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Comparative Dosimetry and Risk Coefficient Calculation for ^{99m}Tc and ^{123}I in SPECT using the Radiological Toolbox and Federal Guidance Report No.13 Databases

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الملخص:

تتناول هذه الدراسة مبادئ الطب الإشعاعي في مجال الطب النووي، من خلال مقارنة النظيرين المشعين تكنيشيوم-99م واليود-123 المستخدمين في تصوير SPECT. وتحلل الدراسة خصائصهما الفيزيائية مثل نصف العمر وطاقة الانبعاث، وتأثير ذلك في الجرعة الإشعاعية والمخاطر المرتبطة بها، بالاعتماد على أدوات تحليل وقاعدة بيانات الجرعات. وتهدف النتائج إلى دعم اتخاذ القرار في اختيار الدواء الإشعاعي الأنسب للإجراء التشخيصي، بما يسهم في تقليل التعرض غير الضروري للإشعاع وتحسين كفاءة التشخيص وسلامة المرضى.

الكلمات المفتاحية: معامل المخاطر؛ قياس الجرعات المقارن؛ mTc99 و I123.

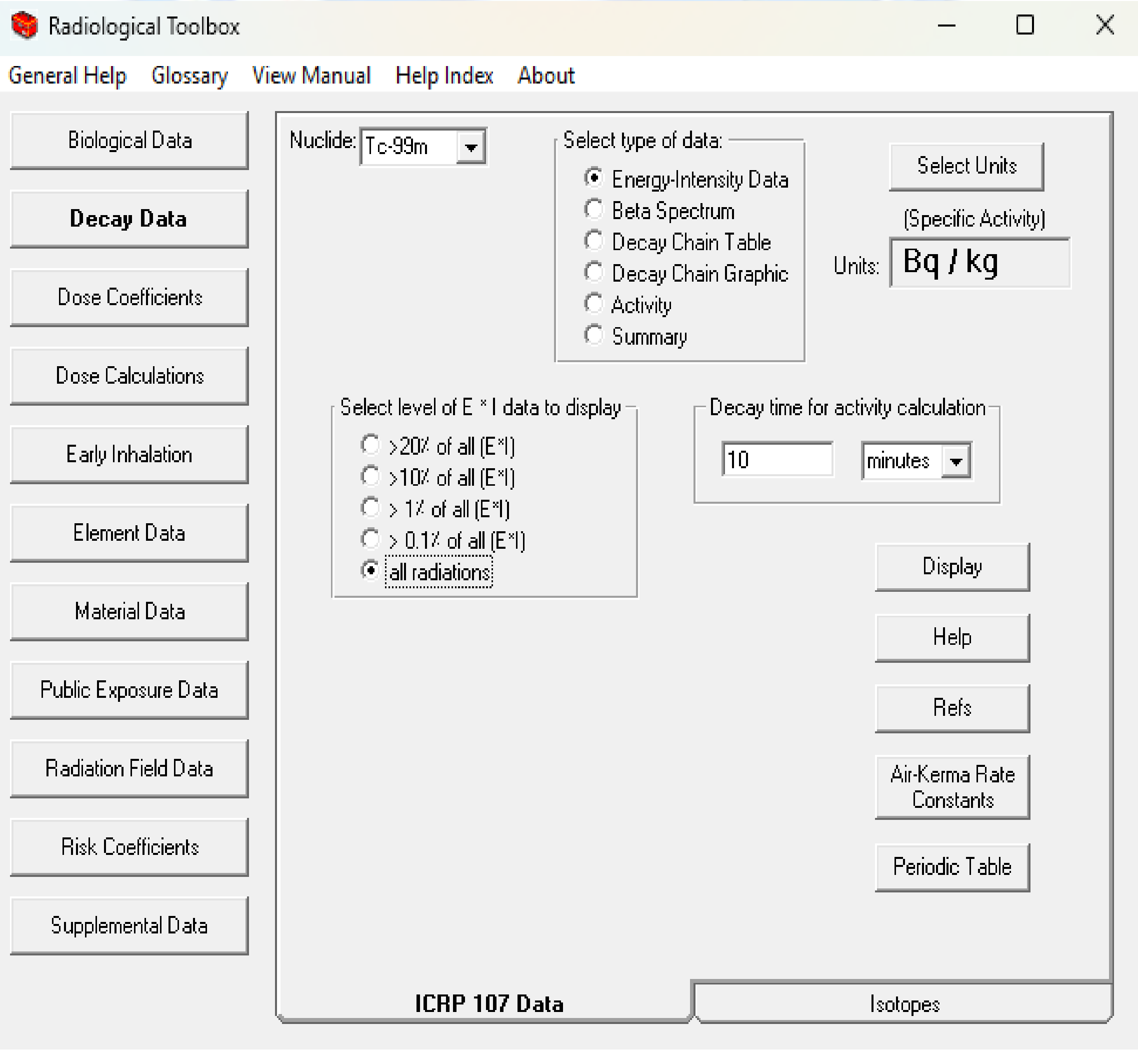
Abstract: This research paper addresses the understanding of radiological principles, more specifically in the context of nuclear medicine diagnostics. The study revolves around two radionuclides, Technetium-99m (^99m^Tc) and Iodine-123 (^123^I), which are both widely applied. They each possess distinctive physical and nuclear properties that have direct and significant influences on both the resulting radiological dose delivered to the patient and risk levels involved. The main methodology of this paper involves an in-depth comparative study of ^99m^Tc and ^123^I used in Single-Photon Emission Computed Tomography (SPECT) imaging. This is achieved using the Radiological Toolbox to analyze in-depth and understand their physical properties, such as half-life and photon emission energies. The Federal Guidance Report data base (FGR13-DB) is employed for estimating the absorbed dose and the risk coefficients of every radionuclide administration appropriately. Finally, this study aims to offer the necessary scientific basis for making informed and logical decisions in selecting the optimal radiopharmaceutical for a specific diagnostic procedure. The resultant data is intended to optimize patient outcomes by mitigating superfluous radiation exposure, consequently minimizing the potential for long-term health compromise, and concurrently improve diagnostic efficacy.

Keywords: Risk Coefficient; Comparative Dosimetry; ^{99m}Tc and ^{123}I.

INTRODUCTION

A medical imaging method called single photon emission computed tomography (SPECT) is based on tomographic reconstruction techniques and standard nuclear medicine imaging. The pictures show functional details about the patients, much like positron emission tomography (PET) does. In contrast to PET, which uses radiopharmaceuticals that emit positrons followed by the generation of two 511-keV annihilation photons, SPECT uses radiopharmaceuticals that are frequently found in nuclear medicine clinics. Radiopharmaceutical amount that can be administered as restricted by the permitted radiation dose to the patient. Although the amount of dose is small, periodic studies of these pharmaceutical drugs are necessary to ensure compliance with public health safety standards and to achieve better outcomes by minimizing radiation exposure (National Research Council, 1996). The ability to accurately calculate the absorbed dose in the body's organs and tissues for individuals exposed to external radiation sources and radiation from internally distributed radionuclides is crucial for radiological protection. Due to the difficulty of measuring the absorbed dose to organs and tissues, computer programs are required. In the case of occupational and environmental exposures involving radionuclides that enter the body through ingestion and inhalation, the Dose and Risk Calculation (Andersson *et al*., 2017).

This study aims to enhance understanding of radionuclides used in nuclear medicine by comparing the dose coefficients and risk coefficients of ^99m^Tc and ^123^I, which are commonly used in SPECT, using the Toolbox for studying physical properties and FGR13_DB for calculating dose and risk coefficients as shown in Fig.1 and 2.



