Comparative dosimetric assessment of ambulatory and inpatient iodine-131 therapy using Monte Carlo simulations.

Abstract:

This work presents a regulatory and dosimetric comparison of three iodine-131 therapy scenarios in which 200 MBq, 3700 MBq, and 7400 MBq were administered to the male phantom ICPR. Monte Carlo modeling was used to evaluate dose distribution in tissues and organs. International radiation protection guidelines were applied according to the scenarios.Dose comparisons across scenarios demonstrate proportional scaling with administered activity, consistent with established Monte Carlo simulations. Occupational exposures and caregiver doses are evaluated relative to ICRP and IAEA release criteria. Results confirm safe feasibility of ambulatory treatment up to 3700 MBq under controlled exposure conditions, whereas higher activity administrations benefit from inpatient isolation due to cumulative exposure considerations.

Keywords

Iodine-131, ambulatory therapy, inpatient therapy, dosimetry, Monte Carlo simulation, radiation protection.

Introduction

Iodine-131 radiotherapy is widely used for hyperthyroidism and differentiated thyroid carcinoma. Historically, patients receiving high activities were hospitalized due to concerns regarding radiation exposure to staff and the public. However, evolving radiation protection standards now permit outpatient therapy under strict regulatory conditions. The ICRP recommends patient release based on doserate measurements and public exposure constraints [1,2], while the IAEA establishes quantitative release criteria, including a doserate threshold of approximately 30 µSv/h at 1 meter [3]. Harmonized guidelines from EANM and SNMMI also support ambulatory therapy up to 3.7 GBq provided that appropriate radiation safety instructions are delivered [4,5,6]. External exposure to patients around I-131 has been extensively studied. Measurements show rapid doserate decay with distance, supporting inverse square law considerations and favoring short duration patient interactions [7]. Monte Carlo simulations have been widely used to predict organspecific absorbed doses in individuals exposed to patients treated with iodine-131 [8,9]. Given these regulatory and radiation protection considerations, comparing staff and caregiver exposures across different therapeutic activities is essential for clinical decision making.

Materials and Methods

Monte Carlo modeling assumptions

The treated patient was modeled as an external photonemitting source corresponding to the iodine-131 decay scheme. A simplified ICRPadult male anthropomorphic geometry was assumed and absorbed and effective doses were calculated for an external receptor located at

1 m from the patient. This configuration reflects standard radiationprotection assessment conditions used for staff and caregiver exposure evaluations.Organ absorbed doses (µGy) and effective doses (µSv) were obtained from Visual Monte Carlo dose calculation software based simulation datasets provided by the scenarios.

Realistic scenario

Three activity scenarios were analyzed: Scenario A: 200 MBq, Scenario B: 3700 MBq, Scenario C: 7400 MBq. Exposure durations ranged from 5 to 60 minutes at a fixed distance of 1 meter. These durations represent conservative upperbound scenarios intended to assess worstcase radiationprotection conditions [10, 11, 12]. Monte Carlo approaches have been validated for similar external dose assessments in the nuclear medicine environment [8,13, 14, 15,16]. These simulations based dosimetric values were crossreferenced with published staffexposure measurements [7,16].

Results

The results of the Monte Carlo simulation calculations are presented in Tables 1, 2, and 3. The histograms in Figures 1, 2, and 3, derived from these tables, respectively illustrate thebiodistribution of absorbed doses by each organ and tissue, as well as the effective whole-body dose.

Dosimetric simulation of scenario A

Table 1: Scenario A, a person is exposed at 1 m from a patient who has absorbed 200 MBq of iodine 131 for durations of 5, 15, 20, 30 and 60 min.

