

Nondestructive Examination (NDE) Technology and Codes
Student Manual

Volume 2

Chapter 6.0

Introduction to Liquid Penetrant Examination

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6.0 INTRODUCTION TO LIQUID PENETRANT EXAMINATION

Learning Objectives:

To enable the student to:

1. Understand the basic principles of penetrant examination.
2. Recognize common interpretation and code requirements of this method.
3. Become aware of the different materials and equipment used.
4. Identify the different common techniques used.
5. Evaluate the different indications that may be observed with penetrant examination.
6. Understand the advantages and limitations of this method.

6.1 History

Penetrant Examination (PT) is the probably the second oldest of all recognized NDE methods. The principle of using liquids to detect cracks in materials has been used for hundreds of years. For example, early blacksmiths soaked forged parts in oil. If there was a crack open to the surface, the oil penetrated into the crack. After some soaking time, the oil was wiped off the surface and the surface was coated with powder.

This powder acted as a blotter and drew the oil out of the crack causing a wet spot on the powder. This method was used extensively in the railroad industry and was termed the “oil and whiting test”.

In the mid and late 1930's, Robert and Joseph Switzer worked with processes incorporating visible colored dyes in the penetrant to give better contrast. In 1941 they introduced processes using fluorescent dyes which, when viewed under a black light, produced contrasts superior to those obtainable with the visible dyes. The fluorescent method was quickly accepted by the military for aircraft part examination. Since then, the use of both color-contrast and fluorescent penetrants has spread to practically all fields of manufacturing, and new and improved PT products are constantly being developed.

PT is a reliable NDE method used for detecting various types of discontinuities that are open to the surface of solid nonporous materials.

6.2 Personnel Qualification and Certification

Of the major NDE methods used in nuclear plants, PT requires the least amount of training and experience to perform. While it may be the easiest in terms of theory that must be mastered, it still requires skills and techniques learned through “hands on experience”. An inexperienced examiner using poor technique can mask or miss discontinuities or, equally as damaging, reject acceptable parts.

The 2007 Edition with 2008 Addenda of the ASME Code Section V requires that NDE personnel shall be qualified in accordance with either:

SNT-TC-1A (2006 Edition), or
ANSI/ASNT CP-189 (2006 Edition)
ACCP

Qualification in accordance with a prior edition of either SNT-TC-1A or CP-189 is considered valid until recertification. Recertification must be in accordance with SNT-TC-1A (2006 Edition) or CP-189 (2006 Edition).

Section XI requires that personnel performing NDE be qualified and certified using a written practice prepared in accordance with ANSI/ASNT CP-189 as amended by Section XI. IWA 2314 states that the possession of an ASNT Level III Certificate, which is required by CP-189, is not required by Section XI. Section XI also states that certifications to SNT-TC-1A or earlier editions of CP-189 will remain valid until recertification at which time CP-189 (1995 Edition) must be met.

A Level II Penetrant Examiner, who is a high school graduate, must complete one of following for Section V and only the CP-189 requirements for Section XI.

The SNT-TC-1A requirements are:

	Training	Experience
Level I	4 hours	70* hrs / 130**hrs
Level II	8 hours	140* hrs / 270**hrs

*hours in Penetrant

**hours in NDE

NOTES:

1. To certify to Level II directly with no time at Level I, the training and experience for Levels I and II must be combined.
2. Training hours may be reduced with additional engineering or science study beyond high school. Refer to Chapter 2 and SNT-TC-1A.
3. Refer to Chapter 2 for details regarding Level III requirements.

The CP-189 requirements are:

	Training	Experience
Level I	4 hours	65*/130**
Level II	8 hours	135*/270**

*Hours in PT/** Total Hours in NDE

NOTES:

1. Experience is based on the actual hours worked in the specific method.
 2. A person may be qualified directly to NDT Level II with no time as certified Level, providing the required training and experience consists of the sum of the hours required for NDT Level I and NDT Level II.
 3. The required minimum experience must be documented by method and by hour with supervisor or NDT Level III approval.
1. While fulfilling total NDT experience requirement, experience may be gained in more than one (1) method. Minimum experience hours must be met for each method.

6.3 Principles

PT can detect discontinuities open to the surface, such as:

- Cracks,
- Laps,
- Porosity,
- Leaks (through wall),
- Seams,
- Pits, and
- Undercuts

NOTE: This is only a partial listing. A listing of discontinuities caused by material forming and processing can be found in Chapter 3.

PT can be used with reliability for virtually any solid, nonporous material.

CAUTION: Since some plastics, rubber, and synthetic products may be affected by penetrant materials, tests should be made before using PT to avoid damaging the part under examination.

6.3.1 Capillary Action

The basic principle of PT, capillary action, is shown in Figure 6-1. Capillary action is the process by which the surface of a liquid, where it is in contact with a solid, is elevated or depressed. The materials, processes, and procedures used in PT are all designed to facilitate capillary action and to make the results of such action visible and capable of interpretation.

The forces of capillary action may be observed when a glass straw is inserted into a glass of colored water. When the straw is inserted, the water molecules enter the straw and begin to attract other nearby molecules, pulling them up the straw by cohesion. This process continues as the water rises higher and higher. The water continues to rise until the pull of the surface tension is equalized. Cohesive and adhesive forces prevent the water from falling back down the straw. Capillary action as applied to PT is somewhat more complex, since various surface conditions hindering or assisting the action are encountered. Penetrants have low surface tension and high capillarity action. The effects of capillary action forces are illustrated in Figure 6-1.

6.3.2 Contact Angle

Contact angle is illustrated in Figure 6-2. A liquid with a large contact angle exhibits less “wetability” and, therefore, has poorer penetrability compared to a liquid with a small contact angle.

6.3.3 Contrast Ratio

The basic objective of a PT examination is to increase the visible contrast ratio between the discontinuity and its background. This is done by applying an appropriate liquid of high mobility and penetrability to the surface of the part being examined and then causing the liquid to emerge from the discontinuity to reveal “a bleedout” to the examiner under daylight conditions (visible dye penetrant) or when exposed to black light (fluorescent penetrants). The contrast ratio between a red dye bleedout and the white developed

background is estimated to be 6:1¹.

6.4 Prerequisites

The following are important prerequisites to performing a PT inspection:

- The type and size of discontinuities to be detected,

NOTE: This factor is important in selecting the proper penetrant process to be used.

- The parts to be examined (i.e., material, size, shape, surface condition),
- The materials and manufacturing processes used;

NOTE: Certain types of discontinuities are inherent in a part made of a particular metal and processed in a particular method.

- The parts intended use;
NOTE: If the part will be used for a critical application, the minutest discontinuity may be detrimental. Therefore, penetrant sensitivity is very important in selecting a process. Similarly, a part to be used for a particular function may develop discontinuities that are common to its use, thereby aiding in the selection of a process through past history.

- Temperature (40°F to 125°F for the PT materials and part),
- The quantity of parts, and

¹The contrast ratio between a fluorescent bleedout and the dark purple/black background while viewing the part under a black light is estimated to be 40:1 and is often much more.

- The equipment and facilities available for examination,
- The environment (ventilation, humidity, etc).

6.5 Penetrant Materials

The term “penetrant materials” is intended to include all solvents, cleaning agents, penetrants, developers, etc., used in the examination process.

6.5.1 Pre-cleaners

The first step in PT is precleaning of the surface to be examined. Detection of any discontinuity depends upon the flow of the penetrant into what may be only a microscopic opening. It is apparent that such flow cannot occur if carbon, oil, dirt, water, paint, oxide, plating, or similar materials covers or fills the discontinuity. Therefore, unless the part is clean and free from foreign materials that may mask discontinuities, reliable penetrant examination may not be accomplished.

6.5.1.1 Selection of Cleaning Technique

Various techniques are available to be used for the pre-cleaning operation. The particular technique to be used in a given situation depends on the following:

- The type of contaminant present,
- The condition of the surface,
- The type of material being examined, and
- Any combination of the above.