Nuclide: Tc-99m

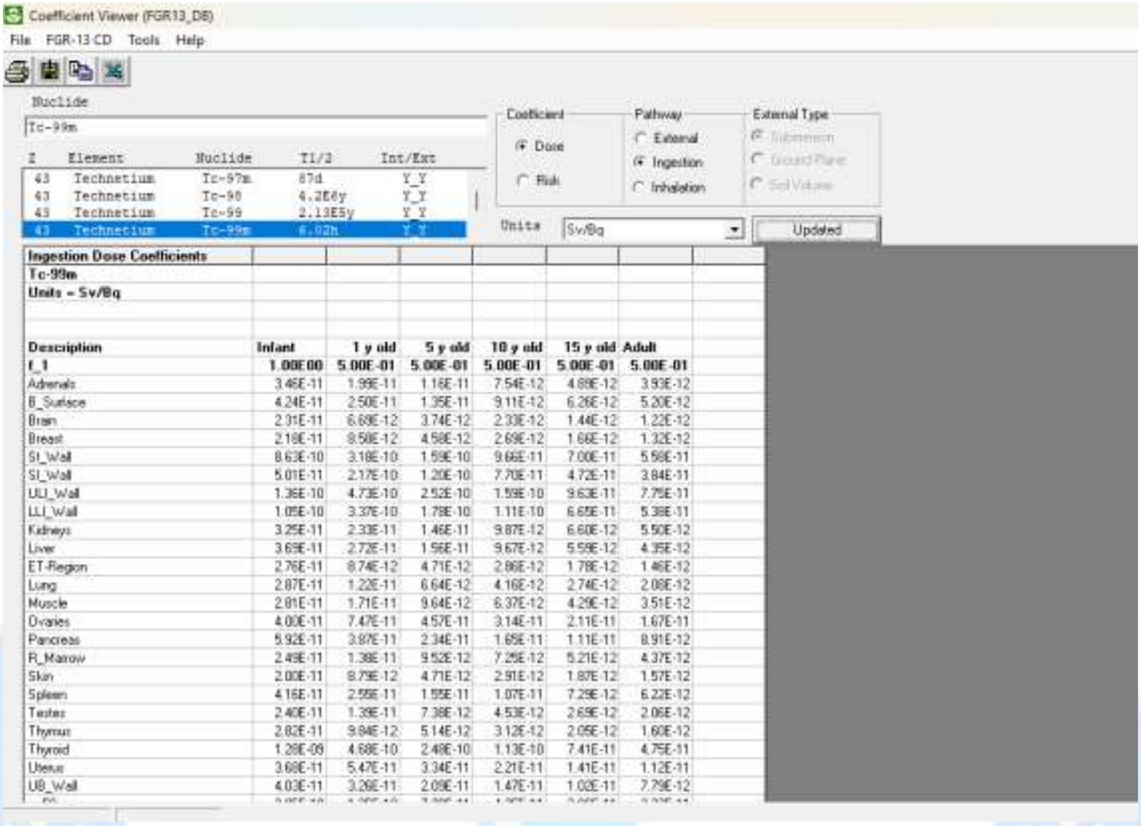
Select type of data:
● Energy-Intensity Data
○ Beta Spectrum
○ Decay Chain Table
○ Decay Chain Graphic
○ Activity
○ Summary

(Specific Activity)
Units: Bq / kg

Select level of E * I data to display
○ >20% of all (E*I)
○ >10% of all (E*I)
○ > 1% of all (E*I)
○ > 0.1% of all (E*I)
● all radiations

Decay time for activity calculation
10 minutes

Fig 1: Radiology Toolbox Database.



Nuclide: Tc-99m

Z	Element	Nuclide	T1/2	Int/Ext
43	Technetium	Tc-97m	87d	Y_Y
43	Technetium	Tc-98	4.2E6y	Y_Y
43	Technetium	Tc-99	2.13E5y	Y_Y
43	Technetium	Tc-99m	6.02h	Y_Y

Coefficient: ● Dose ○ Risk

Pathway: ○ External ● Ingestion ○ Inhalation

Units: Sv/Bq

Ingestion Dose Coefficients
Tc-99m
Units = Sv/Bq

Description	Infant	1 y old	5 y old	10 y old	15 y old	Adult
f_1	1.00E00	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01
Adrenals	3.46E-11	1.99E-11	1.16E-11	7.54E-12	4.89E-12	3.93E-12
B_Surface	4.24E-11	2.50E-11	1.35E-11	9.11E-12	6.26E-12	5.20E-12
Brain	2.31E-11	6.69E-12	3.74E-12	2.33E-12	1.44E-12	1.22E-12
Breast	2.18E-11	8.50E-12	4.58E-12	2.69E-12	1.66E-12	1.32E-12
St_Wall	8.63E-10	3.18E-10	1.59E-10	9.66E-11	7.00E-11	5.58E-11
SI_Wall	5.01E-11	2.17E-10	1.20E-10	7.70E-11	4.72E-11	3.84E-11
ULI_Wall	1.36E-10	4.73E-10	2.52E-10	1.59E-10	9.63E-11	7.75E-11
LLI_Wall	1.05E-10	3.37E-10	1.78E-10	1.11E-10	6.65E-11	5.38E-11
Kidneys	3.25E-11	2.33E-11	1.46E-11	9.87E-12	6.60E-12	5.50E-12
Liver	3.69E-11	2.72E-11	1.56E-11	9.67E-12	5.59E-12	4.35E-12
ET-Region	2.76E-11	8.74E-12	4.71E-12	2.86E-12	1.78E-12	1.46E-12
Lung	2.87E-11	1.22E-11	6.64E-12	4.16E-12	2.74E-12	2.08E-12
Muscle	2.81E-11	1.71E-11	9.64E-12	6.37E-12	4.29E-12	3.51E-12
Ovaries	4.00E-11	7.47E-11	4.57E-11	3.14E-11	2.11E-11	1.67E-11
Pancreas	5.92E-11	3.87E-11	2.34E-11	1.65E-11	1.11E-11	8.91E-12
R_Marrow	2.49E-11	1.38E-11	9.52E-12	7.25E-12	5.21E-12	4.37E-12
Skin	2.00E-11	8.79E-12	4.71E-12	2.91E-12	1.87E-12	1.57E-12
Spleen	4.16E-11	2.55E-11	1.55E-11	1.07E-11	7.29E-12	6.22E-12
Testes	2.40E-11	1.39E-11	7.38E-12	4.53E-12	2.69E-12	2.06E-12
Thymus	2.82E-11	9.84E-12	5.14E-12	3.12E-12	2.05E-12	1.60E-12
Thyroid	1.28E-09	4.68E-10	2.48E-10	1.13E-10	7.41E-11	4.75E-11
Uterus	3.68E-11	5.47E-11	3.34E-11	2.21E-11	1.41E-11	1.12E-11
UB_Wall	4.03E-11	3.26E-11	2.09E-11	1.47E-11	1.02E-11	7.79E-12

Fig 2: The Federal Guidance Report data base (FGR13_DB).

METHODOLOGY

Utilizing data from International Commission on Radiological Protection (ICRP) Publication 107, the radiology Toolbox software will be used. The extensive radionuclide decay data within the toolbox covers detailed information on the energy and intensity of radiation emitted during nuclear transformations (decays), types of emitted radiation, and radioactivity/time-integrated radioactivity calculations over different time intervals (Eckerman *et al*., 2013).

Activity (A) and Integrated Activity (A_I):

Radioactivity is a natural and spontaneous property possessed by the nuclei of unstable atoms (radionuclides). These nuclei strive to reach a more stable state through decay, and this decay process is accompanied by the emission of various types of radiation and energy. This phenomenon is expressed by the following equation:

$$A(t) = A_0 e^{-\lambda t} \qquad (1)$$

Where $A(t)$ is the remaining activity at time t, A_0 is the initial activity, λ is the decay constant.

