COURSE MATERIAL FOR PT20A

Liquid Penetrant Inspection Level 2

NZNDTA

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USED FOR Theory training material for CBIP
PT2

FOREWARD

The material in this publication is for training purposes **only**

It is not intended, in any way, to replace or supplement company manuals or OEM procedures and is **UNCONTROLLED**

In any specified work situation reference **MUST** be made to the relevant current customer requirements and published specifications for correct instructions.
It is important therefore that this publication not be used as an authoritative source, but only for information purposes

Purpose:

The body of technical knowledge required of non-destructive testing (NDT) personnel is essential for maintaining the quality level of all NDT inspections regardless of method or technique. The content and expected outcomes of this course are designed to cover the Liquid Penetrant inspection of product forms (including welds) for evaluation of surface discontinuities at qualification Level 2 (ISO 9712).

This course is also designed to prepare the trainee for the **Theory** part of the CBIP Liquid Penetrant Inspection Certification **PT2**

Practical training and assessments have been included in this course for demonstration purposes and to confirm the adequacy of the training.

Competency Standards:

This course and associated training materials have been designed to comply with the following documents

ISO 9712-2012 - Non-Destructive Testing - Qualification and Certification of NDT Personnel
ISO/TS 25107:2019 - Non-Destructive Testing - NDT training syllabuses
CBIP PRO-CER-18 - Guidelines for certification General
CBIP PRO-CER-15 - Guidelines for certification Liquid Penetrant testing

Learning Outcome

Trainees will be able to demonstrate knowledge of the Liquid Penetrant inspection process including practical applications and Interpretation and Evaluation at Level 2

They should be able to perform the following;

- Select the PT technique to be used based on general specifications (AS 2062 and ASTM E1417)
- Define the limitations of PT (Liquid Penetrant Testing) method.
- Translate PT standards, specifications and procedures into written instructions.
- Set up and verify equipment settings
- Perform PT inspections including interpretation and evaluation of results according to applicable standards
- Provide supervision and guidance for personnel at or below Level 2,
- Report the results of Penetrant Inspections.

Course Duration

The course will be delivered over a period of 40 hours covering 5 days.

A course plan detailing the expected timetable will be issued to the trainee at the start of the course. The course will consist of theory lecturers, practical exercises and assessments as detailed in the course programme and syllabi.
The practical content of this course can be delivered in the classroom or at the trainee's workplace.

The following referenced material has been used to develop the structure and content of this MT course

- CBIP PRO-CER- 15 and 18 Training Guidelines
- ISO/TS 25107 Non-destructive testing — NDT training syllabus
- ANSI/ASNT CP-105 Qualification outlines
- ASNT Training handbook – Liquid Penetrant Testing
- NDE/NDT Resource Centre
- OEM supplied equipment training material

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Module 1
Introduction to NDT certification and Liquid Penetrant Inspection (PT)

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1 - INTRODUCTION TO NDT

Role of NDT

An NDT method explores a particular physical property of a material or component in an effort to detect changes in that property which may indicate the presence of a discontinuity

It is sometimes referred to as Non-Destructive Inspection (NDI) or Non-Destructive Evaluation (NDE). Either terms are acceptable and depend on the country of origin or whether the test applies to a particular industry, e.g.: Manufacturing, Nuclear, or Aviation. The "non-destructive" description was adopted to differentiate it from the various "destructive" mechanical tests already in use.

Non-destructive testing makes an important contribution to the safety, economic and ecological welfare of our society.
NDT is the choice for the testing of an object which cannot be destroyed, modified or degraded by the testing process. This is generally required for objects which are to be used after testing, for example: newly manufactured pipelines, power plants, and building constructions. In-service parts are also checked for on-going serviceability.
NDT is based on physical effects at the surface or the inner structure of the object under test. Often, the outcome of the test needs to be interpreted to give a useful result. Sometimes NDT results are verified and confirmed by other test methods.
Non Destructive Testing (NDT) can be defined as an inspection using methods which do not affect the subsequent use or serviceability of the material, or part being inspected.

People have been using NDT methods unknowingly for centuries – e.g. ringing drinking vessels and tapping train wheels to discover whether they were cracked However, it is generally accepted that NDT as a technology dates from the 1st world war (1914). Although magnetic methods of inspection existed before then, it was during that war that radiography was first used for inspection in the armaments industry. Liquid penetrants were first used during the 1930s; Ultrasonic methods were developed during the early 1940s with the first practical immersion testing system credited to William Hitt and Donald Erdman

In Magnetic Particle inspection a material may be inspected by magnetising and then looking for areas were the magnetic field has been disrupted. In ultrasonic inspection a material may be explored using pulses of ultrasonic energy, searching for local changes in acoustic impedance; in eddy current inspection electric currents are used to search for changes in electrical conductivity and so on. The important point is that all NDT methods are two-stage processes. Firstly, we must find a change in some physical property and secondly, the significance of that change must be interpreted.

The decision regarding whether a particular inspection result or indication is caused by the presence of a crack will be made by the NDT technician and will be based on a number of factors. Thus, there are two phases involved in training NDT technicians. They must first learn how to use the NDT equipment and having learned these basic skills, it is then necessary to learn how to interpret the results of inspections. This is to a large extent a matter of experience gained in the field.

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1.1 NDT Certification

New Zealand CBIP NDT Certification

CBIP Non-Destructive Testing Inspector certification permits an individual to be certified as competent to perform the specific types of inspection defined in PRO-CER-14,15,16 and 17. Non-Destructive Testing Inspector is an individual who has met the experience, training, examination and competence requirements as outlined in PRO-CER-18.

Competence Certification will be issued for a one (1) year period and must be renewed annually. Individuals must recertify 10 yearly on the anniversary of the original certification

Qualification and certification are carried out in accordance with international Standard ***ISO 9712*** - Non-Destructive Testing - Qualification and Certification of NDT Personnel

Confusion sometimes exists between Qualification, Certification and Authorisation

Qualification: *Demonstration of physical attributes, knowledge, skill, training and experience required to properly perform NDT tasks (AQB)*

Certification: *Procedure used by the **certification body** to confirm that the qualification requirements for a method, level and sector have been fulfilled, leading to the issuing of a certificate.*

Authorisation: *Written statement issued by the **employer**, based on the scope of certification, authorising the individual to perform defined tasks*

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There are three basic levels of certification are Level 1, 2 and 3

NDT Level 1 Engineer

An individual certified to Level 1 has demonstrated competence to carry out NDT **according to written instructions** and under the supervision of Level 2 or Level 3 personnel. Within the scope of the competence defined on the certificate, Level 1 personnel may be authorized by the employer to perform the following in accordance with NDT instructions:

a) Set up NDT equipment;
b) Perform the tests in accordance with a written instruction
c) Record and classify the results of the tests according to written criteria;
d) Report the results.

NOTE - Level 1 certified personnel shall neither be responsible for the **choice of test method or technique to be used, nor for the interpretation of test results.**

NDT Level 2 Engineer

An individual certified to Level 2 has demonstrated competence to perform NDT according to NDT procedures. Within the scope of the competence defined on the certificate, Level 2 personnel may be authorized by the employer to:

a) Select the NDT technique for the testing method to be used;
b) Define the limitations of application of the testing method;
c) Translate NDT codes, standards, specifications, and procedures into NDT instructions adapted to the actual working conditions
d) Set up and verify equipment settings;
e) Perform and supervise tests;
f) Interpret and evaluate results according to applicable standards, codes, specifications or procedures;
g) Carry out and supervise all tasks at or below Level 2;
h) Provide guidance for personnel at or below Level 2;
i) Report the results.

CBIP Experience and Examinations

Applicants for Level 2 shall have at least **three months (or 480 hours) experience in the Liquid Penetrant Testing method at Level 1**. If qualifying directly to Level 2 experience shall be 640 hours (four months in total), not including any organised theory or practical training courses. For the experience to be valid it should be gained under the control of a Level 2 or 3 certified person who also holds a CBIP Competence Certificate

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EXAMINATION REQUIREMENTS Level 2

PT2, requires three examinations consisting of **two written examinations and a practical examination**

General Paper (Written)

40 multi choice questions at level 2 covering the general theory of the PT method.

Specific Paper (Written)

20 multi choice and 10 short answer questions covering specific applications of the PT Testing method.
Permitted reference material - AS 2062, ISO 9712 and the CBIP GCPTP.

PT2: Practical examination

The practical examination shall consist of two (2) parts. Time allowed for both parts will be 4 hours, 3 hours for the practical samples plus one hour for the written work instruction.

Practical Test – The practical test shall consist of an inspection and reporting on at least 3 samples in the relevant product sectors. The examination shall be carried out in accordance with a Standard Practice or General Procedure such as AS 2062. This will require the level 2 candidate to interpret the document and determine the inspection procedure.

Permitted reference material – AS 2062 and/or the candidates Company Penetrant Testing procedure.

Written examination reports, including defect indications, datum and interpretation, will be required to be presented to the examiner at the end of the test. No pro-forma worksheet will be supplied, but candidates may use their own company report sheets.

Written Instruction (Procedure) – The second part shall consist of producing a written instruction for the inspection of a specific part nominated by CBIP. The instruction shall be such that it complies with the requirements of AS 2062 or ASTM E1417 and can be used by a level 1 with no interpretation required. – Permitted reference material – AS 2062 and ASTM E1417.

CBIP examination pass marks
CBIP require at least 70% in each of the written exams to be eligible for certification.

The practical exam pass-mark requirement is based on all of the following conditions being met.

- ***Achieving a minimum overall mark of 70%***
- ***Identifying and documenting all mandatory defects correctly.***
- ***Achieving a minimum of 70% in the production of the Written Instruction***

Eyesight test – In addition to the above pre requisite requirements for certification there is also minimum eyesight acuity required – Refer to the CBIP PRO-CER- 15

Access the CBIP website for exam information and sample questions

https://www.cbip.co.nz/page/supporting-documents/12/14

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1.2 Definitions

Discontinuity	Any break or interruption in the normal physical structure of a component.
Defect	A flaw**,** the nature or size of which renders a material or component unserviceable
Indication	That which indicates a presence of a discontinuity. Indications may be direct, as in the visual images associated with Liquid Penetrant and Magnetic particle, or remote as in a LED or meter display
False Indication	An indication caused by anything other than the item under test. E.g. Lint/dirt, fingerprints, couplant, contamination etc
Non-relevant Indication	An indication caused by the item under test which is not associated with a discontinuity. E.g. Splines, sharp radii etc.
Relevant Indication	An indication caused by a discontinuity.

For the purpose of this training, the terms and definitions given in AS 1929 apply

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The following are some common abbreviations that are used within the body text of these notes

NDT	Non Destructive Testing
PT	Penetrant Testing.
LPI	Liquid Penetrant Inspection.
FPI	Fluorescent Penetrant Inspection

1.3 Discontinuities

Non Destructive Testing's main job within any Quality Assurance program is the detection of defects and flaws in the structure of components.
All of these defects can be summed up within one word: DISCONTINUITIES.

A discontinuity is a ***break or interruption in the normal physical structure of a component*** and may be a hole, crack, manufacturing flaw or anything else that breaks the continuity of the metal. It may be found on the surface of the metal or within the metal itself.
Discontinuities can originate from many sources and generally can be divided into two categories

A Manufacturing discontinuities
B Service induced discontinuities

When using NDT methods to inspect for manufacturing discontinuities it is necessary to understand their origin and nature. This will assist in the interpretation and evaluation process.

Additionally many customer requirements will specify an allowable "class" or severity of discontinuity. This requires the inspector to be able to "***Interpret***" the indication so that it can be "***Evaluated*** against the acceptable criteria

NDT Methods

Below is a list of some of the more common Non destructive Testing methods used today.

Liquid Penetrant
Magnetic Particle
Ultrasonic
Eddy Current
Radiography
Thermography
Acoustic Emission

There are a variety of techniques within each of these that require an in depth knowledge in order to achieve a satisfactory inspection.

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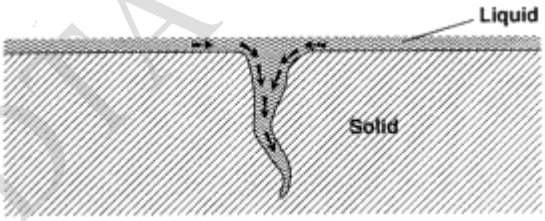
1.4 Introduction to Liquid Penetrant Testing

This is one of the oldest methods of N.D.T, going back to the early part of this century. Originally used as an enhancement to the visual inspection it has become a powerful tool for the detection of very fine surface defects.

Basic Processing Steps

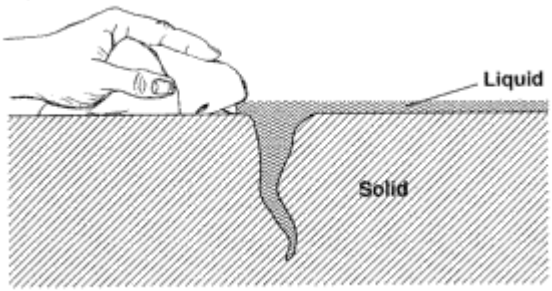
1 **Surface Preparation**: One of the most critical steps of a liquid penetrant inspection is the surface preparation. The surface must be free of **all** contaminants that may prevent penetrant from entering flaws. **The most common failure of the penetrant inspection system occurs because this step is either omitted or not carried out correctly.** The part may also require etching if mechanical operations such as machining, sanding or grit blasting have been performed. These and other mechanical operations can smear the surface of the sample, thus closing the defects.

2 **Penetrant Application**: Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing or immersing the parts in a penetrant bath.



2A **Penetrant Dwell**: The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn into a defect. Penetrant dwell time is the total time that the penetrant is in contact with the part surface. Dwell times are usually recommended by the penetrant procedure and vary depending on the penetrant used, the type of defect and the surface condition of the part.

3 **Penetrant Removal**: This is a most delicate part of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects. Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treated with an emulsifier and then rinsing with water.. In order that the penetrant form a proper clean-cut indication the surface should be dry. If the surface has been wiped or a solvent used, it will dry, as soon as the operation is complete. If water has been used to clean the surface a further sub step - drying - is usually necessary. Drying can often be done by wiping with a cloth, but often a special hot-air dryer is used.



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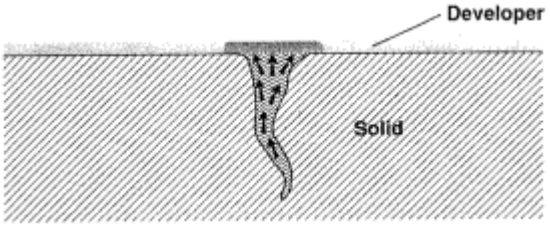
4 **Developer Application**: A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a variety of forms that may be applied by dusting (dry powdered) or dipping or spraying (wet developers).



4A **Indication Development**: The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes and significantly longer times may be necessary for tight cracks.

5 **Inspection**: Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

6 **Post Clean**: The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

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1.5 History of Penetrant Inspection

Liquid penetration inspection is a method that is used to reveal surface breaking flaws by using a coloured or fluorescent dye to produce an indication.
The technique is based on the ability of a liquid to be drawn into a surface breaking flaw by **capillary action**. After a period of time called the "dwell", excess surface penetrant is removed and a developer applied. This acts as a "blotter". It draws the penetrant from the flaw to reveal its presence. Coloured (contrast) penetrants require good white light while fluorescent penetrants need to be used in darkened conditions with an ultraviolet "black light".

A very early surface inspection technique involved the rubbing of carbon black on glazed pottery, whereby the carbon black would settle in surface cracks rendering them visible. Later it became the practice in railway workshops to examine iron and steel components by the "oil and whiting" method. In this method, a heavy oil commonly available in railway workshops was diluted with kerosene in large tanks so that locomotive parts such as wheels could be submerged. After removal and careful cleaning using dry rags, the surface was then coated with a fine suspension of chalk in alcohol so that a white surface layer was formed once the alcohol had evaporated. The object was then vibrated by striking with a hammer, causing the residual oil in any surface cracks to come out and stain the white coating. This method was in use from the latter part of the 19th century through to approximately 1940, when the magnetic particle method was introduced and found to be more sensitive for the ferromagnetic iron and steels.

Many of these early developments were carried out by Magnaflux, under license to R. C. Switzer. More effective penetrating oils containing highly visible (usually red) dyes were developed to enhance flaw detection capability. This method, known as the visible or colour contrast dye penetrant method, is still used extensively today. In 1942, fluorescent dyes were added to the liquid penetrant which would then fluoresce when exposed to ultraviolet light (sometimes referred to as "black light") rendering indications from cracks and other surface flaws more readily visible to the inspectors' eyes.

The major difficulty encountered with the early fluorescent penetrants (Water washable) was that, unless the component was cleaned immediately following the test, the penetrant would solidify in the discontinuity thus preventing any repeatability. Also the penetrant would lose most of its fluorescence. These problems meant that the first universally recognised specification related only to the “Visible” “Dye” Penetrant method (As it was solvent removable, repeatability was obtained)

The tendency towards lower margins of safety and higher stress levels used in current aircraft design means that the size of significant defects is becoming progressively smaller and even very small cracks or flaws can produce disastrous results. The increasing sensitivity now being attained with fluorescent penetrants mean that this is the only acceptable technique for most aircraft manufacturers.

The term "**Dye Penetrant Inspection**" was originally used to describe the penetrant system using a coloured dye mixed in with the penetrant. Today the more common inspection system in the industry uses a Fluorescent dye for greater sensitivity. This is now known as the Liquid Penetrant Inspection, or Fluorescent Penetrant Inspection (FPI).

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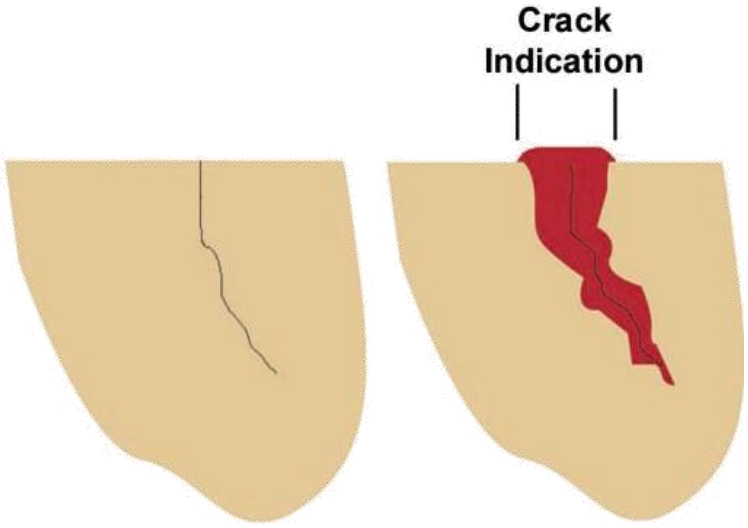
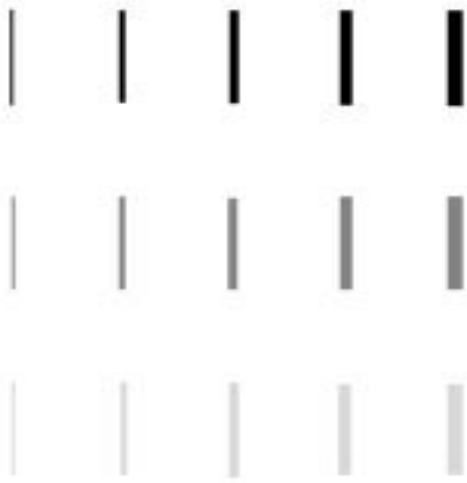
1.6 Why Penetrant Inspection Improves the Detectability

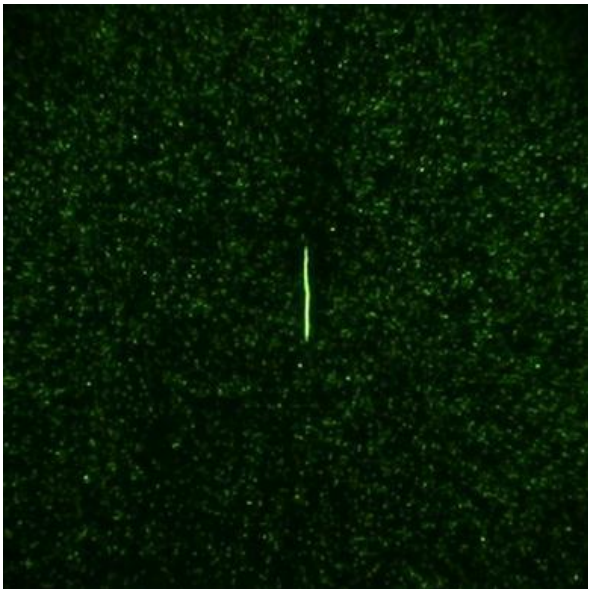


The advantage that a liquid penetrant inspection (LPI) offers over an unaided visual inspection is that it makes defects easier to see by the inspector. There are basically two ways that a penetrant inspection process makes flaws more easily seen. First, LPI produces a flaw indication that is much **larger and easier for the eye to detect** than the flaw itself. Many flaws are so small or narrow that they are undetectable by the unaided eye. Due to the physical features of the eye, there is a threshold below which objects cannot be resolved. This threshold of visual acuity is around 0.003 inch for a person with 20/20 vision

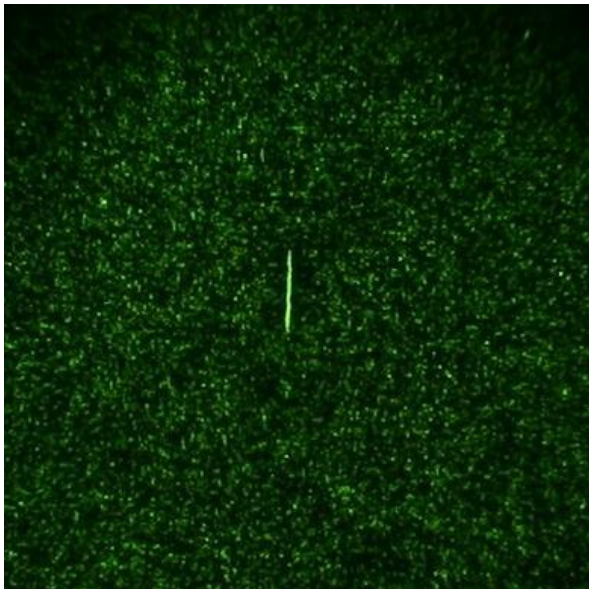


The second way that LPI improves the delectability of a flaw is that it produces a flaw indication with a **high level of contrast** between the indication and the background which also helps to make the indication more easily seen. When a visible dye penetrant inspection is performed, the penetrant materials are formulated using a bright red dye that provides for a high level of contrast between the white developer that serves as a background as well as to pull the trapped penetrant from the flaw. When a fluorescent penetrant inspection is performed, the penetrant materials are formulated to glow brightly and to give off light at a wavelength that the eye is most sensitive to under dim lighting conditions.

