

# Shielding Evaluation for Mobile PET/CT Facilities

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## Mobile PET/CT?

From **Medical Imaging**  
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Have Nuclear Medicine, Will Travel: Taking PET/CT on the Road  
by Dana Hinesly  
"Mobile imaging brings diagnostic imaging to the far-flung and cost-conscious."

When mobile diagnostic imaging first rolled onto the scene—some 20 years ago now—it often was assumed to be substandard to stationary systems operating in hospitals and freestanding centers. But thanks to technology's advancements constantly shrinking in size and some custom-built trailers, those times are long gone. Housed in high-tech trailers, today's portable PET/CT units bring with them the same quality of system and images as any in-house scanner. ...

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## Mobile PET/CT Unit



Image courtesy of Calutech Mobile Solutions, Inc.

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## PET/CT Coach Manufacturers

- Calutech Mobile Solutions
  - Siemens Biograph only
    - <http://www.calutechmobiles.com>
- Medical Coaches
  - Siemens Biograph
  - Philips Gemini
  - GE Discovery ST
    - <http://www.medcoach.com>
- Oshkosh Specialty Vehicles (formerly AK Specialty Vehicles)
  - All three mobile PET/CT models.
    - <http://www.oshkoshsv.com>
- Note: All "courtesy" figures are available to the public from the manufacturer's web sites.

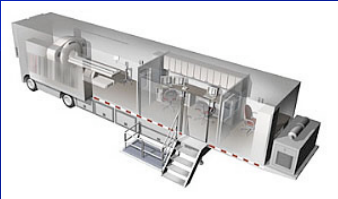
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## PET/CT Shielding Statement

- From one of the manufacturers:
  - "It is the responsibility of the customer to perform a proper radiation survey in order to determine the exclusion zone."
  - "Operator needs to make their own exposure dose measurements to include radiation from patients when determining the outside 'Keep Away Zone' (chained-off area)."

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## Mobile PET/CT Specifications



Ambient magnetic field at PET gantry must not exceed 1 gauss.

Warning: Site pad must be level to less than 0.125 inches over 10 feet!

- Overall size: 52.2' long, 8.5' wide, 13.5' high
- Trailer weight: 60,580 pounds (rear axles carry 37,840 lbs; king pin carries 22,740 lbs)
- Minimum site pad: 10' x 4' front and 10' x 16' rear (better if 11' x 40.7' is used).

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### Shielding Design Considerations for Mobiles

- Target injected activity.
  - Unless otherwise stated, all calculations herein use 555 MBq (15 mCi).
- Weight is limited by US-DOT and state DOT regulations pertaining to length, height and weight per axle.
  - Increasing weight has regulatory ramifications.
- Mobile PET/CT units with “standard” shielding
  - Gross Vehicle Weight approaches 80,000 pounds.
  - Are mainly shielded to protect the staff.
  - Limited floor shielding is provided.
  - No ceiling shielding (pure sky-shine conditions).
  - Distance and Occupancy Time MUST be used to protect the public in the surrounding environment

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### Special Challenges in Mobile PET/CT

- GWV per axle cannot exceed DOT regulations
  - Physicist may not be able to place as much shielding into coach as desired.
  - Increased number of axles to carry more shielding raises road tolls and taxes for the mobile unit.
  - Increased weight limits routing options as bridges and road surface may have weight restrictions.
- Siting (operating location relative to the surrounding occupied spaces) becomes a part of the time-distance-shielding considerations.

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### More Special Challenges in Mobile PET/CT

- Mobile units do not carry an on-board restroom (hot toilet).
  - Patients must enter the facility to void after the incubation period.
  - Facility may provide a dedicated (locked) patient “temporary” hot toilet.
    - If not, some jurisdictions require survey for contamination after each patient.
    - Hot toilet end-of-week surveys will be required at each site.
- Every Licensing agency wants an assurance that there is no shielded or unshielded toilet aboard a mobile facility.
  - May need to evaluate occupancy around off-coach (site) toilets.

