Well, it's always a little bit embarrassing to be a physicist and to struggle so much with the audiovisual equipment. As Melissa said, I'm Jerry White. I'm with Colorado Associates in Medical Physics and representing the AAPM professional council here. I'd like to especially thank Melissa for telling me I could talk on this topic but I didn't necessarily have to focus on regulatory issues, I could speak on whatever I thought was interesting. So for better or for worse, I hope that your focus agrees with that. >>>So someone objects to my concept of more free form talk. The talk is going to be somewhat of an overview of imaging and radiation oncology, but I'm also going to make it somewhat of an under view because I think folks here have probably some first hand or at least some didactic experience with ordinary imaging applications in radiation oncology. So, I am going to, in addition to talking about the normal things, I'm going to spend some time talking about imaging applications that you may not have seen or may not have been aware of or will be able to look at in a different fashion. Some of them are non-ionizing radiation applications that you won't encounter in your normal work, but you still get to keep the CE credits and I hope that you'll find that this will put some of the radiation oncology processes into perspective. Let's see now if I can, there look at that. At home once my children criticized me for trying to change to the next section on the VCR tape while I was pointing at the television set while the VCR player was on the other side of the room. I find that these work much better in the hands of teenagers than in the hands of an adult.

Well, some acknowledgements. These are folks that who have either helped me with providing me images or consultation on the topics that you're going to hear about. Well, first a bit of a quiz. I'm going to ask is there anyone in the room that can recognize this television personality from years gone by? And, I see a very few people who might be able to recognize this space traveler. No takers? I'm sure some of you recognize, but you just don't want to admit that you are that old now. What you are looking at there is a picture of Captain Video and his Video Rangers. Actually, that's one of his rangers. Now, I see Tom is shaking his head yes. Anybody remember Captain Video? Oh yeah, okay, at least one brave soul. This is, Captain Video was just a great, a great guy and he had a lot of technical innovations. One of them is on the slide there and that is the Opticon scillograph and that was the control unit for a system that would allow people to see on the other side of walls at great distance. It was really quite the machine, somewhat appropriate to the talk today. But, I put this up there because I want, as we think about this, to think about different phases in the imaging process in radiation oncology and I think this slide is illustrative of what I think of as Phase I, which I call early, maybe pre-1970s although depending on the clinic you can put plus or minus a decade on any of these advancement sections. But, it was basically point and shoot radiation oncology. The radiation oncologist would have a high energy x-ray machine, orthovoltage, perhaps a stand-mounted cobalt machine and her or she would say "Here is where I want to treat", point towards a certain place on the patient, upper left lung, lateral pelvis, and say "Treat" and the imaging applications were sometimes a transmission radiograph, but more universally a drawing. There would be a therapist or a technologist who would take the portal and the imaging record would be either a sketch or a pre-made diagram of that part of the patient's stomach or head or lung with the radiation field drawn. Rudimentary, but that's really what we had. I consider that our Captain Video period. During the talk today, we'll move forward through what I hope is the Star Trek and then the Star Trek

Next Generation periods of imaging. I'd like to say, though, as we consider the technical advancements, I'd like to call up just one more image of Captain Video. You can tell this was a very important television show for me. But, Captain Video was known for having the technical expertise. He was known as guardian of the safety of the world. That was his overview. That's what he and the rangers did and as we think about imaging in radiation oncology, we're going to talk about specific techniques and specific technology, but I'd like you to keep in mind that through all these eras there was a broad overview analogous to being guardian of the safety of the world because in radiation oncology our goal is to take a tumor and destroy it without destroying the adjacent healthy tissue. And, so in some cases we are the guardians of health and the pain free living of the future of the oncology patients that come to us and that part hasn't changed. Just as Captain Video is the guardian of the safety of the world, Jean-Luc in Star Trek was, I can't remember the prime directive right now, but you get the big picture.

The second phase, I think which lasted a very long time, which I kind of consider the "Dwight Eisenhower" phase. I love this quote. I think it indicates sort of a being pleased with the status quo. Change is something that one might consider to be a bit suspicious and we're not sure if it is desirable or not and I call this in radiation oncology the "Image Participation Era", that is, images were not used as a directive for planning, but they participated in the treatment process, and this for most of us is probably from the 70s to the mid-80s maybe for some folks a little later and some folks are still in this era, but it involves the radiation therapy simulator and what we call port films – transmission images of the patient. Simulators are essentially x-ray machines that are mounted on a gantry very much like a treatment gantry, like a linear accelerator gantry and it's a radiographic imaging world. There were two sections, both a fluoroscopic and a radiographic mode. The radiographic image was kind of the standard rad technique that many of you are familiar with. These systems also had image intensifiers for fluoroscopy. Some of them had image amplifiers. I don't know if anyone remembers those. Those were designed to be lower cost. Blurry images. They were suitable for folks who had poor vision because if a radiologist or physician had poor vision they were very happy with the image amplifier but the rest of us were never quite pleased with it.