The integrated activity is defined as the total number of nuclear transformations that occur in a source over a specified time period. The calculation involves integrating the source's activity (A) over the duration of the exposure (t), and the result is typically expressed in units of Becquerel-seconds (Bq.s):

$$A_I = At \qquad (2)$$

Or

$$A_I = \int_0^t A(\acute{t})\, d\acute{t} \qquad (3)$$

Specific Activity (S_A):

Specific activity is undoubtedly one of the most critical factors in the production of radiopharmaceuticals. When administering low doses of radiotracers, it is important to note that the mass of the supplied compound is often less than the amount required to elicit a biological response. This observation forms the core of the radiotracer concept. In nuclear medicine, specific activity for both therapeutic and diagnostic radiopharmaceuticals is defined as the substance's radioactivity per unit mass or per mole, typically expressed in Bq. mol^{-1} or Bq. Kg^{-1}:

$$S_A = \frac{\lambda N_a}{M} \qquad (4)$$

where M is radionuclides molar mass, and Na is the Avogadro number (Lapi & Welch, 2012)

Dose Coefficient:

Dose coefficients are applied to measured or anticipated concentrations of radionuclides in the environment or workplace to determine the equivalent dose and effective dose values for radiation protection. These coefficients are derived from anatomical and physiological data for Reference Individuals (e.g., Reference Adult Male). The radiation protection community has a shared foundation thanks to these reference data (ICRP, 2007).

Internal exposure to ionizing radiation happens when a radionuclide is inhaled, eaten, or enters the bloodstream in any other way (for instance, through an injection or a wound). The end of internal exposure occurs when the radionuclide is eliminated from the body, either spontaneously (for instance, through faeces) or as a result of medical treatment. For internal exposure, the dosage coefficients for ingestion and inhalation will be estimated. Age-specific biokinetic models will be used to determine the time-dependent actions of the radionuclides after they enter the body.

The following calculations will be conducted for six age groups: infants, 1year, 5 years, 10 years, 15 years, and adults. There are two kinds of body regions are considered in dosimetric models for internal emitters: source regions and target regions. "Source regions" identify the areas of the body where radioactivity is found. "Target regions" are the tissues and organs that can be used to calculate the radiation dosage. These organs and tissues will be evaluated: Adrenals, Bone surface (B_Surface), Brain, Breast, Stomach wall (St_Wall), Small intestine wall (SI_Wall), Upper large intestine wall (ULI_Wall), Lower large intestine wall (LLI_Wall), Kidneys, Liver, Extra-Thoracic airway (ET-Region), Lung, Muscle, Ovaries, Pancreas, R_Marrow, Skin, Spleen, Testes, Thymus, Thyroid, Uterus, Urine Bladder wall (UB_Wall) (Bellamy *et al.*, 2017; U.S. EPA, 1999). The dose coefficient takes into account factors such as the specific organs or tissues that are exposed to radiation and the particle size of the material that is consumed.

The absorption of radionuclides into the blood is defined by values of fractional absorption from the small intestine, or "f_1 value," which indicate the portion of the element's ingested quantity that is absorbed to blood (Melo *et al.*, 2022). For the purpose to calculate inhalation dose coefficients, the ICRP defined numerical values for model parameters and classified absorption into three categories: slow (Type S), medium (Type M), and fast (Type F). According to the particle deposition model, smaller particles are mostly found in the extra-thoracic airways, whereas larger particles are more likely to be deposited in the upper respiratory tract. Although larger particles may result in higher expulsion rates and less deposition in alveolar regions, larger particles tend to deposit more in bronchial, bronchiolar, and alveolar areas (Melo *et al.*, 2022).

Risk Coefficient:

The risk coefficient allows quantification of the average risk per unit exposure to radionuclides over a lifetime or a short period. According to FGR 13 (U.S. EPA, 1999), the coefficient refers to the general public, which is based on age and gender distributions from a hypothetical population, drawing cancer death rates from recent data (Kim *et al.*, 2016). The risk coefficients for morbidity and mortality from cancer resulting from indoor exposure to radionuclides will be calculated for the 0–110-year age group, and the results for both radionuclides will be compared.

RESULT AND DISCUSSION

A. Activity (Bq) and Integrated Activity (Bq.s):

The activity was calculated using Eq 1. and the toolbox software. Fig.3 shows the instantaneous activity of the radionuclides ^{99m}Tc and ^{123}I during a short period of time, up to around 7 days. At first (3 hours), the activity of ^{123}I was a little greater (about 0.85 Bq) than that of ^{99m}Tc (about 0.7 Bq). Both isotopes decay rapidly in an exponential manner, but ^{99m}Tc reaches near-zero activity (≈ 0.05 Bq) after 864000 seconds (1 day), whereas the ^{123}I continues to persist.

This fast initial drop of ^{99m}Tc is in line with its much shorter physical half-life as opposed to that of ^{123}I. The accumulation of total decays (in Bq.s) over an extended period of time is shown in Fig.4. The amount of radiation delivered to the tissue is directly proportional to this value. This figure clearly demonstrates the critical role of the half-life in determining the cumulative dose: the integrated activity curve for ^{99m}Tc rapidly stabilizes (plateaus) at approximately 31240 Bq·s by 345600 s (4 days), confirming the near completion of all decay events. On the other hand, the combined activity for ^{123}I continues to increase steeply for a longer period, reaching a significantly higher final plateau of around 68920 Bq.s by 1209600 s (2 weeks). Even though the initial instantaneous activities are similar, the total integrated activity of the ^{123}I nuclide is almost 2.3-fold higher than ^{99m}Tc. This means that the cumulative radiation dose delivered to the patient per unit of administered activity is significantly higher than ^{99m}Tc.

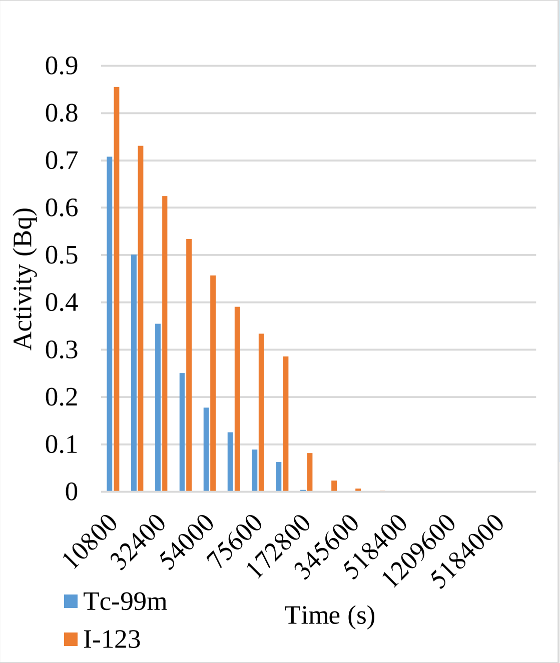


Fig 3: Comparison of the activity of ^{99m}Tc and ^{123}I isotopes as a function of time.

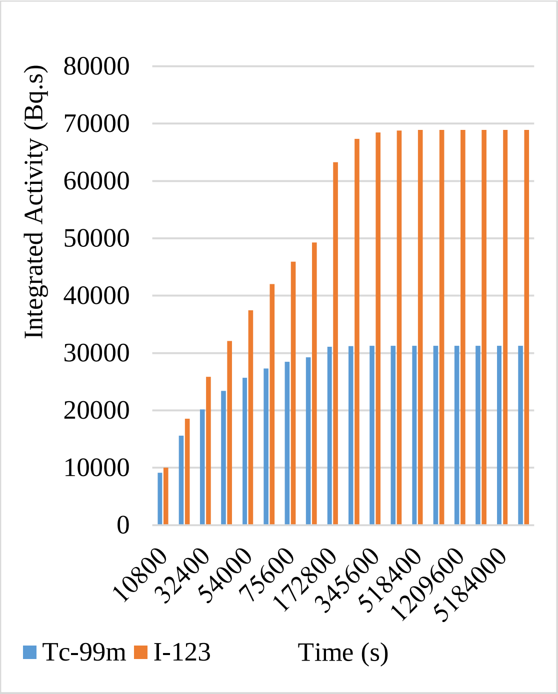


Fig 4: Integrated activity of ^{99m}Tc and ^{123}I.

