ABSTRACT

**James M. Brindle. Radiological Hazards of Iodine-131 Therapy.
(Under the direction of Dr. Carmine M. Plott and Dr. James E. Watson, Jr.)**

Once iodine-131 is administered to a patient undergoing therapy, the individual becomes a significant source of radiation exposure to attending staff and other patients. The patient also becomes a source of radioactive contamination since much of the administered radioiodine is gradually eliminated via urinary excretion, exhaled air, and perspiration. Duke University Medical Center uses iodine-131 for three different types of cancer treatments: sodium iodide for thyroid carcinoma, monoclonal antibodies for neoplastic meningitis, and metaiodobenzylguanidine (MiBG) for neuroendocrine tumors.

The primary focus of this study was to assess the radiological hazards to the medical staff attending these isolated patients and to members of the general public near the patient rooms. In addition, data from this study were used to design special rooms to house patients undergoing radioiodine therapy. The amount of radioiodine administered to the 17 patients in this study ranged from 2.2 GBq (60 mCi) to 11.2 GBq (303 mCi).

Exposure rates were measured using an ion chamber at several locations within patient rooms as well as in the hallway and accessible adjacent rooms. Measurements taken within patient rooms ranged from 4.1×10^{-8} C kg^{-1} hr^{-1} (0.16 mR hr^{-1}) to 1.7×10^{-5} C kg^{-1} hr^{-1} (67 mR hr^{-1}). Exposure rates ranged from 8.3×10^{-9} C kg^{-1} hr^{-1} (0.032 mR hr^{-1}) to 4.1×10^{-7} C kg^{-1} hr^{-1} (1.6 mR hr^{-1}) in the hallways and accessible adjacent rooms. Thermoluminescent dosimeters (TLDs) mounted on the walls, floor, and ceiling of patient rooms were used to determine accumulated dose equivalents for the duration of the patient treatments. The TLD results ranged from 0.20 mSv (20 mrem) to 19.5 mSv (1,950 mrem). Using a portable GM detector, contamination surveys were performed in patient rooms after the patients were discharged from the hospital. Detected contamination levels ranged from 100 c min^{-1} to 240,000 c min^{-1}. Air sampling was also performed to determine the concentration of radioiodine in the air and to evaluate the necessity for "negative pressure" patient therapy rooms.

Exposure rate measurements and dose equivalent measurements suggest that a potential hazard exists for both the attending medical staff and the general public. Dedicating two new lead lined rooms for iodine-131 therapies would greatly reduce hazards to the general public as well as ease the patient room decontamination process for the radiation safety staff. Air sampling results proved to be inconclusive since activity was seen throughout the air sampling units.

ACKNOWLEGDEMENTS

I wish to thank Dr. James E. Watson, Jr. for his patience and guidance throughout this study. I would like to thank Dr. Carmine M. Plott for her influence and support throughout the entire study. Without the combined support of both of you, the completion of this project would not have been possible. I also wish to thank Dr. Lori Todd and Mr. Bob Wilson for their insight and serving as committee members.

I would also like to thank Dr. Wayne R. Thomann, Director of Occupational and Environmental Safety at Duke University/Duke University Medical Center, for providing me with the opportunity and the funding to perform this study. A special thanks goes to the Radiation Safety Staff at Duke University Medical Center for their assistance in completing this project.

I would like to recognize and thank the entire Radiopharmacy staff in the Department of Nuclear Medicine for allowing me perform the analyses of the air sampling units. I would like to extend a special thank you to Capt. William H. Briner for sharing his expertise with me throughout this project.

Most importantly, I have to thank my parents, especially my mother, for supporting and encouraging me throughout this entire project. Without your support I would not be where I am today.

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I. INTRODUCTION

Iodine-131 can be used for the therapy of several types of cancerous tumors. The therapeutic use of iodine-131 poses potential radiological hazards for any of the medical staff caring for the therapy patient as well as any member of the general public near the therapy patient's room. The focal point of this study was to assess the radiological hazards associated with the following three types of iodine-131 therapies performed at Duke University Medical Center: sodium iodide therapy, radioimmunotherapy (monoclonal antibodies), and meta-iodobenzylguanidine (MiBG) therapy. Dependent upon the type of therapy, the administered activities seen in this study ranged from 2.2 GBq (60 mCi) to 11.2 GBq (303 mCi). Exposure rate measurements, dose equivalent measurements, contamination surveys, and air sampling were used to examine the radiological hazards.

According to the Nuclear Regulatory Commission (NRC), any patient receiving a large amount of a radiopharmaceutical must remain isolated until the amount of activity remaining in the patient is less than 1.1 GBq (30 mCi) (NRC 1996a). The duration of the isolation period varies depending upon the type of therapy, the amount of activity administered, and characteristics of the patient such as metabolism. Radioiodine is removed from the body via urinary excretion, exhaled air, and perspiration. At this point in time, Duke University Medical Center does not have rooms dedicated solely for radioiodine therapies. Therapies are performed in various rooms throughout both Duke Hospital North and Duke Hospital South.

II. BACKGROUND

Characteristics of Iodine-131

Iodine-131 has both diagnostic and therapeutic applications in medicine. Iodine-131 emits several beta particles with varying energies as well as several gamma rays with varying energies. The gamma rays are easily detected with conventional nuclear medicine imaging equipment. The beta particle deposits significant energy in the tissue thereby inducing therapeutic effects. Table 1 summarizes the principal radiation emissions for iodine-131 (DuPont, 1991).

TABLE 1: Iodine-131 Radiation Emission Data

Radiation Emission	Energy (MeV)	Emission Frequency
Beta Particles	0.248 (max.)	2.1%
	0.334 (max.)	7.4%
	0.606 (max.)	89.3%
Gamma Rays	0.723	1.8%
	0.637	7.3%
	0.364	81.2%
	0.284	6.1%
	0.080	2.6%

The physical half-life of iodine-131 is 8.04 days (DuPont, 1991). Based upon the emission frequency, the beta particle with the energy of 0.606 MeV and the gamma ray with the energy of 0.364 MeV are the most significant radiations associated with iodine-131. For every 100 decays of iodine-131, approximately 89 of those decays will produce a beta

particle with a maximum energy of 0.606 MeV. Likewise for every 100 decays of iodine-131, approximately 81 of those decays will produce a 0.364 MeV gamma ray.

Treatment Review

Sodium Iodide Therapy:

Most forms of iodine have an affinity for the thyroid gland. Maynard (1969) states that upon "the entry of iodine into the body (mainly by diet and, to a lesser degree, by inhalation), that which is in the iodide form or can be changed to iodide is trapped and concentrated by the thyroid gland..." Sodium iodide treatments are prescribed for patients who suffer primarily from hyperthyroidism or thyroid carcinoma. After an attempt is made to surgically remove as much of the cancerous thyroid as possible, a small tracer quantity of radioiodine is administered to the patient. Utilizing the properties of iodine-131, namely 0.364 MeV gamma ray emission, a thyroid scan is performed to determine how much of the thyroid gland remains.

If residual thyroid tissue is detected, a therapeutic dose ranging in activity from 3.7 GBq (100 mCi) to 7.4 GBq (200 mCi) of radioiodine is prescribed. The therapeutic dose, which is administered orally to the patient, consists of a solution of NaI-131 in water combined with a stabilizing preservative (Briner, 1997). The radioiodine is absorbed into the blood stream through the digestive system and circulates throughout the entire body, concentrating in any residual thyroid tissue. Beierwaltes et al. (1957) note that iodine is absorbed so rapidly it can often be detected in the thyroid and salivary glands within minutes after ingestion. Beierwaltes et al. also state "that absorption has been found to be quite complete within a hour after ingestion." The principal pathway for excretion of iodine is through the urine. It has been observed that during the first twenty four hours of

the therapy approximately one half of the administered dose is excreted via the urine. While the majority of the iodine-131 is excreted via the urine, smaller concentrations can also be detected in saliva, perspiration, and exhaled air. It should be noted that only thyroid carcinoma patients are included in this study since procedures utilizing an activity less than 1.1 GBq (30 mCi), such as therapies for hyperthyroidism, are performed on an outpatient basis.

Radioimmunotherapy (Monoclonal Antibody Therapy):

Duke University Medical Center uses monoclonal antibodies chemically bound with iodine-131 to treat patients suffering from malignant brain tumors. The basis for this treatment is the relationship between antigens and antibodies. Antibodies will bind with the sites or determinants of a particular antigen and form an antigen-antibody complex (Lehninger, 1970). Since it is possible for a molecule or nuclide to be bound or "tagged" to the antibody, the antibody acts as the transport system for the molecule or nuclide to a particular antigen. When the antibody forms the complex with the antigen, the decay of the radioiodine, via beta particles, begins to damage the antigens of the tumor cells. The damage done by the radioiodine prohibits cells from dividing properly which usually leads to cell death.

Keenan et al. (1985) state that "antibody molecules, or immunoglobulins, are produced by plasma cells in higher animals in response to the introduction of foreign substances (antigens)..." This point is reinforced by Lehninger (1970) who states that the "immune response is given only by vertebrates and sharks and is thus a rather recent product of biological evolution." A mouse is used for the development of the antibodies. When human cancerous tumor cells are injected into the mouse, the mouse produces anti-

bodies in response to the foreign species or, in this case, particular tumor cells. These antibodies are harvested from the mouse and used for the administrations to humans.

Prior to treatment of the patient, in vitro studies are performed to determine whether or not the harvested antibodies will bind with the respective patient's tumor cells. After establishing whether the antibody will bind with the cancerous brain cells, a neurosurgeon performs the surgery to insert an Ommaya reservoir under the scalp directly into a small hole in the skull. This reservoir provides a location and a means for injecting the labeled antibody into the brain (Briner, 1997). The actual treatment consists of drawing fluid out from the reservoir and injecting the labeled antibody back into the reservoir.

Meta-iodobenzylguanidine Therapy (MiBG):

Radioiodine meta-iodobenzylguanidine (MiBG) administrations are prescribed for patients suffering from neuroendocrine tumors. Hoefnagel et al. (1987) note that it has been reported that more than 50 percent of carcinoids, a particular type of neuroendocrine tumor, have the potential to concentrate iodine-131. This type of treatment consists of two components. First, in order to block the uptake of the iodine-131 in the thyroid, patients must take two drops of a saturated solution of potassium iodide (SSKI) twice a day. This saturated solution of potassium iodide is taken the day the therapeutic dose is to be administered and is taken continuously twice daily for several days after the patient is discharged. The therapeutic dose with an activity of 11.1 GBq (300 mCi) is administered to the patient intravenously. The vial containing the MiBG dose is connected to the intravenous line and travels into the body just like normal intravenous fluid. The MiBG solution enters the bloodstream and circulates throughout the body. The ability of the MiBG to

concentrate in carcinoids varies from patient to patient and as Hoefnagel et al. (1987) point out "it is not yet known which factor determines this ability."

The pattern of excretion for MiBG therapy patients is similar to that of the thyroid carcinoma patients. The primary pathway for excretion is through the urine. The excretion of I-131 MiBG was monitored in a study by Sisson et al. (1984) where patients were administered both tracer doses and therapeutic doses. The activity used in the tracer studies was 0.0185 GBq (0.5 mCi) while the activity used for the therapeutic doses ranged from 3.6 GBq (97 mCi) to 7.3 GBq (197 mCi). In the Sisson et al. study excretion in the tracer studies was found to be "about 40% of dose at 24 hr. and 65-70% at 72 hr. by each patient." Sisson et al. (1984) notes that the excretion rates for several of the patients receiving therapeutic doses did not vary from excretion rates measured in patient who received tracer doses.

Hazards

External:

Once the patient is administered the iodine-131 he or she becomes a source of radiation exposure to personnel and members of the general public. Since beta particles cannot penetrate the tissue and "escape" the patient's body, only the gamma rays pose exposure hazards to individuals in the immediate area. The thickness of the shielding and the type of shielding material influence the exposure to gamma rays. The interior walls of the hospital, comprised of sheet rock, may not provide adequate shielding of the gamma rays associated with iodine-131. As a result, patients and visitors in adjacent rooms and people in the hallway may be exposed by these iodine patients.

Internal:

With a vapor pressure of 0.305 mmHg at room temperature (25°C), iodine (I_2) is considered to be a volatile compound. Volatility and contamination create the internal hazard for workers associated with these therapies. The air the patient exhales along with any particles containing radioiodine pose a hazard to any of the attending medical staff. The vapor which can be potentially inhaled by any attending medical staff will pass through the alveoli and into the bloodstream. Once the radioiodine is in the bloodstream of a healthy person it will be taken up by the thyroid and begin to decay. The beta particles associated with decay of the iodine-131 atoms pose the internal hazard. In fact, any attending medical staff present in the room during the administration of the therapy dose must have a thyroid uptake study performed within 72 hours (NRC 1996e).

Surface contamination may also be a factor contributing to the airborne concentration of iodine-131. One of the focal points in the Austin (1993) study was the relationship between room contamination and the iodine-131 air concentration in the room. There was little correlation observed between the surface contamination left by the patient and air concentrations measured in the room (Austin, 1993).

Regulations

The Nuclear Regulatory Commission has established radiation dose limits for occupational workers as well as members of the general public. The annual occupational dose limit for adults is broken down into two parts and is the more restrictive of its two components. The total effective dose equivalent of 0.05 Sv (5 rem) should not be exceeded in the period of one year (NRC 1996b). Also the sum of both the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than

the lens of the eye should not exceed 0.5 Sv (50 rem) in one year (NRC 1996b). The limit for the dose equivalent to the eye is 0.15 Sv (15 rem), while the shallow dose equivalent limit to the skin and extremities is 0.5 Sv (50 rem) (NRC 1996b). This occupational dose limit applies to all radiation workers such as the administering physicians, nuclear medicine technologists, nurses, and radiation safety staff.

The annual dose limit for members of the general public is considerably less than the limit for occupational workers. The regulations state that licensees of radioactive material should perform operations in such a manner to ensure the "total effective dose-equivalent to members of the general public from the licensed operation does not exceed 0.1 rem (1 mSv) in a year" (NRC 1996c). The regulations also state that the operations of the radioactive material licensee should not produce a dose in an unrestricted area exceeding 0.02 mSv (0.002 rem) in any one hour (NRC 1996c). Areas surrounding the patient's therapy room are classified as unrestricted. Regarding iodine-131 therapies, these limits apply to anyone in the vicinity of the therapy patient, including patients in rooms adjacent to the therapy room.

In addition to the dose limits for occupational workers and members of the general public, the regulations specify air concentration limits for these two classifications of people to protect against internal hazards. For iodine-131, the derived air concentration (DAC) for radiation workers is 2×10^{-8} $\mu Ci\ ml^{-1}$ while the effluent air concentration limit is 2×10^{-10} $\mu Ci\ ml^{-1}$ (NRC 1996d). The derived air concentration is based upon breathing the respective concentration for a period of one working year (2,000 hours). Inhaling a concentration equal to the derived air concentration for a period of one year will result in an intake of activity equal to the annual limit on intake (ALI). The annual limit on intake

is the yearly intake of a nuclide resulting in a dose equivalent equal to the occupational limit, specifically "a committed effective dose equivalent of 5 rems (stochastic ALI) or a committed dose equivalent of 50 rems to an organ or tissue (non-stochastic ALI)" (NRC 1996d). The effluent air concentration is the limit for the public, and it is based upon breathing its respective air concentration for a period of one calendar year. If a concentration equal to the effluent air concentration limit is inhaled for a period of one calendar year, the resulting total effective dose equivalent would be 0.5 mSv (0.05 rem) (NRC 1996d).

Once a patient is treated, the potential is great for contamination in the room to which the patient is restricted. Since Duke does not have a room solely dedicated for the purpose of radioiodine therapy, before an iodine therapy room is released from radiation precautions it has to be thoroughly cleaned and decontaminated down to levels set forth by the NRC. The NRC regulations explicitly state that a "room must not be reassigned until removable contamination is less than 200 disintegrations per minute per 100 square centimeters" (NRC 1996e). Radiation survey instruments are used to identify areas of contamination and wipe tests or smears, analyzed using a liquid scintillation counter, are used to verify compliance with the previously stated regulation.

Literature Review

Austin Study

The Austin study (1993) addressed whether or not exposure to radioactive materials remained As Low As Reasonably Achievable (ALARA) for sequential iodine-131 therapies performed in the same hospital room. In the study by Austin, patients were treated orally with sodium iodide in capsule form for thyroid carcinoma. A total of twelve

patients were included in the study and the administered activity ranged from 5.5 GBq - 11.1 GBq (150 mCi - 300 mCi). Contamination surveys, wipe tests, and air sampling were performed. The isolation room was prepared before the therapy patient arrived. Once the therapy patient was discharged and before any type of decontamination in the room was performed contamination surveys and wipe tests were performed. A pancake GM detector was used to locate contamination or "hot spots" and these areas were noted. Areas noted as hot spots were then wiped with smears to determine whether or not the contamination was removable. Air samples were taken during as well as after the patient therapies. Air sampling units were set up in several locations within the isolation rooms. At each location two 5.08 cm. (2 in.) and one 20.32 cm. (8 in.) charcoal cartridges were connected in series to the hospital vacuum system. The 20.32 cm. charcoal cartridge was used to prevent the hospital vacuum system from becoming contaminated. Air samples taken after the patient was discharged examined the possible revolitalization of the iodine-131 contamination back into the air.

After each patient was discharged contamination surveys were performed. After the fourth patient was discharged the therapy room was completely decontaminated and cleaned. Six more patients were then treated sequentially in the same therapy room. After the tenth patient was discharged, the therapy room was again completely decontaminated and cleaned. It should be noted that soiled pads, such as those around the toilet, were removed periodically to maintain a clean and sanitary therapy room. All of the contamination levels measured in the room for one patient were averaged to give an average contamination level for each patient. Using an iodine-131 efficiency of 18% for the PGM detector, the average disintegrations per minute (dpm) for the twelve patients ranged from

1,387 dpm to 82,147 dpm. However, Austin does point out that the detector's upper limit of 2,800,000 dpm (500,000 cpm) was exceeded on sixteen occasions.

Smears were also taken in the same locations as where the contamination surveys were performed. As with the contamination surveys, an average smear contamination level in the room was determined for each patient. The average smear contamination results ranged from 159 dpm to 351,740 dpm. The contamination measured with the PGM detector reflects the total amount of contamination present which includes both fixed contamination and removable contamination while the smears only reflect the amount of removable contamination present. Since the GM surveys and smears were taken at the same location, Austin notes that it is not possible for the amount seen on the smear to exceed the amount of contamination detected with the PGM detector. Apparently one of the patients in the study had a problem with vomiting while another patient left food particles and hair particles scattered throughout the therapy room. Since there was a small period of time between the time the contamination survey was conducted and when the smears were taken, it was possible for a particle of food or a piece of hair to have been inadvertently moved. When a smear was taken of the area that piece of food or hair may have been wiped up and collected. This would account for the smear result being higher than the contamination survey.

