ASNT Level II Study Guide

Visual and Optical Testing Method

by
Douglas Krauss

The American Society for Nondestructive Testing, Inc.

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Contents

Introduction

Overview of the Study Guide

This study guide contains basic information intended to prepare a candidate for Level II visual and optical testing examinations administered within the ASNT Central Certification Program (ACCP). This study guide does not present all of the knowledge necessary for certification; the candidate is expected to supplement this guide with the recommended references that follow.

This study guide is divided into three chapters; Chapter 1 and Chapter 2 cover the information found on the Level II General (written) Examination, and Chapter 3 covers the information found on the Level II Hands-on Practical Examination. At the end of Chapter 1, there are questions typical of those that could appear within a portion of the Level II General Examination. These questions contain references for further study, and they are intended to aid the candidate in determining his/her comprehension of the material.

Following each section of Chapter 1 is a "Recommended Reading" box containing references to where additional information on the subjects identified can be found. Listed under "Reference" there is an acronym for a book (*NDT Handbook* = HB, *ASM Metals Handbook* = ASM, *IES Lighting Handbook* = IES) followed by a colon and the specific page range where the topic is discussed.

At the end of the study guide there are several appendices relevant to successful preparation for the ACCP Level II visual and optical testing examinations, particularly Appendix 3, which describes pertinent NDT qualification and certification documents allowing for better understanding of the NDT qualification and certification options available to industry.

Acknowledgments

The author acknowledges the support of the EG&G Florida, Inc., the Kennedy Space Center, and the ASNT Technical Services Department staff.

Recommended References

Nondestructive Testing Handbook, second edition: Volume 8, *Visual and Optical Testing* [ASNT order #133]

ASM Metals Handbook, 9th edition, Volume 17, *Nondestructive Evaluation and Quality Control, Ultrasonic Inspection*, [ASNT order #105]

Resource Materials

Lighting Handbook, 8th edition, *Reference & Application*, Illuminating Engineering Society of North America: New York, 1993.

Inspection and Gaging, 6th edition, [ASNT order #157]

Recommended Practice No. SNT-TC-1A, 1996 edition [ASNT order #2055]

ANSI/ASNT CP-189-1995: Standard for Qualification and Certification of Nondestructive Testing Personnel [ASNT order #2505]

ASNT Central Certification Program (ACCP) [ASNT order #6001]

Chapter 1
Overview of Visual Testing

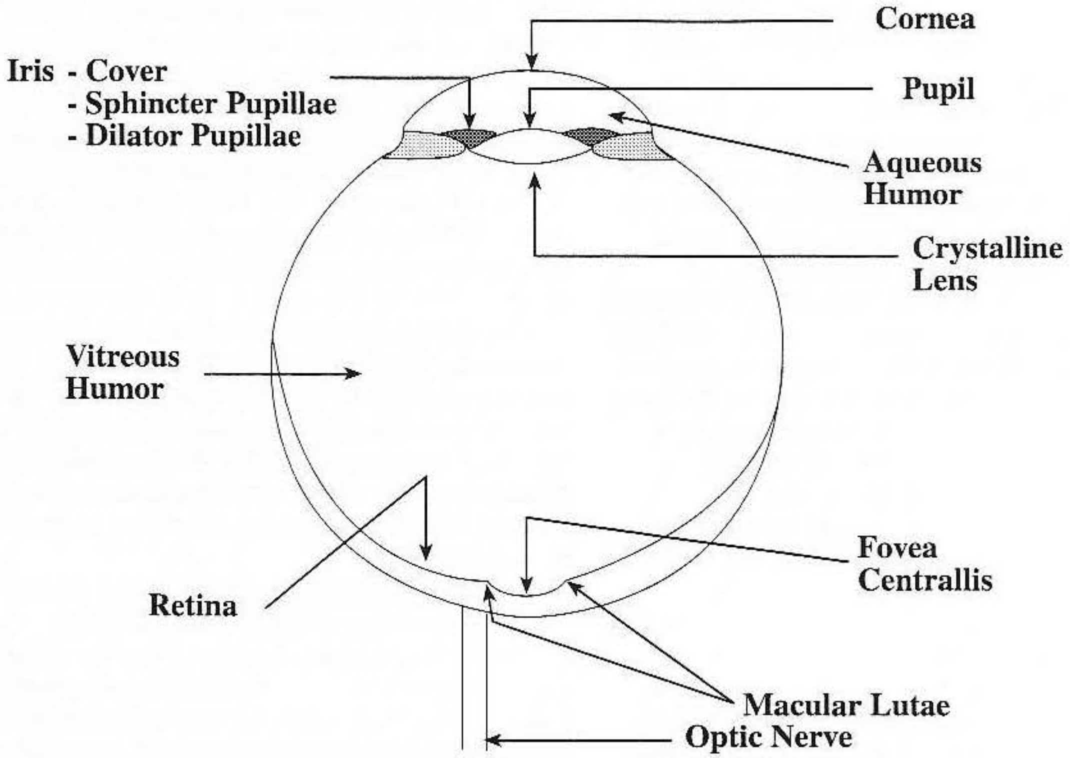
Fundamentals of Visual Testing

Visual testing (VT) is perhaps the oldest and most widely used inspection technique. Often, the eyes of the inspector are the only "equipment" used for the inspection. VT is applicable to virtually any material, at any stage of manufacture, at any point in its service life. To perform a successful direct visual examination, adequate lighting and good inspector eyesight is required. If access to specific areas of the test article is limited, borescopes, fiberscopes, videoprobes, and closed-circuit television (CCTV) can be used to perform remote VT. For a thorough understanding of the VT method, the listed references and resource materials are recommended.

Vision

The inspector's eyes are the most important element in VT. The eye is a complex organ composed of many structures — all of which must function properly for reliable examinations to be performed. The components of the human eye are shown in Figure 1.1. Reflected light enters the eye through a tear film in the cornea where the majority of light refraction occurs. This refracted light then passes through the iris, the thin colored membrane that controls the amount of light entering the eye. Past the iris is the crystalline lens, which changes shape in order to focus the light on the retina at the back of the eyeball. To maintain its shape, the eyeball is filled with a clear gel called the vitreous humor. The retina

Figure 1.1: Components of the human eye



is covered with specialized cells, called rods and cones, that convert the incoming light into nerve impulses through a photochemical process. These nerve impulses travel to the brain through the optic nerve, where they are decoded.

Eyesight can be adversely affected by a malfunction of any one of these structures. Glaucoma, an increase in the fluid pressure within the eye, may produce slight aberrations or complete blindness. Myopia, hyperopia, and astigmatism occur when light is focused on a plane other than the retinal plane. As an individual ages, the crystalline lens loses its ability to flex for focusing, and cataracts may occur.

To ensure that the eyesight of a visual inspector is adequate, periodic vision examinations are performed to verify visual acuity, depth perception, and color discrimination. An individual diagnosed with a deficiency that can be remedied by corrective lenses will be required to wear them during any visual examination.

Visual Perception

Visual perception is the comparison of what the eyes see with what the mind sees. Although there is a tremendous amount of information available in any given image that is directed to the retina, only a small percentage is used for detail recognition. This is due to the overall make-up of the human vision system. The eye is nothing more than a receptor that gathers and focuses the incoming information contained in the entering photons, while the brain takes the provided information and processes it into a mental image that will be interpreted.

The individual does not necessarily notice all of the information available in a particular field of view. The portion of the image that appears on the fovea is the sharpest because of the large grouping of rods and cones in this area. It is this information that the brain processes regarding the qualities of the object of attention. The parts of the image that extend farther away from the fovia toward the retina decrease in resolution as the distance from the fovea increases due to a decrease in the number of rods and cones. Peripheral vision is not completely ignored, but it serves largely as a reference for orientation and motion and does not enhance perception. For this reason, an object being examined should be observed with a series of intermittent scans, where the inspector looks at a small area, scans a few degrees and looks again, repeating this sequence over the entire area of interest. Even though the field of view may completely encompass the entire object being examined, only a small portion of that field is usable for detailed information.

Lighting

To understand the importance of lighting in an inspection atmosphere, it is essential to know the fundamentals of light, how it is measured, and the recommended lighting levels for inspections.

Fundamentals of Light

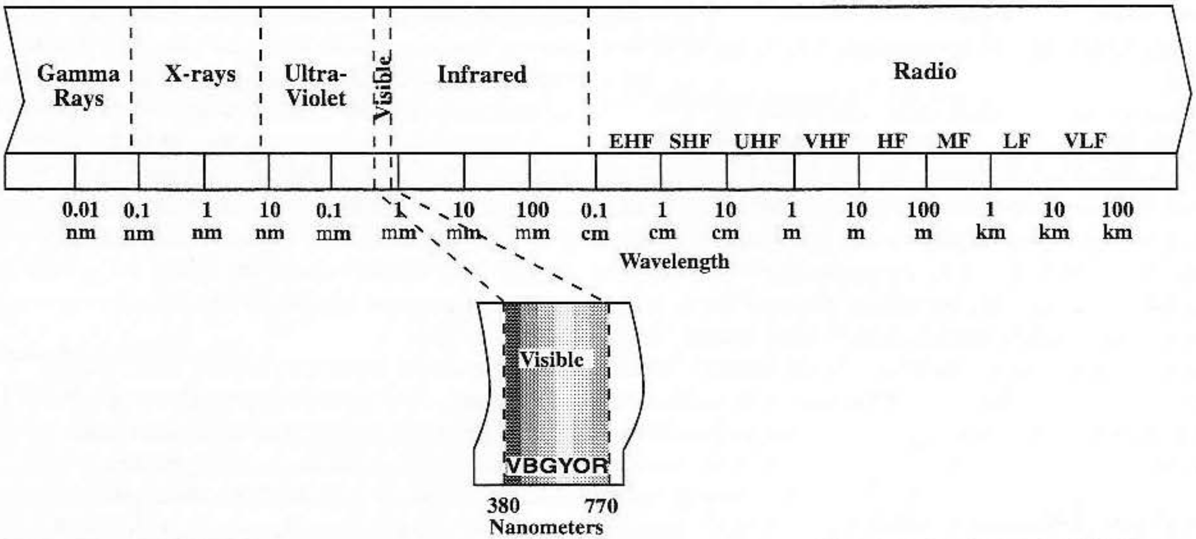
There are several existing theories that describe the phenomena of radiant energy. The wave theory and the quantum theory are the two most widely-accepted theories. The wave theory proposes that radiation originates from accelerating charged particles (i.e., vibrating electrons) and travels through space and time in wave-like movements. The quantum theory, developed through modern physics, proposes that energy is emitted and absorbed in discreet quanta or packets of energy (photons). While both models are based on a massless, chargeless transfer of energy at a speed of 3×10^{10} cm/s, each proposes a different explanation of light's interaction with matter.

Visible light, the energy that stimulates the receptors of the human eye, is generally defined as energy in the wavelength range of 380 to 770 nm. Visible light exhibits properties of both the wave model and the quantum model.

The electromagnetic spectrum is a convenient way to graphically depict electromagnetic radiation. It is based on the wave theory model. The electromagnetic spectrum encompasses the range of energies from extremely short wavelength cosmic rays to long wavelength electrical waves as shown in Figure 1.2.

Visible light is produced from the electron cloud of an atom when an external force disturbs its electrons. Energy from the external force removes an electron from its original energy level and, upon its return to that energy level, the excess energy is emitted as quanta of

Figure 1.2: The electromagnetic spectrum



light. This light travels in a nearly straight line until it encounters a medium or force that reflects, refracts, or diffracts it.

Visible light, known as "white" light, is actually a broad spectrum of frequencies. When white light is passed through a prism, it is separated into the constituent frequencies that produce the vision sensation of color.

An important point to remember is that all electromagnetic radiation is similar in nature and that it is the specialized properties of the eye that allow the visible portion of the spectrum to stimulate sight.

Measurement of Light

Photometry, the measurement of light, is a means of quantifying the radiant energy of visible light. Measurements are obtained with a photometer, which converts the radiant energy of the light into a measurable electrical signal.

When measuring visible light, the inverse square law and the Lambert Cosine law are frequently used. The inverse square law (Equation 1 and Figure 1.3) states that the illumination of a surface varies inversely as the the distance between the light source and surface is squared.

$$E = \frac{I}{d^2} \qquad \textbf{(Eq. 1)}$$

where:
- I = luminous intensity
- E = illuminance
- d = distance between the point and source

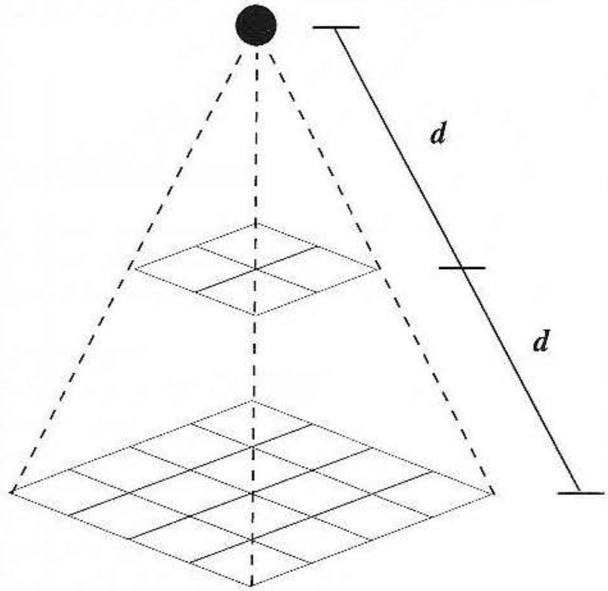
For example, a light source with a luminance of 1000 lm measured at 0.3 m (1 ft) will be reduced to 250 lm at a distance of 0.6 m (2 ft).

The Lambert Cosine law (Equation 2) states that the luminance of a surface varies as the cosine of the angle of incidence.

$$E = I \cos \theta \qquad \textbf{(Eq. 2)}$$

where:
- I = source illuminance
- E = surface illuminance
- θ = angle of incidence

Figure 1.3: The inverse square law



Combining the inverse square law with the Lambert Cosine law (Figure 1.4) allows illuminance at angles other than normal to be calculated.

Measurements of visible light are made in reference to primary standards established by national physical laboratories. In the United States, the National Institute of Standards and Technology (NIST) maintains most physical standards. From these primary standards, working standards are prepared for use in calibrating photometry equipment. Using the basic laws of photometry with readings from photometric or photoelectric instruments, measurements of unknown light sources may be made.

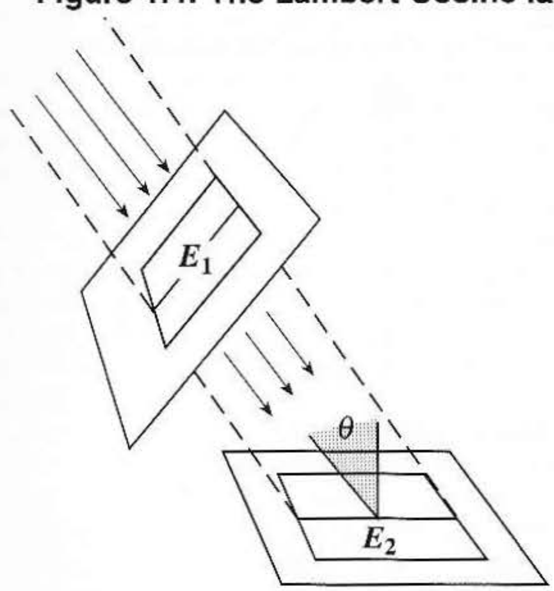
Recommended Lighting Levels

Adequate lighting at the inspection surface is essential for the proper identification of indications. Often, the general illumination of the work area is sufficient for visual examination; however, the governing code or specification should be referenced for the minimum lighting level required.

Lighting Techniques

When the illumination level at the inspection surface is determined to be inadequate, every effort should be made to provide the necessary lighting. To provide the necessary illumination during VT, flashlights, portable shop lights, and high-intensity lamps should be considered. Another option would be to move the test piece to a brighter inspection area if possible.

Figure 1.4: The Lambert Cosine law



$$E_2 = E_1 \cos \theta$$

In addition to the illumination intensity at the inspection site, the color of the light is also important. Color plays a significant role in increasing contrast in the inspection area. For example, the inspection of chromium plating over nickel may be enhanced by using a bluish light such as that provided by "daylight" fluorescent lamps.

Surfaces and the detectability of indications can vary greatly due to the characteristics of the light source; therefore, the characteristics of the light source used during an inspection should be as close as practical to the light source used to examine reference standards.

Whatever illumination source is chosen, consideration should be given to its location. The distance of the light source from the test piece and its angular position determine the intensity of the light and the amount or absence of glare. As with the lighting characteristics, the physical configuration of the equipment should closely approximate the conditions that were used during the examination of the reference standard.

Light Sources

As mentioned previously, light sources used to provide adequate illumination range from the penlight flashlight to the brilliant high-intensity sources that are used with videoprobes. Although a candle will provide light (its luminance used to be the standard measure of light), candles are inadequate for the purpose of visual examination. Electric light sources are generally used to enhance visual examinations. There are three types of artificial light — incandescent light, fluorescent light, and discharge (arc) light.

