IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

The future NDE radiography department

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ABSTRACT

With more Non-Destructive Evaluation (NDE) departments converting to both Digital Radiography (DR) and Computed Tomography (CT), special considerations have to be given to the design of the radiography bay and "reading room".

Due to increased throughput associated with digital operations, the radiography bay of the future must accommodate a significantly increased radiation dose. Its physical design and associated shielding must minimize radiation scatter and adequately protect the operator as well as the public from neutrons and high energy x-rays created as a result of high energy operations. To be commercially viable, the bay configuration must also be capable of accommodating the inspection of very large objects.

In a digital department the "reading room", or film interpretation area, requires special attention. In the film-screen department, radiographs are reviewed on a view-box which is back-illuminated with an extremely bright white light; the concomitant set-up and viewing protocol is quite straight-forward. In the digital department, the soft copy environment requires a significantly greater emphasis on quality assurance, monitor resolution, calibration, viewing angle and ambient lighting conditions. These are particularly important and frequently overlooked parameters. Ergonomics also plays an important role in the digital era.

In this presentation, we will conceptually "build" a radiography department. Design considerations for the radiography bay, including methods to reduce radiation scatter, such as various types of collimation, high energy grids, and back wall scatter reduction, and optimal construction of the maze, will be discussed. Tradeoffs will be evaluated quantitatively. Recommendations for creating a user friendly reading room (physical space, lighting, and ergonomics) and soft copy requirements to include monitor characteristics (CRT and LCD) will also be presented.

KEYWORDS: Digital radiography, NDE, nondestructive evaluation, nondestructive inspection, scatter reduction, collimation, monitors, displays, reading room, ergonomics

INTRODUCTION

In the past, film/screen has been the "work-horse" for Nondestructive Testing (NDT) radiography. Now, digital radiography (DR) is replacing film/screen radiography due to (a) recent improvements in digital detector technology (phosphor screens, amorphous silicon and amorphous selenium flat panels and associated scintillators), and (b) the fact that radiographic film is being produced in smaller quantities and by fewer manufacturers.

With film/screen radiography, image degradation due to scattered radiation was an issue typically dealt with using part masking and partial collimation. With the advent of digital radiography and the use of high energy linear accelerators, more attention must be paid to the radiation scattered from the accelerator, the collimation, the object being radiographed (part), and the back wall. In digital radiography (DR), the energy of the scattered radiation is low enough to be detected by the digital panel and it therefore can cause significant image degradation. In this paper, the primary sources of scattered radiation and methods to reduce this scatter are considered. For scatter, the ALARA concept- "As Low As Reasonably Achievable" is employed.

When migrating radiographic operations from film/screen to digital detectors, design and technical specifications for the reading room (what use to be known as the film viewing room), and computer monitors (formerly film viewing boxes or light boxes) on which the digital images are reviewed, have to be taken into consideration. Recommendations depending upon whether one is building a new room from the ground up or modifying an existing room will be presented. In addition, characteristics that one should consider when determining which of the many commercially available monitors to purchase will be discussed.

In high energy radiography, radiation scatter is caused primarily by four (4) sources: leakage radiation, improper pre-object collimation, post object collimation, and back wall scatter. In this study the Monte Carlo Neutron-Photon code MCNPX was used to simulate the leakage radiation and the wall back scatter, while laboratory experiments were performed to determine the effect of collimation and wall back scatter.

RADIOGRAPHY BAY

1. *Leakage Radiation* is defined as all radiation, except for the useful beam, coming from within the accelerator head or x-ray tube head, and other beam-line components. Leakage radiation is attenuated by shielding in the protective source housing as specified by IEC-2992. The leakage radiation can be approximately 0.1% to 0.002% of the useful beam.

Calculations were made using a specified geometry to determine the maximum energy and associated wavelength of the scattered x-ray impacting on the detector as a function of ceiling height (Figure 1). The governing equations are:

$$\lambda(f) - \lambda(i) = 0.024(1 - \cos\theta) \tag{1}$$

where “λ(f)” is the scattered photon wavelength
“λ (i)” is the incident photon wavelength
“θ” is the scattering angle

and:

$$E = 12.4 / \lambda \tag{2}$$

where “E” is the energy of either the incident or scattered photon.