Austin compared time integrated air concentrations with corresponding time integrated maximum permissible concentrations (MPC-hr)*. The time integrated maximum permissible concentration was determined by multiplying the limit of 9×10^{-9} $\mu Ci\ ml^{-1}$ by a particular time period. Austin determined the average length of the patients' stay to be 59

hours. In order to determine integrated air concentrations, Austin multiplied the concentrations measured in the air by the average length of patients' stay. Using a time period equivalent to the average length of the patients' stay, most of the time integrated concentrations were below the corresponding MPC-hr limit of 5.31×10^{-7} μCi hr ml^{-1}. For any time integrated concentrations that may have exceeded that limit, a specific MPC-hr limit was determined for that particular patient's length of stay. Upon comparing time integrated concentrations using a particular patient's length of stay with its corresponding MPC-hr limit, it was observed that all of the time integrated concentrations were below their respective time integrated limits.

Using contamination survey data, Austin illustrated that build up of contamination was not observed between patient therapies. She also pointed out that the air concentrations measured in the isolation room as well as in unoccupied rooms were below the maximum permissible concentration limit. There was no strong relationship between the surface contamination left by the patient and the air concentrations observed in the room. Therefore, ALARA would be maintained using the same isolation room for sequential therapies without complete decontamination.

McBaugh Study

In 1990 a study performed at the University of Washington by McBaugh focused on the radiation hazards to attending medical staff and the general public pertaining to a new type of cancer therapy, radioimmunotherapy. McBaugh defines radioimmunotherapy as "a process in which monoclonal antibodies are radiolabelled and administered to a cancer patient in an attempt to selectively irradiate and treat malignancy" (McBaugh, 1990).

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* Currently, the NRC references a derived air concentration (DAC) of 2×10^{-8} μCi ml^{-1} for iodine-131.

This study addressed three issues: radiation exposure associated with this therapy, methods to reduce the exposure associated with this therapy, and exposures due to this therapy versus exposures associated with iodine-131 sodium iodide therapies for thyroid cancer. Four radioimmunotherapy patients and three thyroid therapy patients were included in the McBaugh study. The administered activities ranged from 11.1 GBq (300 mCi) to approximately 22.2 GBq (600 mCi). Two patient rooms were dedicated for iodine-131 therapies. One therapy room was centered between two other patient rooms. The other therapy room was centered between a patient room and a stairwell.

Exposure rates were taken at distances of one and two meters from the patient. Exposure rates were also taken in the doorway to the patient rooms and at select locations within any available adjacent rooms. Contamination surveys were also performed to evaluate areas where contamination was the highest. Surveys were performed during the clean-up process using a Ludlum Model 18 Geiger counter in conjunction with a Model 44-9 pancake probe. Wipe tests were not performed.

McBaugh showed that exposure rates differed depending upon the patient location in the room. Readings ranging between 7.7×10^{-7} C kg^{-1} hr^{-1} (3 mR hr^{-1}) to 1.0×10^{-6} C kg^{-1} hr^{-1} (4 mR hr^{-1}) were seen at the bed in an adjacent room when the radioactive patient was standing near the wall inside the therapy room. McBaugh includes a table displaying the exposure rates for patient number three who received 16.6 GBq (448 mCi) via radioimmunotherapy. McBaugh states that the data measured for patient number three is representative of the data measured for the other radioimmunotherapy patients (McBaugh, 1990). At one location behind a wall in the hallway the reading was normally background. McBaugh (1990) notes that while the radioactive patient was in the bathroom, the meas-

urement at this same location "could be as high as 20 mR/hr." Due to the exposure rate measurements measured in adjacent rooms, the adjacent rooms remained unoccupied during therapies (McBaugh, 1990).

All of McBaugh's results for the contamination surveys were noted in counts per minute (cpm). A comprehensive table summarizing the results from the four radioimmunotherapy patients was provided. Contamination levels before cleaning ranged from 500 cpm to 100,000 cpm. The highest value was seen on the toilet after one patient vomited the first night of the treatment. For all of the patients, the toilet and the floor pads around the toilet were the greatest areas of contamination, ranging from 20,000 cpm to 40,000 cpm. Contamination levels after cleaning ranged from 100 cpm to 2,500 cpm. In particular, areas around the toilet were decontaminated down to levels between 1,000 cpm to 2,000 cpm. McBaugh notes that the surveys were performed during clean up and were very labor intensive, taking two people several hours to complete.

In order to measure the total accumulated dose, film badges were also mounted at six locations in and around the therapy rooms. One film badge was placed on the floor in the room above the patient therapy room while another film badge was placed on the ceiling in the room directly below the therapy room. One badge was placed on the wall near the patient's bed and another was placed at the doorway to the patient therapy room. Finally, a film badge was placed on the wall in an adjacent room and, depending upon which of the two therapy rooms the treatment was taking place, the other badge was either placed on a wall in the other adjacent room or on a wall in an adjacent stairwell.

The maximum dose equivalent measurement seen in the patient room 17.7 mSv (1,770 mrem) for a radioimmunotherapy patient who received 23.4 GBq (633 mCi). The

maximum measurement seen at the doorway was 4.3 mSv (430 mrem) for a radioimmunotherapy patient who received 22.2 GBq (600 mCi). It was unclear as to whether the film badge was placed on the inside or the outside of the patients' doors. The maximum dose equivalent measurement made in the room above was 1.4 mSv (140 mrem) for the radioimmunotherapy patient who received 23.4 GBq (633 mCi). Values for the other locations were not presented. Although the duration of the treatments were not explicitly stated for the patients, McBaugh implied that the length of a radioimmunotherapy was eight days.

Air sampling was performed both inside the patient rooms as well as just outside the door of the patient rooms. This was accomplished with the use of two sampling heads. Using vinyl tubing, each sampling head was connected to a flowmeter and then to the hospital vacuum system. With a flow rate of 15 L min^{-1}, air was pulled through a glass fiber filter and then through a Triethylene di-Amine (TEDA) impregnated carbon cartridge. Most of the samples were changed every 24 hours with the exception of some samples taken at 48 hour intervals towards the end of the patient's stay. According to McBaugh (1990), the manufacturer of the glass fiber filters states the lowest efficiency of 99.98% occurs at an aerosol size of 0.3 μm, while the manufacturer of the carbon cartridges states that for a flow rate of 30 L min^{-1} the retention rate is 98% for methyl iodide. McBaugh notes that the reason tests are done with methyl iodide is because methyl iodide has the poorest retention efficiency. In the study by McBaugh (1990), the retention rate for I_2 was determined to be 99.9%.

A 1.5 in. by 1.5 in. sodium iodide crystal probe in conjunction with a Ludlum model 2200 scaler rate meter was used to perform the analysis of the carbon cartridges

and filters. "A 10 minute background count was done before each counting session prior to retrieving air samples" (McBaugh 1990). The efficiency was determined to be 12.3% for the filters and 9.4% for the carbon cartridges. McBaugh used the following equation for both the carbon cartridges and filters to determine the iodine-131 concentration in air in microcuries per milliliter ($\mu Ci\ ml^{-1}$).

$$\frac{\mu Ci}{ml} = \left(\frac{C-B}{T}\right) * \left(\frac{1}{Eff.}\right) * \left(\frac{1\ \mu Ci}{2.22 * 10^6\ dpm}\right) * \left(\frac{1}{F}\right) * \left(\frac{1\ L}{1000\ ml}\right) * \left(\frac{1}{M}\right)$$

Where:

C = Gross Counts
B = Background Counts
T = Count Time (min.)
Eff. = Efficiency
F = Flow Rate of Air Sampler ($L\ min^{-1}$)
M = Time Air Sampler Was Running (min.)

For the four patients who received the radioimmunotherapy treatment, McBaugh presents maximum and minimum air concentrations in both the patients' room, considered a restricted area, and just outside the patients' door, considered an unrestricted area. All of the concentrations measured in the patients' rooms were below the restricted area limit of 9×10^{-9} $\mu Ci\ ml^{-1}$. The maximum concentration measured in the patient rooms was 4.45×10^{-9} $\mu Ci\ ml^{-1}$ during a 22 GBq (600 mCi) administration. For all four patients, the concentrations just outside the patients' door exceeded the unrestricted limit of 1×10^{-10} $\mu Ci\ ml^{-1}$. The maximum concentration measured in an unrestricted area was 17.6×10^{-10} $\mu Ci\ ml^{-1}$ for the same 22 GBq (600 mCi) administration. McBaugh notes that the limits "are based on having a constant release of that value for the entire year" and the releases observed in the study "were only for a few days."

McBaugh points out that the accumulated dose equivalents, exposure rates, and the air concentrations were all greater for the radioimmunotherapy patients than for the thyroid therapy patients. McBaugh attributes this to the fact that both the activity administered and the length of the therapy were longer for the radioimmunotherapy patients than for the thyroid therapy patients. McBaugh points out that upon normalizing the air concentration values per 3.7GBq (100 mCi) "values are comparable for both types of therapies." When the values for the one meter exposure rate measurements were normalized per 3.7 GBq (100 mCi) it was observed that the values for the thyroid therapies were greater since " more of it (Iodine-131) localizes as a point source in the thyroid than spreads throughout the whole body as with the radioimmunotherapy patients" (McBaugh, 1990).

McBaugh (1990) concludes that "there is nothing inherently unique about high dose monoclonal antibody therapy." The high exposure rates, contamination levels, and airborne exposures are attributed to the high administered activity. McBaugh points out that contamination control practices should be more extensive than standard therapies and air filters used in conjunction with ventilation controls can be used to reduce airborne exposures. McBaugh concludes that most problems associated with this therapy can be solved with the practice of standard radiation safety techniques.

Miller Study

Miller et al. (1979) performed a study examining the hazards associated with therapeutic radioiodine use. Air sampling was performed to assess airborne concentrations, and contamination surveys were performed to address the problem of external contamination. Film badges were also used to determine the dose a patient in an adjacent

room would receive. In addition to providing an evaluation of the hazards, Miller et al. (1979) also provided insight into room preparation, instructions for attending medical staff, and protocol for proper handling of the dose.

Miller et al. (1979) refer to several instances where medical staff were significantly exposed to concentrations of radioiodine. Air sampling was performed in the breathing zone during sodium iodide therapies of 2.8 GBq (75 mCi) to 7.4 GBq (200 mCi). One technologist was exposed to a concentration "several thousand times higher than the maximum permissible concentration of 9×10^{-9} μCi/ml" (Miller et al., 1979). Miller et al. also point out that a thyroid burden of 4.4×10^{-4} MBq (1.2×10^{-2} μCi) was measured on one of the technologists after a dose of 0.56 GBq (15 mCi) was administered to a patient outside of a dose administration fume hood.

In addition to air sampling, film badges and contamination surveys were used to address the external hazards. The use of film badges "indicated that a patient next door to a 100 mCi (3.7 GBq) treatment patient might receive as much as 150 mrem (1.5 mSv)" (Miller et al., 1979). Surveys were performed after patients received their treatments and were discharged from the therapy room. With the use of a composite diagram, Miller et al. illustrated the typical levels of contamination found in a therapy room after a patient is discharged. According to the diagram, the following locations and items were often found to be contaminated to microcurie (10^6 dpm) levels: pillow, telephone, commode, shower floor, sink, and the room exhaust air filter. Activity levels between 10^5 and 10^6 disintegrations per minute were seen on the bed, bathroom floor, chair, nightstand, floor next to the bed, and the countertops. Activity levels ranging from 10^2 and 10^5 dpm were seen on the

floor where the patient was likely to have walked and on the television while all other areas were noted to be "generally free of contamination" (Miller et al., 1979).

Ibis Study

A study by Ibis et al. (1992) focused on iodine-131 contamination associated with thyroid cancer patients. The purpose of the study by Ibis et al. (1992) was to determine the activity released by therapy patients during treatment and to determine the associated room and air concentrations. Eight patients were treated in this study and the administered activity ranged from 3.7 GBq (100 mCi) to 14.8 GBq (400 mCi). Alcohol pads were used to take wipe samples of patients' skin. Alcohol pads were also used to take wipe samples of room surfaces such as the telephone receiver, faucet, door handle, tray stand, and the toilet bowl. Cotton swabs were used to collect saliva samples. These saliva samples as well as the wipe samples of the room surfaces and the patients' skin were taken 4, 24, and 48 hours into the therapy. Average room concentrations were also determined at 24 hours and 48 hours after administration. Air was continuously drawn at a flow rate of approximately 1 L min^{-1} through a charcoal filter sampler located approximately 1.5 meters from the head of the patient. Samples of the patients' exhaled breath were also collected 4, 24, and 48 hours into the therapy. These exhaled breath samples were collected for five minute periods and were obtained with the use of a vacuum pump, a ventilator mask, and a plastic tube containing a charcoal filter mounted inside.

Ibis et al. (1992) determined that activities associated with the wipe samples of the body ranged from approximately 10 Bq cm^{-2} (600 dpm cm^{-2}) to 250 Bq cm^{-2} (15,000 dpm cm^{-2}). Ibis et al. (1992) observed for most of the patients that the maximum level for removable skin activity was reached 24 hours after the administration. Ibis et al. (1992)

make a very interesting observation with respect to the removable activity found on the skin. Ibis et al. (1992) note that "the level at the time of discharge (48 hr.) greatly exceeded the recommended level for unrestricted areas of 0.036 Bq cm^{-2} (2.2 dpm cm^{-2}) and represents a source of potential contamination for the patients' home and office." The removable contamination found on the surface of articles within the room ranged from approximately 1 Bq cm^{-2} (60 dpm cm^{-2}) to 190 Bq cm^{-2} (11,400 dpm cm^{-2}). Ibis et al. note, in general, as the dose activity increased the removable contamination increased as well. The activity from the saliva, ranging from 0.3 MBq g^{-1} (8.1 μCi g^{-1}) to 4.5 MBq g^{-1} (122 μCi g^{-1}), proved to show a positive relationship with both administered activity and the time. As both the administered activity and the time increased the activity per gram of saliva increased as well (Ibis et al., 1992). Activities seen in the patients' exhaled breath ranged from 20 Bq hr^{-1} (0.54 nCi hr^{-1}) to 190 Bq hr^{-1} (5.1 nCi hr^{-1}). The exhaled activity reached its maximum value during the first 24 hours after the administration. The average room air concentration for the first 24 hours after the administration ranged from 0.08 Bq L^{-1} (2.2×10^{-9} μCi ml^{-1}) to 0.44 Bq L^{-1} (1.2×10^{-8} μCi ml^{-1}). Only one patient exceeded the maximum permissible concentration of 0.33 Bq L^{-1} (9×10^{-9} μCi ml^{-1}) (Ibis et al. 1992). By the second day all of the average room concentrations were less than one half of the maximum permissible concentration.

III. MATERIALS AND METHODS

Exposure Rate Measurements

Exposure rates for thirteen patients were measured at several locations within the patient therapy rooms as well as in the accessible adjacent rooms and the hallway. Figure 1 illustrates the twelve locations where exposure rates were measured in Duke Hospital North while Figure 2 illustrates the seven locations for exposure rate measurements in Duke Hospital South. These measurements were taken with a Victoreen Model 450P (S/N 2427) ionization chamber and read in both milliroentgen per hour (mR hr^{-1}) and microroentgen per hour ($\mu R\ hr^{-1}$). All of the readings were taken approximately one foot from the nearest wall. With the exception of the bathrooms, measurements taken in rooms in Duke Hospital North were made at waist level. For the measurements made in the bathroom, one measurement was taken at eye level behind the toilet while the other measurement was taken at eye level in front of the shower. All of the exposure rate measurements in Duke Hospital South were made at waist level. The background reading for the ionization chamber was approximately 5×10^{-9} C kg^{-1} hr^{-1} (20 $\mu R\ hr^{-1}$).

Dose Equivalent Measurements

Thermoluminescent Dosimeters (TLDs), manufactured by Landauer, Inc., were used to determine accumulated dose equivalents during patient treatments. Beginning with patient number seven, the TLDs were mounted prior to the patient therapy and removed after the patient was discharged. For patients treated in Duke Hospital North