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### Siting Problem

- Sites may not have
  - Occupied structures above the unshielded roof
    - Unoccupied canopies or service catwalks may be acceptable in certain jurisdictions.
  - Fully occupied structures immediately adjacent to the hot lab and incubation room.
    - Rule-of-thumb: an exclusion zone of at least 3 feet from coach to structure, or fixed shielding, is needed to keep the external exposure rate below 2 mrem/hr (0.02 mSv/hr). More distance is needed to an office to meet the 100 mrem/year (1 mSv/yr).

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### And NORM, Too!

- LSO, LYSO, LSO(Zr) all have radioactive Lutetium in the scintillator.
  - 97.4% Lu-175 (stable)
  - 2.6% Lu-176 ( $t_{1/2} = 3 \times 10^{10}$  years)
    - 250 keV photon emitter (beta-minus decay).
  - All such PET scanners are mildly radioactive, which can confound background surveys.
  - 10 CFR Part 20, Appendix C lists a labeling quantity for Lu-176 of 100 microcuries.

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### Mobile PET/CT Unit Sections

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### Discussions with Architects and Engineers

- Architects and structural/civil engineers tend to think in terms of distributed loads.
  - You tell them “three tons of lead in the hot lab” and they calculate the static ratio of total weight to floor area, which will look great (to them).
  - Some of the weight will move around, forming a dynamic load (e.g. mobile shields, shipping cases).
- The physicist needs to get the architects and engineers to think in terms of point loads for PET shielding (e.g., the loads on the leveling posts, the 2” thick lead L-shield and dose calibrator chamber shielding).

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### Rear Side

A/C Units
Bump-out (slide out)



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### Entry Stair and Lift at Hot Lab End



Interior finished floor is at bottom of exterior door. Located 53 inches above exterior grade. The incubation (& hot lab) shielding is 1/16 inch and extends to 84” AFF, for a total of 11.4’ above exterior grade.

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### Scan Room Wall




Booth Shielding is 3 mm (1/8”) Pb-equivalent. Windows are 3 mm Pb-equivalent. The sliding door is very heavy, and is interlocked.

Control booth wall is on-axis.

Booth wall shielding is floor to ceiling and wall to wall.

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### View of Scan Room Door Track




Interlock microswitch should be verified to function properly.

Wall and window are 3 mm Pb (or 1/8”) from floor to ceiling and wall-to-wall.

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### Mobile PET/CT Scan Room




Standard Wall Shielding: Finished floor to 84 inches AFF of 1/16 inch Pb.

Standard Floor Shielding: Bump-out floor and 2 feet into scan room of 1/16 inch Pb. When operating, 4+ feet of shielded floor.

No ceiling shielding.

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### The Slide-outs' Weak Spot (1 of 4)




Note the light leak after 3+ years!

Check for gaps after accidents and annually.

Floor shielding is 2 feet into scan room and bump-out floor.

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### Scanner In-gantry Ge68 Pin Source Storage




Notice the UN2911 label, required to transport with source left loaded in-gantry.

Source "pig" inside gantry holds external exposure below 2 mR/hr (0.02 mSv/hr).

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### Bump-out (front)




Notice:

- (1) the cone to help prevent damage to sliding structure;
- (2) the escape hatch.

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### Escape Hatch



The escape hatch is often only shielded with 1/32 inch Pb for weight and operational characteristics.

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### Hot Lab and Incubation Room Door




Notice this door is adjacent to the entry door. The shade is to reduce incubation room ambient light level to minimize ocular, and strap (etc.) muscle uptake.

Hot lab & incubation area door and window is 1/4" (sometimes 1/8") of Pb.

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### The Incubation Area



Two chair version. The partition wall often has NO shielding to save weight.


Some jurisdictions restrict the incubation room to one injected patient to keep inter-patient exposure below 100 mrem and 2 mrem/hour.

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### Mobile Hot Lab

Standard 2" Pb L-shield (with 4" Pb-equivalent glass viewing window).  
 2" Pb-shielded dose calibrator chamber below counter.  
 2" Pb-shielded well counter.  
 1/4" Pb in full wall behind cabinet.  
 Exterior walls (3) shielded from finished floor to 48" AFF with 1/16" Pb.