Incandescent Lighting

Incandescent light is produced by passing a current through a tungsten filament that is heated to incandescence. The common tungsten incandescent lamp is basically a thin coiled tungsten wire surrounded by a vacuum in a sealed envelope. As a current is passed through the wire, it heats and glows. The halogen lamp is a refinement of the tungsten lamp, which uses an inert gas with an active halogen compound within the envelope instead of a vacuum. The halogen lamp design maximizes the service life of the filament because the inert gas minimizes the evaporation of tungsten from the filament and its subsequent deposition on the lamp wall, and any tungsten that does evaporate is combined with the halogen and redeposited on the filament when the lamp is de-energized. This also minimizes the blackening of the lamp as is commonly observed with incandescent lamps.

Fluorescent Lighting

Fluorescent light is produced by a gas within a glass envelope that fluoresces when it is excited by an electron discharge. Electrons are discharged by filaments at one or both ends of the tube and their interaction with the gas atoms causes the gas atoms to emit radiation in the infrared, visible, and ultraviolet frequency range. The powder coating on the inside surface of the tube is excited by the ultraviolet radiation, and in turn emits visible light.

Discharge (Arc) Lighting

Discharge (arc) lamps use an electric arc to produce light. This lamp type is used in some videoprobe imaging systems as a source of high-intensity illumination. The electrodes are housed in a vacuum or gaseous filled envelope and a reflector focuses the light on a specific exit point. Sapphire and quartz are commonly used at the exit point because of their light transmission and thermal properties. The electrode gap, arc voltage, reflector shape, and material used at the light exit point determine the intensity and efficiency of this type of lamp. When a sufficient voltage is applied, a rapid transfer of electrons crosses the electrode gap and produces the visible light.

Recommended Reading

Subject	Reference*
vision	HB: 9-16; IES: 69-86
visual perception	IES: 86-90
fundamentals of light	HB: 30-34; IES: 3-9
measurement of light	HB: 35-44; IES: 27-64
lighting techniques	HB: 54-55; IES: 629-684
light sources	IES: 9-17, 179-246

*See *Introduction* for explanation of references.

Factors that Affect Visual Testing

Factors that affect VT include material attributes, the inspection environment, and physiological factors that affect the inspector.

Material Attributes

The physical size and condition of the object(s) to be examined play a significant role in the outcome of an examination. Knowledge of how each variable influences the examination will aid the inspector in alleviating the possibility of missed indications.

Surface Conditions

Some surface conditions that affect VT include cleanliness, color, condition, shape, size, temperature, and texture.

Cleanliness

One basic requirement for an effective visual examination is a clean test item. Unwanted foreign material such as dirt, oil, grease, etc. can mask the surface of actual discontinuities or present false indications. A clean inspection surface helps to prevent the possibility of missed indications.

Color

The color of the incident light relative to the color of the object being examined can play a significant role in the detection of discontinuities. The color of the light can be used to increase contrast by intensifying or subduing certain colors. To intensify a color, the light source should be strong in that color. Conversely, to subdue a color, the light source should have a relatively low output of the color. For example, as previously mentioned, when examining chromium plating over nickel plating, a blue light such as that provided by daylight fluorescent lamps can enhance any imperfections in the chromium.

Texture

The surface of a material is important in relation to the amount and quality of light reflected from it to the examiner's eye. A surface that is reflective can produce unacceptable glare, which may interfere with the examination of the test surface. In this case, light applied during the examination should be considered carefully. Conversely, an extremely rough surface may also require special lighting to sufficiently illuminate the area without masking. Glare can be reduced by increasing the angle between the glare source and line of sight or by dimming the light source. Decreasing the angle between the light source and the line of sight is also helpful when examining rough surfaces because it decreases the shadow effect of surface irregularities.

Physical Conditions

Physical conditions such as specimen condition, shape, and size can act as limiting factors during VT.

Specimen Condition

The stages of the manufacturing process, service environment, and applied surface coatings, all influence the condition of the item being examined. Mill scale and weld slag remaining after manufacture can mask discontinuities, and painted or plated surfaces can mask other surface defects.

Shape

The shape of an object also affects the outcome of an examination. Complex-shaped objects, such as keyways and splines, may hinder an examination and care should be taken in these areas.

Size

When examining objects of substantial size, certain precautions should be taken to ensure that a complete examination has been performed.

Temperature

Elevated temperatures limit the service life of many metal components. Using metal components in high temperatures can result in creep, thermal fatigue, and overload failure. Creep is the deformation of a metal under stress, generally at higher temperatures than normal. Thermal fatigue cracks are the result of repeated thermal cycles that cause expansion and contraction within the metal. If thermal cycles are caused by friction, as in the case of brake components, thermal fatigue cracks called heat checking can occur. Engine exhaust manifolds that are restrained during repeated heating and cooling cycles may develop fatigue cracks due to residual tensile stress. Repeated thermal cycles of certain materials in an oxidizing atmosphere can create scaly oxide layers over the material. These flaky layers may mask surface discontinuities and care should be taken when inspecting areas of this nature.

Environmental Factors

Environmental factors that can affect a visual inspection include atmosphere, cleanliness of the object being inspected, and the position of object in relation to the inspector.

Atmosphere

Atmosphere in this context refers to the portion of the environment that has a physical or psychological influence on the examiner. An atmosphere free of high noise levels, dust, smoke, and other distractions is more conducive to the performance of the examiner.

Cleanliness

As previously mentioned, the cleanliness of the item to be examined is important when performing a visual examination. Of equal importance is the cleanliness of the examination environment. The primary source of contamination in the inspection environment is the movement of parts from one area to another. While the movement of parts during an examination is necessary, dirt and other contaminants can be transferred to the part surface if the surrounding area is not reasonably clean. An examination environment can become contaminated in many different ways. One such way would be smoke and vapors in the air that settle on reflective surfaces and reduce the contrast needed to locate potential discontinuities.

Humidity and Temperature

Humidity and temperature are environmental factors that affect the proper performance of visual examinations. While people differ in their ability to tolerate heat and humidity, it is known that increased body core temperature decreases the mental ability of an inspector. The National Institute for Occupational Safety and Health (NIOSH) recommends a wet globe bulb (WGB) temperature of 32° C (90 °F) as a maximum for the typical amount of time between work breaks (approximately 2 hours). If a WGB temperature is not available and the combined temperature and humidity seem excessive, sound judgment should be exercised regarding the length of time that an individual is exposed to the conditions.

Safety

Of all environmental factors relating to examinations, safety is the key issue. There are very few truly safe places in any industry; however, precautions can be taken to minimize potential hazards and risks involved.

Information obtained before the work is to begin can be used by inspection personnel to prepare for and lessen the potential risks. Knowledge about the actual item or component (i.e., physical size and shape), the location of the inspection, time of the inspection, and accessibility can help the inspection personnel gather the appropriate equipment to perform the task or have arrangements made for the necessary equipment to be provided.

Inspection personnel should also have knowledge of or access to the appropriate regulations concerning safety and all necessary personal protective equipment should be issued to them or it should be accessible.

Physiological Factors

Physiological variables that may influence the outcome of an examination are the physical comfort, health, and mental attitude of the inspector, fatigue, and the position of the test item to be examined in relation to the inspector.

Physical Comfort

Although physical comfort is determined by the tolerance of the person involved, a comfortable arrangement for the inspector will result in greater attention to detail and less attention to distractions and annoyances. An inspection performed from an awkward position, or from the same position for an extended period of time, may result in missed indications, because the inspector will tend to hurry the examination in order to return to a more comfortable position.

Health

Many physical conditions can affect one's eyesight. Some perceptual problems are inherited, some are affected by one's emotional state or circulation, and others may be the result of ocular structure deterioration due to tumors, cataracts, glaucoma, or hemorrhaging. Age also plays a role in vision. As one gets older, the accommodation response of the eye decreases due to a stiffening of the lens. This condition is called presbyopia, the inability to focus on near objects. Other factors that compromise inspection integrity include blurring, light sensitivity, watery eyes, pain, burning, or other discomfort. If these symptoms occur, a thorough eye examination is necessary.

Mental Attitude

The inspector's mental attitude may affect an inspection because preconceived mental images may be formed prior to the inspection. Preconceived mental images may alter the way in which an image entering the eye is perceived and interpreted, therefore, affecting inspection results.

Vision is a selective sense that is strongly guided by what the observer wants and expects to see. The intent of the inspector can affect perception if the inspector is looking only for certain aspects of a particular scene. Even though there is a large amount of information available at the time of viewing, many new characteristics may not be recognized until another viewing is performed. For example, a person may walk into a crowded room and immediately recognize a familiar face across the room while completely missing another familiar face that was not expected to be present. The same holds true for visual inspection. If an inspector is prepared to only find porosity on the surface of a weldment, fusion problems at the weld toes may be inadvertently ignored.

Fatigue

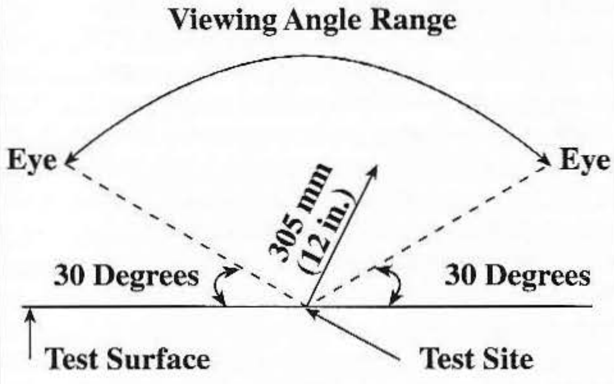
The effect that the general well being of the inspector has on VT cannot be overstated. Fatigue not only affects the overall physical feeling of the inspector, but it reduces the efficiency and accuracy of the interpretation of the visual data. Fatigue of the eye muscles, caused by poor illumination and awkward body positions, leads to oscillation of the eye and eyelids and causes ineffective examinations.

Test Item Position

The position of the item and its distance from the inspector has an effect on the inspection outcome. Again, the recommended viewing distance and angle for visual examination is to have the eye within 610 mm (24 in.) of the object and positioned at an angle not less than 30° to the inspection surface as shown in Figure 1.5. If the examination surface is immovable and situated so that the eye cannot be placed within this region, suitable visual aids, such as mirrors, must be used.

Elevated objects present another obstacle to proper examination. A component elevated to a point beyond the reach of the inspector cannot be thoroughly examined without adequate means to provide access except in cases such as component location or object verification.

Figure 1.5: The Lambert Cosine law



Recommended Reading

Subject	Reference*
material attributes	HB: 54-55; IES: 17-19
environmental factors	HB: 55-56
physiological factors	HB: 59-60; IES: 97-101

*See *Introduction* for explanation of references.

Equipment

Visual inspection equipment includes borescopes, fiberscopes, rules, calipers, mechanical gages, weld gages, magnifiers, mirrors, automated systems, computer-based systems, imaging systems, special optical systems, and closed-circuit television.

Borescopes

Rigid borescopes allow visual inspection to be performed on areas inside assemblies, on remote objects that are out of the normal inspection environment, or on remote objects or assemblies with restricted physical access. Using a system of lenses and prisms, borescopes can magnify the image of the area of interest while permitting examination. Light at the inspection site is provided by a bulb at the distal end of the scope or through a fiber optic bundle or liquid light guide from a remote, high-intensity light source. Borescopes are available in many diameters and working length combinations.

Borescopes can use a convex lens relay system, a hybrid rod and convex lens relay system, or a rigid glass rod, plus objective and ocular lenses. The convex lens relay system transmits images by relaying them from one lens to another along the length of the borescope.

The hybrid rod lens consists of a series of rod lenses to relay the image. Rod lens trains have an advantage over simple lens trains in that there are fewer refraction points resulting in less light scattering, and they may be made in smaller diameters, which in turn reduces the borescope diameter.

The slimmest borescope available uses a single rod to transmit the image along the length of the scope without the need for lenses. The image refracts within the rod at certain intervals similar to that with lenses. Because the diameter of the rod is minimized, the effective aperture is small and results in an infinite depth of field — eliminating the need for focusing.

Regardless of the light transmitting system used internally, borescopes also have lenses at each end of the scope. An objective lens at the distal end (far end) gathers the image light and relays it to the optical train. After the light has been relayed along the length of the scope, it is picked up by the ocular lens (eyepiece) and subsequently relayed to the eye. The ocular and objective lenses are made moveable on focusing scopes to compensate for observer eyesight differences, to expand the depth of field, and to present a crisp image to the viewer.

Fiberscopes

Fiberscopes are similar to borescopes because they allow access to normally inaccessible areas; however, they operate on a different principle. The borescope uses a system of lenses to transmit the image from the object to the eye, while the fiberscope uses a bundle of light transmitting fibers made of glass or quartz. This bundle is called the image guide. The flexible nature of the image guide gives the fiberscope the ability to negotiate bends and corners while the more rigid borescope can only travel in a straight path.

The fiberscope collects the image with an objective lens and relays the light through a bundle of extremely thin fibers, some as small as 8 µm (0.0003 in.). These fibers transmit light along their entire length by total internal reflection of the light within the fiber. This is possible because the fibers are coated with a thin layer of glass, which has a lower refractive index than that of the fiber. This causes the light to reflect within the strand without escaping into the air or into other adjacent fibers. Because each fiber transmits only a small portion of the image, the bundle must be arranged so that each fiber ends at the ocular lens in the same position it originates in at the objective lens. This is called coherent alignment, which allows for a cohesive image at the eyepiece. If the fibers were randomly placed at each end, the resultant image would be an unrecognizable jumble of dots or pixels.

Also, a fiberscope can be focused by a moveable objective lens, or fixed focus where the objective lens cannot be moved.

Light for the inspection area is generally provided by another bundle of fibers that transmits light produced by an external, high-intensity source. These fibers have a larger diameter than the image fibers and they do not need to be aligned coherently because they do not transmit an image.

An articulating tip is an optional piece of equipment that can be used on a fiberscope. Articulating tips are mechanical or pneumatic devices that allow the distal end of the scope to to achieve a greater field of view.

Visual Inspection Instruments

Many different instruments are available as aids in visual inspection. These instruments are used to determine length, diameter, height, surface texture, thread pitch, and many other characteristics that are not quantifiable by the eye alone.

Some common instruments that are useful for examination include the steel rule, caliper, mechanical gage, depth gage, weld fillet gage, Cambridge weld gage, and pit gage.

Rules

The simplest mechanical instrument for linear measurement is the 6 in. machinists steel rule. While accurate to 0.016 in. if applied properly, misinterpretation is common. Accuracy is also limited by the inherent width of the graduation etching itself.

To obtain accurate measurements with a steel rule, use the 1 in. mark for the beginning reference instead of the zero end, and then subtract 1 in. from the obtained dimension. This method is suggested because it is more difficult to align the zero end with the edge of the work piece than it is to align the graduations of the rule. Also, the possibility of unseen damage to the zero end of the rule could affect the measurement.

When performing the measurement, the rule should be aligned perpendicular to the test piece so the graduations are as close as possible to the measurement area as shown in Figure 1.6. This alignment also minimizes parallax error. Because steel rules have several scales with different graduations, attention should be paid to the selection of the proper scale to avoid approximation. If the measurement made with the selected scale falls between graduations, the next finer scale should be used.

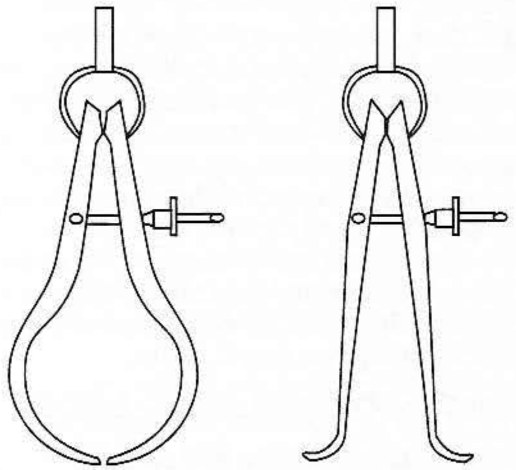
Steel rules come in lengths other than 6 in. and they can be made of rigid or flexible material.

Calipers

Calipers are are used to obtain accurate linear measurements. Calipers come in a wide variety of sizes and configurations for measuring length, width, height, diameter, and depth, and they can be either direct reading or indirect reading.

Indirect, or transfer type, reading calipers (Figure 1.7) are used to "transfer" the dimension of an item from the item to a steel rule. For example, the measurement of an outside diameter is made by adjusting the caliper so that both legs lightly touch the widest portion of the item. This distance is then transferred to a steel rule to obtain the measurement. If performed properly, this type of measurement is accurate to 1/64 in.

Figure 1.7: Indirect calipers



Direct reading calipers are available in a variety of types. A direct reading caliper can be simple — a rule with jaws for coarse measurements; or it could be of the vernier, dial, or electronic digital type, which are used for very accurate measurements, as shown in Figure 1.8. All types of direct reading calipers consist of a fixed jaw on a beam along which a moveable jaw slides. The measurements are taken with the item between the jaws of the instrument.

