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Standard Guide for Computed Tomography (CT) System Selection[1]

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1. Scope

1.1 This guide covers guidelines for translating application requirements into computed tomography (CT) system requirements/specifications and establishes a common terminology to guide both purchaser and supplier in the CT system selection process. This guide is applicable to the purchaser of both CT systems and scan services. Computed tomography systems are complex instruments, consisting of many components that must correctly interact in order to yield images that repeatedly reproduce satisfactory test results. Computed tomography system purchasers are generally concerned with application requirements. Computed tomography system suppliers are generally concerned with the system component selection to meet the purchaser's performance requirements. This guide is not intended to be limiting or restrictive, but rather to address the relationships between application requirements and performance specifications that must be understood and considered for proper CT system selection.

1.2 Computed tomography (CT) may be used for new applications or in place of film radiography, provided that the capability to disclose physical features or indications that form the acceptance/rejection criteria is fully documented and available for review.

1.3 Computed tomography (CT) systems use a set of transmission measurements made along a set of paths projected through the test object from many different directions. Each of the transmission measurements within these views is digitized and stored in a computer, where they are subsequently conditioned (for example, normalized and corrected) and reconstructed by one of a variety of techniques. An in-depth treatment of CT principles is given in Guide E 1441.

1.4 Computed tomography (CT), as with conventional radiography and radioscopic examinations, is broadly applicable to any material or test object through which a beam of penetrating radiation may be passed and detected, including metals, plastics, ceramics, metallic/nonmetallic composite material and assemblies. The principal advantage of CT is that it provides densitometric (that is, radiological density and geometry) images of thin cross sections through an object. Because of the absence of structural superposition, images are much easier to interpret than conventional radiological images. The new purchaser can quickly learn to read CT data because images correspond more closely to the way the human mind visualizes 3-D structures than conventional projection radiology. Further, because CT images are digital, the images may be enhanced, analyzed, compressed, archived, input as data into performance calculations, compared with digital data from other nondestructive evaluation modalities, or transmitted to other locations for remote viewing. While many of the details are generic in nature, this guide implicitly assumes the use of penetrating radiation, specifically X rays and gamma rays.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1316 Terminology for Nondestructive Examinations[2]

E 1441 Guide for Computed Tomography (CT) Imaging[2]

E 1570 Practice for Computed Tomographic (CT) Examination[2]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology E 1316 and Guide E 1441, Appendix X1.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *purchaser*—purchaser or customer of CT system or scan service.

3.2.2 *scan service*—use of a CT system, on a contract basis, for a specific examination application. A scan service acquisition requires the matching of a specific examination application to an existing CT machine, resulting in the procurement of CT system time to perform the examination. Results of scan service are contractually determined but typically include some, all, or more than the following: meetings, reports, images, pictures, and data.

3.2.3 *subsystem*—one or more system components integrated together that make up a functional entity.

3.2.4 *supplier*—suppliers/owners/builders of CT systems.

3.2.5 *system component*—generic term for a unit of equipment or hardware on the system.

[1] This guide is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

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[2] *Annual Book of ASTM Standards*, Vol 03.03.

3.2.6 *throughput*—number of CT scans performed in a given time frame.

4. Summary of Guide

4.1 This guide provides guidelines for the translation of examination requirements to system components and specifications. Understanding the CT purchaser's perspective as well as the CT equipment supplier's perspective is critical to the successful acquisition of new CT hardware or implementation, or both, of a specific application on existing equipment. An understanding of the performance capabilities of the system components making up the CT system is needed in order for a CT system purchaser to prepare a CT system specification. A specification is required for acquisition of either CT system hardware or scan services for a specific examination application.

4.2 Section 7 identifies typical purchaser's examination requirements that must be met. These purchaser requirements factor into the system design, since the system components that are selected for the CT system will have to meet the purchaser's requirements. Some of the purchaser's requirements are: the ability to support the object under test, that is, size and weight; detection capability for size of defects and flaws, or both, (spatial resolution and contrast discrimination); dimensioning precision; artifact level; throughput; ease of use; archival procedures. Section 7 also describes the trade-offs between the CT performance as required by the purchaser and the choice of system components and subsystems.

