 mBq (megabecquerel) for New York City residents. Nozaki *et al.* from Japan reported a uranium intake of 32.86 mBq, whereas Hamilton has reported an intake of 25.28 mBq for adults in the United Kingdom; however, there is little information available from India about the daily intake of uranium. Singh *et al.* (1995) measured the uranium levels in drinking waters from Punjab (Bathinda and Amritsar). Observed concentrations ranged from 11 to 113 μg/l.

Further, Singh *et al.*, (1996) measured the uranium concentrations in 24 water samples collected from various important sources of drinking water in Uttar Pradesh. Concentrations were found to range between 0.87 and 11 μg/l. Singh *et al.* (1998) also determined the uranium concentration in a range of contaminated soils (due to release from fertilizer and thermal power plants) in the areas of Uttar Pradesh, Rajasthan and Kerala (India). Their results indicated levels of uranium ranging between 0.24 and 9.20 mg/kg, with the most elevated levels being recorded in the proximity of a coal-fired power plant.

Recently, the concentration of Uranium was also determined in individual food items collected from Cancer prone areas of Bathinda district located in the central southern part of Punjab state of India[1-3] [Table 2]. The concentration has been found to vary from 0.38 mBq/g (mBq/g: millibecquerel per gram) in mustard seeds to 4.60 mBq/g in wheat, with a mean of 1.67 mBq/g. The measured value of 0.90 mBq d^{-1}(millibecquerel per day) contributes to 1.12 mSv (millisievert) to the cumulative effective dose to the population, and is greater than the limits recommended by the International Commission on Radiological Protection (ICRP).

Table 2: The percentage increase, grater than the limits recommended by international commission on radiological protection in cumulative effective exposure of different elements to the population in Bathinda region

Element presence	Kids under age 12 years (%)	Children 12-18 years (%)
Uranium	87	82
Aluminium	81	56
Barium	32	6
Cadmium	13	6
Elsen	72	24
Mangan	87	24
Blei	43	33
Strontium	78	63

The original unit for measuring the amount of radioactivity was the curie (Ci). It was–first defined to correspond to one gram of radium-226, and more recently has been defined as:

1 curie = 3.7×10^{10} radioactive decays per second [exactly].

In the International System of Units (SI), the curie has been replaced by the becquerel (Bq), where

1 becquerel = 1 radioactive decay per second = 2.703 10^{-11} Ci.

The unit for the dose equivalent is the rem if the absorbed dose is in rads, and the sievert (Sv) if the absorbed dose is in grays. Thus, 1 Sv = 100 rem.

Effect of uranium on tooth eruption and development and oral mucosa

Eruption and development are ongoing processes that begin during foetal development and continue until the age of 18 years. One of the mechanisms involved in tooth eruption is bone formation, and it is well documented that uranium inhibits bone formation. Acute high dose of uranyl nitrate can thus delay tooth eruption and mandibular growth and development,[4] probably due to its effect on the target cells. In the 1940's, manufacturers began adding uranium to the porcelain powder used to make dentures [Table 3]. The idea was that the fluorescence of the uranium would help mimic the look of real teeth under a variety of natural and artificial light conditions, and thus improve the aesthetics. Uranium had the advantage over some of the alternative materials because its fluorescence is unaffected by the high temperatures (800-1400 °C) used to bake the porcelain.

Table 3: Uranium content in dental procelain material

Uranium content in dental porcelain material (ppm)	
Porcelain material	**Uranium content**
Clay	1.5
Silica	0.024
Fieldspar	0.024
Porcelain	0.089

Table 4: Inhalation of Uranium

Inhalation of uranium (based on chemical toxicity)	TAC [µg/m³]
[ATSDR1999] intermediate duration, soluble	0.4
[ATSDR1999] intermediate duration, insoluble	8
[ATSDR1999] chronic, soluble	0.3
[Jacob1997]	0.07

ATSDR = Agency of toxic substances and diseases registry.