Scenario	**Sc1A**	**Sc2A**	**Sc3A**	**Sc4A**	**Sc5A**	**Sc6A**
^{131}I activity (MBq)	200	200	200	200	200	200
Exposure duration (min)	5	10	15	20	30	60
Distance source(x :-100cm,y :26.5cm ,z :126.5cm) -worker (m)	1	1	1	1	1	1
Organs and tissues absorbed dose (µGy)						
Red bonemarrow	0.45	0.90	1.35	1.80	2.70	5.41
colon	0.62	1.24	1.86	2.48	3.72	7.45
lung	0.64	1.28	1.91	2.55	3.83	7.65
stomach	0.75	1.51	2.26	3.01	4.52	9.04
Breast	0.83	1.65	2.48	3.31	4.96	9.92
Remainder	0.55	1.09	1.64	2.18	3.28	6.55
Testes	0.48	0.95	1.43	1.91	2.86	5.72
bladder Wall	0.73	1.47	2.20	2.94	4.40	8.81
Oesophagus	0.63	1.27	1.90	2.53	3.80	7.59
Liver	0.64	1.28	1.92	2.56	3.84	7.67
Thyroid	0.97	1.95	2.92	3.89	5.84	11.68
Bone surface	0.45	0.91	1.36	1.82	2.72	5.45
Brain	0.43	0.87	1.30	1.73	2.60	5.19
Salivary gland	0.52	1.07	1.57	2.09	3.14	6.28
Skin	0.51	1.02	1.54	2.05	3.07	6.14
Eye lens	-	-	-	-	-	-
Wholeeye	0.59	1.17	1.76	2.34	3.51	7.03
Effective dose (µSv)	0.64	1.27	1.91	2.55	3.82	7.64

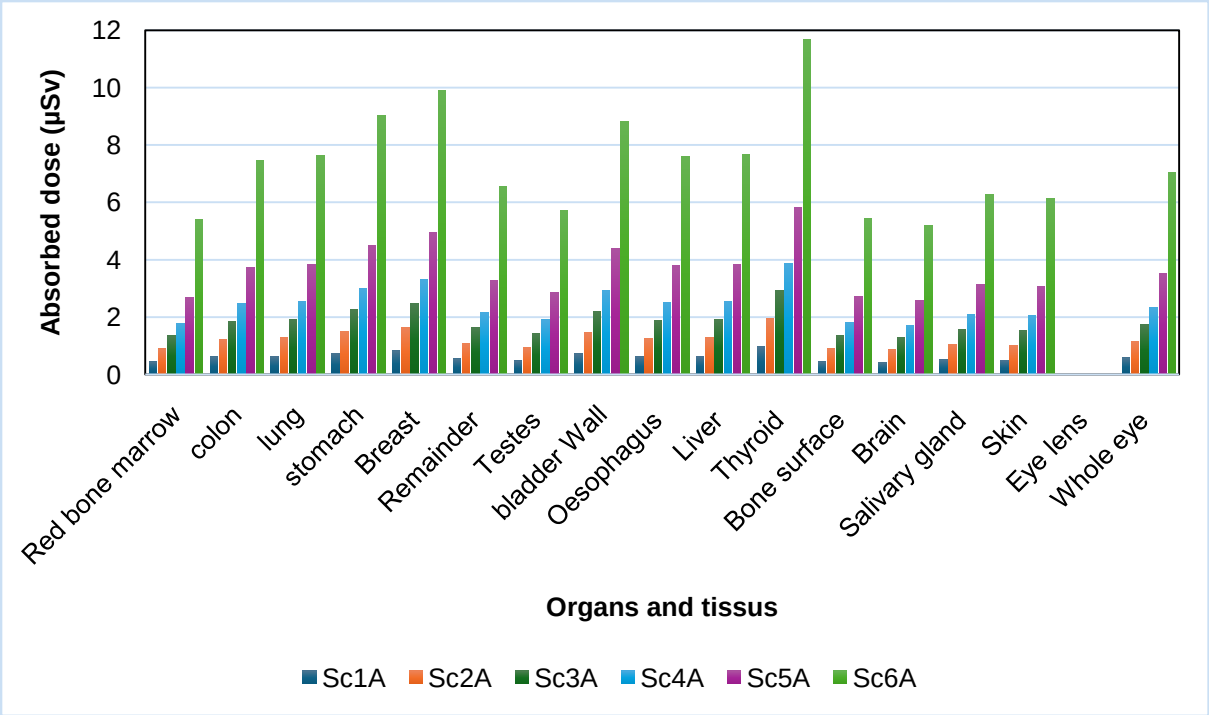

Figure 1: Absorbed dose of the exposed person in scenario A

Dosimetric simulation of scenario B

Table 2: Scenario B: a person is exposed at 1 m from a patient who has absorbed 3700 MBq of iodine 131 for durations of 5, 15, 20, 30 and 60 min.