4.3 Section 8 covers some management cost considerations in CT system procurements.

4.4 Section 9 provides some recommendations for the procurement of CT systems.

5. Significance and Use

5.1 This guide will aid the purchaser in generating a CT system specification. This guide covers the conversion of purchaser's requirements to system components that must occur for a useful CT system specification to be prepared.

5.2 Additional information can be gained in discussions with potential suppliers or with independent consultants.

5.3 This guide is applicable to purchasers seeking scan services.

5.4 This guide is applicable to purchasers needing to procure a CT system for a specific examination application.

6. Basis of Application

6.1 The following items should be agreed upon by the purchaser and supplier.

6.1.1 *Requirements*—General system requirements are covered in Section 7.

7. Subsystems Capabilities and Limitations

7.1 This section describes how various examination requirements affect the CT system components and subsystems. Trade-offs between requirements and hardware are cited. Table 1 is a summary of these issues. Many different CT system configurations are possible due to the wide range of system components available for integration into a single system. It is important to understand the capability and limitations of utilizing one system component over another as well as its role in the overall subsystem. Fig. 1 is a functional block diagram for a generic CT system.

TABLE 1 Computed Tomography (CT) System Examination Requirements and Their Major Ramifications

Requirement	Components/Subsystems Affected	Reference
Test object, size and weight	Mechanical handling equipment	7.27.2
Test object radiation penetrability	Dynamic range	7.37.3
	Radiation source	7.3.17.3.1
Detectability		7.47.4
Spatial resolution	Detector size/aperture	7.4.1.17.4.1.1
	Source size/source spot size	7.4.1.27.4.1.2
	Mechanical handling equipment	7.4.1.57.4.1.5
Contrast discrimination	Strength/energy of radiation source	7.4.27.4.2
	Detector size/source spot size	7.4.2.17.4.2.1
Artifact level	Mechanical handling equipment	7.4.37.4.3
Throughput/speed of CT process		7.57.5
Scan time	(Spatial resolution) (Contrast discrimination)	7.5.17.5.1
Image matrix size (number of pixels in image)	Number/configuration of detectors Amount of data acquired Computer/hardware resources	7.5.27.5.2
Slice thickness range	Detector configuration/collimators System dynamic range	7.5.37.5.3
Operator interface		7.67.6
	Operator console	7.6.17.6.1
	Computer resources	7.6.27.6.2
Ease of use		7.6.37.6.3
Trade-offs		7.6.47.6.4

7.2 *Test Object, Size and Weight*—The most basic consideration for selecting a CT system is the test object's physical dimensions and characteristics, such as size, weight, and material. The physical dimensions, weight, and attenuation of the test object dictate the size of the mechanical subsystem that handles the test object and the type of radiation source and detectors, or both, needed. To select a system for scan services, the issues of CT system size, test object size and weight, and

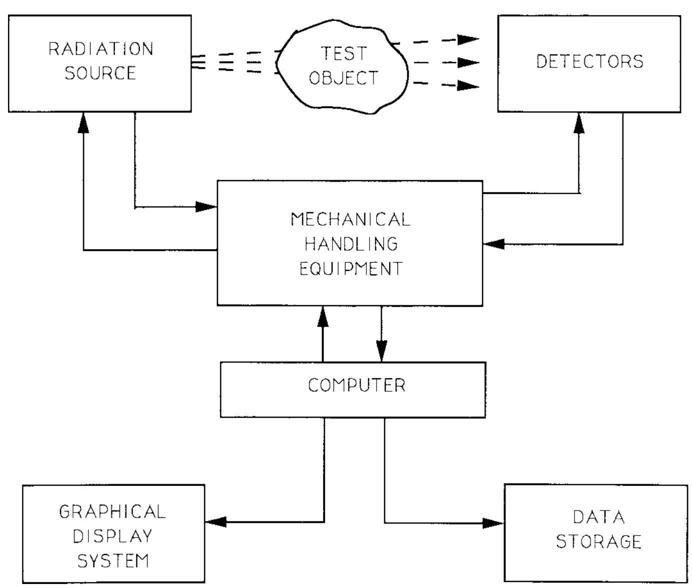

FIG. 1 Functional Block Diagram for a Generic CT System

radiation energy must be addressed first. Considerations like detectability and throughput cannot be addressed until these have been satisfactorily resolved. Price-performance tradeoffs must be examined to guard against needless costs.