B. Specific activity (Bq.s):

As previously mentioned, specific activity is defined as the activity per unit mass. We can calculate this value either using the general Eq.4 or by obtaining it from a database (Toolbox). The data indicates that the specific activity of ^{99m}Tc is higher than that of ^{123}I due to the inverse relationship with the radionuclide's half-life. TABLE I presents the specific activity values and their corresponding half-lives for both radionuclides.

Table I: Specific Activity and Half-Lives of the 99mtc and 123i.

Radionuclide	Half-life (h)	S_A (Bq/kg)
^{99m}Tc	6.02	7.11×10^{19}
^{123}I	13.2	1.949×10^{20}

C. Comparative analysis of Ingested Dose Coefficients:

The organ sensitivity to radiation exposure is shown in Fig. 5 and 6 for $^{99\,m}$Tc and ^{123}I for different age groups (ranging from infants to adults). The dose coefficient represents the equivalent dose delivered to a particular organ per unit of administered activity. The dose coefficients for $^{99\,m}$Tc are usually lower than those of ^{123}I. It has been shown that the Thyroid is the organ receiving the highest dose coefficient for infants, while the ULI_Wall was the most exposed organ to these coefficients in other age groups. These coefficients generally range between 7.75×10^{-11} and 4.73×10^{-10} Sv/Bq for most of the age categories included in the study. The results show an inverse relationship with age, which is consistent with radiological principles: dose coefficients are typically highest for infants and decrease with patient age, with the adult receiving the lowest dose per Becquerel. In addition to other biological factors, the main cause of this increase is children's smaller organ mass, which concentrates the administered activity in a smaller volume and results in a higher absorbed dose. The ^{123}I dose coefficients exhibit a very different pattern, which is mostly explained by iodine's strong biological affinity for the Thyroid. The Thyroid is the organ with the overwhelmingly highest dose coefficient. The Thyroid dose coefficient for infants is close to 1.00×10^{-08} Sv/Bq. In terms of quantitative comparison, the Thyroid dose coefficient for ^{123}I ($\approx10^{-08}$ Sv/Bq) is two orders of magnitude higher than the highest dose coefficient found for $^{99\,m}$Tc ($\approx10^{-10}$ Sv/Bq). The high dose disparity for the Thyroid is significant across all age groups, even though the coefficients decrease with age. In conclusion, the Thyroid receives a substantially greater dose from ^{123}I for the same administered activity than any other organ would from ^{99m}Tc. This important distinction emphasizes how important it is to carefully plan doses when using iodine isotopes, particularly in pediatric populations. Table II. shows a comparison between these two radioactive isotopes and their effect on diagnostic nuclear medicine.

Table II: Comparison And Impact on Nuclear Medicine.

Feature	^{99m}Tc	^{123}I
Organ with the Highest Dose	St_ Wall / ULI_Wall	Thyroid
Maximum Value	$\approx2\times10^{-10}$ Sv/Bq	$\approx10^{-08}$ Sv/Bq
Main Conclusion	The dose is mainly affected by the excretion pathway of radiopharmaceutical.	The dose is mainly affected by the excretion pathway of the radiopharmaceutical.

D. Analysis of Inhaled Dose Coefficients for ^{99m}Tc.:

A rigorous examination of Fig.7, 8, and 9 reveals that the spatial distribution of the absorbed dose is fundamentally dictated by the kinetics of the radionuclide's transfer from the pulmonary system to the systemic circulation, a process critically dependent upon its inherent solubility characteristic. In all three solubility types F, M, and S, the ET region (trachea and upper respiratory tract) and the Liver receive the highest dose coefficients. The highest values in the ET-Region range from approximately 1.79×10^{-10} Sv/Bq for adults up to 1.52×10^{-09} Sv/Bq for infants. Type F exhibits the highest dose in non-pulmonary organs such as the Liver, Thyroid, and St_Wall. This reflects the rapid absorption of the radionuclide from the lung into the bloodstream, followed by systemic distribution. Analysis of the Type S data confirms substantial dose deposition in both the ET region and the Lung, indicative of extended residence time and sluggish clearance from the respiratory tract. Furthermore, the Type M behavior is clearly delineated as an intermediate state, bridging the differences observed between Type F and Type S particulates.

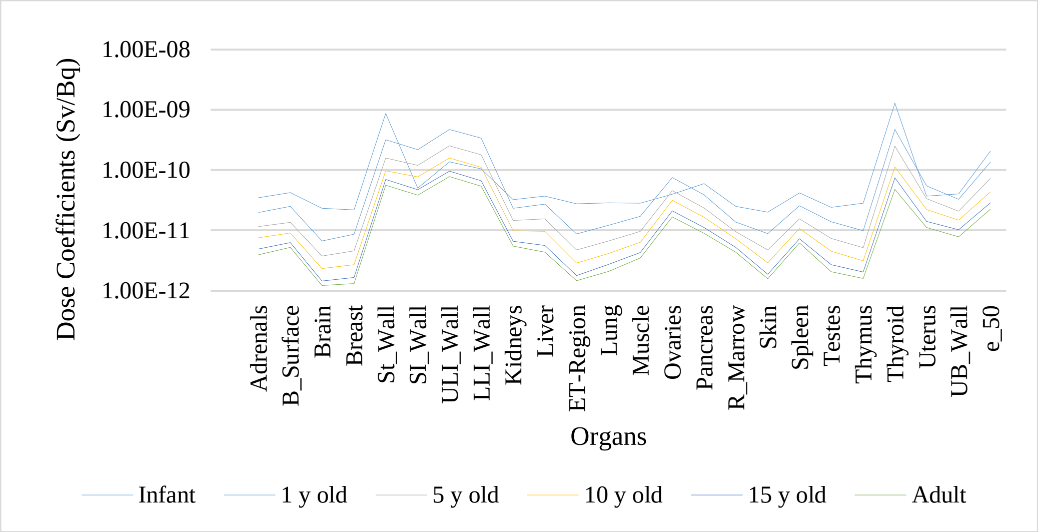


Fig 5: Variation in Organ Dose Coefficients (Sv/Bq) for ^{99m}Tc.

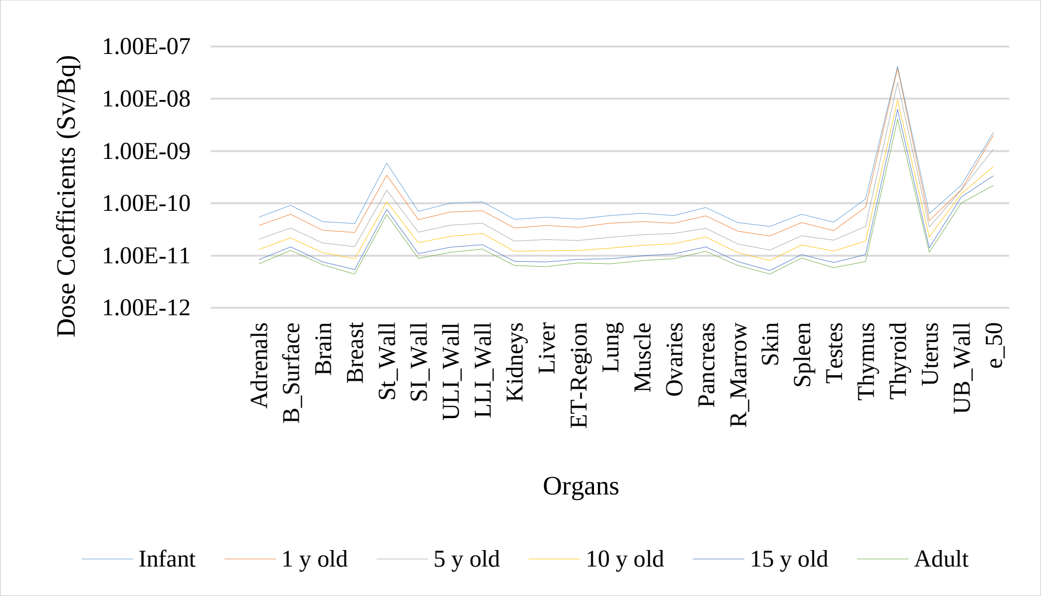


Fig 6: Variation in Organ Dose Coefficients (Sv/Bq) for ^{123}I.

