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Feasibility of Administering High-Dose ^{131}I -MIBG Therapy to Children with High-Risk Neuroblastoma without Lead-Lined Rooms

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Abstract

Background—Although ^{131}I -metaiodobenzylguanidine therapy (^{131}I -MIBG) is increasingly used for children with high-risk neuroblastoma, a paucity of lead-lined rooms limits its wider use. We implemented radiation safety procedures to comply with New York City Department of Health and Mental Hygiene regulations for therapeutic radioisotopes and administered ^{131}I -MIBG using rolling lead shields.

Procedure—Patients received 0.67GBq (18mCi)/kg/dose ^{131}I -MIBG on an IRB-approved protocol (NCT00107289). Radiation safety procedures included private room with installation of rolling lead shields to maintain area dose rates $\leq 0.02\text{mSv/h}$ outside the room, patient isolation until dose rate $<0.07\text{mSv/h}$ at 1m and retention of a urinary catheter with collection of urine in lead boxes. Parents were permitted in the patient's room behind lead shields, trained in radiation safety principles and given real-time radiation monitors.

Results—Records on 16 ^{131}I -MIBG infusions among 10 patients (age 2–11 years) were reviewed. Mean $\pm$ standard deviation ^{131}I -MIBG administered was 17.67 ± 11.14 (range: 6.11–40.59) GBq. Mean maximum dose rates outside treatment rooms were 0.013 ± 0.008 mSv/hr. Median time-to-discharge was 3 days post- ^{131}I -MIBG. Exposure of medical staff and parents was below regulatory limits. Cumulative whole-body dose received by the physician, nurse and radiation safety officer during treatment was 0.098 ± 0.058 , 0.056 ± 0.045 , 0.055 ± 0.050 mSv respectively. Cumulative exposure to parents was 0.978 ± 0.579 mSv. Estimated annual radiation exposure for inpatient nurses was 0.096 ± 0.034 mSv/nurse. Thyroid bioassay scans on all medical personnel were $<$ detectable activity. Contamination surveys were $<200\text{dpm}/100\text{cm}^2$.

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Conflict of Interest

The authors have no conflicts of interest to disclose.

Conclusions—The use of rolling lead shields and implementation of specific radiation safety procedures allows administration of high-dose ^{131}I -MIBG and may broaden its use without dedicated lead-lined rooms.

Keywords

neuroblastoma; MIBG therapy; radiation safety; radiation exposure

INTRODUCTION

Neuroblastoma, the commonest solid tumor of infancy, is often metastatic at diagnosis and accounts for 15% of cancer-related deaths in children.[1] Patients with high-risk neuroblastoma are characterized by age >18 months and metastatic disease at diagnosis, and tumors with amplification of the *MYCN* oncogene.[2] Despite aggressive multimodality treatment including high-dose chemotherapy, surgery, external beam radiotherapy and anti-GD2 immunotherapy, many patients do not achieve remission after induction chemotherapy and relapse-free survival rates remain <50%.[3,4] Outcomes in patients with relapsed disease are much poorer.[5] ^{123}I -metaiodobenzylguanidine (MIBG) scans are the “gold standard” for staging of neuroblastoma with >90% of patients having MIBG-avid disease.[6] MIBG targeting exploits the expression of the norepinephrine transporter on cell surface of neuroblastoma cells facilitating MIBG uptake. ^{131}I -MIBG (MIBG therapy) can deliver therapeutic radiation to sites of metastatic disease via the same mechanism and is being increasingly considered in an effort to improve response rates and outcomes in patients with chemoresistant neuroblastoma.[7] High doses of MIBG therapy are preferred in children especially with autologous hematopoietic stem cell support and a dose of 0.67GBq (18mCi)/kg is generally accepted as the maximum dose per administration.[8] MIBG therapy is well tolerated; acute adverse events can be easily managed and include mild hypertension[9], transient sialoadenitis[10] and nausea.[11] Challenges to the use of high-dose MIBG therapy in young children with neuroblastoma include limiting radiation exposures to parents, maintaining doses as low as reasonably achievable (ALARA) to medical staff caring for the patient, limiting dose rates in contiguous clinical areas and contamination concerns. In order to comply with regulatory standards established by the Nuclear Regulatory Commission (NRC) for occupational (10 CFR par 20.1201) and community (10 CFR par 20.1201) exposure to radioactivity, high-dose MIBG is often administered in dedicated lead-lined rooms.[12] The latter, however, are not available in many hospitals, restricting the wider use of MIBG therapy. Even when lead-lined rooms are present, therapy might be delayed if they are in use for other radioisotope therapies for more common diseases e.g. radioiodine therapy for thyroid cancer. In fact, the current national Children’s Oncology Group study that adds high-dose MIBG therapy (clinicaltrials.gov identifier NCT01175356) to multi-agent induction therapy for high-risk neuroblastoma, many patients are required to travel to centers distant from their primary institutions to receive MIBG therapy.