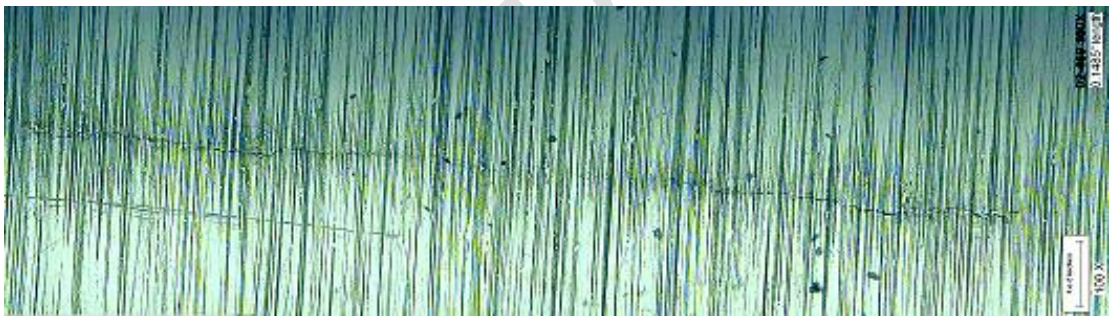
Contrast



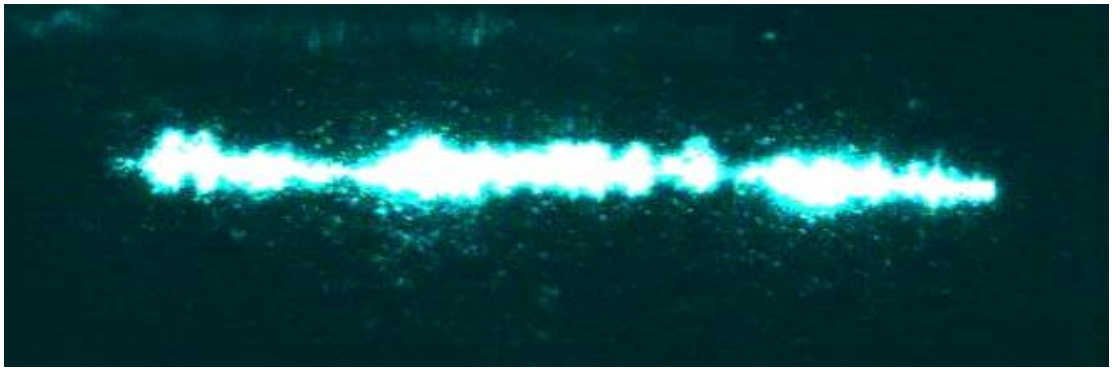
Contrast Ratio =10.5



Contrast Ratio = 6.25



Magnified visual inspection of surface crack in machined plate



Fluorescent Penetrant indication of the same crack

1.7 Capabilities of PT

Since penetrant testing produces indications by means of a liquid bleeding out from a discontinuity, it follows that it can only detect defects which have an opening to the surface into which the liquid can originally penetrate. Although this is a major limitation, especially when relating to manufacturing discontinuities, almost all of the surface defects can be detected by this method.
Defects such as; fatigue cracks, shrinkage, porosity, cold shuts, grinding and heat treatment cracks, seams, forging laps and bursts, welding cracks are all able to be found. In addition, Penetrant testing is used successfully on all metals in common use as well as many non-metals for example, plastics, rubber, ceramics and glass.

The penetrant inspection method is not restricted to external applications of liquid and powder chemicals. For instance, in the testing of wings for fuel leaks the Boeing Company uses ammonia gas inside the tanks and a specially developed indicator fluid on the outside of the tank. The actual sensitivity of this process can pick up a leak of l milligram/hour of ammonia which is equivalent to the leakage of l LB of fuel in 50 years.

Advantages of the PT method

The main advantage of the penetrant method is its simplicity both in principle and application. However, it must be clearly understood that there are certain rules and principles to be observed if consistent and reliable results are to be obtained.

- Penetrant materials and associated equipment are relatively **inexpensive**
- Indications are produced **directly** on the surface of the part and constitute a visual representation of the flaw.
- Large areas and large volumes of parts/materials can be inspected rapidly making this a very **economic** process
- No limitation on the **size of or shape** of the article to be inspected and parts with complex geometric shapes are routinely inspected.
- Because of the simplicity of equipment and the advent of aerosol spray cans the penetrant method is extremely **portable**
- The method has few **material limitations**, i.e. metallic and non-metallic, magnetic and nonmagnetic, conductive and nonconductive materials may be inspected.
- The penetrant fluid having been developed over the years has a remarkable ability to enter extremely fine cracks. This **sensitivity** can in the case of fine cracks can give penetrant testing an advantage over other methods in cases where clarity of indication is of prime importance.

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1.8 Limitations

- The prime limitation of the method is that only discontinuities that are open to the surface are detectable by the penetrant method.
- Some materials are susceptible to attack by the penetrant liquid and this precludes the penetrant process from these. However, special penetrants are produced for various materials and in these eases the problem is overcome e.g. oil-based penetrants will attack rubber, whilst water or alcohol-based penetrants will not.
- The penetrant itself suffers from contamination from foreign material, especially water.
- Only materials with a relative nonporous surface can be inspected. However special penetrant procedures that use the filtered particle technique can be used on very porous material.
- Precleaning is critical as contaminants can mask defects.
- Metal smearing from machining, grinding and grit or vapour blasting must be removed prior to LPI.
- The inspector must have direct access to the surface being inspected.
- Surface finish and roughness can affect inspection sensitivity.
- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper **disposal** is required.

Applications of PT

There are a number of reasons for selecting penetrant inspection over other non-destructive testing methods. Some of the reasons for choosing penetrant inspection are:

- Penetrant inspection, under ideal conditions, can detect very small discontinuities.
- Penetrant inspection permits examination of all accessible surfaces of a component in one operation. Other non-destructive methods cover a specific area or location and must then be repeated to cover other areas or locations.
- Penetrant inspection magnifies the apparent size of discontinuities so the indications may be more readily detected without optical aids.
- Penetrant inspection indicates the location, orientation and approximate length of the indication directly on the component, making interpretation possible.
- The sensitivity level of penetrant inspection may be adjusted through selection of materials and technique. This allows suppression of indications from small, inconsequential discontinuities while indicating larger discontinuities of more concern.

The selection of the best penetrant process depends upon:

1. Sensitivity required
2. Number of articles to be tested
3. Surface condition of component being inspected
4. Configuration of test specimen
5. Availability of water, electricity, compressed air, suitable testing area, etc.

The term "sensitivity" when used to describe a penetrant performance characteristic, is the ability to produce indications from very small, tight cracks. This ability involves both penetrating ability and brightness

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Module 2
Penetrant Properties and Classification

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2 Penetrant Properties.

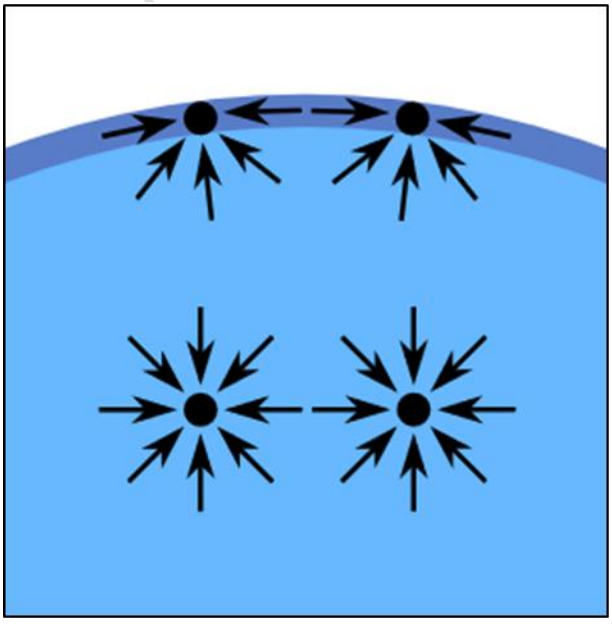
The key material in penetrant testing is of course, the penetrant itself. The name penetrate comes from the most essential property of the material, the ability to penetrate or enter the finest openings or discontinuities.

The ability to enter fine openings does not come from simply being a liquid of low viscosity i.e. a thin liquid but from a phenomena called **capillary action**. Capillary action is the force that causes sap to rise in trees, kerosene to travel up a lamp wick and ink to be absorbed by blotting paper. The capillary action force generated by a given liquid in a tube of given diameter and material is a function of a variety of properties. Two of these being; the surface tension of the liquid and its ability to wet the surface.

2.1 Surface Tension

The surface tension of a liquid is created by the molecular attraction forces within the liquid. Each molecule creates an attraction force which is felt in all directions around it. By this means the individual liquid molecules bind together making the liquid one body. This is the property that causes the surface of a liquid to behave as if it were covered with a weak elastic skin; this is why a needle can float on water. It is caused by the exposed surface's tendency to contract to the smallest possible area because of cohesive forces between molecules at the surface

In order for a penetrant to be drawn into small openings by capillary action this liquid should have a relatively high surface tension



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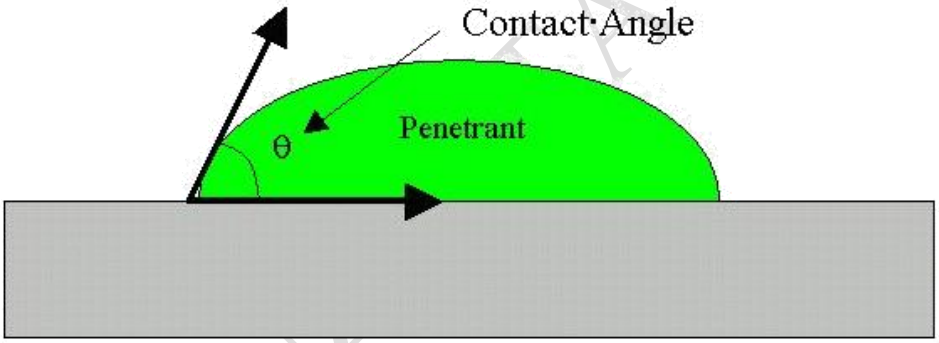
2.2 Wetting Ability

As previously mentioned, one of the important characteristics of a liquid penetrant material is its ability to freely wet the surface of the object being inspected. At the liquid-solid surface interface, if the molecules of the liquid have a stronger attraction to the molecules of the solid surface than to each other (the adhesive forces are stronger than the cohesive forces), then wetting of the surface occurs. Alternately, if the liquid molecules are more strongly attracted to each other and not the molecules of the solid surface (the cohesive forces are stronger than the adhesive forces), then the liquid beads-up and does not wet the surface of the part.
One way to quantify a liquid's surface wetting characteristics is to measure the contact angle of a drop of liquid placed on the surface of the subject object. The contact angle is the angle formed by the solid/liquid interface and the liquid/vapour interface measured from the side of the liquid. See the figure below. Liquids wet surfaces when the contact angle is less than 90 degrees. For a penetrant material to be effective, the contact angle should be as small as possible. In fact, the contact angle for most liquid penetrants is very close to zero degrees.



The wetting ability of a Liquid is something that does not depend on the liquid alone, the surface that it is against being equally important. This can be seen with water, which will wet clean glass easily but doesn't wet oily glass at all.

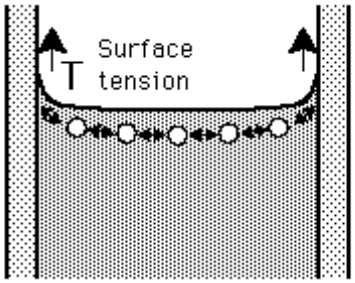
Where a liquid has a high surface tension and good wetting ability, then the liquid will be able to pull itself into the finest gap i.e. .000013" or less, with a force large enough to raise a column of water 30ft.

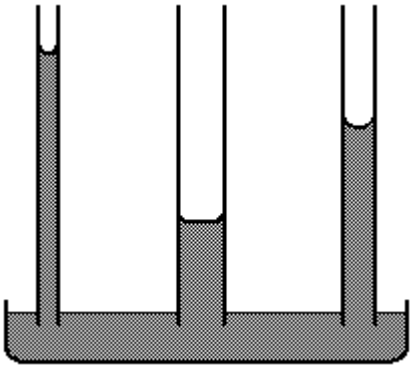
The following Static Penetrant Performance formula is sometimes used to measure the capillary force (or pressure) driving the penetrant into the opening. However this does not take into account the size of the opening and nature of the defect

SPP = r X **cos θ**

Where r = Surface tension (Liquid Gas)
θ = Contact angle (usually given a value of 1 for angles less than 5 degrees

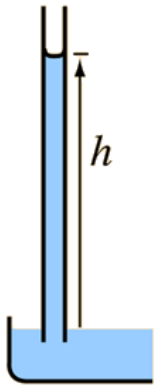
As previously discussed this is only a guide to the penetrants performance as there are many other properties that will affect the Capillary action needed to ensure a good penetrant





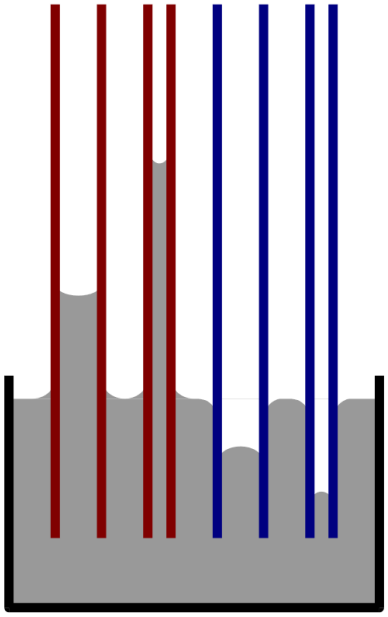
Capillary action is the result of **adhesion** and **surface tension**. Adhesion of water to the walls of the vessel is the result of the contact angle and will cause an upward force on the liquid at the edges and result in a meniscus which turns upward. The surface tension acts to hold the surface intact, so instead of just the edges moving upward, the whole liquid surface is dragged upward.

The height **h** to which capillary action will lift water depends upon the weight of water which the surface tension will lift:



Since it is weight limited, it will rise higher in a smaller tube.

Illustration of capillary rise and fall.
Red=contact angle less than 90°
Blue=contact angle greater than 90°



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2.3 Viscosity.

Viscosity (measurement of a fluid's resistance to flow) has been thought to have an important effect on penetrability, but this is not necessarily true. Many relatively highly viscous materials have been found to be good penetrants. It does affect the **speed of penetration** and as such will determine the time it takes for the penetrant to enter a defect and also how long it will take for the penetrant to "bleed out" during the development stage. This is directly related to the **Dwell** and **Development** times within the process and must be strictly controlled in order to achieve repeatable results.
Another consideration for the viscosity of penetrants is the temperature range over which the penetrant will retain its viscosity rating. Most modern penetrant standards require the viscosity be maintained below 5 centistokes over a temperature range of 5 to 55 degrees C.

In addition to the above, the viscosity will affect the amount of penetrant that drains off the part during the dwell step of the process and may require to be re dipped more frequently. This also will increase drag out losses when moving the part through the penetrant line.

Kinetic Penetrant Performance (KPP) =SPP dived by the Viscosity

2.4 Additional penetrant properties

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In addition to the penetrant being able to flow into discontinuities, it must also have '**body**' so that it will stay on the surface of the article during the period of its application. Body will also allow the penetrant to hold a dye in suspension.

Removability
Removing the penetrant from the surface of the sample without removing it from the flaw is one of the most critical operations of the penetrant inspection process. The penetrant must be removed from the sample surface as completely as possible to limit background fluorescence. In order for this to happen, the adhesive forces of the penetrant must not be so strong that they cannot be broken by the removal methods used. However, in order for the a penetrant to have good surface wetting characteristics the adhesive forces, which are the forces of attraction between the penetrant and the solid surface being inspected, must be stronger than the cohesive forces, which are the forces holding the liquid together. Proper formulation of the penetrant materials provides the correct balancing of these forces.
Another consideration in the formulation of the penetrant liquid is that it should not easily become diluted by the cleaning solution. Dilution of the penetrant liquid will affect the concentration of the dye and reduce the dimensional threshold of fluorescence.

Flash Point. For safety in use, penetrant materials should have a reasonably high flash point.

Chemical Inertness. Obviously, penetrant materials should not react with the materials on which they are used. For example, they must not initiate or aggravate corrosion and for parts which will be exposed to oxygen, the penetrant must be practically inert.

The fluorescence of most dyes is seriously affected by contact with **acids**. No dye really resistant to acids is yet available. Chromates and chromic acid also destroy the fluorescence of dyes.

Stability under Changes of Temperature. Since penetrant materials may be shipped, stored, or used under very wide temperature ranges, their formulations should be such as to prevent separation or appreciable changes in their operating capabilities.

Specific Gravity. SG of less than 1 is required for dip tanks in order to ensure water contamination associated with the PE penetrants lies at the bottom of the tank.

2.5 Ultraviolet and Thermal Stability

Exposure to intense ultraviolet light and elevated temperatures can have a negative effect on fluorescent penetrant indications. Fluorescent materials can loose their brightness after a period of exposure to high intensity UV light. One study measured the intensity of fluorescent penetrant indications of a sample that was subjected to multiple UV exposure cycles. After eight exposure cycles the brightness of the indications was less than one half their original values.

At elevated temperature, penetrants can experience heat degradation or "heat fade." Excessive heat:

1) Evaporates the more volatile constituents which increases viscosity and adversely affects the rate of penetration;
2) Alters wash characteristics;
3) "Boils off" chemicals that prevent separation and gelling of water soluble penetrants; and
4) Reduces the fluorescence of tracer dyes.

Generally thermal damage occurs when fluorescent penetrant materials are heated above 71C (160F). It should be noted that the sensitivity of an FPI inspection can be improved if a part is heated prior to applying the penetrant material, but the temperature should be kept below 71C (160F). Some high temperature penetrants in use today are formulated with dyes with high melting points, which improves resistance to heat damage. The penetrants also have high boiling points and the heat related problems are greatly reduced. However, a loss of brightness can still take place when the penetrant is exposed to elevated temperatures over an extended period of time.

Penetrant Colour

The colour of the penetrant material is of obvious importance in visible dye penetrant inspection, as the dye must provide good contrast against the developer or part being inspected. The dye used in visible dye penetrant is usually vibrant red but other colours can be purchased for special applications.
When fluorescent materials are involved, the effect of colour and fluorescence is not so straightforward. LPI materials fluoresce because they contain one or more dyes that absorb electromagnetic radiation over a particular wavelength and the absorption of photons leads to changes in the electronic configuration of the molecules. Since the molecules are not stable at this higher energy state, they almost immediately re-emit the energy. There is some energy loss in the process causing the photons to be re-emitted at a slightly longer wavelength, which is in the visible range. Two different fluorescent colours can be mixed to interact by a mechanism called cascading. Since the human eye is the most commonly used sensing device, most penetrants are designed to fluoresce as close as possible to the eyes peak response. And that is in the Yellow Green range (550 nm)

2.6 Penetrant Brightness

Fluorescent brightness was once thought to be the only controlling factor with respect to flaw detection sensitivity. It has recently been established that the dimensional threshold of fluorescence (discussed below) has just as much influence on the sensitivity as the penetrant brightness. The amount of brightness associated with a particular penetrant is directly due to the amount and quality of dye present. As this dye is generally the most expensive part of the penetrant most manufacturers will only use the minimum required to achieve the sensitivity rating. The process of turning UV energy into visible light is carried out through dye "Cascading", where several dyes are used to convert the energy (Activator and Colour forming dyes).

2.7 Dye Threshold and Sensitivity

The "Dye Threshold" is a measure of the minimum thickness of penetrant needed to produce an indication and will change as the Dye Concentration is changed

The dimensional threshold of fluorescence appears to largely determine the **sensitivity** of a fluorescent penetrant How this threshold thickness affects the FPI process can be seen when two optically flat plates of glass are clamped tightly together. A drop of fluorescent penetrant is placed at the interface of the plates. The penetrant can be seen migrating in between the plates but when exposed to black light, no fluorescence is seen.

The degree of fluorescence response, under a given intensity of ultraviolet radiation, is dependent on the absorption of ultraviolet radiation, which in turn depends on dye concentration and film thickness. Therefore, the ability of a penetrant to yield an indication depends primarily on its ability to fluoresce as a very thin film. The performance of penetrants based on the physical constraints of the dyes can be predicted using Beer's Law equation.

$$I = I_o x E^{-ACt}$$

Where:
I = Transmitted light intensity
I_o = Incident light intensity
E = Base of natural log (2.71828)
A = Absorption coefficient per unit of concentration
C = Dye concentration
t = Dye Film Thickness

This equation states that the intensity of the transmitted energy is directly proportional to the intensity of the incident light and varies exponentially with the thickness of the penetrant layer and its dye concentration. Therefore, when the dye concentration is increased, the brightness of a thin layer of penetrant generally increases.
A Meniscus-Method Apparatus can be used to measure the dimensional threshold of fluorescence

Typical Dye Threshold thickness for fluorescent penetrant = 4 μ inches (0.0001mm)
And 10 μ inches for colour contrast penetrants

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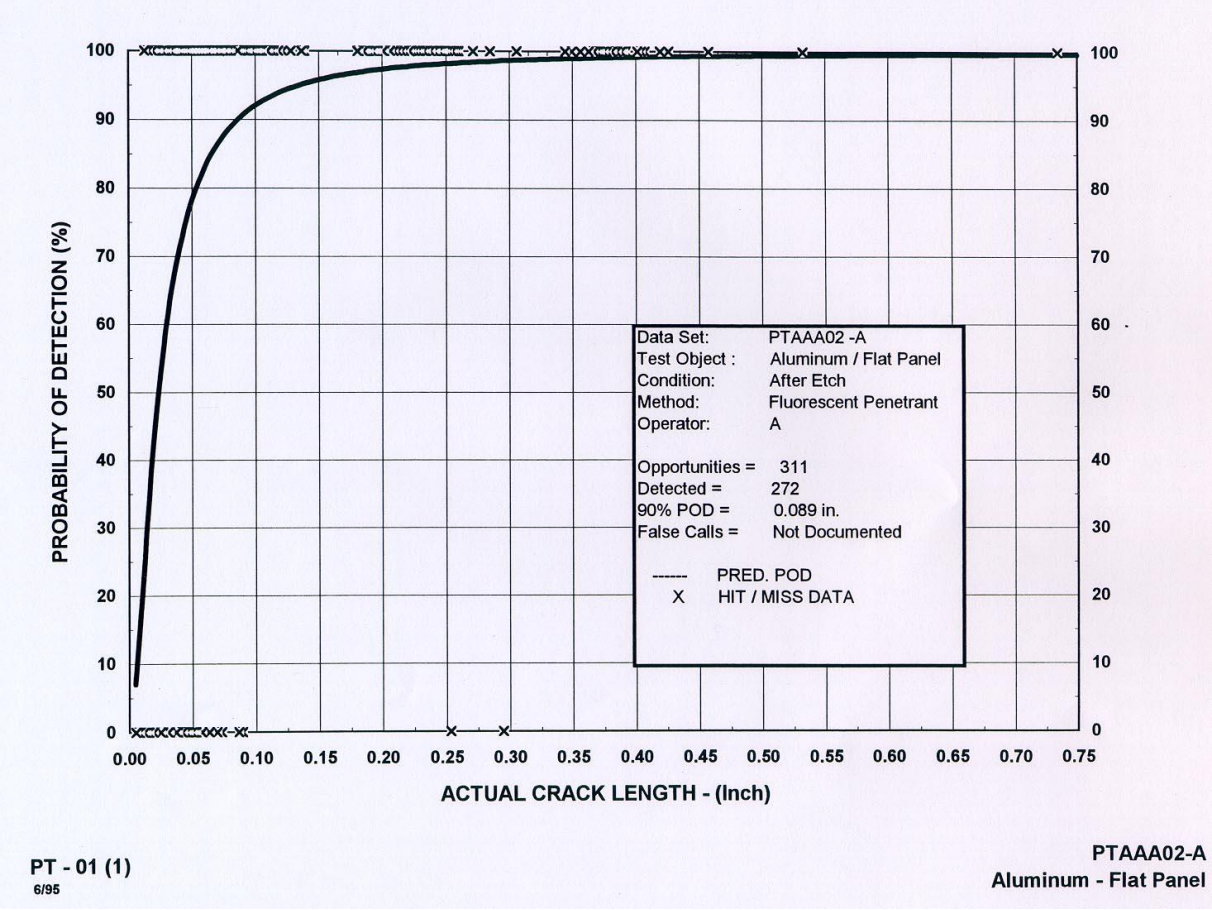
Sensitivity and defect size

The nature of the defect can have a large affect on sensitivity of a liquid penetrant inspection. Sensitivity is defined as the smallest defect that can be detected with a high degree of reliability. Typically, the crack length at the sample surface is used to define the size of the defect. A survey of any probability-of-detection curve for penetrant inspection will quickly lead one to the conclusion that crack length has a definite effect on sensitivity. However, the crack length alone does not determine whether a flaw will be seen or go undetected. The volume of the defect is likely the more important feature. The flaw must be of sufficient volume so that enough penetrant will bleed back out to a size that is detectable by the eye or that will satisfy the dimensional thresholds of fluorescence.