Figure 1: Location of Exposure Rate Measurements in Duke Hospital North

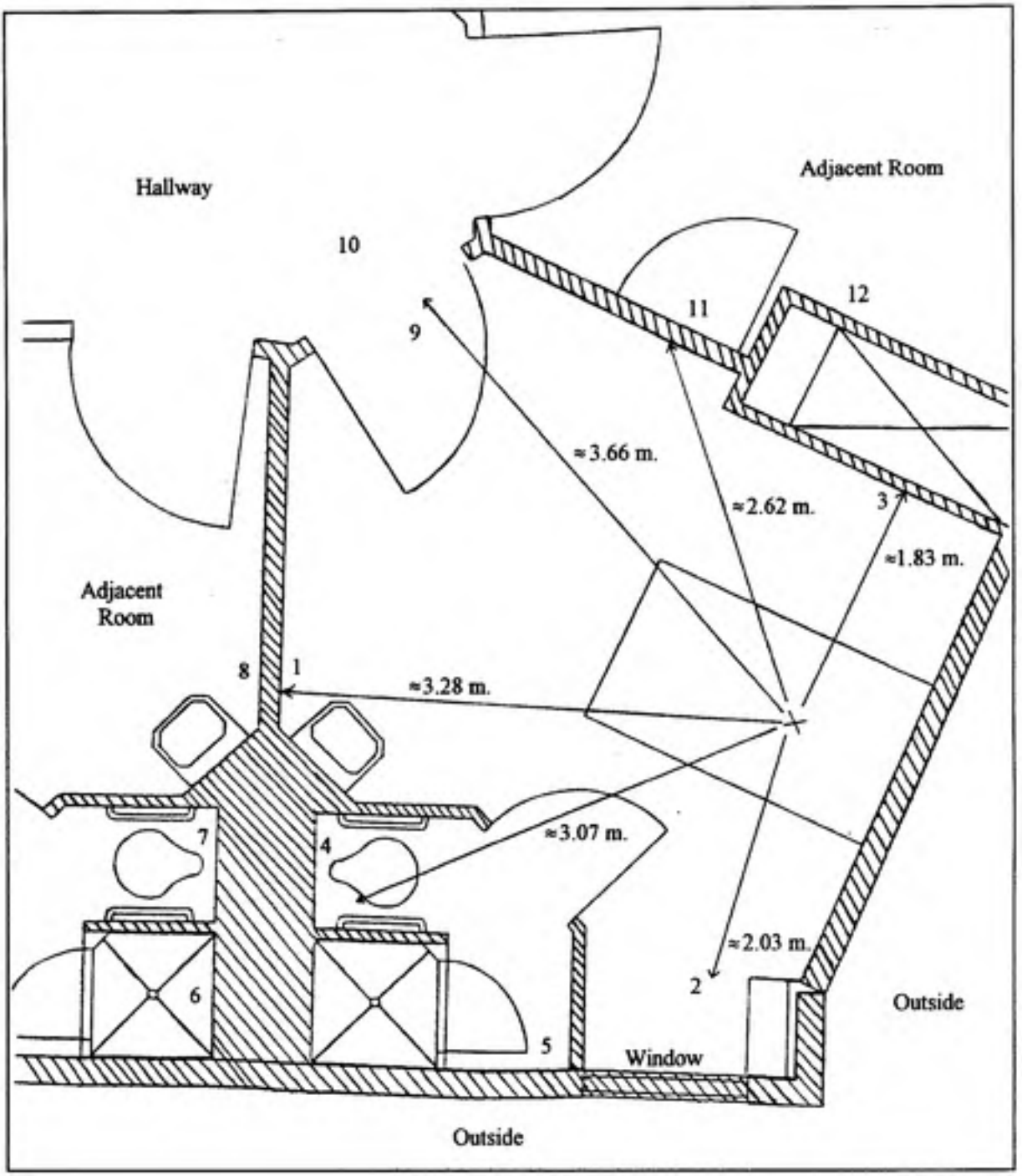
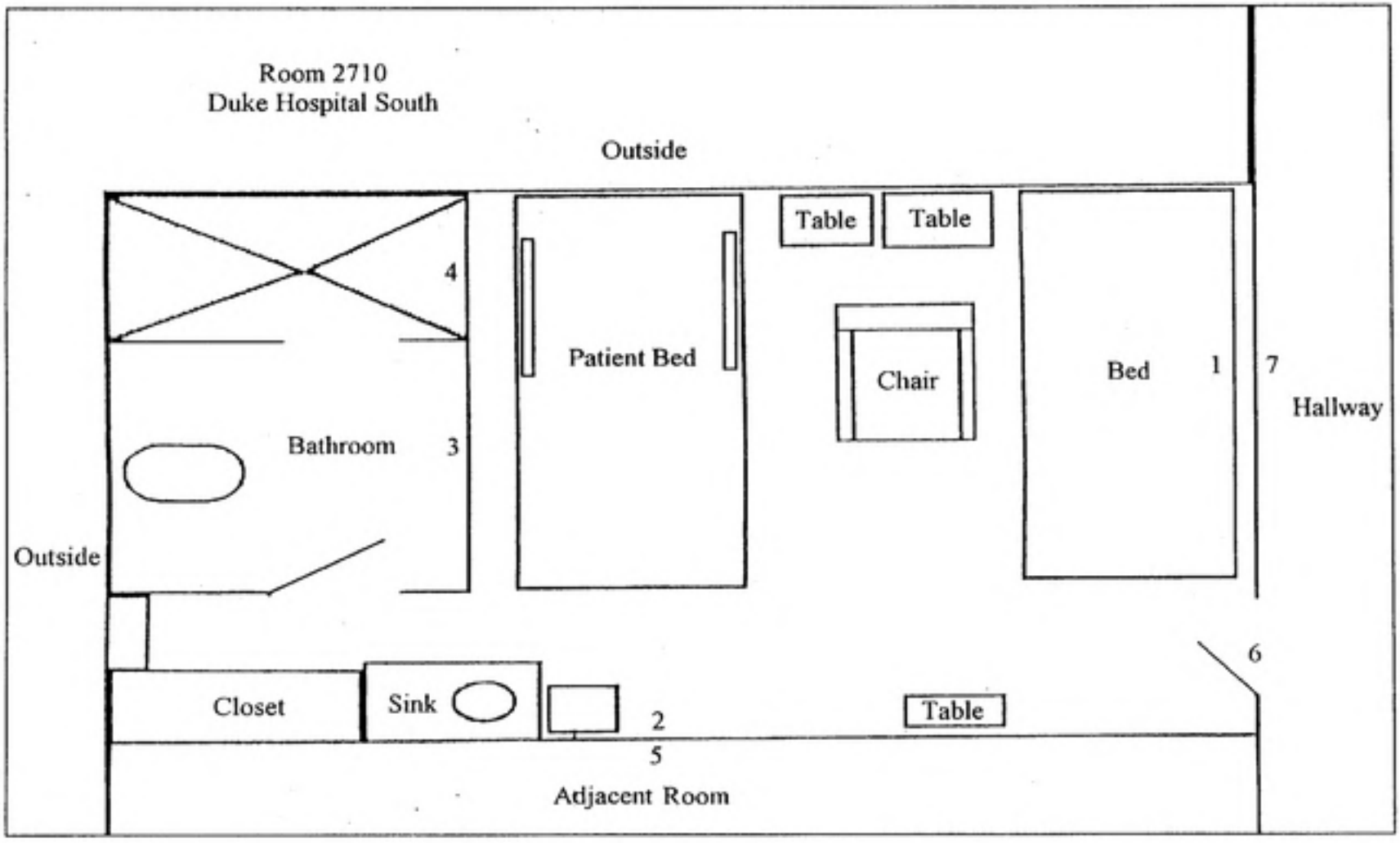


Figure 2: Location of Exposure Rate Meaurements in Duke Hospital South

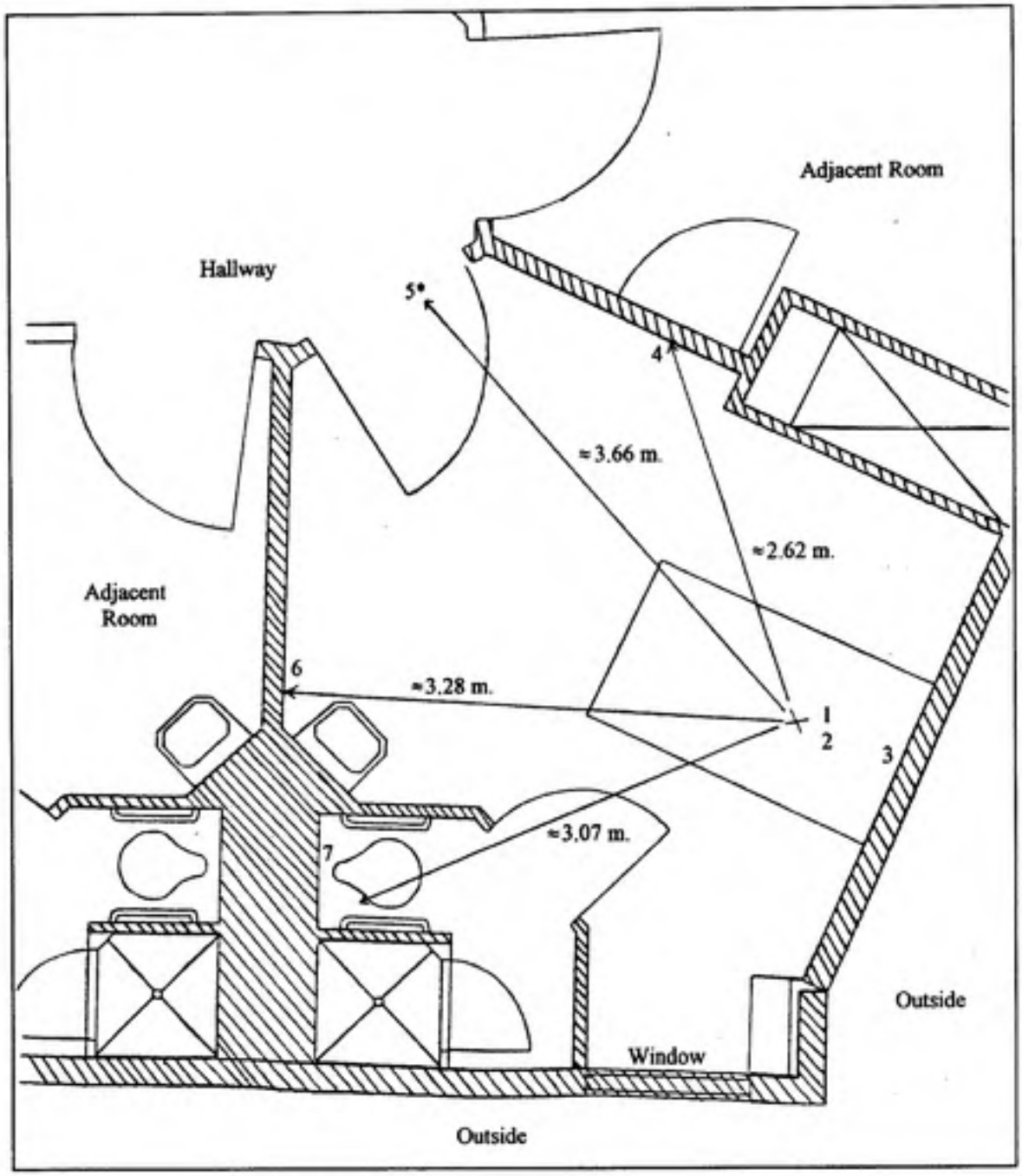


seven locations (see Figure 3) were chosen inside the patient therapy rooms. Patient number 15 was treated in room 6306 in Duke Hospital North where the configuration (see Figure 4) was slightly different than the other therapy rooms used in Duke Hospital North. Although the room configuration was slightly different, seven locations within the therapy room were still chosen for placement of the TLDs. For patients treated in Duke Hospital South, four locations (see Figure 5) were chosen inside the patient therapy rooms. The selected locations were all inside of the therapy rooms to reduce the chance of the housekeeping staff removing or tampering with the TLDs. Each individual TLD was placed inside of a small plastic bag to prevent external contamination and mounted in its respective location. Once the TLDs were removed, they were sent back to Landauer, Inc., for processing. "Control" TLDs were sent along with every shipment of dosimeters to determine any radiation exposure while the dosimeters were being shipped. The "control" TLDs remained in the radiation safety office during the patient treatments.

Contamination Surveys

With the exception of the first three patients, contamination surveys were performed to identify hot spots within the patient therapy rooms. These surveys were performed using pancake Geiger-Mueller detectors (PGM). Any one of four PGMs were used and the display on the detectors ranged from zero to 240,000 cpm. Background values were not recorded for the first six patients. These surveys were performed after the therapy room had been stripped of the blue pads placed throughout the room during the room preparation process. The rationale for performing the surveys after removal of the room preparation material was that dedicated rooms did not exist so regardless of the

Figure 3: Location of Dose Equivalent Measurements in Duke Hospital North



* Indicates location of TLD when door was in the closed position.

Figure 4: Location of Dose Equivalent Measurements in Room 6309 Duke Hospital North

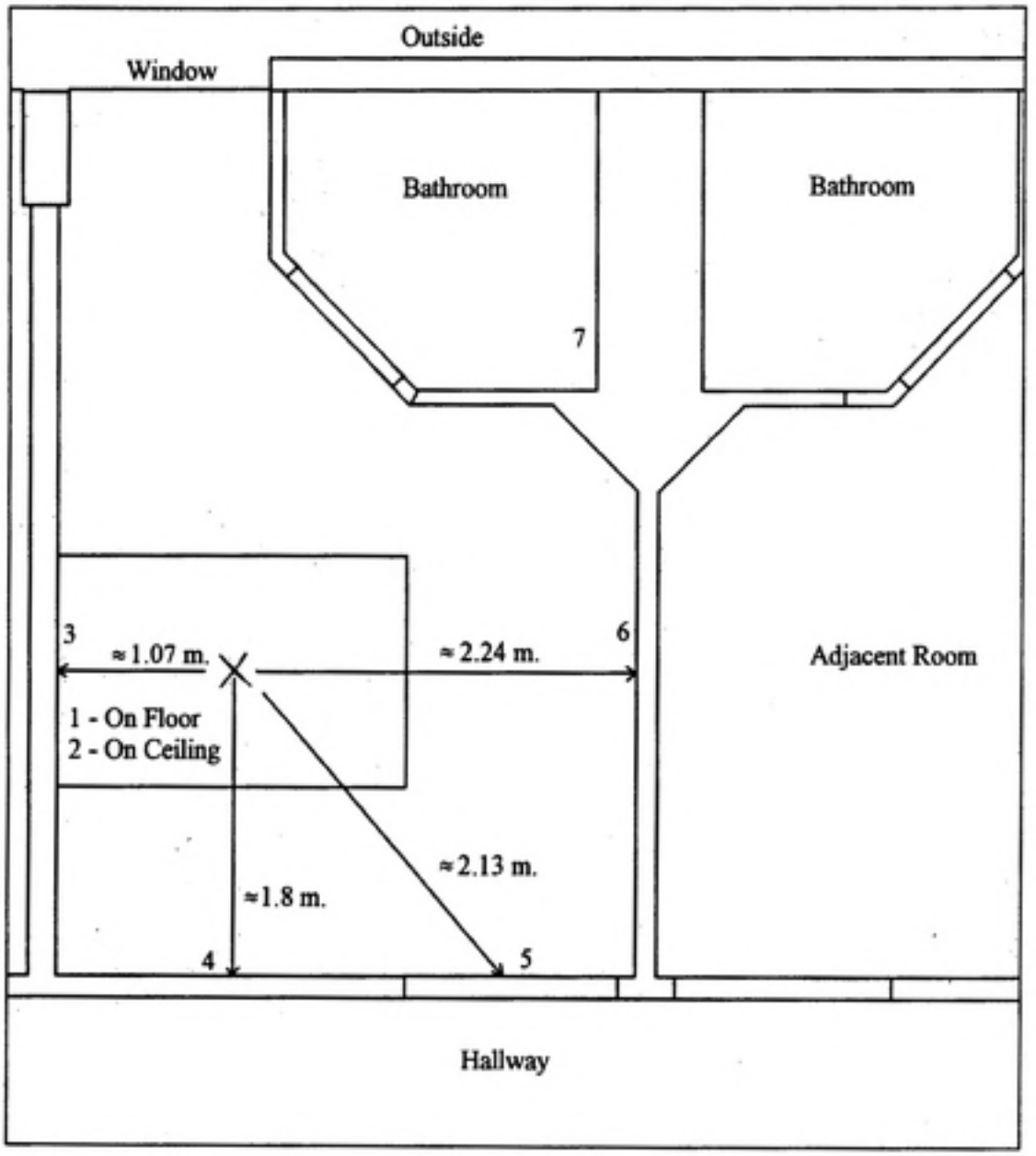
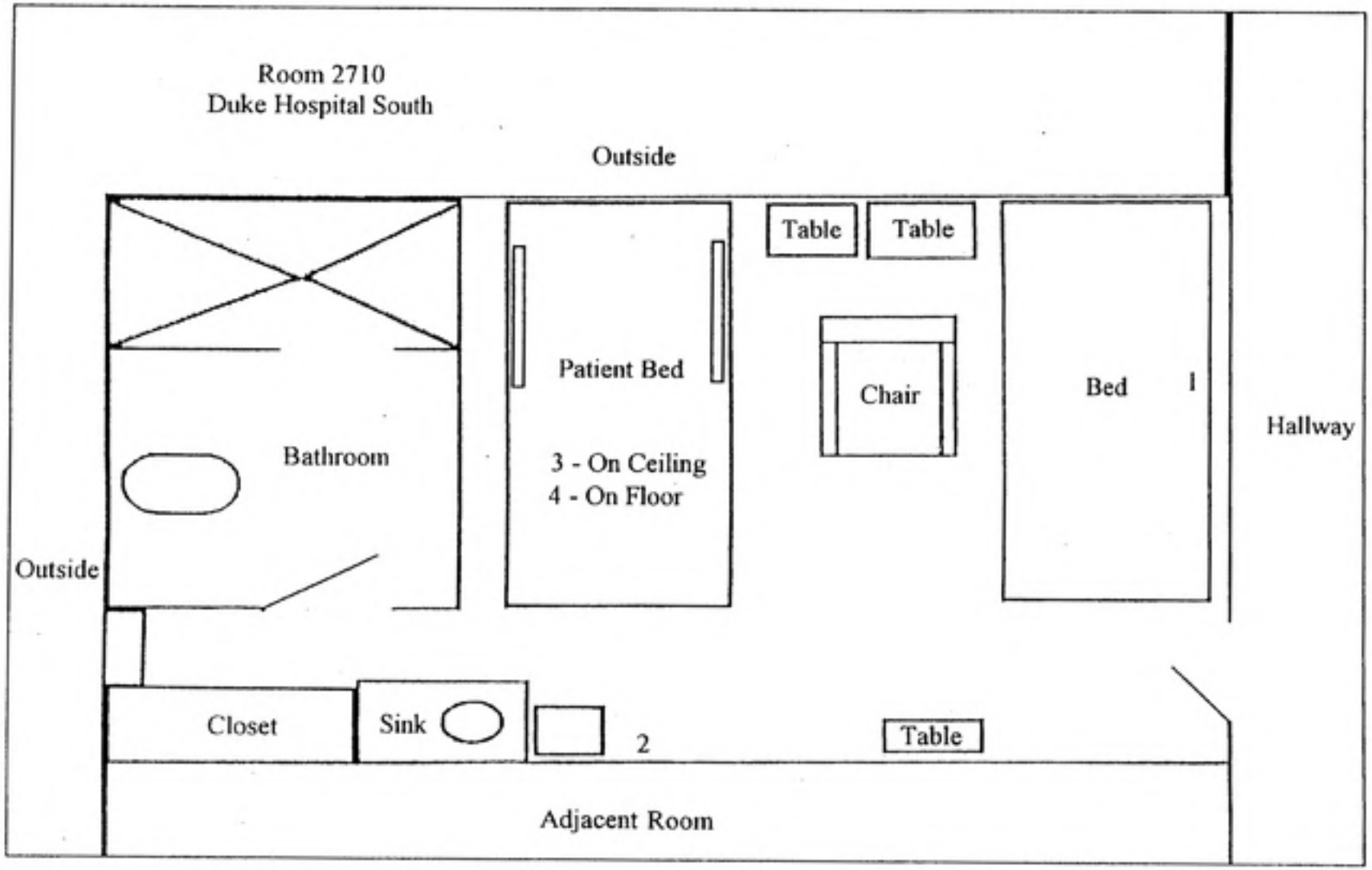


Figure 5: Location of Dose Equivalent Measurements in Duke Hospital South



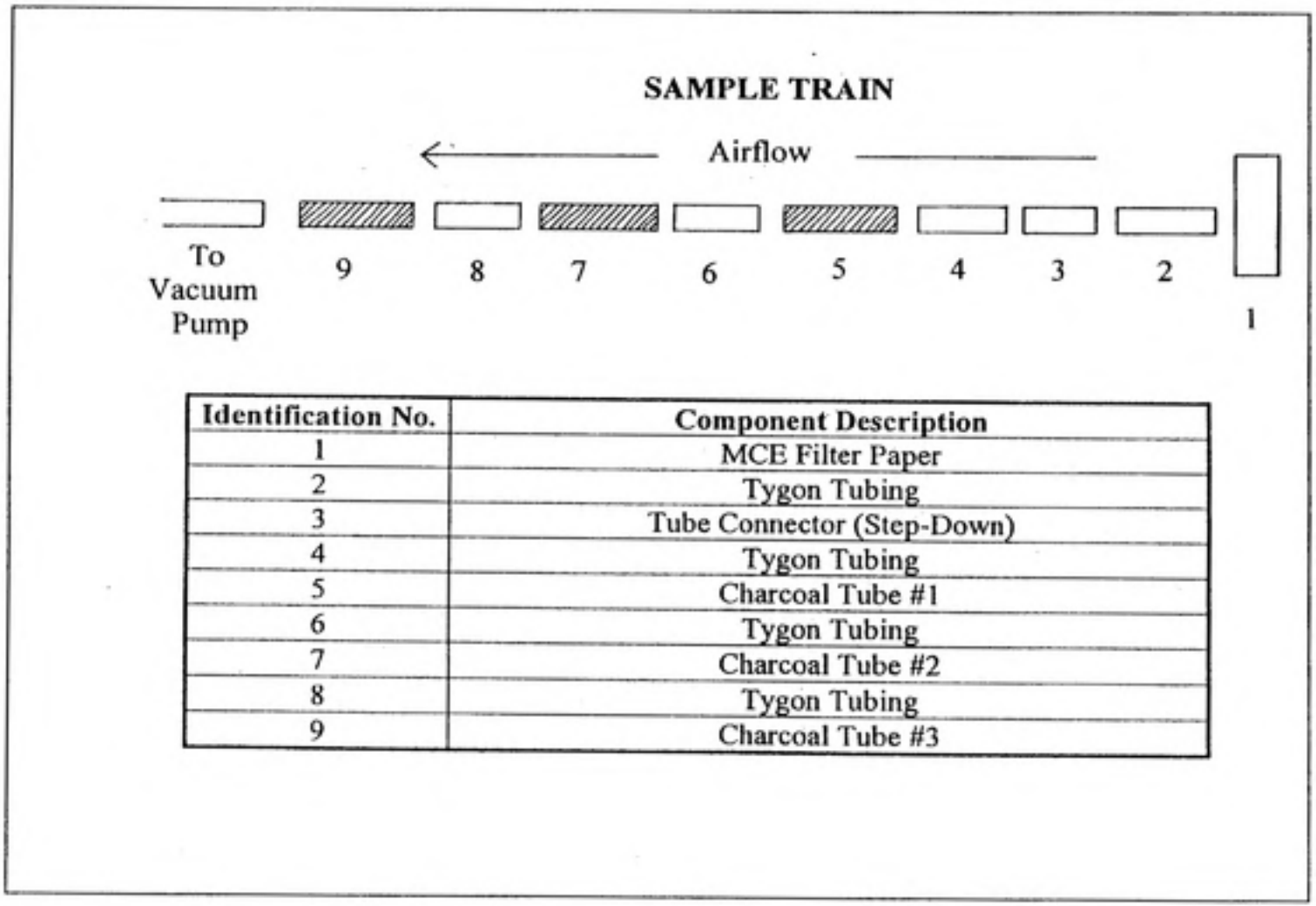
amount of contamination found on the room preparation material it had to be removed. These therapies had the potential to be performed in almost any room within the hospital. It was very likely that a non-radioactive patient would be the next patient admitted into a room that was just previously used for an iodine-131 therapy.