At Memorial Sloan Kettering Cancer Center (MSKCC), eligible children with chemoresistant neuroblastoma receive one or two doses of high-dose MIBG therapy on an institutional review board approved (IRB) protocol (NCT00107289). Specific procedures

devised and implemented by the Radiation Safety Service at MSKCC ensured compliance with New York City Department of Health and Mental Hygiene (NYCDOHMH) and Nuclear Research Council (NRC) regulations for therapeutic radioisotopes while administering high-dose MIBG therapy in non-lead-lined private rooms using rolling lead shields instead. We describe these procedures and report on our internal audit of radiation exposure to parents and environment.

METHODS

MIBG Therapy

Patients were eligible and enrolled on to the abovementioned protocol. Salient eligibility criteria included patient age >1 year, recurrent or refractory chemoresistant neuroblastoma, and ability to comply with radiation safety instructions. Planned ^{131}I -MIBG dose was 0.67GBq/kg. Salient eligibility criteria for patients to receive a second dose included objective disease response after the first dose, and absence of major toxicities or severe myelosuppression. Planned second dose of ^{131}I -MIBG was determined based on organ dosimetry calculated from serial ^{123}I -MIBG scans. Each dose was provided in 1–5 syringes (7.4GBq/syringe), enclosed in a shielded lead-lined pump (Graseby injection pump shield, Biodex) administered intravenously over 15–60 minutes by an experienced nuclear medicine physician (authorized user). Other members of the team present during administration included radiation safety officer, pediatric oncologist and a nuclear medicine nurse, the latter having received training as described below. Routine nursing procedures were followed including vital sign measurements post-MIBG therapy and every 6 hours while in-patient.

Radiation Safety Procedures

Choice of room—The objective in selecting a treatment room was to ensure compliance with the regulation restricting patient-contributed dose rates in unrestricted areas to <0.02mSv (2mrem)/hr. These areas included but were not limited to adjacent rooms, outside hallways, stairwells, and floors above and below the treatment room. A further consideration was the size of the room, allowing for greater distance between patient and parent and the ability to create a low-exposure area to allow for the parent to be in the room with the patient. Ideal in-patient rooms at MSKCC were large, corner, rectangular rooms with exterior walls on two sides, a wall abutting a fire-stairwell and a bathroom separating it from the adjacent patient's room (Figure 1). With planned dose of >18.5GBq (500mCi), a specific room was used because areas above and below were limited-occupancy, transiently-utilized areas. Reservation of the appropriate room required close coordination with the admitting service at MSKCC.