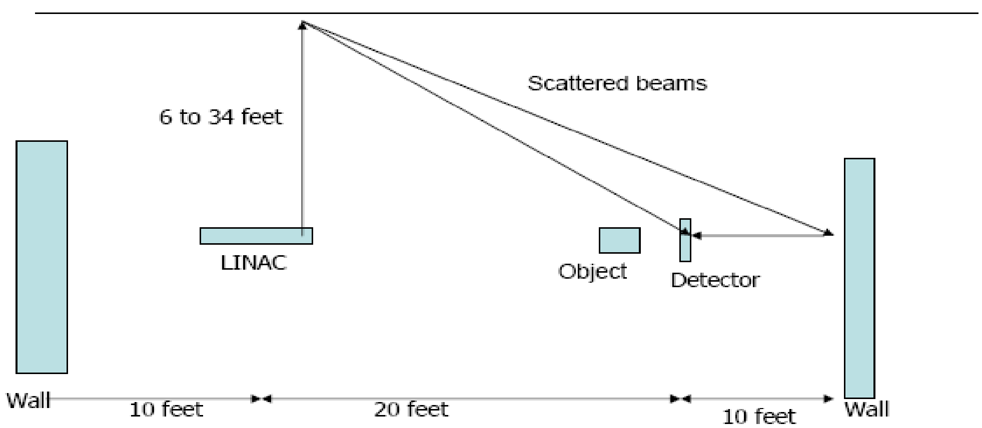

Figure 1. Simulation geometry.

A 9 MV beam was used in simulations to investigate the relationship between the scattering angle and scattered energy. As the ceiling height is increased the scattered x-ray energy decreases and the dose rate decreases. For example, the change in energy between a 6 foot and a 34 foot ceiling is 113 keV, and dose rate decreases from 0.75 R/min to 0.023 R/min for a 0.1% leakage accelerator and from 0.015 R/min to 0.0005 R/min for a 0.002% leakage accelerator (Table 1).

Table 1. Scattered x-ray energy as a function of ceiling height for room configuration shown in Figure 1. Results are presented for two accelerators with leakage values at either end of that typically found in commercial units.

Ceiling height (ft)	Scattering angle (degrees)	Scattered Energy (keV)	Dose Rate at Ceiling (R/min) 0.1%	DR at ceiling (R/min) 0.002%
6	106.7	379	0.75	0.0150
10	116.6	339	0.275	0.0055
14	125	313	0.135	0.0027
18	132	296	0.083	0.0017
20	135	289	0.067	0.0013
24	140.2	279.6	0.047	0.0009
34	149.5	266	0.023	0.0005

As one might intuitively anticipate, the scattered x-ray energy decreases as the ceiling height is increased. Also, the incident dose rate from the ceiling decreases as the ceiling height is increased.

2. *Pre-object collimation* is important because as the radiation cone beam is increased, there is an increase in both primary and scattered radiation impinging on the part leading to an increase in overall scattered radiation as shown in Table 2.

Table 2. Collimator scatter as a function of collimator hole.

Collimator degrees	*1*	*1.5*	*3.5*
6 MV	1.000	1.153	1.310
10 MV	1.000	1.292	1.313
15 MV	1.000	1.248	1.378
20 MV	1.000	1.245	1.202

Not using the proper collimator will increase the amount of radiation impacting on the detector and not interacting with the object. Therefore, some type of collimation is needed between the source and the object. Examples of several commercially available collimation options are shown in Figures 2 and 3.

Figure 2. Multileaf Collimator (MLC)

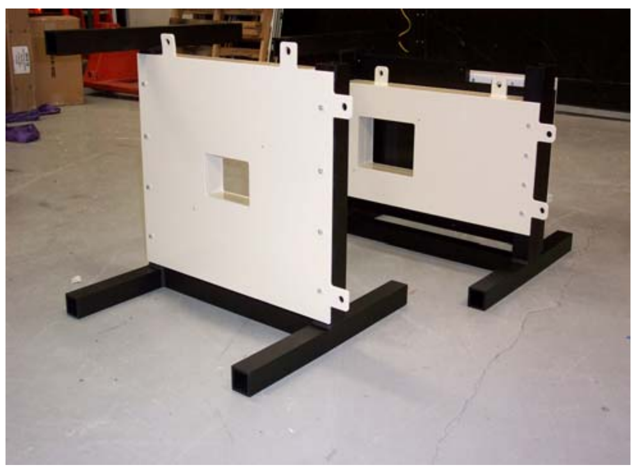

Figure 3. A series of square holes of decreasing size used to reduce beam scatter.

