

Good morning, my name is Jon Anderson and I'm going to be talking to you about site planning and radiation safety in PET facilities. The point of view of my talk today is that I will address practical design issues for PET and PET/CT facilities that are involved in cancer imaging of the whole body with fluorine-18 FDG. Of course there are many other types of PET and I will touch briefly on those other types, but by-and-large I'm going to be addressing the use of fluorine-18 FDG and I'm going to be talking about a facility that uses unit doses of FDG that are obtained from an external radiopharmacy and that have dedicated PET or PET/CT scanners. So I won't be talking about cyclotrons or radiopharmacies or isotope generators today. In PET and PET/CT imaging, of course, we either use conventional PET scanners or, much more likely these days, a PET/CT scanner. Several years ago if I was giving this talk, I'd really only be talking

about a conventional PET scanner. Nowadays, the vendors aren't making anything except for PET/CT for all intents and purposes, but there are plenty of conventional PET's still left around. They use rotating isotopic sources in order to acquire the transmission image that you need to make attenuation correction to your PET images. About 70% of the time is spent acquiring the emission image coming from inside the body, and 30% is spent while you're using these rotating sources to obtain the transmission image. Typically scanners like this have a 15 cm axial field of view. Data in the PET world is acquired in beds. We'll acquire 15 cm worth of data in the body and we will then shift the field of view, shift the patient and take another 15 cm with a little bit of overlap in the scanning. Data can be acquired as either 2D or 3D acquisitions, with the difference being that you either have or do not have a set of collimators in the field of view.

Clearly if you don't have the collimators in there, you're probably taking data at a higher rate, so 3D acquisitions take less time. There are newer crystals that are used in these things than were some five years ago, that allow for lower noise and shorter acquisition times. In a PET/CT scanner, shown down here, essentially the manufacturer has bolted a CT scanner at the front of the gantry onto a PET scanner at the back. It uses the coupled system to acquire a transmission image from CT, which clearly instead of taking 30% of the time, now requires only 60 seconds. Doing this provides an automatic registration of the anatomic CT and the functional PET images and allows faster scans through the reduced transmission image time. Here are the types of machines you're going to be seeing if you buy one now. You have the Biograph series that's available from Siemens. GE makes a set of machines that they call the Discoveries, and Philips

markets what they call the Gemini scanner. I don't think there are any other major vendors, but if there are they have my apologies. At any rate, this is what you're designing for when you're putting in a new PET facility. What is different about PET from conventional nuclear medicine? Now in my hotel when I came in, I found this little tag that was available. It says "PET in Room," which I thought was very appropriate. As a physicist and as a facility designer, we need to know that PET is in the room, rather than just conventional nuclear medicine, for several reasons. First of all, the requirements for patient handling during injection and uptake are different. Secondly, PET involves, of course, the use of 511 keV photons. These are much higher energy photons and we have increased exposure rate from the doses and from the injected patients. It greatly increases the thickness of shielding that is required, and hence we want to use

time and distance, when at all possible, when we put together our facility plan. Finally, we may

have combined modality scanners like the PET/CT that require consideration of both the gamma ray and x-ray hazards. When you come into a PET center this is what happens. Here's the patient over on this side, the radioactive material on this side. The patient comes in, the technologist will talk to them and tell them about what's going to go on and then puts them in the injection room. The doses come in, they go to the hot lab, they get assayed and then taken to the injection room. An injection occurs and then the patient will sit there for about an hour while the uptake of the radiopharmaceutical occurs. After that, these things are excreted to the bladder. If they don't empty their bladder, you're going to have a hot spot down in the bladder that may mask things you want to see. Therefore they go to the hot toilet, or as we say around our place,

“the hot potty,” and they empty their bladder. Then they get transported to the scanner bay, positioned in the scanner and scanned. The PET scan can take between 10 and 60 minutes, depending on what you're doing and what type of equipment you have. After the scan, the tech checks the images, sees that they are okay, kicks the patient loose if everything's okay, and then the images get sent to the reading room and to the PACS system. Now I've identified these steps here, the injection of the patient, the transport of the patient and the positioning of the patient, as being the steps with the highest technologist exposure. When we're going to consider how to set up our operation to minimize technologist dose, then we need to consider these steps in particular. How many patients can we do in a day? This little chart shows the workflow. So (at) 8:00 the doors open up, the patient comes in and gets injected. They're going to sit around for an