Preparation of room and contents—Treatment rooms were prepared to reduce external irradiation and prevent contamination. Access to the room was restricted to trained nurses, nursing aides and parents. Pregnant staff, general visitors and children <18 were not allowed to enter the room. Food service and other ancillary hospital workers were required to wear a dosimeter prior to entering the patient's room. The patient's bed was covered with a maze of portable lead shielding. Commonly used items such as the telephone and television remote controls were covered with transparent plastic wrap to protect them from

trace amounts of radioactive material excreted in sweat. Floors were lined with an absorbent polyester vinyl compound (Bruin Herculite, Atlantic Nuclear) padding to cover the floor from the patient bed to the exit door. Absorbent pads were used to cover the bathroom sink counter and beneath the toilet seat. Additional contamination controls included disposable shoe covers which were donned and doffed onto a clean landing pad in front of the room (Figure 2). Clear notices cautioning the presence of radioactive materials and communicating specific instructions for staff and caregivers entering the room were posted: these included 24-hour contact telephone numbers for a member of the radiation safety team, requirement for all personnel to wear monitoring badges, and need for disposable food trays, linens and trash to stay in the room. Waste receptacles inside and outside the room were marked with signs emphasizing that radiation safety personnel were responsible for waste management. Waste receptacles and urine collection reservoirs were removed on a daily basis for collection and radioactive decay.

Lead Shielding—Customized rolling shields fabricated to have an equivalent thickness of 1" of lead (Atlantic Nuclear) (Figure 3) were brought into the room at time of treatment and arranged so as to ensure a dose rate of $<0.02\text{mSv/hr}$ in the area outside the lead shield.

Waste Disposal—In order to reduce radiation dose to the bladder[13] all patients had an indwelling urinary catheter inserted into their bladder that was maintained for a minimum of 72 hours or until the patient was released from radiation isolation. Intravenous fluids were administered to help maintain adequate urine flow. Urine collection bags were placed in a 1" thick lead-equivalent box (Figure 3) to minimize radiation and eliminate contamination. When urine bags were full, they were exchanged with new ones also placed in the box. Radiation safety staff removed the urine-bag-containing boxes on a daily basis and held the urine for radioactive decay, minimizing the potential for contamination. Patients were allowed to pass stool in the toilet. Blood samples were labeled with radiation safety stickers and held for radioactive decay after analysis.

Education and monitoring parents/guardians—Prior to treatment, parents involved in caring for the patient were educated in radiation safety procedures by a member of the radiation safety team. Topics discussed included the need to avoid close contact with, maintaining distance from and time spent interacting with the patient, use of lead shield between them and the patient, the potential for contamination, and use of real-time dosimeters and ALARA precautions. One parent was permitted to remain in the patient room behind the lead shield in an area designated and confirmed to have a dose rate $<0.02\text{mSv/hr}$. Rotation of parents was recommended to try to reduce exposure to either individual. The parent caring for the patient was provided with a real-time radiation dosimeter (Eckert and Ziegler Isotrak) which measured exposure and also alerted the parent by beeping when he/she remained too close to the patient or for too long a duration. Radiation dosimeters were shared if two parents were involved in patient care. Only the parent wearing the dosimeter was permitted to stay in the room. Regulatory dose limits, based on current United States NRC 10 CFR regulations and in accordance with NYCDOHMH Article 175 were limited to 5mSv (500mrem) for parents. The potential for contamination and the need for personal hygiene was discussed in depth with parents

emphasizing that the primary excretory pathway of ^{131}I -MIBG was urine with additional small amounts being excreted saliva, sweat and feces.[14] Patients and parents were permitted to bring personal effects such as electronic devices and toys into the room, albeit these items were minimized to the extent practical. These were scanned prior to discharge to confirm the absence of radioactive contamination.