In evaluating the biological effects which may be caused by radiation exposure due to uranium and its descendant nuclides, it is necessary to take into consideration factors such as the depth of the basal cell layer.[5,6] The dose rate due to alpha particles decreases steeply as the depth increases, and therefore the depth of the basal cell layer is critically important for the evaluation of potential biological effects. The epidermal thicknesses were 10-470 μm in lips (mean: 178 μm), 10-460 μm in tongue (mean: 101 μm), and 23-140 μm in the gingival tissues (mean: 56 μm). Therefore, the basal cells may possibly be irradiated when the epidermis is only 10 μm (10 micrometer) thick.[7]

Uranium toxicity

Inhalation

Inhalation of uranium powder is an occupational hazard and of prime concern for the mine workers. However, inhalation of uranium is a very minor source of exposure for the general population. Exposure scenarios include inhalation of contaminated air and dust from the following sources:

- Communities where remediation activities are ongoing,
- Enrichment, or recycling activities,
- Mining and milling,
- Site remediation activities,
- The combustion of coal (since it contains uranium), and
- Worker's skin, hair, and clothing.

In Punjab and particularly in Bathinda and Ropar regions, the areas of residence close to the thermal plants are affected due to the combustion of coal in these plants. In areas where uranium enrichment processes occur, atmospheric concentrations of uranium have been measured at 200 times higher than the normal background levels. Inhaled uranium deposits in the various portions of the respiratory tract and the lungs based on the particle size (i.e., larger particle size deposited higher in respiratory tract). Most of the deposited uranium clears rapidly via the mucociliary transport to the throat. Once there, the uranium is cleared via sputum or swallowing and primarily fecal excretion. Soluble uranium dissolves and is absorbed into the circulatory system more rapidly than the insoluble forms. A portion of the uranium can reside in the lungs for years. An analysis of uranium in the mill crushermen (workers in the dustiest section of the mill) found that 1-5% of the inhaled uranium was absorbed systemically and excreted in urine, and 95% was excreted in the feces [Fisher *et al.* 1983]. Other studies have suggested that only a small portion of the inhaled uranium penetrates to the alveolar region, and can remain there for years [West and Scott 1969].

The study by Agency of Toxic Substances and Diseases Registry (ATSDR) 1999[8] has reviewed all published data on animal studies known on uranium toxicity [Table 4]). The study by *Rothstein* (1949a) on dogs has been used for estimating the hazard from intermediate duration inhalation of soluble forms of Uranium. From this figure, a "minimal risk" inhalation level for humans of 0.4 μg/m^3 has been derived, applying a number of safety factors. The study by *Stokinger* (1953b) on dogs was used for for estimating the hazard from chronic duration inhalation of soluble forms of Uranium. From this figure, a "minimal risk" inhalation level for humans of 0.3 μg/m^3 is derived, applying a number of safety factors. In another review by *Jacob* (1997), performed for the German Federal Environmental Agency, another study performed by *Stokinger* (1953a) on rats was used: The rat study showed slight impact to the kidneys at uranium resorption rates of 2.6 μg per kg per day. This rate corresponds to the uranium concentrations of 40 μg per m^3 in air. Applying a number of safety and conversion factors, the authors obtained a "tolerable" level of 0.07 μg/m^3 uranium in air.

Oral ingestion

The "minimal risk" level for intermediate-duration ingestion proposed by ATSDR1999[8] is an oral uptake of 2 μg of uranium per kg body weight per day. This is based on adverse effects observed by *Gilman* (1998b)

in rabbits with an uptake of 0.05 mg per kg per day [Table 5]. Jacob (1997) proposed a "tolerable" uptake of 0.7 μg per kg per day. This value is based on adverse effects observed by McDonald-Taylor (1992) on kidneys of rabbits at resorption rates of 3.2 μg U per kg and day. The World Health Organization (WHO) has established a Tolerable Daily Intake (TDI) for uranium at 0.6 μg/kg body weight per day. Based on the higher uranium resorption in humans compared to experimental animals, Konietzka (2005) assumed a Tolerable Daily Intake of 0.2 μg/kg body weight per day and recommended a safe concentration in drinking water of 10 μg/L for lifetime exposure.