hour, then they're going to get scanned. I have assumed that we have a one hour uptake for the studies we're doing and (that) with the equipment we have, it takes 30 minutes in the scan bay. At 9:00 they go into the scan bay and they're going to be released at 9:30. Now your second patient has come in at 8:30, been injected, they'll be ready to go onto the bed just as soon as the other patient walks out. You notice this is a little bit of a utopian ideal here, and that it assumes that you have a technologist made of iron that can actually accomplish this. The bottom line is that if you want to estimate the number of patients per day, then you look at the total number of hours in your work day less the uptake time and divide by the time in the scan bay. That'll tell you, for example, that under this scenario you could at a maximum run 16 patients through. Now you've got all these patients sitting around that are radioactive and you need to put them

somewhere. How many uptake areas do you need? Well you're going to take the uptake time and divide it by the time in the scan bay to figure out the minimum number of uptake areas that you need. This gives you an idea of how much space you're going to have to have to spot your patients in. Here is a picture of our facility. The radioactive materials get delivered at our place early in the morning, before we come in. The deliveryman comes in and spots them in the hot lab, which is just around the corner from the injection rooms. Patients come in down here. This is a stand-alone facility, so they come into our own waiting room, get taken down to the injection room, injected, go through the uptake period, step across this little hallway into the hot toilet, empty their bladder and then are escorted to one of our two scan bays. Let's start where the radioactive material comes in at the hot lab. The shipping containers for this 511 keV stuff

weigh 66 pounds, so we don't want the techs to be trying to hoist those things around. The

delivery man brings them in on a two-wheeler and he just spots them here. We've put a piece of masonite down there to avoid knocking holes in the floor, which can easily happen. We've got our shipping container set here. How much space you need there, of course, depends on how far away from the radiopharmacy you are. If you're going to do, say, half a days' worth of patients before you get another delivery, you're going to have a fair amount of space for spotting these containers. Then you can see over here a little radioactive trashcan. There's not much waste accumulation in a PET or PET/CT operation because of the two-hour half-life (of fluorine-18). So we don't have to have a separate storage room to take care of this stuff, you just wait a few days. It is disposable, so we build up our sharps containers and just keep them in a regular cabinet. We don't have to have any type of shielded storage for them. The other thing you

notice here is that you go from where the isotope is delivered up here to the calibrator. It's very convenient, the tech can just reach down, grab the syringe out of the case and drop it into the calibrator. Here's the close up showing this area here. So he drops it into the calibrator, verifies the dose and then either puts it into a PET-rated syringe carrier here (there's a cart that's not shown so he can drop that onto the cart and take it around the corner) or, if he needs to do something with that dose, he can put it down into the L block. You see this L block doesn't look much like a conventional nuclear medicine L block. It's got two inches of lead around the back and actually more than two inches of lead in front on this one and this very thick lead window. I think I've mentioned all of these points and the fact that you have a quick transfer so that the source stays bare for a minimal amount of time. Let's look at some more pictures here. Here's

our dose calibrator. You can see that there's a two inch lead ring that goes around the outside of the calibrator to provide protection to the technologist while he has the dose in there. Here's our well counter for counting wipe tests. It's sitting over here. You'll notice it's got some extra shielding around the backside of it. That's because there's a conventional PET scanner on the far side of this wall. When the transmission source that is in that PET scanner comes out, the well counter picks it up. We have to provide extra shielding there. Down here is a picture of the syringe shields. We use tungsten syringe shields for the technologist in order to reduce their hand dose. Now one thing that you need to do when you're putting one of these things together is that back in this area here you have to have a heart-to-heart talk with a cabinetmaker. I had this talk with the cabinetmaker. You can imagine that this whole setup up here weighs about

1,000 pounds. I told the cabinetmaker how much was going to be up there and he said "Not to worry." When we set it up there, the whole table top bowed down and we very rapidly took it back off of there as a consequence. I don't show the space underneath the L block, but in fact it's all filled up with timbers that carry the weight of this stuff all the way down to the floor. This is one of our injection rooms. The patient is going to be lying here for an hour and the patient is going to be the hottest (that he is) at any point while he's in the facility. This room actually has the most lead shielding in it of any of the rooms. You're going to have shielding in the injection room, the hot lab, and the PET/CT bay, of course. To minimize anomalous uptake in the patient, you want to minimize external stimuli. You need to keep the patient quiet and still on the gurney, or in an injection chair. The fluorodeoxyglucose is a glucose analog that gets taken up

by any muscle that's doing any work. If the patient is listening to music and bopping around, or