Dial and electronic calipers are simple to use and read. Electronic calipers are the easiest to read because the actual measurement is displayed on a digital readout. The dial caliper requires some interpretation between the beam scale, which is divided in graduations of

Figure 1.6: Steel rule

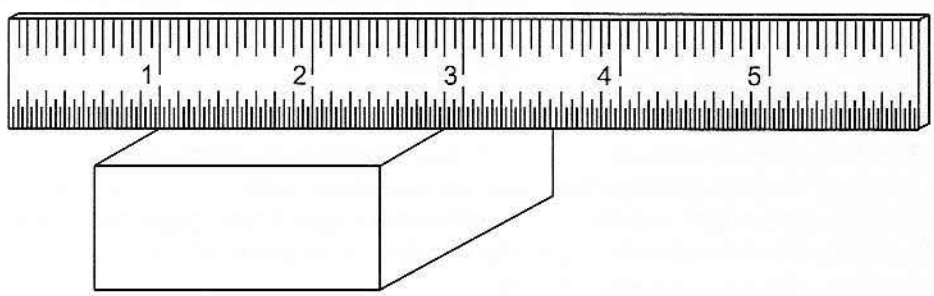
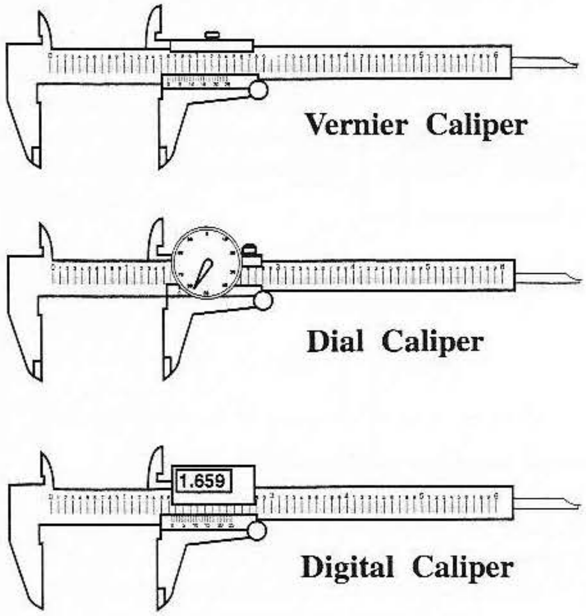


Figure 1.8: Vernier reading



0.1 in., and the rotating indicator on the dial that represents 0.1 in. for every revolution and is divided into 100 segments each representing 0.001 in.

Vernier calipers are more difficult to use because the scale used requires more care during interpretation. The vernier consists of the fixed main scale, which is etched into the beam, and the sliding vernier scale that is attached to the moveable jaw. Each inch of the main scale is divided into 10 equal divisions, which are further divided into quarters so that each graduation represents 1/40 in. The vernier scale on the sliding jaw is divided into 25 subdivisions and is arranged so that the total span of those 25 divisions equals the span of 24 divisions on the main scale. This is so that the difference between the divisions of each scale is 1/25 of a main scale division. Therefore, because the main scale divisions are 1/40 in., and the vernier scale division is 1/25 of the main scale division, the caliper is capable of reading to 1/1000 in. as 1/25th of 1/40th equals 1/1000 or 0.001 in.

To take a measurement with the vernier caliper, open the jaws larger than the maximum dimension of the item to be measured and slowly close the jaws around the item until light contact is made. For the greatest accuracy, the item must make even contact all along the thickness of the jaw faces. Note the number of inches and subdivisions of an inch that the zero mark of the vernier scale has passed. This gives a reading to 1/100 in. The additional thousandths are obtained by observing the graduation of the vernier scale that coincides with a graduation on the main scale, and adding this to the tenths obtained. Figure 1.9 shows a reading of 1.659 in.

Gages

Some gages that are commonly used during VT include mechanical gages, weld fillet gages, and Cambridge gages.

Mechanical Gages (Micrometers)

Mechanical gages perform extremely accurate measurements of linear dimensions. Mechanical gages are available in a wide variety of configurations for inside and outside measurements of flat, curved, threaded, and cylindrical dimensions. The mechanical gage is a form of caliper that operates by determining how far the end of a screw travels after one complete revolution.

To better understand the operation of the mechanical gage, it is useful to know the components of the instrument. This includes the frame, anvil, spindle, barrel, thimble, screw, ratchet, and clamp ring. These components are illustrated in Figure 1.10.

Measurement with the mechanical gage occurs between the anvil and spindle. The screw of the spindle has a thread pitch of 40 threads per inch, so 1 revolution of the screw equals 0.025 in. The thimble is divided around its circumference into 25 graduations, so that 1/25 of a revolution equals (1/1,000 in.) because 1/25 of 1/40 is 1/1,000. A 1 inch section of the micrometer barrel is divided into

Figure 1.9: Direct reading calipers

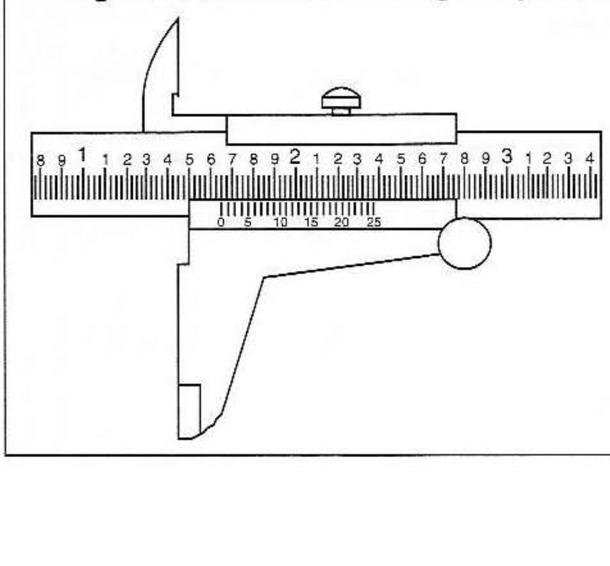
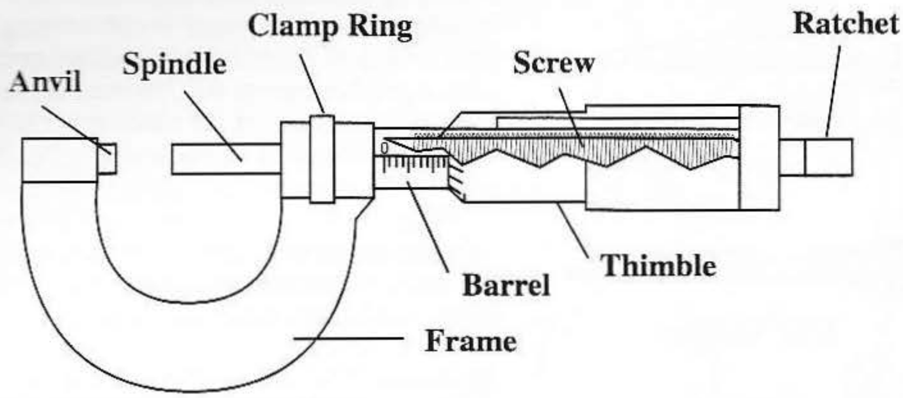


Figure 1.10: Mechanical gage (micrometer)

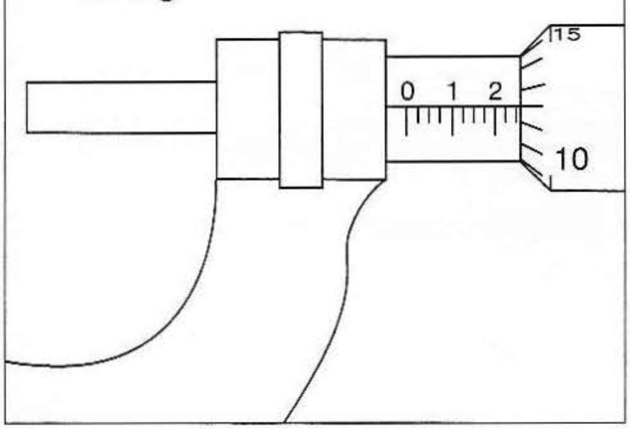


tenths of an inch, and each tenth is divided into four equal divisions. As the thimble is rotated counterclockwise, the spindle and anvil separate and the barrel graduations are revealed in succession.

To make a measurement with a standard mechanical gage, rotate the thimble counterclockwise until the spindle is a far enough away from the anvil to allow the item to be measured to fit in between them. With the part between the anvil and spindle, slowly turn the thimble clockwise to obtain contact between the anvil, part, and spindle. A gentle pressure is all that is necessary to make an accurate measurement — too much pressure could distort the frame reducing accuracy, and too little pressure could result in improper contact with the part, producing an inaccurate measurement. The part should be able to be rotated about the spindle axis with the feeling of a slight drag.

Barrel graduations are revealed by the outward travel of the thimble. To read the dimension, note the largest major division uncovered, the graduation closest to the thimble, and the thimble division aligned with the barrel reference line. Referring to Figure 1.11, the "2" or 0.2 in. division is revealed, and the closest graduation to the thimble is the second, or 0.05 in. and the "12" or 0.012 in. graduation on the thimble is aligned with the reference line of the barrel. Adding these together, 0.2 plus 0.05 plus 0.012 gives the dimension 0.262 in. as shown in Figure 1.11.

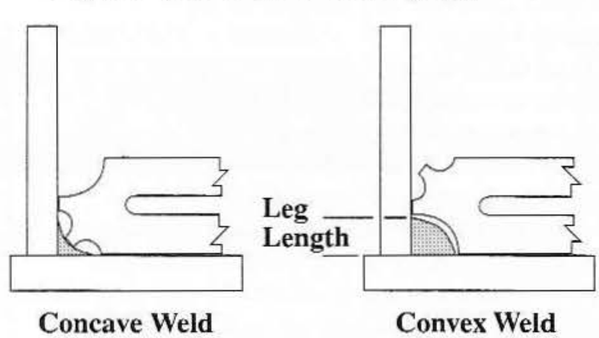
Figure 1.11: Mechanical gage reading



Weld Gages

A common tool used in visual examination of weldments is the weld fillet gage. This simple, easy-to-use device measures leg lengths and determines if there is sufficient throat in weld fillets. This gage is basically a comparator — the acceptable size is etched into the gage and arcs are cut into the gage to allow space for the weld bead. The gage is placed square against the welded components and the actual weld is compared to the standards of the gage as shown in Figure 1.12. This type of gage offers a quick and precise

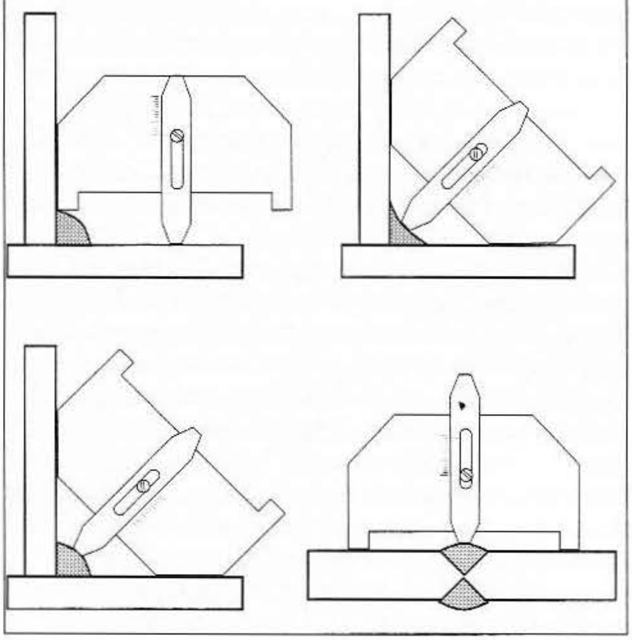
Figure 1.12: Fillet weld gage



means of measuring concave and convex fillet welds from 3 mm (0.13 in.) to 25 mm (1 in.).

The Palmgren weld gage, shown in Figure 1.13, can be used to measure the size of fillet welds, the actual throat size of convex and concave fillet welds, reinforcement of butt welds, and root openings of 8 mm (0.3 in.) and 3 mm (0.13 in.)

Figure 1.13: Palmgren weld gage



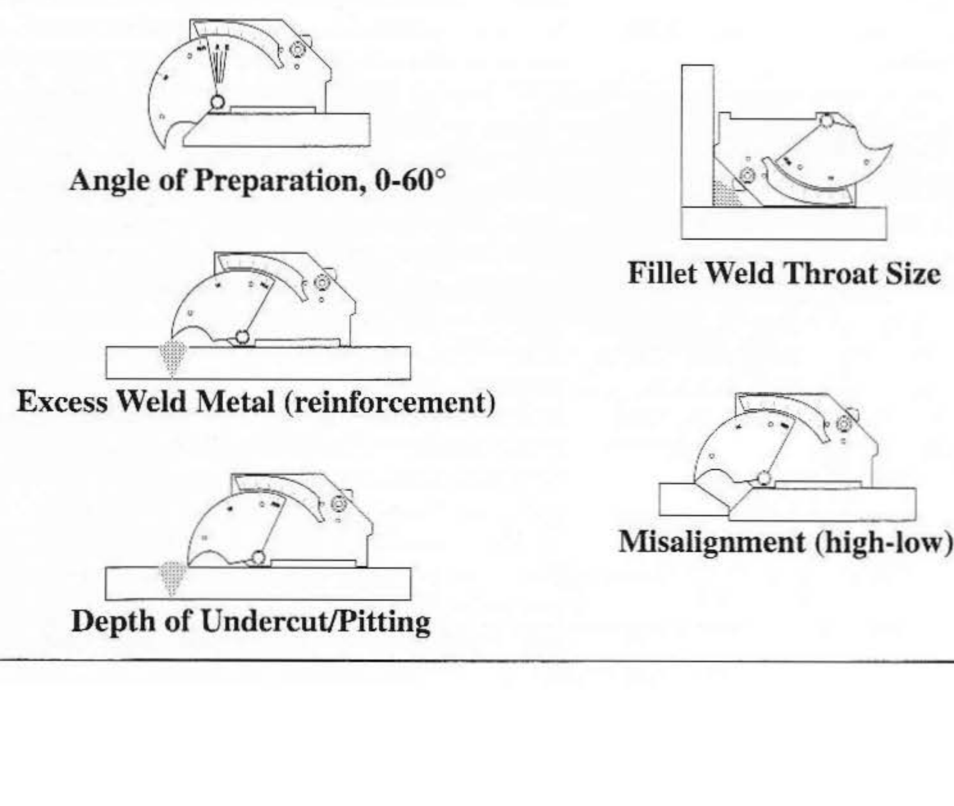
Another more versatile device used for weld inspection is the welding gage, commonly referred to as the Cambridge gage. The Welding Institute of Cambridge, England developed this versatile tool, hence the name. With this device, joint preparation angles, joint misalignment, weld fillet size and depth measurements can be easily obtained. Figure 1.14 shows some typical applications.

Magnifiers

Occasionally, the visual range of the human eye is not sufficient when observing for desired characteristics. In these cases, visual aids such as magnifiers are employed to enhance natural vision. Magnifiers are available in magnification powers that range from 1.5× to 2,000× with fields of view from 89 mm (3.5 in.) to 0.15 mm (0.006 in.). Resolving power can range from 0.05 mm (0.002 in.) to 2 µm (0.000008 in.). Microscopes, loupes, and optical comparators are variants of magnifiers.

When selecting magnifiers, the attributes of magnification power, working distance, and field of view should be considered. These are related in that a high power magnifier has a short working distance and narrow field of view. Conversely, a low power magnifier has a long working distance and wide field of view.

Figure 1.14: Cambridge gage



Mirrors (reflectors)

The use of mirrors is sometimes necessary when all or portions of the inspection area cannot be placed easily within the recommended viewing range (610 mm or 24 in. at 30°). Many types of inspection mirrors are available with articulating joints, extendible handles, and self-contained light sources to allow placement of the mirror and sufficient illumination at the inspection site.

Automated Systems

Automated visual examination systems make use of the recently developed "machine vision" that "sees" and interprets information about the test object. The apparatus examines the object with a vidicon camera or a charged-coupled device (CCD), laser, thermometer, etc., it processes the data in a microprocessor, it compares this data with a known acceptable example stored in memory, and it determines the acceptability of the object. Manufacturers using automated systems can obtain cost-effective, reliable inspections that are not affected by the vagaries of the human condition such as fatigue or attitude.

For example, the steel industry uses CCD cameras to scan hot slabs of steel for discontinuities as they pass by on roller tables. The automobile industry is using automated systems to examine the paint finish of automobiles for characteristics such as mottling, blotch, and distribution of the metal particles in metallic paint.