6.5.1.2 Typical Cleaning Techniques

Typical cleaning techniques include the fol-

lowing:

Vapor Degreasing - Vapor degreasing is highly preferred, especially when heavy oils and grease may be present.

Solvent Type Cleaners - Solvent-type cleaners may be selected for cleaning when other equipment is not available. The solvent may be applied manually but care must be taken to ensure that all discontinuities and surfaces are free from contamination.

Alkaline Cleaners - Alkaline cleaners are nonflammable water solutions containing special detergents for wetting, penetrating, and emulsifying various types of soils.

Water/Detergent Cleaning - Washing machines using hot water and detergents may be used to clean parts. Their use depends greatly on the type of contaminant present. Parts covered with oil or grease are not satisfactorily cleaned by this method.

Steam Cleaning - Steam cleaning is a modification of the hot-tank, alkaline cleaning method that can be used for cleaning large unwieldy parts.

Ultrasonic Cleaning - When discontinuities are filled with hard contaminants, such as oxides, carbon, or varnish, ultrasonic cleaning can be used to loosen and remove these contaminants.

Chemical Cleaning - Typical chemical cleaning methods are:

- Etching. Materials previously machined or

materials subjected to mechanical cleaning may be etched to remove smeared metal that could mask discontinuities.

- Acid or Alkaline Baths. Acid or alkaline baths may be used in some cases to remove rust, surface scale, or chromates. When used, however, an additional cleaning method (i.e., detergent washing) must follow.

Mechanical Cleaning - Abrasive blasting is used to clean metals only if the surface of the metal is not peened by the blasting process or if surface discontinuities are not sealed or contaminated with the abrasive materials.

6.5.1.3 Cleaning Precautions

Cleaning precautions include the following:

- The cleaning method selected and used should not, in itself, mask any discontinuities or cause the contamination of penetrants.
- Caution should be exercised when handling flammable, toxic, or other cleaning agents.
- All parts cleaned should be rinsed and thoroughly dried.

6.5.1.4 Drying Process

After the precleaning operation, the drying process is used to assure the evaporation of any water, solvents, or other cleaning agents that might remain in a discontinuity and thereby contaminate the penetrant when it is applied. Typically a 5-minute minimum drying time is required by the procedure.

Common drying methods include:

- Hand wiping with dry cloth or paper towel,
- Compressed air drying,
- Room air drying,
- Warm air drying,
- Oven drying, and
- Recirculating hot air drying.

When using oven drying or recirculating hot air drying, care must be taken not to overheat the parts. Overheated parts may require cooling before application of the penetrant in order to comply with the restrictions of the applicable code or specification.

6.5.2 Penetrants

The proper selection of a penetrant is dependent on many factors such as penetrability, visibility, type of discontinuity expected, configuration of part, surface conditions, facilities and equipment available, etc. Selection of the proper penetrant, therefore, should be based on penetrant sensitivity.

Penetrant sensitivity is defined as the ability of the penetrant materials and application techniques to effectively detect discontinuities of the type and size as required. Therefore, the penetrant materials most adaptable to these conditions are the proper penetrant materials.

6.5.2.1 Penetrant Family

Penetrant materials are supplied by many qualified manufacturers. Some codes and specifications state that only a group of materials made by

the same manufacturer known as a “family group” (or system) should be used. A family of penetrant materials includes the penetrant, emulsifier or solvent remover, and developer, as applicable, which is produced by a single manufacturer. Intermixing of penetrant material families is not permitted in many cases unless the “mixed family” has been previously qualified together as a system. The materials to be used must be compatible.

6.5.2.2 Technique Selection

When a specific PT technique is not specified by the contract, the selection of a suitable penetrant examination process is made by the Level III who makes this decision based on several basic factors:

- Requirements previously established by component drawings or applicable documents for material or parts to be placed under examination,
- Type and size of discontinuity to be detected,
- Surface condition of part to be examined,
- Configuration of part to be examined,
- The number of parts to be examined,
- Facilities and equipment available, and
- Effect of the penetrant chemicals on material being examined.

6.5.3 Developers

6.5.3.1 Properties

Developers should exhibit the following properties:

- Absorptive to secure maximum blotting action;

- Fine grain with a particle shape that will disperse and expose the small amount of penetrant at a discontinuity, over as large a surface as practical, while retaining strong indications and sharp definition of the discontinuity;
- Capable of masking, as much as possible, interfering background, and providing a contrast background for indications with contrast penetrants;
- Easy application to give a thin uniform coating;
- Must not fluoresce if used with fluorescent penetrants;
- Easily removable;
- Chemically stable in conditions of storage;
- Noncorrosive;
- Inexpensive;
- Nonflammable;
- Should not be harmful nor toxic to the operator; and
- Environmentally friendly.

6.5.3.2 Developer Types

Developer types include the following:

- Dry,
- Wet, (water suspendible or water soluble)
- Non-aqueous wet (Solvent suspension)

6.6 Penetrant Techniques

PT techniques described in this section are classified in accordance with ASME Section V Article 24 (SE-165). See Table 6-1.

Type I - Fluorescent Penetrants

- **Method A (I-A)** Water-washable penetrant (Figure 6-3)
 - Dry, wet, or nonaqueous developer
- **Method B (I-B)** Post-emulsifiable penetrant (Figure 6-4).
 - Lipophylic emulsifier
 - Dry, wet, or nonaqueous developer
- **Method C (I-C)** Solvent removable penetrant (Figure 6-5).
 - Solvent remover/cleaner
 - Dry, wet, or nonaqueous developer, and
- **Method D (I-D)** Post-emulsifiable penetrant (Figure 6-4).
 - Hydrophilic emulsifier
 - Dry, wet, or nonaqueous developer.

Type II - Visible Penetrants

- **Method A (II-A)** Water-washable penetrant (Figure 6-3).
 - Wet or nonaqueous developer
- **Method B² (II-B)** Post-emulsifiable penetrant (Figure 6-4)
 - Lipophylic or hydrophilic emulsifier
 - Wet or nonaqueous developer, and
- **Method C (II-C)** Solvent removable penetrant (Figure 6-5).
 - Solvent remover/cleaner
 - Wet or nonaqueous developer.

6.6.1 Water Washable

6.6.1.1 Water Washable (Fluorescent)

²Method II-B is not in SE-165 Table I.

Type 1 Method A uses a water-washable fluorescent penetrant and a dry, wet, or nonaqueous wet developer (Figure 6-3). The penetrant has self-emulsifying properties to make it water removable.

Note: Wet developers are not recommended for use with water washable penetrant systems.

Type 1 Method A is generally used when:

- Examining large volume of parts,
- Discontinuities are not wider than their depth,
- Surfaces are rough,
- Examining large areas,
- Examining parts with threads and keyways, and
- The lowest fluorescent penetrant sensitivity is sufficient to detect most discontinuities.

Advantages and Disadvantages of Type 1, Method A

Advantages include:

- Use of fluorescent penetrant ensures high visibility of indication;
- Detect a wide range of discontinuities;
- Easily removed with water;
- Easily adaptable to a large volume of small parts;
- Excellent for rough surfaces, keyways, and threads; and
- Relatively inexpensive.

Disadvantages include:

- Darkened area required for examination;
- Affected by acids and chromates;
- Not reliable on anodized surfaces;
- Susceptible to over-washing;
- Water contamination may destroy usefulness of penetrant; and
- Wide, shallow discontinuities (width greater than depth) may not be detected.

6.6.1.2 Water Washable (Visible)

Type II Method A process uses a water-washable visible dye penetrant and wet or nonaqueous developer (Figure 6-4). The penetrant is a brilliant red and has self-emulsifying properties to make it water removable.

Type II Method A is generally used when:

- High sensitivity is not required,
- Examining large volume of parts,
- Discontinuities are not wider than their depth,
- Surfaces are rough,
- Examining large areas,
- Examining parts with threads and keyways.