something like that, you'll see uptake in all the muscles that are involved. You want to keep them quiet and in a secluded place where they're not being bombarded with a lot of external stimuli. You need the adjacent hot toilets so that after the uptake period they can get up and empty their bladder. We use indirect lighting, we use curtains and noise control back in this area to keep the patient isolated. So now, we have our patient, he's been injected, he has gone through the uptake period, he has emptied his bladder. It's time to get him down to the imaging suite and I show you imaging suites of a conventional PET and of a PET/CT. Now these rooms aren't too awfully different from any other imaging suites, but they may require some special features, depending on what type of equipment you buy. This equipment here has a closed fluid-

loop cooler that keeps the gantry temperature constant. You have to have plumbing coming in here and this little access cover back there covers the valves that will shut that loop off for service time. It may require special cooling in here to keep the gantry cool. In our particular case we found that temperature control was vital and you have to make sure that the air conditioning plan is adequate. The equipment, depending on what type you have, may shut down automatically when the temperature in the scan bays or the control room gets too hot. You have to make sure you've got enough air conditioning. Just to point out a deficiency that we discovered in our own design, you need to have the air conditioning zoned so that the uptake areas are separate from the scan, the control and the reading rooms. In our case, the air conditioning engineer put the uptake rooms on the same control that the reading room has.

We've got a zillion work stations in the reading room. That's where the thermostat was, so the patients were freezing back in the uptake rooms until we rectified this. These are just miscellaneous things I want to mention for design purposes. In the control room, you can never have too many network drops, because you've got a lot of computers in there. You need to provide for IV contrast injection and the injector control unit in your scan bay and in the control room, (respectively). The technologist spends a lot of time in this area so you need to be sure to evaluate the shielding so that you can maintain their exposure as low as reasonably achievable. If you're standing in our control room we have it set up so that one technologist can stand in there to look into the conventional PET room or turn 180 degrees and be looking into the PET/CT scanner. As I mentioned, here in the foreground you can see you've got a lot of

computer equipment associated with this operation. Here is the PET/CT gantry. In our particular case, because of some steel columns that we had to live with, we had to put the scanner in there paralleling this window. There has to be a closed circuit TV that looks down the gantry from the top end out here, so that the technologist can visualize the patient here. Some scanners may require a utility room that holds the computer equipment and cooling equipment associated with the scanner. You may have heat exchangers for cooling the gantry. Some gantries just exhaust their heat into the scan room instead and you have to make sure that the AC engineer has included enough capacity of this system to accommodate that. You may have a UPS in that room, surge suppressors and power conditioning equipment. As I noted before, some vendors' equipment may shut down if the temperature in this room exceeds their

specifications. We had problems. The air conditioning engineer assured me that I didn't

understand energy and that it took equations to figure out how much heat this equipment was giving off, but that I should trust him and he would make sure that it would cool. He put three tons of air conditioning into this room to cool it, but unfortunately it required four tons as I had told him originally. You have to work with your engineers here to make sure they understand the types of loads you're talking about and the fact that this is a 24/7 type of a load. (This error can be ascribed to communication problems between the vendor, architect, engineer, and user regarding the nature and magnitude of the heat loads.) This is an example site plan for a PET/CT scanner, in this case a Siemens Biograph. You can see these three different areas we just talked about: the scan bay proper, a utility room that may have power conditioning equipment and chillers in it, and then the control room with the console equipment. How much room do you need to put one of these scanners in? This is a summary of some fairly recent site planning

guides from Siemens, GE and Philips. The numbers in parentheses are in square feet. The numbers without parentheses are in square meters. If you're looking at square feet, the minimum size that you can get away with is somewhere between 500 and 600 square feet. I would seriously advise you to get more space than this if at all possible, because it's going to reduce the shielding requirements that you have for the facility if you can get further away from other occupancies. Another set of miscellaneous personal advice on planning and start up of such a facility is to keep the hot areas in the basic architectural design away from adjacent uncontrolled occupancies to reduce the amount of lead or concrete you're going to have. For multiple scanners, use a common control room to improve the technologists work flow and buy enough specialty workstations in the original purchase to allow techs, docs and researchers enough

