

# New Digital Radiography Standards Simplified for Radiologists and Technologists

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## 1. Objective

Both the International Electrotechnical Commission (IEC 62494-1) [1] and the American Association of Physicists in Medicine (AAPM) Task Group 116 [2] have developed similar standards for monitoring exposure in digital radiography (DR) to eliminate proprietary and confusing terms. **The objective of this exhibit is to educate radiologists and technologists about the clinically relevant portion of the new DR standards.** DR encompasses both computed radiography and direct radiography.

## 2. Background

Traditional screen-film radiography has a direct relationship between exposure and optical density dictated by the H and D curve of the film (Figure 1a). Radiologic technologists have immediate visual feedback regarding whether or not the study was properly exposed, overexposed, or underexposed. Quality control is straightforward: checking the waste bin can document the number of underexposed or overexposed examinations, as well as other causes of repeat examinations.

The dynamic range of screen-film radiography, however, is limited [3]. DR overcomes the limitations of the dynamic range of screen-film systems because the digital detector responds linearly to exposure, with a dynamic range greater than 10<sup>4</sup>. Its dynamic range is on the order of 100 times that of screen-film radiography [3]. Image processing will adjust the image to produce acceptable grayscale (Figure 1b). The trade-off is a lack of visual feedback to the technologist regarding whether or not the study was properly exposed.

All manufacturers' systems measure the receptor exposure. For example, computed radiography was first introduced by Fuji in the mid 1980s [4]. To measure the amount of receptor exposure, they coined the term "S number". The S number mimicked the film-screen system speed to aid in acceptance of the new technology.

This was fine until other vendors developed their own proprietary systems of reporting receptor exposure (Table 1). One can see that with the Fuji system, the exposure indicator is inversely related to receptor exposure, while Carestream and Agfa have a direct but logarithmic relationship to receptor exposure. Other vendors introduced still other exposure indicators. In a department that uses only one vendor's systems, the radiologists and technologists can learn a single set of parameters. Many departments, however, have DR systems from multiple vendors. It can be difficult to remember all the exposure values in order to ascertain whether or not an exposure was appropriate.

As DR systems have wide dynamic range, image processing can compensate for underexposure and overexposure and still produce ideal grayscale. Underexposed images have quantum mottle, and appear noisy, while overexposed images appear ideal without noise. Radiologists prefer images without noise, so there is a tendency over time to increase exposure factors, known as "exposure-factor creep" or "dose creep" [5]. Additionally, there are currently no widely available quality control programs to monitor the exposure indicators and other factors in order to document that proper technique was used for each examination.

Adding significant challenges for radiologists and technologists to maintain optimal diagnostic image quality at the lowest possible exposure to the patient are factors including: vendor-specific exposure indicators; preference for noiseless images; and no immediate visual feedback as to overexposure or underexposure.

Vendor	Value	Symbol	Unit	Formula
Fuji	S value	S	Unitless	200/mR
Carestream	Exposure Index	EI	Mbels	2000 + [1000 × log <sub>10</sub> (mR)]
Agfa	Log(Median)	IgM	Bels	2.2 + Log <sub>10</sub> (mR) <sup>*</sup>

<sup>\*</sup>For a speed-class system of 200

## 3. New Standards Developed

Image analysis techniques may vary from manufacturer to manufacturer, but the overall goal is the same, to select a clinically appropriate ROI to which the proper image processing can be applied.

If the ROI selection is done incorrectly either by the system or through manual intervention by the operator, the exposure index will be incorrect. Figure 2 demonstrates the effect of ROI selection on exposure index using the same exposure technique.