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### Mobile Hot Lab in Transport Condition



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### Side (At escape hatch)



Exposure rate at hatch = background for LSO & LYSO scanners when no other sources or CT scan.  
 Exposure rate at hatch with patient in PET = ~background.  
 During CTAC scan of patient = 0.5 mR/hr. (1/32" Pb in hatch).

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### Front Support Posts



If there is no incubation area floor shielding, the space around and under the king pin must be restricted.  
 An exclusion zone around the incubation end is necessary.  
 Support posts (11,370 lbs on each).

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### Bump-Out

Sliding "bump-out" to permit operation without becoming a "Wide Load" vehicle in transit.



Sliding "bump-out" is approximately 163 inches front-to-back and 24-28 inches wide of coach.

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### Cones to establish exclusion zone



The kingpin of the coach is under the hot lab (and incubation room) portion of the coach.  
 Cones or stanchions with chain and warning signs may be used.

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### A/C and Power at Scanner End

ER Driveway and Parking

Sidewalk and Support Services

Smoker's Hut

A/C and Power Equipment add shielding to scanner end of coach.

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### What about the shielding?

- Scan room is shielded with 1/16 inch Pb
  - Except:
    - Escape hatch is 1/32 inch Pb
    - Control booth sliding door is 1/8 inch Pb
    - Above the 84 inch AFF level
    - Ceiling
    - Possibly center section of floor under the coach.
- Incubation room is shielded
  - (1/8 to) 1/4 inch Pb in common wall
  - 1/16 inch Pb in exterior walls
  - No floor or ceiling shielding

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### Bump-out/Slide-out Shielding

Red arrow shows extent of floor shielding in operating condition.

Notice that coach may be equipped with flat gantry pallet and even CT-sim alignment lasers.

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### Two Chair Injection Room/Hot Lab

Typical design. Courtesy of Oshkosh Specialty Vehicles.

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### Two Chair Injection Room/Hot Lab

Each bay is 1.19 m wide.

Exterior wall is < 2.625" thick, or 0.07 m.

Distance (horizontal, parallel to ground) from either chair when centered in bay = 0.67 m.

Left side Right side

Typical design. Courtesy of Oshkosh Specialty Vehicles.

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### Where's The 0.02 mSv Line?

For a surface reading of 0.06 mSv/hr at point closest to patient and a P-value of 0.02 mSv/hr. How far from the surface of the coach is the P-point?

$$D = \{ [X * (0.67)^2] / 0.02 \}^{1/2} - 0.67$$

$$D = \{ [0.06 * 0.449] / 0.02 \}^{1/2} - 0.67$$

$$= 0.49 \text{ m} = 19.3" = 1.61'$$

Left side Right side

Typical design. Courtesy of Oshkosh Specialty Vehicles.

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### More Lead in Injection Room?

- 5 mm Pb (1 HVL at 511 keV) weighs:
  - 12.6 lbs/ft<sup>2</sup>
- To place 5 mm Pb into the floor
  - 44" x 97.375" = 3.667' x 8.12' = 32.5 ft<sup>2</sup>
  - At least 280 pounds
- To increase side walls to 5 mm Pb
  - 4' x 8' = 32 ft<sup>2</sup>, or 275 lbs
- To increase front to 5 mm Pb
  - 4' x 8.12' = 32.5 ft<sup>2</sup>, or 280 lbs
- Total increase (not including frame size increase and height trade-off)
  - At least 930 lbs for increases in 4 shielded sides

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### Keeping Your Neighbor "ALARA"

- With a patient in injection chair #1, and another in injection chair #2, what's the kerma rate?
- If Patient #1 emits 0.06 mSv/hr at 0.67 m (edge of their "cell"), Patient #2 will receive 0.027 mSv/hr, exceeding 0.02 mSv/hr!
- To reduce the exposure by shielding will require a 35% reduction. Will need almost 4 mm Pb.