7.2.1 The maximum height and diameter of a test object that can be examined on a CT system defines the equipment examination envelope. The weight of the test object and any associated fixturing must be within the manipulation system capability. For example, a very different mechanical subsystem will be required to support and accurately move a large, heavy object than to move a small, light object. Similarly, the logistics and fixturing for handling a large number of similar items will be a much different problem than for handling a one-of-a-kind item.

7.2.2 *Two Most Common Types of Scan Motion Geometries*:

7.2.2.1 *Translate-Rotate Motion*—The test object is translated in a direction perpendicular to the direction and parallel to the plane of the X-ray beam. Full data sets are obtained by rotating the test article between translations by the fan angle of the beam and again translating the test object until a minimum of 180° of data have been acquired. The advantage of this design is simplicity, good view-to-view detector matching, flexibility in the choice of scan parameters, and ability to accommodate a wide range of different object sizes, including objects too big to be subtended by the X-ray fan. The disadvantage is longer scan time.

7.2.2.2 *Rotate-Only Motion*—The test object remains stationary and the source and detector system is rotated around it. A complete view is collected by the detector array during each sampling interval. A rotate-only scan has lower motion overhead than a translate-rotate scan, and is attractive for industrial applications where the object to be examined fits within the fan beam, and scan speed is important. Irrespective of whether the sample translates and rotates, or both, or the source/detector system rotates, the principles of CT are the same.

7.2.3 The purchaser of CT equipment should be aware that important cost trade-offs may exist. For instance, the cost of a mechanical subsystem with translate, rotate, and elevate functions incorporated in one integrally constructed piece of hardware is relatively cost invariant for vertical motions up to some limit, but increases drastically above that point. The casual specification of an elevation could have severe cost implications; whereas the simple expediency of turning the test object over could effectively extend the examination envelope with no cost impact. Similarly, the specification of a large field of view could drive system size and cost soaring; whereas the application of prior information or limited angle reconstruction techniques, or both, could enable the examination with a much smaller scanner.

7.2.4 Automatic material handling equipment is an option that can be acquired with a CT system for mounting and removing test objects. The advantages are lower overhead and greater throughput. The main disadvantages are added costs and complexity to the system design.

7.3 *Test Object Radiation Penetrability*—Next to examination envelope and weight, the most basic consideration is radiation penetrability. Test object penetrability determines the minimum effective energy and intensity for the radiation source. As in any radiological situation, penetrability is a function of test object material, density and morphology (shape and features/geometry). The rules for selecting CT source energy are approximately the same as those for conventional radiography, with the understanding that for CT, the incident radiation must be able to penetrate the maximum absorption path length through the test object in the plane of the scan. The lowest signal value should be larger than the root-mean-square (RMS) of the electronic noise. The required flux is determined by how many photons are needed for statistical considerations. The spot size is determined by the spatial resolution and specimen geometry requirements.

7.3.1 *X-ray Sources*—Electrical X-ray generators offer a wider selection in peak energy and intensity and have the added safety feature of discontinued radiation production when switched off. The disadvantage is that the polychromaticity of the energy spectrum causes artifacts such as cupping (the anomalous decreasing attenuation toward the center of a homogeneous object) in the image if uncorrected. X-ray tubes and linear accelerators (linacs) are typically several orders of magnitude more intense than isotope sources. However, X-ray generators have the disadvantage that they are inherently less stable than isotope sources. X rays produced from electrical radiation generators have source spot sizes ranging from a few millimetres down to a few micrometres. Reducing the source spot size reduces geometric unsharpness, thereby enhancing detail sensitivity. Smaller source spots permit higher spatial resolution but at the expense of reduced X-ray beam intensity. Reduced X-ray beam intensity implies that only smaller or less dense objects can be inspected. Also to keep in mind, unlike radiography, CT can require extended, continuous usage of the X-ray generator. Therefore, an increased cooling capacity of the X-ray generator should be considered in the design and purchase, or both, in anticipation of the extended usage requirements.