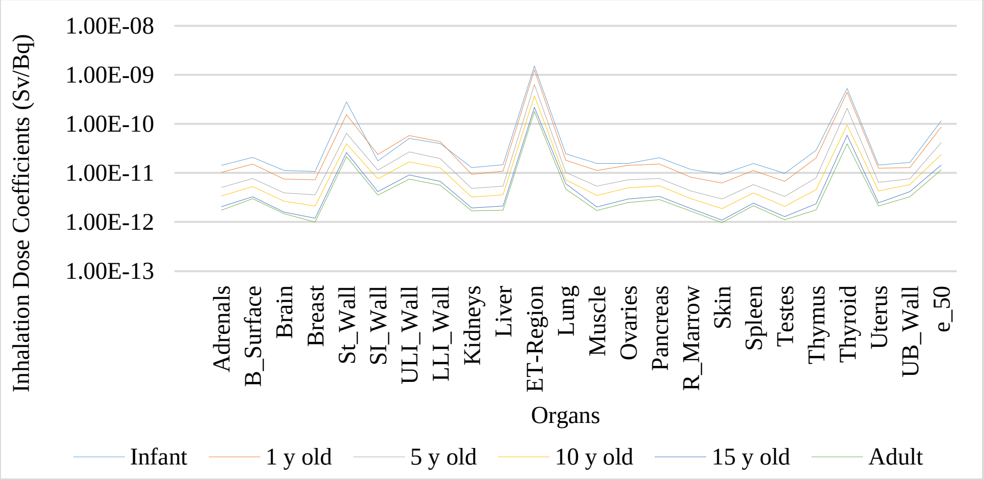


Fig 7: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type F Particulates.

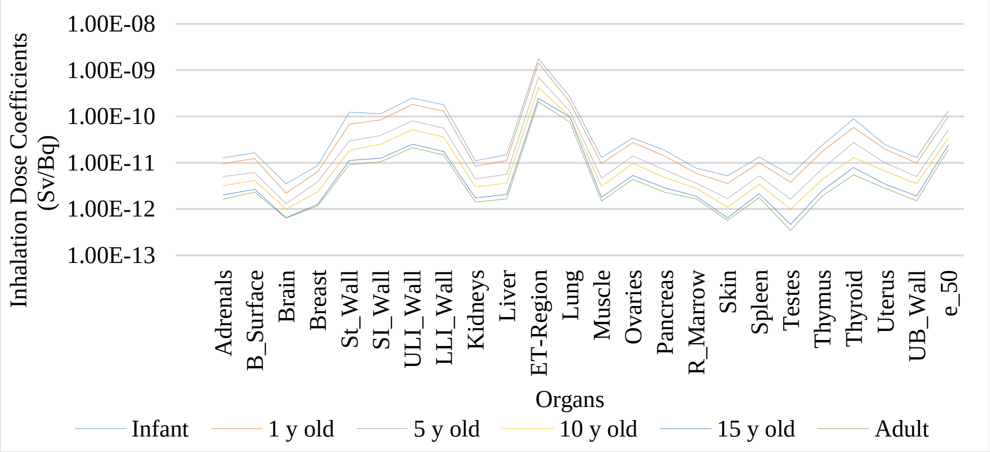


Fig 8: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type M Particulates.

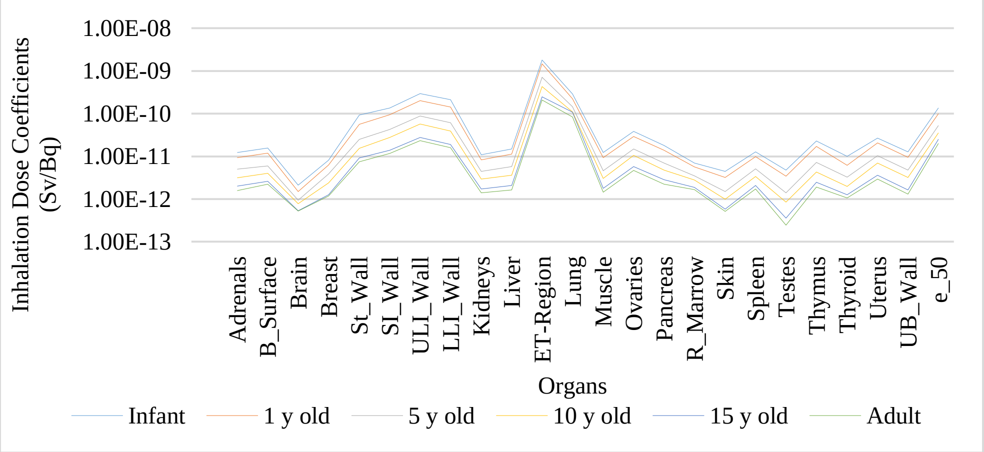


Fig 9: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type S Particulates.

E. Analysis of Inhaled Dose Coefficients for ^{123}I.:

A focused analysis of Fig. 10, 11, and 12 reveals a distinct and consistent pattern characterized by a highly concentrated absorbed dose. Specifically, the Thyroid Gland unequivocally emerges as the critical organ, receiving the maximal dose coefficient for the Type F particulate. This is attributable to the rapid absorption of iodine from the lung into the blood, followed by extremely fast biological uptake by the thyroid. The dose in the Thyroid peaks at 1.68×10^{-08} Sv/Bq for infants and 1.39×10^{-09} Sv/Bq. Types M and S show slightly lower thyroid doses compared to Type F, due to partial retention in the ET_Region which delays its arrival into the bloodstream. With values ranging from 5.85×10^{-10} to 4.97×10^{-09} Sv/Bq for particles of type M and from 5.90×10^{-10} to 5.02×10^{-09} Sv/Bq for particles of type S. TABLE III. shows a comparison between these two radioactive isotopes and their effect on diagnostic nuclear medicine.

Table III: Comparison Between the Two Radionuclides and Clinical Effects.

Feature	^{123}**I**	^{99m}**Tc**
Maximum Dose Limit	≈10^{-09} Sv/Bq (In Liver / ET-Region)	≈10^{-07} Sv/Bq (In Thyroid)
Dose Difference	Approximately 100 times less than ^{123} I	Approximately 100 times higher than ^{99m} Tc
Crucial Dose Coefficient	Pulmonary/Intestinal Clearance and Chemical Compound Distribution	Biologically Determined Thyroid Binding Sites

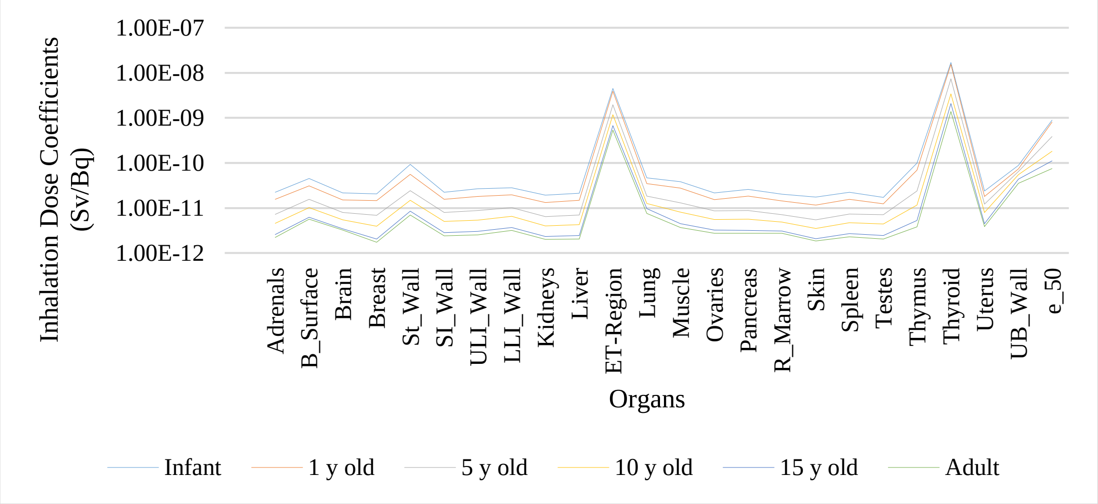


Fig 10: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type F Particulates.