In regulatory space, and I'll just say a few things just to keep it clean, I'll say a few things about regulations. These systems had some exemptions for maximum fluoro dose rate. There were some exemptions for light field intensity and for image receptor shielding capabilities. I'll say a little more about this later as it moves us into the contemporary radiation oncology stuff. The fluoroimage quality was sufficient in most of these machines to see things like bones, or at least large bones. The image quality compared to the fluorosystems that we saw in diagnostic radiology most of the time could be described as horrible. I am not sure how many people have direct experience with these machines, but emphasis was not on image quality, it was on localization of the x-ray beam. And then, once the fields were guided in this way, again no longer draw on the skin, point and shoot, rather let's take some simulator x-rays and see where we think we want to treat. The physician and the staff could verify the images by essentially repeating the whole process on the treatment machine on a linear accelerator. One of the big differences is that now the treatment machines were in the megavolt world. The machines were anywhere from 1.2 meV for a cobalt-60 machine to 18 meV or even higher for high energy photon machines and the image receptors were generally film, but instead of image intensifier light emitting screens, the cassettes would have thin pieces of lead in them because the x-rays were of such high energy that you needed a tad of something to create some electron spray to prevent the photons from just passing right through the film with essentially no effect. Focal spot sizes for these images are fairly large on the treatment machines, 2 mm roughly for a linear accelerator. For a cobalt image, the focal spot, the effective source size, could be as large as 20 mm. And the other interesting thing is that the compton interactions at this energy predominate so the differentiation between soft tissue and bones is virtually nill. Remember the reason we can see things so well on diagnostic KV level x-rays is because of the Z effect, the photoelectric effect interacting with the bones. If you don't have that the images, the first one of these I saw was amazed that there was an image on there. Someone had to point out to me exactly where things were. I thought it was just a blank dark piece of film.

So with a 20 mm focal spot and compton interactions, these images left a lot to the eye of the beholder, the imagination of the beholder and they give about 2-5 rads per image. But this is the basic way things worked for 15 or 20 years and in some places this is the way things still work. Here is a classic simulator. I tried to introduce a little age in the image and I tried to make this a sepia color to make it like those old western pictures, but I couldn't quite do that. This was the Cadillac of simulators in its' day and some people still have these and you can see on the top of the picture. Let me see if I can operate this without hitting myself in the eye. X-ray tube on the top, image intensifier on the bottom, patient on the table and this whole schmizole would rotate around the patient. Very stable. It was designed to have an isocentric precision around here of about 2 mm. We happen to own this system and it's just as a little side or anecdote, the two would rotate down, you can see these guys, big, thick hummers. When it would rotate down there would be some sag in this that put it outside of the 2 mm specification. When we got our new unit, and I hope you don't mind, but I love to tell little stories. When we got our new unit, we complained about that and for about two or three months we were told that we were the only people in the world having this problem and it couldn't possibly be the manufacturer and about in two months and one day, "Oh, and by the way we have a fix for it, this problem that only you have". And what they did was they took the collimator, put a little motor in it so that when the gantry moved down, the collimator wires and alignment shifted over 2 mm to make it good. It was really quite the kluge.

We recently replaced ours and I'll just mention that the used market for these is fairly soft. We had to pay someone to cut it up and take it to the junkyard. Well, this system is out of touch with reality. Why is that? Well, it produces two-dimensional images and all of our patients, uniformly are three dimensional, so we have a problem right there. The soft tissue contrast is poor and it wasn't a real problem when radiation oncologists were designing radiation treatment fields on bony landmarks, but now with soft tissue three dimensional volumetric imaging common in the diagnostic world, there is a great deal of dissatisfaction with not being able to see soft tissue imaging on the pictures we're using for planning and also there is no tissue density information. Modern treatment planning computers use density information to make corrections for lung and bone and fat and with a 2-D x-ray flat image based imaging it just wasn't possible to make those corrections, for the calculations with those machines lung, bone, muscle all looked the same. So, with new calculation algorithms for density corrections, this system just took a nosedive actually. We then move to what I call the third section, Image Based

Treatment Planning and this is a picture of a CT simulator. It performs the same function as the system you saw previously except it creates 3-D data image sets, actually sequential 2-dimensional image sets, but if they are acquired with sufficient precision in the patient's head to foot region they can be reconstructed into what are essentially 3-D image sets.