Example - fluorescent penetrant inspection probability of detection (POD) curve from the Nondestructive Evaluation (NDE) Capabilities Data Book. Please note that this curve is specific to one set of inspection conditions and should not be interpreted to apply to other inspection situations

2.8 Colour Contrast and Fluorescent Penetrants

The sensitivity and overall reliability of red dye penetrants is lower than the fluorescent penetrants. Two of the main reasons relate to the relative visibility of the two types of dye and the necessity to use more developer powder in the case of the red dye materials. The potential difference in performance between the two types of penetrant is so marked that most of the aviation industry no longer permits the use of red dye penetrants. Thus, in the case of the commercial industry, the question then is not one of when should fluorescent penetrants be used but rather one of under what circumstances might the use of red dye penetrants be tolerated.
The answer to this last question is, "only when the cracks to be detected are relatively wide or when the surface condition of the part to be inspected is too rough to permit proper inspection using fluorescent materials".
Small cracks in "bulky" parts, i.e. parts manufactured from rolled plate, forgings or extrusions, may be very tight due to the restraint imposed by the surrounding material. There may also be residual stresses in the material serving to close the crack. Such parts should always be inspected using fluorescent materials.

In the case of structures fabricated from sheet materials, a different situation exists. Because of the thinness of the sheet material, cracks cannot propagate very far before they have penetrated the sheet. It is usually true that cracks initiating at fastener holes (the most usual situation) will be through the sheet before they have propagated out from under the head of the fastener. Once a crack has propagated through the sheet it is unlikely to be tight and can be detected by a low sensitivity penetrant such as the red colour contrast penetrant.
The liquid penetrant method is at best marginally better than careful visual inspection of these structures.
In the general case of structures fabricated from sheet materials **visual must accompany the penetrant inspection.**

The second situation in which red dye penetrants may be tolerated relates to the surface condition of the part. As the surface roughness increases, the excess penetrant becomes more difficult to remove completely. This can result in an unacceptable background fluorescence. An example of this would be an aluminium alloy crankcase the surface of which is in an as-sand-cast condition. In this situation red dye penetrant inspection may be acceptable.

From the above, it can be seen that, although the use of red dye penetrant may be acceptable for some very limited applications, there is no situation for which a fluorescent penetrant would not be equally satisfactory or superior.

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2.9 Penetrant Classification

Penetrant

Type I	Fluorescent dye
Type II	Visible dye,
Type III	Visible and Fluorescent dye (Dual mode)

Method

A	Water washable
B	Post emulsifiable, lipophilic
C	Solvent removable
D	Post emulsifiable, hydrophilic

Sensitivity

Level l/2	Ultra Low
Level l	Low
Level 2	Medium
Level 3	High
Level 4	Ultra high

Developer-

Form a	Dry powder
Form b	Water soluble
Form c	Water suspendable
Form d	Non aqueous
Form e	Specific application

Solvent Removers

Class(l)	Halogenated
Class(2)	Non Halogenated
Class(3)	Specific application

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All penetrant materials do not perform the same and are not designed to perform the same. Penetrant manufactures have developed different formulations to address a variety of inspection applications. Some applications call for the detection of the smallest defects possible and have a smooth surface where the penetrant is easy to remove. In other applications the rejectable defect size may be larger and a penetrant formulated to find larger flaws can be used. The penetrants that are used to detect the smallest defect will also produce the largest amount of irrelevant indications.

AMS 2644

Penetrant materials are classified in the various industry and government specifications by their physical characteristics and their performance. Aerospace Material Specification (AMS) 2644, Inspection Material, Penetrant, is now the primary specification used to control penetrant materials.

Historically, Military Standard 25135, (MIL-I-25135E,) has been the primary document for specifying penetrants but this document is slowly being phased out. Other specifications such as ASTM 1417, Standard Practice for Liquid Penetrant Examinations, may also contain information on the classification of penetrant materials but they generally refer back to AMS 2644.

AMS 2644 controls the penetrant materials and stipulates certain physical properties of the penetrant materials that must be met. Some of these requirements address the safe use of the materials, such as toxicity, flash point and corrosiveness, and other requirements address storage and contamination issues. Still others delineate properties that are thought to be primarily responsible for the performance or sensitivity of the penetrants. The properties of penetrant materials that are controlled by AMS 2644 include surface wetting capability, viscosity, colour, brightness, UV stability, thermal stability, water tolerance, and removability

Penetrant materials come in three basic types. These types are:

- Type 1 - Fluorescent Penetrants
- Type 2 - Visible Penetrants
- Type 3 - Dual Mode (Visible and Fluorescent)

Fluorescent penetrants contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation. Visible penetrants contain a red dye that provides high contrast against the white developer background. Fluorescent penetrant systems are more sensitive than visible penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants do not require a darkened area and an ultraviolet light in order to make an inspection. Visible penetrants are also less vulnerable to contamination from things such as cleaning fluid that can significantly reduce the strength of a fluorescent indication. There are other types, eg. Type 3 above, which contain dyes which may be used both as colour contrast and fluorescent penetrants. These are sometimes known as "dual sensitivity" penetrants on the basis that indications of relatively large discontinuities will be visible under both white and UV illumination while those of smaller discontinuities will only be visible under UV light

Penetrants are then classified by the method used to remove the excess penetrant from the part. The four methods are:

- Method A - Water Washable
- Method B - Post Emulsifiable, Lipophilic (Oil based)
- Method C - Solvent Removable
- Method D - Post Emulsifiable, Hydrophilic (Water based)

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Water washable (Method A) penetrants can be removed from the part by rinsing with water alone. These penetrants contain some emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone. Water washable penetrants are sometimes referred to as self-emulsifying systems. Post emulsifiable penetrants come in two varieties, lipophilic and hydrophilic. In post emulsifiers, lipophilic systems (Method B), the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible. Post emulsifiable, hydrophilic systems (Method D), use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash. Solvent removable penetrants require the use of a solvent to remove the penetrant from the part.

Penetrants are then classified based on the strength or detectability of the indication that is produced for a number of very small and tight fatigue cracks. The five sensitivity levels are:

- Level ½ - Ultra Low Sensitivity (Colour/Visible Dye)
- Level 1 - Low Sensitivity
- Level 2 - Medium Sensitivity
- Level 3 - High Sensitivity
- Level 4 - Ultra-High Sensitivity

The major industry specifications currently rely on the US Air Force Materials Laboratory at Wright-Patterson Air Force Base to classify penetrants into one of the five sensitivity levels. This procedure uses titanium and Inconel specimens with small surface cracks produced in low cycle fatigue bending to classify penetrant systems. The brightness of the indication produced is measured using a photometer.
The sensitivity levels and the test procedure used can now be found in **Aerospace Material Specification AMS 2644, Penetrant Inspection Materials QPL (Qualified Products List)**

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Developers

The four developer forms listed (specific application is there to cover special, undefined applications) differ with respect to the way they are used. The names given are self explanatory. Dry developers are applied to a surface as a dry powder. Water soluble and suspendable developers are applied by immersing parts in the solution and subsequently precipitating a coating of powder on the surface by evaporation. The last form listed, non-aqueous, refers to developer powders suspended in a volatile solvent. These are almost exclusively applied to a surface from an aerosol can. The solvent, having conveyed the particles to the surface, evaporates quickly to leave a dry powder coating.

Form a	Dry powder
Form b	Water soluble
Form c	Water suspendable
Form d	Non aqueous
Form e	Specific application

Solvent Removers

Class(l) Halogenated
Class(2) Non Halogenated
Class(3) Specific application

The two classes of solvent removers listed differ only with respect to whether they contain halogens. The common halogens are chlorine, fluorine, bromine and iodine. It is the first two of these - chlorine and fluorine - which are present in many solvents (eg. chlorine in trichloroethylene and fluorine in the freons). **If residues of halogens are left on parts made from austenitic stainless steels or titanium alloys, they may subsequently cause problems with stress corrosion cracking;** particularly if the parts are subjected to high temperatures in service. For this reason, only halogen free solvents should be used as penetrant removers for these materials. Naturally the same precaution should be taken in the case of solvents used at the pre-cleaning stage.

There is also a similar problem with contamination of nickel based alloys with sulphur.
Some specifications stipulate tests for corrosive properties which would be difficult to pass for a material containing significant amounts of sulphur or halogens. Turbine engine manufacturers are particularly careful and will usually have their own specifications requiring that contaminates in penetrant materials do not exceed certain limits. A requirement typical of that of a turbine manufacturer would be sulphur - 0.1% max., sodium 0.01% max., fluorides 50 ppm max., chlorides 1,000 ppm max.

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2.10 Family Concept

Each penetrant material's manufacturer has its own formulation for penetrants, Lipophilic emulsifiers and Hydrophilic removers.

Penetrant and Lipophilic emulsifiers or hydrophilic removers are qualified as a system (Family). This system consists of very specific materials from the **same manufacturer**. Additionally, the hydrophilic removers are qualified at a specific concentration. **Therefore, only products that comprise a system and listed as such may be used together.**

Mixing of manufacturers materials from the same manufacturer that are not part of the system will not provide for optimum performance and, in some cases, this practice will eliminate any chance of detecting defects, therefore, it should not be done.

Industry has accepted that any manufacturer's developer could be used with combined penetrant and emulsifier or remover system of another manufacturer. The condition in which developers can be used is the same for solvent removers

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Module 3
PT process steps

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3 Penetrant Inspection Process

3.1 Surface Preparation

The effectiveness of liquid penetrant testing is based upon the ability of the penetrant to enter surface discontinuities. The part to be tested must be clean and free from foreign matter that may cover or fill any discontinuities. The cleaning technique used is in each case is determined by the nature of the part being tested and the type of soil that must be removed.

In this module the word contaminant is used to denote any substance or condition that may invalidate or interfere with the liquid penetrant inspection - for instance, paint would not normally be looked upon as a contaminant but it may certainly be so as far as liquid penetrant inspection is concerned.

Contaminants may be divided into three categories as follows;

1 Those that restrict the entry of penetrant into a defect. These may include paint, oils and greases, water, cleaning solutions and mechanical smearing due to previous rework.
2 Contaminants which may not exclude penetrant but the presence of which may be damaging to it. These may include acids, alkalis, di chromates, paint removers and other penetrants.
3 Contaminants which may result in confusing indications. These may include corrosion products, unsealed anodic coatings, surface scratches etc.

Type 1 contaminants are very common and will normally be removed by a selection of cleaning methods such as: Solvent cleaning, Detergents, Vapour Degreasing and in the case of water by applying heat. The problem of mechanical surface smearing is discussed later and usually results from using mechanical cleaning methods such as glass bead peening, shot or sand blasting and blending. This danger is high for relatively soft metals such as aluminium.

Type 2 contaminants are particularly a problem in the case of fluorescent materials, the fluorescence of which may be destroyed by contact with acids and alkalis. These are most likely to be present following chemical treatment such as the use of paint strippers, surface etching, anodising etc. **Dye penetrants** can also damage the fluorescence of a fluorescent penetrant.

A good cleaning procedure will remove all contamination from the part and not leave any residue that may interfere with the inspection process.

Water-Break Test

A water-break test uses water added to the surface of the part to be inspected **to assess the adequacy of the precleaning process**. If there is any contamination in the form of oils or other soils, the water will separate around those areas that are not clean, showing a “break” in the water surface (Beading).

This can sometimes be noticed during the washing stage of the inspection process. If this is suspected the part needs to be completely reprocessed including pre cleaning

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Alkaline Cleaners

Alkaline cleaners are chemicals which remove contaminants by chemical action such as saponifying (conversion of fat or oil into soap) or displacement rather than dissolving the contaminants. These cleaners after lifting/displacing the contaminant can carry it in suspension, it may separate or it may react with the cleaner to form water soluble soap.
The cleaning is usually carried out in tanks with the fluid at or near its boiling point. The cleaning action can be quickened by the use of agitation. Following alkaline cleaning the components shall be thoroughly rinsed to remove all cleaning chemicals and dried.

Acid Cleaning

Solutions of acids or their salts can be used to remove rust, scale, corrosion products and dry soils. The type of acid and its concentration depends on the component material and contamination to be removed. Acid cleaners are not effective on oils or greases and must first be removed so that the acids can react with the scales etc.

Detergent Cleaning

Detergent cleaners are water based chemicals called surfactants which attach themselves to the soil. The soil and detergent is then washed away by solution agitation, hand wiping or pressure spraying. Detergent cleaners can be alkaline, acidic or neutral
Refer also to aqueous degreasers

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Aqueous Degreasers

Aqueous Degreasers, such as Ardrox 6333 are being used in place of the solvent de greasers because they are more environmentally friendly. Since these cleaners may be either acid or alkaline in nature, precautions are taken to ensure that the selected detergent is non corrosive to the specimen. Hot Detergent cleaning is most effective when accomplished with agitation, though it may also be used with scrub, rinse and wipe techniques. After detergent cleaning, the specimen is carefully rinsed in cold water to remove all detergent residue and **then dried in a dryer or immersed in a hot water bath to "Flash Dry"**
The drying process is very critical as all water must be removed prior to penetrant application.

Vapour Degreasing

Vapour degreasing is the most effective means of pre-test cleaning. The process not only thoroughly cleans, it also heats the specimen so that after cleaning no moisture remains in discontinuities. When allowed vapour degreasing is the preferred cleaning method and should be used whenever practicable. The solvents generally used with these baths evaporate very quickly and are effective in removing most oil based contaminates found in the aircraft industry.
The toxic nature and ozone depletion properties of most of these solvents have forced the industry into replacing these with a more friendly process.

Solvent Cleaning

In field operation it is generally necessary to use a hand applied washing solvent. Suitable solvents are normally supplied as part of the penetrant kit and these should be used and applied liberally while the part is scrubbed with a bristle brush. Most solvents used today have a trade off between volatility and being non flammable. Low volatility solvents such as kerosene, and turpentine should be avoided unless the part can be heated subsequently to remove the solvent from defects. Solvents remaining in defects will make entry of penetrants less effective. Volatile solvents such as lacquer thinner, clear gas and spotcheck SKC-HF quickly evaporate but are highly flammable.

Rust and Surface Scale Removal

Rust removers (descaling solutions, either alkaline or acid), pickling solutions (acid), or wire brushing are used to remove rust and surface scale. Mechanical removal may be performed using a wire brush or some form of blasting. When this is used there is a possibility of closing surface discontinuities or filling them with smeared metal.
Descaling solutions are chosen so that they are noncorrosive to the specimen. Regardless of the method selected for rust and scale removal, after the process is completed the specimen must be completely clean, dry, and so treated that surface discontinuities are not clogged, filled or contaminated.

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Paint Removal

Most LPI general procedures today require the removal of paint prior to inspection. The exceptions usually allow the inspection to be performed providing the paint is thin and in very good condition. Any method of paint removal that does not harm the specimen is satisfactory. Chemical means such as solvent stripping and dissolving type hot tank stripping are preferred since any mechanical removal process adversely affects the surface of the specimen. **Paint removal using abrasive means such as blasting and scraping can cause the surface defects to become "closed" due to the smearing of the metal especially, with soft material such as aluminium**. Further processing is required to remove this material.

Etching

As mentioned above certain mechanical and chemical cleaning processes may tend to close the discontinuities by peening or smearing of the surface metal. Under these conditions etching may be required. The etching is accomplished with either an acid or an alkaline solution which is then neutralised. After neutralisation the article must be water washed and dried or otherwise cleaned to remove all traces of the etching and neutralising agents.

Some of the cleaning methods that fall into this category are listed below

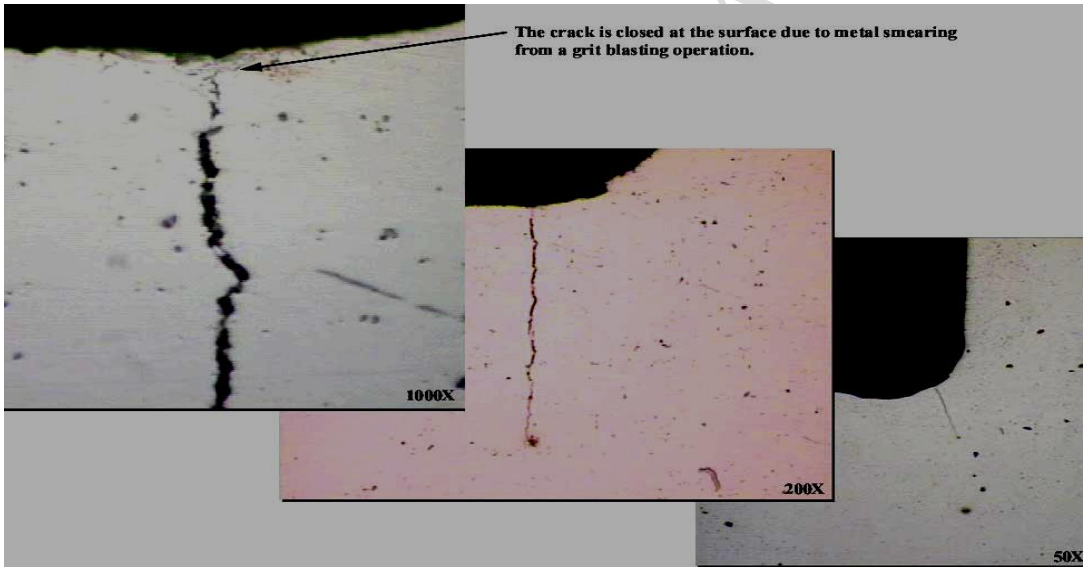
- **Shot or Grit blasting**.
- **Blending / Filing / Machining**
- **Plastic Media Blasting above 40psi**

Etching metals with acids and alkalis can provide a surface free from minute obstructions such as smeared metal. The surface is prepared to an acceptably smooth finish and the etching solution applied. The etchant will attack the grain boundaries first, exposing the granular structure of the metal. **If a crack is present, the edges will become more exposed**. Usually a greater reaction will be noticed in the area of a discontinuity and a **dark stain line** may accentuate the defect. After washing the area with water and drying, the surface will now be ready for inspection either by visual methods or liquid penetrant.

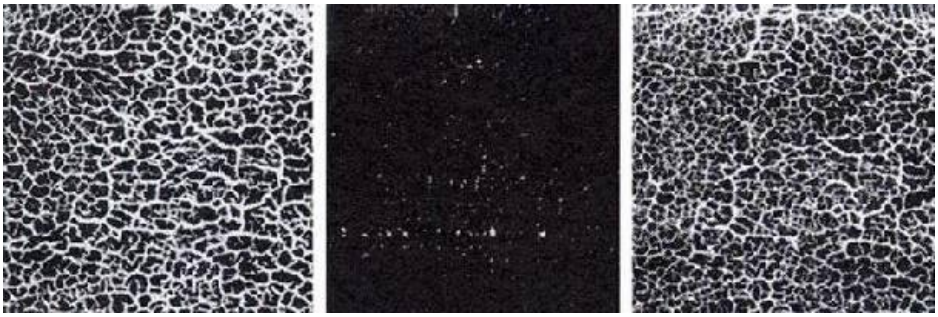
The concentration of the etch solution and the contact times used will determine the amount of material that is removed. Typically this is between 0.0002" and 0.001"

For most of the common metals, etchants are readily available and instructions for their use should be rigidly adhered to. Listed below are some common etching solution

Steel	Nitric acid and acetic acid.
Inconel	Hydrochloric acid and Ferric Chloride – (Cold Ferric Chloride etch)
Titanium	Hydrofluoric acid and Nitric acid
Aluminium	Hydrofluoric acid and hydrochloric acid or Sodium Hydroxide



Grit blasting causing crack to be "closed"



Left Image: Original fluorescent penetrant inspection pattern in a quench cracked aluminium sample.
Centre Image: Fluorescent penetrant inspection pattern after sanding with 240 grit paper.
Right Image: Fluorescent penetrant inspection pattern after etching to remove 0.0003 inch.

Pre Cleaning studies

Due to the critical nature of the Penetrant Inspection and its use in the industry and the changes in cleaning processes and materials, a number of studies have been carried out to evaluate the effectiveness of some of the more common cleaning methods. The following is a brief summary of these studies.

Oil contaminants
Even with the most stringent cleaning processes (Vapour degreasing) it was noted that there was still a reduction in sensitivity and this was believed to be a result of the incomplete removal of the contaminant.

Etchants
Acid entrapment from a pre-penetrant etch was shown to have a disastrous effect on the penetrant inspection, with a reduction in brightness being the result. Careful cleaning of both acid and caustic etches before penetrant inspection is required.

Residue from Previous Penetrant Inspections
The effectiveness of a penetrant inspection was significantly reduced if the part had been previously inspected with a different penetrant, although proper pre- and post- cleaning (degreasing) operations had been performed. This was the case when the previous inspection was performed with a different fluorescent penetrant or a **visible dye penetrant**. When the same penetrant system was used for both inspections, there was no extensive loss in sensitivity when the specimens received the required pre- and post-cleaning. The study also showed that even the most careful post-cleaning operations leave some penetrant in the defects.

Repetitive inspections produce greatly reduced indications.

To illustrate the degrading effect of type II penetrant on type I penetrant, mix one percent visible and 99 percent fluorescent penetrant together and note the almost complete lack of fluorescence under black light. The red dye acts as an UV filter and stops nearly all fluorescence.

Cleaning solution contamination
Studies have shown that a small amount of solvent, from the Precleaning operation, if left trapped in a flaw, can also have a drastic effect on the performance of a penetrant.

It is also important that the cleaning process itself does not cause a reduction in penetrant sensitivity. Some mild alkaline cleaners include sodium metasilicate as an ingredient. Sodium metasilicate, sodium silicate, and related compounds can adhere to the surface of parts and form a coating that prevents penetrant entry into cracks.

Aqueous Precleaners used for Penetrant Inspection have also shown that they can have an effect on the inspection results. Some domestic soaps and commercial detergents impaired detectability. By forming deposits in the cracks that were difficult to remove. It is recommended that components be rinsed in water and then thoroughly dried

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3.2 Penetrant Selection

As previously discussed penetrants can be divided into several types, dye penetrants and fluorescent penetrants. In the case of dye penetrants, a dye is dissolved in the liquid penetrant. The colour of the dye is selected to give a high colour contrast between the developer and penetrant. In fluorescent penetrants a fluorescent dye is dissolved in the penetrant which when viewed under black light will emit visible light

These two processes may further be subdivided into three further categories, water washable (WW) penetrant, post emulsifiable (PE) penetrant, and solvent removable penetrant. The water washable penetrant contains an emulsifier before being applied to the specimen which allows it to be water washed immediately after penetrant dwell time has been completed. The post emulsifiable penetrant does not contain this emulsifier and therefore cannot be removed by water until an emulsifier has been applied. Solvent removable penetrants are as their name suggests, removable only by the use of solvents, and these have special application.

Water washable Penetrants

Water-washable penetrant method is the least sensitive of the three methods involving fluorescent penetrants. The method utilises an oil based penetrant to which has been added an emulsifier, to make it water washable. After application of the penetrant, the test surface is washed to remove the surplus penetrant, and a developer is applied. Either a wet or a dry developer can be used. In both instances, when viewed under black light, any discontinuities in the test surface glow with a bright yellow-green light against a dark background. The intensity of the fluorescence is related to the volume of penetrant retained in the surface flaw.

WW Penetrant Advantages

- Does not require the application of an emulsifier as a separate operation.
- Water is readily available and environmentally friendly as a washing agent
- Fewer processing steps than the PE method
- Very good for inspecting materials with a rough surface i.e. castings

PE penetrants

Post Emulsification (PE) fluorescent penetrants utilise an oil base penetrant to which a highly fluorescent dye has been added. As the penetrant does not contain an emulsifier, it has the ability to seep into very fine surface defects. The surface film of penetrant is made water soluble by the application of an emulsifier in a separate operation. The sensitivity of the operation can be partially controlled by proper judgement of the time between the application of the emulsifier and the rinsing operation.

Careful application of this technique makes possible the detection of shallow scratches, tool marks, and shallow imperfections that are wider than they are deep. The following is a brief summary of the advantages of each method

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PE Penetrant advantages

- High sensitivity for detecting very fine defects.
- Controlling emulsifier time reduces the possibility of over washing
- Can detect wide shallow defects.
- Good for inspecting large batches of parts
- Can be automated
- Less operator dependant

Solvent removable penetrant.

PE penetrants generally fall into the category of being Solvent Removable due to the fact that they can be removed using a solvent. Solvent removable penetrant inspection is a relatively high sensitivity process and is used for the detection of stress or intergranular corrosion, but may be used as a general inspection method on parts where the use of water is unsatisfactory or inconvenient.

A solvent is used to remove the surface film of penetrant, and the developer used is a quick drying, non aqueous type. This developer, when applied in the form of a fine spray, forms a thin, uniform coating that provides the highest degree of inspection sensitivity.