3. *Post collimation* is important because after the primary beam interacts with the object, there is a mixture of primary and scattered photons. What is needed is a way to reduce the scattered photons. In low energy radiography (less than 200 kV), one could increase the distance between the object and the detector to reduce the scatter.

For high energy radiography, simply increasing the object-to-detector distance is inappropriate because the scatter is primarily in the forward direction. For high energy radiography one solution is a "high-energy grid". A grid is a device that allows most of the primary radiation to pass and absorbs or attenuates most of the scattered radiation. Watson and others (1) have designed a high energy grid to attenuate the forward scattered radiation. This grid produced a scatter rejection ratio of 30:1, compared with the theoretically possible rejection rate of 100:1. The difference between the theoretical and actual scatter rejection was attributed to the "facility" background, *i.e.*, scatter off of the back wall, ceiling, and floor. These sources were never seen by the grid.

Another popular scatter-reduction method is to have a collimator on the other side of the object that just encompasses the object. A complete system encompassing pre- and post-collimation devices is shown in Figure 4.

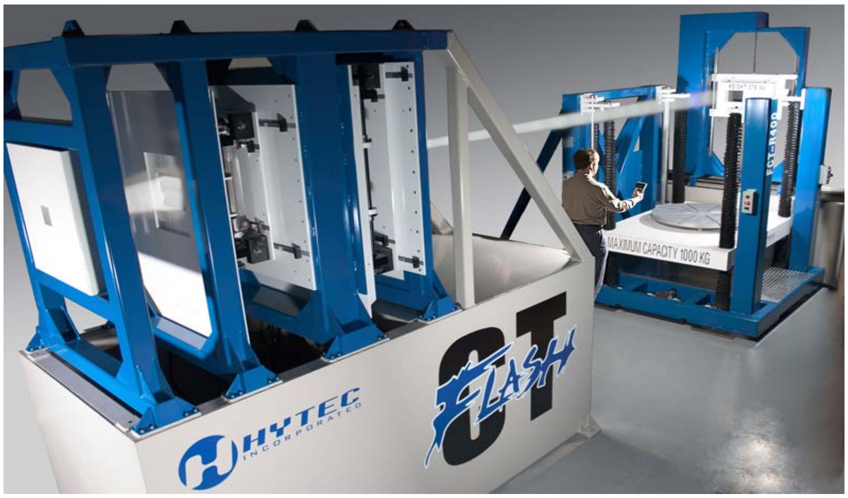

Figure 4. A complete radiography system with pre- and post-collimators. The collimator next to the detector masks the detector, effectively shielding it from scattered photons.

4. *Back wall scatter* or *backscatter* arises when a photon (either primary or scattered) does not interact with the detector, but rather interacts with the back wall and is scattered in some direction via Compton scatter. The scattered photon now has the opportunity to interact with the detector, thus increasing the noise level in the image. To reduce the amount of backscatter, either a beam pipe or "wall mounted grid" can be considered. Both of these methods will require that the linear accelerator be in a "fixed" position.

A beam pipe is a hole in the back wall. It is typically 50 cm larger in width than the size of the radiation beam. The depth of the pipe is approximately 2 m. When the beam enters the pipe, it is scattered many times before reemerging at a reduced flux level, as illustrated in Figures 5 and 6. To generate these results, a 6 MV Betatron with a dose rate of 3 rad/min was collimated onto an 18 cm hole in the wall with a depth of 95 cm.