Education and monitoring medical staff—In-service training was provided by a member of the radiation safety team to each member of the nursing staff involved in caring for the patient and reiterated prior to treatment. Topics discussed included routes of excretion, ALARA, maintaining distance from and time spent interacting with the patient, use of real-time dosimeters in addition to passive personnel monitors, and voluntary declaration of pregnancy policy. Additionally a checklist (Supplemental Table I) was created for each treatment and reviewed by radiation safety personnel with medical and nursing staff prior to each treatment. Each nuclear medicine physician, pediatric oncologist and nuclear medicine nurse involved in treatment administration was provided with a real-time radiation dosimeter. All in-patient nurses were required to wear a personal optical luminescence stimulated (OSL; Landauer) monitor that detects exposures 0.01mSv. Historical dosimeter records for all nurses caring for patients receiving MIBG therapy for the years 2012, 2013 and 2014 were accessed and averaged. Readings below the detectable level were conservatively assigned an exposure of 0.009 mSv. Regulatory dose limits to occupational staff, based on current US NRC 10 CFR 20 regulations and in accordance with NYCDOHMH Article 175.02 were 50mSv (5000 mrem) annually and 5mSv (0.5 mrem) for a declared pregnant woman during her gestation period. Thyroid bioassays using a gamma sodium iodide detector (Ludlum 44–11 Probe and Ludlum 2200 Scaler) were performed on all medical staff involved in administering MIBG therapy 24–72 hours after infusion to ensure that the committed dose equivalent (CDE) to the thyroid was 10% of the Annual Limit of Intake (ALI).

Environmental monitoring—External radiation exposure was monitored with a hand-held ion chamber (Fluke 451B) capable of detecting gamma emissions >7keV and radiation ranges from 0.1 to 500 $\mu\text{Sv/hr}$. Readings were taken at skin surface of the patient and 1m away immediately after MIBG administration and twice daily thereafter. Readings were also taken in unrestricted areas outside the patient's room: hallways, adjacent rooms, stairways and rooms above and below the treatment room immediately after MIBG administration.

Discharge procedures—Patients were eligible for discharge when measured dose rate at 1 meter from the patient was <0.07 mSv/hr.[15] This discharge dose-rate was determined to allow for exposure of <5 mSv to members of the public in accordance with 10 CFR 37.75 and local NYC DOHMH regulations.[15] At discharge, patients were provided instructions to reduce radiation exposure to others for one week after treatment. Specifically, we provided written and verbal instructions to parents that included: (a) information that patients will continue to emit small amounts of radiation and radioiodine will continue to be excreted in the urine; (b) patients were to sleep in a separate bed for one week; (c) separate utensils and linens were to be used for one week after discharge and (d) emphasis on good hygiene practices including frequent handwashing.

Personal effects were scanned with a Geiger Muller (GM) pancake type detector (Ludlum Model 3 and probe model 44–9). Removal contamination surveys were performed using a gamma counter (2470 Wizard 2, Perkin Elmer). The patient room was released to general use after contamination levels <200 disintegrations (3.3Bq)/minute/100cm² were demonstrated.

Audit and Statistics

16/25 infusions performed between September 2012 and January 2015 were randomly selected and data audited and analyzed after IRB approval. Components of the audit included: (a) radiation exposure to parents, physicians, radiation safety officers and nurses, (b) environmental radiation exposure, (c) maintenance of checklist, (d) thyroid bioassays, and (e) contamination scans. Radiation exposure to parents and medical staff was correlated by Pearson's test (Microsoft Excel)

RESULTS

MIBG Therapy

Sixteen ¹³¹I-MIBG infusions (0.67GBq/kg/dose) were administered to 10 patients with a mean $\pm$ standard deviation age of 6.4 ± 3.2 (range 2–11) years. Mean dose administered was 17.67 ± 11.14 (range: 6.1–40.6) GBq No unexpected adverse events were encountered. Median in-patient stay was 3 days (Table I).