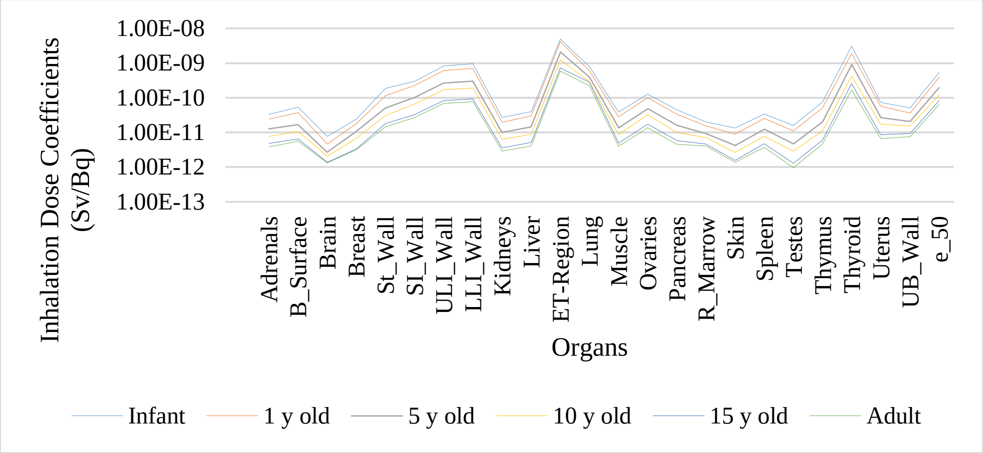


Fig 11: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type M Particulates.

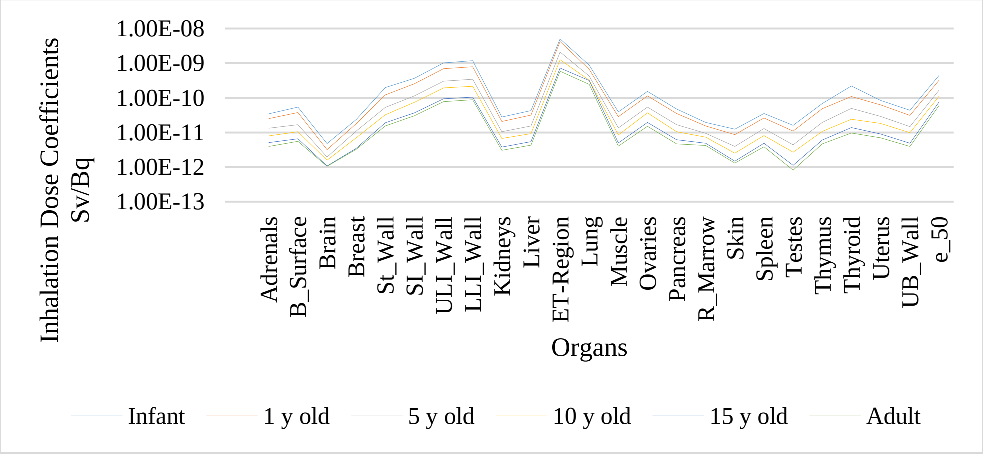


Fig 12: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type S Particulates.

F. Risk Coefficient (Bq^{-1}):

1. Comparative Analysis of Ingestion Risk Coefficients (^{123}I and ^{99m} Tc):

The data clearly shows the risk coefficients for different organs resulting from the consumption of ^{123}I and ^{99m} Tc through two routes: drinking water (D Water) and food consumption, as shown in detail in Fig. 13 to 16.

Iodine-123: Exhibits a highly concentrated dose distribution pattern. The organ that unequivocally receives the highest risk coefficient is the Thyroid, with ingestion risk coefficients of 1.74×10^{-12} Bq^{-1} for mortality and 1.74×10^{-11} Bq^{-1} for morbidity for the 0-110 years age group. This is due to the high biological specificity of iodine towards this organ (rapid and vital uptake).

Table IV: General Behavior and Maximum Risk Coefficients.

Radionuclide	Organ Receiving the Highest Risk Dose	Approximate Maximum Risk Value
^{123}I	Thyroid	Ranges between 10^{-10} - 10^{-09} Bq^{-1}
^{99m} Tc	Colon	Ranges between 10^{-11} - 10^{-10} Bq^{-1}

Technetium-99m: Shows a less concentrated dose distribution pattern. The organ that receives the highest risk coefficient is the Colon (and, to a lesser extent, the Stomach), with ingestion risk coefficients of 7.78×10^{-13} and 2.28×10^{-13} Bq^{-1}, respectively for mortality and 7.78×10^{-13}, 2.53×10^{-13} $Bq^{-1}$for morbidity, for the 0-110 years age group. This indicates that the crucial dose factor is the excretion pathway and the passage of the radionuclide through the gastrointestinal tract before it is eliminated or partially absorbed.

For both radionuclides, there is no significant difference in risk coefficients between the drinking water and dietary intake pathways, indicating that the absorption and biological distribution mechanisms are key in determining final doses. Total risk values are higher for ^{123}I compared to ^{99m}Tc, primarily due to the larger dose received by the Thyroid ^{123}I.

All graphs demonstrate that younger age groups (specifically 0-5 years and 5-15 years) generally receive the highest risk coefficients compared to older age groups (25-70 years and 0-110 years).

2. Impact on Morbidity and Mortality Rates:

The final health risks are represented by the Total values, which include the subsequent cancer risks (morbidity and mortality).

Iodine-123: The Total risk is very high, driven mainly by the risk of Thyroid cancer.

Technetium-99m: The Total risk is much lower than that of ^{123}I. The organs that contribute most to the overall risk are those receiving the highest dose (the Colon and Stomach).

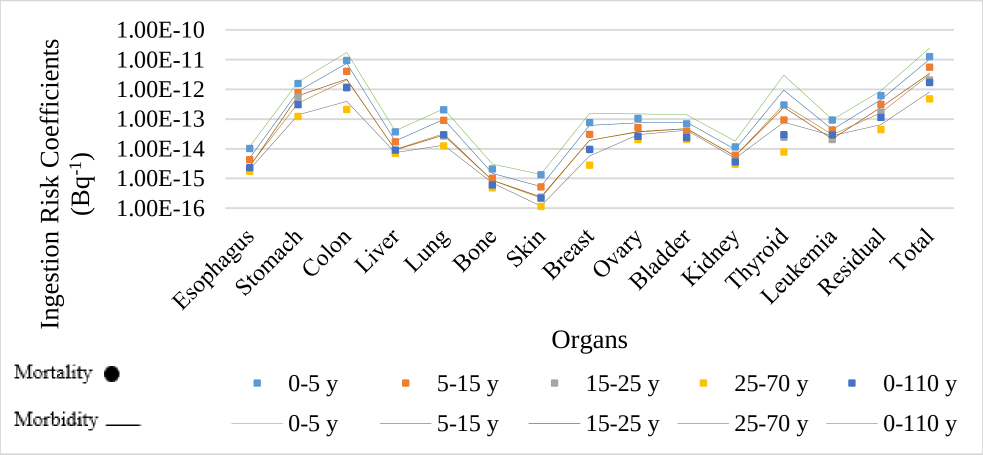


Fig 13: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{99m}Tc via Dietary.