Scenario	**Sc1B**	**Sc2B**	**Sc3B**	**Sc4B**	**Sc5B**	**Sc6B**
^{131}I activity (MBq)	3700	3700	3700	3700	3700	3700
Exposure duration (min)	5	10	15	20	30	60
Distance source(x :-100cm,y :26.5cm ,z :126.5cm) -worker (m)	1	1	1	1	1	1
Organs and tissues absorbed dose (µGy)						
Red bonemarrow	8.21	16.43	24.64	32.86	49.28	100
colon	12.72	25.45	38.17	50.89	76.34	150
lung	11.40	22.80	34.19	45.59	68.39	140
stomach	12.40	24.80	37.19	49.59	74.39	150
Breast	13.23	26.46	39.69	52.92	79.38	160
Remainder	11.20	22.40	33.61	44.81	67.21	130
Testes	10.42	20.83	31.25	41.67	62.50	120
bladder Wall	10.86	21.72	32.59	43.45	65.17	130
Oesophagus	15.66	31.31	46.97	62.62	93.94	190
Liver	11.83	23.66	35.49	47.32	70.98	140
Thyroid	12.51	25.03	37.54	50.05	75.08	150
Bone surface	8.40	16.80	25.19	33.59	50.39	100
Brain	7.41	14.82	22.23	29.64	44.47	90
Salivary gland	11.87	23.74	35.60	47.47	71.21	140
Skin	9.42	18.83	28.25	37.66	56.50	110
Eye lens	-	-	-	-	-	-
Wholeeye	10.15	20.31	30.46	40.62	60.93	110
Effective dose (µSv)	11.54	23.08	34.62	46.15	69.23	140