Advantages and Disadvantages of Type II Method A

Advantages include:

- No black light or darkened examination area required;
- Can be used for detecting a wide range of discontinuities;
- Penetrant can be easily removed with water;

- Adaptable to a large volume of small parts;
- Excellent for rough surfaces, keyways, and threads; and
- Relatively inexpensive.

Disadvantages include:

- Fine discontinuities may not be detected,
- Can be affected by acids and chromates,
- Not reliable on anodized surfaces,
- Susceptible to over-washing,
- Water contamination may destroy usefulness of penetrant, and
- Wide, shallow discontinuities (width greater than depth) may not be detected.

6.6.2 Post Emulsifiable (Figure 6-4)

6.6.2.1 Post Emulsifiable (Fluorescent)

The Type I Methods B and D use a post-emulsifiable fluorescent penetrant, an emulsifier, and a dry, wet, or nonaqueous wet developer (Figure 6-4). The materials used in this process are very similar to that described for Type I Method A process, except that these penetrants are not self-emulsifiable. A lipophylic (I-B) or hydrophilic (I-D) emulsifier is used to make the penetrant water washable.

These processes (I-B and I-D) are generally used when:

- Examining large volume of parts;
- The part is contaminated with acid or other chemicals that will harm water-washable, penetrants;

- Discontinuities are wider than their depth;
- Examining parts which may have discontinuities containing in-service contaminants;
- Examining for stress, cracks or intergranular corrosion;
- Examining for very small tight cracks; and
- High visibility is required.

Advantages and Disadvantages of Type I Methods B and D

Advantages include:

- High sensitivity for very fine discontinuities,
- Good for detection of wide shallow discontinuities (width greater than depth),
- Good for high volume production,
- Not as susceptible to over-washing.

Disadvantages include:

- Requires more time (emulsifier is an additional step),
- Additional equipment is required for the application of the emulsifier,
- Not as good on parts with complex shapes (e.g., threads) as Method A,
- Additional material cost, and
- Emulsification time and dwell time are very critical.

6.6.2.2 Post Emulsifiable (Visible)³

The Type II Method B uses a post-emulsifiable visible dye penetrant, an emulsifier, and wet, or

³This type is not in SE-165 Table I.

nonaqueous developer. The materials used in this process are very similar to that described for Type II Method A; however, the penetrants are not self-emulsifiable. An emulsifier is applied to the penetrant to make it water washable.

Type II Method B is generally used when:

- Examining large volume of parts,
- The part is contaminated with acid or other chemicals that will harm water-washable, penetrants,
- Discontinuities are wider than their depth, and
- Examining parts which may have discontinuities containing in-service contaminants.

Advantages and Disadvantages of Type II Method B

Advantages include:

- No black light or darkened area required,
- Good sensitivity for fine discontinuities,
- Effective for wide shallow discontinuities (width greater than depth),
- Adaptable for high volume examination,
- Normally not affected by acids, and
- Not as susceptible to over-washing.

Disadvantages include:

- Requires more time (emulsifier is an additional step),
- Additional equipment is required for the application of the emulsifier,
- Not as good on parts with complex shapes (e.g., threads) as Method A,

- Additional material cost, and
- Emulsification time is very critical.

6.6.3 Solvent Removable

6.6.3.1 Solvent Removable (Fluorescent)

Type I Method C includes a solvent-removable fluorescent penetrant, a solvent remover, and a wet, dry or nonaqueous developer (Figure 6-7).

The penetrant is not water washable and requires the use of a solvent remover.

Type I Method C is generally used when:

- Spot examination is required.
- Water-rinsing method is not feasible.

Advantages and Disadvantages of Type I Method C

Advantages include:

- Process can be used for spot examination on large parts.
- Process can be used when water-removal methods are not feasible or possible.

Disadvantages include:

- Use of solvent to remove penetrant makes examination of large areas difficult and labor intensive.
- Sensitivity can be reduced by the application of excessive amounts of remover.

6.6.3.2 Solvent Removable (Visible)

Type II Method C uses a solvent-removable visible dye penetrant, a solvent remover and a wet or nonaqueous developer. The penetrant is not water washable but is removed instead with the solvent remover. It is the most widely used PT technique in the power industry.

Type II Method C is generally used when:

- Spot or small area examination is required.
- Water-rinsing is not feasible.

Advantages and Disadvantages of Type II Method C

Advantages include:

- Portable,
- Can be used virtually anywhere,
- No black light or darkened area required, and
- Process is highly versatile.

Disadvantages include:

- Use of solvent to remove penetrant makes examination of large areas virtually impossible.
- Sensitivity can be reduced by the use of excessive amounts of remover.
- Visibility of indications is less than type 1 penetrants.

6.6.4 Compatibility

Each penetrant compatibility group is compatible only when used within its own “family”.

Manufacturers generally supply data to ensure compatibility between the various system components. Intermixing of penetrant material outside of the family is prohibited.

6.7 Procedures

The following is a summary of general procedural steps for a PT examination:

1. Selection of the appropriate examination process: This should be determined by the examination agency based on the type and quantity of parts to be examined, and the anticipated and required results.
2. Contamination: If the parts to be examined could be affected by oil, sulphur, chlorine, or other contaminant, alternate material or processors should be considered.
3. Prerequisites: Conditions such as temperature, ventilation, lighting, etc., must be considered.
4. Precleaning: The part to be examined should be precleaned in order to remove any contaminating material. Inadequate precleaning is the source of most of the false indications encountered.
5. Drying: Parts which have been precleaned must be dried to assure removal of all traces of cleaning material.
6. Penetrant Application: Penetrant is applied to the part in a manner that assures complete coverage.
7. Dwell time: Sufficient dwell time is allowed to permit optimum penetration of the penetrant.
8. Penetrant Removal: Excess penetrant is removed from the surface of the part in the manner dictated by the type of penetrant used.
9. Developer Application: Developer is applied to

the part, based on the process being used and the configuration of the part.

10. Development time: The time specified to permit adequate development of the indication after developer application must be allowed.

11. Interpretation: The part is interpreted and evaluated to the applicable acceptance criteria.

12. Post Cleaning: The developer and all traces of the penetrant is removed after evaluation and prior to returning the part to service.

6.7.1 Penetrant Application

Penetrant materials can be applied by either:

- Dipping the part in the penetrant,
- Flowing the penetrant over the part,
- Spraying the pen on the surface of the part,
- Brushing the penetrant on the part, and
- Any other method where the penetrant completely covers the area of interest.

6.7.2 Penetrant Dwell Time

The length of time the penetrant remains on the part or material is referred to as dwell time. Dwell times typically range from 10 to 20 minutes. During the dwell time, the following should be observed:

- The dwell time specified in the procedure must be observed.
- Parts should be positioned in such a manner (after penetrant application) to allow the penetrant to drain and not accumulate in pools.
- Penetrant on the surface of the part must not be

allowed to dry during the dwell time. It may be necessary to apply additional penetrant to prevent drying.

6.7.3 Removal of Excess Surface Penetrant

After the penetrant dwell time the excess surface penetrant must be removed. The technique employed for the removal of excess surface penetrant is outlined below for the appropriate penetrant used.

6.7.3.1 Method A (Water Washable)

Water-washable penetrants are removed with either a manual or automated water spray. Immersion in agitated water is also sometimes permitted.

When an agitated immersion rinse method is used, the dwell time in the rinse should be the minimum required to remove the surface penetrant. When either a manual or automated spray rinse method is used, the water pressure must not exceed 345 kPa (50 psi), and the water temperature must not exceed 110°F (43°C). Washing should be conducted under appropriate illumination to assure that over-washing does not occur. In the event over-washing does occur, the part must be cleaned and reprocessed.