Adverse health effects

Verified adverse health effects [Figure 1] as mentioned by physicians and from personal reports from individuals with known DU (Depleted Uranium) exposures include:[9-11]

- Reactive airway disease.
- Neurological abnormalities.
- Kidney stones and chronic kidney pain.
- Rashes.
- Vision degradation and night vision losses.
- Gum tissue problems.
- Lymphomas.
- Various forms of skin and organ cancer.
- Neuro-psychological disorders.
- Uranium in semen.
- Sexual dysfunction.
- Birth defects in the offspring.

Table 5: Ingestion of Uranium

Ingestion of uranium (based on chemical toxicity)			
	TDI [μg/(kg/d)]	ALI [mg]	DDWC [μg/l]
[ATSDR1999]	2	51.2	102
[Jacob1997]	0.7	17.9	36
[WHO1998]	0.6	15.3	31
[Konietzka 2005]	0.2	5.1	10

ATSDR = Agency of toxic substances and diseases registry; WHO= World Health Organization

Uranium in drinking water

The Federal– Provincial– Territorial Committee on Drinking Water calculated the health-based guideline value of uranium in drinking water to be at 10 μg/L. The committee has recommended an interim maximum acceptable concentration of 20 μg/L.[12,13] On an average, 1%-2% of ingested uranium is absorbed in the gastrointestinal tract in adults. The absorbed uranium rapidly enters the bloodstream and forms a diffusible ionic uranyl hydrogen carbonate complex ($UO_2HCO_3^+$) in equilibrium with a nondiffusible uranyl albumin complex. In the skeleton, the uranyl ion replaces calcium in the hydroxyapatite complex of

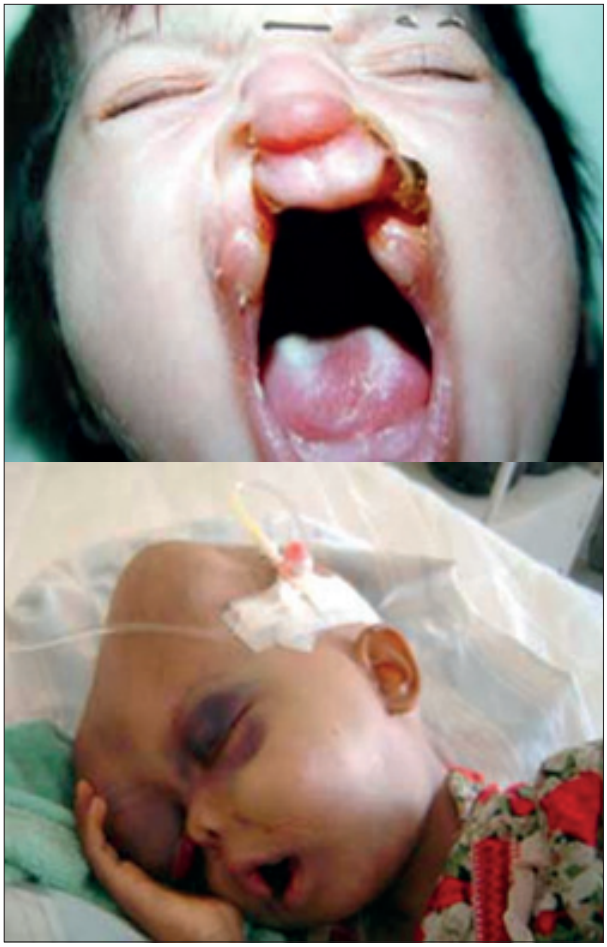

Figure 1: Adverse health effects

Table 6: Potential health effects of concern for intermediate and chronic oral exposure to the mixture uranium, fluoride, cyanide, and nitrate