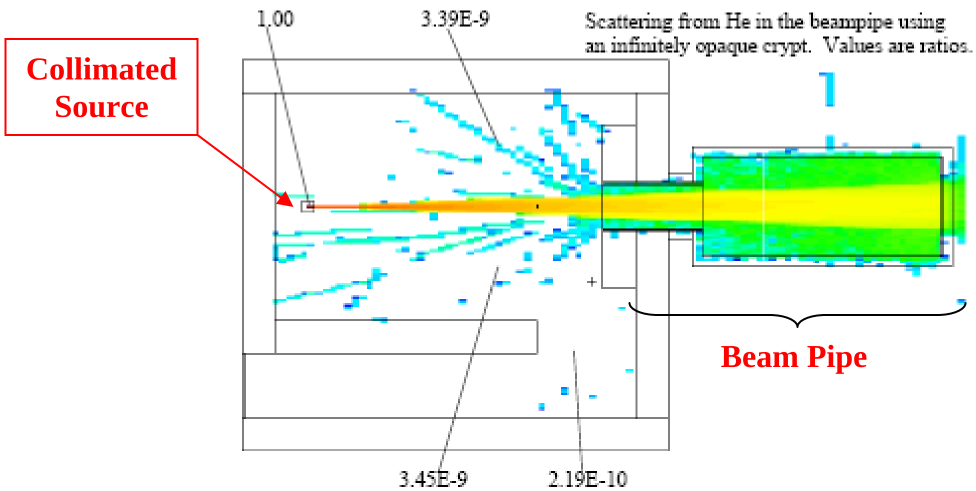

Figure 5. A well-collimated system impacting on a beam pipe. Note that only a minimal amount of radiation (light blue and green traces occurring at various angles to the central [yellow] beam) escapes back into the room.

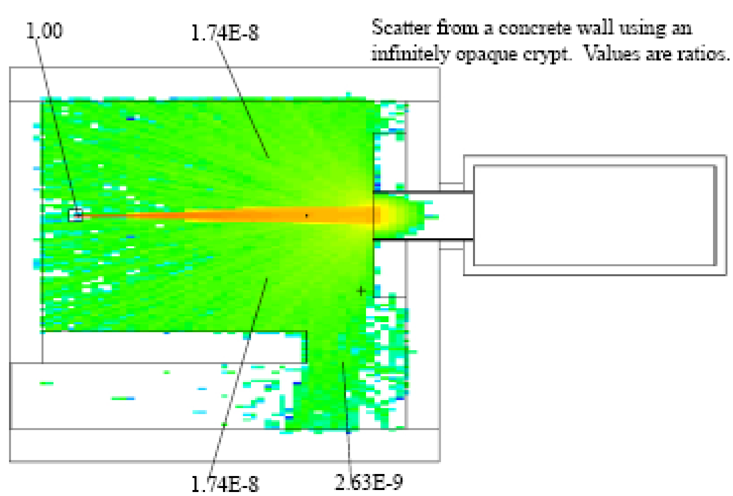

Figure 6. Blocking the beam pipe, or equivalently not using a beam pipe behind the object being imaged, results in significant scatter that essentially fills the radiography bay.

Another method that can be used to reduce backscatter is to mount an anti-scatter grid on the back wall. As with the beam pipe, the grid is situated in a fixed position. The primary purpose of the grid is to immediately absorb backscattered photons generated at the back wall, thus reducing the scatter introduced into the radiography bay. This method was proposed by Abdul-Majid at the 3rd MENDT 27-30 Nov 2005 (2). For the case of a 6 MV Betatron, it would be necessary to design the grid to attenuate a 250 keV scattered photon with a scattering angle of 170 degrees.

READING ROOM

After the actual x-raying of a part is complete, the next step to consider is the reading room and its important elements. When one thinks about the reading room, one typically envisions lots of space and many film illuminators (film viewers). With the advent of digital radiology and PACS (Picture Archiving and Communication Systems) the concept of the reading room optimized for film interpretation has to morph into a room optimized to accommodate interpretation of digital images displayed on computer monitors (LCDs, CRTs, etc). The University of Maryland School of Medicine and the Veteran’s Administration (VA) Maryland Healthcare System in Baltimore Maryland was the first truly “filmless” department. Siegel [(3)] and others [(4)] have documented the significant and often unappreciated trials and tribulations associated with changing from film-based to digital-based reading room.

There are many rules for designing the reading room, whether it is for one person or three or four. The basic elements to consider when discussing a reading room are: physical space, ergonomics, environment, lighting, and monitors. Each of these elements is discussed in detail in the following sections.