Exposure to parents and medical staff

No parent was exposed to >5 mSv regardless of the patient receiving one or two ¹³¹I-MIBG infusions. Mean exposure to one or both caregivers over the entire in-patient stay was 0.98 ± 0.58 mSv (range 0.7–2.50) mSv. When two parents were involved in patient care (n=9 infusions), mean exposure was 0.543 ± 0.323 mSv/parent. For patients receiving double ¹³¹I-MIBG infusions, mean cumulative exposure for both infusions to one or both parents was 2.08 ± 1.09 mSv. Respective cumulative mean exposures over the treatment administration to the attending pediatric oncologist, nuclear medicine physician, nuclear medicine nurse and radiation safety staff were 0.010 ± 0.012 , 0.098 ± 0.093 , 0.056 ± 0.045 and 0.055 ± 0.050 mSv respectively (Table I). Parent exposure did not correlate with administered dose ($r=0.38$, $p=0.16$) however there was a significant positive relationship between the administered dose and the average radiation dose to medical staff (pediatric oncologist, nuclear medicine physician, nuclear medicine nurse and radiation safety officer) involved in administering MIBG therapy ($r=90$, $p<0.001$) although exposure was well below permissible levels. Similarly to administered dose, there was no significant difference ($r=0.12$, $p=0.65$) between patient age and parent exposure. However, there was a positive correlation between patient age and radiation exposure to medical staff likely due to the higher dose administered ($r=0.77$, $p<0.001$). Thyroid bioassays did not reveal any increased thyroid burden, all activity being measured background levels. Annual mean exposure for all pediatric in-patient nurses involved in MIBG therapy in the years 2012, 2013 and 2014 were all <50 mSv with a mean exposure of 0.096 ± 0.034 mSv/nurse. Additionally, annual mean exposures for nuclear medicine physicians, nuclear medicine nurses, pediatric oncologists and radiation safety personnel involved in therapy were 5% of the occupational dose limit of 50 mSv.

Environmental exposure

After shielding, maximum exposure rates to all unrestricted areas were <0.02 mSv hr for injected activities <29.78 GBq (Table II). Two uninhabited areas on the floor below the treatment room had maximum exposure (immediately after MIBG infusion) of 0.027 and 0.032 mSv/hr for <3 hours after two patients were injected with 29.78 GBq and 40.63 GBq respectively. Surveys for removable contamination which included but were not limited to the bathroom, floor, bed, chairs, handles and the room in its entirety exhibited levels <200 dpm (3.3 Bq)/100 cm² after discharge.

DISCUSSION

New York State is one of 37 Agreement States under a program established by the NRC that relinquishes regulatory authority to license and regulate byproducts of radioactive materials to the state. NYCDOHMH has a unique charter to regulate all aspects of ionizing radiation within New York City.[16] MSKCC has a broad scope medical use license to use therapeutic radioisotopes and NYCDOHMH regularly inspects our institution to ensure strict adherence to NRC regulations. In 2003, a notice of violation was issued by the NRC to a hospital in Ann Arbor, Michigan.[17] The violation contended that the licensee did not take adequate action towards family members not following radiation safety instructions while visiting a patient treated with radioactive iodine. Specifically, the NRC noted the lack of shielding for urine, failure to issue available electronic dosimeters, and lack of repeated patient education on maintaining distance and minimizing time at close distances. In addition, the institution was cited for not making measurements of the radiation levels in contiguous areas after the patient was administered a radiopharmaceutical therapy dosage. In response to this notice of violation and in working to facilitate such treatments for our patient population while implementing best practices for managing patients receiving radioactive materials for therapy, we reviewed our radiation safety practices and adapted them to derive the procedures described above.[18,19] Using these radiation safety procedures which emphasized education of parents and medical staff, shielding and prevention of contamination, we were able to administer high-dose MIBG therapy to children with high-risk neuroblastoma without excessive exposure to parents or medical staff caring for the patient. This was achieved without expensive dedicated lead-lined rooms. Furthermore, each treating institution will need to determine its own discharge criteria in order to meet regulations regarding radiation exposure to the general public.

Our internal audit determined that exposure to parents, medical staff and environment was well within maximal permitted levels. There was almost 100% compliance noted for all components of the audit with the exception of two items: two uninhabited areas had dose rates of >0.02 mSv/hr, though for <3 hours during which time the area was monitored by a radiation safety officer. The use of rolling lead shields under the bed was not possible due to the vertical design, castors and weight (approximately 1250 lbs) of the shields. Our institution had the ability to control access to the areas below the patient's room. A second item was the lack of recording of two readings on the real time electronic dosimeter for the pediatric oncologist. However, conventional dosimeter readings did not reveal significant exposure in this case.