Uranium	Uranium radiation	Fluoride	Cyanide	Nitrate
Renal	Cancer	Musculoskeletal	Reproductive	Haematological
Hepatic		Reproductive	(Testicular)	
Endocrine		(Testicular)	Developmental	
(Thyroid)		Neurological	Neurological	
		Renal	Renal	

the bone crystal. Although there is a risk of radiological toxicity from orally ingested natural uranium, the principal health effects are of chemical toxicity. Uranyl compounds have a high affinity for phosphate, carboxyl and hydroxyl groups and readily combine with proteins and nucleotides to form stable complexes. The skeleton and kidney are the primary sites of uranium accumulation; and, little is found in the liver.

Joint toxic action

Potential Health Effects of Concern for Intermediate and Chronic Oral Exposure to the Mixture Uranium, Fluoride, Cyanide, and Nitrate are presented in Table 6.[14] No studies that examined health effects in humans or animals exposed to mixtures containing uranium, fluoride, cyanide, and nitrate were found in our literature review. No physiologically-based pharmacokinetic (PBPK) models were found for mixtures of these three components.

Uranium and fluoride

Uranium and fluoride are often found in combination in the nuclear power industry, where uranium hexafluoride is used to enrich uranium mixtures and to increase their activity. Upon contact with moisture, including moisture in the air, uranium hexafluoride rapidly hydrolyzes to uranyl fluoride (UO2F2) and hydrogen fluoride. None of these studies have shown the effects of the fluoride ion on the measured toxicity of uranium, and also similar toxic effects have been noted in animal studies when uranium compounds not containing fluoride were examined.

Fluoride and cyanide

Both fluoride and cyanide ions have been demonstrated to affect cellular energy metabolism, with fluoride primarily resulting in decreased glycosylation reactions, while cyanide is an inhibitor of oxidative phosphorylation. Szabo *et al.* (1973) demonstrated that fluoride and cyanide have opposite effects on cellular glucose metabolism, with fluoride treatment resulting in a decrease in the cellular glucose uptake in cultured cells, while cyanide treatment resulted in an increased uptake.

Prevention

Water (prevention & control) act 1974: The objectives of the Water (Prevention and Control of Pollution) Act are to provide for the Prevention and Control of Water Pollution and the maintenance or restoration of the wholesomeness of water for the establishment, with a view to carrying out the purposes aforesaid, of Boards for the prevention and control of water pollution, for conferring on and assigning to such Boards powers and functions relating thereto and for matters connected therewith: Air (Prevention And Control of Pollution) Act 1981; Environmental (Protection) Act, 1986.

- International Commission on Radiological Protection (ICRP) Recommendations: Moving to a situation-based approach applying justification and optimization of protection to all controllable exposure situations (planned, emergency, and existing exposure situations).
- Keeping the dose limits.
- Developing a framework to demonstrate radiological protection of the environment.All depleted uranium contamination must be physically removed and properly disposed of to prevent future exposures.
- Radiation detection devices that detect and measure alpha particles, beta particles, X-rays, and gamma rays emissions at appropriate levels from 20 dpm (decay per minute) up to 100,000 dpm, and from. 1 mrem/hour to 75 mrem/hour (roentgen equivalent man per hour), must be acquired and distributed to all individuals or organizations responsible for medical care and environmental remediation activities, involving depleted uranium / uranium 238 and other low level radioactive isotopes that may be present.
- Medical screening of all individuals who may have inhaled, ingested, or had wound contamination with uranium, to detect the mobile and sequestered internalized uranium contamination must be completed.
- All individuals who enter, climb on, or work within 25 meters of any DU (Depleted Uranium) contaminated equipment or terrain must wear respiratory and skin protection.
- Uranium 238 contaminated and damaged equipment or materials should not be recycled to manufacture new materials or equipment.