6.7.3.2 Method B (Lipophylic Emulsifier)

Post emulsified penetrants are removed by either water immersion or water spray after application of an emulsifier and an appropriate emulsification time.

The lipophylic emulsifier should be applied by

dipping or flowing, but **not by brushing** or spraying. The emulsifier should not be agitated while on the surface of the part. The dwell time must be the minimum required to produce an acceptable background on the part under examination and should be qualified by actual performance tests.

After the emulsification time, the emulsified surface penetrant is removed by either a manual or automated water spray. The water pressure must not exceed 345 kPa (50 psi), and the water temperature must not exceed 110°F (43°C). Washing should be conducted under appropriate illumination to assure that over-washing does not occur. In the event over-washing does occur, the part must be cleaned and reprocessed.

6.7.3.3 Method D (Hydrophilic Emulsifier)

Post emulsified penetrants are removed with a water pre-rinse application of the hydrophilic emulsifier and a post rinse.

The water pre-rinse is applied for the minimum amount of time required to achieve removal of the bulk surface penetrant. Either a manual or an automated spray rinse method may be used. The water pressure must not exceed 345 kPa (50 psi), and the water temperature must not exceed 110°F (43°C). Washing should be conducted under appropriate illumination to assure that over-washing does not occur. In the event over-washing does occur, the part must be cleaned and reprocessed.

The hydrophilic emulsifier is applied by dipping, flowing, or spraying. For dipping applications, the concentration should be as recommended by the manufacturer. The emulsification time **must be determined by qualification tests** but usually will not exceed 2 minutes. The emulsifier or the part should be gently agitated. For flow-on or spray applications, the concentration should be as recommended by the manufacturer, and the flow or spray should only be long enough to adequately remove the surface penetrant.

After the emulsification time, the surface of the part being examined is rinsed with a water spray. Either a manual or automated spray rinse may be used. The water pressure must not exceed 345 kPa (50 psi), and the water temperature must not exceed 110°F (43°C). Washing should be conducted under appropriate illumination to assure that over-washing does not occur. In the event over-washing does occur, the part must be cleaned and reprocessed.

If a manual system is used, the part should be observed under black light during the removal process to assure adequate penetrant removal and to prevent over-removal.

6.7.3.4 Method C (Solvents)

Solvent removable penetrants are removed in the following manner:

The surface of the part is first wiped with a clean, lint free, dry cloth or absorbent paper towel to remove as much of the surface penetrant as possible. The remainder of the surface penetrant is then removed by wiping the surface with a lint free

cloth or absorbent paper towel that has been dampened with the penetrant remover (solvent). The surface of the part must not be flushed with the remover, and the cloth or paper towel should not be saturated with the remover.

NOTE: It may be necessary to repeat this step in order to adequately remove the surface penetrant.

The surface of the part and the cloth or towel should be observed under appropriate illumination to assure adequate removal of the surface penetrant. Care must be exercised to prevent over-removal. Following removal of surface penetrant, the surface of the part must be dried by blotting with a lint free, dry cloth or towel, or by air evaporation.

6.7.4 Drying

When a dry or nonaqueous wet developer is used, the specimen is dried after removal of excess penetrant and prior to application of the developer. When an aqueous wet developer is used, the specimen is dried after the developer has been applied. Any means of drying that does not interfere with the test process by overheating, or by contamination of materials, is acceptable. A thermostat controlled dryer is often used. Required drying time is determined by the size and shape of the specimen. It should be only long enough to dry the surface of the specimen without affecting the penetrant in the discontinuities. Part temperature must not exceed 125°F.

6.7.5 Development

The manner in which the developer is applied

depends upon the type of developer used.

6.7.5.1 Dry Developer

Dry developer is applied by:

- Dusting (preferred),
- Dipping, and
- Flowing.

NOTE: Dusting may be accomplished by air fluffing the dry powder in a sealed chamber so that the circulation of air deposits the absorbent powder on all surfaces of the object being examined.

6.7.5.2 Aqueous Wet Developer

Aqueous wet developer is applied by:

- Dipping,
- Flowing,
- Spraying.

6.7.5.3 Nonaqueous Wet Developer

Nonaqueous wet developer is applied by spraying.

This developer should be agitated while in use to keep the developer particles in suspension. For pressurized spray cans, the can should be shaken vigorously before each use until the agitator in the can rattles.

Development time depends on the type of developer used. Sufficient time should be allowed for an indication to form, but the penetrant should not be allowed to diffuse into the developer

so as to cause a loss of definition. The surface being developed should be observed to permit flaw characterization and to determine the extent of the bleedout.

When an aqueous wet developer is used, the time in the drying oven is normally considered adequate development time. A 10 minute minimum to a 60 minute maximum development time is required by Section V.

6.7.6 Evaluation

Final evaluation/interpretation must be made within 10 to 60 minutes of developer application. Longer periods are permitted by the code if the bleed outs do not alter the examination results.

6.7.7 Post Cleaning

After evaluation, the penetrant materials must be removed from the part. The post cleaning method is specified in the procedure and will usually employ the steps or techniques as described in section 6.5.1.

6.8 Procedure Qualification

The penetrant material manufacturer should include material certifications and the materials should be qualified prior to their first use. This generally consists of a “dry run” following their procedure using controlled test specimens or cracked panels.

6.9 Nonstandard Temperatures

When it is not possible to conduct a PT within

the specified temperature range, an examination procedure at the proposed lower or higher temperature range requires qualification. This requires the use of a cracked aluminum block, which is designated as a penetrant comparator block (Figure 6-6).

Penetrant comparator blocks are usually made of aluminum, 3/8-inch thick, and have approximate face dimensions of 2 by 3 inches. At the center of each face, an area approximately one inch in diameter should be marked with a 950°F temperature-indicating crayon or paint. The marked area should be heated to a temperature between 950°F and 975 °F. The specimen should then be immediately quenched in cold water; this produces a network of fine cracks on each face.

The block shall be cut across the middle of the block and the two sides are designated “A” and “B” for identification in subsequent processing. As an alternate, two comparator blocks with closely matched crack patterns may also be used. The blocks should be marked “A” and “B”.

If it is desired to qualify a penetrant examination procedure at a temperature outside the stipulated range, the proposed procedure should be applied to block “B” at the proposed examination temperature. Block “A” is then examined in the code-acceptable temperature range of 50°F to 125°F. The indications of cracks should be compared between blocks “A” and “B”. If the indications obtained under the proposed conditions on block “B” are essentially the same as obtained on block “A” during examination at acceptable temperatures, the proposed procedure is considered qualified for use.

6.10 Control Panels

Control of the penetrant process is essential in order to maintain consistency and quality. Test panels are an integral part of any control program for penetrant process. The test panels contain discontinuities, which are excellent for controlling quality. A wide range of test panels are available commercially. Some test panels are prepared from stainless steel plates and have two areas: one is roughened under standard conditions and the other is smoother with a number of star-shaped cracks (usually five). Each usually has a different degree of severity.

The roughened surface allows comparison of the fluorescent background remaining after processing and indicates the removal characteristics of the process.

Other test panels, which are of great value in assessing penetrant processes, contain nickel chrome plating on a softer base metal. The panel is bent resulting in cracks in the plating. The bent panel is then flattened. Such panels have well-characterized crack depth because the plating thickness can be controlled and measured. Crack width can also be measured at the surface. Test panels of this design tend to be expensive, but they are very useful for comparing penetrant processes, development of processes and new materials, and for PT material and procedure qualification.

A third type of panel can be prepared by fatigue loading. These can be made with a variety of materials, and varying degrees of severity of cracking can be incorporated.

6.10.1 Limitation of Test Panels

When test panels are used for day-to-day control of a penetrant process, the limitations are few. However, when any panel is used in assessing the performance of various processes, some care is required. It is essential that all these panels are cleaned thoroughly after use as quickly as possible, since penetrant residues when left in discontinuities become very viscous and extremely difficult to remove.