Air Sampling

Air sampling was performed within the patient room during some of the patient therapies. Based upon information from NIOSH Analytical Method 6005, sorbent sampling tubes (SKC 226-67) measuring seven centimeters in length were used to sample for iodine vapor. These tubes contained two sections of charcoal treated with potassium hydroxide. Sampling for particulates was also performed using a mixed cellulose ester filter (SKC 225-5) with a diameter of 37 millimeters and a pore size of 0.8 μm. Sampling with the filter was performed in the open faced position. With the use of a rotameter, a flow rate of 0.5 L min^{-1} was verified both before and after each sampling period. Vinyl tubing was used to connect the mixed cellulose ester filter with three charcoal tubes in series (see Figure 6). The entire sampling unit was then connected to the hospital vacuum system. Sampling was performed for periods ranging from 20 to 24 hours. At the end of the sampling period the entire sampling unit was removed from the room and dismantled. In all cases, the sampling unit was positioned as close to the patient's head as possible without inhibiting care for the patient.

Analysis of the components of the sampling unit was performed using a Packard Auto-gamma counter. The detector's efficiency for iodine-131 is 34%. All the pieces of the sampling unit were analyzed except for the filter casing and the tygon tubing connecting the sampling unit with the hospital vacuum system. The components were placed into

Figure 6: Diagram of Air Sampling Unit



Identification No.	Component Description
1	MCE Filter Paper
2	Tygon Tubing
3	Tube Connector (Step-Down)
4	Tygon Tubing
5	Charcoal Tube #1
6	Tygon Tubing
7	Charcoal Tube #2
8	Tygon Tubing
9	Charcoal Tube #3

separate vials and inserted into the gamma counter. Each piece was counted for twenty minutes. Wipe tests were performed on the components of the sampling unit, including the pieces of tygon tubing between the charcoal tubes and the filter. Wipe tests were used to evaluate the external contamination of the sampling unit components. The counting period for the wipe samples ranged from 30 seconds to five minutes.

The air concentrations were calculated using a method very similar to the method McBaugh (1990) utilized to calculate the concentrations. For each component of the sampling unit, a net count rate was calculated by subtracting the background count rate from the component's respective measured count rate. The net count rate for each of the components was summed to produce a total net count rate (Net Rate). The following equation was then used to determine the concentration.

$$\frac{\mu Ci}{ml} = (NR) * \left(\frac{1}{Eff.}\right) * \left(\frac{1\ \mu Ci}{2.22 * 10^6\ dpm}\right) * \left(\frac{1}{F}\right) * \left(\frac{1\ L}{1000\ ml}\right) * \left(\frac{1}{M}\right)$$

Where:

NR = Net Rate (cpm)
Eff. = Efficiency
F = Flow Rate of Air Sampler (L min^{-1})
M = Time Air Sampler Was Running (min.)

Decision levels were calculated for the analysis of all of the samples. The decision level is the level or net count rate which, if exceeded, indicates the presence of activity in the sample (Hickey et al., 1993). According to Hickey et al., the decision level (DL) can be calculated using the following equation:

$$DL = 1.645\sqrt{R_b\left(\frac{1}{T_b} + \frac{1}{T_g}\right)}$$

where R_b represents the background count rate, T_b represents the background counting time, and T_g represents the sample counting time. The value of 1.645 "corresponds to a 5% false alarm rate" (Hickey et al., 1993). Simply stated, the decision level is the level at which one would be 95% confident that activity is present in the sample.

IV. RESULTS

Exposure Rates

Exposure rate measurements were taken for thirteen patients, and the values ranged from 8.3×10^{-9} C kg^{-1} hr^{-1} (0.032 mR hr^{-1}) to 1.7×10^{-5} C kg^{-1} hr^{-1} (67 mR hr^{-1}). Appendix A contains the exposure rates measured for all thirteen patients. Exposure rates measured in patients' rooms, characterized as a restricted area, ranged from 4.1×10^{-8} C kg^{-1} hr^{-1} (0.16 mR hr^{-1}) to 1.7×10^{-5} C kg^{-1} hr^{-1} (67 mR hr^{-1}). The maximum reading of 1.7×10^{-5} C kg^{-1} hr^{-1} (67 mR hr^{-1}) was measured on patient number ten. The reading was made on the first day of a 11.2 GBq (303 mCi) MiBG therapy while the patient was sitting in the chair. The location (number two) was just in front of the window and next to the chair in the room. The reading was just to the left of the patient's head. Data for this patient are presented in Table 2.

Exposure rates measured in adjacent rooms, and the hallway ranged from 8.3×10^{-9} C kg^{-1} hr^{-1} (0.032 mR hr^{-1}) up to 4.1×10^{-7} C kg^{-1} hr^{-1} (1.6 mR hr^{-1}). The maximum value of 4.1×10^{-7} C kg^{-1} hr^{-1} (1.6 mR hr^{-1}) was measured for patient number two at location number 11, which is in one of the adjacent rooms (see Figure 1). This measurement was taken on the first day of a 5.6 GBq (150 mCi) sodium iodide therapy while the patient was lying in the center of the bed. Data for patient number two are included in Table 3.

TABLE 2: Exposure Rate Data for Patient Number 10

Room Number: 9110 Duke Hospital North **Therapy Activity:** 303 mCi
Type of Therapy: MIBG **6 ft. Reading:** 11.8 mR/hr.

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	3.7	1.71	1.08	0.75	0.54
2	67	7.0	3.4	3.5	2.0
3	3.2	4.1	3.3	2.7	2.5
4	1.15	1.57	4.7*	0.5	0.31
5	10.5	12.7	0.85*	2.4	1.8
6	Not Taken	0.6	0.35*	0.191	0.09
7	1.41	0.46	0.33*	0.2	0.1
8	1.0	0.7	0.8*	0.34	0.25
9	1.38	0.65	0.43	0.27	0.40
10	0.62	0.4	0.35	0.22	0.25
11	1.25	0.26	0.29*	0.12	N/A*
12	0.35	0.3	0.2*	0.19	N/A*

Comments

Day 1:
Patient sitting in chair
Two lead shields placed around bed
No urine in patient room

Day 2:
Patient lying in center of bed; One urine jug in castle
Time: 11:00 am; 6 ft. Reading = 6.0 mR/hr. = 154 mCi remaining
Two lead shields still in place

Day 3:
Patient lying in center of bed; One urine jug in castle; Two lead shields still in place
Time: 11:30 am; 6 ft. Reading = 3.6 mR/hr. = 92 mCi remaining
* Patient moved to sitting position on right side of bed (facing)

Day 4:
Patient lying in center of bed; One urine jug in castle
Time: 9:45 am; 6 ft. Reading = 2.4 mR/hr. = 62 mCi remaining
One lead shield at foot of bed remains in place

Day 5:
Patient lying in center of bed; One urine jug in castle
Time: 10:15 am; 6 ft. Reading = 1.7 mR/hr. = 44 mCi remaining
One lead shield at foot of bed remains in place

* Not Accessible

TABLE 3: Exposure Rate Data for Patient Number 2

Room Number: 3124 Duke Hospital North **Therapy Activity:** 150 mCi
Type of Therapy: Sodium Iodide **6 ft. Reading:** 8.4 mR/hr.

Location	Day 1	Day 2	Day 3
1	2.7	1.03	0.31
2	4.3	2.2	0.68
3	6.9	2.4	1.5
4	1.59	0.55	0.25
5	2.0	6.4	2.5
6	N/A*	0.1	0.032
7	N/A*	0.15	0.067
8	1.0	0.5	0.2
9	1.75	0.7	0.35
10	1.1	0.4	0.196
11	1.6	N/A*	N/A*
12	Not Taken	N/A*	N/A*

Comments

Day 1:
No urine in patient room
Patient lying in middle of bed

Day 2:
Time = 2:30 pm
One urine jug in castle; Patient lying in middle of bed
6 ft. Reading = 2.5 mR/hr. = 44 mCi remaining

Day 3:
Time = 9:10 am
One urine jug in castle; Patient lying towards left side of bed (facing)
6 ft. Reading = 1.0 mR/hr = 18 mCi remaining → **Discharged**

* Not Accessible

Dose Equivalent Measurements

The dose equivalent measurements determined for ten patients ranged from 0.2 mSv (20 mrem) to 19.5 mSv (1,950 mrem). The dose equivalent measurements were determined for the duration of each patient's therapy period. The dose equivalent measurements for all ten patients can be found in Appendix B. The maximum measurement of 19.5 mSv (1,950 mrem) was determined for patient number ten who was administered 11.2 GBq (303 mCi) for a MiBG therapy. The measurement was registered on a TLD mounted on the floor beneath the patient's bed. The patient was in isolation for seven days. Data for all seven TLD locations (see Figure 3) are presented in the following table:

TABLE 4: Dose Equivalent Measurements for Patient Number 10

Badge Location	1	2	3	4	5	6	7
Reading (mrem)	1,950	410	890	90	80	110	100

A reading of 19.4 mSv (1,940 mrem) was measured on a TLD mounted behind the head of patient number 14. Patient number 14 was administered an activity of 3.7 GBq (100 mCi) for a radioimmunotherapy or monoclonal antibody therapy. This patient was in isolation for eight days. The dose equivalent results for all seven TLD locations are included in Table 5.

TABLE 5: Dose Equivalent Measurements for Patient Number 14

Badge Location	1	2	3	4	5	6	7
Reading (mrem)	810	560	1,940	190	130	200	160

Contamination Surveys

Contamination levels were measured in counts per minute (cpm) and varied from 100 cpm to 240,000 cpm. Background values ranged from 50 cpm to 100 cpm. The

maximum value of 240,000 cpm was detected in a localized area on the mattress cover for patient number 14. The following composite table provides ranges of contamination levels for selected areas. A complete contamination survey for each patient can be found in Appendix C.

TABLE 6: Selected Contamination Levels

Location	Counts Per Minute
Sinks	300 - 180,000
Toilet Seats	100 - 100,000
Toilet Bowls	400 - 100,000
Mattress Covers	400 - 240,000
Telephones	400 - 20,000
Linens (Pillows, Blankets)	800 - 120,000

Air Sampling

Air sampling was performed for three different patients. For the patients isolated in Duke Hospital North, the sampling unit was positioned horizontally about four feet from the floor and approximately two to three feet from the patient's head. For the patient isolated in Duke Hospital South, the sampling unit was positioned vertically about six feet from the floor behind the patient's head. The concentration calculated from each sampling period was below the derived air concentration (DAC) of 2×10^{-8} $\mu Ci\ ml^{-1}$. The concentration was determined by summing the activity above background measured for each piece of the sampling unit. Not only was the filter paper and the three charcoal tubes counted to determine the concentration, but the pieces of vinyl tubing used to connect the charcoal tubes were counted as well (see Figure 6). A brief summary of the results can be seen in Table 7. The count rate for each component as well as the Net Rate for all of the samples are presented in counts per minute. In Table 7, the calculated air concentrations

are displayed in microcuries per milliliter ($\mu Ci\ ml^{-1}$). A more comprehensive description of the results can be found in Appendix D.

TABLE 7: Air Sampling Data

	Patient 15				Patient 16	Patient 17
	Sample 1		Sample 2		Sample 3	Sample 4
Component	Count #1	Count #2	Count #1	Count #2		
1	45	41	18	17	69	40
2	8	6	1	5	62	30
3	0	2	0	1	15	0
4	30	25	5	4	71	12
5	28	24	14	18	105	97
6	32	31	6	10	61	32
7	3	3	1	0	26	32
8	46	41	8	8	56	31
9	5	2	1	0	36	35
Net Rate	197	175	54	63	501	309
Concentration	3.6×10^{-10}	3.2×10^{-10}	9.9×10^{-11}	1.1×10^{-10}	1.0×10^{-9}	6.8×10^{-10}

Each piece of the sampling unit used for the first sampling period was counted twice. Patient number 15 was isolated in room 6306 Duke Hospital North after receiving a 11.2 GBq (303 mCi) meta-iodobenzylguanidine (MiBG) therapy. The concentrations were calculated to be 3.6×10^{-10} $\mu Ci\ ml^{-1}$ and 3.2×10^{-10} $\mu Ci\ ml^{-1}$ for the first and second count respectively. The majority of the counts were seen on the filter paper (Component No. 1) and on a piece of tygon tubing connecting the second and third charcoal tubes (Component No. 8). Wipe tests were performed to examine the possibility of the charcoal tubes being externally contaminated. The decision level corresponding to the wipe tests performed on the components used in first sampling period (Sample 1) was calculated to be 36 cpm. The results from the wipe tests do not suggest external contamination, but it should be noted that each piece was only counted for 30 seconds. This short counting pe-

riod may inhibit the ability to be confident that activity was not present on the external surfaces of the component of the sampling unit.

Another sampling unit was set up and sampling was performed during the second twenty four hour period of the same patient's therapy. During the first twenty four hours of therapy, the patient had excreted a portion of the iodine-131. According to the radiation safety technician's measurement, the activity remaining within the patient at the start of the sampling period was 5.7 GBq (155 mCi). Again, the components of the sampling train were counted twice and the calculated concentrations were 9.9×10^{-11} $\mu Ci\ ml^{-1}$ and 1.1×10^{-10} $\mu Ci\ ml^{-1}$ respectively. As with the first sampling unit, wipe tests were performed on each piece of the sampling unit and those samples were counted for one minute. The decision level corresponding to the wipe tests performed on the components used in second sampling period (Sample 2) was calculated to be 17 cpm. The results from the wipe tests did not suggest the components became externally contaminated.

Sampling was performed on a patient who received 2.2 GBq (60 mCi) for a monoclonal antibody therapy. This patient was isolated in room 2710 located in Duke Hospital South. Sampling was performed for a 22 hour period and the concentration was determined to be 1.0×10^{-9} $\mu Ci\ ml^{-1}$. The greatest number of counts was seen in the first charcoal tube although activity was observed in each component of the sampling unit. Wipe tests were performed on the components of the sampling unit. The decision level for the wipe samples was calculated to be 20 cpm. Wipes from three components of the sampling unit had count rates greater than the calculated decision level. Theoretically, it can be said with 95% confidence that some activity was present on the outside of the components. It should be pointed out that the counting time for these components was only one minute.

Air sampling was also performed for a patient who was isolated in room 3123 of Duke Hospital North in order to receive 3.7 GBq (100 mCi) for a sodium iodide therapy. The components from this sampling unit were counted prior to their use for sampling in order to verify no contamination was present. Sampling was performed for a 20 hour period and the concentration was calculated to be 6.8×10^{-10} $\mu Ci\ ml^{-1}$. The greatest number of counts was seen on the first charcoal tube but, as with all of the other samples, activity was also observed on the other components of the sampling unit as well. Wipe samples were taken and counted for five minutes. The decision level for these wipe samples was calculated to be 7.5 cpm. Based upon the decision level, it appears that activity was not present on the exterior of the sampling components.

V. DISCUSSION

Exposure Rates

In both Figure 7 and Figure 8 exposure rate measurements were plotted for each day of certain patients' therapies. Each graph consists of four patients who were the recipients of radioimmunotherapies in Duke Hospital North. Patient number three, patient number four, and patient number eight received 3.0 GBq (80 mCi) while patient number 14 received 3.7 GBq (100 mCi). Figure 7 was generated for exposure rates at location number one and Figure 8 was generated for exposure rates at location number nine. For patient number three, data was not taken on day five at location number nine. As one might expect both of these figures illustrate a downward trend in the exposure rates as the duration of the treatment progressed.

Two similar figures were developed for four patients who received sodium iodide therapies in Duke North Hospital. Figure 9 illustrated the exposure rates for each patient at location number one while Figure 10 illustrated the exposure rates for each patient at location number nine. Patient number one, patient number two, patient number five, and patient number seven each received 5.5 GBq (150 mCi). As with the results from Figure 7 and Figure 8, the exposure rates for the sodium iodide therapies as a function of time also illustrate a downward trend.