The maximum dose constraint for workers is 20 mSv in a year (milli sievert). Exceeding a dose constraint may be a statutory offence.

What should happen next?

Depleted uranium munitions and the use of depleted uranium must be banned.

All individuals who were exposed or who may have been exposed to any form of depleted uranium and its various integral contaminants or other contaminants created during combat, research, or training activities,

must receive a through physical examination and medical care to alleviate or cure the physiological consequences caused by inhalation, ingestion, or uranium wound contamination.

All depleted uranium penetrator fragments, depleted uranium contaminated equipment, and depleted uranium oxide contamination must be cleaned up and disposed of at secure sites.

Uranium removal from drinking water

Equipment [Figure 2]: Res-Kem equipment for contaminant removal uses the process of activated carbon filtration, ion exchange (IX), reverse osmosis (RO),[8] and/or other technologies as appropriate for specific use.[15] The U.S. Environmental Protection Agency (EPA) sets standards in the Safe Drinking Water Limits. These are calculated levels of contaminants in water based on an assumption that a person consumes 2 litre of water per day for 70 years. EPA has set a Maximum Contaminant Level (MCL) for uranium at 30 μg/L. The relative order of affinity of strong base anion resins for some common ions in drinking water showed uranium at the top of the list:

Uranium/Perchlorate >> Sulfate/Chromium > Selenium/ Arsenate > Nitrate > Chloride > Bicarbonate > Fluoride.

Resin selection

Cation resin in the hydrogen form has been found to remove uranium, probably by converting the uranium complex to the uranium cation. Removal rates are in the 90-95% range, but the pH of the effluent will be low (about 2.5 to 3.5) and the resin used in this method is not selective, and removes all the cations. Cation resin in the sodium form, operating as a softener, has limited use in uranium removal and is very pH dependent. At pH 8.2, there is no uranium removal, and at pH 5.6 there is about 70% removal. As the resin exhausts to the calcium form, removal is even less effective, with no removal at pH 8.2 or 7, some removal beginning to occur at pH 5.6, and 60% removal at pH 4.

Figure 2: Uranium removal from drinking water

Obviously, cation resin is not a viable ion exchange removal method because of the pH requirements and especially when the technique is compared to strong base anion resins. Anion resin in the chloride form can easily reduce uranium levels by over 90%. It can be used in a regenerable process or once-through. A mixed bed of cation and anion resins can be considered for some applications that are used to remove both radium and uranium.

Estimating capacity

At pH above six, uranium exists in portable water primarily as a carbonate complex which is an anion, and has a tremendous affinity for strongly basic anion exchange resins. The process has been tested and found to be very effective at pH of 6 to 8.2. Higher pH could result in uranium precipitation which would then necessitate the physical removal of uranium. Lower pH changes the nature of uranium to non-ionic and/ or cationic forms which would prevent the exchange reactions from operating effectively. Tests have shown effective removal (over 95%) of uranium at a pH as low as 5.6. However, after the pH was reduced to 4.3, the removal rate dropped to 50%, and the run lengths (throughput capacities) were reduced by over 90%.

Estimated costs

The EPA estimates that the annual costs of compliance for individual community water systems to be as follows:[8]

- Smallest systems $9,000 (Rs. 4,50,000/-)
- Systems serving 3,300 to 10,000 people : $150,000 (Rs.75,00,000/-)
- Large systems $500,000 (Rs. 250,00,000/-)

CONCLUSIONS

Uranium is a naturally occurring element present in rocks and soil. Water passing through and over geologic formations can contain dissolved uranium. The role of the dentist is to educate the masses regarding the adverse effects of uranium with an overall as well as dental health perspective. The authors recommend

that the addition of uranium to porcelain should be discontinued, and non-radioactive porcelains should be developed. Public community water supplies must comply with the EPA standards of no more uranium than 30 ppb (parts per billion). Options exist for uranium removal; however, the best treatment system for given situation will depend on several factors and may require a combination of the various systems used.

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