access. Some people will come in and they'll say you can use your PACS station or you could use an existing nuclear medicine workstation, but they are inadequate for evaluation and processing or reading PET studies in general and PET/CT fusion studies in particular. Now let's move on to the question of radiation protection in the PET facility. First of all, of course, we have regulations and those regulations are found in Part 10 of the Code of Federal Regulations, Chapter 20. As all in this room know, radiation workers are limited to 50 mSv per year, or 5,000 mrem per year. A pregnant worker's fetus is limited to five mSv over nine or ten months of the term of the pregnancy, corresponding to 500 mrem over that term. Members of the public are limited to one mSv or 100 mrem per year. Not to be exceeded in any uncontrolled area is a dose of .02 mSv (corresponding to two mrem) in any given hour. This is from each "licensed

operation" is the way the regulations are set up. On top of those regulations, then, we also have a guidance that we should maintain all doses as low as reasonably achievable and we're going to look at seeing how we can do that. Now in addition to the regulations, of course, we also have goals established by the NCRP. The recommendations from the NCRP are in NCRP 116 and they're given in terms of effective dose, a little bit different from the regulations, which were done in effective dose equivalent. Radiation workers still have the same limit that the regulations have, but the NCRP says you should establish a goal of a lifetime limit of the person's age times ten mSv. That corresponds, then, to one rem per year, or ten mSv per year. They also say that new facilities should be designed to limit exposure to a fraction of the ten mSv per year implied by the lifetime dose limit. A pregnant worker's fetus still has the same type of

limits here, 50 mrem per month over a ten months term (long pregnancy there!). Members of the

public are again restricted to one mSv or 100 mrem per year. They say you should look at all sites and all sources and that if you have a single site that you're in charge of, you should limit your contribution to 25 percent of this limit, or demonstrate that the maximally exposed individual will not exceed one mSv for all contributions. In other words, you know this person is going down to Smoky Joe's nuclear waste plant after hours and working down (near) there, and you know he's going to be getting some dose down there. You should take account for that when you're calculating what you would be giving him. Of course, we do not know what individuals do outside of this (our own site). This particular area, if you happened to listen to Doug Simpkin's speech earlier in the week, is perhaps going to be reviewed. This particular

recommendation was promulgated to deal with effluents from plants (factories) and they were considering members of the public being exposed to radioactive material coming out of operations when they did this. What are we going to do? We're going to do the same thing that physicists have always done when they're looking at radiation protection. We're going to use time, distance and shielding to reduce the dose that any individual receives. It's just that shielding for the case of 511 keV photons is a lot harder to come by than it is when we're dealing with x-rays. A common view point is that nuclear medicine departments don't need shielding and if you go into older facilities, often times you won't find any shielding at all over there. Under the older regulatory limits of more than ten years ago, where members of the public could receive five mSv per year, little or no additional shielding would probably be required in many

cases, but when we operate under one mSv per year limits that are five times less, you have to re-evaluate that. Another way of putting this, at least in my experience, is that much of the shielding required in practice in a PET facility is on the order of two to three half value layers, perhaps four half value layers in some cases, given your factors of 4-8. You see that 4-8 corresponds to this five over here (the factor of five in protection limits), so a decade ago we wouldn't need any additional lead, but now it might be different. Each one of these half value layers is at least an eighth of an inch thick, so when you're talking about putting in three half value layers, all of a sudden you have got three eighths of an inch. Maybe you've got half an inch if you need four half value layers. That's a lot of lead. We have to figure out the most efficient way of approaching this problem. Right now the way of doing this is not very well

standardized. These are excerpts I took out of a web discussion thread back in 2000, but the same discussions are being held today. You have one person say the requirements were to be determined to be one inch and a half an inch of lead in the wall. They're talking about shielding between the scan bay and the control area here. You need an inch of lead in that wall, says one. Someone else comes back and says we don't have any special shielding and a third party says most do not shield this room. Someone else says this leads to a lead thickness of about two centimeters as they calculated it. Someone else says we don't have any lead shielding, or we have two millimeters of lead in the wall, or we have a lead glass window and a quarter inch of lead shielding on this wall. Things were not well standardized then and they are not well standardized now. The AAPM has established a task group on PET facility shielding chaired by

Mark Madsen and having this cast of dubious characters on that committee. We're hoping to

generate a report by the end of this year. Because the work of the task group is unfinished, today's talk which you hear from me, except when noted, just represents my opinions. It doesn't represent the committee's conclusions, but we hope to have some official conclusions out fairly soon. Let's look at the sources we have to consider when we establish our shielding plan. We have doses before they get injected. They're sitting in there on the floor in the hot lab. We have the calibration sources for the scanner. These will be sitting in the scan bay. Some of them are actually inside the gantry: they're in a pig and they slide out of that pig during the calibration procedure. While they're out either way--whether the tech is handling them manually or they're handled by the robot--while they're out, the gantry is giving off gamma rays. You have the patient after being injected and while he's lying in the injection and uptake rooms. Then he's going to get up, he's going to go to the hot toilet, and he's going to be in there for a few minutes.