Exposure rate measurements varied throughout this study. Several factors were responsible for the variations. Unless otherwise noted, it was assumed that the patient

Figure 7: Exposure Rate Measurements at Location Number 1 for Radioimmunotherapy Patients Isolated in Duke Hospital North

Day	Patient 3	Patient 4	Patient 8	Patient 14
1	1.05	1.3	0.43	3.8
2	1.03	1.92	1.2	4.7
3	0.7	1.5	0.75	2.1
4	0.69	1.3	0.61	1.3
5	0.34	1.14		1.86
6	0.42	1		1.9
7		0.93		1.2

	Activity
Patient 3	80 mCi
Patient 4	80 mCi
Patient 8	80 mCi
Patient 14	100 mCi

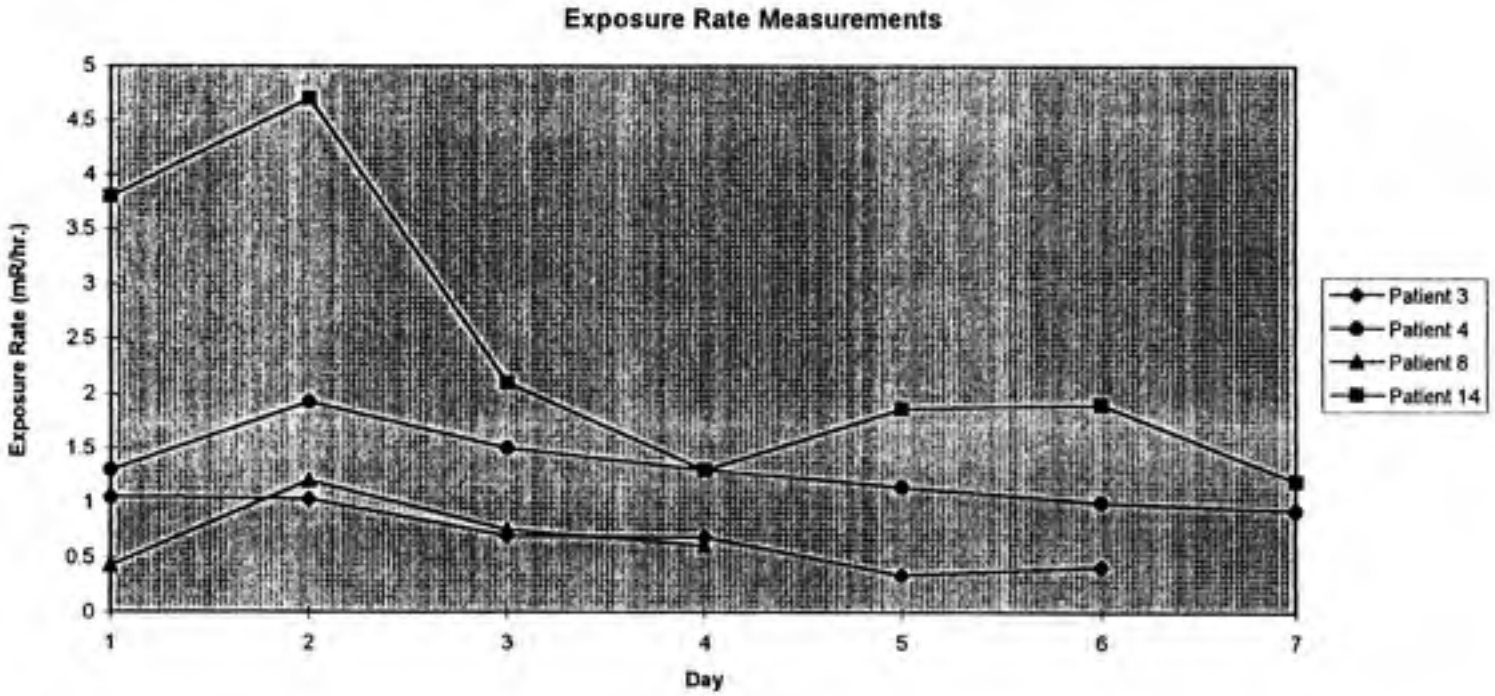


Figure 8: Exposure Rate Measurements at Location Number 9 for Radioimmunotherapy Patients Isolated in Duke Hospital North

Day	Patient 3	Patient 4	Patient 8	Patient 14
1	1.03	1.2	0.44	2.2
2	1	1.1	0.71	1.8
3	0.7	1	0.4	1.2
4	0.6	0.81	0.37	0.8
5	Not Taken	0.72		1
6	0.45	0.7		0.91
7		0.59		0.5

	Activity
Patient 3	80 mCi
Patient 4	80 mCi
Patient 8	80 mCi
Patient 14	100 mCi

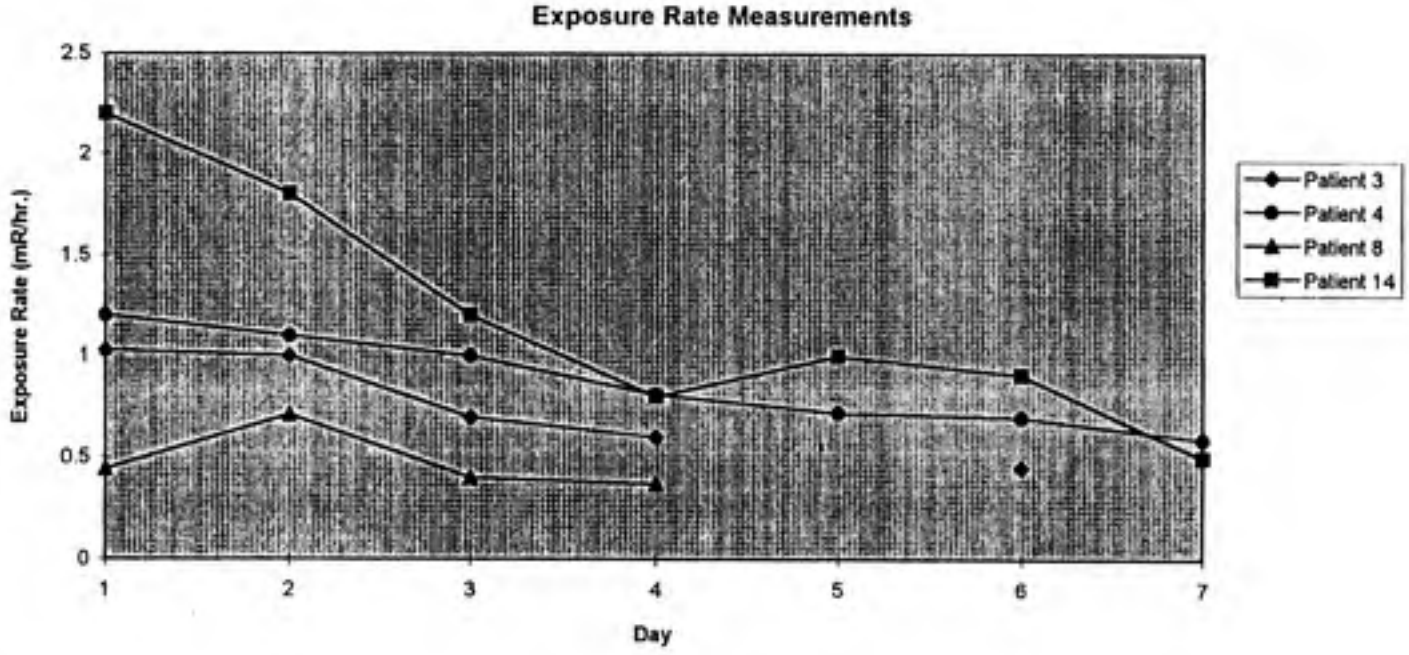


Figure 9: Exposure Rate Measurements at Location Number 1 for Sodium Iodide Therapy Patients Isolated in Duke Hospital North

Day	Patient 1	Patient 2	Patient 5	Patient 7
1	1.85	2.7	2.9	2.5
2	0.91	1.03	1.04	1.2
3	0.36	0.31	0.52	0.33

	Activity
Patient 1	150 mCi
Patient 2	150 mCi
Patient 5	150 mCi
Patient 7	150 mCi

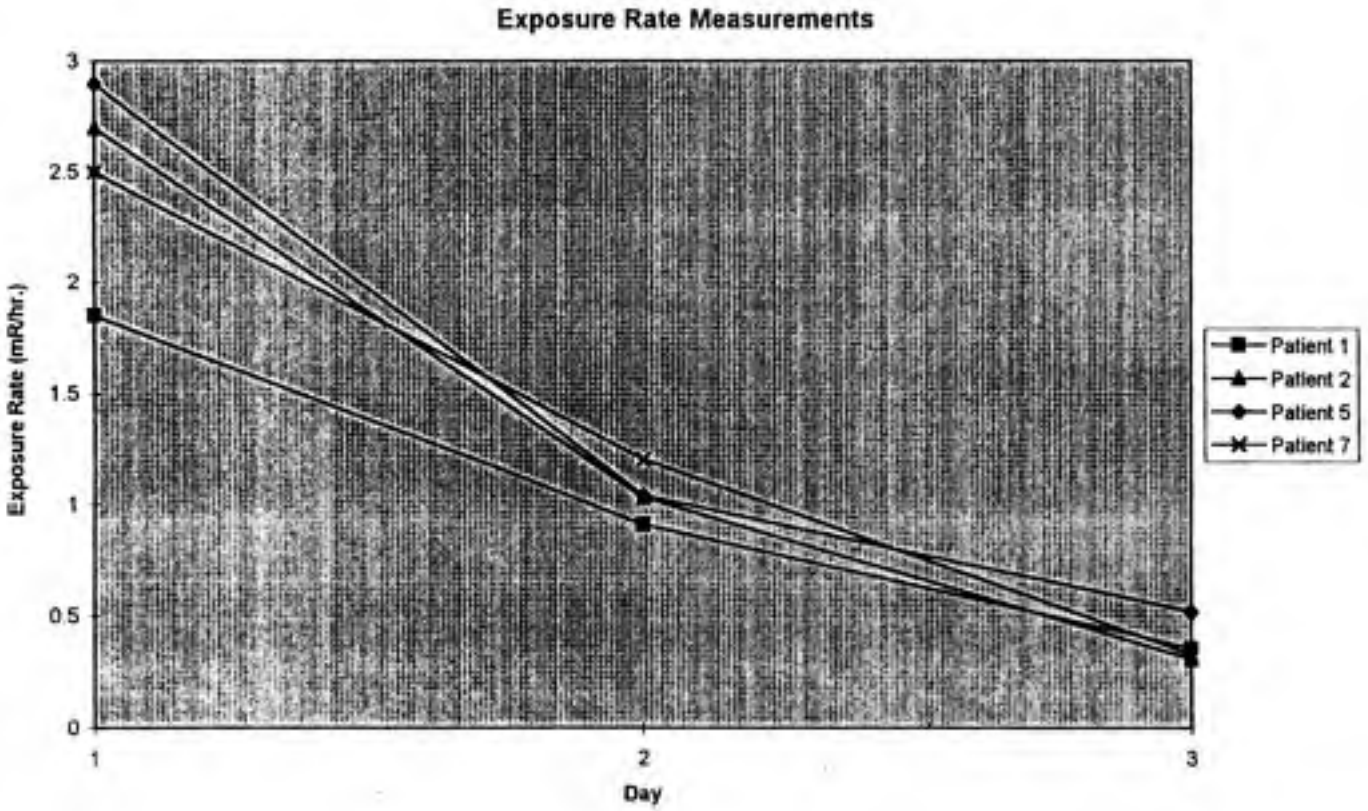
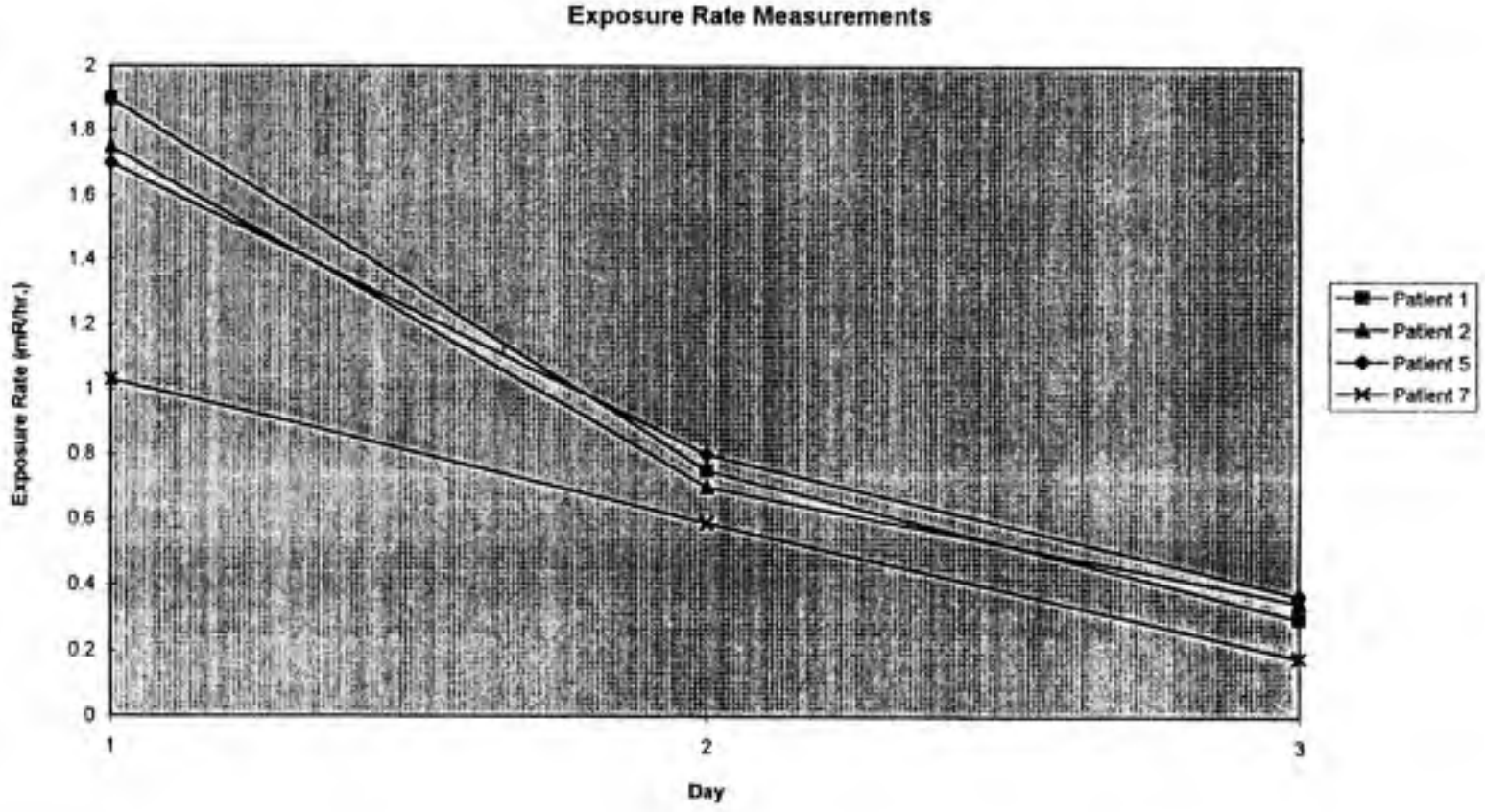


Figure 10: Exposure Rate Measurements at Location Number 9 for Sodium Iodide Therapy Patients Isolated in Duke Hospital North

Day	Patient 1	Patient 2	Patient 5	Patient 7
1	1.9	1.75	1.7	1.03
2	0.75	0.7	0.8	0.59
3	0.3	0.35	0.37	0.18

	Activity
Patient 1	150 mCi
Patient 2	150 mCi
Patient 5	150 mCi
Patient 7	150 mCi



remained in the same location for all twelve measurements. However, it is not certain as to whether the patient actually remained in the same location for all twelve measurements on a given day.

Not only did the patient's location during the measurements vary but it was also likely that the patient's location when the measurements were taken would vary from day to day. For instance, on the first day the measurements may have been taken while the patient was lying in the middle of the bed. On the second day the measurements may have been taken while the patient was sitting on the side of the bed as opposed to lying down. Variations such as these must be taken into account when examining the data.

The urine from these patients was likely another source of variation in the exposure rate measurements. At Duke University Medical Center, the urine excreted from each therapy patient is collected in large plastic bottles. While the urine is in the patient's room it is stored in a lead "castle." This lead "castle" is a mobile lead container specifically designed to temporarily store one plastic urine bottle. The urine is removed from the "castle" in the patient's room at least once every 24 hours. The exposure rate measurements were taken while the urine was still in the room. Often patients filled the first plastic bottle with urine and began to use a second bottle. Patients were instructed to leave the bottle containing the most urine in the lead "castle." When measurements were made, the plastic urine bottles were sometimes found on the shelf behind the toilet as well as on the floor near the lead "castle." Since the patient's urine was one of the principal pathways for the excretion of the iodine-131, the amount and the location of the patient's urine would be sources of variation for these exposure rate measurements.

Dose Equivalents

Figure 11 illustrates dose equivalent measurements for each of the seven locations. Only patients isolated in Duke Hospital North receiving either a sodium iodide therapy or a radioimmunotherapy were included in this figure. Of the ten patients for whom dose equivalent measurements were made, only five patients were selected for this illustration. Patient number seven, patient number 11, and patient number 12 each received 5.5 GBq (150 mCi) for a sodium iodide therapy. Patient number eight and patient number 14 were isolated for radioimmunotherapy and the administered activity was 3.0 GBq (80 mCi) and 3.7 GBq (100 mCi), respectively.

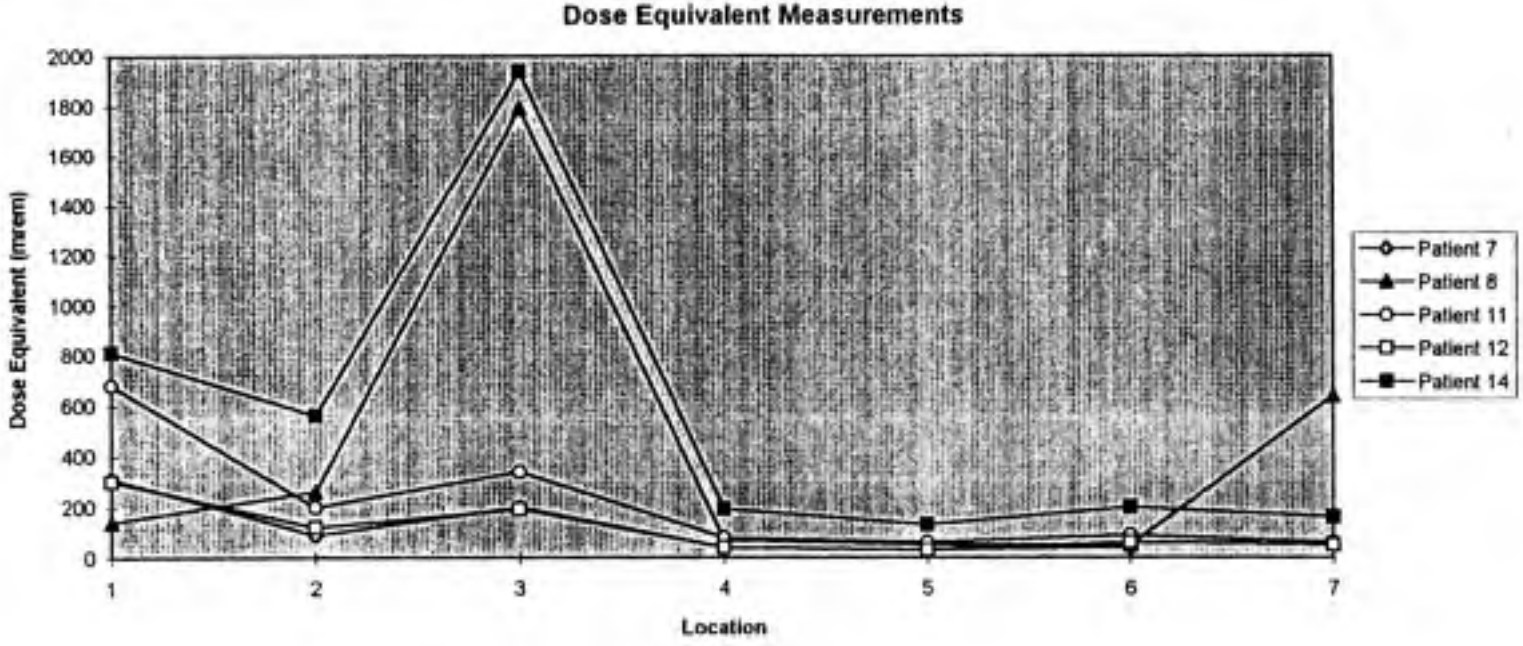
Most notably, the figure illustrates a significant increase in the measurements for the radioimmunotherapy patients at location number three. Location number three was on the wall directly behind the head of the patient's bed. One characteristic of radioimmunotherapy may explain why the measurements behind the head of the radioimmunotherapy patient's bed is greater than the measurements behind the head of the sodium iodide therapy patient's bed. With respect to radioimmunotherapy, the therapeutic dose is administered to patients suffering from neoplastic meningitis, a form of brain cancer. The dose is injected into a reservoir located within the patient's head. Elevated measurements for radioimmunotherapy patients at location number three are not surprising since location number three is behind the patient's head.