The CT simulator generally includes two separate parts, the CT scanner, which you see there, and then some software to reconstruct the image in a fashion that is useful for folks who want to do radiation therapy planning. This is just a picture of a CT scan. I am sure you have all seen this sort of thing, but I just gives you some idea of the soft tissue differentiation that is possible. I have to tell you this is a physicist's eye view of a CT scan. The CT images that come off the machine raw don't have the little cheater pointers there to show what organs are which. This is also a contrast study, but you can see fairly clearly the amount of information about anatomy is just incredibly different than what you get on a plain radiograph. You all knew that but I think just to emphasize the point of how different this makes the treatment planning process if one is trying to miss a kidney or miss the gallbladder or treat the gallbladder, the information is here and only here. Equipment characteristics for CT simulators, well, they're very much similar to CT scanners but I just wanted to say about some of the things that are important to folks in radiation oncology for these applications. One is a very high heat capacity tube with multi-slice capability and when we present these purchase requests to administrators they always respond, "You only do four or five patients a day on these simulators. You don't need a big x-ray tube" and our response is "Well, we do something different. We need high heat capacity, lots of very thin slices and for us, as opposed to the diagnostic radiologist, as you scan through the patient from let's say head to shoulders or from shoulders to pelvis, not only is it important for us to get xy information, but we also have to have invariant images from top to bottom. So, we have to have a scanner that is fast enough and has a high enough MA so the patient doesn't wiggle during the scan because when we do the treatment we have to have registration though the whole field and not just the x and y, to the lateral, anterior, and posterior dimensions." So, we spend a lot of money on high heat capacity tubes. We have to have stable density resolution since we do calculations based on the CT numbers, the electron density in the patient. Those numbers have to be accurate and the have to be invariant no matter what field of view, what KV, what MAS, or what slice thickness we use. We need an oncology specific flat tabletop and most CT scanners have a curved tabletop.

Our tabletops we use are flat and have little indexing marks to which we can sort of not quite bolt the patient down to the table, but fix the patient to the table in a reproducible fashion. A large bore is desirable. You can now get CT scanners that have 80 cm bores for radiation oncology. More and more radiation oncology centers are using contrast injectors for treatment planning and that's a new development and turned out to be very important and they have to be DICOM compliant. In diagnostic radiology, sending the images to somewhere else is often a nice thing, a handy thing, but there is always film and in radiation oncology, all the images are always sent to some sort of treatment planning computer system and the transfer has to be flawless. And it is not unusual in a radiation oncology department to have three or four different treatment planning to which images have to go and if they are not all DICOM compliant there could be a real problem. And just another, a side, DICOM is a tough thing. I mean it is a miraculous thing and it's a wonderful effort and I commend the ACR for all the work, but it does seem to be a system that works best in November within 500 feet of Lake Michigan during the RSNA meeting. That's where we see it demonstrated and it's always flawless there, but as you get farther away from Chicago we seem to have more problems with it.

Other equipment characteristics. Well, I listed this as the first one again because it is so important. External lasers. You have all seen positioning lasers on CT scanners, but in radiation oncology we often time will mount a second set of very high precision lasers either on the walls or on pillars in the room and sometimes these lasers are moveable up and down so we can change the position of the lasers. The therapists use these lasers to create alignment marks on the patient for future use and the precision that is required of them is far in excess of what is required for the internal CT lasers on a machine. Accurate table iteration - I think I have described the importance of head to foot accuracy. Moveable scan field of view - not an issue now, almost all CT scanners have that. It was a problem in the past. Storage for big data sets – we often do 200 slice image sets on a patient and may even do several of those at a single sitting. And lastly, it's the possession thing. It needs to be ours. The CT scanner needs to be in our department. It can't reside in a radiology department and have us compete for time and patient space with other departments. We need to own the thing and we're very possessive of that and we're having a great deal of success in most departments. What are some equipment characteristics that are important to folks who have CT scanners in diagnostic radiology, but for radiation oncology is kind of ho-hum and we're not quite so interested, well some interest. I see Dr. Morin thinking all these things are important but we're not quite as interested. Laser alignment with the scan slice location. We don't much care about that. We'll figure out where the slice location is later on. We have our external lasers that must be absolutely aligned so that they are in the same plane as the CT scanner scan plane, but we don't care much exactly whether they are identified in the plane for us. CTDI – dose, I hesitate to say this before the group, dose is not important. A 3 rad CTDI versus a 5 rad CTDI is not important for a patient that is going to get 7,500 rads to the same area. High contrast resolution, again, not an issue. A big selling point to salespeople. We do very little inner ear work in radiation oncology. We're looking for the big picture.