7.3.2 *Radioisotope Sources*—A radioisotope source can have the advantages of small physical size, portability, low power requirements, simplicity and stability of output. The disadvantages are limited intensity per unit area, limited peak energy, and increased regulatory concerns.

7.3.3 *Synchrotron Radiation (SR) Sources*—Synchrotron radiation (SR) sources with special equipment (like monochromaters) produce very intense, naturally collimated, narrow bandwidth, tunable radiation. Thus, CT systems using SR sources can employ essentially monochromatic radiation. With present technology, however, practical SR energies are restricted to less than about 20 to 30 keV. Since any CT system is limited to the examination of samples with radio-opacities consistent with the penetrating power of the X rays or gamma rays employed, SR systems can, in general, image only small (1- to 5-mm) objects.

7.3.4 Oftentimes, filters and compensators are used to tune the source to the desired output. The use of filters and compensators will reduce the full capability of the source, causing additional limitations to source output.

7.4 *Detectability*—Once the basic considerations of test size, weight, and radiation penetrability have been addressed, the specific examination requirements are handled. The most important is the capability of the CT system to image the characteristics of concern in the test object. This is a detectability issue. Detectability is an all-encompassing term that includes elements of spatial resolution, contrast discrimination, and artifacts. Spatial resolution characterizes how faithfully the CT system reproduces the features of the test specimen in an image. Contrast discrimination characterizes the amount of random noise in the CT image. The former quantifies our knowledge of a test object, the latter our uncertainty. Together, they form a complementary pair of variables that fully characterize any imaging system. Artifacts are reproducible features in an image that are not related to actual features in the test object. The purchaser is normally interested in detecting geometrical (dimensional) and material (density, porosity, inclusions, etc.) anomalies. From experience, allowable variations are generally known and codified. They usually take the form of simple declarative statements: Critical dimensions must be accurate to $\pm$ 25 µm (0.001 in.); Void diameters must be less than 1 mm; Porosity must represent less than 1 % missing volume; Density variations over 1 cm^2 must be less than 1 %; etc. These so-called application requirements are often explicitly known. The system component engineer must determine the spatial resolution and contrast discrimination needed to obtain the specified dimensional accuracy and defect sensitivity. This in turn sets upper limits on the amount or type, or both, of artifacts that can be tolerated. Making this connection between specifications and performance requirements is generally a difficult task that is best solved collaboratively between purchaser and supplier.

7.4.1 *Spatial Resolution*—All imaging systems, CT included, are limited in their ability to reproduce test object morphology. That is, an infinitely small, infinitely dense point in the object will be imaged not as a point, but as a spot—possibly a very small spot, but a spot of finite size nonetheless. Hence, the image of a real object will exhibit a certain amount of unsharpness. Computed tomography (CT) spatial resolution is a measure of this unsharpness and obeys much the same rules as any radiological imaging modality: it is limited by the effective in-plane size of the detectors, the in-plane size of the source spot, and the relative position of the test specimen with respect to the source and detector. Other factors, such as sampling, reconstruction matrix size, image display matrix, and reconstruction algorithms, can degrade the inherent spatial resolution.

7.4.1.1 *Radiation Detection*—The detection system converts the transmitted radiation into an electronic signal. The detector element is typically a scintillation detector that is optically coupled to a photo-conversion device like a photodiode or photomultiplier tube. Alternatively, some systems use other types of detectors. The in-plane detector width is determined in part by the spatial resolution requirement. This detector width is either designed in the system or, for variable aperture systems, can be set by some kind of shielding aperture plates that define the detector's field of view. The detection system may consist of a single sensing element, an area array of sensing elements, or a linear array of sensing elements. The more detectors used, the faster the required scan data can be collected; but there are important trade-offs to be considered.

(1) A single detector provides the least efficient method of collecting data but entails minimal complexity, eliminates concerns of scatter between elements and differences in detector response, and allows an arbitrary degree of collimation and shielding.

(2) An area detector provides the most efficient method of collecting data but entails the transfer and storage of large amounts of information, forces trade-offs between scatter, elements, and detector efficiency, and creates serious collimation and shielding challenges.

(3) Linear arrays have performance characteristics intermediate between these two extremes, for example, reasonable scan times at moderate complexity, acceptable scatter between elements, and differences in detector response. Linear arrays have a flexible architecture that typically accommodates good collimation and shielding.