The measurement at location number seven is greater for patient number 14 than for the other four patients. Location number seven was in the bathroom on the wall behind the toilet. One possible explanation for the increased reading at location number

Figure 11: Dose Equivalent Measurements for Sodium Iodide (NaI) Patients and Radioimmunotherapy (MAb) Patients Isolated in Duke North Hospital

Location	Patient 7	Patient 8	Patient 11	Patient 12	Patient 14
1	310	140	680	300	810
2	90	260	200	120	560
3	200	1790	340	190	1940
4	40	70	80	40	190
5	30	50	60	30	130
6	40	50	90	60	200
7		640	60	50	160

	Activity	Therapy
Patient 7	150 mCi	NaI
Patient 8	80 mCi	MAb
Patient 11	150 mCi	NaI
Patient 12	150 mCi	NaI
Patient 14	100 mCi	MAb



seven may be the urine temporarily stored in the bathroom. Although this was not specifically noted for patient number 14, it was possible that at some point in time a urine container may have been placed outside of the lead "castle." This would have contributed to an elevated measurement at location number seven.

Since TLDs were not mounted in the unrestricted areas surrounding the therapy rooms, one can not be sure whether a patient in an adjacent room would receive a substantial dose equivalent. Using the TLD data from the restricted areas, with a few assumptions, it is possible to examine the dose equivalents to the general public. One assumption is that the average dose equivalent per day can be calculated by dividing the accumulated dose equivalent measurement by the length of the therapy in days. The second assumption is that a non-radioactive patient is located in a room adjacent to a therapy room for the same duration of time as an iodine-131 patient.

The maximum dose equivalent reading measured on the floor was 19.5 mSv (1,950 mrem) for patient number ten. Utilizing the first assumption previously mentioned, with an accumulated dose equivalent of 19.5 mSv (1,950 mrem), one can calculate an average of 2.8 mSv (280 mrem) per day registering on that TLD. If a non-radioactive patient is in the room below for the same duration of time as patient number ten (seven days), the patient in the room below would be allowed to receive on average approximately 0.14 mSv (14 mrem) per day. If the average of 0.14 mSv (14 mrem) were exceeded, the person in the room below would exceed the annual general public dose equivalent limit of 1 mSv (100 mrem). A TLD mounted on the ceiling in the room below the patient's therapy room would provide the necessary dose equivalent measurement to determine if the average daily dose equivalent of 0.14 mSv (14 mrem) is being exceeded.

The maximum dose equivalent recorded on the ceiling above the bed was 5.6 mSv (560 mrem). This measurement was recorded at location number two (see Figure 3) in Duke Hospital North for patient number 14. With the use of the assumptions previously stated, the average dose equivalent measured in one day could be calculated to be 0.8 mSv (80 mrem). Patient number 14 was isolated for a period of eight days. A non-radioactive patient in the room above for the same duration of time as patient number 14 would be allowed to receive 0.125 mSv (12.5 mrem) per day for the same eight days before exceeding the annual dose equivalent limit of 1 mSv (100 mrem). Mounting a TLD on the floor in the room directly above the patient's therapy room would provide the necessary data to examine whether or not average dose equivalent per day exceeds 0.125 mSv (12.5 Sv).

The maximum accumulated dose equivalent recorded on the wall behind the patient's head was 19.4 mSv (1,940 mrem). With the exception of patient number 15, location number three (see Figure 3) for the patients treated in Duke Hospital North represented an outside wall and the reading at this location had no direct association with the general public. The TLD reading behind the head of patient number 15 was 4.4 mSv (440 mrem). Patient number 15 received a 11.2 GBq (303 mCi) MiBG therapy and was in isolation for seven days. One can calculate the average daily dose equivalent reading on the TLD to be 0.62 mSv (62 mrem). If a non-radioactive patient were in the adjacent room for the same seven days as patient number 15, that particular patient could only receive an average of 0.14 mSv (14 mrem) each day before exceeding the general public dose limit of 1 mSv yr^{-1} (100 mrem yr^{-1}). A TLD mounted in the adjacent room could

determine whether or not the average daily dose equivalent measurement exceeded 0.14 mSv (14 mrem).

For the TLDs mounted on the walls and doors, the maximum reading registered was 6.4 mSv (640 mrem) on a TLD mounted on the wall behind the toilet. Patient number eight received 3.0 GBq (80 mCi) via radioimmunotherapy and was in isolation for six days. The way that the rooms in the hospital were configured the bathroom in a therapy room was adjacent to the bathroom in the adjacent room (see Figure 3). The average daily dose equivalent deposited on this particular TLD can be calculated to be 1.1 mSv (110 mrem) per day. If a non-radioactive patient spent the same six days in an adjacent room that patient could only receive 0.16 mSv (16 mrem) per day without exceeding the annual general public limit of 1 mSv (100 mrem). The accumulated dose equivalents at locations four, five, and six ranged from 0.5 mSv (50 mrem) to 0.7 mSv (70 mrem). For a period of time during this patient's therapy two containers of urine were located on top of the shelf above the toilet. This may explain why the TLD reading from behind the toilet (location number seven) is greater than the TLD readings at locations four, five, and six.

In the study by Miller et al. (1979) film badges were used to illustrate how a "patient next door to a 100 mCi (3.7 GBq) treatment patient might receive as much as 150 mrem (1.5 mSv)." As mentioned previously, a similar conclusion would be difficult to formulate in this study since TLDs were not mounted in adjacent rooms. Although it is likely that the room configurations in the Miller et al. (1979) study differ from the room configurations at Duke University Medical Center, it may be worth mentioning that since the administered activities used at Duke are, in most cases, greater than 3.7 GBq (100

mCi) a potential to exceed the dose equivalent limit for the general public of 1 mSv (100 mrem).

Contamination Surveys

According to Shapiro (1990), "a G-M tube requires a certain recovery time (dead time) after each pulse." At high count rates calculations must be performed to account for pulses or counts missed due to the instrument's recovery time. The instruments used in this study had a recovery or "dead time" of 50 microseconds (μs). A correction to account for the number of pulses or counts missed can be determined using the following equation:

$$\text{Correction} = \frac{R^2 * d}{1-(R * d)}$$

"R" represents the measured count rate while the "d" represents the instrument's recovery or "dead time." The correction represents the number of pulses missed and should be added to the measured count rate to produced a corrected count rate. For a measured count rate of 240,000 counts per minute, the correction was determined to be 60,000 counts per minute. Therefore, the corrected count rate would be 300,000 counts per minute. At lower count rates this recovery or dead time would not significantly alter the results. For a measured count rate of 20,000 counts per minute, the correction was determined to be approximately 340 counts per minute producing a corrected count rate of 20,340 counts per minute.

An average contamination level can be determined by averaging all of the contamination levels recorded during the contamination survey after a given patient was discharged from the hospital. In the study by Austin (1993) the maximum average

contamination level determined for one therapy room was 82,147 dpm. With respect to this current study performed at Duke, the maximum average contamination level was determined to be 31,067 cpm. Utilizing an approximate iodine-131 detection efficiency of 17% (Steinmeyer, 1997), the maximum average contamination level in this study performed at Duke was determined to be approximately 182,000 dpm. The iodine-131 detection efficiency noted in the article by Steinmeyer (1990) is very close to the iodine-131 detection efficiency of 18% utilized by Austin (1993). The maximum average contamination levels determined in the Austin study and the maximum average contamination levels determined in this study differed by approximately a factor of two.

In the Austin study, approximately 30-35 locations and contamination levels were recorded. The maximum contamination level seen in the Austin study of 500,000 cpm was approximately twice the maximum contamination level of 240,000 cpm seen in this study. It should be noted that in this study, the number and location of the contamination levels recorded varied from patient to patient. In the Austin study contamination levels in excess of 500,000 cpm were seen in the bathroom around the toilet of patients who were administered 5.5 GBq (150 mCi).

The maximum contamination level recorded in the study by McBaugh (1990) was 100,000 cpm. The maximum value was seen during a therapy where the patient vomited during the first night after receiving 16.6 GBq (448 mCi) via radioimmunotherapy. It was not clear as to the number and location of the contamination levels recorded in the study by McBaugh. In the McBaugh study the values seen on the toilets ranged from 20,000 cpm to 40,000 cpm. In this study, the highest contamination level of 100,000 cpm was seen in the bathroom area on two occasions. This maximum contamination level was seen

on the toilet seat of one patient who received 3.7 GBq (100 mCi) via radioimmunotherapy and on the toilet bowl of another patient who received 5.5 GBq (150 mCi) via a sodium iodide therapy.

It is difficult to determine specific relationships between a type of patient and corresponding contamination levels. Miller et al. (1979) point out that "levels of contamination vary considerably depending on the activity administered and the cooperativeness of the patient." In the study performed at Duke, a relationship was not observed between the levels of contamination and the activity administered. It is possible that levels of contamination may be attributed to patient cooperation. Upon explaining to the patient how the iodine-131 was excreted some patients acted very meticulously while others did not alter their habits in any manner. Since the patient was already restricted to the therapy room it was difficult to try to tell the patient what he or she could not do during the isolation period.

Air Sampling

The air concentrations determined from the air sampling data (see Table 7) are well below the DAC of 2×10^{-8} $\mu Ci\ ml^{-1}$. It should be noted that activity was seen on all components of the sampling units used for all three of the patients. As a result, it is not clear as to how much iodine vapor may have passed through the entire sampling unit for a given sampling period. Therefore, the air concentrations seen in Table 7 may be an underestimation of the actual concentrations in the patient room.

After the first three samples were performed, a suggestion was made to wrap the sampling train with some type of plastic to ensure external contamination would not be a factor. Due to an oversight this suggestion was not carried out. Wipe tests and

corresponding decision levels were used to address this problem of external contamination. However, wipe samples can only address the problem of removable contamination on the exterior of the components. Although wipe tests and decision levels allow one to be 95% confident that there either is or is not activity present on the exterior of the components, wrapping the sampling unit in plastic allows one to be virtually 100% confident that external contamination has not interfered with the results.

In conjunction with the problem of external contamination, the wipe samples may have been more useful had they been counted for a longer period of time. As the time the sample is counted increases the value representing the decision level decreases. With a lower decision level one could be more confident whether or not the count rate seen actually represents activity.

NIOSH Analytical Method 6005 suggests a flow rate of 0.5 L min^{-1} to 1 L min^{-1} and a recommended maximum volume of air to be sampled of 225 L (NIOSH, 1994). The flow rate used in this study was 0.5 L min^{-1}. With a flow rate of 0.5 L min^{-1} and a maximum volume of air equal to 225 L min^{-1}, theoretically sampling with these tubes should have been done for only 7.5 hours. Since sampling in this study was performed for periods of 20 to 24 hours, it is apparent that breakthrough may have been a problem.

NIOSH Analytical Method 6005 claims that the tube capacity of the front section is six milligrams of iodine vapor (NIOSH, 1994). Using the specific activity for iodine-131 of 4.59×10^6 GBq g^{-1} (1.24×10^5 Ci g^{-1}), the amount of activity corresponding to six milligrams is 2.75×10^4 GBq (744 Ci). Clearly the amount of activity seen in one tube would not exceed 2.75×10^4 GBq (744 Ci) since the greatest amount of activity administered to a patient was 11.2 GBq (303 mCi).

Although one can be fairly confident that the activity seen on the components of the sampling unit is attributed to iodine-131, it may have been beneficial to count the components again at a later date. Counting the same components a second time at a later date and taking into account the half life of iodine-131 of eight days would verify that iodine-131 was responsible for the activity present and not some other nuclide such as radon-222.

VI. CONCLUSION

Iodine-131 therapy patients will continue to pose a potential hazard to the medical staff responsible for the patient's care. The basic radiation protection principles of time, distance, and shielding should be utilized to minimize the external hazards associated with these therapies. Although patient care should not be sacrificed, no member of the medical staff should spend any unnecessary time within the patient's therapy room. Good housekeeping practices, especially the utilization of gloves and shoe covers, are necessary for any medical staff entering the therapy room (NCRP, 1970).

Based upon the results from the air sampling performed within the patient's therapy room, whether or not the volatility of iodine-131 poses a significant hazard can not be determined. Since it is not known how much activity passed through the sampling units, it is possible that the actual iodine-131 air concentrations are greater than the results from this study suggest. It should be noted that even though this study may not prove volatile iodine-131 to be a hazard, in accordance with the principle of ALARA, the time spent in the therapy room should be minimized.

Recently, Duke University Medical Center had two lead lined room constructed on the ninth floor of the Duke Hospital North. These room were designed for the iodine-131 therapies to reduce exposure to patients in adjacent rooms. These rooms are not restricted to patients receiving iodine-131. If there are no patients in the hospital undergo

ing iodine-131 therapy then non-radioactive patients can be placed in the lead lined rooms. One recommendation is that these lead lined rooms be utilized for iodine-131 therapies only and permanently classified as restricted areas.

Although no exposure rates exceeded the general public dose limit of two mrem in any one hour, one reading of 4.1×10^{-7} C kg^{-1} hr^{-1} (1.6 mR hr^{-1}) was measured in an adjacent room for a patient receiving 5.5 GBq (150 mCi) for a sodium iodide therapy while another reading of 3.6×10^{-7} C kg^{-1} hr^{-1} (1.4 mR hr^{-1}) was measured in another adjacent room for a patient receiving 11.2 GBq (303 mCi) for a MiBG therapy. All of the measurements were made with the patient either in or near the bed. It is possible that if the patient remains in an area other than near the bed for an extended period of time, the exposure rates in the unrestricted areas may exceed the general public dose limit. This possible scenario helps support a recommendation that the therapies should only be performed in the lead lined rooms in Duke North Hospital. If this is not possible an alternative may be to close down the rooms adjacent to the therapy room.

Results from dose equivalent measurements also help support the exclusive use of the lead lined rooms for iodine-131 therapies. For one particular patient, an average daily dose equivalent of 0.62 mSv (62 mrem) was determined for a seven day isolation period on a wall inside of a therapy room. A non-radioactive patient in an adjacent room for the same period of time could only receive 0.14 mSv (14 mrem) per day before exceeding the annual general public limit of 1 mSv (100 mrem). Assuming a non-radioactive patient was in a room adjacent to an iodine-131 therapy patient for the same length of time, it appears as though it is possible that the non-radioactive patient could receive a dose equivalent in excess of the general public limit.

If the lead lined rooms were considered restricted areas and only utilized for iodine-131 therapies the recommended action level for removable surface contamination could increase to 2,200 dpm per 100 cm^2 (NRC 1981). This is approximately a factor of ten greater than the present NRC regulation stating that a "room must not be reassigned until removable contamination is less than 200 disintegrations per minute per 100 square centimeters" (NRC 1996e). A greater action level would likely result in a quicker decontamination process. The decontamination process after each therapy would not have to be as thorough if only radioactive patients are treated in these lead lined rooms. As soon as a prospective iodine-131 patient is treated, the activity in the therapy room associated with the contamination from the previous radioactive patient would not be significant.

Restricting iodine-131 therapies to two rooms would also enable a small group of medical personnel to be specially trained for iodine-131 therapy patient care. It would appear to be more advantageous to have a small group of medical personnel with special training exposed to iodine-131 patients rather than unnecessarily exposing a greater number of medical personnel, which resembles the present situation. Dedicating two patient rooms for iodine-131 therapies has its disadvantages as well as its advantages. Ultimately, any decision regarding these rooms will lie with the administration at Duke University Medical Center.

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APPENDIX A

Exposure Rate Data

Patient Number: 1
Room Number: 3109 Duke Hospital North
Therapy Date: 6/6/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Time of Therapy: 3:00 pm
6 ft. Reading: 6.0 mR/hr.

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.85	0.91	0.36		
2	2.0	1.0	0.6		
3	8.7	1.17	0.67		
4	0.8	0.44	0.24		
5	1.33	5.9	1.4		
6	N/A	Not Taken	Not Taken		
7	N/A	0.131	0.074		
8	N/A	0.3	0.2		
9	1.9	0.75	0.3		
10	0.9	0.44	0.26		
11	N/A	0.5	0.25		
12	N/A	0.3	0.16		

Comments

Day 1:
No urine in patient room
Patient sitting on bed's edge

Day 2:
Time = 1:55 pm
Urine jug in castle; Patient lying in middle of bed
6 ft. Reading = 1.65 mR/hr. = 41 mCi remaining

Day 3:
Time = 9:20 am
Urine jug in castle; Patient lying towards left side of bed (facing)
6 ft. Reading = 0.6 mR/hr = 16 mCi remaining → **Discharged**

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 2
Room Number: 3124 Duke Hospital North
Therapy Date: 6/6/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Time of Therapy: 2:45 pm
6 ft. Reading: 8.4 mR/hr.

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	2.7	1.03	0.31		
2	4.3	2.2	0.68		
3	6.9	2.4	1.5		
4	1.59	0.55	0.25		
5	2.0	6.4	2.5		
6	N/A	0.1	0.032		
7	N/A	0.15	0.067		
8	1.0	0.5	0.2		
9	1.75	0.7	0.35		
10	1.1	0.4	0.196		
11	1.6	N/A	N/A		
12	Not Taken	N/A	N/A		

Comments

Day 1:
No urine in patient room
Patient lying in middle of bed

Day 2:
Time = 2:30 pm
One urine jug in castle; Patient lying in middle of bed
6 ft. Reading = 2.5 mR/hr. = 44 mCi remaining

Day 3:
Time = 9:10 am
One urine jug in castle; Patient lying towards left side of bed (facing)
6 ft. Reading = 1.0 mR/hr = 18 mCi remaining → **Discharged**

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 3
Room Number: 6323 Duke Hospital North
Therapy Date: 6/13/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Time of Therapy: 3:00 pm
1 m. Reading: 11.3 mR/hr.