This method is very portable with all fluids being able to be contained in aerosol pressurised cans. The portable kits are useful in field operations, however, when using a fluorescent penetrant, the ambient white must be reduced to an acceptable level for adequate indications under black light. The indications are the same as those obtained with other fluorescent penetrant inspection methods.

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Penetrant Sensitivity Selection.

Typical defect openings are usually restricted and the volume is such that only a very small amount of penetrant can be entrapped. The penetrant must enter and exit the flaw with enough dye to produce a noticeable indication.

Selection of the sensitivity level to be used depends on a number of factors: potential flaw size, width of opening and volume; component size, shape, surface finish and intended service of the component. The rule is to use the lowest sensitivity that will reveal the flaws. Difficulties can be experienced if the sensitivity level is either too low or too high. Low sensitivity levels may not reveal the potential flaws while excessive sensitivity can result in a background that could obscure any discontinuity indications.

A Type and Size of Potential Flaws. Large flaws, such as those caused by overstress, can be detected with low sensitivity materials. Small, tight fatigue cracks, such as those occurring in engine rotating components, require ultrahigh sensitivity materials.

B Surface Condition of the Component. Components with rough surfaces, such as casting, welds and forged components, tend to retain some of the penetrant. The use of high or ultrahigh sensitivity penetrants on rough surfaces may produce an excessive residual background that could obscure potential flaws.

C Material and Process Control Costs. The higher sensitivity materials are considerable more expensive than lower sensitivity materials. This is due mainly to the increased amount of costly dye stuffs.

3.3 Penetrant Dwell (Contact) Time

Penetrant contact time is the total length of time from the initial application of the penetrant until it is removed. This includes immersion and drain times. The purpose of the contact time is to allow the penetrant to be drawn into and fill any surface discontinuity.
There are a number of factors that influence the length of time required for the penetrant to fill a discontinuities. Some of these factors are:

a. Width and depth of the void (Defect).
b. Type and sensitivity of the penetrant
c. Component material and form
d. Type of discontinuity
e. Penetrant viscosity
f. Cleanliness or contamination of the void
g. Temperature of the penetrant and part

Defect Size

The time required for a penetrant to enter and fill a surface void depends largely on the width of the surface opening and depth of the void. Penetrant enters and fills voids with wide openings more rapidly than those with narrow openings. Very narrow or tight flaws, such as those associated with fatigue cracking may require 2 to 5 times the length of time needed for a wider flaw caused by over-stressing. Capillary action is also a function of the width of the void and appears to increase as the width of the flaw decreases, however this is usually not enough to reduce the contact times.
The void depth is simply a matter of volume with more time required to fill a deep void.

Penetrant Sensitivity

The type and sensitivity level of penetrants affect the length of penetrant contact. The differences in contact times are due to the differences in surface tension, contact angle and viscosity of the various penetrant types and sensitivities.

While viscosities between manufacturers of the same type and sensitivity level vary, the combination of factors tends to stabilize contact time for each type and sensitivity. This allows penetrants within each of the sensitivity levels to have equivalent contact times

Component Material

The effect of component material (steel, magnesium, aluminium, etc.) on penetrant contact relates to the width of the surface opening of the discontinuities. For example: cold shuts in steel casting tend to have tighter openings than cold shuts in magnesium castings. Discontinuities occurring in forgings are tighter than in castings and require more penetrating time.

Stainless Steels.
Defects associated with SS are generally finer and tighter. Also Susceptible to stress corrosion cracking and normally associated with critical applications requiring increased sensitivity and dwell time.

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Contaminated discontinuities

Previously stated, various types of discontinuities differ in the width of the opening. Laps are tighter than porosity and fatigue cracks are tighter than either laps or porosity. If the discontinuity is contaminated, penetration cannot occur. A discontinuity that is only partially contaminated will produce a smaller and less visible indication. Increasing the contact time will not improve the indication. However, a more sensitive penetrant with its higher dye content will produce a more visible indication.
When discontinuities contain contaminants that are soluble in penetrants, such' as grease and oils, the situation is different. The penetrant will fill any vacant space in the discontinuity and then stop. Diffusion then begins between the penetrant and soluble soil. In a short time, the penetrant and oil become evenly mixed.
This mixture will fluoresce much less and may not give a useful indication. An increase in contact time will improve the visibility of the indication.
Using a more sensitive penetrant will also improve the visibility of the indication as the higher dye content can withstand more dilution and still fluoresce

In summary, when a flaw is partially filled with an insoluble soil, an increase in contact time will not improve the visibility of the indication. However, if the soil is soluble in the penetrant, the visibility will improve with increases in contact time. In both cases (insoluble and soluble contamination) a higher sensitivity penetrant will improve the results.

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Additional considerations

Although not specifically mentioned above there are several other considerations that will have an effect on the time it takes for the penetrant to fill the void
The atmospheric pressure at the flaw opening and the pressure of the gas trapped in the flaw by the penetrant will change the capillary characteristics of the penetrant. These may not be able to be controlled by the inspector but depending on the environment and nature of the defect, may reduce the inspection quality.

Contact Times

The number of factors influencing the entry of penetrant into a discontinuity complicates setting standard minimum penetrant dwell times. Most contact times are based on past experience with similar components, materials and potential flaws.

Once the penetrant has completely filled a void, extending the contact time will not improve the indication, except for contaminated flaws. However, very tight fatigue cracks, flaws in surfaces under compressive loading, and stress corrosion cracks may require contact times measured in hours instead of minutes.

It is good practice to apply fresh penetrant at 30 minute intervals when long contact times are required.
When intermediate contact times, 45 minutes or more, are involved, the fresh penetrant should be applied 15 minutes before removal. Application of fresh penetrant improves the rate of penetration and makes it easier to remove the excess surface penetrant at the end of the contact period.
If for some reason the penetrant is allowed to become tacky or dry the component should be subjected to a complete reprocessing through the pre-cleaning and penetrant inspection cycle.

Temperature Limitations

Penetrant inspection should not be performed when the component temperature is less than 4°C. There are several reasons for this:

A. At 0°C or less, any moisture, even from the inspectors' breath, will form ice crystals on the component, which will interfere with the penetration process.
The evaporation rate of solvent cleaners and non-aqueous developers is reduced at lower temperatures.
B. The viscosity of the penetrant increases as the temperature decreases. When temperatures are below 16°C and above 4°C, it is recommended that the contact time be increased due to the increased viscosity.

Penetrant inspection should not be performed when the component temperature is greater than 49°C. The reasons are as follows:

Sensitivity is improved slightly when the test components temperatures are 49°C to 65.5°C. The higher temperature evaporates some of the liquid which increases the dye concentration and reduces viscosity which speeds penetration. However, the disadvantages of elevated temperatures outweigh the advantages. During penetrant contact the layer of penetrant is very thin and with a component temperature of more than 49°C, the loss of volatile constituents will drastically change the composition of the penetrant and its capillary action. Additionally elevated temperatures will reduce visible dye colour and fluorescence (heat fade), making indications less visible.
Heat fade or permanent loss of fluorescence starts at about 78°C and increases rapidly with increased temperatures and time. This could mean that fine indications disappear.
Therefore, when drying components in re-circulating ovens etc. the temperature and times must be very carefully controlled.
Most penetrant manufacturers will specify the temperature range over which their penetrant will maintain the required viscosity. **Generally this will be between 5 and 55 degrees C**

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Typical minimum penetration times (minutes)

MATERIAL	FORM	TYPE OF DISCONTINUITY	LEVEL 2 PENETRANT	LEVEL 3/4 PENETRANT
Aluminium	Castings	Porosity	**10**	**10**
		Cold shuts	**15**	**10**
		Hot tears	**15**	**10**
	Forgings & Extrusions	Laps	**20**	**10**
		Bursts	**20**	**10**
	Welds	Lack of Fusion	**15**	**10**
		Stress Cracks	**30**	**15**
Steel	Castings	Porosity	**20**	**10**
		Cold shuts	**20**	**15**
		Hot tears	**Not recommended**	**20**
	Forgings & Extrusions	Laps	**Not recommended**	**20**
		Bursts	**Not recommended**	**20**
	Welds	Lack of Fusion	**20**	**15**
		Stress Cracks	**30**	**20**
All Metals	All Forms	Cracks	**20**	**15**
		Fatigue cracks	**40**	**30**
		Stress corrosion	**Not recommended**	**60**

3.4 Penetrant Application

The application of the penetrant can take many forms, the object is to cover the part to be inspected with a wet film of penetrant. This film is to be kept wet for the entire penetration (dwell) time.
There are numerous ways to apply this penetrant some of the more common are

CONTACT MODES

There are two basic penetrant contact modes:

1 Immersion contact, where the component remains submerged in a tank of liquid penetrant for the entire contact period.

2. Drain contact, where the component is first covered with penetrant by spraying, brushing, or immersion. Once coated, the component is placed on a rack or rest and allowed to drain during the contact period.

IMMERSION CONTACT

Previous theory considered immersion contact to be more sensitive than drain contact. The logic of this theory was based on the penetrant being more migratory or flowing easier with lower viscosity when evaporation is reduced. The theory also reasoned that the solvent properties of a penetrant are based on the lighter petroleum oils. These lighter oils tend to evaporate first and keeping a component immersed during the contact period improved the solvent action.

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DRAIN CONTACT

Laboratory tests have demonstrated the improved performance of drain contact mode compared to that of immersion contact mode. This improved performance is due to the changes in penetrant composition that occur during the contact period. The penetrant vehicle is a mixture of heavy oils which dissolve and hold the dye materials in solution, and thin or lightweight solvents or oils which reduce the penetrants viscosity
During the drain contact period, the lighter weight liquids evaporate which increases the concentration of the dye materials entrapped in discontinuities. The increased dye concentration enhances the visibility if the indication. The drain contact mode is also more economical than immersion contact mode as the excess penetrant drains from the component and is recovered. The savings with drain contact is two-fold the drained penetrant is recovered and since the remaining penetrant layer is much thinner than an immersion contact layer, less emulsifier is required during removal

As noted above the penetrant must be kept wet during the entire dwell time. This is to ensure the penetrant does not dry out while keeping a supply of new fluid available to enter any defects.
When applying the penetrant the **penetration** or **dwell** time is that time between applying the penetrant and washing the penetrant off at the wash or rinse stage. This includes any draining time.

Brush

Immersion

Spray

Electrostatic Application

Applying penetrant to large components such as fan casings and HPC drums etc, has previously been carried out by immersion tanks or by conventional air spray. The immersion system involves the installation of large tanks, which not only occupy valuable floor space but also require large quantities of materials, necessitating careful control and eventually complete replacement Some of the more complex components will entrap penetrant in areas from which it is almost impossible to obtain complete removal, thus increasing cost through "dragout". Conventional air or aerosol spraying methods have the disadvantage of high material consumption.
To overcome these problems, electrostatic application systems have been developed from the well known and proved electrostatic method of paint spraying: it combines the desirable features of **speed** of application; eliminates the necessity for material control; offers **economy** in consumption of material, minimises **floor space** requirements and ensures **complete coverage** of the part.

Principles of Electrostatic Spraying

The process is based on the fundamental 'law that electrically charged particles of opposite polarity attract one another: when these particles are placed within an electrical field they align themselves to the lines of force of that field. In practice, this electrical field is obtained by creating a potential difference between the work piece, which is connected to earth, and the hand gun which is connected to the electrical generator. The negative charge on the particles is produced via a rotating atomiser in the liquid gun, and by a charged electrode surrounding the nozzle in the powder gun. The result is a "wrap-round" which allows all shapes of components to be evenly coated front and back with one pass of the gun. To ensure an adequate coverage the penetrant should be of a relatively low viscosity to assist in the atomisation. In addition the penetrant should have a high electrical resistance so that it can accept and retain the charge.

The equipment consists of a D.C. high voltage generator and two pressurised spray units, one for penetrant and one for developer, each feeding a spray pistol connected to the H.T. supply.

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3.5 Penetrant Removal

Following application of the penetrant and elapse of sufficient time for penetration, the penetrant is removed from the surface of the specimen. This operation, commonly referred to as the "Wash Cycle", is meant to remove the penetrant from the surface without disturbing any penetrant which has entered a discontinuity. Adequate removal is necessary to ensure against formation of irrelevant indications or interfering background.
Confusion can sometimes exist when using the term "Rinse Cycle" to identify this stage of the process. As discussed below, when removing a post emulsifiable penetrant there are several steps which include a pre water rinse and a post water rinse.

Several options are available to remove the excess penetrant but the choice of method is mainly driven by the penetrant itself and whether the inspection is being performed in processing line such as an engine overhaul shop or a portable inspection out on the job
Within a processing tank line arrangement, the use of water is the preferred option. Water is readily available, reasonably cheap and environmentally friendly. It is also non-flammable and non-toxic.
In addition, water can easily be controlled by the operator to ensure over and under-washing does not occur. This will be discussed further below

Water Washable Method A

Water Washable (**WW) penetrants have a built in emulsifier** and the removal of this type of penetrant is easily accomplished by a water wash.

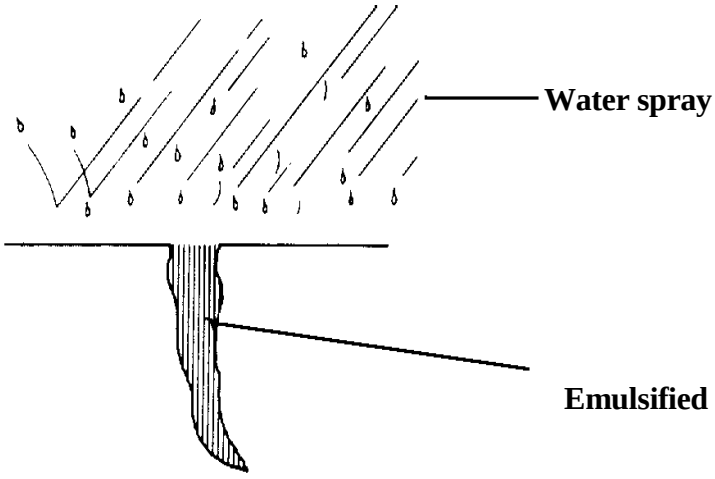
The best method of washing is by the use of a hose and spray nozzle. The water Washable Penetrant is converted into small suspended oil droplets by mechanical force of the water spray. A separate process step of applying emulsifier is not required. Water Washable penetrants are often called "self emulsifying" and are the most widely used.

High performance WW penetrants approach the capabilities of the Post Emulsifiable penetrants and some have been qualified to sensitivity Level 4

The character of the water spray developed is important with care being taken to ensure that the spray volume and force do not wash the penetrant out of discontinuities. It should be strong and forceful, and composed of large coarse droplets which cut through the film of penetrant, and then 'roll' it off the surface. Water with a fine mist would have a higher probability of removing some of the penetrant trapped in the defects. Some of the other considerations regarding the water wash are listed below

Removal is controlled by length of wash time and must be stopped when an acceptable background is reached. **Water washing of Fluorescent penetrant must be carried out under UV lighting**. The wash station should also be in subdued light were possible.

- Reasonably coarse water droplets (not mist or solid stream)
- The spray should be applied so that it reaches the surface of the specimen at an angle of approximately 45 degrees
- Water temperature should fall within the range of **10^0 to 35^0 C (50 to 100 degrees F)** with temperatures being held reasonable constant preferably at the higher end of the range.
- A maximum safe water pressure not to exceed **40 pounds per square inch (276 kPa).** If the water is air assisted then the maximum pressure should not exceed 25 psi (170 kPa).



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PE Penetrant Removal Method B and D

Post emulsifying penetrant removal is a two step process because the penetrant does not contain an emulsifier. When penetration is complete, a coating of emulsifier is applied over the surface as a separate step. Time is allowed for the emulsifier to mix with the surface film of penetrant, after which washing with a water spray results in a clean surface. In this case the wash water removes only that penetrant, which has become impregnated with emulsifier, and prolonged washing will not remove penetrant in either the fine or the open defects into which emulsifier has not entered. This technique is especially sensitive for wide shallow discontinuities.
The amount of time that the emulsifier is permitted to remain acting on the penetrant is very critical and will vary dependent on the type and size of defect. Over emulsification can result in penetrant being washed from defects particularly those of a shallow nature.

Exact emulsifier dwell time is in accordance with the manufacturer's recommendation and the technique. The emulsifier may be applied by immersion or spray when allowed by the technique, however application by brushing is prohibited. Brushing is not recommended because the action of the brush mixes the emulsifier with the penetrant prematurely and irregularly making control of emulsification time impossible.

Previously all post emulsifiable penetrants were removed using a Lipophilic or oil based emulsifier. Recent advancements have given rise to the more popular Hydrophilic or water based emulsifier. The action and advantages of both these are discussed below. In these notes, the words "emulsifier" will be used when referring to lipophilic material and the word "Remover" will be used when discussing hydrophilic material. This is a practice generally used by industry

The Hydrophilic post emulsifiable method (Method D) was introduced in the mid-1970's and since it is more sensitive than the Lipophilic post emulsifiable method it has made the later method virtually obsolete. The major advantage of Hydrophilic emulsifiers is that they are less sensitive to variation in the contact and removal time. While emulsification time should be controlled as closely as possible, a variation of one minute or more in the contact time will have little effect on flaw detectability when Hydrophilic removers are used However, a variation of as little as 15 seconds can have a significant effect when a Lipophilic system is used.

During the removal process that uses an emulsifier care must be taken to stay within the technique requirements regarding timing, temperature and pressure.
If at any stage these are not adhered to or the operator suspects that the process is not being carried out correctly, the part **shall** be re processed from the beginning **including pre cleaning**.
An example of this could be too much penetrant background indicating a longer emulsification time is required.

All emulsifier contact times are determined by experience and may vary even between process shops. Each part shall be processed several times using different emulsification times. The time selected will be such that a very small amount of penetrant background will still be evident at the inspection stage. Although this will not interfere with the sensitivity it can be used to confirm the washing stage has been carried out correctly

Lipophilic Emulsifier Method B

Lipophilic emulsifiers, being oil base, dissolve readily and **diffuse** into oily penetrants at a uniform rate. The rate of diffusion is dependent on the activity and viscosity of the emulsifier. These emulsifiers are used as supplied by the manufacturers. The diagram shows the basic action of lipophilic emulsifier during removal of surface penetrant. The diffusion rate will vary depending on the viscosity and activity as previously stated and also on a number of other factors such as;

- The surface condition of the part.
- Defect size and shape.
- Temperature

Emulsifiers with high viscosity (above 50 centistokes) are relatively slow acting as emulsifiers. Low viscosity emulsifiers in the range of (below 30 centistokes) are relatively fast acting emulsifiers (under 2 min emulsification). In most cases, the emulsification time is critical and must be carefully controlled to assure reproducible performance. When using lipophilic emulsifiers the time is critical and can only be determined by experimentation. Once the time has been established no changes are allowed to the processing steps

When used in a tank system there is a tendency for the emulsifier to become contaminated with penetrant. Because of this it is a requirement for these emulsifiers to be able to withstand a 5% penetrant contamination without any noticeable reduction in efficiency.

Lipophilic emulsifier is usually applied by dipping or immersing the component in a tank. Components can be immersed one at a time, or placed in a basket for processing. Application by spraying the emulsifier is not recommended. The problem with spraying is the difficulty of applying enough emulsifier without the mechanical force of the spray scrubbing the penetrant layer.
Emulsifier SHALL NOT be applied by brushing or wiping. Brushing or wiping produces an uncontrolled and uneven mixing action.

When the component surface has been coated with emulsifier, the component should be removed from the liquid and allowed to drain. The component should not remain in the emulsifier during the contact time. Care must be exercised to prevent pooling in cavities during the contact time.
Total immersion contact would nullify one of the modes of emulsifier action. It was once thought that emulsification occurred only through the chemical action of diffusion. It is now recognised that two modes are involved. The first mode occurs as the emulsifier drains from the component surface during the contact time. As the emulsifier drains, the movement carries with it considerable surface penetrant. This scrubbing or mechanical action reduces the amount of penetrant to be emulsified and also initiates the chemical or diffusion action. Without this mixing action, emulsifier contact time might be as long as ten or twenty minutes. Post-emulsified penetrant entrapped in flaws and not diffused with emulsifier is relatively resistant to water spray and rinse time is not critical. However, excessive spray pressure or hot water can remove entrapped penetrant and must be avoided

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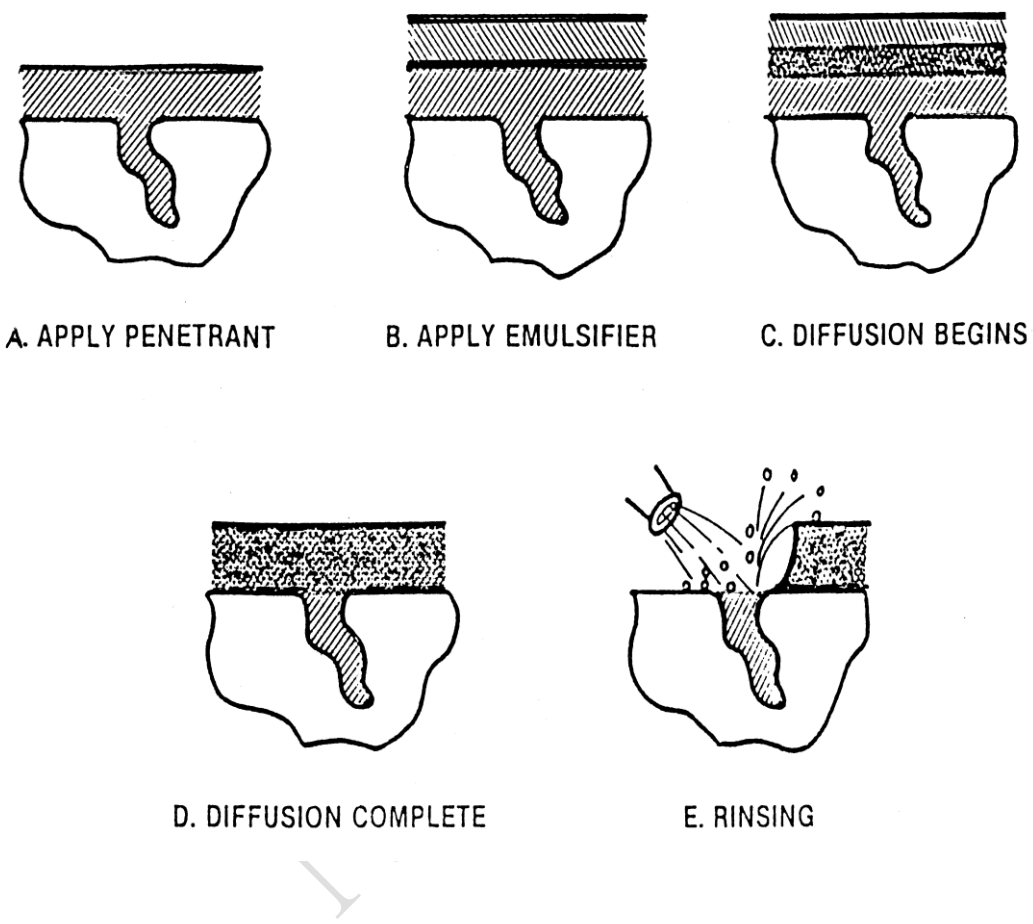
PE Penetrant Removal



The above diagram shows how the excess penetrant is removed using an oil based emulsifier (Lipophilic)

Hydrophilic Remover – Method D

Hydrophilic Removers (Method D) differ from the lipophilic emulsifiers in that they are water based and very close in chemical composition to detergents. Referred to as "Removers", these emulsifiers remove the excess penetrant with a mechanical and chemical action, sometimes referred to as **Scrubbing**. This **Scrubbing** action is different than the lipophilic process because no diffusion takes place. Hydrophilic emulsifiers are basically detergents that contain solvents and surfactants. The hydrophilic emulsifier breaks-up the penetrant into small quantities and prevents these pieces from recombining or reattaching to the surface of the part. The mechanical action of the rinse water removes the displaced penetrant from the part which then allows fresh remover to contact and lift newly exposed penetrant from the surface.