6.11 Penetrant Systems

A typical fluorescent penetrant system is shown in Figure 6-7.

6.11.1 Pre-cleaning Station

This station is used to pre-clean parts before they are processed for examination. It should be noted that the pre-cleaning station may be located elsewhere.

6.11.2 Penetrant Application Station

This station provides an area where the penetrant is applied to the part under test.

6.11.3 Penetrant Draining Station

This station provides an area where parts can be set aside in order for the excess penetrant to drain, and where penetrant dwell time occurs. As its name implies, the penetrant draining station is located adjacent to the penetrant application station.

6.11.4 Emulsifier Application Station

This station is included only if post-emulsifiable penetrants are used. The emulsifier is applied to the penetrant to make it washable. This station is located adjacent to the penetrant draining station.

6.11.5 Washing or Rinsing Station

This station is included when water-washable or post-emulsifiable penetrants are used. This area is used to remove surface penetrants and emulsifiers, when water-washable or post-emulsifiable penetrants are used. The washing station can also be a draining station because of the usual short emulsification time. When fluorescent penetrants are used, effectiveness of the removal step can be monitored since rinsing will be done under a black light mounted over this station.

6.11.6 Developer Application Station

This station is used to apply wet (or dry) developer to the part and is normally located after the washing station for wet developers or after the drying station for dry developers.

6.11.7 Drying Station

This station is used to dry parts after they have been rinsed. This station is located before or after the developer application station depending on the type of developer used.

6.11.8 Examination Station

This station provides the area where the parts under test are thoroughly examined and contains one or more black lights.

6.11.9 Post-cleaning Station

This station may be the same as the pre-cleaning station, and is used for cleaning parts prior to returning them to production or service.

6.12 Portable Systems

PT is practical for field use because the penetrant materials are supplied in portable kits. Both fluorescent and visible dye penetrant kits are available.

A typical visible dye penetrant kit is illustrated in Figure 6-8 and usually contains:

- Spray cans of cleaner or remover solvents,
- Spray cans of visible dye penetrant,
- Spray cans of nonaqueous developer, and
- Wiping cloths and brushes.

A typical fluorescent penetrant kit is illustrated in Figure 6-9 and usually contains:

- Spray cans of cleaner or remover solvents,
- Spray cans of fluorescent penetrant,
- Spray cans of nonaqueous developer,
- Wiping cloths and brushes, and
- Portable black light.

6.12.1 Black Lights

“Black light” is a term applied to the visible radiant energy in that portion of the spectrum having wavelengths in the range of 320 to 380 nm. The “black light” utilizes a mercury vapor bulb of the sealed reflector type that must be equipped with a suitable filter to eliminate high intensity light of longer wavelengths.

A deep red-purple filter is used to pass only those wavelengths of light that activate the fluorescent material. A 5-minute warm-up period is required to reach the maximum intensity when using black light.

The Code establishes minimum black light intensities expressed in microwatts per centimeter squared ($\mu\text{W}/\text{Cm}^2$). Section V requires a minimum of $1,000 \mu\text{W}/\text{Cm}^2$ and measured at the surface of the part to be examined.

CAUTION: Exposure of the eyes to a black light with a damaged filter should be avoided. Therefore, it is important that the black light not be used if it has a cracked or broken filter. Looking directly into the black light should be avoided. Operators must give their eyes 5 minutes to adjust to the darkened area. No photosensitive glasses are permitted when performing evaluation.

6.13 Examination Procedure

PT examinations should be performed in accordance with a qualified procedure. Such a procedure should contain at least the following information:

- Materials, shapes, or sizes to be examined, and the extent of the examination;
- Type (number or letter designation if available) of each penetrant, penetrant remover, emulsifier, and developer;
- Processing details for pre-examination cleaning and drying, including the cleaning materials to be used and minimum time allowed for drying;
- Processing details for applying the penetrant; the length of time that the penetrant will remain on the surface (dwell time), and the temperature of the surface and penetrant during the examination, if other than standard;
- Processing details for removing the excess penetrant from the surface and for drying the surface before applying the developer;
- Processing details for applying the developer and length of development time before interpretation;
- Evaluation/interpretation data;
- Processing details for post-examination cleaning; and
- Reporting.

6.13.1 Procedure Revision

A revised procedure may be required in the following situations:

- Whenever a change or substitution is made in the type or family group of penetrant materials (including developers, emulsifiers, etc.) or in the processing techniques;
- Whenever a change or substitution is made in the type of precleaning materials or processes; and
- For any change in part processing that can close

surface openings of discontinuities or leave interfering deposits, such as the use of grit blast cleaning or acid treatments.

6.14 Applications

6.14.1 Welds

PT processes for welds are no different from the standard technique previously described; however, material differences related to the prevalence of porosity and/or other common discontinuities in the various welds should be understood thoroughly to aid in the evaluation. Generally, as-welded surfaces are suitable for PT examination but some preparation may be necessary. The weld and at least 1 inch on each side should be suitably prepared. If the area to be examined is stipulated as the weld and ½" adjacent base material then 1 ½" of the adjacent base material must be cleaned.

6.14.2 Castings

As-cast surfaces may require a light surface preparation (grinding, buffing) to minimize confusing background.

6.14.3 Through Leaks

Application of penetrant to detect leakage through joints, seals, and porosity can be easily achieved. One side of the material is covered with penetrant, and the other side is examined after an appropriate period for through leakage. Developer is sometimes applied to improve sensitivity.

6.15 Unacceptable Techniques

The following techniques are not acceptable:

- Fluorescent penetrant examinations should not follow a color contrast penetrant examinations. A retest with fluorescent penetrants may cause loss of marginal indications due to contamination.
- Intermixing of penetrant materials from different families is not permitted.
- Flushing the surface with solvent, after the penetrant dwell time and prior to developing, is prohibited. This may wash out or remove the penetrant from discontinuities.

6.16 Variables

Many variables require control during PT examination that can affect results including:

- Penetrant types,
- Temperature of part,
- Penetrant dwell times,
- Lighting,
- Removal techniques,
- Emulsifier dwell times,
- Agitation of wet developers,
- Rinse temperature,
- Rinse pressures,
- Drier temperature,
- Drying time,
- Developer types,
- Developer temperature,
- Black light condition,

- Examiner vision acuity, and
- Examiners condition.

6.17 Evaluation

Correct evaluation of a discontinuity is important to the examination process. The examiner must carefully follow the procedure, detect the indications, and then make the correct disposition of the parts. Poor processing can be worse than no examination, since improper processing may not disclose indications for interpretation.

6.17.1 Indications

Based on Chapter 2, it must be remembered that all indications are not caused by discontinuities. Some indications are the result of faulty processing, while other indications are the result of part design. The penetrant examiner must be able to recognize the various indications that can appear.

Penetrant indications fall into one of three categories:

- False indications,
- Nonrelevant indications, and
- True indications.

There are specific differences between all three. A qualified examiner using acceptable procedures and codes can determine the cause and category of each penetrant indication.

6.17.1.1 False Indications

In PT, the most common causes of false indica-

tions result from the improper or inadequate precleaning of the part, and the improper or inadequate removal of the excess surface penetrant. If all the surface penetrant is not completely removed, the remaining penetrant may produce false indications. This is true for both the fluorescent and visible penetrants. The use of the black light during the removal of fluorescent penetrants is very helpful in assuring that adequate removal has been achieved.

A properly cleaned part shows only a very faint, or no pink background if visible penetrants are used, or only very faint, or no areas of background fluorescence when fluorescent penetrants are used. False indications due to incomplete removal are usually easy to identify because the penetrant is faint and broad rather than in the sharp patterns found in the true discontinuities.

The danger of poorly cleaned parts and resulting false indications is that true indications could be masked by the false indications. If false indications interfere with interpretation, complete reprocessing of the parts is required.