Computer-based Systems

Some visual examination systems use computers to enhance and manipulate the image of the test specimen. These instruments digitize the image and convert each picture cell (pixel) into a number, generally binary, which can be interpreted by computer software. Using this digitized image data, extremely accurate measurements are made of selected areas, and the image can be electronically enhanced to compensate for poor lighting or variations in surface texture. The digitized data may also be saved to a storage medium (magnetic tape, disk, etc.) for future retrieval.

Imaging Systems

The equipment used to obtain an image of a test surface and relay it electronically to a display device is called an imaging system. A videoprobe borescope is a good example of an imaging system. The videoprobe borescope combines a borescope with video processing technology, which reduces some of the difficulties encountered when using typical borescopes or fiberscopes. Difficulties such as eyestrain and operator fatigue, induced by the need to assume awkward positions, are lessened when the image is transferred from the eyepiece to a display such as a CRT video monitor. Imaging systems that combine a videoprobe with an image processor are ideal for displaying, manipulating, and storing obtained images.

Early imaging systems simply used a camera mounted on the eyepiece of a borescope or fiberscope, with the resulting image displayed on a monitor. Videoprobes place the camera in the distal end of the probe behind the objective lens, and connect a monitor in place of an eyepiece.

The videoprobe is similar in appearance to the fiberscope; however, the videoprobe uses fiberoptic strands only to deliver illumination to the observation site. Reflected light (the image) is collected on a CCD and transmitted as electric signals to the video processor. The signals are transmitted along a wire assembly (this replaces the fiberscope image bundle) to the video processor. The processor then decodes and amplifies the data for display on a CRT screen. Videoprobes are also available with pneumatic or mechanically operated articulating ends for a greater field of view.

The CCD is an array of semiconductor capacitors that gains a charge as photons of light impinge on them. Color is provided by a color wheel that rotates between the light source and light guide, or by placing a primary color filter over each chip and grouping the primary colors as a pixel of information. While both of these are effective at providing "false" color, the use of color filters requires a CCD approximately two times larger than sequential color lighting (use of the rotating wheel).

The operating system software installed in these units allows the operator to perform several functions — adjust the image (i.e., edge and contrast enhancement) and zoom of selected areas. Measurement capabilities are available, along with the ability to add text and pointers, compare selected images, and store, retrieve, and duplicate images. A character generator (keyboard) is provided with special function keys to facilitate the data entry and cursor functions.

Special Optical Systems

Optical flats and optical comparators are two common visual examination tools that are used to enhance certain characteristics of the item being examined.

Optical Flats

Optical flats are used to check the flatness of surfaces that require a high degree of accuracy. An optical flat is a cylinder of glass or quartz that has been made with one or more extremely flat surfaces. When applied to the inspection surface, any deviation of that surface will result in an air gap between the flat and the specimen, causing patterns to appear in the optical flat. These patterns are interference patterns created when light reflected from the inspection surface interferes with light transmitted through the flat.

Optical Comparators

Optical comparators are available in several varieties and they are used to compare a characteristic of the inspection surface to a known standard. Surface finish, threaded fasteners, and gear teeth are some of the conditions that may be inspected with comparators.

Some comparators are small enough to be taken to the inspection site, while others are large, stationary pieces of equipment into which test items must be placed. This type of comparator is also called a contour projector. The item to be inspected is placed in the unit and a light source behind the item projects a magnified shadow of the item onto a screen over which a standard profile is laid. A comparison is then made between the standard and the item.

Closed-circuit Television

Closed-circuit television (CCTV) uses a television camera tube to convert reflected light from the observed object into an electrical image that is transmitted and displayed on a cathode ray tube (CRT). Camera tubes are either the image orthicon tube that works by photoemission or the vidicon tube that works by photoconduction.

Photoemission occurs when electrons are emitted by a photosensitive surface that is stimulated by light. Photoconduction is the process by which the conductivity of the photosensitive surface changes in relation to the intensity of the light striking it.

Both processes produce an electric current that is the video signal. This signal is processed, amplified, and displayed on the CRT.

Recommended Reading

Subject	Reference*
borescopes	HB: 4-8, 82-89; ASM: 3-10
fiberscopes	HB: 82-89; ASM: 5-10
magnifiers	HB: 76-81; ASM: 10-11
mirrors (reflectors)	IES: 17-18
automated systems	HB: 128
imaging systems	HB: 95-96, 134-139; ASM: 5-8
special optical systems	HB: 131-144; ASM: 10-11
closed-circuit television	HB: 139

*See *Introduction* for explanation of references.

Discontinuities

VT is used to locate discontinuities in many stages during the manufacturing process. VT is commonly performed on castings, forgings, and welds and it is performed after machining processes as well.

Castings

Castings are made by pouring molten metal into a preformed mold. They are subject to various discontinuities inherent in the process. Typical casting discontinuities that appear on the surface include inclusions, porosity, hot tears, shrink cracks, and cold shuts.

Inclusions may result from the sand used to make the mold, slag from the poured metal, refractory materials, or other materials that do not melt and alloy with the molten metal. Inclusions appear anywhere on the surface and give the surface a rough, porous appearance.

Porosity is the result of gasses emanating from the molten metal that have been trapped during freezing.

Hot tears and shrink cracks are caused by an uneven rate of freezing of the metal or drastic changes in material thickness due to an irregular shape of the pattern. Hot tears and shrink cracks are usually evident in areas of tension such as corners, areas where portions of the casting are restrained, or areas where large thickness transitions occur.

Cold shuts are an incomplete fusion of the cast metal that results from an interrupted pour of metal, or in areas where freezing has occurred before the pour is complete. Cold shuts can appear anywhere on a casting but are generally found near an area of interrupted flow near the core.

Forgings

Forgings are made by placing a heated blank of metal between two dies and forming the blank into the finished part using great pressure or repeated blows. Several discontinuity types may be evident during visual examination, notably laps, bursts, and flash line tears.

Laps are produced when material folds over due to the forging process. The material is subsequently pressed down onto adjacent material but does not fuse due to surface oxidation. Laps can appear almost anywhere on a forging, but they usually appear along the flash line. A burst is a rupture of the material that occurs due to forging at an improper temperature or a drastic change in section thickness as the material is forced throughout the die. Flash line tears are cracks along the flash line caused by improper trimming of flash.

Machining Processes

A machining process performed on raw material as the name implies, forms machined components. Turning on a lathe, milling, grinding, drilling, and cutting are various machine processes, and may result in discontinuities. Grinding cracks result from excessive heat generated in the item during the grinding process and they appear as fine, tight cracks. Tears occur due to improper stock or tool bit speed and they result in a tearing of material rather than the desired cut.

Welds

Welding, the process of joining members together by applying enough heat to melt and fuse the material, results in a number of discontinuities apparent during visual examination. Porosity, cracks, slag, fusion, penetration, undercut, and overlap are the discontinuities that may appear on a completed weldment.

Porosity, as in the casting process, is the result of gasses emanating from the molten weld pool that are trapped during the freezing of the metal.

Cracks can occur due to the portion of the base material being restrained during the cooling process. As the weld metal cools it contracts, and any restraint may cause cracking.

Slag is the remains of the flux shielding used to protect the molten weld pool from atmospheric contaminants. If slag is not completely removed prior to depositing additional weld metal, it may get trapped in the weld. Slag appears as an elongated indication between weld beads.

Fusion is the melting and mixing of weld metal and base metal, or previous weld layers. If complete fusion does not occur, a linear indication may be evident between weld beads or between the weld bead and the base metal.

Penetration is the term used to define the degree to which the weld metal has entered the weld joint. Penetration is important for determining if the opposite side of the weldment is accessible to the inspector. A weld root that is at least as high as the base metal that blends smoothly with the base metal will evidence the correct amount of penetration. Undercut is caused by a failure of the weld metal to flow into the reduced area vacated by the melting base metal. This creates a notch type discontinuity at the transition between weld and base material or weld toe. Overlap occurs when the weld metal flows over the underlying material but does not fuse with it. The resulting notch type discontinuity produced results in a concentration of stresses at the base of the notch.

Visual Testing Documents

There are may types of documents involved in the regulation of VT examinations including codes, standards, and specifications, and others designed to record inspection results.

Welding Specifications

Because certain specifications require a more thorough examination of welds than simply observing for surface discontinuities, this section will discuss some of the more common welding symbols in use.

Welding symbols are used to represent the desired weld on a drawing, and the American Welding Society (AWS) has developed ANSI/AWS A2.4 to standardize welding symbols throughout industry. It should be noted that a "welding" symbol differs from a "weld" symbol in that a weld symbol indicates the type of weld while a weld symbol is incorporated into the welding symbol on the drawing. The welding symbol has many elements that describe the characteristics of the desired weld. Characteristics such as weld type, size, length, preparation, penetration, finish, and location are all delineated on the welding symbol.

Acceptance/Rejection Criteria

Due to the wide variety of accept/reject criteria among the different codes and specifications, it is impractical to list the differences and similarities this document. The inspector should be aware of the applicable governing document prior to performing the examination so that the appropriate criteria may be employed in determining acceptability.

Examination Results

VT examination results are recorded on forms designed for the purpose of permanently recording pertinent data regarding the examination procedure and results. Supplemental forms are available when the primary record is insufficient and sketch forms are available to record illustrations of specific items of interest for future reference.

Recommended Reading

Subject	Reference*
VT inspection of forgings/forging discontinuities	HB: 274-276; ASM: 498-499
VT inspection of castings/casting discontinuities	HB: 276; ASM: 512-521
VT inspection of welds/welding discontinuities	HB: 163; ASM: 582-591
VT inspection of machining processes	HB: 86
VT acceptance criteria	HB: 163-172
VT codes, standards, specifications	HB: 177-191

*See *Introduction* for explanation of references.

Chapter 1
Questions

Some questions in this section can only be answered after using the recommended references on page 5.

1. During visual fillet weld examination, the inspector would use:

   a. a fillet weld gage.
   b. a Palmgren weld gage.
   c. a Cambridge gage.
   d. all of the above.

2. Many video probe systems use a CCD to collect the light image at the inspection site. CCD stands for:

   a. Closed Circuit Device.
   b. Charged Coupled Device.
   c. Color Camera Detection.
   d. Cold Cathode Delivery.

3. A groove melted in the base metal at the toe of the weld during the welding process is called:

   a. underfill.
   b. undercut.
   c. a cold lap.
   d. lack of fusion.

4. A borescope transmits the light image collected at the inspection site:

   a. through a series of lenses and/or mirrors.
   b. through a light guide bundle.
   c. through electric signals.
   d. none of the above.

5. Seams and laps are longitudinal base metal discontinuities found in:

   a. cast products.
   b. rolled products.
   c. welded products.
   d. none of the above.

6. Forged products display two major types of discontinuities:

   a. laps and bursts.
   b. laps and laminations.
   c. hot tears and craters.
   d. shrinkage and cold shuts.

7. Which of the following welding methods uses a gas shielded continuous consumable electrode?

   a. GTAW.
   b. GMAW.
   c. SMAW.
   d. SAW.

8. Which of the following welding methods could produce a tungsten inclusion discontinuity?

   a. GTAW.
   b. GMAW.
   c. SMAW.
   d. SAW.

9. A groove weld symbol located on top of the reference line of the welding symbol indicates that the weld is to be located on:

   a. either side of the joint.
   b. the side of the joint the arrow points to.
   c. on the side of the joint opposite the side the arrow points to.
   d. on both sides of the joint.

10. The graduations etched on the thimble of a micrometer are in:

   a. 1/100 in.
   b. 1/40 in.
   c. 1/1,000 in.
   d. 1/10 in.

11. In a normal, healthy eye the incoming light is focused on the:

   a. fovea.
   b. iris.
   c. optic disk.
   d. cornea.

12. When examining objects of substantial size:

   a. a scanning plan should be formed and followed.
   b. glare should be increased.
   c. the use of mirrors and magnifiers is prohibited.
   d. partial examination is acceptable.

13. The component of the eye that responds to light intensity and gives the eye its color is the:

   a. cornea.
   b. lens.
   c. retina.
   d. iris.

14. The result of gasses becoming trapped in molten metal during freezing is called:

   a. slag.
   b. burst.
   c. porosity.
   d. shrink.

15. The element of the welding symbol where specifications or other reference items may be placed is called the:

   a. reference line.
   b. tail.
   c. arrow.
   d. weld symbol.

16. Incomplete penetration occurs at the:

   a. root of the weld.
   b. face of the weld.
   c. toe of the weld.
   d. end of the weld.

17. The best equipment to use to measure the inside diameter of a pipe or tube would be a:

   a. micrometer
   b. cambridge gage
   c. comparator
   d. dial caliper

18. A joint that is considered to be two members to be joined lying in parallel on the same plane is called a:

   a. butt joint.
   b. corner joint.
   c. edge joint.
   d. lap joint.

19. Laminations would most likely occur in:

   a. castings.
   b. forgings.
   c. plate.
   d. all of the above.

20. The main difference between a borescope and fiberscope is that:

   a. a borescope is rigid and transmits light through a system of lenses, a fiberscope is flexible and transmits light through a bundle of fibers.
   b. a borescope is flexible and transmits light through a system of lenses, a fiberscope is rigid and transmits light through a bundle of fibers.
   c. a borescope will supply light to the inspection site, the fiberscope will not.
   d. borescopes are available in only one basic length, fiberscopes are available in various lengths.

21. If there is a substantial thickness transition in a casting, the result may be:

   a. a cold shut.
   b. a hot tear.
   c. lamination.
   d. porosity.

22. Porosity, pipe, and other inclusions remaining in the original ingot after cropping may be modified after rolling into plate form. If this type of discontinuity is not fused together during rolling, it becomes:

    a. a cold shut.
    b. a hot tear.
    c. lamination.
    d. porosity.

23. Shielding gas used in the GTAW welding process is used to:

    a. prevent the weld from cooling rapidly.
    b. protect the weld from arc blow.
    c. protect the molten weld from atmospheric contaminants.
    d. accomplish all of the above.

24. To provide color to the light used with the videoprobe which of the following could be used:

    a. a color monitor.
    b. a color wheel.
    c. a color camera.
    d. a color form.

25. Forged products are manufactured using:

    a. dies.
    b. molds.
    c. rams.
    d. punches.

26. Visible light is one of the radiation types graphically represented on:

    a. the periodic table.
    b. the electromagnetic spectrum.
    c. the IES lighting table.
    d. none of the above.

27. The flux on a SMAW welding electrode is used for:

    a. introducing alloying elements.
    b. controlling the rate of cooling.
    c. protecting the molten weld metal from atmospheric contaminates.
    d. all of the above.

28. Which of the following are visual examination methods?

    a. Direct and indirect.
    b. Shear and longitudinal.
    c. Manual and automatic.
    d. Visible and fluorescent.

29. In a blast furnace, pig iron is the result of combining:

    a. silica, soda ash, and limestone.
    b. iron ore, coke, and limestone.
    c. bauxite and caustic soda.
    d. magnesite and zinc.

30. To detail which member is to receive any preparation, which of the following is used on a welding symbol?

    a. A note in the tail.
    b. The reference line.
    c. A break in the arrow.
    d. A flag at the intersection of the arrow and reference line.

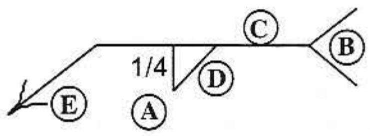
31. Failure to adequately remove the residual flux from a previously deposited weld bead prior to deposition the next layer can result in:

    a. slag.
    b. porosity.
    c. a crater crack.
    d. incomplete penetration.

32. The size of a convex fillet weld refers to the:

    a. width of the face.
    b. total length of the fillet.
    c. leg length.
    d. sum of the leg lengths.

Figure Q.1



For questions 33-35, please refer to Figure Q.1.

33. The tail is shown by:

    a. A.
    b. B.
    c. C.
    d. D.
    e. E.

34. The reference line is:

    a. A.
    b. B.
    c. C.
    d. D.
    e. E.

35. The weld size is:

    a. A.
    b. B.
    c. C.
    d. D.
    e. E.

36. A Cambridge gage may be used to:

    a. verify bevel angle.
    b. measure weld reinforcement.
    c. measure undercut.
    d. do all of the above.

37. A soft drink can is produced by:

    a. forging.
    b. casting.
    c. rolling.
    d. extrusion.

38. SMAW is commonly referred to as:

    a. MIG welding.
    b. TIG welding.
    c. Stick welding.
    d. Sub-arc welding.

39. If the focal point of the light entering the eye falls in front of the retina the result is:

    a. hyperopia (far-sightedness).
    b. myopia (near-sightedness).
    c. astigmatism.
    c. presbyopia.

Chapter 1
Answers

1.	d	11.	a	21.	b	31.	a
2.	b	12.	a	22.	c	32.	c
3.	b	13.	d	23.	c	33.	b
4.	a	14.	c	24.	b	34.	c
5.	b	15.	b	25.	a	35.	a
6.	a	16.	a	26.	b	36.	d
7.	b	17.	d	27.	d	37.	d
8.	a	18.	a	28.	a	38.	c
9.	c	19.	c	29.	b	39.	b
10.	c	20.	a	30.	c		

Chapter 2
Procedure Comprehension and Instruction Preparation (PCIP) Examination

Overview of the PCIP Examination Process

Candidates for ASNT Central Certification Program (ACCP) Level II certification come from different industries with differing experiences and unique terminology regarding what constitutes written directions that guide an individual in performing a nondestructive test. Some of the terms that may be familiar are procedure, instruction, job card, technique, and practice; often words like "specific" and "general" appear with these terms to further define the level of detail these written directions convey. To maintain consistency within the ACCP examination process, ASNT adopted a particular set of terms. The following description of these terms is presented to familiarize the candidate with the ACCP examination terminology.