He's going to go down to scanner and stay there for somewhere between 10 minutes and an hour. You're going to have the transmission sources that are in the scanner. Again, these are automatically retracted into lead shields when they're not in use, but while they're out, the gantry again is a source of gamma rays. So to develop your shielding plan, you need to have the workload parameters pertinent to this stuff. What isotopes they are, how much you have on hand--or how much you're likely to have on hand, depending on how many delivers you get everyday--and how many patients you're going to do. You need to know something about the scanner, because you need to know what type of scanner it is and how long the patient is going to be in the scan bay. You need to know something about the studies. You also need to know something about what you're doing with the CT machine. You're going to use that CT machine

to generate attenuation correction data. You're going to take a whole body scan when you take the PET scan, but you may go back and take additional CT studies on that patient with contrast at a different acquisition technique than is appropriate for getting the attenuation map. You may have additional studies on the same patient. Maybe this place is figuring "We're only going to do PET in the morning. In the afternoon we've got a 16 slice scanner sitting in there. We're going to use it as a CT scanner!" You need to know any additional non PET/CT work load that's going to be going on in that room. It's turned out that the committee has spent a lot of time looking at trying to figure out dose rate constants. At any rate, before we inject, we've just got some kind of dose rate constant, like we learned about on the pages of Johns and Cunningham. Now dose rate constants are actually a little bit more complicated than that. You know we used to work in

mR (milliRoentgen). We measured exposures or, equivalently, air kerma and that's a good thing. I say that's a good thing because you can use a meter and measure exposure or air kerma. Regulations now are given not in air kerma but in effective dose or effective dose equivalent. When you look in these tables of gamma ray constants, it may take some digging to figure out exactly what those constants are phrased in. The constants I show here were out of a paper by Unger and Truby. It came out of Oak Ridge, the Radiation Shielding Information Center, and they're actually given in microSieverts of deep dose. That's a regulatory term defined in 10 CFR 20. Being an old fella, I'm going to use conventional units here, but I've also shown the SI units, without parentheses. The older conventional units are in parentheses. You can see that for fluorine-18--with its 110 minute half life and almost, but not quite, 100 percent decay through

positron emission with positrons having an energy of about half of an MeV--the dose rate

constant is, in this schema of deep dose, 0.695 millirems per millicurie at a meter. If we were to rephrase that in terms of air kerma or exposure we would get .56 mR per hour, per mCi, I'm sorry I left off the complete set of units here; this is mrem per hour, per mCi at a meter. So that's for the bare dose in this range, neglecting any type of attenuation. When we inject the dose into the patient, it rapidly distributes itself within the patient and the patient's body will attenuate some of the gamma rays being given off. The question is how much, and can we use that when we're doing our evaluation of dose delivered to protected areas? This graph summarizes the results that have been found in the literature. Down at the end it includes a result that we presented last year in a poster (2003 AAPM Annual Meeting). You can see that the dose rates

reported range from 0.2 mrem per hour, per mCi at a meter, up to almost the unshielded value up here at 0.5 something or another mrem per hour at a meter from these different literature values. If you're just going to take an average or drop the more extreme values you're going to get some value between 0.3 and 0.4 for this constant. In essence, we see an attenuation of about 40 percent. The body transmits about 60 percent of the gamma rays that are given off here. And I make the note down here that when the patient goes to the hot toilet and empties their bladder that it will eliminate between 10 and 20 percent of the retained dose. That's how much will have accumulated in their bladder over the one hour uptake time. In this work here, we got a value of 13 to 14 percent that they eliminated on average. Here I've drawn this little man. Of course we're not isotropic, we're not spheres, so if you measure from different positions either

superiorly or inferiorly, or laterally you get different values from the anterior value. The anterior value is the largest value and if you want to stay on the safe side you just take this larger value. Now it's not quite as anisotropic as it might seem, because the investigators measures these dose rates at a meter from the skin surface, so here they're measuring at a meter from the soles of this guy's feet, or a meter from the top of his head. Clearly they're much further away from the core of the body where most of the dose is, and it's not quite such a bad assumption to think he is, in fact, a fairly isotropic source. You can compare the values that I've shown here. This was an average value from the previous page without any real serious data analysis as to whether the data should be included or not, but it's an average value, as I say between .3 and .4 millirem per hour, per mCi. You can compare this to the dose rate from technetium-99m, where you see