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.05	1.03	0.7	0.69	0.34
2	2.6	3.1	1.9	1.9	1.5
3	3.9	2.5	2.0	2.1	1.15
4	0.52	7.3	8.4	12.2	0.162
5	1.1	1.7	1.08	1.0	0.6
6	Not Taken	Not Taken	Not Taken	0.2	Not Taken
7	0.165	0.6	0.51	0.5	0.063
8	0.65	0.62	0.37	0.47	0.28
9	1.03	1.0	0.7	0.6	Not Taken
10	0.6	0.5	0.43	0.21	0.21
11	N/A*	N/A*	N/A*	0.39	0.11
12	N/A*	N/A*	N/A*	0.4	0.32

Comments

Day 1:
No urine in patient room
Patient lying in center of bed
* Patient from previous radioiodine therapy in 6324

Day 2:
Time: 1:45 pm; 1 m. Reading = 10.2 mR/hr. = 72 mCi remaining
Urine jug located on shelf behind toilet; Patient lying in center of bed
* Patient from previous radioiodine therapy in 6324

Day 3:
Time: 11:15 am; 1 m. Reading = 8.7 mR/hr. = 62 mCi remaining
Urine jug located on shelf behind toilet; Patient lying in center of bed
* Patient from previous radioiodine therapy in 6324

Day 4:
Time: 11:30 am
Two urine jugs located on shelf behind toilet; Patient lying in center of bed
1 m. Reading = 6.4 mR/hr. = 45 mCi remaining

Day 5: **Patient 3 data continued to next page.**
Time: 2:45 pm
Minimal urine; Patient lying in center of bed
1 m. Reading = 5.9 mR/hr. = 42 mCi remaining

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 3
Room Number: 6323 Duke Hospital North
Therapy Date: 6/13/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Time of Therapy: 3:00 pm
1 m. Reading: 11.3 mR/hr.

Location	Day 6	Day 7	Day 8	Day 9	Day 10
1	0.42				
2	1.22				
3	1.45				
4	0.7				
5	0.8				
6	Not Taken				
7	0.15				
8	0.36				
9	0.45				
10	0.25				
11	0.38				
12	0.38				

Comments

Day 6:
Time: 1:15 pm
Minimal urine; Patient lying in center of bed
1 m. Reading = 3.8 mR/hr. = 27 mCi remaining → **Discharged**

Day 7:

Day 8:

Day 9:

Day 10:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 4
Room Number: 6324 Duke Hospital North
Therapy Date: 6/20/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Time of Therapy: 3:00 pm
1 m. Reading: 13.9 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.3	1.92	1.5	1.3	1.14
2	5.8	3.9	3.1	3.0	2.3
3	6.7	4.7	5.0	3.9	4.4
4	0.83	8.0	2.1	2.2	3.3
5	1.5	1.5	1.23	1.18	0.9
6	N/A	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A
9	1.2	1.1	1.0	0.81	0.72
10	0.6	0.85	0.65	0.61	0.5
11	1.2	0.25	0.95	N/A	0.61
12	1.5	1.0	0.70	N/A	0.44

Comments

Day 1:
No urine in patient room
Radioactive patient in room 6323

Day 2:
Urine jug located on shelf above toilet; Patient lying in center of bed
Time: 10:45 am; 1 m. Reading = 11.5 mR/hr. = 66 mCi remaining
Radioactive patient in room 6323

Day 3:
Urine jug located on shelf above toilet; Patient lying in center of bed
Urine spilled in bathroom
Time: 9:45 am ; 1 m. Reading = 9.7 mR/hr. = 56 mCi remaining

Day 4:
Urine jug located on shelf above toilet; Patient lying in center of bed
Time: 10:15 am
1 m. Reading = 8.1 mR/hr. = 47 mCi remaining

Day 5: **Patient 4 data continued to next page.**
Urine jug located on shelf above toilet; Patient lying in center of bed
Time: 10:05 am
1 m. Reading = 7.1 mR/hr. = 41 mCi remaining

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 4
Room Number: 6324 Duke Hospital North
Therapy Date: 6/20/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Time of Therapy: 3:00 pm
1 m. Reading: 13.9 mR/hr

Location	Day 6	Day 7	Day 8	Day 9	Day 10
1	1.0	0.93			
2	2.1	1.8			
3	3.0	3.1			
4	2.3	3.5			
5	0.9	0.8			
6	N/A	N/A			
7	N/A	N/A			
8	N/A	N/A			
9	0.7	0.59			
10	0.39	0.42			
11	N/A	N/A			
12	N/A	N/A			

Comments

Day 6:
Urine jug located on shelf above toilet; Patient lying in center of bed
Time: 10:00 am
1 m. Reading = 6.3 mR/hr. = 37 mCi remaining

Day 7:
Urine jug located on shelf above toilet; Patient lying in center of bed
Time: 9:15 am
1 m. Reading = 5.2 mR/hr. = 29.9 mCi remaining → **Discharged**

Day 8:

Day 9:

Day 10:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 5
Room Number: 2110 Duke Hospital North
Therapy Date: 6/27/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Time of Therapy: 3:15 pm
6 ft. Reading: 6.6 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	2.9	1.04	0.52		
2	2.5	1.9	0.61		
3	7.6	4.4	1.6		
4	0.95	0.57	0.25		
5	0.79	4.4	1.5		
6	N/A	N/A	N/A		
7	N/A	N/A	N/A		
8	N/A	N/A	N/A		
9	1.7	0.8	0.37		
10	0.62	0.4*	0.25		
11	N/A	0.33*	0.28		
12	N/A	0.37*	0.055		

Comments

Day 1:
Patient sitting on left side of bed (facing)
No urine in patient room

Day 2:
Patient sitting on left side of bed (facing); One urine jug in castle
Time: 11:30 am; 6 ft. Reading = 2.6 mR/hr. = 59 mCi remaining
* indicates patient may have moved (possibly back in bed)

Day 3:
Patient sitting on left side of bed (facing); One urine jug in castle
Time: 10:45 am; 6 ft. Reading = 0.7 mR/hr. = 15.9 mCi remaining → **Discharged**
* indicates patient may have moved (possibly back in bed)

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 6
Room Number: 2710 Duke Hospital South (Rankin Ward)
Therapy Date: 6/28/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 60 mCi
Time of Therapy: 3:00 pm
1 m. Reading: 9.8 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	3.6	0.55			
2	1.4	0.5			
3	0.65	1.54			
4	0.58	1.16			
5	0.3	0.085			
6	1.1	0.3			
7	0.63	0.11			

Comments

Day 1:
Patient sitting in chair
No urine in patient room

Day 2:
Patient lying in bed
Time: 11:20 am; 1 m. Reading = 2.9 mR/hr. = 18 mCi remaining → **Discharged**
One urine jug sitting on bathroom floor.

Day 3:

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 7
Room Number: 8110 Duke Hospital North
Therapy Date: 7/9/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Time of Therapy: 5:20 pm
6 ft. Reading: 6.9 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	2.5	1.2	0.33		
2	3.8	36	0.45		
3	8.7	1.18	0.78		
4	1.0	30	0.45		
5	1.44	3.9	1.5		
6	N/A	Not Taken	N/A		
7	N/A	1.35	N/A		
8	N/A	0.48	N/A		
9	1.03	0.59	0.18		
10	0.71	0.4	0.15		
11	0.25	N/A	N/A		
12	0.42	N/A	N/A		

Comments

Day 1:
Patient lying on left side of bed (facing)
No urine in patient room

Day 2:
Patient sitting in chair
Time: 1:45 pm; 6 ft. Reading = 2.0 mR/hr. = 44 mCi remaining
Two urine jugs on shelf above toilet

Day 3:
Patient lying in center of bed
Time: 10:00 am; 6 ft. Reading = 0.5 mR/hr. = 11 mCi remaining → **Discharged**
One urine jug in castle

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 8
Room Number: 6324 Duke Hospital North
Therapy Date: 7/9/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Time of Therapy: 3:45 pm
1 m. Reading: 14.0 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	0.43	1.2	0.75	0.61	
2	3.5	1.88	2.0	2.2	
3	3.3	2.6	1.17	2.1	
4	0.65	2.1	15.5	3.4	
5	1.0	5.9	0.8	0.92	
6	N/A	N/A	N/A	Not Taken	
7	N/A	N/A	N/A	0.35	
8	N/A	N/A	N/A	0.32	
9	0.44	0.71	0.4	0.37	
10	0.5	0.59	0.32	0.25	
11	0.53	0.6	0.34	N/A	
12	0.24	0.15	0.185	N/A	

Comments

Day 1:
Patient lying in center of bed
No urine in patient room

Day 2:
Patient lying in center of bed
Time: 1:30 pm; 1 m. Reading = 11.0 mR/hr. = 63 mCi remaining
One urine jug in castle

Day 3:
Patient lying in center of bed
Time: 1:30 pm; 1 m. Reading = 7.6 mR/hr. = 43 mCi remaining
Two urine jugs located on shelf above toilet

Day 4:
Patient lying in center of bed
Time: 10:15 am; 1 m. Reading = 4.6 mR/hr. = 26 mCi remaining → **Discharged**
One urine jug located on shelf above toilet

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 9
Room Number: 2710 Duke Hospital South (Rankin Ward)
Therapy Date: 7/10/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 100 mCi
Time of Therapy: 3:30 pm
1 m. Reading: 14.8 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.71	1.24	0.77	0.52	
2	1.28	1.5	0.72	0.81	
3	2.3	2.4	1.65	2.0	
4	2.4	1.9	1.75	2.2*	
5	0.27	0.23	N/A	0.16	
6	0.9	0.65	0.39	0.33	
7	0.35	0.18	0.13	0.11	

Comments

Day 1:
Patient lying in center of bed
No urine in patient room

Day 2:
Patient lying in center of bed
Time: 4:20 pm; 1 m. Reading = 10.0 mR/hr. = 68 mCi remaining
One urine jug in castle

Day 3:
Patient lying in center of bed
Time: 4:00 pm; 1 m. Reading = 5.0 mR/hr. = 34 mCi remaining
One urine jug in castle

Day 4:
Patient lying in center of bed
Time: 10:25 am; 1 m. Reading = 3.5 mR/hr. = 24 mCi remaining → **Discharged**
* Two urine jugs (One in castle and sitting in shower near location #4)

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 10
Room Number: 9110 Duke Hospital North
Therapy Date: 7/12/96
Type of Therapy: MIBG
Therapy Activity: 303 mCi
Time of Therapy: 2:55 pm
6 ft. Reading: 11.8 mR/hr.

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	3.7	1.71	1.08	0.75	0.54
2	67	7.0	3.4	3.5	2.0
3	3.2	4.1	3.3	2.7	2.5
4	1.15	1.57	4.7*	0.5	0.31
5	10.5	12.7	0.85*	2.4	1.8
6	Not Taken	0.6	0.35*	0.191	0.09
7	1.41	0.46	0.33*	0.2	0.1
8	1.0	0.7	0.8*	0.34	0.25
9	1.38	0.65	0.43	0.27	0.40
10	0.62	0.4	0.35	0.22	0.25
11	1.25	0.26	0.29*	0.12	N/A
12	0.35	0.3	0.2*	0.19	N/A

Comments

Day 1:
Patient sitting in chair
Two lead shields placed around bed
No urine in patient room

Day 2:
Patient lying in center of bed; One urine jug in castle
Time: 11:00 am; 6 ft. Reading = 6.0 mR/hr. = 154 mCi remaining
Two lead shields still in place

Day 3:
Patient lying in center of bed; One urine jug in castle; Two lead shields still in place
Time: 11:30 am; 6 ft. Reading = 3.6 mR/hr. = 92 mCi remaining
* Patient moved to sitting position on right side of bed (facing)

Day 4:
Patient lying in center of bed; One urine jug in castle
Time: 9:45 am; 6 ft. Reading = 2.4 mR/hr. = 62 mCi remaining
One lead shield at foot of bed remains in place

Day 5: **Patient 10 data continued to next page.**
Patient lying in center of bed; One urine jug in castle
Time: 10:15 am; 6 ft. Reading = 1.7 mR/hr. = 44 mCi remaining
One lead shield at foot of bed remains in place

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 10
Room Number: 9110 Duke Hospital North
Therapy Date: 7/12/96
Type of Therapy: MIBG
Therapy Activity: 303 mCi
Time of Therapy: 2:55 pm
6 ft. Reading: 11.8 mR/hr

Location	Day 6	Day 7	Day 8	Day 9	Day 10
1	0.2				
2	1.4				
3	1.38				
4	0.24				
5	1.2				
6	N/A				
7	N/A				
8	N/A				
9	0.183				
10	0.174				
11	0.13				
12	0.11				

Comments

Day 6:
Patient lying in center of bed; One urine jug in castle
Time: 9:30 am; 6 ft. Reading = 1.1 mR/hr. = 28.2 mCi remaining → **Discharged**
Shields removed

Day 7:

Day 8:

Day 9:

Day 10:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 12
Room Number: 3123 Duke Hospital North
Therapy Date: 7/19/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Time of Therapy: 3:30 pm
6 ft. Reading: 6.7 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.9	1.7	0.5		
2	4.8	4.9	2.5		
3	11.7	2.9	0.27		
4	1.4	1.8	0.75		
5	1.8	13.4	7.3		
6	N/A	N/A	N/A		
7	N/A	N/A	N/A		
8	N/A	N/A	N/A		
9	1.0	1.05	0.23		
10	0.9*	0.6	0.15		
11	0.9*	N/A	N/A		
12	0.3*	N/A	N/A		

Comments

Day 1:
Patient sitting on right side of bed (facing)
* Patient sitting in chair in back corner of room.
No urine in patient room

Day 2:
Patient lying in center of bed; One urine jug in castle
Time: 9:05 am
6 ft. Reading = 3.2 mR/hr. = 72 mCi remaining

Day 3:
Patient sitting in chair in back corner of room; One urine jug in castle
Time: 8:00 am
6 ft. Reading = 0.8 mR/hr. = 18 mCi remaining → **Discharged**

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 13
Room Number: 2710 Duke Hospital South (Rankin Ward)
Therapy Date: 7/24/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 60 mCi
Time of Therapy: 4:00 pm
1 m. Reading: 9.7 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	1.1	0.64			
2	1.4	0.61			
3	1.5	1.33*			
4	3.0	0.63			
5	0.29	0.08			
6	0.6	0.32			
7	0.13	0.094			

Comments

Day 1:
Patient lying in center of bed
No urine in patient room

Day 2:
Patient lying in center of bed
Time: 1:30 pm; 1 m. Reading = 4.7 mR/hr. = 29 mCi remaining → **Discharged**
*Two urine jugs (One in castle; one sitting in bathroom near location #3)

Day 3:

Day 4:

Day 5:

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 14
Room Number: 4123 Duke Hospital North
Therapy Date: 8/1/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 100 mCi
Time of Therapy: 3:45 pm
1 m. Reading: 12.7 mR/hr

Location	Day 1	Day 2	Day 3	Day 4	Day 5
1	3.8	4.7	2.1	1.3	1.86
2	2.5	3.3	3.7	3.5	2.1
3	12.0	4.8	5.8	4.2	4.6
4	1.15	0.8	1.1	0.7	0.83
5	1.5	2.3	1.5	0.9	0.93
6	0.33	N/A	0.175	N/A	N/A
7	0.6	N/A	0.26	N/A	N/A
8	1.35	N/A	0.84	N/A	N/A
9	2.2	1.8	1.2	0.8	1.0
10	0.9*	0.5*	1.0	0.64	0.85
11	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A

Comments

Day 1:
Patient sitting on right side of bed (facing)
* indicates patient may have moved
No urine in patient room

Day 2:
Patient sitting at foot of left side of bed (facing); One urine jug in castle
Time: 2:25 pm; 1 m. Reading = 10.6 mR/hr. = 83 mCi remaining
* indicates patient may have moved

Day 3:
Patient lying in center of bed; One urine jug in castle.
Time: 10:55 am
1 m. Reading = 9.0 mR/hr. = 71 mCi remaining

Day 4:
Patient lying in center of bed; One urine jug in castle
Time: 10:45 am
1 m. Reading = 7.5 mR/hr. = 59 mCi remaining

Day 5: **Patient 14 data continued to next page.**
Patient sitting up at foot of bed; Urine in castle
Time: 1:00 pm
1 m. Reading = 7.0 mR/hr. = 55 mCi remaining

N/A - Not Accessible

All measurements in mR/hr.

Patient Number: 14
Room Number: 4123 Duke Hospital North
Therapy Date: 8/1/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 100 mCi
Time of Therapy: 3:45 pm
6 ft. Reading: 12.7 mR/hr

Location	Day 6	Day 7	Day 8	Day 9	Day 10
1	1.9	1.2			
2	1.3	1.4			
3	3.5	3.1			
4	0.92	0.6			
5	1.0	0.65			
6	0.32	0.1			
7	0.29	0.18			
8	0.8	0.35			
9	0.91	0.5			
10	0.55	0.42			
11	N/A	N/A			
12	N/A	N/A			

Comments

Day 6:
Patient sitting in center of bed; One urine jug in castle
Time: 2:45 pm
1 m. Reading = 4.7 mR/hr. = 37 mCi remaining

Day 7:
Patient lying in center of bed; One urine jug in castle
Time: 9:20 am
1 m. Reading = 3.8 mR/hr. = 29.9 mCi remaining → **Discharged**

Day 8:

Day 9:

Day 10:

N/A - Not Accessible

All measurements in mR/hr.