Definitions of PCIP Examination Terminology

Specification

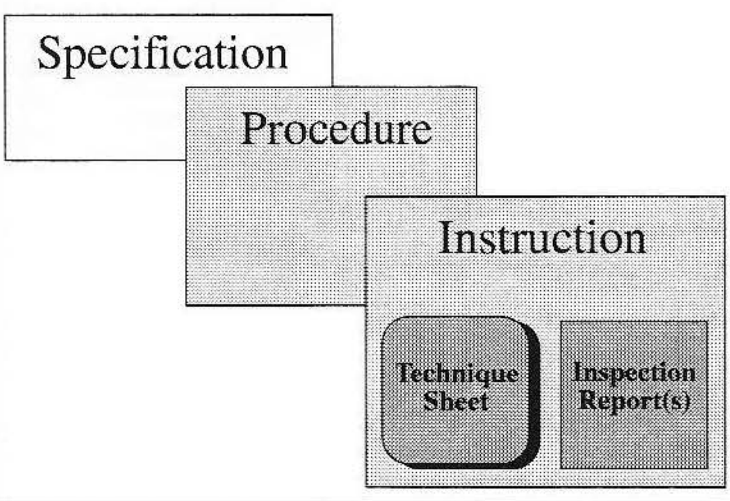
Figure 2.1 shows the hierarchy of ACCP documents. It begins with a specification that is usually received from a client and it often references a national standard or code. A specification is a list of requirements and qualifying conditions for the test object and the NDT that is to be performed on the test object. For the purposes of the ACCP, the specification is not significant; however, the Level II candidate should understand what a specification is in relationship to the other ACCP documents.

Procedure

A procedure is a written description that establishes minimum requirements for performing an NDT method on any object and it is written in accordance with established standards, codes, or specifications. A procedure is written by certified Level III personnel in that NDT method for which the procedure applies. Its primary purpose is for use in developing NDT instructions. A procedure may be used to perform an NDT technique; however, due to its rather general nature concerning requirements, conditions, and limitations for an NDT method, it demands greater knowledge, some interpretation, and judgment on the part of the inspector in order to develop a specific NDT technique and apply it to a specific part.

The PCIP portion of the ACCP Level II General Written Examination requires a candidate to read and comprehend a procedure. Because Level III personnel prepare procedures

Figure 2.1: The hierarchy of ACCP documents – note that the technique sheet and inspection report are integral parts of the instruction



within the ACCP, each procedure will be different. However, a procedure will generally have a structure similar to the following:

1. scope,
2. references,
3. personnel certification requirements,
4. equipment and materials requirements,
5. calibration and verification requirements,
6. part preparation requirements,
7. test sequence requirements,
8. interpretation and evaluation requirements,
9. documentation requirements,
10. instruction and technique sheet requirements, and
11. post-inspection requirements.

Instruction

An instruction is a description of the steps to be followed when performing an NDT technique on a specific part or a set of similar parts, developed in conformance with a procedure. An instruction is written by personnel certified to at least Level II in that NDT method for which the instruction applies. Its primary purpose is to provide sufficient direction to enable Level I and Level II personnel, as applicable, to perform an NDT technique that yields consistent and repeatable testing results. While a procedure is generally written around an NDT method, an instruction provides specific details concerning a particular technique for a given NDT method. An instruction is also valuable because it reduces or eliminates different inspector interpretations of a procedure or divergent NDT techniques performed on the same test object. A technique sheet and an inspection report are integral parts of an instruction.

An instruction usually contains a scope, information about personnel/equipment and material/calibration, and the test sequence.

The scope identifies the procedure (the minimum requirements) to which the instruction applies as well as any conditions that apply before the inspection is to be conducted. For example, a scope might indicate that heat treating, forming, and hydro-testing processes be performed before the inspection and that preapproval of approaches and agreements to exclusions should be negotiated. The title or the scope should indicate the NDT method and technique of interest.

The personnel/equipment and materials/calibration categories are addressed under separate headings or within other areas of the instruction such as the test sequence or the technique sheet as appropriate. While some techniques are relatively simple and require less headings, others are complex and require a greater number of headings to sufficiently inform the inspector of the necessary details.

The test sequence is the step-by-step listing of actions that are to be taken in the order in which they are to be carried out. Generally, each step is an action and it should begin with a verb such as "prepare," "conduct," "verify," "interpret," or "report." To guide the candidate in performing the inspection, reference to the applicable technique sheet should be made where quantitative or graphical information is to be used.

Technique Sheet

A technique sheet identifies all of the parameters required to set up the technique for which the instruction applies. A technique sheet should have a diagram that shows the test object and pertinent areas of inspection. It may be necessary to present more than one view to adequately inform other inspectors of the set-up. The part's identification and acceptance criteria are also present on the technique sheet.

Included in a technique sheet are:

1. equipment settings;
2. part identification, material, and other unique information;
3. areas of inspection interest;
4. acceptance criteria; and
5. identification and certification of the individual who developed and wrote the instruction, the date it was written and revised, and it should be cross referenced to the applicable instruction.

Further, a technique sheet accompanies any instruction and identifies all parameters required to set up the technique for which the instruction applies. Technique parameter requirements are to be incorporated into a technique sheet that, when used by a qualified Level II or Level I, will address the operational parameters necessary to conduct the inspection. The text of the instruction, being broaderbased, identifies all of the steps to be taken including nonquantitative matters such as the general administration of the test and the recording of test results. The generally qualitative text of the instruction follows the generally quantitative, technical requirements listed in the technique sheet. Specific quantitative values, or values of limited extent, are to be used in the technique sheet (as opposed to the broad allowable ranges commonly found in standards and procedures).

A typical listing of the contents of a VT technique sheet for examining austenitic welds is shown in Table 2.1.

VT equipment and applications will vary considerably by technique. Details concerning light levels, gages, and other miscellaneous equipment are all necessary. See Figure 2.2 (page 35) for a sample technique sheet.

Inspection Report

An inspection report usually identifies all detected discontinuity indications and whether they have been interpreted as relevant or nonrelevant. Identified relevant indications are evaluated as acceptable or rejectable in accordance with the part's acceptance criteria. The inspection report should include the location, direction, and dimensions of all rejectable indications detected on the part(s), and the identification of the rejectable part(s). The inspection report may include the location, direction, and dimensions of all acceptable indications detected on the part(s).

Forms used for reporting inspection results, logging actions, and other record keeping and administrative actions are to be addressed in the instruction. The forms to be used in recording the results of the inspection should be identified and included as attachments to the instruction, because they are required actions while performing NDT to an instruction. A typical listing of the contents of a VT report is shown in Table 2.2.

While a procedure is generally written around an NDT method, an instruction provides specific details concerning a particular technique for a given NDT method.

For each instruction there is an accompanying technique sheet and inspection report. The instruction identifies and details all information not on the technique sheet. The instruction's quantitative details are contained in the technique sheet and not in the instruction's general text. See Figure 2.3 (page 36) for a sample instruction report.

Figure 2.4 (page 37) summarizes the contents of a specification, a procedure, an instruction sheet, a technique sheet, and an inspection report.

Table 2.1: VT technique sheet for the examination of austenitic welds

Categories	Relevant Information (as applicable)
Test part	identification, model, material, product form
Authorization	contract number, drawing number, instruction number
Equipment and materials	7× magnifier, 152 mm (6 in.) rule, Palmgren weld gage
Sketch of part/setup	reference markings, areas of interest
Acceptance criteria	relevant and nonrelevant indications, acceptable/rejectable indications, length, diameter, groups, particular discontinuities of interest
Part preparation	cleaning
Author's identification	name, level, date, revision

Table 2.2: VT report form for the examination of forged materials

Categories	Relevant Information (as applicable)
Test part	identification, model, surface condition
Authorization	instruction number, technique sheet number
Calibration and verification	lighting
Coverage	areas inspected (in.^{2}, ft^2, etc.)
Test results	rejectable indications, sizes, locations, etc.
Sketch of results	location, orientation, etc.
Inspector	name, level, date, revision

Format of the PCIP Examination

The PCIP portion of the ACCP Level II General Examination examines the candidate's ability to comprehend a procedure and requires the candidate to demonstrate the ability to prepare an instruction for NDT personnel with respect to a given procedure and technique parameters. However, during the examination the candidate is not required to write an instruction from beginning to end. Instead, a technique sheet and an inspection report form are provided so the candidate can extract information from the given procedure, make technique judgments, and then complete the appropriate areas on the technique sheet and inspection report. The candidate's comprehension of the given procedure and his/her ability to prepare instructions is further assessed by approximately 30 multiple-choice questions (these multiple-choice questions are in addition to the minimum of 60 multiple-choice General Examination questions that assess the candidate's knowledge of fundamentals and principles in the method). Figure 2.5 (page 38) graphically presents the PCIP portion of the Level II General Examination in relation to the entire Level II General Examination.

Figure 2.2: Sample technique sheet

Technique Sheet

Material:	Carbon Steel	**Instruction No.:**	1-100-VT
Form:	Casting	**Candidate:**	John Smith
Part Identification No.:	C-431-00	**Date:**	07-10-98

Equipment and Materials

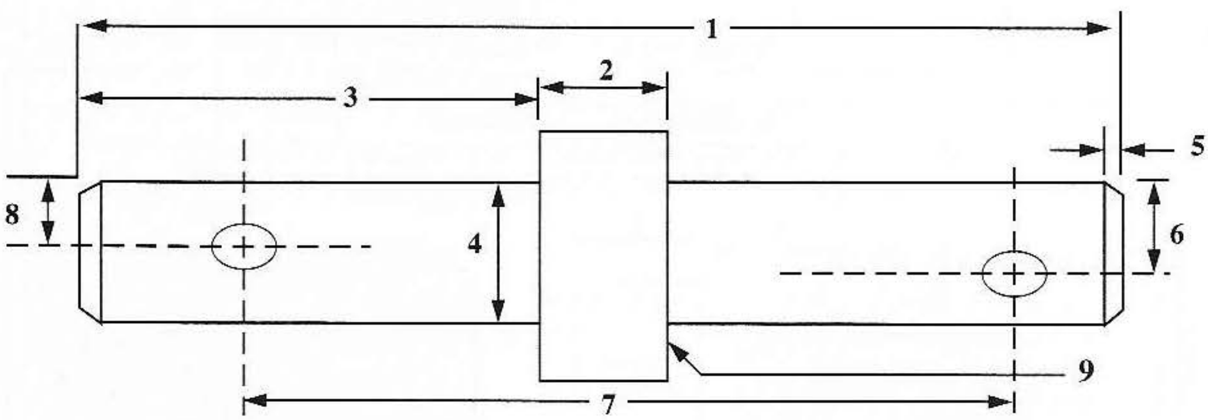
Lighting Source:	Ambient	**Rule:**	305 mm–0.8 (12 in.–1/32) increments
Light Intensity Meter:	serial #1010	**Micrometer:**	0-76 mm (0-3 in.)
Comparator:	N/A	**Borescopes:**	N/A
Mirror:	N/A	**Gages:**	N/A
Magnifier:	7×	**Bevel Protractor:**	N/A
Calipers:	152 mm (6 in.)/digital	**Square Head:**	N/A

Visual Test Parameters

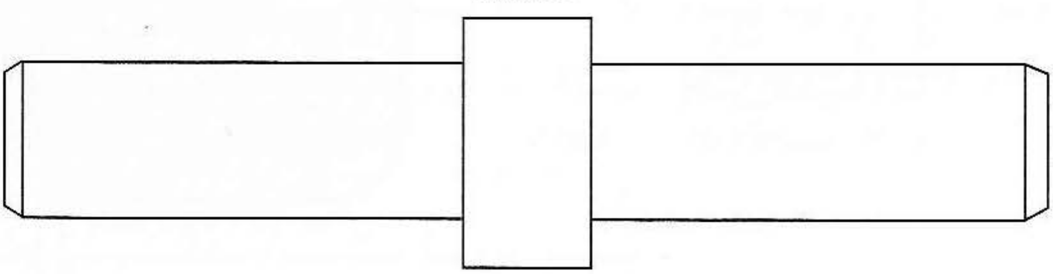
Working Sight Distance:	610 mm (24 in.)
Angle of Sight:	45 degrees
Light Intensity at Surface:	1076 lx (100 ftc)

Sketch

Area(s) to be tested/measured



Side A*



Side B*

*** Note: 100% coverage – no cracks, cold shuts, or hot tears allowed.**

Figure 2.3: Sample inspection report

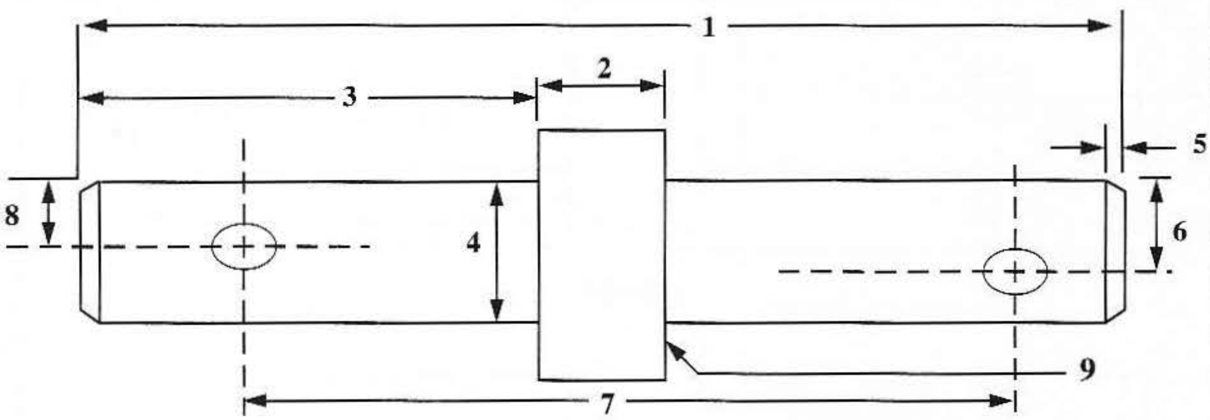
Inspection Report

Part Identification No.: C-431-00 **Instruction No.:** I-100-VT **Candidate:** John Smith

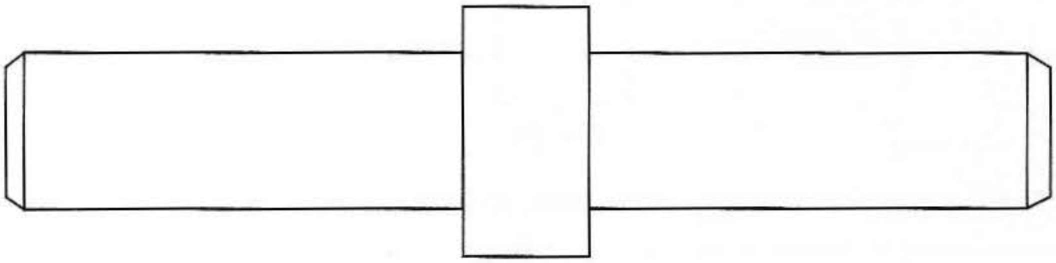
Acceptance Criteria (paragraph): ☒1.0 ☐2.0 ☐3.0 ☐4.0 ☐5.0 **Date:** 07-10-98

Table 1: Discontinuities/Measurements

Indication # (on sheet below)	Discontinuity Description	Measured Size/Attributes	Allowable Size/Attributes	Accept	Reject
1	–	279 mm (11 in.)	279 mm (11 in.) ± 1.6 mm (0.06 in.)	X	
2	–	25 mm (1 in.)	25 mm (1 in.) ± 1.6 mm (0.06 in.)	X	
3	–	127 mm (5 in.)	127 mm (5 in.) ± 0.8 mm (0.03 in.)	X	
4	–	79 mm (3.1 in.)	76 mm (3 in.) ± 1.6 mm (0.06 in.)	X	
5	–	6 mm (0.25 in.)	4.8 mm (0.2 in.) ± 0.8 mm (0.03 in.)		X
6	–	51 mm (2 in.)	51 mm (2 in.) ± 0.4 mm (0.02 in.)	X	
7	–	229 mm (9 in.)	229 mm (9 in.) ± 1.6 mm (0.06 in.)	X	
8	–	38 mm (1.5 in.)	38 mm (1.5 in.) ± 0.4 mm (0.02 in.)	X	
9	crack	81 mm (3.2 in.)	not allowed		X



Side A



Side B

Figure 2.4: Contents of a *Specification*, a *Procedure*, an *Instruction Sheet*, a *Technique Sheet*, and an *Inspection Report*

Specification

- What and where to inspect
- How to inspect (usually to a referenced code or standard)
- Acceptance criteria (if not in the reference materials)
- What and how to report results
- Who can inspect (certification)

Procedure

- Minimum requirements for the NDT method in general, including technique limitations:
  - Scope
  - References
  - Personnel certification requirements
  - Equipment and materials requirements
  - Calibration and verification requirements
  - Part preparation requirements
  - Test sequence requirements
  - Interpretation and evaluation requirements
  - Marking, reporting, and other documentation requirements
  - Requirements for instructions including technique sheets and inspection reports
  - Post-inspection requirements

Instruction

Description of the steps to be followed when performing an NDT technique (developed in conformance with a procedure)

Technique Sheet

- Test part identification
- Authorization
- Inspection areas of interest
- Part diagrams
- Equipment and materials
- Equipment settings
- Details of processing
- Acceptance criteria
- Cleaning/part preparation
- Other unique information
- Author's name, certification, and date

Scope

Test sequence

Other categories as necessary

Inspection Report(s)

- Test part identification
- Authorization
- Equipment and materials
- Calibration and verification
- Coverage
- Test results
- Sketch of results
- Other unique information
- Inspector's name, certification, and date

Figure 2.5: PCIP portion of the Level II General Examination in relation to the entire Level II General Examination

Level II Visual and Optical Testing General Examination

Part A (general multiple-choice portion)

- answer 60 multiple-choice questions that assess the candidate's knowledge of fundamentals and principles

Part B (PCIP portion)

- provided with a procedure and supplementary information such as acceptance criteria
- complete technique sheet and inspection report
- answer 30 multiple-choice questions

Chapter 3
Level II Hands-on Practical Examination

Overview of the Level II Hands-on Practical Examination

The Level II Hands-on Practical Examination assesses the candidate's ability to perform visual and optical testing, including the capability to interpret and evaluate test results. There are two categories of Hands-on Practical Examinations, a General Hands-on Practical Examination and a Specific Hands-on Practical Examination. An additional examination associated with the Specific Hands-on Practical Examination is the Specific Written Examination.