about .05 mrem per hour, per mCi, or about eight times less. When you're evaluating the contribution from the calibration sources and the transmission sources in a conventional PET scanner or when you're looking at the CT dose from a PET/CT, the manufacturer provides you with isodose curves that you can use for estimating what's coming out of the gantry. Now I will say that it would be unwise (I have put *caveat shieldor*, the shielder beware, comparable to *caveat emptor* or the buyer beware, here) to say, as the vendor somewhat implies, that this is what happens when you have so many mCi inside a patient, inside the gantry. He's showing you the isodose curve from a volume phantom that's about this long (25 cm). Well that's not a good idea, because most of the patient's body sticks out of the gantry. You can't use these curves in estimating what the dose coming out of the gantry when you have a patient in the gantry would

look like. And likewise the manufacturer provides us with those isodose curves when we're

doing CT shielding calculations, but those scatter isodose curves are based on a standard dose phantom or one of the vendor's proprietary phantoms, which is again a relatively restricted object on the axis. Those curves don't probably reflect what it looks like when you really have a patient inside the scanner. We've examined the different sources that you need to accommodate in your shielding plan. Now we'll look at the materials. Of course, our favorite materials for shielding are lead and concrete, because they're readily available, and concrete is pretty cheap. Now if you go to the handbook and you look up what the half value layer of lead is at 511 keV you'll find that it's about 4 mm, a bit over an eighth of an inch, and that concrete would be 34 mm, a bit over an inch, an inch and a half or there about. These values can't really be used because they are narrow beam values. They don't reflect the scatter occurring inside the shield

when you have a broad beam. You need to figure out something to use other than these. These will underestimate the amount of lead that you have to have in your shielding design. We have another *caveat shielddorr* here. I'll also point out that although, if you look in the handbooks, you'll see concrete listed at 2.35 grams per cubic centimeter, in fact in much modern construction they use a lower density concrete. It's poured in place over steel decking and that lower density concrete has a significantly lower density. You have to correct for that. The effect of the gypsum wall board that is omnipresent in our buildings has been investigated, but it turns out, as you would expect, that at these energies of 511 keV, gypsum provides relatively little attenuation. So what do we do? Well, the correct curves for 511 keV are not in NCRP-49, our old standby which does, in fact, have information about shielding isotopic sources. The new

replacement for that, which will be NCRP-147, does not include any information on radioactive material shielding at all. What are our alternatives? Well, we can interpolate between existing curves from NCRP-49 and probably no one could get after us too much because this is still THE source for shielding information. We can use gamma ray transport codes, as was done in the study where they evaluated the effect of gypsum in the wallboard, to calculate a set of curves or tables. We can use build-up or other semiempirical formulations. The build-up formalism models the intensity as  $I$  is equal to  $I_0$  times the exponential factor times another factor called  $B(x)$ .  $B$  is a function of the shield thickness and  $B$  is called the build-up function. You have to use the correct factors! In fact, it turns out that if you go to the sources you'll find tables of these factors, but they will not be appropriate. They'll be for infinitely thick shields and things like

that, where you have backscatter going on. So you need to find the right set of  $B$ 's if you're going to do this. The final option is to wait until the AAPM task group report comes out, because Doug Simpkin is generating a set of graphs and tables to show the shielding effect of the common shielding materials at these energies. What information do we have to have? Just as in any shielding problem, we need to know the use of adjacent space and the occupancy factor for that space. We need to know how many patients per week and the isotopes in use. The activity injected per patient, which will depend on the equipment and the type of study. The type of PET studies to be performed (head, whole bodies, cardiac, etc.) because the studies are done differently. When you are doing heads, of course, you're only taking one bed. Typically you might take that bed for 15 minutes, instead of five minutes that you might do in a PET/CT

scanner (for whole body scanning). At any rate, the technique is different, so the patient is in the

room for a different amount of time. You need to know the dose delivery schedule from the radiopharmacy, and the maximum activity you'll have on hand back in the hot lab. You need to know your CT technique factors. The kVp, the mAs per scan, which of course is going to depend on the number of beds you're doing on the PET side. The number of scans per patient (you may be doing some additional scans), and the amount of non PET/CT workload. This is my own personal paradigm and you can take it for what it is worth. I sit down and I identify the magnitude and location of all my sources, including the CT. I integrate over the appropriate decay period that the source that I'm considering is in that location, and I end up expressing it as dose per week, or dose per hour at one meter given the work load, the number of patients per week that I have. I identify all the barriers that contribute to the shielding including the pigs in