Variety of reconstruction algorithms, again, we don't do that, we just look at soft tissue algorithms. Multi-planar reformatting, again, a big sales issue with CT scanners, but we do all that in the off CT scanner treatment planning system. Hard copy – hard copy is so not today. It's just old and none of our CT simulators even have the capability of printing out a film. If somebody really needs a hard copy image, we give them a pencil and a piece of tissue paper and they can put it over the screen and do a tracing. And nobody's ever done that so I guess it must not be important. Well, I'm going to talk a little bit about how we use these images and I know many of you have seen external beam Linac therapy radiation planning images, so just to be a bit contrary, I'm going to focus a bit on brachy-therapy, on internal therapy images. Just for those of you who are remaining awake and can still see, no, I can see everyone is still very alert out there. These are some, there's an anterior and a lateral image of internal radiation therapy. You can see some seeds up there and this is an AP, this is a lateral and you can see some dummy sources for seeds, contrast in the rectum, a little contrast in the bladder, but basically that same bony detail but essentially no soft tissue detail. This is an AP radiograph of a GYN placement and again, you can see the tandem that goes into the uterus, some applicators to the lateral vaginal fornices, but I call your attention to this blue line, which is the rectal outline. Well, someone may have been able to see a rectum there, but there is quite a bit of guesswork involve in that and in fact, often times you really just can't see the rectum even if there is a fair amount of contrast in there. These are some CT images and a bit dark and screen captured, but you can see the 3-D soft tissue and you can see some contrast in the rectum. You can see the uterine wall, you can see the pubic symphysis. So you can see things in three dimensions that you just cannot see on plain films and in fact in our institution all of the brachy-therapy planning is done with three-dimensional planning now. Again, a concession to the fact that our patients are three dimensional rather than three-dimensional. Has anyone ever read the book "Flat Land"? It's a great book and it's about a universe that's only two dimensional and I have a couple of copies of it and in the early days when we were making these transitions and physicians were unconvinced that this was necessary, I would ask them to read my copy of "Flat Land" and if they thought it was applicable to their patients then we would not proceed and we now have CT scanners everywhere. This is some ultrasound imaging from a prostate implant and you can see an outline of the prostate gland. These are ultrasound echos with the prostate in the center, and some red dots that indicate the location of lines of radiation sources. This was a 2 ½ D data set. You can see a series of prostate contours on the bottom that were merged into this 3-D image of the prostate and this ultrasound imaging has become really essential in brachy-therapy internal radiation therapy planning in radiation oncology.

The good news is that we can now get really exquisite ultrasound images of the prostate which involve the transperineal implant of seeds, radioactive seeds or needles in the prostate gland for prostate cancer. So the good news I'll mention is that we get great images. Somewhat of the bad news is, I'll show you a picture of how we get those images. This is done either in surgery or under sort of a light sedation in an imaging suite with a transrectal ultrasound probe where the organ, its image, is only a few centimeters away from the probe. And that's just a picture of how the needles are placed in the prostate gland. This is a very common procedure. There are probably 40 or 50 thousand of these procedures done annually in the United States for temporary seeds and quite a number for permanent brachy-therapy. I'll just also mention, if you look at the prostate gland there, the prostate, the bladder, the rectum, and the ultrasound probe. One of the frustrating things with medical imaging in general is that if you look at other imaging applications, folks looking at galaxies through radiotelescopes or people looking at long distance with telephoto lenses, the thing that you are trying to see is at some distance from you. But in medical imaging, the thing that you want to see is generally within only about five or ten centimeters of where you are at. It's so close, but so hard to actually delineate, but we're trying, we're trying. This is another image of a prostate.

