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Dose Estimation and Risk Assessment of Contaminated Biological Waste by Tc-99 in Repository

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Abstract

Radioisotope Tc-99m is used in medical diagnostic procedures, making it the most commonly used medical radioisotope. Molybdenum-99 (Mo-99) has a short half-life, which is usually an estimate of 66 hours, and decays to an even shorter half-life till it reaches 6 hours. Tc-99m that emits 140.5 KeV gamma rays is only suitable for diagnosis but not for therapeutic purposes. Technetium-99m is a metastable nuclear isomer of Technetium-99, having a half-life of 213,000 years, which then decays to stable Ruthenium-99. It emits beta particles without the emission of gamma rays. The maximum activity of dose from the nuclear medicine examination of intravenously-administered diagnostic amounts of Radio pharmaceuticals 99mTc-MIBI (methylene bisphosphonate) is 30mCi to heart nuclear medical scan. In the case of a patient that has been exposed to radioactive material (Tc-99m); the possibility that the patient may die before the radioactive material has decayed away is still present. Accordingly, dangerous consequences take place after the burial of the dead patient whereas the body of the patient carries T-99 even after decomposition. T-99 decays in the cemetery afterwards, which leads to a higher possibility of contamination by the radioactive fluids released from the dead corps. As a consequence, T-99 will be transmitted from the cemetery soil to man through ingestion. This is why the dose and the potential risk of getting cancer both needs to be assessed after an interval of time, and this is in order to evaluate the *level of safety of the people involved. To do this, RESRAD code version 7.0 is used under certain conditions. This program was used in performing probabilistic dose and risk analysis. The results from this study explain that the major dose and risk that people are exposed to from radioisotope Tc-99 comes from drinking water contaminated with Tc-99 resident, and not through ingesting the component.*

Key words: Biological waste, Tc-99 isotope, Dose estimation. Risk assessment, Human safety

INTRODUCTION

Technetium (Tc) is the lowest molecular weight element that is exclusively radioactive. One of its isotopes is Tc-99, have half-life of 213,000 years. This long half-life makes Tc a potentially dangerous source of radiation. Large amounts of a radioactive material make the production and disposal of Tc-99 an important environmental consideration. Medical and academic institutions use molybdenum/technetium generators as a source of Tc-99m for diagnostic tests or research, including evaluating the medical condition of the heart, kidneys, lungs, liver, spleen, and bone, among others, and also for blood flow studies. In this case, the nuclear reactor provides the radioactive parent, molybdenum-99, for the technetium generator. Molybdenum-99 (Mo-99) has a short (66 hour) half-life, and decays to the even shorter half-life (6 hrs). Technetium-99m is a metastable nuclear isomer of technetium-99 (itself an isotope of technetium), symbolized as ^{99m}Tc, that is used in tens in medical diagnostic procedures annually, making it the most commonly used medical radioisotope. It is used as a radioactive tracer and can be detected in the body by medical equipment (gamma cameras). The relatively "short" physical half-life of the isotope and its biological half-life of 1 day (in terms of human activity and metabolism) allows for scanning procedures which collect data rapidly but keep total patient radiation exposure low. The same characteristics make the isotope suitable only for diagnostic but never therapeutic use. Technetium-99 (^{99}Tc) is an isotope of technetium which decays with a half-life of 213,000 years to stable ruthenium-99, emitting beta particles, but no gamma rays. It is the most significant long-lived fission product of uranium fission, producing the largest fraction of the total long-lived radiation emissions of nuclear waste [1].

Tc-99 into the body may occur by eating food or drinking water contaminated with Tc-99. Once gets in the human body, Tc-99 concentrates in the thyroid gland and the gastrointestinal tract. The body, however, excretes half of the ingested Tc-99 within 60 hours. It continues to excrete half of the remaining Tc-99 every 60 hours that follow. After 120 hours, only one fourth of the ingested Tc-99 remains in the body. Nearly all of ingested technetium will be excreted from the body within a month. [2]

Occupational and public exposures, environmental effects, human health, safety, and social and economic factors, are to be considered when deciding between options in the predisposal management of radioactive waste. However, the preferred option, as far as is reasonably practicable, is to concentrate and contain the waste and to isolate it from the biosphere [3].