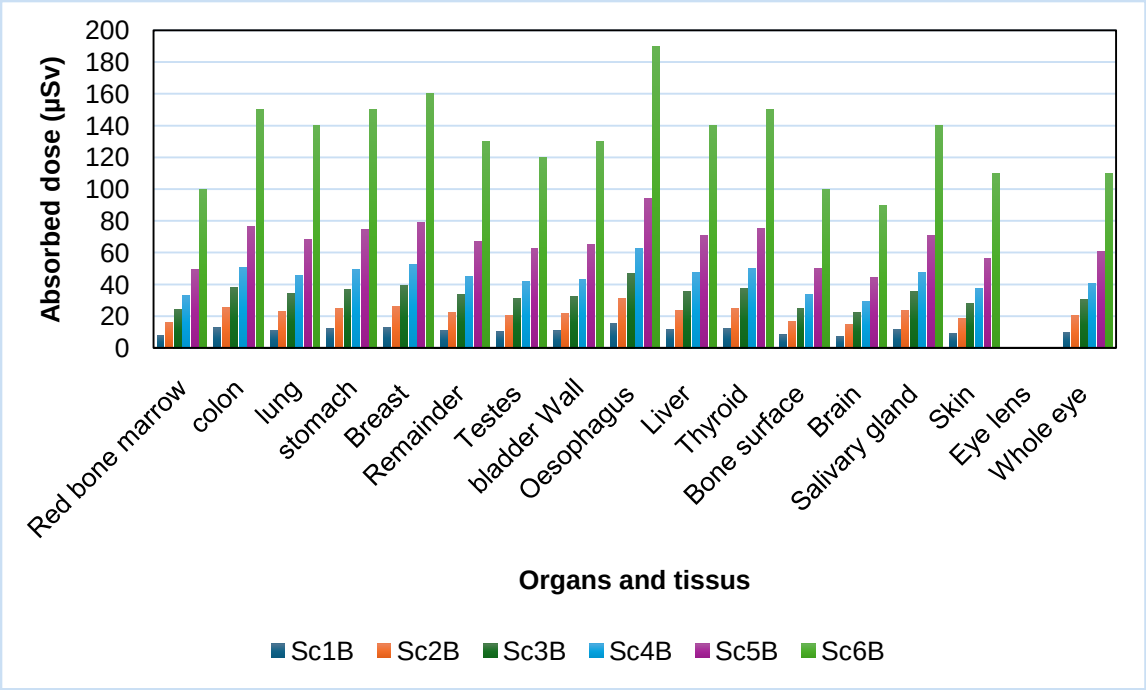

Figure 2: Absorbed dose of the exposed person in scenario B

Dosimetric simulation of scenario C

Table 3: Scenario C, a person is exposed at 1 m from a patient who has absorbed 7400 MBq of iodine 131 for durations of 5, 15, 20, 30 and 60 min.

Scenario	**Sc1C**	**Sc2C**	**Sc3C**	**Sc4C**	**Sc5C**	**Sc6C**
^{131}I activity (MBq)	7400	7400	7400	7400	7400	7400
Exposure duration (min)	5	10	15	20	30	60
Distance source (x :-100cm,y :26.5cm ,z :126.5cm) -worker (m)	1	1	1	1	1	1
Organs and tissues absorbed dose (µGy)						
Red bonemarrow	16.43	32.86	49.28	65.72	100	200
colon	25.46	50.89	76.34	101.78	150	310
lung	22.80	45.59	68.39	91.18	140	270
stomach	24.80	49.59	74.39	99.18	150	300
Breast	26.46	52.92	79.38	105.84	160	320
Remainder	22.40	44.81	67.21	89.62	130	270
Testes	20.83	41.67	62.50	83.34	120	250
bladder Wall	21.72	43.45	65.17	86.9	130	260
Oesophagus	31.31	62.62	93.94	125.24	120	380
Liver	23.66	47.32	70.98	94.64	190	280
Thyroid	25.03	50.05	75.08	100.1	150	300
Bone surface	16.80	33.59	50.39	67.18	100	200
Brain	14.82	39.64	44.47	79.28	90	180
Salivary gland	23.74	47.47	71.21	94.94	140	280
Skin	18.83	37.66	56.50	75.32	110	230
Eye lens	-	-	-	-	-	-
Wholeeye	30.31	40.62	60.93	81.24	120	240
Effective dose (µSv)	23.08	46.16	69.23	92.32	140	280