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### Methods for Shielding Evaluation

- Pre-delivery physical inspection (during construction).
- Delivery acceptance testing
  - Non-destructive transmission testing with positron-emitting source
    - Good approximation of broad-beam and dynamic emissions.
    - Requires availability of F18, Ge68, Na22 or other positron emitter.
  - Non-destructive transmission testing with other photon emitting sealed sources (e.g., Cs137).
- Operational Evaluation (in-operation monitoring)
- Area and Technologist Occupational Dose Monitoring

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### Operational Evaluation

- Measurements performed at the perimeter and within an operating mobile unit at one or more sites.
  - Survey meter measurements of exposure rate or dose per procedure at defined points of interest.
  - Used for public dose calculation on a per-site and per #days of operation each year.

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### Scan Room No Patient or CT

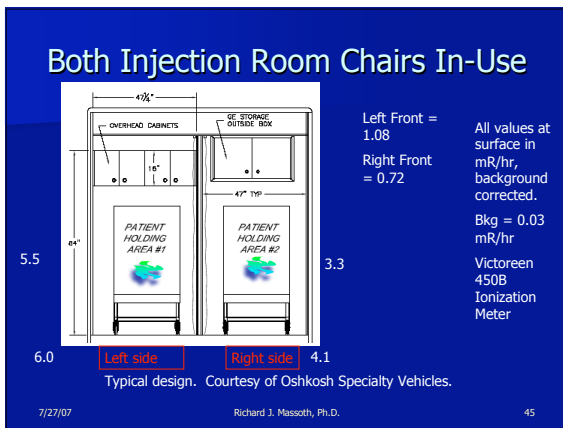
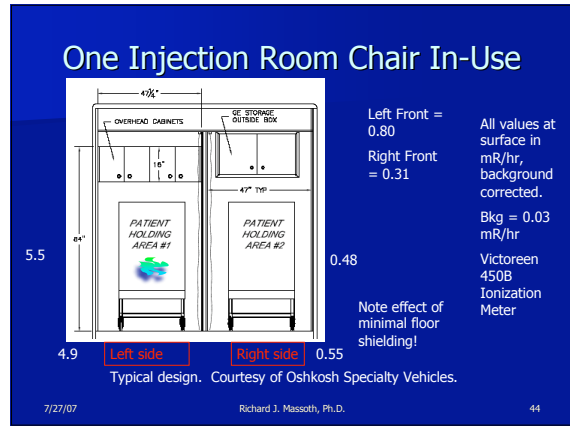
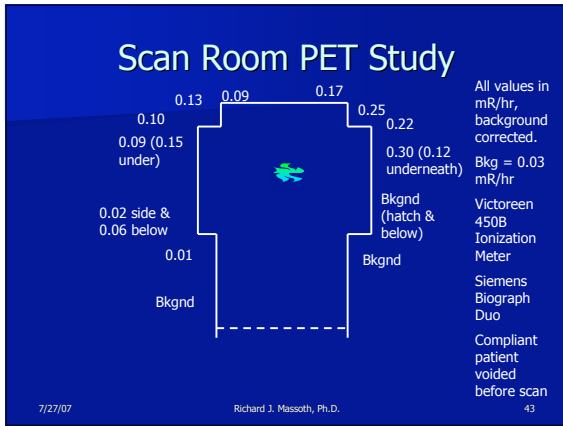
All values in mR/hr, background corrected.  
 Bkg = 0.03 mR/hr  
 Victoreen 450B Ionization Meter  
 Siemens Biograph Duo

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### Scan Room CT Atten. Corr.