1. Physical space: The minimum workspace should be 125 square feet. This allows for work surfaces to be 18-20” deep and allows an additional person to view the images along side the primary interpreter. In addition this allows for one to use variable types of ergonomic furniture, typical examples of which are shown in Figures 7 and 8. There are many companies that can provide reading room design services. One crucial consideration is the size, shape and personal preferences of this film interpreter occupying the area. Within the medical industry, properly sized, ergonomically correct work spaces have demonstrated improved efficiency and accuracy of the interpreter significantly. The walls and work surfaces should have a non-reflective surface. To provide for a quiet and comfortable work environment, the inclusion of sound absorbing materials (e.g., floor, wall, and ceiling treatments) is a preferred option.

2. Environment/ Lighting: The temperature and humidity of the room is very important- both for the occupant(s) and also the equipment. For the winter, it is recommended that the room temperature be between 63-71^{o}F, while in the summer the optimal temperature, as determined by equipment manufacturers and ergonomics engineers, is about 65-75 ^{o}F. The relative humidity should remain between 20-60%.

Lighting has an important effect on image interpretation. One has to juggle the lighting for interpretation and other normal everyday tasks. To improve ambient lighting, one must have: (a) general illumination levels for computer tasks; (b) illumination for reading tasks using localized light sources; (c) balance of brightness in the user’s field of view; and (d) control of monitor reflection/surface glare.

Figure 7. Adjustable furniture that allows the radiographer to stand while interpreting the digital images.

Figure 8. An ergonomic desktop allows radiograph interpreters to position their digital review stations to minimize fatigue and repetitive stress injuries.

3. Monitors: The display, or monitor, is the final element in the digital radiography department. Vendors will always tell the customer that their monitor is the best. Many authors have discussed the issues pertaining to monitors [5-7]. Ehsan Samei, PhD gave an interesting presentation at the 2006 Radiological Society of North America Annual Scientific Assembly (RSNA 2006) where he discussed the issue of what to consider when choosing a monitor (Tables 3 and 4) and identified the 9 top concerns in his department's experience. Samei's issues are common, recurring themes throughout the medical imaging community.

Table 3. Important issues to consider when choosing a display monitor for DR applications.

Issues pertaining PACS displays

1. CRT or LCD?
2. How many Mpx, 1, 2, 3, 5, or 9?
3. What about contrast ratio?
4. How many bits, 8, 10, 16?
5. Monochrome LCD or color LCD?
6. Consumer-grade or medical grade display?
7. What about PDAs?
8. What about ambient condition?
9. Do displays need testing?

Table 4. Preferred options within the medical imaging community at one major center.

Summary

1. CRT or LCD? LCD
2. How many Mpx, 1, 2, 3, 5, or 9? 5+
3. What about contrast ratio? 250+
4. How many bits, 8, 10, 16? 9-10
5. Monochrome LCD or color LCD? Color
6. Consumer-grade or medical-grade? Medical
7. What about PDAs? Do NOT use!
8. What about ambient condition? Modest, LR' ~250
9. Do displays need testing? Yes, TG18, IEC, ACR

One very important issue that to date has given very little attention is that of display quality and display testing. Display quality is susceptible to variations in hardware, calibrations, and degradation over time. This can lead to missed indications, low confidence in reading ability, increased reading times, and reduced overall inspection accuracy.

In setting up a DR inspection program, it is essential that a robust display (monitor) quality control (QC) methodology be put in place from the start. Standards such as those set forth by the American Association of Physicists in Medicine AAPM Task Group 18, April 2005 (http://deckard.mc.duke.edu/!samei/tg18) and the IEC 62B-Working Group 36 (draft in review) should be reviewed and implemented to ensure that a high level of consistency is maintained. The aforementioned documents assure a uniform minimum quality by defining what should be characterized, and how it should be characterized using a common, commercially available metrology system (comparable measurements and common terminology).

CONCLUSIONS

An overview of essential considerations that must be addressed when migrating from a film-screen based to a digital NDE radiography department has been presented. The most important design elements are summarized as follows:

1. Leakage shielding: Should have 0.1% to 0.002% of primary beam output
2. Pre-object: Collimate the beam
3. Post-object: Some type of grid
4. Wall backscatter: Grid attached to the wall or beam pipe
5. Reading room: Space ergonomics, lighting, and monitors

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