These emulsifiers are supplied in concentrated form by the manufacturer and are diluted with water prior to use. **The acceptable concentration will be specified by the manufacturer.**

Hydrophilic removers consist of water soluble chemicals, usually non-ionic surface active agents called surfactants. They are supplied as concentrated liquids and are mixed with water either before or during the removal process. The surface active agent in the remover displaces a small quantity of penetrant from the surface and prevents it from recombining with the remaining penetrant layer. Unlike Lipophilic emulsifier, hydrophilic remover is immiscible in penetrant and diffusion does not occur. All of the removal action takes place at the exposed surface and penetrant just below the surface is not involved until it becomes exposed. Agitation of the liquid removes the displaced penetrant and allows fresh remover to contact the remaining penetrant layer

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Pre-Rinse

The clean, pre-clean, penetrant and penetrant contact time steps are identical in both the Lipophilic and hydrophilic methods. **However, the processes diverge with the pre-rinse step in the hydrophilic method**. The component is subjected to a plain water spray following the penetrant contact when using the hydrophilic method. The mechanical action of the water spray removes over 80 percent of the excess surface penetrant, leaving only a very thin layer on the component
This pre-rinse step cannot be used in the Lipophilic process as the oil base emulsifier does not tolerate water. The pre-rinse reduces the amount of remover consumed and in immersion set-ups, minimizes contamination of remover due to penetrant carry-over. It also reduces remover contact time as, in general, contact time is about 50 percent less when the pre-rinse step is used.
The pre-rinse cycle should be similar to that used with the Water Wash penetrant. The objective is to reduce the amount of surface penetrant, while leaving a thin layer remaining on the component.

Spraying

Hydrophilic emulsifiers, when applied by spraying, function by their detergent and scrubbing (kinetic) action. As a spray the emulsifier concentrate is metered into the forceful water spray rinse in low concentrations in the range from 0.1% to 5%. The spray scrubs layer after layer of excess surface penetrant off the test parts, always providing a fresh solution of detergent and water. The surface-active agent in the remover helps to displace surface penetrant from the test object surface and prevents its re-disposition on this surface.

Immersion

In an immersion or dip mode, removal of excess surface penetrant with hydrophilic removers is accomplished in a tank. Mild agitation separates the displaced penetrant from the part. Concentrations are generally from 5 to 50% in water. At lower concentrations, such as 5%, the penetrant tolerance of the hydrophilic emulsifier bath is very low. This can require rather frequent recharging of the tank. At 33% concentration, the tank life of the hydrophilic emulsifier appears maximised. It should also be pointed out that the hydrophilic emulsifier contact time is directly related to the emulsifier concentration. Less emulsifier contact time is needed with higher concentrations of emulsifier. This applies to both immersion and spray applications.

It is also noted that specific remover concentrations are specified by the manufacturer as these concentrations are used for material qualification per AMS 2644

Experimental determinations are required to establish the correct emulsifier contact time for the removal of excess surface penetrant. The optimum emulsifier contact time depends upon factors such as:

1. Emulsifier concentration.
2. Method of emulsifier application (dip or spray).
3. Size of test objects and means for handling them.
4. Shape and surface finish of test objects.
5. Pre rinse operation.

Generally, an emulsifier contact time of 1 or 2 min is adequate for removal of excess surface penetrant by the agitated hydrophilic remover dip tank. In contrast to the Lipophilic emulsifiers, most of the penetrant is removed while the test part is in the immersion tank.

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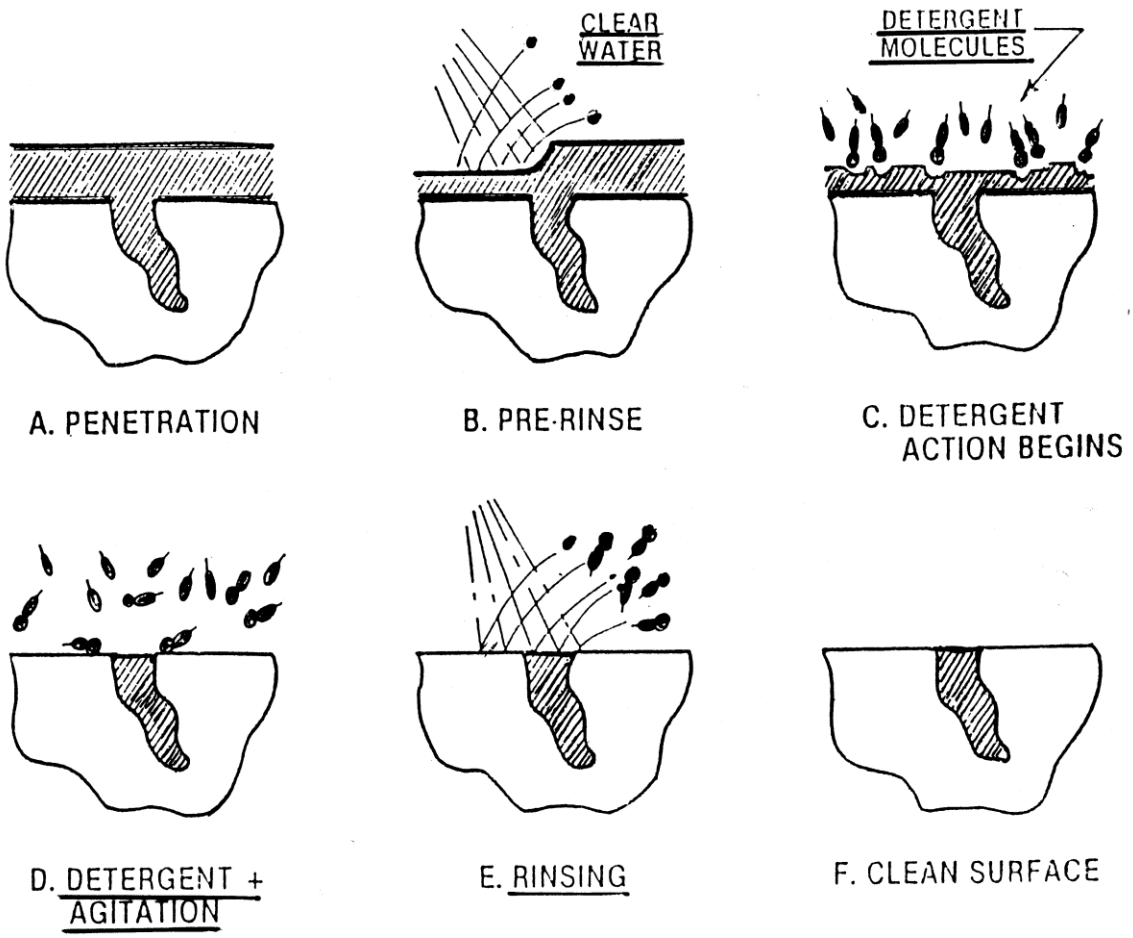


The Hydrophilic removers are all water based and can either be used in a bath or sprayed on as shown in this diagram

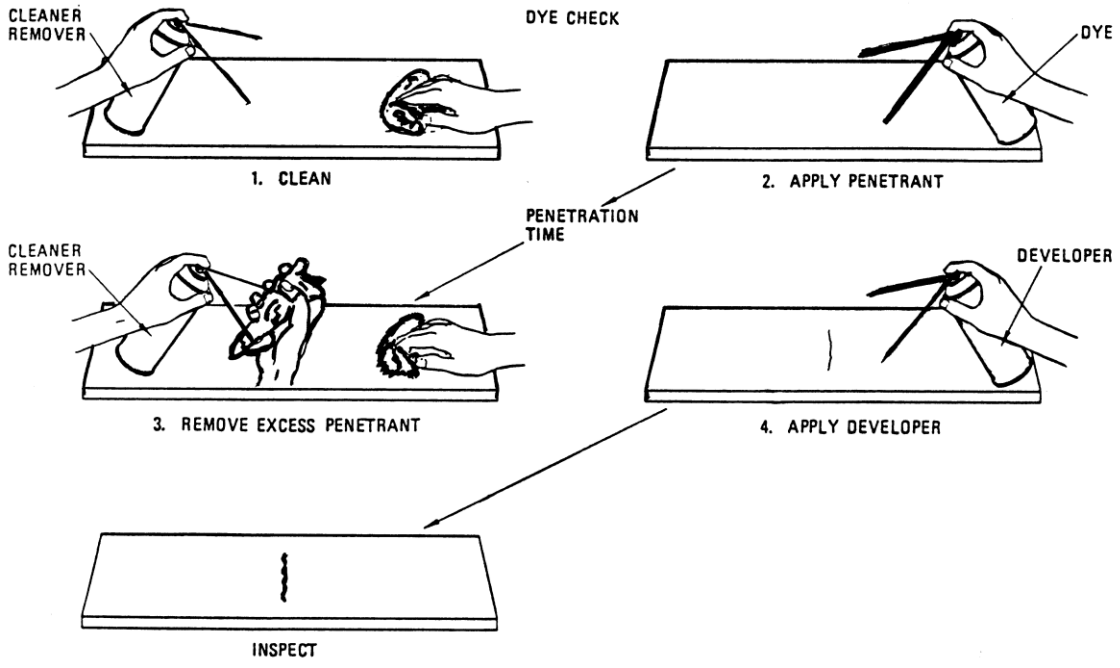
Solvent Removable Method C

Solvent removable penetrants are properly removed only by the solvent designated for that particular penetrant by its manufacturer. Prior to use of the solvent, excess penetrant is wiped from the specimen with absorbent dry lint free towels. After the excess penetrant has been wiped off, the specimen surface is cleaned with clean towels **dampened** with solvent. Solvent is never applied directly to the specimen since it might wash out or dilute the penetrant in a discontinuity.

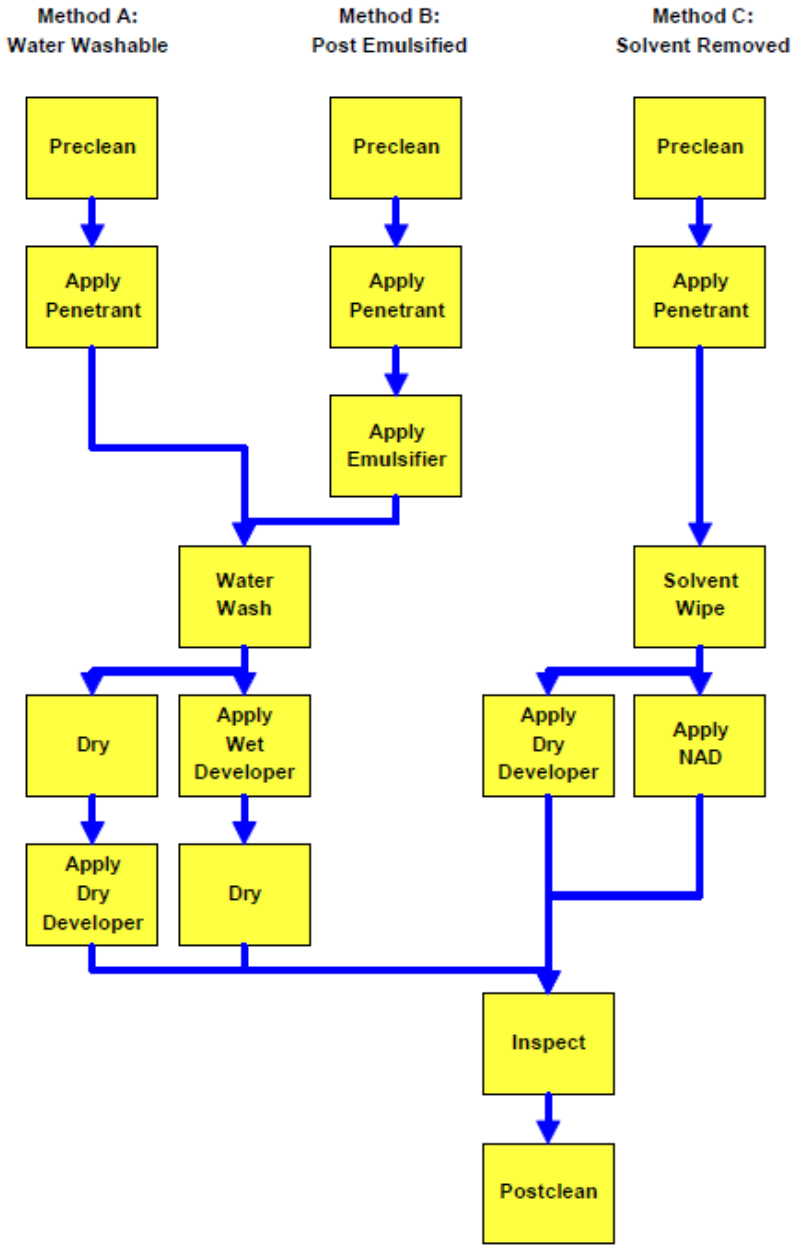
Solvent removable method C inspections are considered to be one of the most sensitive techniques. This is due to a combination of factors such as;

- The use of high sensitive penetrants
- Non Aqueous spray developers used
- The use of a solvent during the removal stage assists with the bleed out process

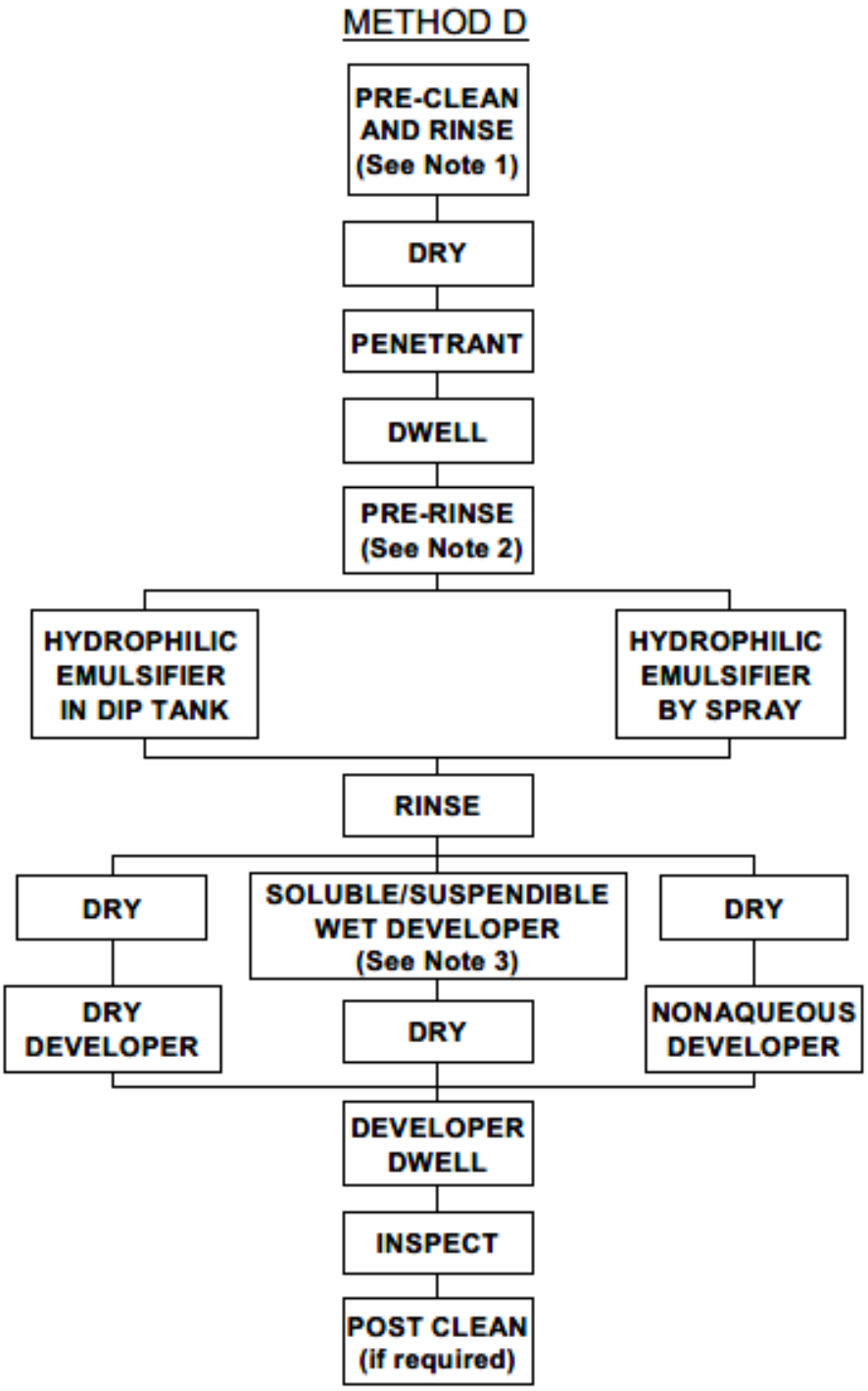
When fluorescent penetrants are used, the removal stage must be carried out using a black light to ensure complete removal of the penetrant. For visible dye penetrants the absence of red traces on the wiping materials ensures complete penetrant removal.



Shown above is the Solvent Removable method used mostly with the portable Penetrant inspection



Typical processing steps for the three penetrant Methods – Note Method D (PE – Hydrophilic) is not shown. This method is similar to B with an additional pre water rinse before applying the emulsifier



Note 1 Use correct cleaning methods
Note 2 Pre rinse only applicable to Method D
Note 3 Soluble wet developer is not recommended for use on critical engine parts

Typical processing steps for method D (AMS 2647)

3.6 Drying

The next stage in the process is generally listed as the Development step, however at some time during the development the part has to be dried. This drying will be performed either prior to or following the developer application. If the developer to be used is dry powder or non aqueous then the part shall be completely dry before the developer is applied. When wet developer is used, the specimen is dried after the developer has been applied.

Prior to drying a visual inspection for pooled water is advisable. These areas will take substantially longer to dry and may also produce water spots that can be evident during the inspection stage.

Pooled water remaining on the part after the water wash stage can be removed by:

- **Blotting with a clean lint free towel**
- **Using air with a max pressure of 25 psi (170 kPa)**
- **Rotating or re positioning the part**
- **Using a hot air dryer**

Any means of drying that does not interfere with the test process by overheating, or by contamination of materials, is acceptable but, controlled drying at even regulated temperatures is preferred. A thermostat controlled forced air dryer with a maximum temperature of 71 degrees C is usually employed in stationary test installations. **Drying should be carried out as quickly as possible in order to dry the surface of the specimen without affecting the penetrant in the discontinuities**.

Some techniques call for the part to be dried within 20 to 30 minutes maximum. During this time the part may need to be turned and wiped with towels in order to achieve these times.

Hot air guns can be used but are not recommended due to the lack of control regarding temperature and air pressure

Typical air dryer cabinet with temperature and timing gages

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3.7 Development

Form a	Dry powder	
Form b	Water soluble	Wet Developers
Form c	Water suspendable	
Form d	Non aqueous wet (NAWD)	
Form e	Specific application	

Because penetrant commences to bleed out of discontinuities immediately following removal of surface penetrant, developer is applied to the specimen as soon as possible after the penetrant removal. Developer assists in the detection of penetrants retained in discontinuities by aiding in the capillary process (the developer acts as a **blotting** agent), and by effectively enlarging the indication. This happens because the developer causes the penetrant from the discontinuity to spread out over a greater area. It also serves as a contrasting background for the visible dye processes. In addition Developers improve the visibility of fluorescent indications by reducing reflections and providing a blue-black background for the yellow-green penetrant indications

Developer is available in both dry and liquid forms and the selection of developer is in accordance with the manufacturers recommendation for the type of penetrant and technique used. When a dry or non aqueous developer is used the specimen must be completely dry before the developer is applied. When a wet developer is used it is applied immediately after the penetrant removal is accomplished, and the specimen is then dried.

In the case of Fluorescent penetrants there is evidence to show that in addition to the widening effect, there is an additional increase in the brilliance of the fluorescence of the penetrant when it is dispersed in the developer. The dry developer coating can be considered to be made up of very small spherical particles which are non absorbent. These individual particles may clump together in aggregates of 50 to 100 microns in diameter. It is considered that the penetrant is drawn by capillary action and spreads around the surfaces of the individual developer particles, without necessarily filling the spaces between them. Thus the eye will not only see the fluorescent light from a thin film of penetrant in the top layers of the developer but also the light from many small films of penetrant scattered throughout a comparatively large volume of developer. With many multiple reflections within the layer this will produce a significant increase in the brilliance of the indication

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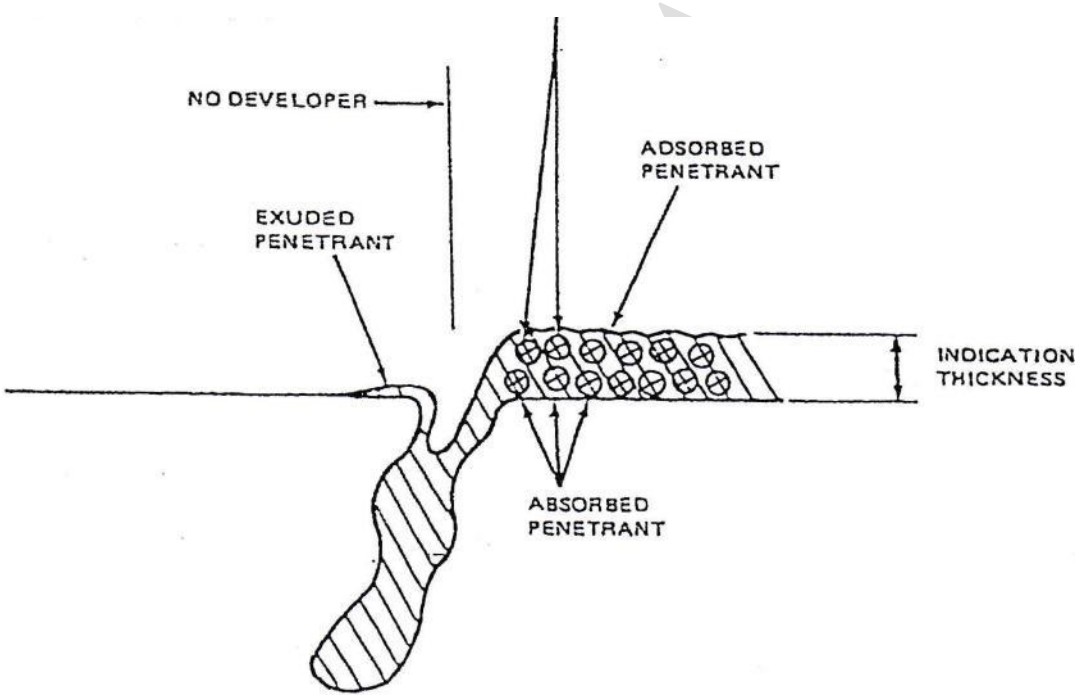
Developer Action

Self -development is the formation of an indication without the application of a developer. All penetrants are capable of some degree of self-development as they will exude from a discontinuity and spread over the surface. The critical factor is the size and volume of the discontinuities that must be detected. A relatively large volume of entrapped penetrant is required and self-development is not reliable in detecting small tight flaws.

One of the principal modes of developer action involves **adsorption** and **absorption**. Adsorption refers to the collection of a liquid on the outer surface of a particle due to adhesive forces. Absorption refers to the blotting action that occurs when a liquid merges into an absorbent particle. The mechanism of development is a combination of both adsorption and absorption.

Developer Particles



THE EFFECTS OF A DEVELOPER

Dry Developer

Dry developers are a loose fluffy talcose powder with high absorbent properties and a low bulk density. They adhere loosely to the surface of a component and are difficult to retain on highly polished surfaces. However, once an indication begins to form, the developer powder wetted with penetrant adheres well. At the inspection stage the excess developer on the surface is removed leaving only that which is associated with an indication. **This results in the one big advantage of dry developer, which is that it is not possible to apply too much developer and mask indications for that reason.**

Dry developers can be applied in many ways. The two most common are by immersing the part completely in a container of developer powder, or by using a "cloud chamber" consisting of a sealed container with a layer of powder at the bottom. This powder is agitated by air jets to form a cloud which settles over the part. Additionally the developer can be injected into the chamber using a pressurised developer supply. Once the required time has elapsed an extraction system removes the unused developer prior to opening the chamber. As this technique uses new developer each time there is no need to regularly check the powder for contamination.

Dry powder developer is generally considered to be the least sensitive but it is **inexpensive to use and easy to apply**. The goal is to allow the developer to come in contact with the whole inspection area, but in most cases this is difficult to achieve unless the electrostatic method is used. Also dry developers do not provide a uniform white background as some other forms of developers do. This contrasting background is very important when using visible penetrants, so the use of dry powder is not recommended under these conditions.