All values in mR/hr, background corrected.  
 Bkg = 0.03 mR/hr  
 Victoreen 450B Ionization Meter  
 Siemens Biograph Duo  
 Compliant patient voided before scan

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- ### Example Operational Evaluation 2
- Technologists survey exterior surface of vehicle at least once per year.
    - Directed to find the hottest spot in each area of the coach along the four vertical sides.
    - Survey performed with G-M survey meter (not the best choice, but it's handy).
    - Survey is performed under various conditions:
      - Sealed sources only
      - Sources and doses
      - Sources, doses and injected patient (scan or incubation phase)
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### Operational Evaluation 2 Results

	1 day/week-site		2 day/week-site		5 day/week-site	
	Corridor (mSv)	Outside (mSv)	Corridor (mSv)	Outside (mSv)	Corridor (mSv)	Outside (mSv)
Sources only	0.02	0	0.03	0	0.09	0.01
Sources + Doses	0.83	0.1	1.67	0.21	4.17	0.52
Sources + Injected patient	8	1	16	2	40	5

Note: results are highly variable, as technique is not sufficiently well controlled.  
Based on NRC-147 occupancy factors applied to technologist survey data from CY2006.

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- ### Area Monitoring
- Use of area monitoring devices within, and at points of interest at operating sites, to continuously monitor the dose delivered to specific locations.
    - Performed continuously with area monitoring permanent dosimeters, changed monthly, bimonthly or quarterly.
    - Used for public dose verification on a per-site and per #days of operation each year.
    - If a scan-room monitor is placed without shielding (e.g., 1/16" Pb), it will record CTAC and patient bremsstrahlung as well as 511 keV photons.
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### Area Monitoring Results

- Area Monitor DDE in mSv for CY2006 (N=18)
  - Changed monthly
  - 555 MBq average injected dose.
  - Covers every site and all patients.

	# transits	Annual	Monthly Average	Monthly Maximum	Monthly Minimum
Control Booth	2	1.4	0.13	0.66	0.01
Scan Room	1	27.0	2.5	4.7	0.75
Injection	1	22.0	2.1	3.9	0.49

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### Public Dose Budget Per Site

Limits in  $\mu$ Sv per 8-hour day, assuming 260 operating days/year.

# Weekly Visits per month	1 day per week	2 days per week	3 days per week	4 days per week	5 days per week
1	83.3	41.7	27.8	20.8	16.7
2	41.7	20.8	13.9	10.4	8.3
3	27.8	13.9	9.3	6.9	5.6
4 = stationary	20.8	10.4	6.9	5.2	3.8

Each site must average to not more than 1 mSv dose to public in any year.

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### Per-Procedure Dosimetry

- For 555 MBq average injection.
- 60 minute incubation and 20 minute scan times.
- Technologist and patient care tech share transport duties. (N = 66)
- Average 8 patients per day.
- Based upon 6 month Data, 2<sup>nd</sup> Half CY2006

	Average	Std. Dev.	Min.	Max.
DDE (mSv/case)	0.02	0.04	0.0	0.24
SDE-ring (mSv/case)	0.08	0.15	0.0	0.81

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### Recommendations

- Annually survey exterior exposure rates or evaluate shielding integrity.
  - Look for damage to shielding in sliding areas and at corners.
- Survey or evaluate shielding integrity after all vehicular accidents – even parking lot collisions (especially if they involve the sliding walls).

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### Recommendations (2)

- Establish an area monitoring program inside of the mobile coach.
  - Potentially also install area monitors at critical points of sites with poor siting distances from occupied areas.
- Verify that all site-based workers on the coach who might receive more than 1 mSv per year receive radiation worker training and film badge or calibrated electronic personnel dosimeters. (E.g., patient care tech, transporter, registering clerk).
- Watch sites for “smoker’s break usages” around PET/CT coach.

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### Conclusions

- Mobile PET/CT coaches may be operated safely below the public dose level of 1 mSv/year with proper siting, occupancy factors and exclusion zones.
- Mobiles used as fixed sites can use a chain-link fence to enforce the exclusion zone around the incubation area.
- Concrete walls (or ferricrete retaining block walls) may be used to form an “igloo” for the incubation area if adjacent or overhanging occupied space needs shielding.
- Distance is as much your friend as shielding.
- Patient self-shielding, site usage and occupancy factors must be considered in calculation of public dose.

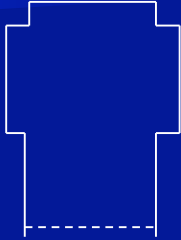
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Any Questions?



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Scan Room No Patient



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