The principle of disposing of radioactive waste in an engineered facility deep underground is to ensure multiple robust and durable barriers to contaminant releases, enabling radionuclides to decay before reaching the accessible environment. Some of the contaminants are very long-lived, so that potential degradation of barriers and release and migration of contaminants need to be considered within an environmental safety case. Key regulatory criteria for evaluating the performance of a geological disposal facility (GDF) are expressed in terms of potential doses and risks that might arise to the most exposed members of future populations. Such exposures will occur in the biosphere and will be largest in the vicinity of any releases to the biosphere. Therefore, safety cases associated with geological disposal need to consider the biosphere (Fig. 1) and its representation on very long timescales (up to hundreds of thousands of years), including potential exposures to human populations and non-human biota.[4]

Figure (1); Biosphere representation

The unsaturated zone, sometimes called the *vadose zone* or *zone of aeration*, plays several critical hydrologic roles. As a storage medium, it is a zone in which water is immediately available to the biosphere. As a buffer zone between the land surface and aquifers below, the unsaturated zone is a controlling agent in the transmission of contaminants and aquifer-recharging water. As an accessible body of material in which physical and chemical processes may be relatively slow, it is a place where wastes are emplaced to isolate them from significant exchange with other environmental components. Thus, the flow processes that occur in the unsaturated zone substantially contribute to a wide variety of hydrologic processes. Scientifically, the unsaturated zone is highly complex and must be studied with an interdisciplinary approach. There is much variety in its natural constituents: soils, rocks, water, air, plants, animals, and microorganisms.[3]

Modern hydrology must consider interactions not only among these constituents themselves, but also with a wide variety of contaminants, including pesticides, fertilizers, irrigation wastewater, manure, sewage, toxic chemicals, radioactive substances, bacteria, mine wastes, and organic liquids.[5]

For a Patient Treated with Radioactive Material (Tc-99m); There is always the possibility that the patient may die before the radioactive material has decayed away, from an unrelated cause. In this case, there is no danger on any person who spent very close to the patient die (decedent) or any amount of time . The exposure rate is neglected and there is no problem remaining in the same room at a distance of any distance. The dangerous comes after burial the patient die. Conventional burial is safe without cremation or autopsy for personnel exposure, but the body after decomposes carrying T-99 with half-life of 213,000 years, where the possibility of contamination by radioactive fluids from the body after Tc-99m radioactive decay in the cemetery. So recommend to the family that they bury the decedent immediately and conduct a memorial service without a viewing. Medical examiners should have provided a label indicating name, date of death, amount of (Tc-99m) injected and the dose rate from the decedent and the distance from which it was measured. [6]

For burial the dead, select a burial container that will delay the release to the environment as long as practicable. Wooden caskets are not sealed. Metal caskets have a seal that will release pressure from inside the casket, but will retard the entry of ground water. Place the body in a metal casket, not a wooden one, and place the casket in a concrete vault lined with plastic. Use the type that has a lid with a butyl compound gasket with a tongue in groove seal. In the cemetery, place the lid on the vault above ground where it can be inspected for a tight fit before lowering into the grave. [7]

METHODOLOGY

Radiopharmaceuticals could be a source of radiation to their relatives. There is always a possibility that the patient may die before the radioactive material (Tc-99m) has decayed away. The dangers come after burying the dead patient. Conventional burial is safe without cremation or autopsy for personnel exposure, but the body carries Tc-99m after its decomposition, knowing that Tc-99m has a half-life of 213,000 years. There is a possibility of contamination by radioactive fluids from the body after Tc-99m radioactive decays in the cemetery. There is a necessity to trace Tc-99m in the soil after it has been released from the dead body until it reaches humans through contamination. This study represents the dose and risks associated with Tc-99m which decays with a half-life of 6 hours to Tc-99. ^{99}Tc is an isotope of technetium which decays with a half-life of 213,000 years in soil. RESRAD CODE version 7.0 was used to explain the pathway of radionuclides when reached to groundwater and after that to human body. It can perform uncertainty/probabilistic analysis. It can calculate the time-integrated dose and risk from residual radioactive materials to human body.[8] The maximum activity of doses from nuclear medicine exam is 30mCi from intravenously administered diagnostic amounts of Radio pharmaceuticals 99mTc-MIBI(methylene bisphosphonate). According to the Heart Nuclear Medical Scan, 99mTc emits 140.5 keV gamma rays (these are about the same wavelength as emitted by conventional X-ray diagnostic equipment), and its half-life for gamma emission is six hours (meaning 94% of it decays to ^{99}Tc in 24 hours. ^{99}Tc is an isotope of technetium which decays with a half-life of 213,000 years to stable ruthenium-99, emitting beta particles, but no gamma rays. The primary hazard when working with technetium is inhalation of dust. The next shortest-lived fission product is Samarium-151 with a half-life of 90 years, though a number of actinides produced by neutron capture have half-lives in the intermediate range. For this reason, the environmental chemistry of technetium is an active area of research. [9, 10]

