Shielding Evaluation for the PET/CT Scanner:

RCOA Imaging Services, Inc.
Mobile PET - CT Coach
Siemens - AK Specialty Vehicles Design

This is a shielding evaluation for a mobile Siemens PET/CT scanner. The appended diagram (#24436) is an integral component of these calculations and is for instruments that are consistent with this design.

By necessity, the calculations are in S.I. and metric units. No lead shielding is being specified as the lead is already installed. Lead and other construction materials will be discussed in the traditional fractions of inches. To aid in readability, the traditional units of Curie, Rad and REM are not expressed parenthetically, however, this table is provided to assist the reader in converting the calculations into the more traditional units.

Traditional Unit	S.I. Unit
One millicurie (mCi)	37 MegaBecqerel (MBq)
One millirad (mrad)	10 microGray (μGy)
One millirem (mrem)	10 microSievert (μSv)
0.1 millirem (mrem)	One microSievert (μSv)

PET - CT Scan Room Shielding:

Ceiling and floor shielding recommendations are not included in this calculation because it is understood that the facility is a mobile coach.

Assumptions:

- Ten (10) patients are scanned daily with a nominal dosage of 555 MBq of [F-18] FDG. Patients are imaged following a period of 45 minutes of uptake and the urinary bladder is emptied prior to scanning. The urinary excretion assumed was 15% in the first hour. For the purposes of calculations, 355 MBq was presumed per patient in the scan room.
- Patient scan times are 30 minutes pre patient for a total of 20 hours per scanning per week.
- Although the published theoretical dose rate for Flourine-18 is 0.147 μSv/MBq-hr at one meter; this is for a point source. Measurements of Flourine-18 in a cylindrical phantom have been shown to be closer to 0.092 μSv/MBq-hr at one meter. Unpublished patient dose rate have been observed to slightly less than this dose value. This calculation uses the AAPM dose rate constant value of 0.092

- Half and tenth value layers were derived from Monte Carlo data modeled by Courtney & Simpkin in the AAPM PET Shielding Taskforce guidance.

Material	Half – Value Layer	Tenth –Value Layer
Steel	2.0 cm	6.5 cm
Concrete	7.0 cm	19 cm
Lead	0.6 cm	1.6 cm

Uncertainties:

- The scanner and couch will undoubtedly attenuate a portion of the F-18 photon. This attenuation approaches 100%. For a “five bed” scan, this would account for a total decrease of 20% in the expected dose. For the purposes of this calculation, a 15% decrease is applied because of the time lost in patient positioning and movement in and out of the room.
- The dose rate for F-18 varies and is uncertain for the geometry we are trying to shield. I used a measured dose rate from a uniform cylinder as reported by Simpkins. This rate, I believe, is the best estimation of the predicted dose rate. Unpublished data on PET shielding from the American Association of Physicists in Medicine support this value.
- The typical administered dosage of [F-18] FDG has risen from 185 MBq to greater than 555 MBq over a very short period of time. It is likely that the dosage will rise as faster detectors are developed and the availability of FDG increases. The optimum dosage, uptake time and scan time for FDG has not been determined. The typical dosage at the time of this calculation is 555 MBq. Changes that increase the dosage, lengthen scan times or lengthen uptake times will adversely affect the shielding plan.
- Ten (10) patients per day are predicted. Presently, FDG is indicted and approved for all breast cancer patients, most lung cancer patients, all melanomas, all lymphomas and the list increases every quarter. The medical indications and the Medicare/Medicaid approval list include a very large patient population. As the diagnostic and therapeutic paradigm shifts the workload can easily double or triple. This will adversely affect the shielding plan.

Methodology

- Since the shielding for the 511 keV photon of Flourine-18 is substantially greater than what is necessary for the CT scanner under any circumstance, the radiation contribution of the CT scanner was not considered.
- Attenuation of the wall materials (gypsum, plywood, laminate, paneling etc.) was not factored into the recommendation.

- All calculated doses that were not whole numbers were rounded to the next highest whole number and all distances that were not whole numbers were rounded down to the next whole number.
- Because of the short physical half-life of F-18, it is legitimate to correct the hourly dose rate by integrating the 110 minute half-life. The measured dose over one hour is less than the product of the dose rate and time. The following formula was used:

$$R_T = 1.443\ (T_{1/2}/T)\ x\ 1\text{-}e^{\lambda T}$$

Time	**R_T**
60 Minutes	0.85
45 Minutes	0.88
30 Minutes	0.91

Regulatory Climate:

In the absence of guidance from the U.S. Nuclear Regulatory Commission, the States have taken a varied stance on PET radiation safety and PET shielding. Uniquely in the State of Florida, disregards any dose stemming from the patient provided that the patient is not hospitalized as a matter of radiation safety. Accordingly, one could not install any shielding for 511 keV at all, shield for the CT component only and be in full compliance. This is not my recommendation because it is not safe.