shipping containers. I establish a grid of points at the perimeter at sensitive locations throughout the facility, and identify which barriers contribute. I calculate the doses, summed over all sources to each of those points, without attenuation, and then I start adding lead or concrete as necessary to my barriers and stop when I meet my goal of 100 mrem per year, or two mrem per hour, depending on which limit I'm concerned with at that stage of the calculation. Now you can do that with a spreadsheet, you can do it with special purpose programs that you or somebody else writes, or you can do it with pencil and paper. It is extremely tedious to do it with pencil and paper, because in PET our barriers don't tend to be absorbing 99.999 percent of the dose. We have to pay much more attention to the dose coming from this source in the hot lab, this source in the injection room, this source in the scanner bay, all contributing to my dose for the

secretary that's sitting at this desk. So I have to include all these sources and all the appropriate barriers at the same time and then play with it to try and optimize my shield design. This graph shows the effect I told you that occurs when I integrate over the length of time that the source is in place. Here I've imagined I'm one meter away from a dose that comes in to my lab and I stay a meter away the whole time that dose travels through the lab. So it's in the hot lab, it goes into the patient, and I stay a meter away from the patient while the patient is in uptake, while the patient goes to the hot potty, while the patient goes to the scanner bay. I've shown what happens here. The redline shows the amount of dose I accumulate as time goes by, a meter away from this dose, if I just take physical decay in to account. The green and the blue lines show me what happens when I add in patient attenuation, that's the blue line, and the green line shows my

further account for some biological elimination at the end of the uptake period. You can see that I get a little bit of gain at each step of the way. Most of the gain is from the self-shielding of the patient. I said that you could do the shielding calculation with a spreadsheet. This is an example. Here I define all the different sources. In this plan I had ten sources that I was worried about. Over here I defined my shielding materials and used a modified build up approach to calculate the thicknesses required for the attenuation from a given thickness. I have all of my test points over here and all of my barrier definitions here. You can do this with a spreadsheet. Now the question is where do we put the lead to be most effective. We've got the alternatives of either just doing it the way we do an x-ray room, where we cover the wall with lead perhaps to seven feet, perhaps to the deck of the floor above depending on the particular situation I'm in.

This has the advantage that contractors are familiar with this technique. The facility I showed

you, the Southwestern facility, ended up that I didn't have to hang any lead thicker than a quarter of an inch, which is 6.3 millimeters. That's easily managed by people that hang leaded sheet rock and it makes sense to follow this approach when you've got a CT in the room. You know you're going to have to have CT shielding on the walls, if nothing else. The alternative is to use shadow shielding. See you put a big slab of lead next to your trouble spots. You can do this and it can reduce the overall cost when you need a lot of shielding in a localized area. It provides you with a lot of flexibility when you're remodeling older work in an established room. These two pictures show examples of the use of shadow shields. Here's your injection chair here, here's an L-shaped thick shield behind it. It's on wheels here and it can be moved around. There's this little shield here. You see there's a little jack there that actually lets you lift up this side of the shield to provide higher angle shielding off in this direction. Here's the scanner bay,

again showing portable lead shielding in place because on the other side of this wall it was found that we had too much exposure over in that area. Installation of these shields brought us back to our shielding target. What is the committee doing? I remind you what I told you: by-and-large so far you've heard just my personal opinion. The committee is evaluating the recommended dose rate constants from the literature, both for point sources and for the patient as a source. A Monte Carlo simulation is being used to create the set of broad beam attenuation graphs and tables for iron, concrete and lead. Archer-equation fits will be given to allow straightforward calculation of shield thickness from the required barrier transmission factor. We're coming up with a set of consistent recommendations on shielding issues I've talked about today. The conclusions may be different--you only heard my opinion today rather than the

committee's conclusions. The formalism proposed by the task group is that you'll calculate a barrier transmission factor that will depend on the occupancy of the space you're protecting, the target dose in that protected space, and the distance away from the source.  $\Gamma$  is the dose rate constant.  $A_0$  is the activity-- not the injected activity, but the activity (retained) when the patient or source entered into the space.  $T$  is the amount of time it stays there.  $R_t$  is what we call a reduction factor. Essentially it takes care of the integration of the physical decay of the dose over the time period you're considering.  $N$  is the number of patients per time period corresponding to this  $P$  factor or target dose factor. So, very much like NCRP-49, you calculate a barrier transmission and then have a mechanism for calculating the shield thickness from that transmission. Now I'm going to talk briefly about technologist exposures. These are literature