COMPUTER CODE

The RESRAD code version 7.0 was used in performing probabilistic dose and risk analyses. It incorporates default parameter distributions (based on national average data) for selected parameters. It calculates doses and risks from radionuclide in environmental media. It calculates doses to persons located beyond the boundary of the site. It calculates doses to members of the general public from the recycle of materials containing traces of radioactive materials and cancer risk. The pathway of contamination is through ingestion. To calculate internal dose from ingestion of; plant foods grown in the contaminated soil and irrigated with contaminated water, milk from livestock fed with contaminated food and water and drinking water from a contaminated well or pond.

The aim of this research was to estimate the dose and assess the risk of recycled Tc-99m which is transfered from the body of a dead patient on the general public. The maximum activity of doses from nuclear medicine exam, for Heart Nuclear Medical Scan, is 30mCi from intravenously administered diagnostic amounts of Radiopharmaceuticals 99mTc-MIBI (methylene bisphosphonate) [10]. Doses and Cancer Risk were calculated by using RESRAD code version 7.0 by following the ingestion pathway . The scenario is; there was a well with 15 meters depth and far from the contaminated area by 10000 meters. We considered the rate of water ingestion for a male resident to be 510 L/yr [8]. All scenario pathways available in the code are explained in figure (2).

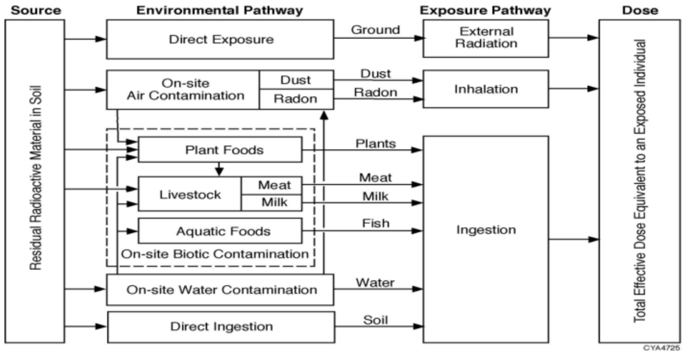

Figure (2) Schematic Representation of RESRAD Pathways [8]

RESULTS AND DISCUSSION

Residual radioactive contamination in soil has the potential to contaminate ground water in either the saturated or unsaturated zones. The primary mechanisms controlling potential ground-water contamination include infiltration and leaching, transport through the unsaturated zone, and transport through the saturated zone. Many additional processes influence these mechanisms, including precipitation rates, land surface properties, soil properties, the chemical nature of the radioactive contamination, spatial distributions of the contamination, and advection/retardation in the aquifer.

The ingestion pathways include: Plant, Meat, Milk, Fish, Soil and water. The food pathways can be classified as water-independent (w. ind.), which is the direct root uptake and foliar dust deposition, or water-dependent (w.d.) which is irrigation water. The radiation dose from ingestion of Tc-99 has been systematically evaluated in ICRP Publication 30. The results explained that, the doses and cancer risk from meat , fish and soil ingestion pathways are very small in relation to drinking water (can be neglected). The doses and cancer risk from milk and plants ingestion pathways are nearly neglected. This is explained in tables (1, 2) and figures (3, 4). The effective component in dose and cancer risk from ingestion exposure was from drinking water (drinking w.) which is assumed to be taken from a well. In this research we considered the rate of water ingestion for the male resident to be 510 L/yr [8]. The time intervals were from 0(yr) to 10(yr). From table (1) and Figure (3); The maximum dose coming from drinking water at time interval 0-6.69(yr) was 3.67E+03 (mSv). This means that the dose of drinking water is the most effective component in ingestion pathway.