General Hands-on Practical Examination

The General Hands-on Practical Examination requires the candidate to perform NDT using different types of equipment and materials in the visual and optical testing method on a number of different product forms, some of which contain discontinuities. This Practical Examination is intended to qualify the candidate's ability to perform NDT over a range of applications. The matrix shown in Figure 3.1 lists the detailed requirements that the candidate must satisfy during the Practical Examination. The matrix allows some flexibility on the part of the candidate in choosing the combination of techniques and product forms for the Practical Examination; however, the number of actual test specimens is determined by ASNT.

Each combination in Figure 3.1 involves a particular visual and optical testing instruction including a technique sheet and an inspection report. The candidate will be expected to use each applicable instruction (with technique sheet and inspection report) to perform applicable calibration and/or system performance verification, to perform applicable VT, and to detect applicable relevant and/or nonrelevant discontinuities. The candidate will complete the inspection report and document significant test parameters along with the location, orientation, and size of the indications. The candidate will then apply the given acceptance criteria and evaluate the discontinuity indications. The key difference between the General Hands-on Practical Examination and the Specific Hands-on Practical Examination is that the General Hands-on Practical Examination is intended to qualify the candidate's ability to perform NDT over a broad range of applications.

Specific Hands-on Practical Examination

The Specific Hands-on Practical Examination may be required by an industrial sector (an industrial sector is an industry, product form or area of technology that possesses common characteristics with respect to NDT considerations) and it is similar to the General Hands-on Practical Examination except that it is intended to qualify the candidate's ability to perform NDT over a limited range of specialized applications. Specific Hands-on Practical Examinations exist because an industrial sector has unique NDT considerations not normally encountered outside of that particular industry.

For example, if the foundry or metal casting industry determines that NDT technicians perform a limited number of VT techniques to unique codes, standards, or specifications for the purpose of detecting particular discontinuities that have little in common with other product forms or manufacturing processes, then it would be desirable for them to establish an industrial sector. Henceforth, as an industrial sector, there would be a Specific Hands-on Practical Examination that might involve a number of different metal castings (alloy, process, geometry) and different VT techniques.

Figure 3.1: Matrix of possible combinations of visual and optical testing techniques, product forms, and corresponding instructions for Level II General Hands-on Practical Examinations

Visual Testing Method (VT) Matrix Selection Form

Make selections by placing an **X** in the appropriate spaces of the following table in accordance with the corresponding criteria (see below). Those spaces of the table that are blackened out *are not* available selections. Please note that ALL candidates are required to perform visual examination of welds.

Table 1: Matrix of possible combinations of techniques and product forms for visual General Hands-on Practical examination.

Product Forms	**Examination Techniques**	
	Direct	**Remote**
Welds		
Castings		
Forgings		
Pipe/Plate/Sheet		

Criteria

The candidate must perform a visual examination on three (3) of the four (4) different product forms, including welds. The candidate must use direct visual examination techniques on all three (3) selected product forms and must use at least one (1) remote visual examination technique on one (1) of the selected product forms.

After completing this form ensure that it has been filled out correctly by completing the following checklist. *This checklist includes the one required box already marked for you.* If any of the following items cannot be answered with a "yes," then the matrix has been incorrectly filled out and requires further attention.

1. Only four (4) spaces in the matrix are marked with an **X**. ☐ yes
2. Three (3) different product forms have been selected. ☐ yes
3. At least one (1) "welds" space has been selected. ☐ yes
4. Three (3) direct visual technique spaces have been selected. ☐ yes
5. One (1) remote visual technique space has been selected. ☐ yes

Some of the tools that candidates should be proficient with are: 1. micrometer, 2. rule, 3. caliper (Vernier, dial, and digital) 4. square head, 5. bevel protractor, 6. rigid borescope, 7. flexible fiber optic borescope, 8. hand held optical comparator, 9. mirror, 10. magnifier, 11. depth gage (dial gage), 12. thread gage, 13. pitch gage, 14. AWS or Palmgren weld gage, 15. Cambridge gage, 16. hi/lo gage, (Gal or Dearman gage), 17. fillet gage, 18. light meter, and 19. surface finish comparator.

Specific Written Examination

The Specific Written Examination may be required by an industrial sector in conjunction with either a General Hands-on Practical Examination or Specific Hands-on Practical Examination. The Specific Written Examination assesses a candidate's specific knowledge of practices and techniques unique to the industrial sector, including applicable procedures, codes, standards, specifications, test equipment, and materials.

Continuing with the foundry or metal casting industrial sector example, it would be the Specific Written Examination that would assess a candidate's knowledge and understanding of applicable procedures, codes, standards, specifications, test equipment, and materials as they are used in testing practices and techniques unique to this industrial sector. An industrial sector may even request that this examination be used for assessing the candidate's knowledge of particular variations of industrial sector manufacturing processes as they relate to discontinuities.

Continuing with the foundry or metal casting industrial sector example, casting discontinuities, as a result of green-sand molds, can be quite different than those as a result of dry-sand molds and the candidate may need to know this to accurately perform interpretation and evaluation of casting discontinuity indications.

Appendix 1
Sample Visual and Optical Testing Examination Acceptance Criteria

The Sample Visual and Optical Testing Examination Acceptance Criteria is intended as reference material for the examinee. The examinee will be given a Specific Visual and Optical Testing Acceptance Procedure for the performance of his/her practical examination in the product forms chosen in Figure 3.1 (page 40).

Castings

Linear Indications

1. 8 mm (0.3 in.) long for materials up to 13 mm (0.5 in.) thick;
2. 13 mm (0.5 in.) long for materials 13-25 mm (0.5-1 in.) thick;
3. 18 mm (0.7 in.) long for materials over 25 mm (1 in.) thick.
4. For linear indications, the indications must be separated by a distance greater than the length of an acceptable indication. A linear indication is one with length in excess of 3 times the width.

Rounded Indications

1. 8 mm (0.3 in.) diameter for materials up to 13 mm (0.5 in.) thick;
2. 13 mm (0.5 in.) diameter for materials over 13 mm (0.5 in.) thick.
3. Four or more rounded indications in a line separated by 3 mm (0.1 in.) or less edge to edge are unacceptable. Rounded indications are those not defined as linear indications.

Welds or Forgings

Only imperfections producing indications with major dimensions greater than 2.5 mm (0.063 in.) shall be considered relevant imperfections.

Linear Indications

1. 5 mm (0.2 in.) long for materials 13 mm (0.5 in.) or less thick;
2. 10 mm (0.4 in.) long for materials over 13-25 mm (0.5-1 in.) thick;
3. 15 mm (0.6 in.) long for materials over 25 mm (1 in.) thick.
4. For linear indications, the indications must be separated by a distance greater than the length of an acceptable indication. A linear indication is one with length in excess of 3 times the width.

Rounded Indications

1. 5 mm (0.2 in.) diameter for materials up to 13 mm (0.5 in.) thick;
2. 8 mm (0.3 in.) diameter for materials over 13 mm (0.5 in.) thick.
3. Four or more rounded indications in a line separated by 3 mm (0.1 in.) or less edge to edge are unacceptable.
4. Ten or more indications in any 15 cm^2 (6 $in.^2$) of area whose major dimension is no more than 15 cm (6 in.) with the dimensions taken in the most unfavorable location relative to the indications being evaluated are unacceptable.
5. Rounded indications are those not defined as linear indications.

Appendix 2
Standard Terminology for Visual and Optical Testing and Materials Processing

Accommodation – The process by which the eye changes focus from far to near objects.

Achromatic – Lacking any amount of a chromatic primary.

Acuity – See **Vision acuity**.

Adaptation – The process by which the retina becomes accustomed to more or less light than it was exposed to during an immediately preceding period. It results in a change of the sensitivity of the eye to light.[1]

Adhesive bonding – A materials joining process in which an adhesive, placed between the faying surfaces (adherends), solidifies to produce an adhesive bond.[5]

Aliasing – Visible as jagged effects on the vertical edges of the image and occurs in a static image when the scan or sample rate is too low for the frequency being digitized.

Ambient light – Light in the environment, as opposed to illumination, provided by a visual or optical testing system.[2]

Angstrom unit (Å) – Unit of length, equal to 0.1 nm.[2]

Arc strikes – Localized burn damage to an object from the arc caused by breaking an energized electric circuit. Also called arc burns.[4,6]

Arc welding – See **Electric arc welding**.

Aspect ratio – The ratio of the width of the raster to its height.

As-welded – The condition of the welded metal, welded joints, and weldments after welding but prior to any subsequent thermal, mechanical, or chemical treatments.[5]

Austenite – A solid solution with iron as the solvent in a face centered cubic structure formed by slow cooling of delta ferrite. Characteristic lattice structure is stable between 906 °C (1663 °F) and 1,390 °C (2535 °F). Also called gamma iron.[2]

Automatic welding (AU) – Welding with equipment that performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work. See **Machine welding (MA)**.[5]

Back gouging – The removal of weld metal and base metal from the other side of a partially welded joint to ensure complete penetration upon subsequent welding from that side.[5]

Background – Short for electrical background noise. Signals from a test object that create noise, or false indications. The higher the level of background, the more difficult it is to distinguish an indication.

Backing – In welding, a material placed under or behind a joint to enhance the quality of the weld at the root. It may be a metal backing ring or strip; a pass of weld metal; or a nonmetal such as carbon, granular flux, or a protective gas.[5]

Bainite – A metastable aggregate of ferrite and cementite resulting from the transformation of austenite at temperatures below the pearlite range but above M_s, the martensite start temperature. Upper bainite is an aggregate that contains parallel lath-shape units of ferrite, produces the so-called "feathery" appearance in optical microscopy, and is formed above approximately 350 °C (660 °F). Lower bainite, which has an acicular appearance similar to tempered martensite, is formed below approximately 350 °C (660 °F).[5]

Base material – The material to be welded, brazed, soldered, or cut. See **Base metal**.[5]

Base metal – (1) The metal present in the largest proportion in an alloy; brass, for example, is a copper-base alloy. (2) The metal to be brazed, cut, soldered, or welded. (3) After welding, the part of the metal which was not melted. (4) A metal that readily oxidizes, or that dissolves to form ions.[5]

Bevel angle – The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.[5]

Borescope – A periscope or telescope using mirrors, prisms, lenses, optic fibers, or television wiring to transmit images from inaccessible areas for visual testing.[2]

Brazing – Joining of metals and alloys by fusion of nonferrous alloys that have melting points above 430 °C (806 °F), but below melting points of materials being joined.[6]

Burn-through – A term erroneously used to denote excessive melt-through or a hole. See **Melt-through**.[5]

Burst – (1) A signal whose oscillations have a rapid increase in amplitude from an initial reference level (generally that of the background noise), followed by a decrease (generally more gradual) to a value close to the initial value.5 (2) In metal, external or internal rupture caused by improper forming.[2]

Butt weld or butt joint – Weld joining two metal pieces in the same plane.[2]

Candela (cd) – Base unit of measure in the SI system for luminous intensity. The luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1.4641 milliwatt per steradian.[2]

Chroma – The difference from gray (the achromatic equivalent) of a color.

CIE – An abbreviation for the French title of the International Commission on Illumination (Commission Internationale de l'Eclairage).

Cold shut – (1) Casting discontinuity caused by two streams of semimolten metal coming together inside a mold but failing to fuse. Cold shuts are sometimes called misruns but the latter term correctly describes incomplete filling of the mold. (2) A discontinuity that appears on the surface of test metal as a result of two streams of liquid meeting and failing to unite. A cracklike discontinuity caused by forging, where two surfaces of metal fold against each other to produce a discontinuity at the point of folding. This is usually at some angle to the surface. It may also be a separate piece of metal forged into the main component. See **Lap**. (3) A portion of the surface of a forging that is separated in part from the main body of metal by oxide.[6]

Color – Sensation by means of which humans distinguish light of different intensities (brightness) and wavelengths (hue).[2]

Complete fusion – Fusion that has occurred over the entire base material surfaces intended for welding and between all layers and weld beads.[5]

Complete joint fusion – Joint penetration in which the weld metal completely fills the groove and is fused to the base metal throughout its total thickness.[5]

Concavity – The maximum distance from the face of a concave fillet weld perpendicular to a line joining the toes.[5]

Convexity – The maximum distance from the face of a convex fillet weld perpendicular to a line joining the toes.[5]

Crack – (1) A break, fissure or rupture, usually V-shaped and relatively narrow and deep. A discontinuity that has a relatively large cross section in one direction and a small or negligible cross section when viewed in a direction perpendicular to the first.
(2) Propagating discontinuities caused by stresses such as heat treating or grinding. Difficult to detect unaided because of fineness of line and pattern (may have a radial or latticed appearance).[6]

Crack, transverse – Cracks at right angles to the length of the test object.[6]

Crater – (1) In machining, a depression in the cutting tool face eroded by chip contact. (2) In arc or gas fusion welding, a cavity in the weld bead surface, typically occurring when the heat source is removed and insufficient filler metal is available to fill the cavity.[6]

Dark current – The unwanted charge that accumulates in each pixel due to the natural thermal processes that occur above absolute zero.

Datum – A theoretically perfect point, axis, or plane that is derived from actual features.

Defect – A condition or discontinuity having a size, shape, orientation, nature, frequency, or location that impairs the useful service of the part or that is rejectable according to a specification or standard.[3]

Discontinuity – An intentional or unintentional interruption in the physical structure or configuration of a part.[4]

Effective throat – In welding, the weld throat including the amount of weld penetration but ignoring excess metal between the theoretical face and the actual face.[2]

Electric arc welding – Joining of metals by heating with electric arc. Also called arc welding.[2]

Electromagnetic spectrum – A continuum or electric and magnetic radiation encompassing all wavelengths.[1]

Electroslag welding (ESW) – A fusion welding process in which the welding heat is provided by passing an electric current through a layer of molten conductive slag (flux) contained in a pocket formed by water-cooled dams that bridge the gap between the members being welded. The resistance heated slag not only melts filler-metal electrodes as they are fed into the slag layer, but also provides shielding for massive weld puddle characteristic of the process.[5]

Endoscope – Device for viewing the interior of objects. The term endoscope is usually used for medical instruments that are equivalent to borescopes.[2]

Evaluation – A review, following interpretation of the indications noted, to determine whether they meet specified acceptance criteria.[2]

False indication – An indication that is not produced by a discontinuity. Compare **Defect.**[2]

Far vision – Vision of objects at a distance, generally beyond arm's length.[2]

Faying surface – The surfaces of materials in contact with each other and joined or about to be joined.[5]

Field of vision – The range or area where objects can be perceived organoleptically (using the eyes only), assuming that the eye's position is fixed.

Filler metal – Metal added in making a brazed, soldered, or welded joint.[5]

Fillet weld – Weld at the corner of two metal pieces.[2]

Flicker – When the frame repetition rate is not high enough to provide an image that is perceived as continuous by a human observer.

Fluorescence – Luminescence produced by a material that is excited by light, electricity, or radiation. The luminescence ceases as soon as the source of excitation is removed.