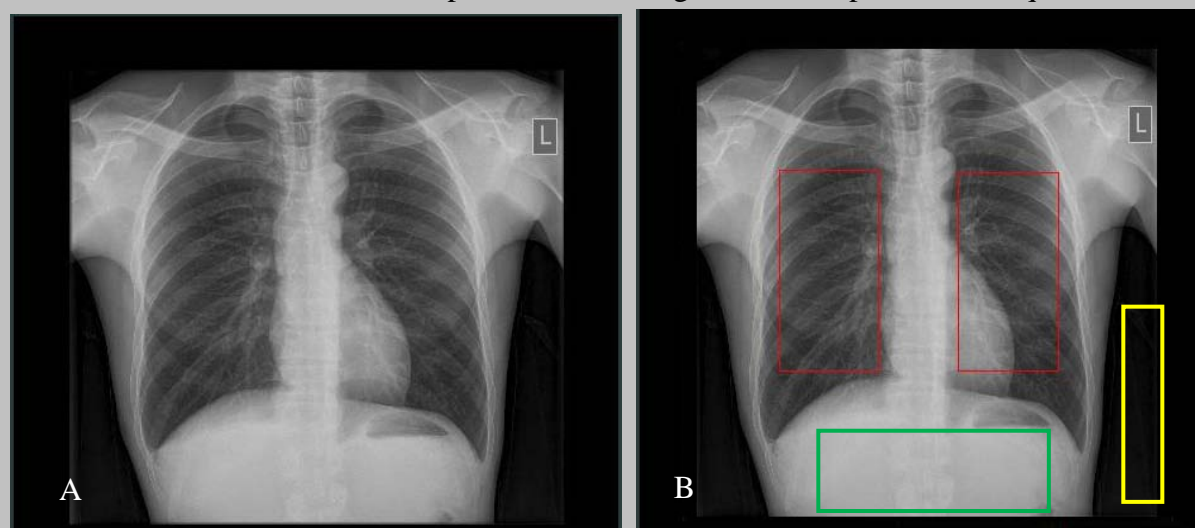


Figure 2. Images demonstrating the effect of modifying the relevant image region. The EI<sub>r</sub> for an adult chest radiograph is currently set at 300 for the Agfa DXG CR system.

A. In this example the relative image region for image processing and the Exposure Index calculation was done automatically. The calculated EI is 264, slightly lower than the EI<sub>r</sub> of 300 yet well within normal variation with a DI of -0.6.  
B. The red regions of interest (ROI) over the lungs were selected by the user and the EI increased to 375 with a DI of 1.0. Selecting only the lungs eliminated some of the soft tissue density and raised the EI by manual processing, but because the region selected was appropriate for the diagnostic task, the EI was within an acceptable range. In the example of the green ROI in the abdomen, which is an incorrectly selected region for chest radiography, the EI is 64 with a DI of -6.7. Since the area selected was significantly lower in exposure than the lungs, there is a dramatic change in EI and DI. In the example of the yellow ROI, which also is an incorrectly selected region for chest radiography, the EI is 1924 with a DI of 8.1. The yellow ROI selected was outside of the diagnostic area and has very little attenuation.

The EI is calibrated using specified beam conditions, e.g., x-ray tube voltage between 66-74 kV, half-value later of 6.8 mm Al, and added filtration of either 21 mm Al or 0.5 mm Cu and 2 mm Al, similar to the RQA-5 standard [1]. The EI is linearly related to receptor exposure; double the mAs and one doubles the EI (Figure 3). It is a relative exposure measure within a type of examination. It is NOT a patient dose indicator. The EI is dependent on the beam spectrum (Figure 3). Thus, one must be careful when comparing two examinations using different kVp's, or different types of examinations.