values on the exposure that technologists receive while performing PET studies and you can see that the average value, if you'll look at all of these different studies is about .06 to .07 mrem per mCi handled. If you're dealing with a 10 mCi injection (a common injection at our place, at any rate; other places use 15 or 20 perhaps for some types of studies using FDG), you're talking about each procedure delivering somewhere between half of a mrem and a mrem to the technologist. I point out here that, consistent with conventional nuclear medicine practice, most of the technologist dose comes from positioning, transport, and injection. I pointed that out in a previous slide. We've found if we look at our area monitors in the control room, which is the place the techs spend most of his time, that (the area) contribution is certainly less than 10 percent of their overall dose. Most of it (their total dose) is coming from direct handling of the

patient. It's often seen, if you look at film badge readings over a period of time, that the technologist dose per millicurie handled drops significantly as a function of experience in the PET clinic. Every tech--of course I say that, but we've only had two techs so far and we have both of them still--but in both cases you can see when they first started working in PET their doses were higher than this value that I showed you and then tailed off. Now I just looked at badge readings from last year and it looks like their average dose has dropped down now to about .4 mrem per patient. That's down by 40 percent from the data I showed you on the preceding slide. They're getting better as they figure out ways to decrease the amount of time spent next to the patient. Well let's assume that we have the average exposure that I gave per mCi handled and we have 10 patients per day, a fairly busy operation, 10 millicuries injected per

patient. That would yield a yearly dose of 1750 mrem. Okay, that's well below (5000 mrem or 50 mSv), so it's within regulation, but most ALARA investigational limits are set down at 500 millirems (5 mSv), so the radiation safety officer comes and talks to us about this. We don't do 10 patients a day, but even so he's coming to talk to us. Although you're within regulation, you're probably above your ALARA investigational limits. Over nine months--if you took this and prorated it over nine months--that would be 1300 millirem. That's well above the declared pregnancy limit. So you can have a problem if you have a pregnant tech in a clinic that is this busy. So what do we do? Well, using unit doses, which I've really been talking about here, keeps the dose down. The tech does not have to be drawing doses with some type of dose draw mechanism. You'll lay out the hot lab to minimize the handling time in the way I showed you.

Use syringe shields, syringe carriers, carts, and so forth, so the tech can stay as far away from the dose as possible. The tech should complete all patient instruction and interaction before the injections. Essentially tell the patient "I'm not going to talk with you after I inject you. You need to ask your questions now, because once I inject you I'm going to leave so that you will be nice and quiet back here." You don't mention that they're so hot you don't want to be near them, and (that) you want to minimize the time the tech spends near the patient after injection. You should establish IV access with a butterfly infusion set, before the injection so all you have to do is go in, flush in your dose and then take out the butterfly. One thing that we're doing (we have a pregnant tech) one thing that we're doing is that we're using other personal for transporting the patient. You're just walking down the hall with the patient to get them from the

uptake area down to the scanner bay, but that's part of the dose that the tech picks up. Also, you have to be a little unfriendly: the tech needs to be unfriendly and walk several steps in front of the patient when they're doing this. Release of radioactive patients, we know is covered in 10-CFR-35 and the regulatory guide 8.39. Release is allowed when others (members of the public) are unlikely to receive more than 5 mSv of dose because of the release. If they're going to receive more than one mSv you have to give the patient instructions about the fact that they're hot. The short half-life allows a release of the patient with normal amounts of administered FDG activity, even under the most conservative of assumptions. One area where you may have a difficulty is that breast feeding mothers may expose infants through proximity, not through the milk necessarily, until the activity has died away. Instruction may be needed and that's covered

in the cited article. The patient in a standard PET scan done in 2D mode, when you inject about 12 millicuries, is going to receive about 1.3 rems as a consequence of this study. They get a little

bit from the transmission scan, but the exposure on axis is about 56 mR in free air or so in the course of a six bed scan with eight minutes per bed. You can see that this is a tiny contribution compared to the injected dose. For the whole body scan done on a PET/CT with 10 mCi injected, the patient receives about a rem due to injected activity and about a rem from the CT part of the scan. So they receive 2 to 2 ½ rems in the course of a whole body PET/CT study. Lots of people have helped me with the material that I have revealed to you. I have come to the end of my discussion.