Flux cored arc welding (FCAW) – An arc welding process that joins metal by heating them with an arc between continuous tubular filler-metal electrode and the work. Shielding is provided by a flux contained within the consumable tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.[5]

Focal distance (lens) – See **Focal length**.

Focal length (lens) – The distance from the principal plane to the focal plane.

Focal plane – Where parallel incident light rays converge after being diffracted by the lens.

Footcandle (ftc) – Former unit of measure for illumination, equivalent to 1 lumen/ft^2 or 1 candle of luminance measured at 1 ft.

Fusion (welding) – the melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence.[5]

Gas metal arc welding (GMAW) – An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filer metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. Variations of the process include short-circuit arc GMAW, in which the consumable electrode is deposited during repeated short circuits, and pulsed arc GMAW, in which the current is pulsed.[5]

Gas tungsten arc welding (GTAW) – An arc welding process that produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture.[5]

Glare – Excessive brightness (or brightness varying by more than 10:1 within the field of view) that interferes with clear vision, critical observation, and judgment.[2]

Graybody – Radiator whose spectral emissivity is uniform for all wavelengths.[2]

Grayscale – A means of defining the image brightness as a function of the brightness of the object being imaged. It is specified by the highlight brightness, contrast ratio, and gamma.

Groove (welding) – An opening or channel in the surface of a part or between two components that provides space to contain a weld.[5]

Groove angle – The total included angle of the groove between parts to be joined. This the sum of two bevel angles, either or both of which may be zero degrees.[5]

Groove face – The portion of a surface or surfaces of a member included in a groove.[5]

Heat affected zone (HAZ) – Base metal not melted during brazing, cutting, or welding, but whose microstructure and physical properties were altered by the heat.[6]

Highlight brightness – The brightness of the brightest area of the image.

Hot tear – A fracture formed in a metal during solidification because of hindered contraction. Surface cracks on castings produced by contraction of the metal during cooling. Hot tears often occur where areas of different thickness adjoin.[2]

Hue – Attribute of color perception by which a color is perceived to be red, yellow, blue, or an intermediate color between these. White, black, and grays possess no hue.

Hydrogen embrittlement – A condition of low ductility in metals resulting from the absorption of hydrogen.[6]

Illuminance ($E_V = d\Phi/dA$) **–** The density of luminous flux on a surface. It is the equivalent to the measure of irradiance in radiometry.[2]

Image – The visual impression of an object produced by a lens, mirror, or optical system. A real image is formed by convergence of light and can be produced on a screen. A virtual image is one from which the rays of light appear to diverge. The virtual image cannot be produced on a screen.

Incandescence – The emission of visible radiation due to thermal excitation.[2]

Indication – An NDT response that requires interpretation to determine its relevance.[2]

Indication, false – An NDT indication that is interpreted to be caused by a condition other than a discontinuity or imperfection.[4]

Indication, nonrelevant – An NDT indication that is caused by a condition or type of discontinuity that requires evaluation.[4]

Indication, relevant – An NDT indication that is caused by a condition or type of discontinuity that requires evaluation.[4]

Interpretation – The determination of whether indications are relevant, nonrelevant, or false.[4]

Irradiance ($E_e = d\Phi/dA$) – Power of electromagnetic radiant energy incident on a surface of given unit area.[2]

Ishihara™ plates – Trade name for a kind of pseudoisochromatic plates.[2]

Lag – A measure of the rate of change of the video signal at a fixed point on the raster.

Lamellar tearing – Occurs in the base metal adjacent to weldments due to high through-thickness strains introduced by weld metal shrinkage in highly restrained joints. Tearing occurs by decohesion and linking along the working direction of the base metal; cracks usually run roughly parallel to the fusion line and are steplike in appearance. Lamellar tearing can be minimized by designing joints to minimize weld shrinkage stresses and joint restraint.[5]

Lamination – Discontinuity in plate, sheet, or strip caused by pipe, inclusions, or blowholes in the original ingot. After rolling, laminations are usually flat and parallel to the outside surface. Laminations may also result from pipe, blisters, seams, inclusions, or segregation elongated and are made directional by working. Lamination discontinuities may also occur in metal powder compacts. May appear in the form of rectangles or plates as inclusion stringers between rolled surfaces. Short, intermittent laminations may be detrimental if the object is subjected to high bending stresses in service.[6]

Lap – Surface discontinuity, usually parallel to the surface, appearing as a fold or tangential seam in a wrought product and caused by the folding over of a hot metal fin or sharp corner in a thin plate, then rolling or forging it into the surface but not welding it. See also **Cold shut**.[6]

Leg of fillet weld – (1) Actual – the distance from the root of the joint to the toe of the fillet weld. (2) Nominal – the length of a side of the largest right triangle that can be inscribed in the cross section of the weld.[5]

Lens – Translucent object that refracts light passing through it in order to focus the light on a target.[2]

Light – Radiant energy between approximately 380 nm and 770 nm. This portion of the electromagnetic spectrum produces a response in the human retina.

Lumen (lm) – Unit of measure in the SI system for luminous flux, equivalent to candela times steradian (cd•sr).[2]

Luminance [$L = d^2\Phi/(d\omega dA \cos\theta)$] – The ratio of a surface's luminous intensity in a given direction to a unit of projected area. Measured in candela/m^2.[2]

Luminous flux – Radiant energy's time rate of flow. Measured in lumens.[2]

Luminous intensity ($I_V = d\Phi/d\omega$) – Luminous flux on a surface normal to the direction from its light source, divided by the solid angle the surface subtends at the source. Measured in candela.[2]

Lux (lx) – Unit of measure for illuminance in the SI system. Equivalent to lm/m^2.

Machine vision – Automated system function of acquiring, processing, and analyzing images to evaluate a test object or to provide information or interpretation for human evaluation.[2]

Machine welding (ME) – Welding with equipment that performs under the continual observation and control of a welding operator. The equipment may or may not load the work. Compare with automatic welding (AW).[5]

Macular lutae – Irregular, diffuse ring of yellow pigment surrounding the fovea that absorbs blue light and changes the spectral energy distribution of the light reaching the receptors under it.

Manual welding (MA) – Welding wherein the entire welding operation is performed and controlled by hand.[5]

Melt-through – Complete joint penetration for a joint welded from one side. To prevent melt-through, the welding current and the width of the root opening should be reduced, and travel speed increased.[5]

Metallograph – A metallographic microscope designed for metallography.

Metallography – The science and practice of microscopic testing, inspection, and analysis of a metal's structure, typically at magnifications in the range of 50× to 2500×.[2]

Microscope – An instrument that provides enlarged images of very small objects.[2]

Monochromatic – Color composed of a single hue, having a very narrow band of wavelength.

Monochromator – Device that uses prisms or gratings to separate or disperse the wavelengths of the spectrum into noncontinuous lines or bands.[2]

Overlap – (1) Pultrusion of weld metal beyond the toe, face, or root of a weld. (2) In resistance seam welding, the area in a given weld remelted by the succeeding weld. See also **Face of weld**, **Root of weld**, and **Toe of weld**.[5]

Oxyacetylene welding (OAW) – An oxyfuel gas welding process in which the fuel gas is acetylene.[5]

Near vision – Vision of objects near to the eye when accommodative ability is required. Generally within arm's length.

Nearsightedness – Vision acuity that is adequate for near vision.

N-type semiconductor – See **Semiconductor**.

Pearlite – Platelet mixture of cementite and ferrite in steels or in alpha and beta phases in nonferrous alloys.[2]

Photometer – The basic measuring instrument of photometry.[2]

Photometry – The science and practice of the measurement of light or photon emitting electromagnetic radiation.[2]

Photons – Discrete particles of light or electromagnetic radiation hypothesized to explain the corpuscular theory of radiant energy.

Photopic vision – Vision adapted to daylight and mediated mainly by the cones. Vision is wholly photopic when the luminance of the test surface is above 0.034 cd•m^{-2} (0.0032 cd•ft^{-2}).[1]

Pipe – (1) The central cavity formed during solidification of metal, especially ingots, by thermal contraction. (2) The discontinuity in wrought or cast products resulting from such a cavity. (3) An extrusion discontinuity due to the oxidized surface of the billet flowing toward the center of the rod at the back end. (4) A cast, wrought, or welded metal tube.[6]

Pixel – Short for picture element, a pixel is an individual light sensor.

Plasma arc welding (PAW) – An arc welding process that produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from hot, ionized gas issuing from an orifice surrounding the electrode and may be supplemented by an auxiliary source of shielding gas, which may be an inert gas or a mixture of gasses. Pressure may or may not be used, and filler metal may or may not be supplied.[5]

Porosity – A discontinuity in metal resulting from the creation or coalescence of gas. Very small pores are called pinholes.[2]

Principal focus – See **Focal plane**.

Process – Repeatable sequence of actions to bring about a desired result.[2]

Pseudoisochromatic plates – Color plates used for color vision examinations.[2]

P-type semiconductor – See **Semiconductor**.

Quality of lighting – Level of distribution of luminance in a visual task or environment.[2]

Radiance [$L_e = d^2\Phi/(d\omega dA \cos \theta)$] **–** Radiant flux per unit solid angle and per unit projected area of the source. Measured in watts per square meter steradian.[2]

Radiant energy (Q_e) **–** Energy transmitted through a medium by electromagnetic waves. Also known as radiation.[2]

Radiant flux ($\Phi = dQ/dt$) **–** Radiant energy's rate of flow, measured in watts.[2]

Radiant intensity ($I_e = d\Phi/d\omega$) **–** Electromagnetic energy emitted per unit time per unit solid angle. Measured in watts per steradian.[2]

Raster – The repetitive pattern whereby the scanning electron beam follows a path of adjacent parallel lines.

Remote visual inspection – Viewing of an object not in the viewer's field of vision.

Resolution – An aspect of image quality pertaining to a system's ability to reproduce objects, often measured by resolving a pair of adjacent objects or parallel lines.[2]

Resolving power – The ability of vision or other detection systems to separate two points. Resolving power depends on the angle of vision and the distance of the sensor from the test surface. Resolving power is often measured using parallel lines.[2]

Rhodopsin – Retinal receptor that responds at low light levels.

Root face – The portion of a weld groove face adjacent to the root of the joint.[5]

Root mean square (RMS) – The square root of the average of the squares of a number of values.

Root of joint – The portion of a weld joint where the members are closest to each other before welding. In cross section, this may be a point, a line, or an area.[5]

Root opening – In a weldment, the separation between the members at the root of joint prior to welding.[5]

Root of weld – The points at which the weld bead intersects the base-metal surfaces either nearest to or coincident with the root of joint.[5]

SI – The International System of units of measurement. Includes most of the base units formerly called metric.[2]

Saturation – Relative or comparative color characteristic resulting from a hue's dilution with white light.[2]

Scab – A flat volume of metal joined to a casting through a small area. Usually set in a depression, a flat side being separated from the metal of the casting proper by a thin layer of sand.[6]

Scan lines – See **Trace**.

Scotopic vision – Dark adapted vision, using only the rods in the retina, where differences in brightness can be detected but the differences in hue cannot. Vision is wholly scotopic when the luminance of the test surface is below 3×10^{-5} $cd{\bullet}m^{-2}$ (2.7×10^{-6} $cd{\bullet}ft^{-2}$). Also known as parafoveal vision.[2]

Seam – (1) On the surface of metal, an unwelded fold or lap that appears as a crack, usually resulting from a discontinuity obtained in casting or working. (2) Mechanical or welded joints. (3) Longitudinal surface discontinuity on metal originating from a surface crack or blowhole near the surface of the ingot, that is drawn out during rolling and follows the rolling direction. Also due to overfill while rolling. After forging, seams generally follow the direction of flow lines.[6]

Semiautomatic arc welding (SW) – Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.[5]

Semiconductor – A solid with an electrical conductivity that is intermediate between those of insulators and metals. Semiconductors are usually metalloid elements such as germanium or silicon.

- n-type semiconductors – a semiconducting material where most of the circuit is carried by electrons when deliberately placed donor impurities in the material form positive ions and release electrons.

- p-type semiconductor – a semiconducting material where acceptor impurities require extra electrons for stable bonding. The ionization of the impurity creates a positive hole creating the current flow.

Shielded metal arc welding (SMAW) – A manual arc welding process in which the heat for welding is generated by an arc established between a flux-covered consumable electrode and a workpiece. The electrode tip, molten weld pool, arc, and adjacent areas of the workpiece are protected form atmospheric contamination by a gaseous shield obtained from the combustion and decomposition of the electrode covering. Additional shielding is provided from the molten metal in the weld pool by a covering of molten flux or slag. Filler metal is supplied by the core of the consumable electrode and from the metal powder mixed with the electrode covering of certain electrodes. SMAW is often referred to as arc welding with stick electrodes, manual metal arc welding, and stick welding.[5]

Size of weld – (1) The joint penetration in a groove weld. (2) The lengths of the nominal legs of a fillet weld. (3) The weld metal thickness measured at the root of a flange weld.[5]

Smear – When the phase response of the imaging system is not capable of reproducing a rapid change in shade or contrast in a static object.

Specification – A set of instructions or standards invoked by a specific customer to govern the results or performance of a specific set of tasks or products.[2]

Spectral power distribution – The radiant power per unit wavelength as a function of wavelength. Also known as spectral energy distribution, spectral density, and spectral distribution.[2]

Spectrophotometer – Instrument used for spectrophotometry.[2]

Spectrophotometry – Measurement of electromagnetic radiant energy as a function of wavelength, particularly in the ultraviolet, visible, and infrared wavelengths.[2]

Spectroradiometer – Instrument used for spectroradiometry.[2]

Spectroradiometry – Measurement of electromagnetic radiant power and spectral emittance, used particularly to examine colors and to measure the spectral emittance of light sources.[2]

Spectrum – Representation of radiant energy in adjacent bands of hues in sequence according to the energy's wavelengths or frequencies. A rainbow is a well known example of a visible spectrum.[2]

Specular – Pertaining to a mirror-like reflective finish, as of a metal.[2]

Standard – Document to control and govern practices in an industry or application, applied on a national or international basis and usually produced by consensus.[2]

Stress corrosion cracking – Failure by cracking under combined action of corrosion and stress, either applied or residual. Cracking may be either intergranular or transgranular, depending on the metal and corrosive medium.[6]

Stud welding (SW) – An arc welding process in which the contact surfaces of a stud, or similar fastener, and a workpiece are heated and melted by an arc drawn between them. The stud is then plunged rapidly onto the workpiece to form a weld. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used. The two basic methods of stud welding are known as stud arc welding, which produces a large amount of weld metal around the stud base and a relatively deep penetration into the base metal, and capacitor discharge stud welding which produces a very small amount of weld metal around the stud base and shallow penetration into the base metal.[5]

Submerged arc welding (SAW) – Arc welding in which the arc, between a bare metal electrode and the work, is shielded by a blanket of granular, fusible material overlying the joint. Pressure is not applied to the joint, and filler metal is obtained from the consumable electrode (and sometimes from a supplementary welding rod).[5]

Throat, actual – Shortest distance from the root of a fillet weld to its face, as opposed to theoretical throat or weld size.[2]

Throat, theoretical – The distance from the beginning of the root of the weld perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross section of the fillet weld. Compare **Size of weld.**[2]

Throat, weld – Distance from the root of a fillet weld to its face. Compare **Size of weld** and **Throat, actual.**[2]

Toe of weld – The junction between the face of a weld and the base metal.[5]

Trace – Line formed by electron beam scanning from left or right on a video screen to generate a picture.[2]

Tungsten inert gas (TIG) welding – See **Gas tungsten arc welding (GTAW)**.

Ultraviolet radiation – Electromagnetic radiation with wavelengths from 4-400 nm, between visible light and X-rays.[2]

Undercut – Undesirable depression or groove left unfilled by weld metal, created by melting during welding and located in base material at the toe of a weld.[2,6]

Underfill – In weldments, a depression on the face of the weld or root surface extending below the surface of the adjacent base metal.[5]

Video – Pertaining to the transmission and display of images in an electronic format that can be displayed on a cathode ray screen.[2]

Visibility – The quality or state of being perceivable by the eye. In many outdoor applications, visibility is defined in terms of the distance at which an object can be just perceived by the eye. In indoor applications, it usually is defined in terms of the contrast or size of a standard test object, observed under standardized view conditions, having the same threshold as the given object.[1]

Vision – Perception by eyesight.[2]

Vision acuity – The ability to distinguish fine details visually. Quantitatively, it is the reciprocal of the minimum angular separation in minutes of two lines of width subtending one minute of arc when the lines are just resolvable as separate.[1]

Visual acuity – See **Vision acuity**.

Visual angle – The angle subtended by an object or detail at the point of observation. It usually is measured in minutes of arc.[1]

Visual perception – The interpretation of impressions transmitted from the retina to the brain in terms of information about a physical world displayed before the eye. Visual perception involves any one or more of the following – recognition of the presence of something (object, aperture, or medium); identifying it; locating it in space; noting its relation to other objects; or identifying its movement, color, brightness, or form.[1]

Visual performance – The quantitative assessment of the performance of a visual task, taking into consideration speed and accuracy.[1]

Visual purple – See **Rhodopsin**.