This is an ultrasound image with the prostate drawn on and this is a post plan, the patient already has their seeds. And this is an interesting set of images because you can see up at the top there, this is an ultrasound image overlaid and fused with a CT image. Some of you may have been here last year when we talked about fusion technologies and this is an example of that. Off here, you see the ultrasound image overlaid on the CT image and they are fused together. Here you can see the rectum on the ultrasound which is nicely shaped, kind of round, and it is shaped that way because there is an ultrasound transducer in it that expands the rectum to make it regular and straight and when we fuse it with the CT there is a bit of an effort trying to get the rectum in its natural state to fuse. Over her, I'll show you, there is a bar that lets you concentrate, make the image primarily ultrasound, primarily CT, or somewhere in between. Let's look at a CT image here. We're now looking at basically just the CT with the seeds in place and the CT rectum. Here we see the same image kind of blended, but with emphasis on the ultrasound. You can still see a little of the seeds. And here the physician now has drawn the prostate on both the CT data set and the ultrasound data set. The ultrasound data set was taken at the time of the implant and the CT data set generally taken a month later to do the dose calculations.

Here you can see just another slice of the prostate moving farther up and what you see here is a bit of a conundrum**.** The ultrasound prostate image is a different shape than the CT data set and I mention that, again just trying to make this regulatory relevant, is that when one is talking about a medical event in brachy-therapy and you like to say "Well we have put a certain number of seeds in the region that we wanted to, which is the prostate", someone has to decide is it the ultrasound prostate, the CT prostate, some mixture of which, which is in, which is out. And so, when one is trying to say "Well, we got the seeds in the prostate", saying what the prostate is not as simple as one might think. So what we complain about, or when enter into discussion about how one defines medical events, those are some of the issues that we have to deal with. This is a high dose rate brachy-therapy prostate procedure where we have a CT data set and you can see these needles are placed in the prostate in very conformal dose distributions and we can also produce a 3-D image from the same data set with the prostate, rectum, and bladder. Just very, very useful. I won't say a whole lot about fusion since we spent a lot of time on that last year. This is an MRI and you can see a lymph node here that is fairly large, but on the MRI you can see as a dramatic standout and we fuse those images together to do radiation therapy treatment planning. Almost all contemporary radiation oncology departments do some sort of image fusion for this sort of thing with the CT scanner that is ours and we have not yet been able to convince administration that the 2 million dollar MRI scanner ought to be ours as well, but if we have this talk in another five or ten years, who knows what we'll own. I want to talk a little about ultrasound guided radiation therapy and this being the entry into the fourth phase of radiation therapy imaging stuff and I call this image guided radiation therapy.

We just talked about image based radiation therapy where we have used the images to tell us where we want to put the beam. Image guided radiation therapy allows you, in the treatment room, to look at pictures of the patient, on the treatment and say "We know where we want the beam to go and this is going to allow us based on images to put the beam there, to treat the exact same spot in the patient." This is an ultrasound machine. It's used for localizing prostate cancer and you can see a patient laying on a pretend table because there is no linear accelerator there. The vendor who supplied this slide was happy to put an ultrasound machine but didn't want to buy an accelerator just for the picture. And you can see the therapist there with an ultrasound transducer on the patient's pelvis with some ultrasound images here and this is an articulated arm that gives it two dimensional picture, but the articulated arm has position information so they know exactly where that is with respect to the treatment part of the accelerator. The interesting thing about this process is within a very few years the procedure went from 2-D ultrasound, the picture you just saw, to three dimensional ultrasound, which has made a really big difference in localizing organs such as the prostate in radiation therapy. And this is a picture of the 3-D ultrasound guided system. It's one that we own and use all the time and it, you can tell that this is a slide that is provided by the vendor because it does not have a computer, it has a high end Linux custom computer and a lot of the slides you are going to see will be vendor supplied, but I'll call to your attention a couple of things. A camera that's mounted on the ceiling, it has infrared detectors in it and an ultrasound transducer that acquires the scan but is indexed to the treatment machine. I'll show you how that works in just a second.