Biologically, a REM has the same biologic effect without regard to the source to the person(s) receiving the dose. It is appropriate to protect these individuals who are typically not monitored and work adjacent to the PET suite.

The regulatory requirements for the protection of members of the public are subject to change. In 1994, the public dose limit was 500 mrem (5000 µSv). Today, it is 1000 µSv and some international and national physics bodies are suggesting a limit of 250 µSv. I personally do not agree with these recommendations but none the less, these recommendations are circulated. Occasionally these recommendations become law. Calculations were simplified to algebraic expressions for ease of reading and understanding of non-physics personnel.

PET/CT Room Walls (Extended Example)

Predicted Dose Rate:

(µSv/MBq-hr)(MBq Injected)(physical decay factor)(urinary void factor) (scan hrs. /week) (R_T) (scanner attenuation factor)

(0.092)(555)(0.75)(0.85)(25)(0.91)(0.85) = 630 µSv/week at one meter

Application of Distance:

The patient is located on the scanner couch that is essentially in the center of the PET/CT room. The distances are 1.845 meters to the east and west bump out walls, 6.04 meters to the rear wall and 4.78 meters to the control room wall. It is presumed that individuals typically stand 30 cm from the nearest wall, so 30 centimeters was added to each distance. (d = distance in meters).

$$\frac{630\mu Sv/week}{(d)^2} = \mu Sv/week \text{ at distance } d.$$

Location	Distance	Predicted Dose per Week
East Bump Out Wall	2.145 Meters	137 µSv
West Bump Out Wall	2.145 Meters	137 µSv
Rear Wall of Coach	6.34 Meters	15.7 µSv
Control Room	5.08 Meters	25.9 µSv

Effect of Shielding:

There is 1/16 inch of lead (attenuation factor 0.84) in each bump out wall and 1/8 inch (attenuation factor 0.69) of lead in the control room wall. This reduces the dose 30 cm from the bump out walls from 137 µSv to 115 µSv and the control room dose to 18 µSv.

Occupancy Factors:

Occupancy factors are used to properly describe the amount of time individuals (either workers or members of the public) spend in a given area. They range from a factor of 1.0 (constantly occupied) to 0.025 (occupied one hour per work week). From NCRP #147 *Structural Shielding Design for Medical X-Ray Facilities*, January 10, 2005.

Location	Occupancy Factor	Predicted Dose
Bump Out Wall (visit one day/week)	0.2	23 µSv/week
Bump Out Wall (visit two days/week)	0.4	46 µSv/week
Rear of Coach	0.2	4 µSv/week
Control Rm.– Occupational Limit	1.0	18 µSv/week

In order to demonstrate a high level of safety with respect to the public dose, the rear of the coach will be posted and cordoned off with traffic cones to ensure that individual do not loiter in the area adjacent to the rear of the coach during operations. These cones will be at least two meters from the coach reducing the predicted dose to between 6 and 12 µSv/week which is just over 50% of the regulatory limit.

Uptake Room Predicted Dose:

In the quiet area, patients rest quietly for a period of 45 minutes following an injection of 555 MBq. The same technique and assumptions as described above were used for these rooms.

(μSv/MBq-hr)(MBq Injected)(# of patients/wk)(R_T)(uptake time) = dose rate at one meter/wk

(0.092)(555)(25)(0.88)(0.75) (0.91) = 768 μSv per week at one meter (patient#1)

Should a second patient be placed in the scan room, this patient (#1) would be decayed fifteen minutes (decay factor 0.91)

(0.092)(555)(25)(0.88)(0.75) = 843 μSv per week at one meter (patient#2)

The integrated dose in this case is 1611 μSv per week at one meter, attenuated by 1/8 inch of lead reduces this dose to 1354 μSv per week. The patient, however, only 0.3 meters from the wall, plus an additional 0.3 meters yields 3759 μSv per week 30 centimeters from the wall of the uptake room.

In order to demonstrate compliance and the highest standard of public safety, an area of five meters will need to be cordoned off the lateral sides of the coach. This would reduce the weekly dose to 151 μSv per week further reduced to 30 μSv per week when an occupancy factor of 0.2 is applied.

It would seem that it is possible to have two patients in the uptake room provided that the hot lab area is cordoned off at least 5 meters during operations that involve two patients undergoing FDG uptake. Most mobile locations do provide for this distance.

Thank you for the opportunity to provide these calculations. If you have any questions, please give me a call at 770.335.0263 or email at d.kane@ampmedphysics.com.

Submitted:

Daniel F. Kane
Medical Nuclear Physicist

Approved:

Frank T. Bloe

Medical Nuclear Physicist