6.17.1.2 Nonrelevant Indications

Nonrelevant indications are true indications produced by known conditions. These conditions are created by design or other features of the part having no relation to discontinuities.

Nonrelevant indications can result due to fillets, threads, and keyways. Sharp fillets and keyways often retain penetrant at their base and produce indications despite a good removal technique. This is particularly true when post-emulsified

penetrants are employed. Because heat-treating or fatigue cracks often occur at such locations, it is essential that the examiner watch these areas develop to verify non-relevant from relevant indications.

Nonrelevant indications due to press fit is another condition that creates nonrelevant indications. If a wheel is press-fitted onto a shaft, the penetrant shows an indication at the fit line. This is perfectly normal since the two parts are not welded together. The only problem with such indications is that penetrant from the press-fit may bleed out profusely and mask a true discontinuity.

6.17.1.3 True Indications

The last classifications of indications are from discontinuities.

ASME Code sections require classification of bleed outs as to whether they are rounded or linear and also require actual bleedout size.

6.17.2 Interpretation

The true size and type of discontinuities are difficult to determine if the penetrant diffuses excessively into the developer. Consequently, the surface should be closely observed during the application of the developer to monitor the behavior of indications that tend to bleed profusely. Final interpretation should be made after allowing the penetrant to bleedout for 10 to 60 minutes. If bleedout does not alter the examination results, longer periods may be permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed time, the surface

should be examined in increments.

All indications should be evaluated in terms of the acceptance standards of the referencing code section. Discontinuities at the surface are indicated by bleedout of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications. Broad areas of fluorescence or pigmentation that could mask indications of discontinuities are unacceptable, and such areas should be cleaned and reexamined.

6.17.2.1 Visible Dye Penetrants

With a visible dye penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleedout of the penetrant, which is normally a deep red color that stains the developer. Indications with a light pink color may indicate inadequately cleaning, which makes interpretation difficult. Adequate illumination is required during the examination and evaluation of indications.

6.17.2.2 Fluorescent Penetrants

With fluorescent penetrants, the process is essentially the same as in section 6.17.2.1 with the exception that the examination is performed using a black light. The examination should be performed as follows:

- It should be performed in a darkened area.
- The examiner should be in the darkened area for at least 5 minutes before performing the examination to enable his eyes to adapt to dark viewing. If the examiner wears glasses or

lenses, they should not be photosensitive.

- The black light should be allowed to warm up for a minimum of 5 minutes before use.
- The black light intensity should be measured with a black light meter. A minimum of $1,000 \mu\text{W}/\text{cm}^2$ at the surface of the part being examined should be achieved.
- The black light intensity should be measured prior to use, whenever the light power source is changed or interrupted and at the completion of the exam or series of examinations.

6.17.3 Specific Types of Discontinuities

Generally discontinuities fall into the following five basic types:

Fine, Tight Surface Cracks - Such cracks may be shallow or deep, but their most significant characteristics is their very small and tight surface opening. Deep cracks of this type, once well penetrated, may provide a reservoir of penetrant, and therefore, will result in a more significant bleedout.

Broad, Open Surface Discontinuities - Discontinuities of this type may be shallow or relatively deep. Their significant characteristic is their width, which tends to permit penetrants to be removed from the discontinuity, especially when water spray removal techniques are employed. Care must be taken to prevent this.

Porosity - In general, porosity is a discontinuity having a cavity below the surface, which can be connected to the surface by a very small channel. Porosity is typically found in castings and welds and is sometimes referred to as gas voids. Porosity causes rounded indications in PT.

Shrinkage - Shrinkage in castings that are open to the surface by machining and etching may be hard to differentiate from cracks. Much care must be used in evaluating this type of indication.

Leaks or Through Cracks - Discontinuities of this type are cracks or openings that pass from one surface to another.

6.17.4 Discontinuity Indication Categories

Five basic groups of indications may be observed based on their bleedout appearance:

- Continuous linear,
- Intermittent linear,
- Rounded,
- Aligned rounded
- Diffused or weak.

It is possible to examine an indication of a discontinuity and determine its cause as well as its extent. Such an evaluation can be made if something is known about the manufacturing processes or the operational use to which the part has been subjected. The extent of the indications, or accumulation of penetrant, indicate the extent of the discontinuity.

The vividness of the visible dye penetrant on the contrasting white developer or the brilliance of the fluorescent penetrant give some indication of the discontinuity's depth. Deep discontinuities hold more penetrant; therefore, they have a large more brilliant bleedout. Very fine discontinuities can hold only small amounts of penetrant and appear as fine bleed outs.

In many instances more accurate evaluations may be obtained by removing the indications and reapplying the developer so that the rate and amount of penetrant bleedout can be closely observed to facilitate the interpretation of the actual discontinuity.

6.18 Advantages and Limitations of Penetrant Examination

The advantages and limitations were discussed in each section separately and are summarized here.

6.18.1 Advantages

Advantages of PT examinations include:

- Relatively inexpensive materials;
- Sensitive (can usually detect discontinuities .0001 inch width or greater);

- Versatile (can be used on any nonporous, non-absorbent material);
- Size and shape of test object normally is not a limitation; and
- Easy to use.

6.18.2 Limitations

Limitations of PT examinations include:

- Time consuming and therefore expensive in man hours,
- Can only detect discontinuities open to the surface and clear of contaminants and water or other fluids
- Surface of part should be within an acceptable temperature range,
- Difficult to use on some rough surfaces,
- Requires good ventilation,
- No permanent record, and
- The process can be messy.

Table 6-1 Penetrant Material Classifications
(SE 165, Standard Test Method for Liquid Penetrant Examinations)

<u>Type</u>	<u>Method</u>	<u>Materials</u>
I (Fluorescent)	A	Water-washable penetrant; dry, aqueous, or nonaqueous developer
	B	Post-emulsifiable penetrant; lipophylic emulsifier; dry, aqueous or nonaqueous developer
	C	Solvent-removable penetrant; solvent cleaner/remover; dry or nonaqueous developer
	D	Same as Type I B, except the emulsifier is hydrophilic
II (Visible)	A	Water-washable penetrant; aqueous or nonaqueous developer
	B*	Post-emulsifiable penetrant, emulsifier, and aqueous or nonaqueous developer
	C	Solvent-removable penetrant; solvent cleaner/remover; aqueous or nonaqueous developer

* Not in SE-165 Table I

NOTE: ASME Section V Article 6, T-651 specifies six (6) “techniques”:

Color Contrast (Visible)

Water Washable

Post-emulsifying

Solvent Removable

Fluorescent

Water Washable

Post-emulsifying

Solvent Removable

The types described in this chapter are those in SE-165 which is a standard referenced in Article 6 and provides additional details for these processes.

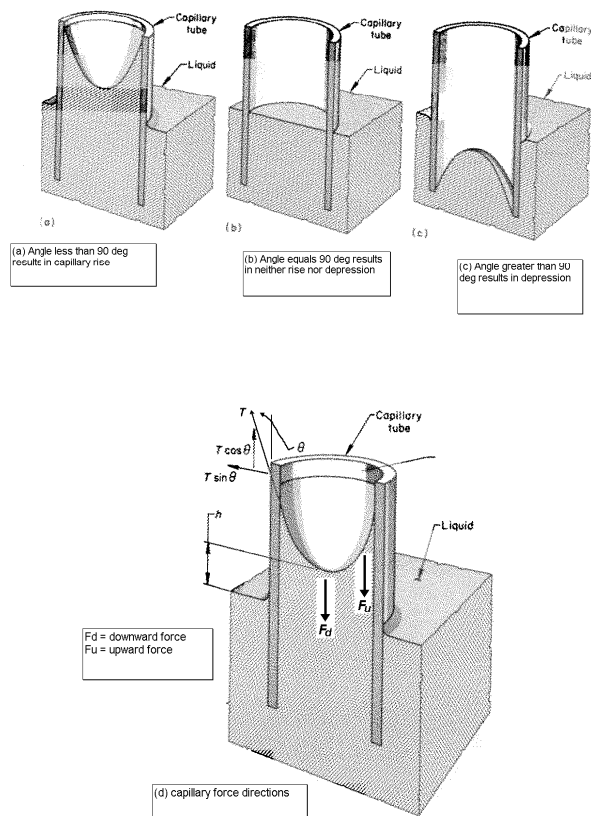
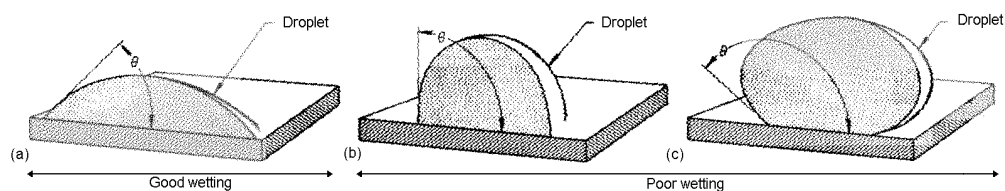