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Dry powder developers can be applied by:-

1. Blowing the powder on with a bulb type blower.
2. Immersing the component in a container of powder.
3. Pouring powder over the component.
4. Using a dust or fog chamber where the particles are blown into an air suspension.
5. Spraying with an electrostatic system or low pressure gun

After application, the excess developer should be shaken off or removed with air. The developer particles are very loosely held and can be easily removed. Wiping, brushing or compressed air in excess of 5 psig should not be used. Care must be taken to prevent contamination of the dry developer. The two most frequent contaminants are water or moisture and penetrant. Water in dry developer comes from components that have not been completely dried or from careless splashing during the wash step. Water or moisture contamination will cause the dry developer to form lumps or to cake, thus reducing its effectiveness. Penetrant contamination occurs when particles of penetrant-soaked developer fall from poorly washed components or heavy indications. Penetrant contamination will cause false indications either on the component being processed or on subsequent components.

Wet Developers

Wet developers generally come in one of two forms, water soluble and water suspendable. With both forms the developer is applied immediately after the penetrant removal step while the part is still wet. Drying then takes place to evaporate the water to leave a uniform developer coating. These developers, due to the water, contain both wetting agents and inhibitors. The wetting agents are used to assist the flow of the water and the inhibitors are to reduce the risk of corrosion.

These wet developers are not recommended for use with the water washable penetrants as some of the penetrant entrapped in a defect could be removed during the development stage.

Water Soluble

As the name implies, water soluble developers consist of a group of chemicals that are dissolved in water and form a developer layer when the water is evaporated away. The best methods for applying water soluble developers are by spraying or dipping. Drying is achieved by placing the wet but well drained part in a recalculating warm air. If the parts are not dried quickly, the indications will be blurred and indistinct. Properly developed parts will have an even, pale white coating over the entire surface.

Water Suspendable

Wet developer is a suspension of absorptive white powder in water. The mixture is prepared in accordance with manufacturers' directions and is mildly agitated prior to and during use so that the powder remains evenly distributed throughout the water vehicle. This developer is normally applied by immersion or spraying. This is a fast and effective method that is well suited for use in rapid, production line and automatic testing. Wet developer is applied so as to form a smooth even coating, and particular care is taken to avoid concentrations of developer in dished or hollowed areas of the specimen. After wet developer has been applied the specimen is thoroughly dried, as above.

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Non Aqueous Wet Developer (NAWD)

Non-aqueous developers are suspensions of developer powder in a solvent. They are supplied ready packed in an aerosol container and are applied to the surface by spraying. The solvent used is highly volatile so that the developer wetted with solvent appears grey when first applied but quickly changes to white as the solvent evaporates at ambient temperatures.

Non-aqueous developers are generally accepted as offering the highest test sensitivity. The reason for their high sensitivity is that the solvent carrier mixes with the penetrant in the crack reducing the viscosity and initiating the capillary action required to form an indication. Also, in many cases where tight, small flaws occur, the dry and aqueous developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary and surface tension forces that serve to pull the penetrant from the flaw.

The solvents are carefully selected for their compatibility with the penetrants. These developers also contain surfactants and dispersants whose functions are to coat the particles and reduce their tendency to clump or agglomerate.

Non aqueous wet developers are always applied by spraying. When applying the developer coating it is essential that it not be applied too thickly. The aerosol should be applied in much the same way as spray painting. The first pass should provide only a very light coating which is added to by subsequent passes. The optimum coating to achieve with Fluorescent penetrants is one that still just shows the metallic lustre of the surface through the penetrant layer. When using fluorescent penetrants, a developer coating which appears completely white is too thick. When applying this developer with Visible Penetrants the coating should be thick enough to just obscure the metallic surface and supply a contrasting background

It can be seen that given a choice, these non-aqueous developers have the advantage of being the most sensitive, are convenient to use and are packaged so that they cannot be contaminated. They also produce a contrasting background, making them suitable for both fluorescent and visible penetrant inspection.

Developer Dwell Time

Extraction of the penetrant entrapped in a flaw is a function of time and volume of available penetrant. Time must be allowed for the developer to assist in drawing some of the entrapped penetrant from the flaw and spreading it on the component surface to form the indication. The length of developing time varies widely with a number of influencing factors. The development time should be at least one-half of the penetrant contact time and should not start until component is completely free of moisture.
Over development, i.e. too long a development time, is possible and must be avoided. Developer action starts when the developer is completely dry and continues until all of the available penetrant is extracted. An indication will gradually form, reach a maximum resolution point and then begin to degrade. The lateral diffusion of penetrant over a period of time can be so great that the indication becomes indistinct. Medium size or large discontinuities will appear as a smear or blob of penetrant. Small indications are especially critical since the small amount of penetrant may not be observed when it diffuses.

Standard developer minimum dwell time of 10 minutes is normally acceptable (ASTM E 11417) and the maximum times vary by developer (1 hour NAWD and 2 to 4 hours for dry)

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Comparison of Developers

The relative sensitivities of penetrant inspection with various forms of developer are influenced by a number of factors. The method of applying the developer produces a range of sensitivities for each of the developer forms. The table below lists some of the common forms of developer and their respective estimated sensitivities

Non Aqueous Wet (Solvent suspended)	**Spray**	**Most sensitive**
Water Soluble	Spray	
Water Suspended	Immersion	
Water Soluble	Immersion	
Dry Powder	Electrostatic spray	
Dry Powder	Fluidized bed	
Dry Powder	Air Agitated Dust Cloud	
Dry Powder	Dip and Pour	Least sensitive

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Module 4
Lighting and Equipment

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4 Lighting

After the appropriate development time has elapsed the parts are inspected. Visible dye (colour contrast) penetrants require good white light conditions, however, where fluorescent penetrants are used the parts are inspected with high intensity black light in a darkened area or booth. Small parts may be held under a fixed light. A portable hand light should be used over the surface of large parts. When using florescent penetrants the indications will glow with a bright **yellow/green colour** when scanned with a black light. The extent of the fluorescent indication is generally a function of the size of defect and the time since developer application. Porosity, blowholes, etc. will show as circular spots, while cracks, cold shuts and hot tears will generally show as continuous or dotted lines.

Where large defects have retained a quantity of penetrant the indications will spread extensively on the surface. Experience in the use of the method allows interpretations to be drawn from the extent of this spread as to the relative size of the defects.

4.2 Inspection Area

The area where final fluorescent inspections are performed must have a low level of visible (ambient) light in order to maximise the contrast of fluorescent indications. Most specifications stipulate a maximum background of visible light of 20 lux (2 foot-candles). Ideally, total darkness would provide the maximum contrast. However, some visible light is required in order to be able to see the parts and find one's way about the area. Once time has been allowed for the eye to accustom itself to the darkened area, it will be usually found that the blue/violet light emitted by the black light lamps will be sufficient for practical purposes.

The inspection area must also be free from distracting reflective surfaces and from fluorescent materials. For this reason, it should be isolated from the area where the fluorescent penetrant materials are used. Hands should also be clean as fluorescent contamination of the hands is very common after processing parts through the inspection process.

A common way to reduce the ambient light when performing a portable fluorescent inspection is to use a black cap. ,This may be draped over the inspector and surrounding area during the :inspection stage of the procedure.

The use of visible penetrants requires a well lit inspection area usually with a minimum of 1000 lux (100 foot candles).

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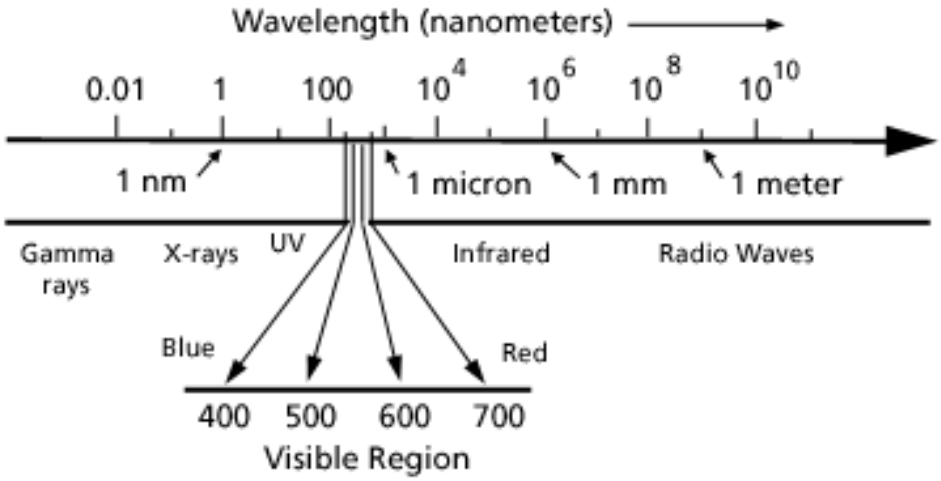
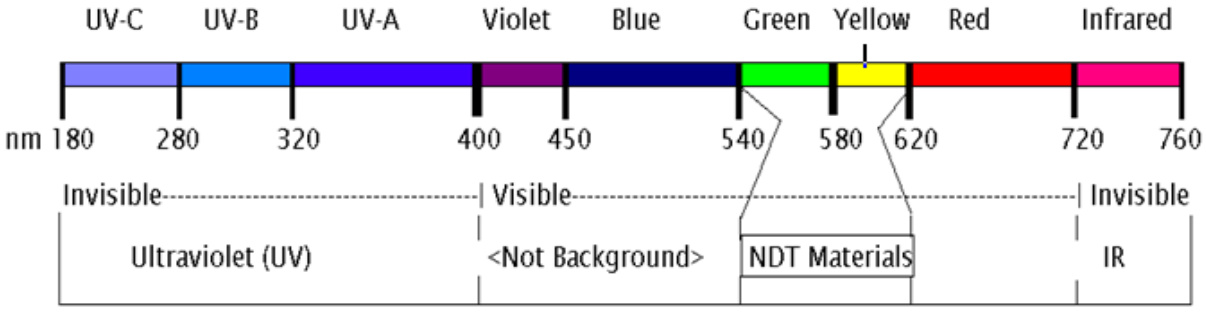
4.3 Electromagnetic Spectrum

The visible spectrum is that part of the electromagnetic spectrum approximately encompassed by the wavelengths 700 nanometers (x 10^{-9}m) at the red end to 400 nanometers at the violet end. (previously known in terms of Angstrom units – x 10^{-10}m). These electromagnetic radiations, when combined, form white light which travel at a speed of 300 meters/sec in a straight line until it meets the surface bounding a new medium. Here it may be reflected, absorbed or transmitted.



Electromagnetic Spectrum



Ultraviolet radiation is an electromagnetic radiation whose wavelengths range between X-rays and visible light. The ultraviolet range is divided into three bands of the following spectral ranges:

a. UV-A 315nm to 400nm. (This is commonly referred to as "**Black Light**").
b. UV-B 280nm to 315nm.
c. UV-C 100nm to 280nm.

The fluorescent dyes in the penetrants fluoresce most brilliantly at approximately 550nm when irradiated with black light. **Suitable black lights produce energy at a wave length of approx. 365 nm**. This light is between the visible and ultra violet in the spectrum. Light in this range is noninjurious to the skin or eyes.

4.4 Fluorescence

Fluorescence is the property of a material to absorb electromagnetic radiation of a particular wavelength and the re-emission of the electromagnetic radiation of a greater or visible wave length and is dependent upon the atomic structure of the fluorescent material and the energy level or wavelength of the radiation source.

The basic component of all matter is the atom which consists of protons, neutrons and electrons. The protons and neutrons form a positively charged nucleus while the negatively charged electrons circulate in orbits around the nucleus. The orbits are not random but are restricted to shells of discrete energy levels with a definite number of electrons in each shell. When a short wavelength photon (UV or X-ray) hits an electron in an atom of fluorescent material some of the photons energy is transferred to the electron which knocks it from its natural shell. This is an abnormal condition for the electron and atom so the displaced electron returns to its natural shell. The excess energy obtained from the photon during displacement is released as electromagnetic radiation. The released radiations wavelength is always longer than the exciting radiation. Each type of fluorescent material emits a specific wavelength ranging from violet (400nm) to red (700nm).

SOURCES OF ULTRAVIOLET ENERGY

There are several methods of generating ultraviolet light. Three of these are:

a. Low pressure fluorescent tubes.
b. High pressure, mercury vapour bulbs.
c. LED’s

LOW PRESSURE FLUORESCENT TUBES

These are similar to the standard fluorescent tubes used in house hold lighting, but instead of an inert gas the tube contains metallic mercury. When an electrical current is applied, the mercury vaporises and emits an ultraviolet radiation with a wave length of approximately 254nm. As this wave length is of no use in non-destructive testing to excite fluorescent dyes, the inside of the tube is coated with a phosphor. The phosphor is excited by the ultraviolet radiation and emits wave lengths in the range of 320nm to 440nm.

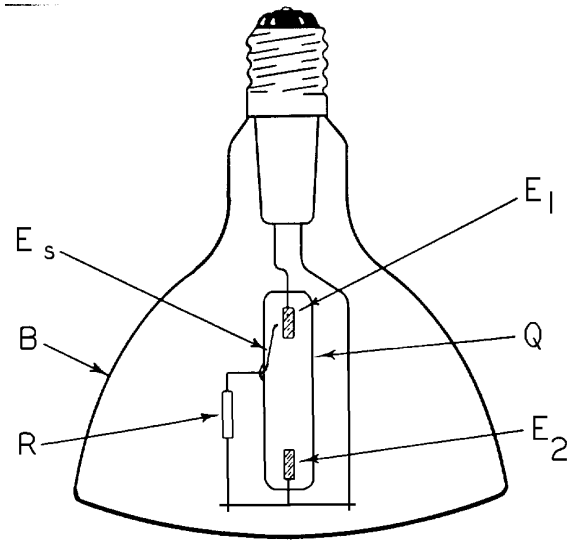
The amount of ultraviolet light at 365nm wavelength is small compared to the harmful short wavelength radiation and the visible light emitted from the tube. The short wavelength and visible light can be removed by making the tube from cobalt glass (Kopp 41). While this removes all undesired wavelengths it also reduces the 365nm wavelength making it unsuitable for inspection purposes. Also the tube cannot be easily focused so its intensity per unit area is very low.

These tubes can normally be found in areas where a high UV intensity is not required e.g. Washing station and general overhead lighting

NZNDTA

Black Light

The source of the black light used in liquid penetrant inspection is usually a high pressure mercury vapour lamp, the essential elements of which are shown in the Fig. The mercury arc is drawn between electrodes E1 and E2 in the quartz tube Q. Es is a starting electrode in which the starting current is limited by the resistor R. The whole is enclosed in the outer glass bulb B. When the lamp is first turned on, the mercury arc is not set up at once. A small low current arc is first set up between E1 and Es bringing about sufficient vaporisation of the mercury to start the arc between the main electrodes. This starting process takes about five minutes. Therefore, no attempt should be made to use the lamp until this starting process is complete and the output is up to the maximum - about ten minutes should be allowed after first switching on, but specific times will be specified by the procedure.



Mercury vapour lamp

These lamps are relatively sensitive to mains fluctuations and the arc will collapse if the voltage deviates outside a narrow band. The arc will not be re-established until the lamp has cooled down. For this reason, lamps should be connected to a lighting circuit rather than a power circuit subject to sudden power demands from heavy equipment. The most widely used lamps are the 100 watt spot lamps. These lamps focus the black light, giving maximum intensity over a relatively small area.

The mercury vapour lamp emits radiation over a large range of wavelengths as shown so it is therefore necessary to filter out much of the radiation. This is done by using a filter (usually a Kopp 41 type). This permits the transmission of the useful black light **peaking at 365 nm**. It is this radiation which causes the penetrant to fluoresce. The filter also permits some radiation of wavelengths over 400nM to be transmitted. This is visible light in the blue/violet part of the visible spectrum - those familiar with UV lamps will be aware that a low level of such light is always present. This visible light is of insufficient intensity to interfere with the perception of indications and can be eliminated by wearing filtered UV glasses. (increasing the contrast). The filter also eliminates the transmission of short wavelength black light in the 310-340 NM range. This is good, since prolonged exposure to radiation in this range can damage the eye.

From the above it can be seen that the high pressure mercury arc bulb is best suited for non-destructive testing uses. The bulb has a good output at a reasonable distance, they can be focused, to increase their intensity on a localised area. Also bulbs range from a 2 watt pencil type, to a 400 watt floodlights

UV-A FILTERS

The glass filter almost universally used, to remove practically all the visible light and all the radiation whose wavelength is below 315nm, is cobalt/woods glass which has been designated woods glass or "Kopp 41". The colour of the cobalt glass is a dense red-purple. The surface of the filter may be smooth or fluted; the fluted surface gives a slightly larger focused spot than the smooth surface filter.
The Filter transmission curve peaks at 365nm with a small amount of visible violet light also transmitted. This violet light is not undesirable since it allows the inspector to see the objects in the immediate vicinity of the ultraviolet source and therefore facilitates the handling of parts during inspection.

It is important that the casing of the lamp and the condition of the filter is such that none of this radiation escapes - DO NOT USE A CRACKED FILTER. Provided that only black light in the desired range is transmitted, there is no danger of harming the eye of the operator. However, looking directly into the lamp is not recommended. The reason for this is that the aqueous humor in the eye contains a substance which will fluoresce under black light causing a blurring of the vision. This effect, although unpleasant, is quite harmless. However, blurred vision is not conducive to good inspection and if an inspector inadvertently looks directly into the lamp, sufficient time for vision to return to normal should be allowed before continuing with the inspection. The parts being inspected may themselves be highly reflective. It is therefore important that direct reflection of the black light into the eye is avoided. This is not usually a problem using a hand-held lamp since the natural thing to do is to hold it to the side at an angle to the part in order that it does not obstruct vision. For the same reasons, highly reflective surfaces in the inspection area should be eliminated - usually by being painted black.

ULTRAVIOLET INTENSITY VARIABLES

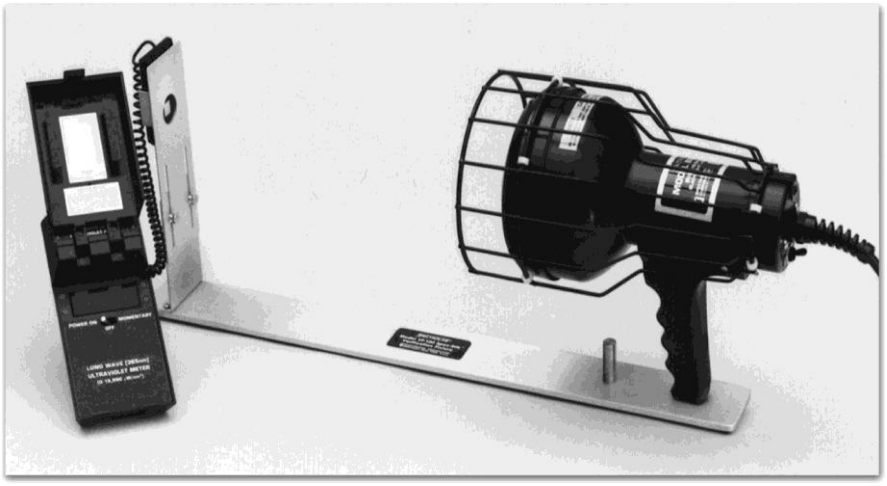
All black lights should be checked daily and after bulb replacement. The minimum acceptable intensity is 1000 micro watts/cm^2 measured at a distance of at least 38 cm (15 inches) from the front face of the filter.. Care should be taken to see that this filter is clean and that there is not a film of dust on either the filter or the bulb. Damaged or dirty reflectors or filters shall be replaced or corrected as appropriate.

A lower than optimum intensity may seriously affect the inspection results. Several of the reasons for intensity variations are as follows:

1 Aging and use (switching on and off) will reduce the effectiveness of the arc and the intensity will gradually decrease to an unacceptable level

2. New bulbs may vary by as much as 50% in their output. This means that with two new bulbs of the same type and manufacture, one may have the intensity that is half the other without being defective.

3. The Ultraviolet intensity varies almost linearly with the line voltage. Below a certain voltage, the lamp will not sustain the mercury arc and the lamp will extinguish. The light will not restart until the bulb has cooled. Ultraviolet lamps should be connected to a stable power supply, to alleviate this problem.



LED UV lights

Recent advancements in the production of UV lights sources have seen the LED (Light Emitting Diode) emerge as the most efficient source and will soon replace most electrical discharge lamps. The LED lights can produce very high intensities but can also produce "white" light that must be monitored to ensure this does not interfere with the inspection.

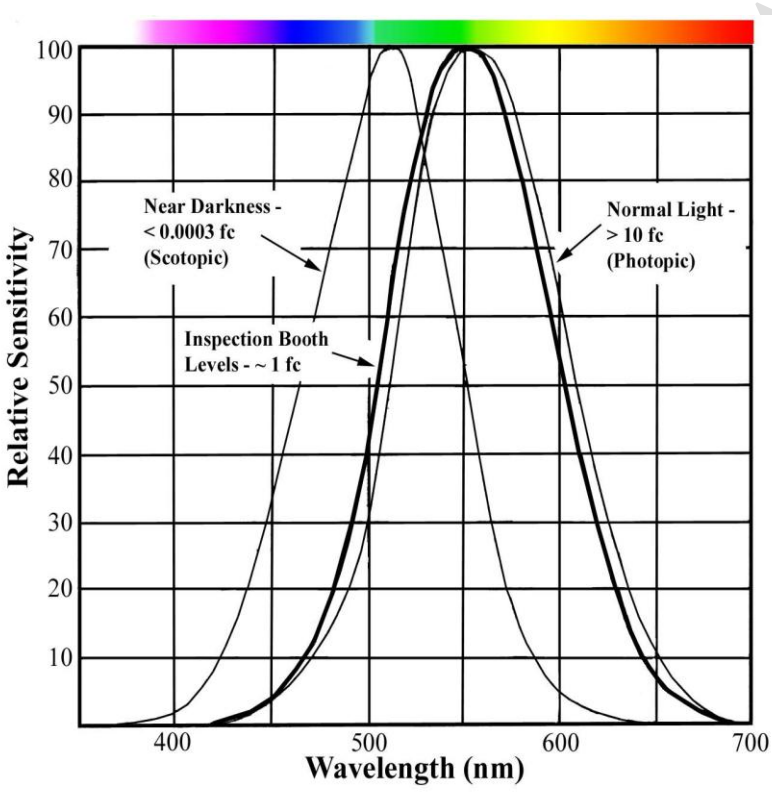
Other considerations, such as light uniformity, edge drop-off and maximum intensity should also be addressed when using LED light from different manufacturers. Ref ASTM E3022

LED Battery powered torches should be checked for their output intensity at the beginning and end of the inspection iaw standard requirements (ASTM E 1417)

Photo-sensitive spectacles - i.e.. the type that darken when exposed to sunlight - must not be worn when performing an inspection. It is the UV radiation in sunlight that cause the darkening process to occur. Therefore the black light radiation from the lamp will also cause a darkening of the spectacle lens, decreasing the ability to perceive the presence of indications

4.5 Dark Adaption

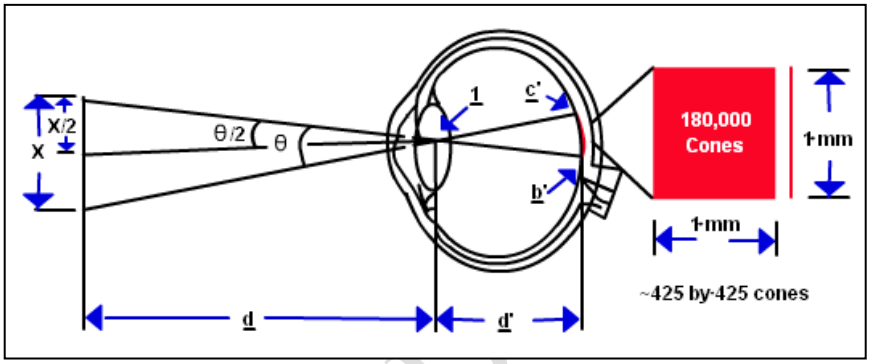
When using fluorescent penetrant, allowing time for the eye to accustom itself to the darkened area was mentioned above. This is important as it is necessary to allow the eye to increase the size of the iris to allow more light in. It should also be appreciated that the mechanism of sight is different under bright light and low light conditions. Under bright light, the eye utilises photopic vision which allows it to perceive small differences in colour and contrast. In darkness, scotopic vision is utilised permitting the perception of small light sources but with very reduced colour/contrast perception. There is also an intermediate light level at which the eye is not very efficient at perceiving anything - this explains that dangerous time on the roads between daylight and night-time conditions. In the case of fluorescent penetrant inspection, it is essential that the eye becomes completely adapted to the very low light level in the inspection area if small indications are to be found. Complete adaptation of both iris size and mechanism of vision can take up to 20 minutes. However, sufficient adaptation for the purpose of black light inspection will usually be achieved with 1 to 5 minutes. Most specifications require a 5 minute dark adaption time, which should also be adhered to when turning on the white light for interpretation.