This is a set of 3-D images. You can see a standard 2-D image of the bladder, prostate, this patient's skin surface and this is swept across the patient, creating a 3-D image data set. We generally acquire anywhere from 200 to 500 of these transverse slices in an acquisition. Takes about 20 seconds. And once the images are acquired, we take this 3-D data set and we overlay it on the CT data sets that we have done doing the treatment planning on which we have the prostate and the rectum and the bladder marked. And here you see the bladder and the prostate and the rectum and these contours are from the planning system. And you can see they are off by just a tad. The operator can them move these contours around until they fall on the ultrasound image that is taken with the patient in the treatment position in the treatment room prior to each treatment. And once they are lined up, this system tells the therapist how they must move the patient or move the table to get the daily images lined up with what we desired. It's a very powerful alignment tool. The other nice thing about this system is that on the screen, you see these little bar graphs, that tell you how far off the alignment is all during the treatment if it a real time system, or at least initially if it's a static system. And this is how it works. You remember the transducer. We bolt on to the transducer this array of four light emitting infrared diodes and the camera on the ceiling tracks the position of the transducer with respect to the isocenter, the target, the central place where all the beams are focused and allow us to align the ultrasound images and the treatment planning images. Oops, wrong button. Again, here is another picture of the alignment. You can see that that's starting to look pretty good. I'll just say a little bit about stereotactic radiosurgery because that's a very important part of what we do and this is a small brain lesion and it's lined up with a head ring. You can't see the entire ring but you can see these are bolts where the head ring immobilization device is bolted into the patient's skull so they don't move for this treatment. The treatment is generally one fraction and it can be 2000 to 2500 rads for that one fraction, so it's important not to miss and we like to get precision of less than a millimeter. How many people, has anybody heard of this treatment? Does this ring a bell with anybody? Oh, okay, a couple of hands. The thing, the reason I include this is historically image guidance for this included CT guidance and then a laser alignment in the room to set up the head ring in the appropriate place. We now do, at our facility, we use the same infrared camera and these little reflective balls that are bolted to the head ring and we can use these reflective bulbs to realign the patient and the head ring without resorting to lasers to within about 2/10ths of a millimeter. It's a very powerful system. We can also mount these on bite blocks, similar to, I don't know if you've, when you go to the dentist and they put that tooth goo in your mouth and they take an impression of your teeth. We make those for patients, bolt these to the front of the mouth mold and we can reproduce the patient with measured reproducibility to an average of 3/10ths of a millimeter for 10 tries of repositioning. It's a very accurate system and I just mentioned this because not all image guidance is pictures. This is image guidance that is essentially for reflective balls, but image guided nonetheless.

Here's a very interesting piece of future, I think. It's a CT scanner mounted in a linear accelerator room. Here is the accelerator. Here is the CT scanner. The CT scanner is on rails and this table can be rotated 180° so that the patient could either be under the accelerator or rotated around, go in the CT scanner, check the alignment, look to see where the prostate or other organs are, and then rotated back, make the table corrections and treat the patient. This is not particularly common, but it certainly is an exciting image guided application. Next I want to say a little bit about some x-ray guided systems.

This is a picture of a Novalis stereotactic system and these slides were provided by the vendor and I left all the, kind of the, glitz in here. As we go through this section, I'd like you to keep in mind that some of the things we've shown earlier and you'll see in a bit are very expensive and I think that the vendor provided glitz will help to remind us of that. As you look at these fancy slides, think about your Visa card and think "3 million dollars and this could be mine". The accuracy you get is tremendous, but it requires a substantial investment on the part of the hospital. This is essentially a linear accelerator with some image guidance and I am going show you, that allows accurate reproducibility for either routine daily treatments of small organs or single fraction stereotactic therapy. I just love the way these little things move in. But you can see that it can be used to treat all sorts of different areas of the body, but the interesting thing that you will see is that the treatment volumes are very conformal, very tight and you can also use these places near the lung where there is some motion and I will talk a little about that towards the end of the talk. They also have reflective balls that allow you to monitor the position of the patient in real time once you set them up the way you think you like them. Infrared cameras on the ceiling, but this also has a series of x-ray guidance systems. There are two x-ray tubes in the floor and amorphous silicone flat panel imagers up on the ceiling that allow you to take a set of stereo x-rays to help align the patient. Get an x-ray image from one view. Get an x-ray image from the other view. These are just standard radiographic images, but then they are used to compare with digital reconstructed radiographs from the CT planning scan and they allow the user to align the patient for the way the patient is in the treatment room to the way the patient was planned in the treatment plan. They can be overlaid and here you see a fusion image and they are also automatic fusion measuring systems that allow you to say how far you need to move the patient on the treatment day to get them to where you had them on the planning day.