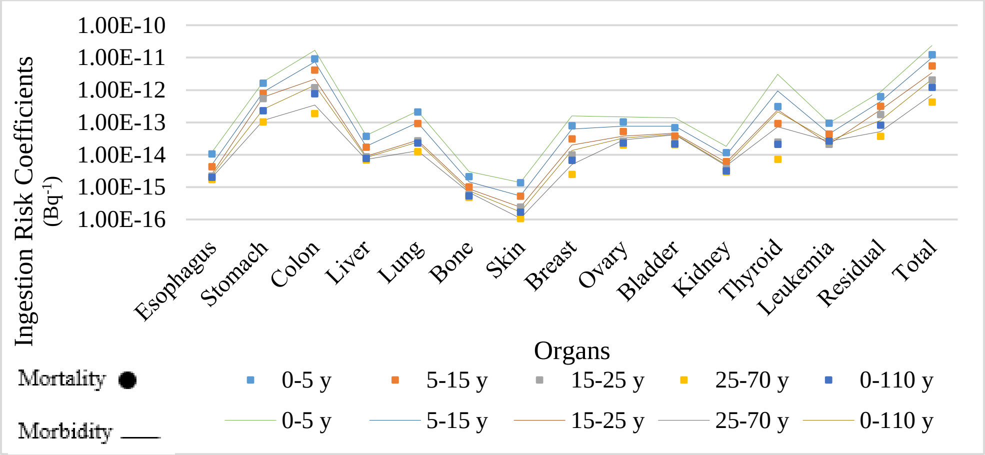


Fig 14: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{99m}Tc via Water Pathways.

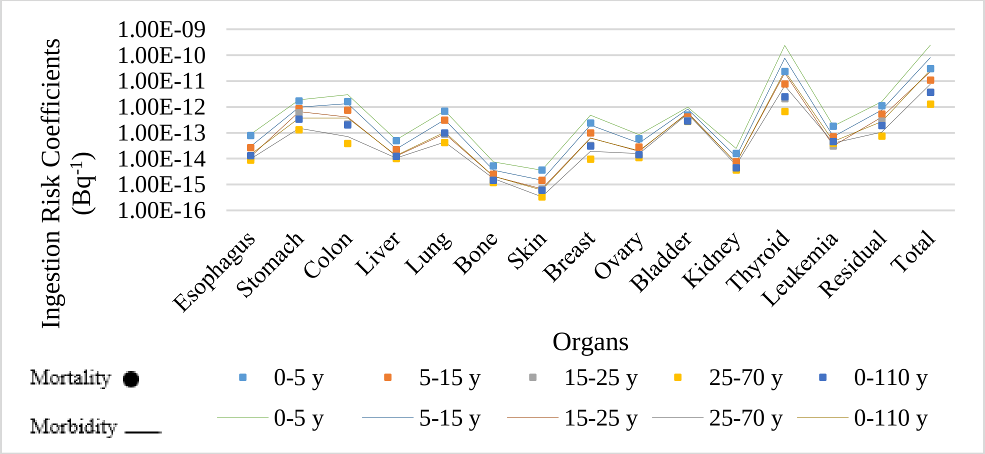


Fig15: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{123}I via Dietary.

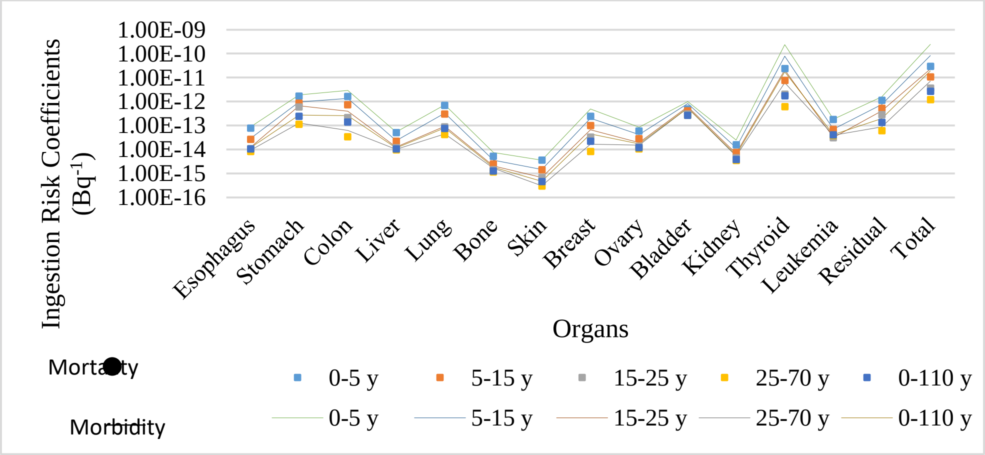


Fig 16: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{123}I via Water Pathways.

3. Comparative Analysis of Inhaled Radiation Risk Coefficients (Bq^{-1}):

A comprehensive dosimetry assessment, depicted across Fig. 17 to 19 for Particulate

Types F, M, and S, precisely quantifies the organ-specific and total-body inhalation risk coefficients over the lifetime (0-110 years). These derived coefficients inherently reflect the estimated probability of both cancer incidence (morbidity) and subsequent mortality per unit of inhaled activity.

- **Fast Absorption Particulates (Type F):** Type F particulates generally show a concentrated risk in organs where the radionuclide accumulates rapidly after reaching the bloodstream. For ^{123}I, the Thyroid stands out as the organ with the significantly highest risk across all types. This is particularly evident in Type F (especially for morbidity) because Iodine is rapidly absorbed by the thyroid. For ^{99m}Tc, which does not undergo organification in the thyroid like ^{123}I, the risk concentration in the thyroid is relatively lower compared to ^{123}I, although it still shows elevated risk in some other organs.
- **Particulates with Moderate and Slow Absorption (Type M & S):** As solubility decreases (from M to S), the residence time of the particulates in the respiratory tract (lungs and airways) increases, leading to a higher local radiation dose in the Lung. Slower absorption also reduces the activity reaching distant organs (such as the bladder, kidneys, and spleen) during the early stages, thereby altering the dose distribution.

In all cases, the risk coefficients for morbidity (cancer incidence) are higher than the risk coefficients for mortality for the same organ and for the total risk. This reflects the fact that the probability of developing cancer (morbidity) is greater than the probability of that cancer being fatal (mortality), a fundamental principle in radiation risk assessment models. TABLE. V illustrates the highest mortality and morbidity risk coefficients for the two radionuclides across all particulate types.

Table V: The Highest Mortality and Morbidity Risk Coefficients for the Two Radionuclides Across All Particulate Types.