The three curves in the figure show the response of an average human eye to various amounts of ambient light. The shift in sensitivity occurs because two types of photoreceptors, cones and rods, are responsible for the eye's response to light. The cones enable colour perception and they peak at 555 nanometres which means that under normal lighting conditions, the eye is most sensitive to a greenish yellow colour. When the light levels drop to near total darkness the rods are most active and the human eye is more sensitive to any amount of light that is present, but is less sensitive to the range of colour. Rods are highly sensitive to light but are comprised of a single photo pigment, which accounts for the loss in ability to discriminate colour. At this very low light level, sensitivity to blue, violet, and ultraviolet is increased but sensitivity to yellow and red is reduced. The heavier curve in the middle represents the eye's response at the ambient light level found in a typical inspection booth. This curve peaks at 550 nanometers, which means the eye is most sensitive to yellowish green colour at this light level. Fluorescent penetrant inspection materials are designed to fluoresce at around 550 nanometers to produce optimal sensitivity under dim lighting conditions.

4.6 Visual Acuity

The standard definition of normal visual acuity (20/20 vision) is the ability to resolve a spatial pattern separated by a visual angle of one minute of arc. Since one degree contains sixty minutes, a visual angle of one minute of arc is 1/60 of a degree. The spatial resolution limit is derived from the fact that one degree of a scene is projected across 288 micrometers of the retina by the eye's lens.
In this 288 micrometers dimension, there are 120 colour sensing cone cells packed. Thus, if more than 120 alternating white and black lines are crowded side-by-side in a single degree of viewing space, they will appear as a single grey mass to the human eye.
When visually inspecting an object for a defect such as a crack at 12 inches, the normal visual acuity of the human eye is 0.00349 inch.



It is essential that personnel concerned with final inspection of parts for the presence of indications should possess a high standard of visual acuity.

ISO 9712 states

a) Near vision acuity shall permit reading a minimum of Jaeger number 1 or Times Roman N 4.5 or equivalent letters (having a height of 1.6 mm) at not less than 30 cm with one or both eyes, either corrected or uncorrected;

b) Colour vision shall be sufficient that the candidate can distinguish and differentiate contrast between the colours or shades of grey used in the NDT method concerned, as specified by the employer.

Colour and Contrast

In the case of liquid penetrant inspection, it is not necessary to discriminate between colours. It is only necessary to recognise the presence of an indication which, in the case of a red dye penetrant, happens to be coloured in order to enhance its contrast with the background - whether the inspector recognises it as red does not matter provided they see it with the same contrast against a white background as others would.

4.7 PT Equipment

Portable

Portable PT Inspections are usually carried out using equipment designed for this purpose. Portable kits can be purchased as a package or put together by the inspection body

Kits usually contain aerosols for ease or transport and application. Typical contents would be:

- Pre Cleaning solvent
- Penetrant
- Solvent Remover (Can be the same as the pre cleaner)
- Developer
- Black (UV) Light for Fluorescent inspection
- Brushes and tissues
- Black Cape

Stationary tank lines

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Manual Penetrant Inspection Lines can be simple in design - Sometimes just being one or two adjacent stations to accommodate a wash-drain area. But Penetrant Inspection Lines can consist of a series of wash, drain and transfer stations, drying ovens, storm cabinets and UV inspection booths. Walk-in and carousel designs are options for the inspection of large components which can include integrated crane systems and process monitoring

Full-automatic processes can also be designed with defect recognition computer software.

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Module 5
Inspection

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5 Inspection

The first purpose of the inspection stage is to locate the presence of indications. In many cases if an indication of a flaw such as a crack is present its nature will be quite obvious. If an indication is present, the nature of which is not obvious, a decision must be made as to whether it is false, non-relevant or is indicative of the presence of a flaw.

The final inspection should not be carried out until after the developer dwell time has elapsed. This does not mean that inspection should not take place during the dwell time. Watching indications develop can provide valuable assistance in interpreting their nature. For instance, penetrant present in a scratch will develop immediately into a static indication while an indication of a tight crack will develop more slowly but continue to grow in width and brightness as the indication is fed from the sub-surface reservoir. If the penetrant removal process has been performed properly and examination under black light following that stage showed no residual fluorescence on the surface, then no false indication should be obtained. If indications due to poor processing are present and are such that they may obscure flaw indications, the part should be cleaned and subjected to complete reprocessing.

It is also at the initial stage of inspection that an assessment is generally made as to whether the processing has been carried out correctly. If there is no background penetrant this usually indicates that the removal stage has been carried out correctly, however this could also indicate over washing has occurred. Some discussion regarding this subject has led to a small amount of background remaining on the part being acceptable as long as it does not interfere with the sensitivity of the inspection.

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5.2 Interpretation and Evaluation

The terms "interpretation" and "evaluation" are often confused by testing personnel. Actually, the terms refer to two entirely different steps in the testing process. To interpret an indication means to decide what condition caused it. Evaluation is the process of determining what effect the discontinuity will have on the serviceability of the part.

Interpretation

Experienced NDT inspectors will have knowledge of the part they are inspecting with respect to critical areas and previous history. With this knowledge interpretation can be performed relatively quickly, eg corrosion in and around the bore of an undercarriage lug.

They size, shape, brightness, and location of the indication will give most of the information needed for interpretation. However, when using a fluorescent penetrant a visual white light inspection, either unaided or using a magnifier, is always required.

The technique of carefully removing the indication using a solvent damped cloth and applying a non aqueous developer is an acceptable method for interpretation. If the indication re appears then there is some cavity within the part that is retaining the penetrant and must be further investigated. This is allowed to be carried out up to two times depending on the procedure used.

5.3 Wipe-Off technique

This procedure is used to assist in assessment of the nature of a discontinuity causing an indication. This consists of removal of the indication followed by a further development process. It shall not be used to remedy general inspection process irregularities such as inadequate removal.
Unless otherwise agreed by the customer or the procedure, repeating the procedure is not permitted.

Caution:
The incorrect use of the wipe off technique can lead to removal of penetrant from a discontinuity which may lead to not finding/reporting this discontinuity.

A. **The wipe-off evaluation technique must not be used to help clean a part that has too much background fluorescence**. Parts must be cleaned and processed again if background is excessive or any processing requirement has not been met.

B. The wipe-off evaluation technique does not need to be used on:
   (1) Non-relevant indications e.g. part / assembly interfaces.
   (2) Discontinuities that clearly cause the part to be rejected.

C. Indications should be wiped with a soft brush, tissue or cotton tipped applicator made moist with solvent.

D When the bleed out from the suspect discontinuity is seen immediately after it is wiped, stop the process and evaluate the discontinuity to applicable approved data.

E. When the bleed out from the suspect discontinuity is not seen immediately after it is wiped, apply developer to the area.

F. If the indication does not appear after the development time, visually inspect with white light and magnification to confirm area is defect free.
   All evaluations must be completed in less than 1 hour from when the developer was applied.

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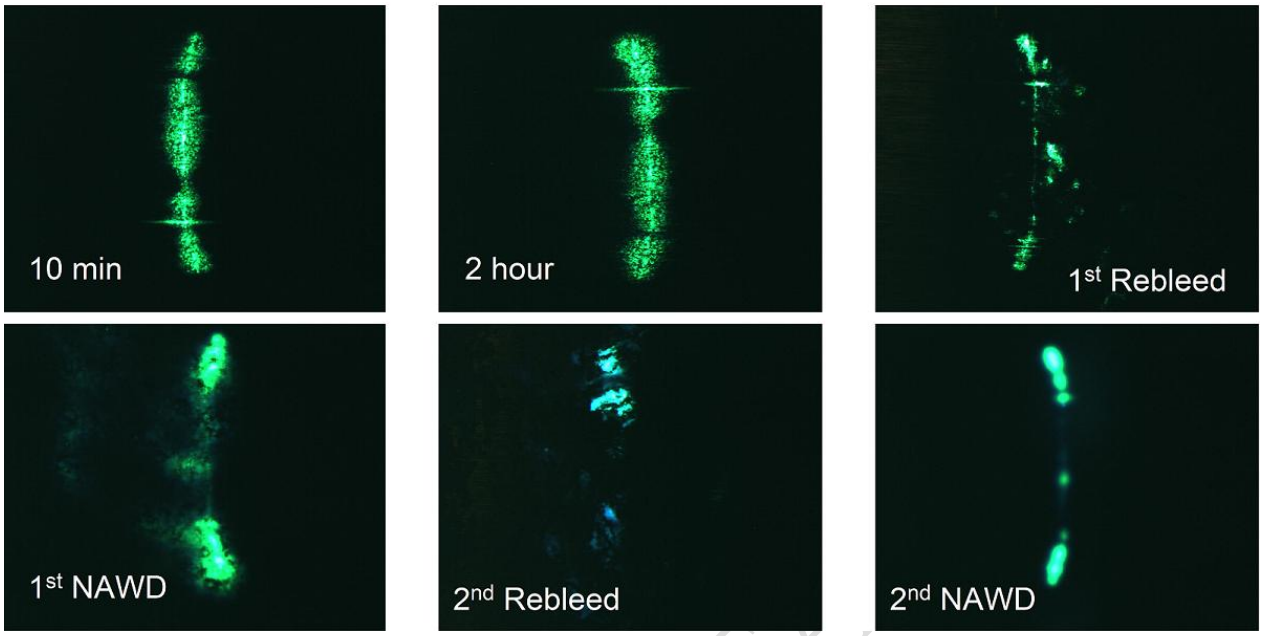
CASR study - Re bleed (wipe) results using NAWD
(FAA Centre for Aviation Systems reliability)



The cracked sample containing a 0.100" long crack was processed using level 4 penetrant

Results above show indication brightness at 10 min and 2 hours. The indication was then "wiped" (1st rebleed) and then developed using NAWD (1st NAWD). This was performed a second time with results shown a marked decrease in brightness

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5.4 Evaluation

If a discontinuity exists, its effect on the usefulness of the article requires evaluation, i.e., the article is either accepted as is, reworked, or scrapped. Most of the accept reject criteria will be contained in the procedure, technique or drawing. However it is not generally the job of the NDT engineer to make judgements on the serviceability of the part without this information.

The success and reliability of the interpretation and evaluation of liquid penetrant test indications depend upon the thoroughness of the process. The liquid penetrant test is not a method by which a specimen is processed through a machine which separates good parts from the bad. Testing personnel are required to carefully process each specimen, interpret indications, evaluate the seriousness of discontinuities, and determine disposition of the specimen.

5.5 Indications

Since penetrant cannot indicate any but surface discontinuities, an indication is caused by a discontinuity in the surface, or by penetrant being placed on the surface from some external source.

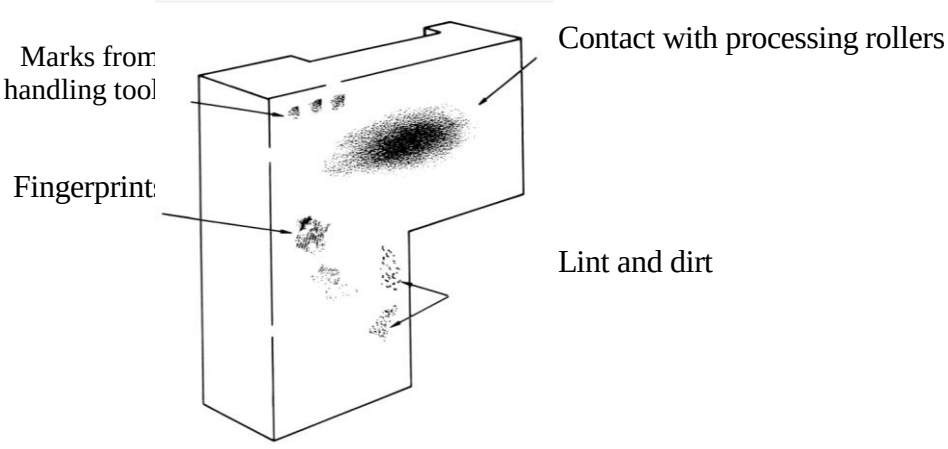
Several words are used to describe these indications depending how they were produced

False Indications

False indications are regarded as those that are produced by penetrant that has been placed onto the surface of the part and has not originated from any cavity or physical feature of the part.
These may include;

- Penetrant from the hands or gloves of operator
- Contamination of wet or dry developer
- Penetrant rubbing off of an indication on one specimen to clean portion of the surface of another specimen.
- Penetrant spots on the inspection table.

To avoid contamination, its causes are eliminated or guarded against. Process tanks and inspection areas are kept clean; only lint-free wiping cloths or rags are used; and specimens are kept free of fingerprints and tool marks.



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True Indications

True indications are those caused by a discontinuity. The interpretation of an indication as true is a matter of observing the indication and eliminating the possibility of it being false. Any true indication immediately becomes subject to determining its cause (type of discontinuity) and the effect it has on the service life of the part.

Non-Relevant Indications

Non Relevant indications are "true" indications in the sense that they are caused by surface openings or discontinuities, but these are there by design and are in no way a true discontinuity. Most of these non-relevant indications are easy to recognise since they are related directly to some feature of the assembly that accounts for their presence. Non-relevant indications include; keyways, splines, rivets, inserts, faying surfaces and a many of other features. Such non-relevant indications must be carefully noted since they may interfere with correct interpretation.

Relevant Indications

These are indications from unintentional discontinuities or imperfections and must be evaluated against the specification or standard

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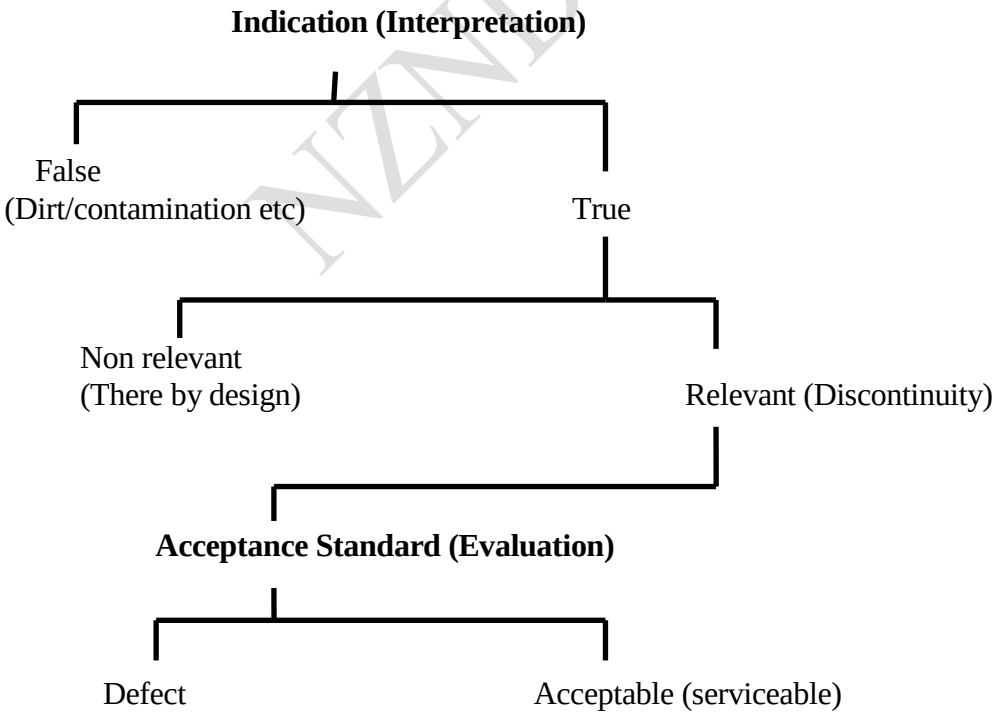

5.6 Categories of relevant indications

General

Discontinuity indications vary widely in appearance but for each indication **two** interpretive questions must be answered. (1) What type of discontinuity caused the indication? And (2) What is the extent of the discontinuity? In addition, each indication also requires an answer to the **evaluation** question. What effect will the discontinuity have on the service life of the specimen? The answers to the interpretive questions are obtained by observing the indication and identifying the discontinuity from the characteristic appearance of the indication. True indications logically fall into several identifiable categories; continuous line, intermittent line, circular, and diffused or weak.

Continuous Line

Continuous line indications (Linear) are generally caused by cracks, cold shuts, forging laps, or scratches. Cracks usually appear as jagged lines; cold shuts as smooth, narrow, straight lines; and forging laps as smooth, wavy lines. Scratches appear in a variety of linear patterns but are readily recognisable when all penetrant traces are removed, since the bottom of the discontinuity is usually visible. **Linear indications may under certain circumstances be intermittent (dotted).** This can be caused by a number of reasons including part of the defect being obscured or filled with contamination. In addition very fine defects such as stress corrosion cracks can be very hard to detect and only produce an intermittent indication

Intermittent (dotted) Lines

The same discontinuities that cause continuous line indications may, under different circumstances, cause intermittent line indications.
When an article is worked by grinding, peening, forging, machining, etc, portions of the discontinuities in the surface of the article may be closed by the metal working process. When this occurs, the discontinuities will appear as intermittent lines. (eg Laps)

Round

Round indications usually are caused by porosity. The porosity may be the result of gas holes, pin holes, or the generally make up of the specimen. Large defects may also appear as round indications since they trap a large amount of penetrant that spreads when the developer is applied.

Small Dots

Small dot indications result from discontinuities caused by pin holes, by the porous nature of the article, or by excessively coarse grains being used in producing a casting. They may also be the result of cast alloy micro-shrinkage.

Diffused or Weak

Diffused or weak indications are particularly difficult to interpret. Weak indications appear the article is to be thoroughly cleaned and retested. Other weak or diffused indications may be caused by surface porosity but more often are the result of insufficient cleaning, incomplete penetrant removal, or excessive developer

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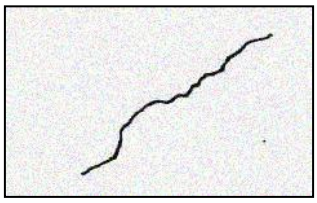
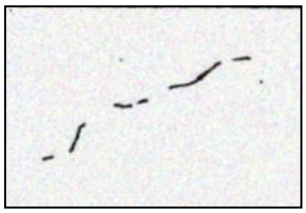


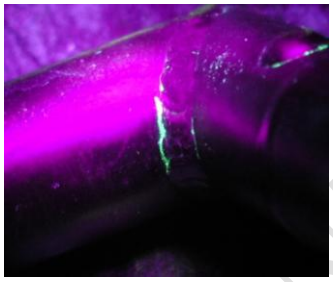
Continuous Line

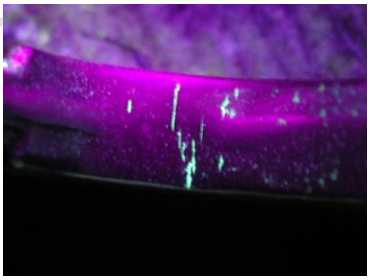


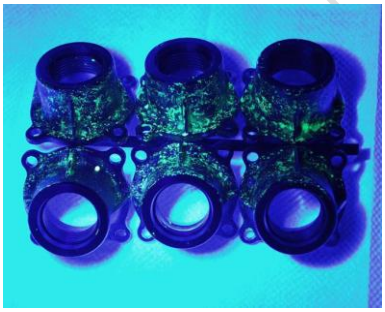
Intermittent Line

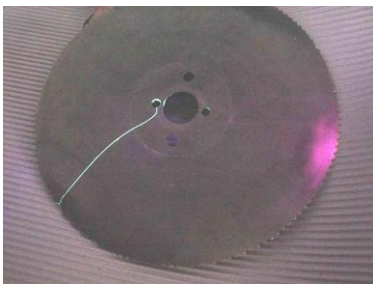
Continuous Line with additional faint indications

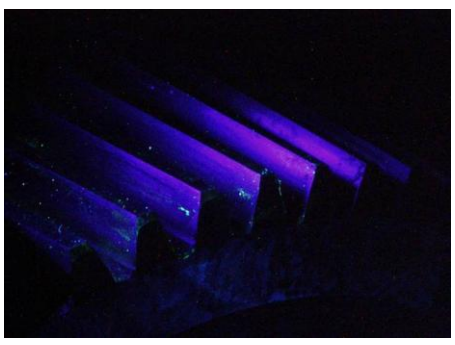
Gross Linear (Continuous) indications











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5.7 Recording indications

When required by the written procedure, the location of all rejectable indications shall be marked on the part, and permanent records of the location, direction, and frequency of indications may be made (including datum) by either: a **Written Description** (location, length, direction, and number of indications in sketch or tabular form) or **Film and Photography**

5.8 Test Record and Report

Test reports need to give the client all of the relevant information required and every effort should be made to ensure that the report is unambiguous. The records pertaining to that test need to support all the information in the report.
All reporting requirements of the test/inspection specification must be included in the report.

When recording and reporting a discontinuity, a standard code of terminology may be used. This code should be normal industry accepted practice and be based on a published standard or code. The code of terminology needs to be quoted in the test report. Reports need to avoid the implication that no imperfections exist merely because none have been found.

Reports must specify any limitations or deviations from the procedure that could affect the test results.

RECORD OF TEST

(a) Name of laboratory or testing authority.
(b) Identification of the component(s) and statement of the number tested.
(c) Product specification
(d) Material specification or type.
(e) Details of the areas of the component(s) that were tested.
(f) Surface condition of the test areas **and the surface cleaning procedure**.
(g) Number of the applicable inspection Standard, i.e. AS 2062, identification of the test procedure used and details of any departures from that procedure.
(h) Identification of each of the test materials used (the name of the manufacturer, the manufacturer's identification of the test materials, and the batch numbers).
(i) The test temperature if outside the range 15°C to 40°C.
(j) Test results.
(k) Any other relevant information required by the purchaser for the assessment of test results.
(l) Date and place of test.
(m) Report number or other means of identifying the report.
(n) Identification and signatures of **testing personnel**.

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TEST REPORT

The test report shall contain at least the following information:

(a) Name of laboratory or testing authority.
(b) Report number and date of issue.
(c) Identification of the component.
(d) Product specification.
(e) Material specification or type.
(f) Areas of the component(s) tested.
(g) Surface condition of the test areas.
(h) Number of the applicable Standard, i.e. AS 2062, identification of the specific test procedure, and details of any departures from that procedure.
(i) Test results.
(j) Any other relevant information required by the purchaser for the assessment of test results.
(k) Date and place of test.
(l) Identification and signature of the person responsible for the test report

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Module 6
Technique Considerations

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6.1 Information prior to testing

Initial determination of the PT procedure or written Instruction to be used will be based on the customer requirements. This would normally be in the form of a drawing specification (eg. AS 2062 or ASTM E 1417)

These specifications need to be interpreted so that the specific inspection procedure adopted is appropriate. This is the job of the Level 2 or 3 personnel.
In order for the right inspection procedure (technique) to be determined, certain information is necessary. The following is a list of the minimum information required.

- **Test Specification**
- **Manufacturing stage -** Cast, Forged, Rolled, In-Service etc.
- **Product form -** Plate, Bar, Pipe, Weld etc
- **Surface condition -** As Cast, Welded, Ground, Machined, Painted, Plated etc
- **Expected discontinuity (Type and position) -** Cracking, Weld defects, Seams,
- **Accessibility and s areas to be covered**
- **Environmental issues**
- **Accept and Reject Criteria and Reporting**

Based on this the correct penetrant technique can be chosen so that the intended quality level of the inspection can be achieved

Depending on the size and shape of the item to be tested, the penetrant technique (portable or tank line) can be addressed.
The surface condition and possible contamination can be identified and the appropriate pre cleaning can be chosen

Sensitivity shall be chosen such that all required defects are detected. . Fluorescent techniques are more sensitive than visible, but require the use of a Black (UV) light and a darkened area. PE is considered more sensitive than WW, however surface condition and expected discontinuities need to be considered

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6.2 Human Factors

As with any inspection involving concentration over an extended time, there needs to be a systematic and planned approach. This involves self-discipline and an awareness of what to look for and which areas require additional focus. Human Factors play an important role in this scenario and should be acknowledged.