There are few reports on exposure to caregivers during MIBG therapy. Markelewicz et al. [20] reported radiation exposures to parents of <5mSv when lead-lined treatment rooms as well as lead-lined adjacent rooms for parents were used for MIBG therapy (mean 13.65 GBq; maximum 23.31GBq). Gains et al reported treatment (median 8.1 GBq; maximum 16.25GBq) without dedicated lead-lined rooms but one caregiver was exposed to a higher than permitted dose.[21] We were able to meet regulatory requirements for exposure for all parents without using lead-lined rooms despite treating with much higher mean (17.67 GBq) and maximum (40.59Gq) doses of ^{131}I -MIBG. The lack of correlation of administered dose with radiation exposure to parent was likely due to younger children (who received lower doses) requiring greater parent presence, while older patients (treated with higher ^{131}I -MIBG doses) were more self-sufficient. Exposure to medical staff involved in administering MIBG therapy was similar to that reported by other investigators who treated patients with lower doses of MIBG therapy using lead-shielded syringe pumps.[20,22] Exposure was highest to the authorized user and the nuclear medicine nurse directly involved in administration of MIBG therapy and correlated with the activity administered. This was likely because at the time of changing syringes there was unshielded exposure to radiation. Alternative methods that allow delivery of MIBG therapy from a single-dose container might reduce this exposure.

Adult patients isolated for radioisotope therapy reported an impairment in quality of life with treatment-related fears compounded by the reluctance of hospital staff to enter the room and interact with them, perception of an unfriendly and hostile environment, and lack of understanding of the treatment among the administering professionals.[23,24] Although similar quality of life measurements are not available for children, feelings of isolation and accompanying stresses are likely to be heightened among young children and their parents. In addition, most children with neuroblastoma are candidates for ^{131}I -MIBG therapy when they are <7 years of age and have uniquely challenging developmental needs, requiring assistance with meals, using the bathroom, and hygiene.[25] In dedicated lead-lined rooms, sedation is often needed to administer high-dose ^{131}I -MIBG therapy to young children, primarily to limit radiation exposure to medical staff but quite possibly due to the stressed-induced isolation.[26] Sedation was not needed for any of our patients.

We were able to accommodate the administration of high-dose MIBG therapy without dedicated lead-lined rooms through the use of rolling lead shields that reduce the feeling of isolation when compared to isolation in dedicated lead-lined rooms where parents observed their children through a leaded glass window or video surveillance.[12] Parents in our institution were allowed to stay in the same room as their children possibly reducing stress in both patient and parent. Stress reduction likely improved compliance with radiation safety procedures in parents and children. However, we acknowledge that testing for patient/parent stress was not performed. A major component of our approach was extensive education in ALARA principles of parent, child, nursing and medical staff. Education for the latter two groups was reinforced prior to every therapy. The use of electronic dosimeters provided real time observation of accumulated dose and instantaneous feedback on behavior. The electronic dosimeters had an alarm set to detect high radiation dose rates and served as a reminder of radiation exposure. They were utilized by parents and staff to minimize the time

spent adjacent to the patient or in front of the lead shield and to increase distance from the patient.

As high-dose MIBG therapy is increasingly being used for children with neuroblastoma, a paucity of dedicated lead-lined rooms that are often expensive to install, requiring a major commitment from treating institutions[12] hampers broader use of an effective therapeutic modality for this aggressive neoplasm. We have described a multipronged team approach focusing on education, portable shielding and contamination reduction that allows administration of high-dose MIBG therapy without the need for lead-lined rooms even for very young children. It is important that individual institutions evaluate internally if the proper expertise, rooms and hospital resources are available and comprehensive plans are in place prior to embarking on high-dose MIBG therapy. These policies and procedures can be adapted to permit administration of other radiopharmaceuticals to children.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Floor plan and diagram of patient room M501 for planned dose $>18.5\text{GBq}$ (500mCi) and adjacent areas. Locations of patient bed, bathroom, position of rolling shields, and area for caregivers are noted.