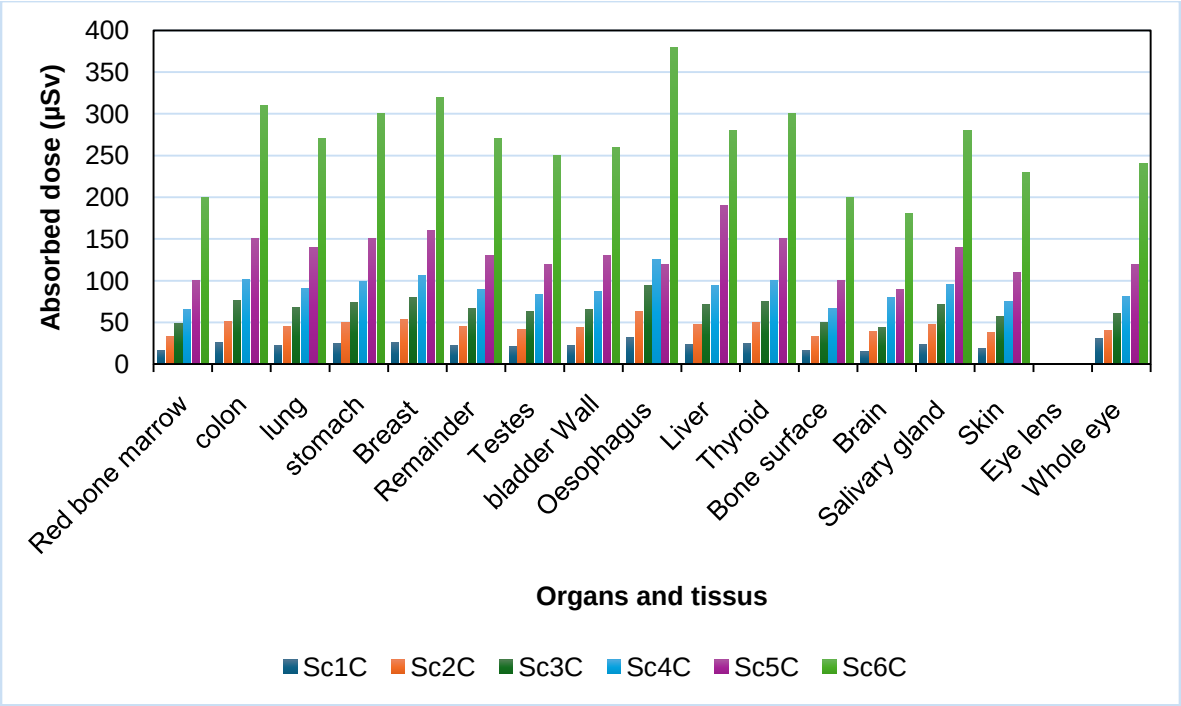

Figure 3: Absorbed dose of the exposed person in scenario C

Discussion

Time-dose linearity

Doses increase linearly with exposure duration for all organs, confirming time-dose proportionality. Comparison of Scenarios A, B, and C shows that doses scale almost exactly with administered activity, consistent with empirical measurements around I-131 patients [6,17]. The maximum effective dose at 1 hour for the Scenario A (200 MBq), Scenario B (3700 MBq) and Scenario C (7400 MBq) equal to 7.64 µSv ≈ 0,00764 mSv, 140 µSv ≈ 0,14 mSv and 280 µSv ≈ 0,28 mSv, respectively. These results align with published external-exposure patterns seen in nuclear medicine workers and caregivers [8,12]. Even the highest scenario (C) remains extremely low compared to the annual regulatory limits but beware of the repetition or cumulative duration of exposures.

Scenario A

At 200 MBq, absorbed doses remain in the low microgray range (0.4-11 µGy). The maximum effective dose of 7.64 µSv for 1 hour is negligible compared with annual regulatory limits [1,2]. These results correlate with low-activity thyroid therapy studies reporting minimal external exposure for staff [18]. Considering the minimum exposure, even 1 hour of close exposure remains at a few µSv. The impact on personnel could be explained by the fact that an individual could be exposed several thousand times before approaching 20 mSv/year. The impact on close contacts would show that the doses remain well below 1 mSv, even with relatively prolonged exposure times. The dose rate for patient release, according to Table 1, is approximately 7.64 µSv/h, significantly lower than 30 µSv/h [3].From a clinical perspective, the scenario falls within a wide safety zone, which justifies very flexible outpatient use,

subject to basic guidelines and an assessment of the home environment. Outpatient management is feasible under standard radiation-protection conditions.

Scenario B

The 3700 MBq scenario corresponds to standard outpatient ablation practice. This represents an approximately 18-fold increase compared to scenario A. The 60 minutes effective dose about 140 µSv or 0.14 mSv is consistent with occupational exposure surveys in nuclear medicine professionals [12], and caregiver measurements after outpatient therapy [16]. This dose is very low, but not negligible if multiplied by numerous interventions or prolonged contacts. Also, this dose level remains significantly below annual occupational limits (20 mSv/year) and below caregiver specific limits (5 mSv per treatment episode) [2,19]. This supports the feasibility of ambulatory administration at 3.7 GBq when distance and time precautions are followed [4]. For relatives of the treated patient, remaining within 1 meter for cumulative durations, doses could reach a few mSv over several days. The dose rate for patient release, according to Table 2, is approximately 140 µSv/h, which is higher than 30 µSv/h [3]. This would necessitate hospitalization in some cases. However, in some developed countries, radiation protection regulations recommend patient release under strict conditions.Other studies have shown doses to caregivers or accompanying people in these orders of magnitude, always with a safety margin for well-managed, one-off interventions.