(4) An important aspect of the detection system is the electronics system used to convert the analog signal received to a digital stream for processing. The front-end analog electronics amplify the detector signal to a magnitude that can be digitized. Fast systems demand good fidelity of the amplified signal. What makes the task especially demanding is that many signals, differing by several orders of magnitude, are frequently multiplexed on the same line in rapid succession; intersignal amplification rates are measured in microseconds. The analog-to-digital (A/D) conversion is performed as close to the analog amplification chain as possible. The accuracy requirement of the A/D must be consistent with the statistical limitations of the largest and the smallest detectable signals.

7.4.1.2 *Source Spot Size*—The source spot is the source region from which X rays or gamma rays emanate. In an electrical radiation generator, like an X-ray tube or linear accelerator, it is the area where the electrons strike the target. In an isotopic source, it is the area from which the radiation effectively emerges. The size and shape of the source spot is an important determinant of the aperture function. For instance, source spots in linear accelerators are typically shape as Gaussian distribution; whereas source spots in X-ray tubes are often double-peaked. Source spots associated with isotopic sources can be either more or less complex. Since source spots do not generally have sharp edges—or even symmetric shapes, it is common practice to define an effective size for convenience. The actual intensity distribution is important information, but is too complex to be readily useful. Consequently, reported source spot sizes are a function of the definition and method used to measure them. For example, the average radius of the region from which 99 % of the emissions emerge will be much larger than the standard deviation of the intensity distribution. In other words, source spot characteristics can be quantified in different ways. For this reason, comparisons between sources, especially those provided by different suppliers, are difficult to make. Another source selection factor to consider is stability. In selecting an electrical source, appreciate that spot position can wander over time, and changes in accelerating potential can occur.

7.4.1.3 Often, the in-plane source spot size and the in-plane detector width can be adjusted over a limited range of options, allowing spatial resolution to be engineered somewhat. In general, the smaller the source spot or detector size, or both, the better the spatial resolution. Since spatial resolution limits dimensional accuracy and resolving power (that is, the ability to distinguish two nearby point objects as separate entities), pressure exists to select the smallest possible source spot and detector sizes. On the other hand, the accuracy of dimensional measurements also depends on the contrast discrimination of the system, which, in turn, depends on the number of detected photons. The smaller the selected source spot or detector size, or both, the fewer the number of photons detected per unit scan time, and the poorer the contrast discrimination. However, pressure to maximize throughput or scanner limitations often precludes arbitrarily long scan times. An evaluation of the trade-offs among spatial resolution, constrast discrimination, and scan time usually comes after it is first determined that adequate spatial resolution can be achieved irrespective of any other considerations. The ultimate selection of the optimum combination of performance parameters is a value judgment best made by the purchaser in conjunction with the supplier.

7.4.1.4 The prospective purchaser can make a preliminary determination as to whether a given CT system has the necessary spatial resolution for a given application using the following guidelines. First, if dimensioning is important, sharp high-contrast edges free of artifacts typically can be located to about one tenth of the effective beam width associated with a given system. For example, if the effective beam width is 1 mm, it should be possible to measure edges to about 0.1 mm (0.004 in.). As long as the estimated accuracy is within a factor of close to two of the dimensional accuracy requirement set by the application, the particular system being considered should be deemed a potential candidate for use. If the application requires dimensional measurements of low-contrast features, the accuracy will be worse, but precisely how much worse is difficult to quantify. Second, if resolving fine features is important, two high-contrast features in an image typically can be distinguished as separate entities provided they are physically separated in the object by at least the effective beam width. For example, if the effective beam width is 1 mm, it should be possible to distinguish features like passageways or embedded wires, as long as they are separated from each other by more than 1 mm center-to-center. As long as the effective beam width is within 25 % or so of the resolving power requirement set by the application, the particular system being considered should be deemed a potential candidate for use. The lower the contrast, the harder it will be to distinguish features. If the application requires resolving low-contrast features, the accuracy will be worse, but precisely how much worse is difficult to quantify. The purchaser should also appreciate that if the object is highly attenuating, the image may exhibit artifacts that could limit or preclude measurements in the affected regions.