Figure 6-1 Forces Involved in Capillary Action



Wetting characteristics as evaluated by the angle (θ), between a droplet of liquid and a solid surface. Good wetting is obtained when angle (θ) < 90 deg (a); poor wetting, when angle (θ) ≥ 90 deg (b) and (c)

Figure 6-2 Contact Angle

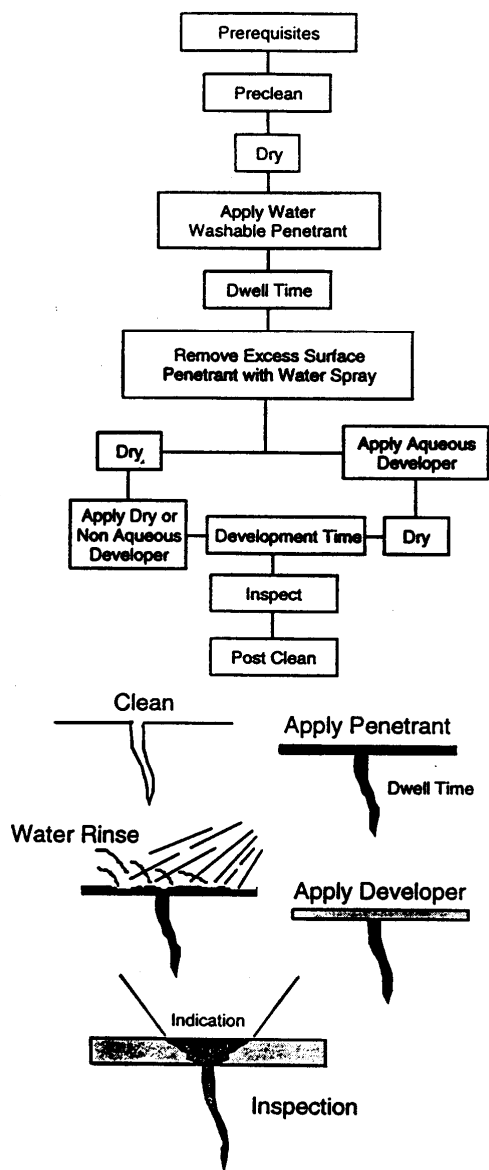


Figure 6-3 Method A-Water Washable

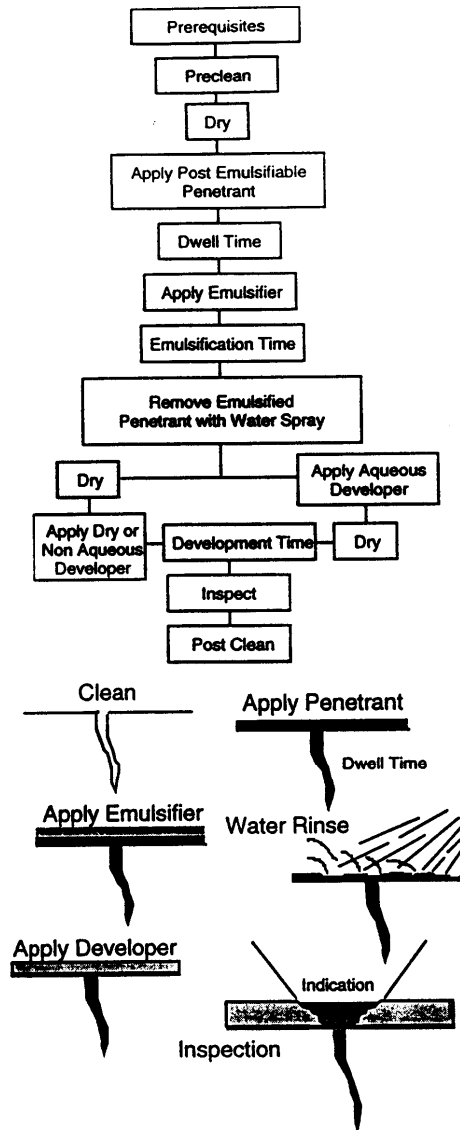