Scenario C

7400 MBq represents high-activity inpatient therapy. Effective doses scale predictably (about 280 µSv at 60 min), matching Monte Carlo predictions for high-dose I-131 treatments [11,20]. While still below occupational thresholds, cumulative exposure must be carefully managed for personnel entering patient rooms repeatedly [12,14]. Regulatory recommendations generally advise inpatient isolation for activities ≥ 5.5–7.4 GBq [21, 22, 23]. The dose is approximately 37 times higher than in scenario A and approximately 2 times higher than in scenario B. For staff, even 1 minute of exposure equates to approximately 0.0047 mSv (assuming linearity), but actual management involves multiple interventions. The dose rate for patient release, according to Table 3, is approximately 280 µSv/h, significantly higher than 30 µSv/h [3]. This would necessitate mandatory hospitalization of the patient.For the patient's family, hospitalization clearly reduces all exposure, which is the safest option when activity levels are high [24]. In a clinical setting, scenario C may be necessary for certain metastatic diseases or high-dose treatments, but the hospital approach directly impacts radiation protection and exposure minimization recommendations, making the reduction of staff time spent on site or the number of admissions a priority.

Most exposed organs

Regardless of scenario A, B, or C, the frontal and anterior organs (thyroid, breast, stomach, esophagus, liver) receive the highest doses, see figure 1,2 and 3. This reflects their relative proximity to the source (the treated patient) and the minimal path taken through the patient's body. The absorption gradient between superficial and deep organs (such as bone marrow, brain, testicles) demonstrates attenuation and anatomical distance. Deeper organs, being more distant or more covered, receive less, but this effect is still linear with duration and activity.

Dosimetricanalysis of Monte Carlo simulation

Recent studies further support the robustness of Monte Carlo–based external dose assessments in nuclear medicine.Monte Carloderived organ doses in iodine-131 therapy are in close agreement with analytical and measurement-based approaches, reinforcing confidence in simulationdriven decision making [25]. Similarly, voxel-based human phantom models have improved the anatomical realism of dose calculations, particularly for organs at varying depths, thereby refining estimates of caregiver and staff exposure [26, 27]. Additional investigations confirm that external doses to caregivers remain well below regulatory constraints when time-distance principles are respected [28]. Taking together, these findings provide supplementary evidence that ambulatory iodine-131 therapy up to 3.7 GBq is dosimetrically justified under controlled conditions, while higher activities benefit from inpatient management to optimize cumulative exposure control [29].The International Commission on RadiologicalProtection (ICRP) 103 recommends 5 mSv as doselimit for caregivers although that for individualswho are not directly caring for the patient shouldbe restricted to 1 mSv/year [30]

Conclusion

Comparative dosimetric evaluation confirms the linear relationship between activity level, exposure duration, and external dose. Ambulatory therapy at 200 and 3700 MBq is safe when proper radiation protection measures are implemented. Higher-activity treatments (7400 MBq) remain safer in controlled inpatient environments where staff interaction time and proximity can be optimized. These findings are fully aligned with international recommendations regarding patient release and occupational radiation protection. Field studies have proposed different thresholds or limits depending on the context, sometimes reaching approximately 370 MBq for exit in certain countries, to limit doses to close contacts and the public while taking local realities into account. They confirm that the external dose measured at 1 m is a crucial indicator for deciding on hospitalization or outpatient care, with thresholds based on conventions, studies and local adaptation.

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Declaration of Authors' Contributions:

The study and the drafting of the manuscript were carried out collaboratively. However, as detailed below, Allangba,Hermann, Affibaand Okrawere involved in dose calculation of the study. Allangba and Affiba collected the data and draftedthe first version of the manuscript. Allangba, Hermann, Affibaand Okra carried out the statistical analyses and data interpretation.

Conflicts of Interest:

The study was conducted without any conflicts of interest.

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