7.4.1.5 *Accuracy of Mechanical Handling Equipment/ Motion Control/Manipulation Systems*—The test object manipulation system has the function of holding the test object and providing the necessary range of motion to position the test object area of interest between the radiation source and detector. Since spatial resolution is limited by many things, including the relative position of the test object with respect to the source and detector, any problems with alignment or accuracy of the mechanical system will show up as degraded resolution. It is typically more difficult to align hardware for translate-rotate motion machines, but the sampling rate is adjustable up to some limit. In contrast, rotate-only motion machines typically are not as difficult to align, but they do not give the option of adjusting linear sampling to satisfy the required sampling rates. In either case, artifacts occur and the resolution is degraded if alignment is compromised.

(1) Because the inherent resolution of a system can be degraded by the mechanical handling equipment, fine spatial resolution requirements can drive mechanical designs and tolerances to extremely high costs. Typically, system designs can accommodate spatial resolutions up to some limit. Beyond that limit, redesign with different, more accurate system components and different assembly procedures is required.

7.4.1.6 *Spatial Resolution Trade-offs*—Spatial resolution requirements can affect an entire range of system components and subsystems. Spatial resolution requirements place limits on the accuracy and repeatability of the mechanical handling equipment. Spatial resolution requirements also limit the source spot size and detector aperture width, and define the geometry between source and detector. The system configuration defines the effective beam width at the test object.[3,4] Thus, a requirement for high spatial resolution at a certain frequency may require a microfocus source or small detector apertures. It might require sampling at smaller spatial intervals. It also might affect the speed of the data acquisition process. Use of reconstruction filters can also increase spatial resolution capability.

7.4.2 *Contrast Discrimination*—All imaging systems, CT included, are limited in their ability to reproduce test object composition. That is, two regions of identical material will be imaged, not as smooth areas of equal CT value, but as grainy areas of statistically variable CT values. Hence, upon repeated examination, the mean value of two regions will vary randomly in relative magnitude. Contrast discrimination is a measure of this variability and obeys much the same rules as any radiological imaging modality: it depends on the number of detected photons, which in turn, depends on all scan parameters affecting the data collection process, such as sampling interval, source spot size and flux, detector size and stopping power, linear and angular sample rates, etc.

7.4.2.1 Often, many of these parameters can be adjusted over a limited range of options, allowing contrast sensitivity to be engineered somewhat. In general, the greater the number of photons detected, the better the contrast sensitivity. Since contrast sensitivity limits the low-contrast discrimination of different materials and influences the accuracy of dimensional measurements, pressure exists to select scan parameters that maximize the number of detected photons. However, contrast sensitivity improves as the square root of the detected flux, and

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[3] Bracewell, R. N., "Correction for Collimator Width in X-Ray Reconstructive Tomography," *Journal of Computer Assisted Tomography*, Vol 1, No. 2, 1977, p 251.

[4] Yester, M. W. and Barnes, G. T., "Geometrical Limitations of Computed Tomography Scanner Resolution," *SPIE Proceedings*, *Applications of Optical Instrumentation in Medicine*, Vol 1, 27, 1977, pp. 296–303.

significant improvements are difficult to achieve by simply scanning longer, because scan times rapidly become impractical. The one option for improving image quality at no expense in scan time is to increase source spot and detector sizes; but pressure to maximize or maintain spatial resolution often precludes arbitrary adjustment of source spot and detector sizes. An evaluation of the trade-offs among contrast discrimination, spatial resolution, and scan time usually comes after it is first determined that adequate contrast discrimination can be achieved irrespective of any other considerations. The ultimate selection of the optimum combination of performance parameters is a value judgment best made by the purchaser in conjunction with the supplier.

7.4.2.2 Rules of thumb can be given to help the prospective purchaser make a preliminary determination as to whether a given CT system has the necessary contrast discrimination for a given application. First, if small-area high-contrast (that is, inclusions) discrimination is important, small (approximately 4 pixels) regions typically can be discriminated against a uniform background when the relative contrast between feature and host is greater than 5 to 6 times the single-pixel image noise in the vicinity. For example, if the image noise in the region of interest is about 2 %, a small feature will need to have a contrast of at least 10 % to be visible. As long as the expected or estimated image noise associated with a given system is within a factor of two or so of the noise requirement set by the application, the particular system being considered should be deemed a potential candidate for use. As a point of reference, 1 % image noise is considered excellent, a few percent is considered good, 5 % is considered mediocre, greater than 10 % is considered poor. The purchaser should also appreciate that if the object is highly attenuating, the image may exhibit artifacts that could mimic or mask small high-contrast features in affected regions.