Table (1): Dose of (Tc-99) in mSv due to ingestion pathway in time intervals

Time (yr)	Meat w.ind	Meat w.d.	Fish	Soil ingestion	Drinking w.	Milk w.ind.	Milk w.d.	Plant w.ind.	plant w.d.
1.00	2.90	0.48	0.65	3.60	6.18E+02	32.50	13.30	1040.6	97.13
2.33	1.01	2.87	2.82	0.022	2.57E+03	11.56	62.30	369.84	433.8
3.00	0.60	3.49	3.34	0.010	3.04E+03	6.850	74.40	219.108	515.61
4.39	0.20	4.08	3.85	0.004	3.49E+03	2.320	85.99	74.340	594.14
5.42	0.09	4.25	3.98	0.002	3.60E+03	1.039	89.28	33.270	616.4
6.69	0.04	4.32	4.04	0.001	3.67E+03	0.530	90.60	16.955	625.0
8.27	0.009	1.58	1.33	0.0002	1.19E+03	0.113	30.77	3.610	208.4
10.0	0.002	0.41	0.35	5.00E-05	3.09E+02	0.029	7.980	9.380	54.07

From table (1), it is obvious that the maximum dose of Tc-99m in time interval from 0-1 years comes from plant ingestion pathway, as it recorded a dose of 1040.60, and it is the highest among the rest. This poses a higher risk of cancer for those relying on plant consumption. On the contrary, the minimum dose of Tc-99m came from soil ingestion at a time range of 10 years, recording the lowest dose of 5.00E-05. Therefore, it poses a lower cancer risk factor. The rest of the ingestion pathways doses including meat, fish, drinking water and milk range from 3.09E+2 to 625.

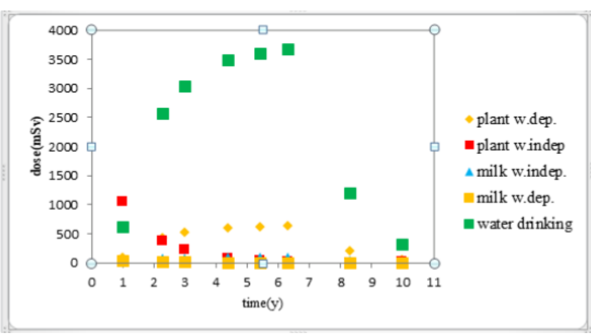

Figure (3): Dose of (Tc-99) due to ingestion pathway

From table (2) and Figure (5); the maximum cancer risk coming from drinking water at time interval 0-1(yr) was 4.2. This means that the cancer risk factor of drinking water is the most effective component in ingestion pathway, as opposed to soil ingestion, which reported a minimim value of 2.09E-8. This means that soil ingestion poses the lowest cancer risk factor among the rest of the ingestion pathways mentioned in table (2). This confirms with the results of table (1) as well.

Table (2): cancer risk due to ingestion of components containing (Tc-99) in time interval

Time (yr)	Meat w.ind.	Meat w.d.	Fish	Soil ingestion	Drinking w.	Milk w.ind.	Milk w.d.	Plant w.ind.	plant w.d.
1.00	0.0010	0.007	0.007	3.00E-05	4.200	0.016	0.150	0.5300	1.0044
2.33	0.0005	0.007	0.006	1.10E-05	3.970	0.005	0.140	0.1900	0.990
3.00	0.0003	0.006	0.005	6.70E-06	3.680	0.003	0.133	0.1100	0.920
4.39	0.0001	0.005	0.004	2.30E-06	2.850	0.001	0.104	0.0400	0.710
5.42	4.60E-05	0.004	0.003	1.00E-06	2.170	0.0005	0.079	0.0200	0.540
6.69	1.70E-05	0.002	0.002	3.80E-07	1.300	0.0002	0.048	0.0062	0.330
8.27	5.00E-06	0.0007	0.0007	1.10E-07	0.410	5.70E-05	0.016	0.0010	0.105
10.0	1.00E-06	0.0001	0.0001	2.90E-08	0.107	1.40E-05	0.004	0.0005	0.027

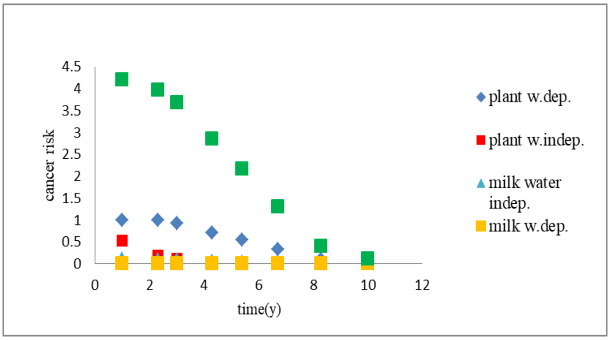

Figure (4): cancer risk due to ingestion of components containing (Tc-99) in time intervals

In this case, 100% of the drinking water is drawn from a well. The results in tables (3, 4) and figures (5, 6) were explained that the maximum dose rate at interval 0-6.69 (yr) from drinking water was 3.67E+03(mSv) and the maximum cancer risk factor at interval 0 - 1(yr) was 4.2.