Figure 6-4 Method B or D-Post Emulsifiable

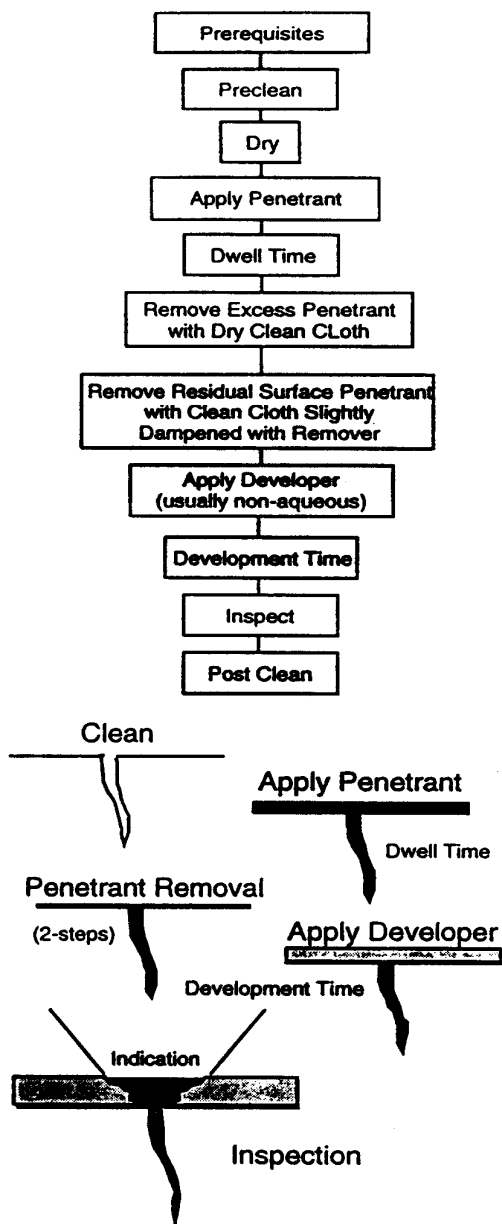


Figure 6-5 Method C-Solvent Removable

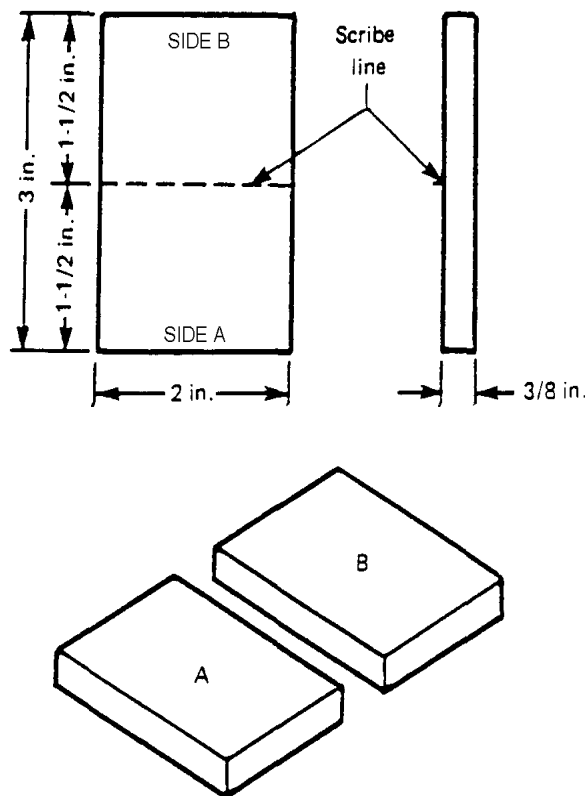


Figure 6-6 Penetrant Comparator Block

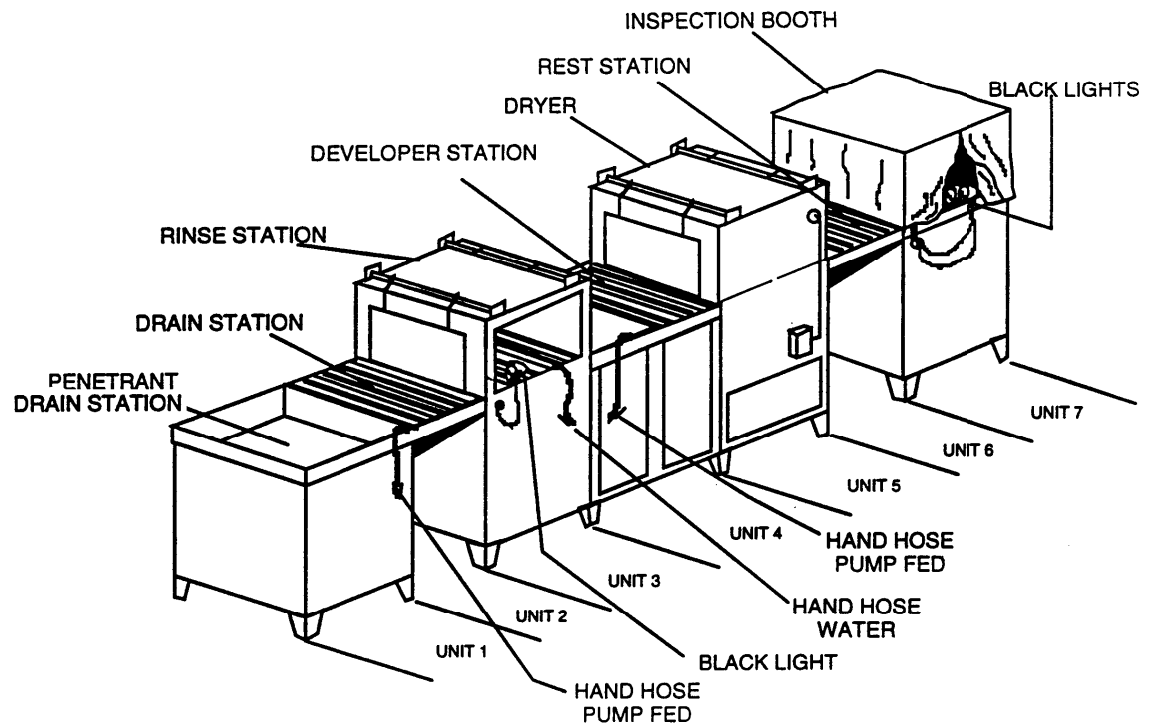


Figure 6-7 Fluorescent Penetrant System

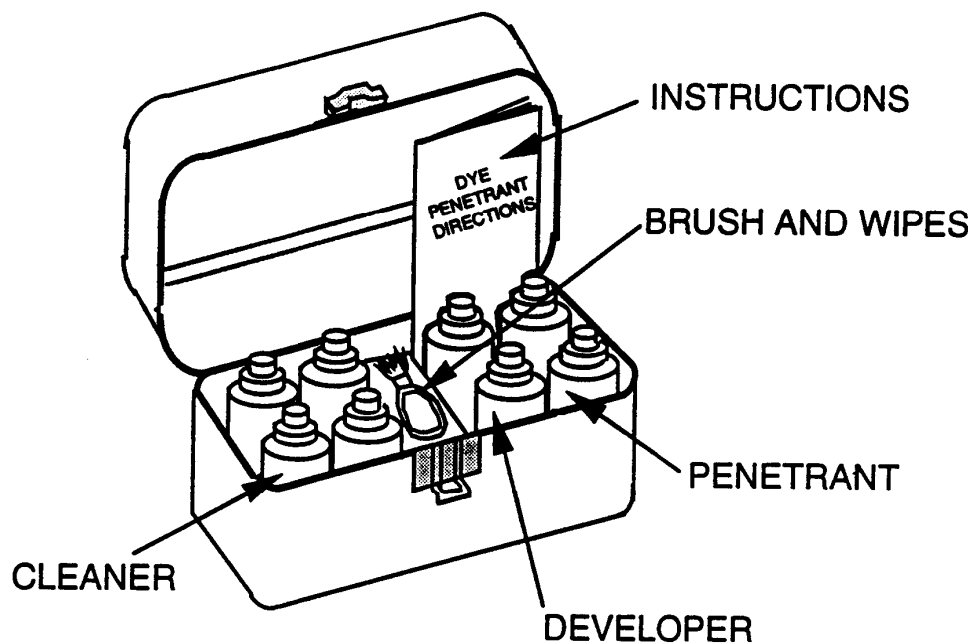


Figure 6-8 Visible Penetrant Kit

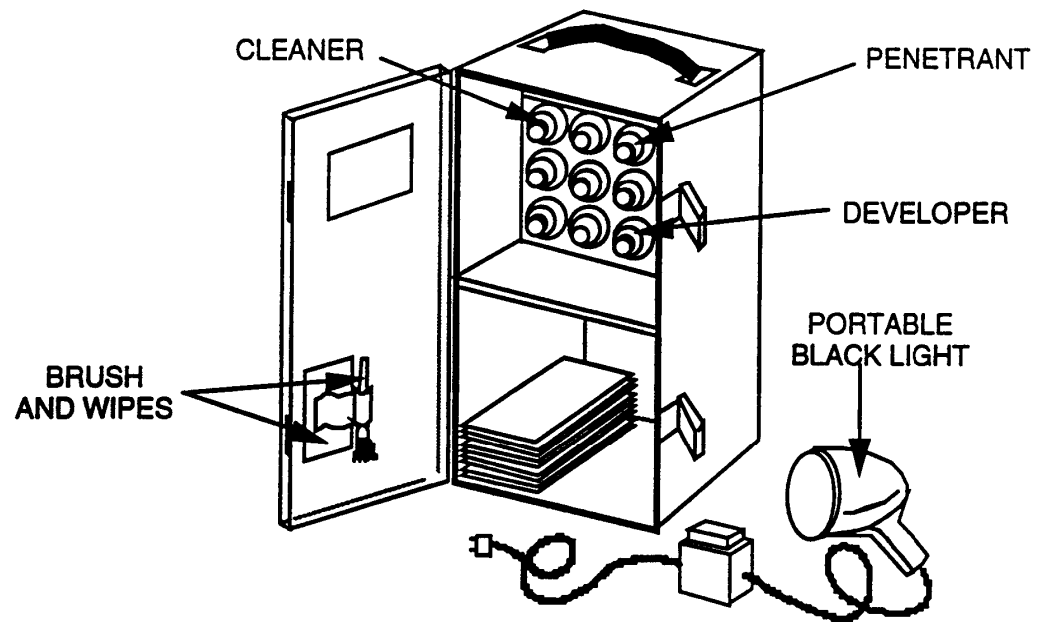


Figure 6 -9 Fluorescent Penetrant Kit