7.4.2.3 Second, if large-area low-contrast (that is, density) discrimination is important, large (greater than 400 pixels) regions typically can be discriminated against a uniform background when the relative contrast between feature and host is greater than about three times the single-pixel image noise in the vicinity divided by the square root of the number of pixels. For example, if the image noise in the region of interest is about 2 %, a compact feature 20 by 20 pixels in size will need to have a contrast of at least 0.3 % (that is, 3 by 2 %/20) to be visible. As long as the expected or estimated image noise associated with a given system is within a factor of two or so of the noise requirement set by the application, the particular system being considered should be deemed a potential candidate for use. As above, if the object is highly attenuating, the image may exhibit artifacts that could mimic or mask large low-contrast features in the affected regions.

7.4.3 *Artifact Content*—Artifacts are reproducible features in an image that are not related to actual features in the test object. Artifacts can be considered correlated noise because they form fixed patterns under given conditions yet carry no test object information. Some artifacts are due to physical and mathematical limitations of CT, for example beam hardening, radiation scatter, and partial volume effects. Some artifacts are due to system deficiencies such as mechanical misalignment, insufficient linear or angular sampling, or both, crosstalk between detectors, etc. Artifacts are always present at some level. Often, they are the limiting factor in image quality. In general, artifacts become important when a CT system is used beyond its design envelope. A common instance is when test object attenuations cause minimum signals to be comparable to, or less than, sensor offsets due to electronic noise and unwanted scatter. Mitigating the effect of artifacts in the image is best done by addressing the underlying problems at their origin. If artifacts cannot be reduced or eliminated at their origin, the next option is to attempt a software fix. As a rule, most artifacts are best corrected before image formation by applying transformations to the data. In the end, if artifacts preclude the use of a given system for a particular application, the purchaser must consider the use of another more capable system if one is available, or the modification of the test object specifications. That failing, the purchaser must work with suppliers to determine if the technology exists to satisfy the application at hand, or conclude that CT is not presently a viable examination technique for the test object.

7.5 *Throughput*—The next step in specifying a CT system is the consideration of throughput. Throughput generally refers to how many scans can be generated per unit time; it is usually implied or taken for granted that any detailed analyses will be performed off-line in a noninterfering manner. The importance of throughput varies depending on the circumstance. For an application study, spatial resolution and contrast discrimination are usually of primary concern and throughput is an issue only insofar as it affects the amount of scan time that must be budgeted. On the other hand, for routine examination use, throughput is usually a major concern, since it is intimately tied to financial considerations.

7.5.1 *Scan Time*—The purchaser should recognize that scan time is intimately related to spatial resolution and contrast discrimination. For a given system, the specification of any two fixes the third. For a new system, the specification of all three may or may not be technically possible, and if a design solution does exist, it may not be economically practical. Ideally, these issues are addressed jointly by purchaser and supplier.

7.5.1.1 For an existing system, the purchaser can normally influence scan time by judicious selection of available scan parameters. Though it must be recognized that it may not be possible to satisfy simultaneously the throughput, spatial resolution, and contrast discrimination requirements of an application for which the system was not designed. Typically, the purchaser selects source and detector parameters yielding the minimum spatial resolution (that is, the largest effective beam width that the application can tolerate). If spatial resolution is unimportant, then the purchaser should select the largest possible effective beam width that the scanner can accommodate. Next, the purchaser should select scan parameters yielding the minimum contrast discrimination that the application can tolerate. If contrast discrimination is unimportant, then the purchaser should select the fastest possible scan time that the scanner can accommodate. Key parameters affecting scan time are: image matrix size, slice thickness, field of view, and sampling interval. The first two warrant further discussion and are covered in 7.5.2 and 7.5.3. Field of view is dictated by the