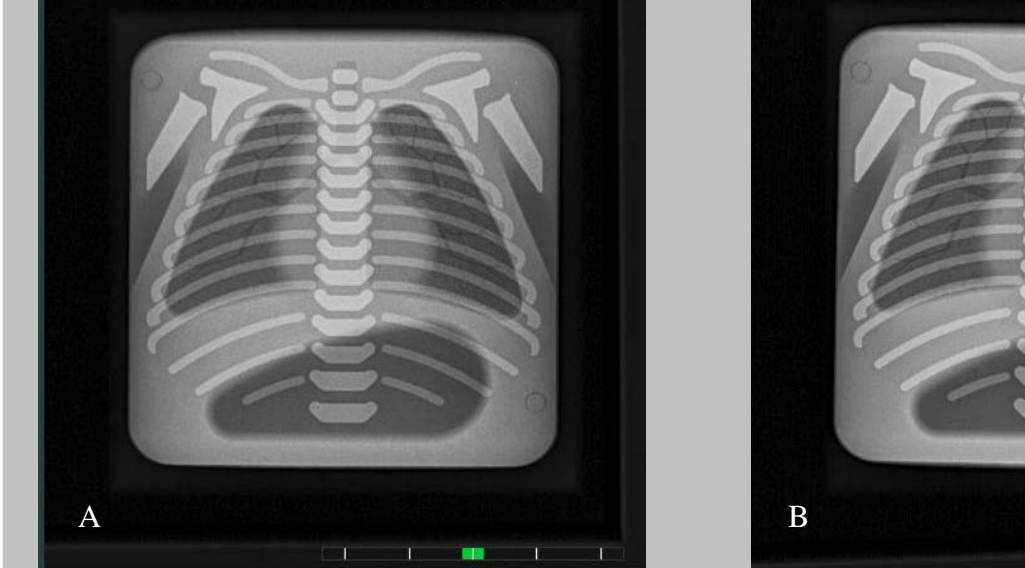
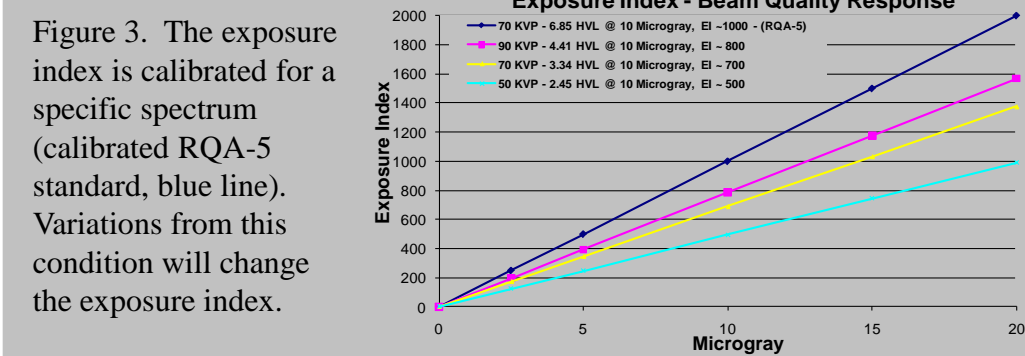


Figure 4. The effects of varying the mAs on EI and DI. The Gammex Neonatal Chest Phantom was used as the test object. The images were obtained on an Agfa DXG CR system using their exposure monitoring quality assurance software with visual feedback. The EI<sub>r</sub> is 450. A. Radiograph exposure of 60 kVp and 1 mAs. The EI is 479 and the DI is 0.3, well within the accepted range. The color bar is green. B. The mAs was increased to 2.5 mAs, the EI was 1258, and the DI increased to 0.25, indicating higher than acceptable exposure. The color bar is yellow and the image flagged for review. C. The mAs was decreased to 0.25, the EI was 102, and the DI decreased to -6.4. Noise is visible. The color bar is red and the image should be reviewed with a radiologist to see if repeat examination is needed.

## 4. IEC /AAPM Differences

From the perspective of the radiologist and technologist, there are few differences between the two standards. One difference is that the AAPM reports the EI in μGy (exposure), while the IEC uses a unitless measure that multiplies the AAPM value by 100. Another difference is that AAPM reports the DI with one significant digit of precision (e.g., 1.3), while the IEC does not specify precision. The AAPM has pledged to work towards adoption of the IEC definitions to create a universal standard.

The Target Exposure Index (EI<sub>r</sub>) is the reference exposure obtained when an image is optimally exposed. It may be set by the vendor or by the local imaging center and can be modified as needed. It is dependent on the body part, view, procedure, and imaging receptor. Because this is a new standard, there are currently no published articles available for reference on EI<sub>r</sub>.