This is another stereotactic imaging system. It's called the CyberKnife. It has this robotically controlled linear accelerator, a 6 mV accelerator. It's on a robot arm and I don't know if you have ever seen the General Motors or Ford Motor Company pictures of how we make cars and we have all these robots. This is the same guy that you saw in those, except instead of a welding unit or something that paints the Ford logo on the front of the car, it moves a linear accelerator around. And again, this time x-ray tubes on the ceiling, detectors down near the patient, but the same sort of thing. This can move up to up to roughly a thousand different positions. It can aim at and generally in clinical use this thing will move to maybe five positions. They'll image the patient, move them if necessary, five more treatment positions, image the patient. So the patient gets image every minute or two in a 30 to 40 minute treatment. Again, a little regulatory content. I'll have you look at the collimators up here. You can see that the collimators are very close to the x-ray tube and the image receptors are very far from the image receptor tube and that makes the penumbra very dramatic for this x-ray tube and so if one is going to be sure that they are going to get the entire x-ray field on the image receptor, the actual x-ray field size can be pretty good size so you avoid penumbra effects on the edge of this. From a regulatory point of view, this is interesting because we spend a lot of time thinking about columnation, but probably not an issue in these patients since they are having radiation therapy and there is no one else in the room at the time these are going on.

Well, I talked a little bit in sort of a semi-dismissive way earlier about KV and MV images, but now we are back to that. Back to the future as it would be. This is Varian. All the major vendors, Varian, Siemens, Electa have similar things where there is a KV imaging system, flat panel detector and an x-ray tube mounted to the linear accelerator. They use an amorphous silicone imaging panel, robotic arms. Again a little vendor specific language, not just retractable, but completely retractable and not just software, of course, but custom software. Nobody just supplies regular software anymore. The way the system works is the patient is going to lay on the table. They can have KV imaging here and then this is this an amorphous silicone flat panel detector that can come out and you can see why this costs 3 million dollars and one of the interesting things is that if you are going to use this for positioning, the precision has to be incredible.

This whole thing that rotates around weighs about 17,000 pounds and the radius of rotation, the spec is less than 2 millimeters and in real life it is about a millimeter and a half or a little less, so it is an incredible piece of engineering, I think. Here is a picture of the flat panel detector. The newer detectors have a very high frame rate, which is handy, and a really large dynamic range, which allows really good imaging for radiation oncology. And this is my Captain Video slide. The control panels for these are just really nifty looking I think and there is a lot now for therapists to do. They've got to monitor lin acc, they've got to monitor the treatment couch, they've got to monitor the images, and they have to monitor the columnation on the machine which is the reason why it is important not to distract these folks when they are doing their treatments. The automatic patient repositioning, the couch that the patient lays on is integral to that and there are three modes of operation for repositioning: radiographic, which is this guy here; cone beam CT, which I'll say a little bit about in a second, which is this guy here; and then fluoroscopic, this guy here as well. A radiographic mode, you can do an AP and a lateral radiograph and do positioning either with bony landmarks or implanted fiducials, you might put gold seeds in the patient and use those for alignment. Here is some marker repositioning. This is kind of a funny picture because this is obviously a phantom, this is a real patient, but you can put gold markers in there that are present during the treatment planning CT and then use those during, on treatment day verification to get the markers lined up in the same place. Again, KV radiographs, this is digital reconstructed radiograph from the CT scan that we did and this is the day of treatment radiograph. Cone beam CT. This is a very interesting thing. These are CT scans that are taken actually on the linear accelerator without a CT scanner. The way it works is you have this x-ray beam that rotates all around the patient just as though it were a CT scanner but instead of taking a lot of slices, it uses a cone beam and creates essentially a three dimensional data set. It's, the physical aperture is about 80 cm, but the acquisition aperture is much smaller in the center because it is limited by the size of this image acquisition device. However, Varian folks, other people are pretty smart, you can do a 360° acquisition and acquire half the field going around in each place, each 180° and get a reconstructed volume that's much, much larger that you would allow otherwise. And these images look pretty darn good for being on a 16,000 pound gantry that is rotating around.

This is typical CT kind of image from a cone beam CT. Here is another with some implanted fiducials and these are wires rather than gold seeds, easily visible there. Here is a comparison of a CT from a CT and a CT from the treatment planning system. Again, a comparison that allows the user to line up these fiducials before they treat the patient. And here is a fusion image where you see the planning CTs and the cone beam CTs overlaid one on another so that you can verify that you are in the right place on treatment day. This, I think, is really neat. I think all this stuff is really neat, but here is, this is fluoroscopy. I mean, we have all seen fluoroscopic images where you see patient motion and you can visualize a tumor here right above the diaphragm as the patient breathes and we hope that occurs during treatment. The tumor moves up and down. And we can now purchase a gating system for our accelerator so that the beam only turns on at let's say full inspiration or full expiration so we can treat the tumor when it's in the right place, turn the beam off, the patient continues their breathing, when their diaphragm is back to the other place we turn the beam on again. And if you have a fluoroscopic imaging capability on the accelerator, you can watch that happening and the operator can verify that the beam is only on when the aperture is in the right place, when the diaphragm is in the right place. Well, one of the things about high tech imaging, as you said at the control console, doing this high tech imaging, you never know what's around the corner, what's next. Well, I would just like to say one brief thing about something that I think is next, that I know is next and that is these, again a non-picture based, but perhaps imaging acquisition.