Table (3): Cancer Risk of (Tc-99) due to water ingestion pathway via time intervals

Time(yr)	Cancer Risk-drinking water
1.00	**4.2**
2.33	**3.97**
3.00	**3.68**
4.39	**2.85**
5.42	**2.17**
6.69	**1.30**
8.27	**0.41**
10.0	**0.107**

Table (3) presents the cancer risk of Tc-99m due to water ingestion pathways throughout 8 time intervals. The highest cancer risk factor witnessed a value of 4.2 throughout the first year, while the lowest cancer risk factor witnessed a minimum value of 0.107, through a time period of 10 years. From the table, we conclude that the longer the time period, the lowest the cancer risk factor is. Meaning that the first years of water ingestion from an area contaminated with Tc-99m poses a higher risk of getting cancer than, say, the later years. Figure (6) explains this thoroughly through a demonstration of the negative slope of Time-Cancer Risk relationship. The more time passes by, the lower the risk of getting cancer and vice versa.

Table (4): Dose (mSv) of (Tc-99) through water ingestion pathway via time intervals

Time(yr)	Dose(mSv)	Dose (mSvX100)
1.00	6.18E+02	6.1837
2.33	2.57E+03	25.7263
3.00	3.04E+03	30.4064
4.39	3.49E+03	34.9001
5.42	3.60E+03	36.1736
6.69	3.67E+03	36.680
8.27	1.19E+03	11.9231
10.0	3.09E+02	3.09408

As shown from the above table, it is obvious that the dose and cancer risk factor are irrelevant or independent. By comparison, in table (3) as more time passes by, the cancer risk factor was in continuous decrease. Holding the time constant, the dose of (mSv) is in continuous fluctuation as shown in the above table. So, dose and cancer risk factor cannot be held relatable. This proves the theory of stochastic effect of ionizing radiation, which states that there is no threshold dose at which cancer cells become triggered.

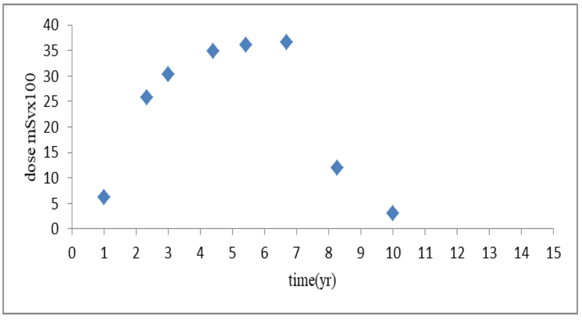

Figure (5): Dose (mSv) of (Tc-99) through water ingestion pathway via time interval

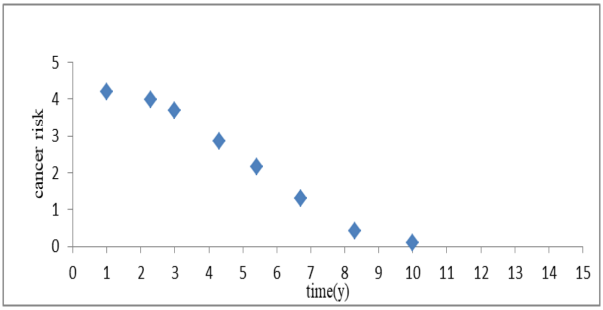

Figure (6): Cancer Risk of (Tc-99) due to water ingestion pathway via time intervals

CONCLUSION AND RECOMMENDATION

Considering that 100% of the drinking water is drawn from a well, the results explain that; the maximum dose rate at interval 0-6.69 (yr) from drinking water was 3.67E+03(mSv) and the maximum cancer risk factor at interval 0 -1(yr) was 4.2. Considering the rate of water ingestion of a male resident to be 510 L/yr, a well with 15 meters depth and far from the contaminated area by 10000 meters. This means that the dose of drinking water is the most effective component in ingestion pathway. We conclude that it is not recommended to consume water from 15 meters deep and that is situated 10000 meters far from an area contaminated by Tc-99m traces. Alternative drinking water supply such as bottled water or water provided by water companies via tankers at distribution points from other drinking water sources must be considered in this case.

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