The Deviation Index (DI) quantifies how much the actual EI varies from the EI<sub>r</sub>, and is defined by the formula:  
 $DI = 10 \times \log_{10} (EI / EI_r)$

In an ideal situation where the EI and EI<sub>r</sub> are the same, the DI will be zero. A DI of ± 1.0 corresponds to one step in mAs on a typical calibrated x-ray tube generator console [2]. A DI of + 1.0 corresponds to a 26% overexposure and a DI of -1.0 corresponds to a 20% underexposure. A DI of + 3.0 corresponds to a doubling of the exposure and a DI of -3.0 corresponds to halving of the exposure. This gives immediate feedback to the technologist about the adequacy of the exposure. The AAPM has made some recommendations on the interpretation of the DI for clinical use [2] (Table 2, Figures 4, 5, 6 and 7).

DI	Exposure	Action
>+ 3	> 2x overexposure	Report to management, repeat if image "burned out"
+1.0 to + 3.0	Overexposure	Repeat if image "burned out"
- 0.5 to + 0.5	Target range	
-1.0 to - 3.0	Underexposed	Consult radiologist for repeat
< - 3.0	< ½x Underexposed	Repeat

<sup>\*</sup>modified from Shepard, et al.

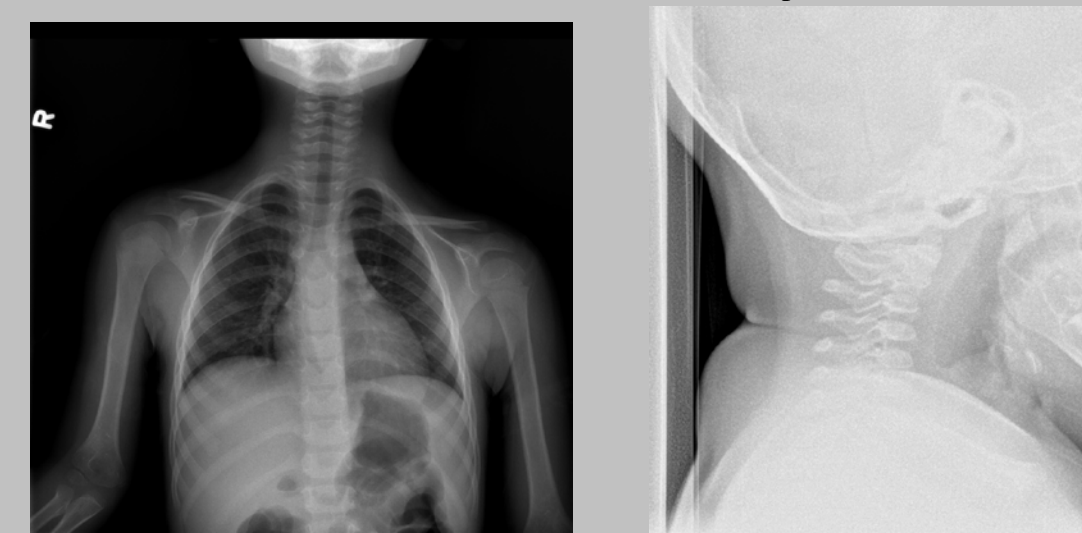


Figure 5. Clinical image using Siemens Ysio. Pediatric chest with the EI 102 and the EI<sub>r</sub> set at 250. While the DI was -3.8, the image was diagnostic and not repeated. It is important not to solely rely on the DI, but to review the image with the radiologist before repeating the image

Figure 6. Clinical image using Siemens Ysio. Soft tissue neck examination with the EI 53 and the EI<sub>r</sub> 250. The DI was -6.7. The noise is excessive and the image was repeated. The explanation of such a low EI was the use of the automatic exposure control but the child was too small for the chamber and was not centered over the chamber.



Figure 7. Clinical image using Siemens Ysio. Left forearm examination with the EI 1780 and the EI<sub>r</sub> set at 400. The DI was 6.5. While the examination was overexposed, there was no saturation and no need to repeat it. The patient received more exposure than necessary yet the image is visually acceptable with no indication of overexposure.