These are implantable sensors, not just gold seeds that you put in a patient, but a little tiny, and you can see how tiny, right, ampule that contains an electromagnetic resonance circuit, no wires, no internal power supply, permanently implanted. You can implant these during the treatment planning process and they are much like the easy pass. Do you have those things on your windshield where you go through the tolls and it beeps and you pay the toll automatically? This is the same thing. They are interrogated by an external RF signal and then they broadcast back. They are inactive until they are energized in some fashion and the way the system works, not yet FDA approved, is you put these guys inside of the patient and you know on the planning system, you know where they're supposed to be in x, y, and z with respect to the isocenter of the machine. And then when the patient goes in for treatment each day there is a flat panel RF excitation device that sits above the patient that excites these wireless transponders and then on top of this there are little infrared emitters that tell the infrared cameras on the ceiling where this is and you know where this is and you know where this determines where the transponders are and you put the whole thing together mathematically and see where they are on the patient. So is there is the beacons and you see the infrared cameras and it tells the whole system through this tracking station where they are with respect to the isocenter and then you can move the patient into the right place. And I don't know if the vendor, Calypso, anticipated I'd be giving this talk to a group of regulators but here you can see there is a radiation barrier there, just in case anybody was worried about that.

Well, again, my acknowledgements. In my first acknowledgement slide I should have said something about the people from our local Colorado Department of Health and Environment. Jack Barr is our x-ray guy and I've benefited greatly from discussions with him about regulatory issues for these emerging technologies because it is not simple and everyone's dedicated to making this technology available to patients, but we want it to be safe, we want it to meet existing regulations and where existing regulations don't work very well, the Department has been very good about deciding how to modify them so that we can do a safe but effective treatment. So, I asked Jack, I said "Can I have a picture?" and he said "Well, this is kind of my standard picture", but he was coming into the hospital actually on Tuesday for a mammo inspection so I said "Can I take a snapshot of you as you come in to do the inspection?" and this is Jack in his inspection entry mode as he comes into the mammo department. He has been talking about putting this picture on his business cards, but I am not sure that the department is going to allow that. But at the conclusion of the inspection, I took a candid shot of Jack at his exit interview with his mammography staff and this is really the way we like regulatory interactions to go. I enjoy working with high technology and I enjoy working with high technology in the regulatory world because it presents challenges to us to make the stuff, the high tech, the Captain Video work not only in the clinic, but in the legal world. So, we have just a bit of time for questions, I think, if anybody would like to ask.

Q: It all seems so futuristic, but we know it's already here. I think the working group X is meeting probably discussing the regulatory side of things as we speak. But just a question on the dose savings, perhaps a segway to the next discussion. Let's say a written directive is 200 rads a day for 14 days, what's the substantial benefit? What's the dose savings, even with the moving leaf collimator estimated margin of say a millimeter compared to the four block or the four field block therapy or the five field therapy of the old days, which I understand is actually still being done by the smaller clinics that are not accredited by an accreditation institution, the outpatient therapy facilities which are large in number compared to the accredited facilities.

A: You're asking would the written directive have a lower dose because

Q: For the tumor to get 200 rads, what's the dose savings to the patient for the unintended tissue that would be irradiated for the block the old way, the four field or the five field?

A: I understand. What happens, actually, is somewhat the opposite. As the precision of dose deposition is better known, the physician is more willing to give a significantly higher dose to the tumor knowing that the normal tissue will be spared and often times willing to give a higher dose to the normal tissue knowing that we know exactly where the normal tissue is. So, if you were to compare written directives, both for normal tissue components and tumor components, what you would find is prescribed doses are higher. What's the dose savings? Obviously, there is some dose savings because in the first case, in the olden days, we didn't know where the healthy tissues were quite so well. But since we didn't know where they were, it's hard to say what the dose savings was because we are not sure what the dose was to those tissues. The big advantage to this is the ability to give what we hope are truly curative doses without inducing debilitating side effects.

Any other questions? (applause)