APPENDIX B

Dose Equivalent Data

Patient Number: 7 **Initial Activity:** 150 mCi

Room Number: 8110 Duke Hospital North **Date Mounted:** 7/9/96

Type of Therapy: Sodium Iodide **Date Removed:** 7/11/96

Badge Location	1	2	3	4	5	6	7
Badge Number	974	975	973	970	976	977	978
Reading (mrem)	310	90	200	40	30	40	Lost

Patient Number: 8 **Initial Activity:** 80 mCi

Room Number: 6324 Duke Hospital North **Date Mounted:** 7/9/96

Type of Therapy: Monoclonal Antibody **Date Removed:** 7/14/96

Badge Location	1	2	3	4	5	6	7
Badge Number	985	848	971	969	972	967	968
Reading (mrem)	140	260	1790	70	50	50	640

Patient Number: 9 **Initial Activity:** 100 mCi

Room Number: 2710 Duke Hospital South **Date Mounted:** 7/13/96

Type of Therapy: Monoclonal Antibody **Date Removed:** 7/15/96

Badge Location	1	2	3	4	5	6	7
Badge Number	884	883	882	881	N/A	N/A	N/A
Reading (mrem)	70	80	190	650	N/A	N/A	N/A

Duke Hospital North Locations:

1. On floor beneath patient's bed
2. On ceiling above patient's bed
3. Wall behind patients head
4. Adjacent wall (actually on closed door)
5. Inside of door to patient's room
6. Adjacent wall
7. Wall behind toilet seat

Duke Hospital South Locations

1. Wall adjacent to hallway
2. Wall adjacent to room next door
3. On ceiling above patient's bed
4. On floor beneath patient's bed

N/A - Not Applicable

Patient Number: 10 **Initial Activity:** 303 mCi

Room Number: 9110 Duke Hospital North **Date Mounted:** 7/12/96

Type of Therapy: MiBG **Date Removed:** 7/18/96

Badge Location	1	2	3	4	5	6	7
Badge Number	849	850	851	852	853	854	855
Reading (mrem)	1950	410	890	90	80	110	100

Patient Number: 11 **Initial Activity:** 150 mCi

Room Number: 3110 Duke Hospital North **Date Mounted:** 7/17/96

Type of Therapy: Sodium Iodide **Date Removed:** 7/22/96

Badge Location	1	2	3	4	5	6	7
Badge Number	856	857	858	859	860	861	862
Reading (mrem)	680	200	340	80	60	90	60

Patient Number: 12 **Initial Activity:** 150 mCi

Room Number: 3123 Duke Hospital North **Date Mounted:** 7/19/96

Type of Therapy: Sodium Iodide **Date Removed:** 7/22/96

Badge Location	1	2	3	4	5	6	7
Badge Number	863	864	865	866	867	868	869
Reading (mrem)	300	120	190	40	30	60	50

Duke Hospital North Locations:

1. On floor beneath patient's bed
2. On ceiling above patient's bed
3. Wall behind patients head
4. Adjacent wall (actually on closed door)
5. Inside of door to patient's room
6. Adjacent wall
7. Wall behind toilet seat

Duke Hospital South Locations

1. Wall adjacent to hallway
2. Wall adjacent to room next door
3. On ceiling above patient's bed
4. On floor beneath patient's bed

N/A - Not Applicable

Patient Number: 13 **Initial Activity:** 60 mCi

Room Number: 2710 Duke Hospital South **Date Mounted:** 7/24/96

Type of Therapy: Monoclonal Antibody **Date Removed:** 7/26/96

Badge Location	1	2	3	4	5	6	7
Badge Number	870	871	872	873	N/A	N/A	N/A
Reading (mrem)	20	20	50	230	N/A	N/A	N/A

Patient Number: 14 **Initial Activity:** 100 mCi

Room Number: 4123 Duke Hospital North **Date Mounted:** 8/1/96

Type of Therapy: Monoclonal Antibody **Date Removed:** 8/8/96

Badge Location	1	2	3	4	5	6	7
Badge Number	874	875	876	877	878	879	880
Reading (mrem)	810	560	1940	190	130	200	160

Patient Number: 15 **Initial Activity:** 300 mCi

Room Number: 6306 Duke Hospital North **Date Mounted:** 8/13/96

Type of Therapy: MiBG **Date Removed:** 8/19/96

Badge Location	1	2	3	4	5	6	7
Badge Number	891	892	893	894	895	896	897
Reading (mrem)	760	290	440	130	150	300	170

Duke Hospital North Locations:

1. On floor beneath patient's bed
2. On ceiling above patient's bed
3. Wall behind patients head
4. Adjacent wall (actually on closed door)
5. Inside of door to patient's room
6. Adjacent wall
7. Wall behind toilet seat

Duke Hospital South Locations

1. Wall adjacent to hallway
2. Wall adjacent to room next door
3. On ceiling above patient's bed
4. On floor beneath patient's bed

N/A - Not Applicable

Patient Number: 16 **Initial Activity:** 60 mCi

Room Number: 2710 Duke Hospital South **Date Mounted:** 8/21/96

Type of Therapy: Monoclonal Antibody **Date Removed:** 8/22/96

Badge Location	1	2	3	4	5	6	7
Badge Number	898	899	900	901	N/A	N/A	N/A
Reading (mrem)	30	20	50	190	N/A	N/A	N/A

Duke Hospital North Locations:

1. On floor beneath patient's bed
2. On ceiling above patient's bed
3. Wall behind patients head
4. Adjacent wall (actually on closed door)
5. Inside of door to patient's room
6. Adjacent wall
7. Wall behind toilet seat

Duke Hospital South Locations

1. Wall adjacent to hallway
2. Wall adjacent to room next door
3. On ceiling above patient's bed
4. On floor beneath patient's bed

N/A - Not Applicable

APPENDIX C

Contamination Survey Data

Patient Number: 3
Room Number: 6323 Duke Hospital North
Survey Date: 6/21/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Comments: Radioactive patient in adjacent room (6324)
Background in 6323 estimated to be 500-600 cpm.

Location Description	Counts Per Minute
Sink Basin	1,200
Toilet Bowl	2,400
Toilet Seat	800
Area of bathroom wall near towel hanger	3,500
Linen hanging on towel hanger	24,000
Area of bathroom wall behind shower door (open)	4,000
Area on seat of chair	600
Area of mattress cover	22,000
Pillow	4,000
Bed Linen	800
Back of door handle	4,000

Patient Number: 4
Room Number: 6324 Duke Hospital North
Survey Date: 6/26/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Comments:

Location Description	Counts Per Minute
Sink Drain	1,000
Toilet Bowl	2,000
Toilet Seat	100
Area of bathroom wall beneath towel hanger	1,000
Floor in doorway to bathroom	1,000
Middle of shelf above toilet	1,700
Area on the external side of shower lip	1,600

Patient Number: 5
Room Number: 2110 Duke Hospital North
Survey Date: 7/2/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Comments:

Location Description	Counts Per Minute
Pillowcase	120,000
Table	20,000
Sink	12,000
Telephone	20,000
Inside left bedrail (facing)	8,000
Top of Bed	2,000
Inside bathroom door handle	5,000
Inside bathroom door	10,000
Toilet rim	12,000
Toilet seat	8,000
Under left edge of table	12,000
Counter near window	120,000
Remote Control	6,000
Chair arms	200
Top of right bedrail (facing)	2,200
Handle in shower (rear)	1,000
On/off shower handle	1,600
Light switch	700
Outside bathroom doorknob	700

Patient Number: 6
Room Number: 2710 Duke Hospital South (Rankin Ward)
Survey Date: 7/1/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 60 mCi
Comments:

Location Description	Counts Per Minute
Pillow	2,400
Chair handle	3,000
Area of vomit	120,000
Mattress	80,000
Right bed handle	35,000
TV/Intercom controller	800
Toilet seat	4,500
Handle near toilet seat	3,000
Toilet rim	1,100
Area on floor	2,000
Area on floor	12,000
Area on floor	1,200

Patient Number: 7
Room Number: 8110 Duke Hospital North
Survey Date: 7/11/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Comments:

Location Description	Counts Per Minute
Area on table	400
Sink top	110,000
Sink basin	180,000
Sink handles	10,000
Lip under paper dispenser	4,000
Inside bathroom door handle	1,300
Toilet Seat	400
Handle near toilet seat (left)	2,500
Outside bathroom door handle	700
Telephone	1,000
Pillow	10,000
Green chair back	800
Area on floor to left of bed (facing)	40,000
Area on floor to right of bed (facing)	1,600

Patient Number: 8
Room Number: 6324 Duke Hospital North
Survey Date: 7/12/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 80 mCi
Comments:

Location Description	Counts Per Minute
Pillow	60,000
Pillowcase	40,000
Bed Linen	900
Sink drain	4,000
Sink basin	700
Sink top (edges)	300
Under toilet seat	20,000
Front of toilet bowl	4,000
Outside bathroom door handle	150
Inside bathroom door handle	150
Underneath right toilet handle	4,000
Underneath left toilet handle	1,000
Toilet flusher	400
Telephone	6,000
Left bed railing (facing)	8,000
Controls on left bed railing	8,000
Mattress cover	1,600
Right bed railing	5,000
Area on green chair	1,600
Area behind back of bed	40,000
Area on bed "headboard"	800
Shelf above toilet	30,000
Area on floor in front of sink	2,000
Area on floor to right of bed (facing)	4,000
Area on floor just outside bathroom doorway	4,000

Patient Number: 9
Room Number: 2710 Duke Hospital South (Rankin Ward)
Survey Date: 7/15/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 100 mCi
Comments:

Location Description	Counts Per Minute
Pillow	800
Area on top of toilet seat	100,000
Area underneath toilet seat	60,000
Area inside front of toilet bowl	800
Toilet paper holder	10,000
Area on the inside of bathroom door	12,000
Area #1 on sink-top	5,000
Area #2 on sink-top	2,000
Remote Control	1,000
Bed Linen	1,000
Telephone	1,300
Wall behind toilet	1,600
Area on floor near left front wheel (facing)	1,400
Area on floor near right front wheel (facing)	8,000
Area #1 to the right of bed	2,200
Area #2 to the right of bed (in front of chair)	800

Patient Number: 10
Room Number 9110 Duke Hospital North
Survey Date: 7/18/96
Type of Therapy: MiBG
Therapy Activity: 303 mCi
Comments:

Location Description	Counts Per Minute
Sink top	1,400
Sink basin	6,000
Sink handles	400
Area on top of toilet Seat	4,000
Area underneath toilet seat	25,000
Area at rear of toilet bowl	8,000
Chair handles	200
Small area on shower floor	1,800
Area on mattress cover	40,000
Area on floor in front of bathroom door	400

Patient Number: 11
Room Number: 3110 Duke Hospital North
Survey Date: 7/22/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Comments:

Location Description	Counts Per Minute
Right sink handle	50,000
Sink top	20,000
Sink basin	40,000
Bed rail	2,300
Mattress cover	400
Liquid streaks on right side of sink	1,800
Handrail to the right of toilet	4,000
Towel dispenser shelf	30,000
Inside bathroom doorknob	800
Area on the outside of bathroom door (near handle)	1,200
Area on top of toilet seat	4,000
Area beneath toilet seat	6,000
Toilet bowl	23,000
Area on the rim of toilet bowl	100,000
Area on shower floor	1300
Shower drain	5,000
Foot stool of green chair	3,000
Area on counter	600
Wall to the right of the sink	6,000
Wall to the left of the sink	12,000
Closet handle (right)	400

Patient Number: 12
Room Number: 3123 Duke Hospital North
Survey Date: 7/22/96
Type of Therapy: Sodium Iodide
Therapy Activity: 150 mCi
Comments:

Location Description	Counts Per Minute
Sink top	1,400
Sink handles	300
Sink basin	4,000
Area on chair	600
Front of toilet seat	600
Telephone	400
Right bed rail controls (facing)	1,600
Front of toilet bowl	30,000
Underneath toilet bowl	8,000
Area on shower floor	600
Shower drain	12,000
Arms of chair	600
Area on floor near bathroom doorway	25,000
Area on floor near right front wheel (facing)	5,000
Spot on sink (bottom of toothpaste streak)	35,000
Linen	1,700
Toilet Hinge	1,000

Patient Number: 13
Room Number: 2710 Duke Hospital South (Rankin Ward)
Survey Date: 7/26/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 60 mCi
Comments:

Location Description	Counts Per Minute
Mattress	12,000
Telephone	1,200
Area on toilet seat	3,000
Area on toilet bowl	4,000
Back of toilet bowl	1,600
Sink top	6,000
Right side of toilet seat	3,000
Left side of toilet seat	5,000
Sink handle	10,000
Remote Control	1,300
Right bed rail (facing)	40,000
Inside right bed rail (facing)	6,000
Bathroom door jam near door catch	4,000
Refrigerator top	160,000
Area on floor near left front wheel (facing)	18,000

Patient Number: 14
Room Number 4123 Duke Hospital North
Survey Date: 7/26/96
Type of Therapy: Monoclonal Antibody
Therapy Activity: 100 mCi
Comments:

Location Description	Counts Per Minute
Area on blanket	20,000
Pillowcase	1,600
Pillow	12,000
Mattress cover	240,000
Sink basin	400
Underneath toilet seat	4,000
Toilet bowl	400
Shower drain	600
Telephone	600

APPENDIX D

Air Sampling Data

Patient 15

	Count 1	17:02	8/14/96		Conc. =	3.62E-10	µCi/ml
Bkgd.	114	CPM	empty vials				
Efficiency	0.34				Decision=	5.55	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1440	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1	159	45	132.35	5.96E-05	5.96E-08	4.81E-16	
2	122	8	23.53	1.06E-05	1.06E-08	8.55E-17	
3	113	0	0.00	0	0	0	
4	144	30	88.24	3.97E-05	3.97E-08	3.21E-16	
5	142	28	82.35	3.71E-05	3.71E-08	2.99E-16	
6	146	32	94.12	4.24E-05	4.24E-08	3.42E-16	
7	117	3	8.82	3.97E-06	3.97E-09	3.21E-17	
8	160	46	135.29	6.09E-05	6.09E-08	4.91E-16	
9	119	5	14.71	6.62E-06	6.62E-09	5.34E-17	
	Net =	197					
	Count 2	21:07	8/14/96		Conc. =	3.22E-10	µCi/ml
Bkgd.	113	CPM	empty vials				
Efficiency	0.34				Decision=	5.53	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1440	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1	154	41	120.59	5.43E-05	5.43E-08	4.38E-16	
2	119	6	17.65	7.95E-06	7.95E-09	6.41E-17	
3	115	2	5.88	2.65E-06	2.65E-09	2.14E-17	
4	138	25	73.53	3.31E-05	3.31E-08	2.67E-16	
5	137	24	70.59	3.18E-05	3.18E-08	2.56E-16	
6	144	31	91.18	4.11E-05	4.11E-08	3.31E-16	
7	116	3	8.82	3.97E-06	3.97E-09	3.21E-17	
8	154	41	120.59	5.43E-05	5.43E-08	4.38E-16	
9	115	2	5.88	2.65E-06	2.65E-09	2.14E-17	
	Net =	175					
	Swipes	14:37	8/14/96				
Bkgd.	125	CPM	empty vials				
Efficiency	0.34				Decision=	36.78	CPM
Run Time	1440	min.			Level		
Ct. Time	0.5	min. each					
Sample #	**CPM**	**CPM (adj)**					
1	-	-					
2	90	-35					
3	-	-					
4	148	23					
5	102	-23					
6	108	-17					
7	102	-23					
8	104	-21					
9	142	17					

Patient 15

	Count 1	17:02	8/15/96		Conc. =	9.94E-11	µCi/ml
Bkgd.	107	CPM	empty vials				
Efficiency	0.34				Decision=	5.38	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1440	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1	125	18	52.94	2.38E-05	2.38E-08	1.92E-16	
2	108	1	2.94	1.32E-06	1.32E-09	1.07E-17	
3	106	0	0.00	0	0	0	
4	112	5	14.71	6.62E-06	6.62E-09	5.34E-17	
5	121	14	41.18	1.85E-05	1.85E-08	1.5E-16	
6	113	6	17.65	7.95E-06	7.95E-09	6.41E-17	
7	108	1	2.94	1.32E-06	1.32E-09	1.07E-17	
8	115	8	23.53	1.06E-05	1.06E-08	8.55E-17	
9	108	1	2.94	1.32E-06	1.32E-09	1.07E-17	
	Net =	54					
	Count 2	21:07	8/15/96		Conc. =	1.16E-10	µCi/ml
Bkgd.	107	CPM	empty vials				
Efficiency	0.34				Decision=	5.38	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1440	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1	124	17	50.00	2.25E-05	2.25E-08	1.82E-16	
2	112	5	14.71	6.62E-06	6.62E-09	5.34E-17	
3	108	1	2.94	1.32E-06	1.32E-09	1.07E-17	
4	111	4	11.76	5.3E-06	5.3E-09	4.27E-17	
5	125	18	52.94	2.38E-05	2.38E-08	1.92E-16	
6	117	10	29.41	1.32E-05	1.32E-08	1.07E-16	
7	105	0	0.00	0	0	0	
8	115	8	23.53	1.06E-05	1.06E-08	8.55E-17	
9	104	0	0.00	0	0	0	
	Net =	63					
	Swipes	10:48	8/16/96				
Bkgd.	106	CPM	10 min.sub				
Efficiency	0.34				Decision=	17.76	CPM
Run Time	1440	min.			Level		
Ct. Time	1	min. each					
Sample #	**CPM**	**CPM (adj)**					
1		8	empty vial				
2		10					
3		0					
4		1					
5		0	tube 1				
6		3					
7		0	tube 2				
8		0					
9		4	tube 3				
		1	empty vial				

Patient 16

	Count 1	15:23	8/23/96		Conc. =	1.01E-09	µCi/ml
Bkgd.	83	CPM	20 min.sub				
Efficiency	0.34				Decision=	4.74	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1320	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1		69	202.94	9.14E-05	9.14E-08	7.37E-16	
2		62	182.35	8.21E-05	8.21E-08	6.62E-16	
3		15	44.12	1.99E-05	1.99E-08	1.6E-16	
4		71	208.82	9.41E-05	9.41E-08	7.59E-16	
5		105	308.82	0.000139	1.39E-07	1.12E-15	
6		61	179.41	8.08E-05	8.08E-08	6.52E-16	
7		26	76.47	3.44E-05	3.44E-08	2.78E-16	
8		56	164.71	7.42E-05	7.42E-08	5.98E-16	
9		36	105.88	4.77E-05	4.77E-08	3.85E-16	
	Net =	501					
	Swipes	9:26	8/23/96				
Bkgd.	76	CPM	empty vials				
Efficiency	0.34				Decision=	20.21	CPM
Run Time	1320	min.			Level		
Ct. Time	1	min. each					
Sample #	**CPM**	**CPM (adj)**					
1	82	7					
2	110	35					
3	86	11					
4	83	8					
5	89	14					
6	80	5					
7	105	30					
8	98	23					
9	79	4					
10	87	12	pump line				

Pre-Patient 17

	BKGD.	14:58	9/5/96				
Bkgd.	81	CPM	20 min.sub				
Efficiency	0.34				Decision=	4.68	CPM
Flow Rate	0	L/min.			Level		
Run Time	0	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1		1	2.94	1.32E-06	1.32E-09	1.07E-17	
2		0	0.00	0	0	0	
3		0	0.00	0	0	0	
4		2	5.88	2.65E-06	2.65E-09	2.14E-17	
5		4	11.76	5.3E-06	5.3E-09	4.27E-17	
6		2	5.88	2.65E-06	2.65E-09	2.14E-17	
7		5	14.71	6.62E-06	6.62E-09	5.34E-17	
8		5	14.71	6.62E-06	6.62E-09	5.34E-17	
9		1	2.94	1.32E-06	1.32E-09	1.07E-17	
	Net =	20					
Empty	Vial #10	2					
Empty	Vial #11	3					

	Count 1	6:17	12/13/96		Conc. =	6.82E-10	µCi/ml
Bkgd.	83	CPM	empty vials				
Efficiency	0.34				Decision=	4.74	CPM
Flow Rate	0.5	L/min.			Level		
Run Time	1200	min.					
Ct. Time	20	min. each				gr. of I_2	
Sample #	**CPM**	**CPM (adj)**	**DPM**	**uCi**	**mCi**	**Vapor**	
1	123	40	117.65	5.3E-05	5.3E-08	4.27E-16	
2	113	30	88.24	3.97E-05	3.97E-08	3.21E-16	
3	91	0	0.00	0	0	0	
4	95	12	35.29	1.59E-05	1.59E-08	1.28E-16	
5	180	97	285.29	0.000129	1.29E-07	1.04E-15	
6	115	32	94.12	4.24E-05	4.24E-08	3.42E-16	
7	115	32	94.12	4.24E-05	4.24E-08	3.42E-16	
8	114	31	91.18	4.11E-05	4.11E-08	3.31E-16	
9	118	35	102.94	4.64E-05	4.64E-08	3.74E-16	
	Net =	309					
	Swipes	10:06	12/13/96				
Bkgd.	83	CPM	empty vials				
Efficiency	0.34				Decision=	7.49	CPM
Run Time	1200	min.			Level		
Ct. Time	5	min. each					
Sample #	**CPM**	**CPM (adj)**					
1	90	7					
2	80	-3					
3	88	5					
4	82	-1					
5	84	1					
6	80	-3					
7	85	2					
8	85	2					
9	84	1					
10	84	1	Long Tygon Tube				