Figure 2. Contamination controls: (A) absorbent landing pad (Bruin Herculite, Atlantic Nuclear) from the patient bed to the exit door, (B) plastic wrap to cover television remote control and telephone, and (C) absorbent pads to cover the bathroom sink and under the toilet seat

Figure 3.
Shielding controls (A) lead boxes for urine collection bags; and (B) rolling lead shields

Table 1

Dose of MIBG therapy and cumulative radiation exposure during treatment and inpatient stay to caregivers and medical staff

Demographics and dose of MIBG therapy				Radiation Exposure (mSv)				Nuclear medicine Nurse	Radiation Safety Officer
Pt No.	Rx No.	Age (years)	Total dose / infusion (GBq)	In-patient stay (days)	Parent(s)	Pediatric Oncologist	Nuclear Medicine Physician		
1	1	3.5	6.11	3	1.45	0.036	0.046	0.076	0.033
2	2	2.8	6.27	2	0.26	N/A	0.005	0.010	0.008
	3	2.9	7.70	2	1.18	N/A	0.008	0.010	0.032
3	4	4.5	10.53	2	0.68*	0.002	0.010	0.033	0.056
	5	4.6	11.13	2	1.08*	0.002	0.097	0.045	0.067
4	6	4.3	11.32	3	1.27*	0.001	0.033	0.093	0.033
	7	4.4	12.38	3	1.08*	0.005	0.099	0.061	0.018
5	8	4.7	11.76	3	0.92*	0.006	0.041	0.078	0.039
	9	5.1	15.06	2	0.31	0.004	0.033	0.018	0.025
7	10	7.4	16.17	3	0.99	0.002	0.042	0.008	0.030
	11	7.5	16.51	4	1.24	0.018	0.103	0.103	0.048
8	12	7.1	18.09	3	0.45	0.001	0.076	0.013	0.051
	13	11.3	29.78	3	0.63*	0.030	0.230	0.106	0.051
10	14	11.4	29.96	3	0.28*	0.017	0.262	0.042	0.077
	15	11	39.30	4	1.54*	0.015	0.283	0.034	0.094
16	16	11.1	40.63	4	2.50*	0.001	0.193	0.169	0.223
Mean		6.7	17.67	2.9	0.98	0.010	0.098	0.056	0.055
Stdev		3.1	11.14	0.7	0.58	0.012	0.093	0.045	0.050

* Cumulative exposure to two parents; Abbreviations: N/A, Not available; Rx, Treatment; Stdev, standard deviation

Table II

Maximum environmental exposure rates (mSv/hr) immediately after MIBG therapy

Rx No.	Total dose (GBq)	Dose Rate (mSv/hr)					
		Outside treatment room	Adjacent room No. 1	Adjacent room No. 2	Floor above treatment room	Floor below treatment room	
1	6.11	0.001	0.004	0.004*	0.006		0.004
2	6.27	0.000	0.001	0.016	0.006		0.006
3	7.70	0.008	0.005	0.013	0.006		0.001
4	10.53	0.005	0.003	0.002	0.005		0.002
5	11.13	0.006	0.001	0.003	0.008		0.003
6	11.32	0.006	0.003	0.003	0.007		0.003
7	11.76	0.004	0.006	0.001	0.007		0.015
8	12.38	0.004	0.006	0.004	0.008		0.002
9	15.07	0.008	0.005	0.003	0.009		0.004
10	16.19	0.006	0.004	0.004*	0.009*		0.013*
11	16.51	0.002	0.002	0.001*	0.01*		0.013*
12	18.09	0.001	0.002	0.007*	0.006*		0.018*
13	29.78	0.005	0.003	0.013*	0.017*		0.032*
14	29.96	0.009	0.009	0.003*	0.016*		0.001*
15	39.30	0.002	0.002	0.001*	0.017*		0.012*
16	40.63	0.007	0.002	0.001*	0.017*		0.027*
Mean	17.6701	0.005	0.004	0.004	0.01		0.01
Stdev	11.1445	0.003	0.002	0.005	0.005		0.009

* Uninhabited areas; Abbreviations: No., number; Rx, Treatment; Stdev, standard deviation