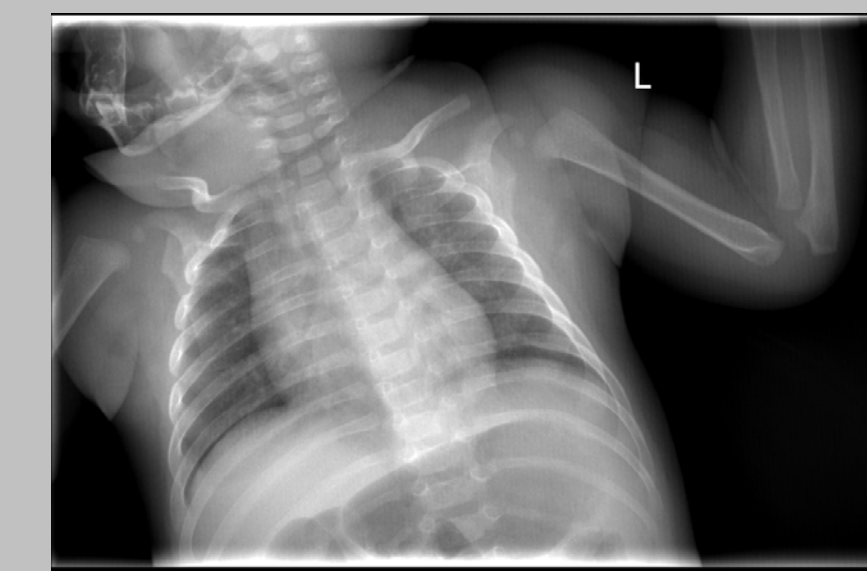


Figure 8. Clinical image on Siemens Ysio. Appropriate EI yet patient dose is excessive. In this infant the EI was 301 with an EI<sub>r</sub> of 250 and a DI of 0.8. In review of the image, grid lines are noted, which should not be used in this age and thickness of a patient. Additionally, the collimation could have been tighter and eliminated exposure to the left extremity (ignoring positioning). Thus, the patient received more dose than needed, even though the EI and DI were in acceptable range.

## 5. Exposure Index and Patient Dose

The EI is a measure of radiation exposure on the image receptor. It is NOT a measure of patient dose. There are many factors that need to be known in order to estimate patient dose, including (Figures 7 and 8) [8]:

- Entrance x-ray beam quality – kVp and total filtration
- Entrance skin exposure
- Distance of patient from source
- Use of a grid
- A target organ – whole body, or specific internal organ, e.g., thyroid or uterus
- The area of the entrance beam covering the organ
- The depth of the organ of interest (if concerned with dose to specific organ)
- The thickness of non-soft tissue structures overlying the organ of interest
- The backscatter factor, which is a function of the irradiated area
- Age (if pediatric patient)

Some radiography units record the technique factors of the generator in the DICOM header. By coupling the technique factors with a dose area product meter, one could also estimate dose.

## 6. Summary & Future Directions

The new standards are helpful in eliminating proprietary terms, thus reducing confusion for radiologists and technologists. **Three new terms are introduced with the standards; EI, EI<sub>r</sub>, and DI. There is immediate feedback to the technologist and radiologist about the adequacy of the technique for each image by using the DI.** Recommendations for corrective action when the technologist notes a DI that is too high or low are suggested, such as review the examination with the radiologist (Table 2).

As this is a new standard, there are factors that need to be addressed to optimize imaging for patients. First, an objective EI<sub>r</sub> for common examinations needs to be established, based on image quality metrics, and not just empiric values set by a vendor or a local imaging center. Second, quality assurance programs are needed, which use exported measures recorded in DICOM structured reports that can be input into the Integrating the Healthcare Enterprise Radiation Exposure Monitoring (IHE REM) profile. Thus, not only can individual examinations with too much or little exposure be identified, but by monitoring over time, systematic trends can be identified and corrected. Using the IHE REM profile, this data can be used to establish national benchmarks. The American College of Radiology has established the CT Dose Index Registry to benchmark CT; a similar program for DR should be created.

## 7. References

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