			Type F				
^{99m}Tc				**^{123}I**			
Mortality		**Morbidity**		**Mortality**		**Morbidity**	
Organs	Value	organs	Value	organs	Value	organs	Value
Stomach	1.08×10^{-13}	Thyroid	2.15×10^{-13}	Thyroid	7.64×10^{-13}	Thyroid	7.64×10^{-12}
Colon	1.04×10^{-13}	Colon	1.89×10^{-13}	Bladder	9.39×10^{-14}	Bladder	1.88×10^{-13}
Lung	5.21×10^{-14}	Lung	5.49×10^{-14}	Lung	8.71×10^{-14}	Lung	9.17×10^{-14}
Type M							
Mortality		Morbidity		Mortality		Morbidity	
Organs	Value	organs	Value	organs	Value	organs	Value
Lung	7.78×10^{-13}	Lung	8.19×10^{-13}	Lung	2.27×10^{-12}	Lung	2.39×10^{-12}
Colon	2.96×10^{-13}	Colon	5.38×10^{-13}	Colon	1.18×10^{-12}	Colon	2.15×10^{-12}
Stomach	4.73×10^{-14}	Stomach	5.26×10^{-14}	Thyroid	9.30×10^{-14}	Thyroid	9.30×10^{-13}
Type S							

Mortality		Morbidity		Mortality		Morbidity	
Organs	Value	organs	Value	organs	Value	organs	Value
Lung	8.59×10^{-13}	Lung	9.04×10^{-13}	Lung	2.51×10^{-12}	Lung	2.65×10^{-12}
Colon	3.25×10^{-13}	Colon	5.91×10^{-13}	Colon	1.35×10^{-12}	Colon	2.45×10^{-12}
Stomach	3.91×10^{-14}	Stomach	4.35×10^{-14}	Stomach	8.20×10^{-14}	Stomach	9.11×10^{-14}

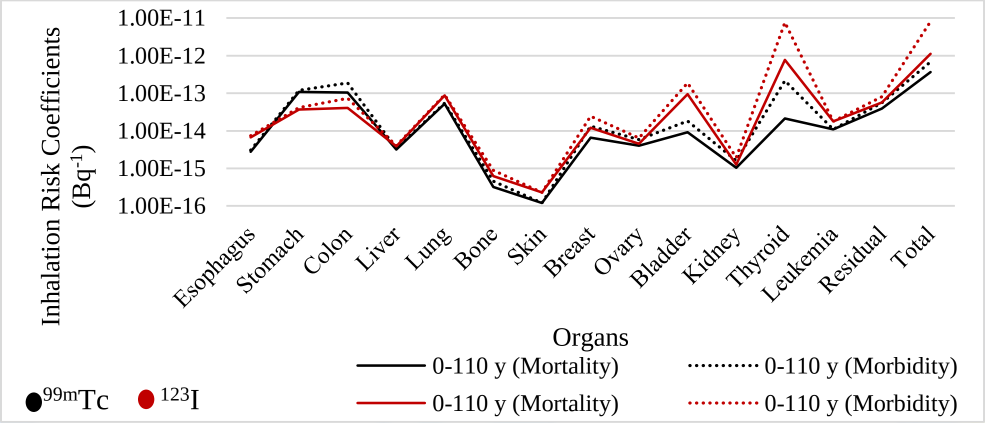


Fig 17: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type F Solubility.

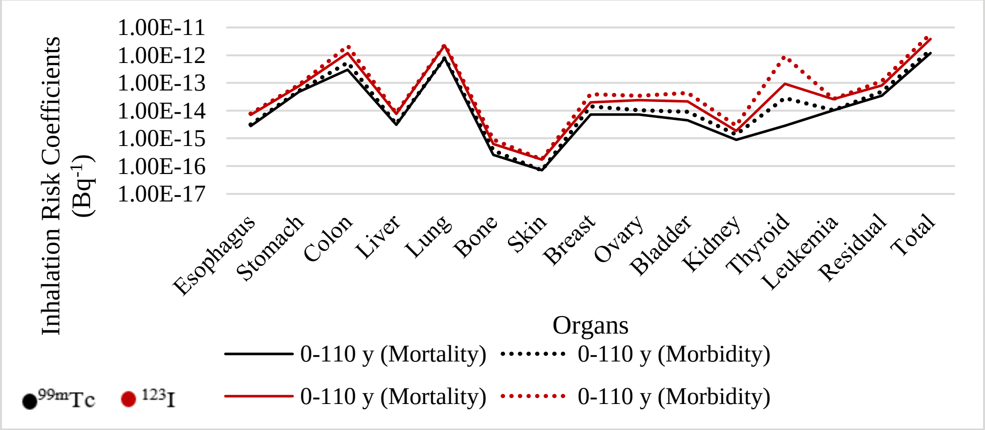


Fig 18: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type M Solubility.

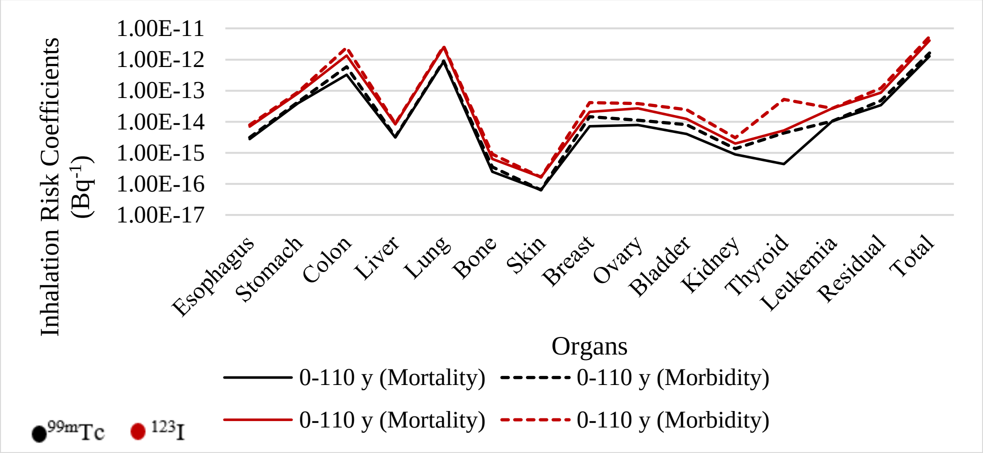


Fig 19: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type S Solubility.

CONCLUSION

Based on the study of the physical behavior of ^99m^Tc and ^123^I, a comparative analysis of dose and hazard parameters according to biological behavior and properties of radionuclides reveals several points, namely:

- The short half-life of ^99m^Tc has the following advantages: Over a very brief time (one day), it produces a concentrated burst of radioactivity. In many medical imaging applications where the lowest radiation dose while maintaining image quality is required, this is the recommended option because it drastically lowers the cumulative radiation dose to which the patient is exposed (about 2.3 times less than iodine).

- An advantage of ^123^I is its comparatively longer half-life. The persistence of its integrated activity over a longer period of time (up to two weeks) may make it appropriate for studies requiring extended biological tracing or when the time required for the radiotracer's absorption and distribution within the body is longer, despite the fact that its decay is slower and its cumulative dose is higher. As a result, choosing a radionuclide in nuclear medicine involves carefully weighing the patient's cumulative radiation dose, which should ideally be kept to a minimum, against the amount of time needed to gather the required clinical data.

- Upon comparing the specific activities, ^99m^Tc exhibited a higher specific activity compared to Iodine, which is attributed to its shorter half-life. A higher specific activity is associated with superior image quality for a very small quantity of the radiopharmaceutical.

- Iodine-123 exhibits a highly specific biological mechanism resulting in an extremely concentrated dose to the Thyroid, leading to a very high localized risk, especially for Thyroid cancer (morbidity). Technetium-99m, by contrast, has a less concentrated distribution, mainly affecting the colon and stomach wall upon intake. In all evaluated scenarios, the overall health risk (including morbidity and mortality) for ^123^I is consistently and significantly higher than that of ^99m^Tc.

- According to a universal principle, the risk coefficients for morbidity (or cancer incidence) are always higher than those for mortality for both radionuclides. This is because there is a greater chance of developing cancer than of it turning out to be lethal. The general principle is that age has an inverse relationship with dose coefficients. Accordingly, the dose received per administered becquerel is lowest for adults and highest for infants.

RECOMMENDATIONS

- Conducting research in the field of dose reduction and the development of radiopharmaceuticals.
- Verification of the clinical implications of the higher overall risks associated with ^{123}I.
- Establish optimized and standardized (or generalized) dosing protocols based on age.

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