Visual task – The appearance and immediate background of those details and objects that must be seen for the performance of a given activity.[1]

Visual testing – Method of NDT using electromagnetic radiation at visible frequencies.[2]

Weld – A localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperatures, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler material.[5]

Glossary References

1. *IES Lighting Handbook – Reference & Application*, 8th Edition. New York, NY – The Illuminating Engineering Society of North America. 1993.

2. Allgaier, Michael W., Stanley Ness, Paul McIntire, and Patrick O. Moore, eds. *Nondestructive Testing Handbook*, second edition – Volume 8, *Visual and Optical Testing*. Columbus, OH – The American Society for Nondestructive Testing. 1993.

3. *EPRI Learning Modules*. Charlotte, NC – The Electric Power Research Institute

4. ASTM E 1316, *1997 Annual Book of ASTM Standards, Section 3, Metals Test Methods and Analytical Procedures*, Volume 03.03, *Nondestructive Testing*. West Conshohocken, PA – The American Society for Testing and Materials. 1997.

5. Davis, J.R., ed. *ASM Materials Engineering Dictionary*. ASM International. 1992.

6. Ness, Stanley, Charles N. Sherlock, Paul McIntire, and Patrick O. Moore, eds. *Nondestructive Testing Handbook*, second edition – Volume 10, *Nondestructive Testing Overview*. Columbus, OH – The American Society for Nondestructive Testing. 1996.

Appendix 3
Qualification and Certification of NDT Personnel

Overview of Personnel Qualification and Certification

Qualification and certification of NDT personnel in the United States (U.S.) has traditionally been through employer-managed programs based on *Recommended Practice No. SNT-TC-1A*, or operated in accordance with the *ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel (ANSI/ASNT CP-189)*. ASNT first issued *SNT-TC-1A* in 1968 while *ANSI/ASNT CP-189* was first issued in 1991. Since 1977, ASNT has actively supported employer-managed NDT qualification and certification programs by offering ASNT NDT Level III certification by examination in various NDT methods to U.S. NDT personnel and to NDT personnel from countries all over the world.

As the global marketplace continues to expand, the need for global standards increases. Global standards help increase harmonization between countries, industries, and technical societies, help facilitate international commerce, and foster mutual acceptance among partners of NDT personnel qualification and certification. With this in mind, ASNT, in 1996, began implementing a new NDT personnel qualification and certification program entitled the ASNT Central Certification Program (ACCP). The purpose of the ACCP is to provide Level III, Level II, and Level I NDT personnel with independent, transportable certification by examination for national and international acceptance. The ACCP is uniquely flexible in that it allows for qualification and certification that satisfies any number of requirements including those of *ISO 9712 - Non-destructive Testing: Qualification and Certification of Personnel.*

The following sections provide an overview of *SNT-TC-1A*, *ANSI/ASNT CP-189*, *ISO 9712* and the ACCP.

Recommended Practice No. SNT-TC-1A

This document is intended to be a guideline for employers to establish their own written practice for the qualification and certification of their NDT personnel. It is not intended to be used as a strict specification. This document was first issued in 1968 and was revised in 1975, 1980, 1984, 1988, 1992, and 1996. The current edition of *SNT-TC-1A*, (1996), includes the following NDT methods:

1. acoustic emission testing (AE),
2. electromagnetic testing (ET),
3. leak testing (LT),
4. liquid penetrant testing (PT),
5. magnetic particle testing (MT),
6. neutron radiographic testing (NR),
7. radiographic testing (RT),
8. infrared/thermal testing (IR),
9. ultrasonic testing (UT),
10. vibration analysis (VA), and
11. visual and optical testing (VT).

SNT-TC-1A defines three levels of NDT qualification (Level I, Level II, Level III) as well as the recommended education, training, and experience requirements for each level. It also establishes the different types of examinations for each level of qualification.

1. Level III:
   a. Basic Examination (required only once independent of the number of methods),
   b. Method Examination (for each method), and
   c. Specific Examination (for each method).
2. Level II:
   a. General Examination (for each method),
   b. Specific Examination (for each method), and
   c. Practical Examination (for each method).
3. Level I:
   a. General Examination (for each method),
   b. Specific Examination (for each method), and
   c. Practical Examination (for each method).

SNT-TC-1A recommends the minimum number of questions for each written examination and the format for practical examinations.

The following excerpts from Section 9 of *SNT-TC-1A* present details concerning certification:

9.1 Certification of all levels of NDT personnel is the responsibility of the employer.

9.2 Certification of NDT personnel shall be based on demonstration of satisfactory qualification in accordance with Sections 6, 7, and 8, as modified by the employer's written practice.

9.3 At the option of the employer, an outside agency may be engaged to provide NDT Level III services. In such instances, the responsibility of certification is retained by the employer.

9.4 Personnel certification records shall be maintained on file by the employer and should include the following:

1. Name of certified individual.
2. Level of certification and NDT method.
3. Educational background and experience of certified individuals.
4. Statement indicating satisfactory completion of training in accordance with the employer's written practice.
5. Results of the vision examinations prescribed in 8.2 for the current certification period.
6. Current examination copy(ies) or evidence of successful completion of examinations.
7. Other suitable evidence of satisfactory qualifications when such qualifications are used in lieu of the specific examination prescribed in 8.8.3(b) or as prescribed in the employer's written practice.
8. Composite grade(s) or suitable evidence of grades.
9. Dates of certification and/or recertification and the dates of assignments to NDT.
10. Signature of employer's certifying authority.

The following portions from Section 9 of *SNT-TC-1A* presents details concerning recertification:

9.5 Recertification

1. All levels of NDT personnel shall be recertified periodically in accordance with one of the following criteria:
   a. Evidence of continuing satisfactory performance.
   b. Reexamination in those portions of the examinations in Section 8 deemed necessary by the employer's NDT Level III.
2. Recommended maximum recertification intervals are:
   a. Levels I and II — 3 years, and
   b. Level III — 5 years.
3. NDT personnel may be reexamined any time at the discretion of the employer and have their certificates extended or revoked.
4. The employer's written practice should include rules covering the duration of interrupted service that requires reexamination and recertification.

ANSI/ASNT CP-189

This document is the U.S. consensus standard for qualification and certification of NDT personnel. The current edition of *ANSI/ASNT CP-189* (1995) includes the NDT methods of AE, ET, LT, MT, NR, PT, RT, VT and UT. It identifies five categories of NDT qualification (Level III, Level II, Level I, Trainee, NDT Instructor); however, only Level III, Level II and Level I personnel are certified while a qualified NDT Instructor is designated by an NDT Level III.

In much the same manner as *SNT-TC-1A*, *ANSI/ASNT CP-189* requires the employer to establish a "procedure" (*SNT-TC-1A* uses the term "written practice") for the qualification and certification of NDT personnel. This standard defines the education, training, and experience requirements for each category of qualification. It also establishes the different types of examinations for each level of qualification.

1. Level III:
   a. ASNT NDT Level III certificate (with a currently valid endorsement for each method in which employer certification is sought).
   b. Specific Examination (for each method),
   c. Practical Examination (for each method; prepare an NDT procedure), and
   d. Demonstration Examination (for each method; hands-on practical examination).
2. Level II:
   a. General Examination (for each method),
   b. Specific Examination (for each method), and
   c. Practical Examination (for each method).
3. Level I:
   a. General Examination (for each method),
   b. Specific Examination (for each method), and
   c. Practical Examination (for each method).

Candidates who fail an examination are required to receive additional documented training addressing the deficiencies that caused failure, or wait at least thirty days before reexamination. *ANSI/ASNT CP-189* requires an NDT Level III with a valid ASNT NDT Level III certificate in the applicable method to be responsible for development, administration and grading of examinations; however, in no case is it permitted that an examination be prepared or administered by one's self or by one's subordinate.

Similar to *SNT-TC-1A*, this standard specifically provides the employer with the option to engage the services of an outside organization to perform the duties of an NDT Level III. *ANSI/ASNT CP-189* states that the training requirements for an NDT Level III are satisfied if the individual holds a current ASNT NDT Level III certificate in the applicable NDT method.

Section 5 of *ANSI/ASNT CP-189* presents details concerning certification:

5.1 Procedure. The employer shall develop and maintain a procedure detailing the program that will be used for qualification and certification of NDT personnel in accordance with this standard.

5.2 Procedure Requirements. The procedure shall describe the minimum requirements for certifying personnel in each NDT method and the levels of qualification desired. The procedure shall satisfy the requirements of this standard. The procedure shall include, as a minimum, the following:

a. personnel duties and responsibilities including, if the employer has more than one NDT Level III for a specific method, the employer shall designate one individual as the principal NDT Level III for each such method;
b. training requirements;
c. experience requirements;
d. examination requirements;
e. records and documentation requirements, including control, responsibility, and retention period; and
f. recertification requirements.

5.3 Approval. The employer's certification procedure shall be approved by an NDT Level III designated by the employer.

Certification also requires successful completion of vision examinations administered in accordance with a procedure, and by personnel approved by the NDT Level III.

Recertification of NDT Level I and Level II personnel is required to be by examination in accordance with certification examination requirements, at least every three years. Recertification of NDT Level III personnel, as a minimum, requires verification of the individual's ASNT NDT Level III certificate for currency in each method for which recertification is sought.

ISO 9712

ISO 9712 is an international standard that establishes a system for the qualification and certification of personnel to perform industrial NDT. Instead of employer-managed certification programs, *ISO 9712* requires certification be conducted by a central, independent body that must be a nonprofit organization with no direct involvement in the training of NDT personnel and that is recognized by the NDT community or the ISO member body of the country concerned.

ISO 9712 introduces a certification process that uses a national certifying body to administer procedures for certification of NDT personnel, and a qualifying body authorized by the national certifying body, to prepare and administer certification examinations. An examination center may be authorized by the national certifying body, or through a qualifying body to administer certification examinations. *ISO 9712* uses the term "industrial sector" to describe an area of industry or technology using specialized NDT that requires specific skill, knowledge, equipment, or training to achieve satisfactory performance.

ISO 9712 defines three levels of NDT qualification (Level 1, Level 2, Level 3) as well as the education, training, and experience requirements for each level of qualification. It also establishes the different types of examinations for each level of qualification.

1. Level 3:
   a. Basic Examination (required only once independent of the number of methods),
   b. Method Examination [for each method; integrating application of the method to the applicable industrial sector(s), and includes drafting one or more procedures in the applicable industrial sector(s)], and
   c. Practical Examination (for each method; Level 2 Hands-on Practical Examination is required when the Level 3 candidate does not hold appropriate Level 2 certification).
2. Level 2:
   a. General Examination (for each method),
   b. Specific Examination [for each method; related to the applicable industrial sector(s)], and
   c. Practical Examination [for each method; related to the applicable industrial sector(s)].
3. Level 1:
   a. General Examination (for each method),
   b. Specific Examination [for each method; related to the applicable industrial sector(s)], and
   c. Practical Examination [for each method; related to the applicable industrial sector(s)].

Certification requires documented evidence of satisfactory vision in accordance with requirements listed in *ISO 9712*. There are a number of requirements associated with validity of certification including no significant interruption of work in the method(s) for which one is certified.

Recertification requirements include continued satisfactory work activity relevant to certification without significant interruption. Recertification is required at least every five years from the date of certification. Every other recertification period, or at least every ten years, the certified individual is also required to pass a limited practical examination if Level I or II, or a written examination if Level III.

ASNT Central Certification Program (ACCP)

The ACCP was adopted by the ASNT Board of Directors 13 July 1996. The ACCP establishes the system for central certification of NDT personnel administered and maintained by ASNT. The purpose of ACCP is to provide independent, transportable NDT certification by examination to promote national and international acceptance of NDT certification and reduce multiple audits of certification programs. The ACCP was developed to improve NDT reliability and accuracy through enhanced performance of personnel as demonstrated by the ACCP examinations and accompanying qualification requirements. The ACCP is intended to provide customers and prospective employers with clear expectations of NDT personnel competency and proficiency.

Management of the ACCP is the responsibility of the Certification Management Council (CMC). An authorized qualifying body (AQB) may be used to prepare and administer NDT qualification examinations and an authorized examination center (AEC) may be used to administer NDT qualification examinations.

Within the ACCP there are several options available to satisfy employer, employee and industry needs. The ACCP is unique in that it allows for qualification and certification that addresses any number of requirements including those of *SNT-TC-1A*, *ANSI/ASNT CP-189*, *MIL-STD-410*, *ISO 9712*, and other international sources of NDT qualification and certification programs based on *ISO 9712*. It also provides a mechanism for specific practical and written examinations to better accommodate industries where product-forms or areas of technology demand specialized NDT. The ACCP uses a combination of traditional practices, national and international conventions and newly evolved concepts to create a system of central certification which represents the next generation of NDT personnel qualification and certification.

ACCP terminology is of key importance; the following are definitions from the ACCP document:

2.1 *ACCP certification*: The process whereby ASNT certifies that an individual has met the requirements of this document for ACCP Professional Level III, ACCP Level II, or ACCP Level I.

2.2 *ASNT NDT Level III*: An individual who, having passed ASNT administered Basic and Method(s) Examinations, holds a current, valid ASNT NDT Level III certificate in at least one method.

2.3 *Authorized examination center* (AEC): A site with facilities and personnel, independent of the employer, approved by the ASNT Certification Management Council (CMC) to administer NDT qualification examinations.

2.4 *Authorized qualifying body (AQB)*: A competent organization, independent of the employer, approved by the ASNT CMC to prepare and administer NDT qualification examinations.

2.5 *Certificate*: Written testimony of qualification.

2.6 *Certification Management Council (CMC)*: Formerly known as the Certification Management Board (CMB), this is the council within ASNT that is responsible for managing the ACCP.

2.7 *Employer*: The corporate, private, or public entity that employs personnel for wages or salary.

2.8 *Employer authorization*: The process whereby an employer's ACCP Professional Level III or ASNT NDT Level III reviews the certificates of ASNT Central Certification for the employer's NDT personnel, determines if further examination (see job specific examinations in paragraph 7.5.) is required, and then, on behalf of the employer, authorizes personnel to perform NDT for that employer.

2.9 *Endorsement*: Written testimony of a particular qualification.

2.10 *Guidance*: See *supervision*.

2.11 *Industrial sector (IS)*: An industry, product-form or area of technology that possesses common characteristics with respect to NDT considerations.

2.12 *Instruction*: A description of the steps to be followed when performing an NDT technique; developed in conformance with a procedure.

2.13 *Procedure*: A written description that establishes minimum requirements for performing an NDT method on any object, written in accordance with established standards, codes, or specifications.

2.14 *Qualification*: Demonstration or possession of education, skills, training, knowledge, and experience required for personnel to properly perform NDT to a level as specified in this document.
2.15 *Recertification examination*: An examination administered by the CMC expressly for the purpose of recertification.
2.16 *Recertification*: The process of extending one's certification after the initial period of validity, and maintaining certification for individual periods thereafter.
2.17 *Renewal*: Same as recertification.
2.18 *Specific procedure*: Same as instruction.
2.19 *Supervision*: The act of an ACCP Level II, ACCP Professional Level III, or ASNT NDT Level III directing the application of NDT performed by other NDT personnel, which includes the control of actions involved in the preparation of the test, performance of the test, and reporting of test results.

The ACCP refers to a number of appendices, each traceable to a source (e.g., *SNT-TC-1A*, *ANSI/ASNT CP-189*, *ISO 9712*, etc.) of differing qualification requirements (education, training, and experience). There are three levels of qualification: Professional Level III, Level II, and Level I. The examinations for each level of qualification are:

1. Professional Level III: candidates with a current, valid ASNT NDT Level III certificate in a method shall be considered to have met all prerequisites, except vision, in that method and to have passed the Basic Examination and the Method Examination.
   a. Basic Examination (required only once independent of the number of methods).
   b. Method Examination (for each method).
   c. Procedure Preparation Examination (for each method).
   d. Hands-on Practical Examination (for each method; general or specific as applicable).
2. Level II:
   a. General Examination (for each method; includes Procedure Comprehension and Instruction Preparation (PCIP) portion).
   b. Hands-on Practical Examination (for each method; general or specific as applicable).
3. Level I:
   a. General Examination (for each method; includes Instruction Comprehension portion).
   b. Hands-on Practical Examination (for each method; general or specific as applicable).

Certification requires documented evidence of satisfactory vision in accordance with requirements listed in the ACCP document. There are a number of requirements associated with validity of certification including no significant interruption of work in the method(s) for which one is certified.

Recertification requirements include continued satisfactory work activity, relevant to certification, without significant interruption. Recertification is required at least every five years from the date of certification. Every other recertification period, or at least every ten years, the certified individual is also required to pass a recertification examination applicable to the level of recertification.

*At the option of the industrial sector (IS), a Specific Written Examination may be required in conjunction with, or in addition to, the Hands-on Practical Examination(s).

The American Society for Nondestructive Testing, Inc.

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