Planned breaks, recognizing potential distractions and maintaining concentration levels are essential for the inspector. Having a formal documented approach will help with this and also maintain the quality of the inspection

6.3 Post Cleaning

Most materials can be damaged by residues of penetrant or developer remaining on the surface. Wet developers and most emulsifiers are **alkaline, and if left on surfaces (like aluminium) which are attacked by alkalis, the surfaces may corrode (Pitting). As mentioned previously small amounts of chlorine and sulphur can also cause severe corrosion on some nickel, titanium and high strength steels**

If parts are to be cleaned after inspection, it should be done without delay, since fresh penetrant and developer are easier to remove at this stage.

Developer requires a separate step for removal. The best way to ensure complete removal is a detergent wash in water. Dry developer can be sufficiently removed with air. Wet developer will easily be removed with water, however NAWD will require an application of solvent and wipe or spray

6.4 Water based penetrants

On April 8, 2019 AMS 2644G1 was published, replacing the 2013 revision F.

One significant change in Revision G is the inclusion of a new class of penetrants, Method A (W). Method A (W) was created to distinguish between Method A penetrants that are water-based, and those that are oil or surfactant based. This change was made to address the increased interest in the market for products that are water-based. Water based penetrants are defined as products that contain 20% or more water.

Made without petroleum solvents or oil, their base ingredient is water; non-polluting, inexpensive, and renewable. Free of petroleum distillates, they biodegrade readily and are more likely to be accepted by sewage treatment facilities.

Water based penetrants have excellent "self-developing" properties which, when conditions permit, eliminate or reduce the need to use a developer.

6.5 Filtered Particle Inspection

Penetrant Testing of porous material sis very limited due to the background “noise” produced by these parts. Standard penetrants techniques can be used but the sensitivity is greatly reduced.
One technique that can be used under these conditions is the Filtered Particle Inspection.

The Filtered Particle technique uses a penetrating liquid (usually clear and non fluorescent) containing fluorescent particles. This liquid is applied to the surface of the part being inspected and then left to dwell for an appropriate time. As the fluid makes its way into any large discontinuities, the particles get caught at the opening and build up over time. This then forms an indication similar to the MT process

This technique is suited for locating cracks open to the surface in porous materials, such as unfired clayware, concrete, and certain fired ceramics.

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Module 7
Equipment Control and EHS

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7 Equipment Control

7.1 Control of Penetrants

Contamination seriously affects the action of most penetrants and great care should be taken to keep this to a minimum. The most common contamination of the water washable penetrants is water and a small amount can reduce the penetrating quality and also adversely affect the wash ability.

Tests for water contamination (Method A WW penetrants only) should be carried out at regular intervals (monthly). The actual interval being determined by the usage of the tank and the water tolerance of the penetrant. Since materials from different manufacturers consist of various chemical combinations, tests and recommended operating limits should be obtained from the manufacturer. Some penetrants can tolerate up to 20 percent water but generally 5% is quoted as the maximum allowed.

Changes in fluorescent brilliance can be caused by contamination or exposure to UV/heat. This can be monitored by placing a drop of used penetrant on a laboratory filter paper alongside a drop of new penetrant and viewing the two under a black light. Any noticeable change in brightness represents a substantial and significant deterioration. Similarly, large changes in wetting ability and drying characteristics can be observed visually.

The liquid level should also be monitored for immersion tanks due to "drag out losses". Tanks shall be replenished with the same material and manufacturer but maybe from a different batch number.
(ISO 3452-1)

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7.2 Control of Emulsifiers

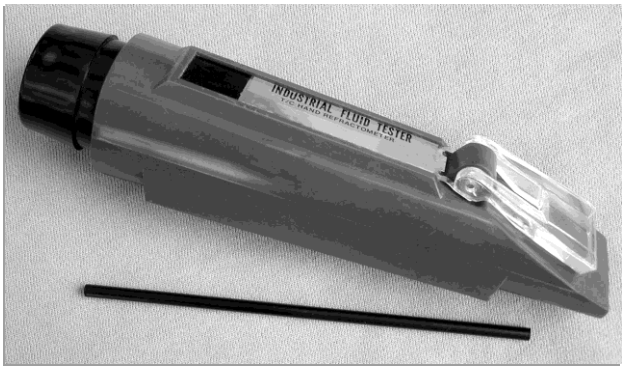
Emulsifiers can suffer from a reduction in activity due to: contamination (usually with penetrant), and a change in concentration (evaporation and water contamination),

If an adequate penetrant draining period is allowed after application of the penetrant, dilution of the emulsifier by the penetrant is reduced. Normal replenishment of the emulsifier can avoid excessive contamination. Loss of effectiveness is usually accompanied by a change in appearance.

Several tests can be performed by the operator to keep a continual check on the emulsifier bath.
Visually inspecting the emulsifier for contamination with penetrant can be performed by the operator at each use. Also comparison with known mixtures of new emulsifier and penetrant can assist with the determination of serviceability. Contamination of 10 percent is probably the safe maximum permissible for critical inspections, though the emulsifier will still function with much higher degrees of penetrant contamination.

Activity and performance can be monitored by the operator using the TAM panel (or equivalent) shot peen surface. This should show a relatively clear background after the post rinse. Any changes in removal characteristics should be further evaluated.

Hydrophilic Removers can be checked for concentration using a **refractometer**



7.3 Developer

Developers
The reused dry developers are subject to contamination by penetrant and moisture. Both can be detected by obtaining a sample of the powder and viewing it under a black light. Penetrant contamination will show as bright yellow/green fluorescence and moisture will cause the powder to become grey in appearance and clump together.

Wet (water) developers can become contaminated by penetrant or change their concentration.
The daily system process checks using Known Defect Standards (KDS) will detect and significant changes in performance

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7.4 Specific Gravity – Penetrant and Wet Developers

Hydrometers are required for specific gravity measurements of both the PE Penetrants and the Wet Developers. PE penetrants need a specific gravity of less than 1 to ensure water contamination sits at the bottom of the tank.
Wet developers require a specific gravity check to ensure the concentration meets the manufacturer's specification

7.5 Timers and Gages

Pressure and Temp Gages
All temperature and pressure gauges should be checked for correct readings and serviceability and calibration. Correct readings and serviceability shall be performed prior to use and during processing

Calibration shall be performed at least 6 monthly

Timers used for controlling the process times currently do not need to be calibrated. However checks need to be carried out regularly to ensure they are accurate

7.6 Portable Inspection kits

Portable kits used for PT inspection must be maintained in a serviceable condition.

Most PT procedures and/or specifications require specific penetrant material checks to be carried out. However if these materials are not reused, as is the case with aerosol cans, the periodic checks are not required and it is left to the manufacturer to determine the period of serviceability (Shelf life).

The shelf life specified will normally be associated with either bulk containers or aerosols. Bulk containers are usually given 5 years (unopened) and aerosols are limited to 2 years due to the deterioration of the propellant

Typical checks requirement for portable kits will contain the following

1 Check contamination of penetrant – Applicable to penetrant in secondary containers (Not aerosols).
2 Check contamination and shelf life of etch if applicable.
3 Check shelf life of aerosols (Penetrant, Cleaner/Remover and Developer)
4 Clean black light filter (if applicable) and UV intensity.
5 Compare kit against inventory. (brushes, tissues, black cape etc)

7.7 Reference Blocks

There are several reference blocks used to evaluate the penetrant and the penetrant process. Typically divided into two categories

Type 1 reference blocks are used to determine the **sensitivity levels** of both fluorescent and colour contrast penetrant product families

Type 2 reference blocks are used for routine assessment of the performance of both fluorescent and colour contrast penetrant testing (**System Performance**)

The Type 1 reference block consists of a set of four nickel-chrome plated panels with 10 µm, 20 µm, 30 µm and 50 µm thickness of plating, respectively. Each area of plating contains transverse cracks through the total thickness of the plating

The 10 µm, 20 µm, 30 µm and 50 µm panels can be used for determination of the sensitivity of fluorescent penetrant systems. The sensitivity of colour contrast penetrant systems is determined using the 30 µm and 50 µm panels.

The Type 2 reference block consists of a single panel of which one half has been plated with nickel and a thin layer of chromium and the other half prepared to achieve areas of specific roughness.
The plated side exhibits five star-shaped discontinuities. **This reference block is used to evaluate the performance of a penetrant line and not to determine the sensitivity.**

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7.8 System Performance Test (Type 2 reference block)

One of the more common checks carried out on the penetrant system is to use "Known Defect Standards" or KDS panels. These panels contain artificial or natural defects of a size small enough to pick up changes in the process.
Generally these panels are processed on a regular basis and the results are compared to those obtained using new materials. Any change in results would require all the materials to be checked.

This test is not designed to show the capabilities of the process including the smallest detectable defect, but merely to detect any changes in overall performance.

One of the common KDS panels is the TAM panel (P&W approved)
This is a fast and reliable means of monitoring the proper functioning of a liquid penetrant inspection system. Water washable, post emulsifiable or post removable, both fluorescent and visible.

The panel's purpose is to ascertain that all parts of penetrant processing system are functioning in the proper manner. Any pronounced shift in the penetrant system's operating parameters will be identified by changes in the panel's indications. This is done by comparison to a picture or counting the number of indications.

Several TAM certified panels are available (Sherwin PSM-5, Hoffmann PT-Guard and Magnaflux Z5).

DESCRIPTION

The TAM test panel is constructed of 0.075 inch thick stainless steel, 4 inches by 6 inches. A strip of heavy chrome plating is deposited on one side of the panel; the remaining front surface is sandblasted to a uniformly toughened surface finish with//100 grit abrasive.
The chrome plated area contains five evenly spaced star crack patterns which are progressively smaller in size.

The test panel can demonstrate sudden shifts in the following penetrant processing parameters:

1. Contamination of Penetrant, Emulsifier and Developer.
2. Changes in hydrophilic emulsifier concentration.
3. Improper concentration of aqueous or solvent developers.
4 Improper dwell times.
5. Improper wash pressure, temperature and duration.
6. Improper drying oven time and temperature.
7. Improper functioning inspection light source.
8. Improper handling

Cleaning of panels essential as this can lead to confusing results

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TAM Panel

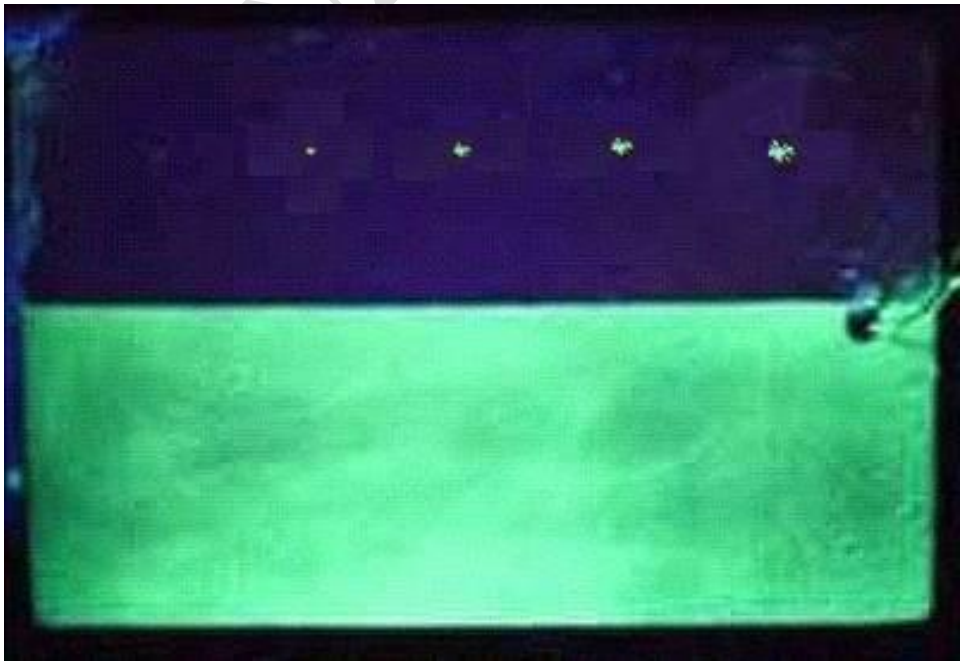
WHAT IT DOES
The "Penetrant System Monitor', provides a quick means of determining the continued serviceability of a liquid penetrant inspection SYSTEM.
It verifies that all elements of the system-penetrant, emulsifier, wash, dryer and developer are functioning properly. This "instrument" brings to attention any drastic change or major shift in the system's operating parameters.

PROCESSING A TAM PANEL AT SCHEDULED INTERVALS ALERTS THE OPERATOR TO A SYSTEM FAILURE AND ESTABLISHES A TIME SLOT IF PARTS MUST BE REINSPECTED.

WHAT IT DOES NOT DO
The TAM panel does not replace periodic examination of materials e.g. pen brightness, emulsifier concentration, developer contamination and inspection of pressure and temperature gauges. A gradual change in performance, in all probability, will not be noted by use of the TAM panel.

IT IS NOT A SENSITIVITY COMPARISON TOOL! It does not determine the min size defect that can be found by the process.

HOW IT IS USED
THE EFFECTIVENESS OF THE TAM PANEL IS DIRECTLY DEPENDENT ON THE SKILL OF THE TECHNICIAN. He must be able to discern a "difference" in the panel appearance from one test to another, such as an increase in background fluorescence or a marked decrease in flaw indication brightness



ASTM E 1417 Process Checks

Penetrant Contamination Daily	**7.8.2.1**
Penetrant Brightness Quarterly	**7.8.2.2**
Water Content—	
Water-Based Penetrant (Method A) Weekly	7.8.2.3
Water Content—	
Non-Water-Based Penetrant (Method A) Monthly	**7.8.2.4**
Lipophilic Emulsifier Water Content Monthly	7.8.2.5
Hydrophilic Emulsifier Immersion,	
Spray, or Flowing Concentration Weekly	**7.8.2.6**
Dry Developer Condition Daily	**7.8.2.7**
Aqueous Developer Contamination—	
Soluble and Suspendable Daily	7.8.2.8
Aqueous Developer Concentration—	
Soluble and Suspendable Weekly	7.8.2.9
Penetrant System Performance Daily	**7.8.3**
Water-Washable Penetrant Removability As required	7.8.3
Emulsifier Removability As required	7.8.3
Comparative Penetrant Sensitivity As required	7.8.3
Black Light Intensity Daily	**7.8.4.1**
Black Light Integrity Weekly	7.8.4.1
Special UV lighting Daily	7.8.4.2
Battery Powered UV-A lights Prior to and after use	**6.7.4.1,**
Visible Light Intensity Weekly	7.8.4.3
Light Meter Calibration Semi-annually	7.8.4.4
Examination Area Cleanliness Daily	**7.8.4.5**
Examination Area Ambient Light Intensity Quarterly	**7.8.4.5**
Water Wash Pressure Check Start of each shift	**7.8.4.6**
Water Pressure Gage Calibration Semi-annually	7.8.4.6
Water Wash Temperature Check Start of each shift	7.8.4.6
Water Temperature Gage Calibration Semi-annually	7.8.4.6
Drying Oven Calibration Quarterly	7.8.4.7
Air Pressure Gauge Check Start of each shift	**7.8.4.9**
Air Pressure Gauge Calibration Semi-annually	7.8.4.9

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7.9 Health and Safety

As penetrant inspection techniques often require the use of harmful, flammable and/or volatile materials, certain precautions shall be taken.

Prolonged or repeated contact of these materials with the skin should be avoided. Working areas shall be adequately ventilated and sited away from sources of heat, sparks or naked flames in accordance with local regulations.

The penetrant testing products and equipment shall be used with care and always in compliance with the instructions supplied by the manufacturer.

When proper health and safety precautions are followed, liquid penetrant inspection operations can be completed without harm to inspection personnel. However, there are a number of health and safety related issues that must be addressed.

Chemical Safety

Whenever chemicals are handled, certain precautions must be taken as directed by the material safety data sheets (MSDS) . Some cleaning solvents are flammable and, therefore, should be used and stored in small quantities. They should only be used in a well-ventilated area and ignition sources avoided. Eye protection should always be worn to prevent contact of the chemicals with the eyes. Many of the chemicals used contain detergents and solvents that can cause dermatitis. Gloves and other protective clothing should be warn to limit contact with the chemicals..
Used penetrant materials and effluent disposal shall be in accordance with the local relevant authorities requirements

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Ultraviolet Light Safety

Ultraviolet (UV) light or "black light" as it is sometimes called, has wavelengths ranging from 180-400 nanometres. Excessive short wavelength UV light exposure can cause painful sunburn, accelerate wrinkling and increase the risk of skin cancer. UV light can cause eye inflammation, cataracts and retinal damage.

Skin and eye damage occurs at wavelengths around 320 nm and shorter which is well below the 365 nm wavelength used in the penetrant process. Therefore, UV lamps sold for use in LPI application are always filtered to remover the harmful UV wavelengths. The lamps produce radiation at the harmful wavelengths so it is essential that they be used with the proper filter in place and in good condition. Provided that only black light in the desired range is transmitted, there is no danger of harming the eye of the operator. However, looking directly into the lamp is not recommended. The reason for this is that the fluid in the eye contains a substance which will fluoresce under black light causing a blurring of the vision. This effect, although unpleasant, is quite harmless, however sufficient time for vision to return to normal should be allowed before continuing with the inspection.

7.10 Penetrant disposal and treatment

Penetrant wastewater includes the presence of a dyes, oils and solvents. Wastewater cannot be simply flushed down the drain. Intensive wastewater treatment technologies such as chemical treatment or filtration are available but it comes at a price. The other option is to have it removed by a waste contractor and disposed of accordingly.

Several options are available for treatment to remove the solid products along with the addition of using ozone to remove the dye colour and odour.

Ultrafiltration uses a very fine filter membrane through which the waste water is pressure feed. Suspended solids and solutes of high molecular weight are removed, while water and low molecular weight solutes pass through the membrane.

Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture.

Activated carbon filtration is another processes commonly used in water treatment to remove contaminants such as organic materials, and since it also can remove odour-causing contaminants, it's often used in the penetrant process.
Activated carbon has finer porosity than normal carbon and also a positively charged activated carbon performs much better in attracting negatively charged chemicals like Chlorine.

Granular activated carbon can be reactivated through thermal oxidation, which allows it to be used multiple times. Granulated activated carbon filtration can be used on its own or paired with other treatments such as ozone and Ultrafiltration.

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Module 8
Manufacturing MF20A

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Module 9 **Written Instruction and Examination Preparation**
Content
Production of written Instruction (Level 2)
Theory, Specific and Practical exams - CBIP
ISO9712
AS 2062, ISO3452-1-2-3
ASTM E 1417

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ISO 9712 / BINDT Practical exam Written Instruction

ISO 9712 Marking schedule

Part 4 — NDT instruction writing (Level 2 candidates):[b]		
a) foreword (scope, reference documents);	—	1
b) personnel;	—	1
c) apparatus to be used, including settings;	—	3
d) product (description or drawing, including area of interest and purpose of the test);	—	2
e) test conditions, including preparation for testing;	—	2
f) detailed instructions for application of the test;	—	3
g) recording and classifying the results of test;	—	2
h) reporting the results.	—	1
Total	—	15

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1 Forward, Scope and Purpose

This section identifies the reason for the written instruction and sets the rules regarding what part, or parts, it is applicable to and when it shall be used.

Any other relevant information that has a direct affect on the quality of the inspection should be included here. Such information could include:

- Previous defect history.
- Critical or highly stressed areas.
- Manufacturing processes used.
- In service operating conditions.

1A Reference documents

The purpose of the reference document in the **Level 1 Written Instruction** is to allow the inspection to be controlled by an internationally recognised standard.
It is also used to control aspects of the inspection procedure not necessarily included within the written instruction.
The following reference standards are generally used for this purpose

- AS 2062 or ASTM E 1417.
- AS 1929 – Definitions
- ISO 9712 – NDT Qualification

Note – If reference is made to these documents then the instructions in the **Level 1 Written Instruction** should comply with the standard identified by the candidate.
Eg Ambient light conditions, water wash pressure etc.

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1B Status and Authorization

As a controlled document the **written instruction** should be traceable (Individual identification, revision/date) and reference to the owner and authorizer (Level 3).

1C Safety

Statement regarding that all equipment and chemicals are used in accordance with manufacturer's instructions and MSDS

2 Personnel

The minimum requirements for training (including job-specific training if necessary), certification and authorization of NDT operators

3 Apparatus and Settings

A list of the specific equipment to be used should be included. The level 1 should not be allowed to choose between any items such as MT bench units or penetrant materials etc

- PT materials
- UV/White lights
- Reference standards used for bath checks
- Support equipment (X10 magnifier, Black cape, Cotton buds etc)

This section should also make reference to any required Pre-Calibrations, Standardizations or Bath Checks. Examples are:

- UV (Black Light checks)
- Process sensitivity bath checks (TAM Panel)
- Bath concentration
- Spray can expiry dates

4 Product description

A description of the product to be tested including surface condition and manufacturing process if applicable.
Pictures and sketches should be used when available

5 Test conditions

Any specific conditions required for testing should be identified.
For Fluorescent PT the maximum ambient white light should be stated.
For visual PT the minimum inspection white light conditions should also be stated

Other considerations could be: Inspection area cleanliness, ambient temperature, safety equipment and personnel clothing.

5A Part preparation

Reference should be made to part cleanliness and any specific cleaning procedures used.
PT inspection requires the most stringent pre cleaning including drying.

Other considerations could be: paint and corrosion removal, etching, blasting scale removal etc.

6 Detailed instructions for performing test

This forms the basic instruction for physically inspecting the part. It also attracts the most examination points.

There are generally two areas that points are allocated for.

The first area is based around the knowledge of the candidate in selecting the most appropriate inspection technique.
An example of an **inappropriate** technique is using a PE penetrant to inspect a casting.

Critical (high stressed) parts and cast housings should be tested using an immersion tank penetrant line, while welded plates will normally use method C (solvent removable).

The second area for allocating points is associated with the actual content of the instructions with respect to the Level 1. Remembering that the Level 1 should not have to guess or decide on any aspect of the inspection.

Examples of items that should be included are:

- Application (penetrant and developer)
- Dwell times
- Temperature considerations
- Washing techniques
- Post cleaning

- A statement instructing the operator on actions to be taken in the event that the instruction cannot be applied

This is not an exhaustive list and will depend on the specific procedure chosen by the candidate.

There are a number of items in this section that can be referenced back to the "Reference Document" and need not be re stated here. Eg water wash temperature and pressure limits.

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7 Evaluation and Classifying results

Instructions on what indications are to be recorded, how to record them and datums used.
The written instruction should include the requirement for all indications to be evaluated by a Level 2 or 3

8 Test Record and Report

Confusion generally exists regarding the difference between a “record” of the test and a “test report”
The test record is used to document the test as it was carried out. This is used to demonstrate conformance to the customer requirements and also so that the inspection can be reproduced at a later date if required.

A test record includes most of the items required for a test report and in addition requires the documentation of the specific equipment/materials used including settings and batch numbers if applicable

The written instruction should include the need for a test record and report and identify the specific items required to be included. Along with the requirement to document all recordable indications including datum’s – Refer AS 2062

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Work Instruction - Question

One of your customers has asked for a Liquid Penetrant inspection to be carried out on a set of welded plates shown below. The plates are required to have an inspection of the weld and HAZ on both sides

The plates are part of a welding test qualification procedure and all defects are to be reported to the customer. A separate visual inspection will be performed by the customer

The customer has asked for a Liquid Penetrant Inspection to be carried out on the welds and HAZ at the customer's workshop using a portable colour contrast procedure in accordance with AS 2062.

The plates are made of 10mm thick Aluminium

As a level 2 technician, produce a written work instruction suitable for a level 1 to carry out this inspection.

The work instruction should contain the minimum information required by AS2062 and shall be clear enough so that the level 1 can perform the inspection without interpreting any codes or standards

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Advice for Candidates Sitting CBIP NDT Theory and Practical Examinations

Prior to the Examinations

Candidates will receive written notification confirming their registration and advising of the following;

1) The examination venue, date and time
2) A candidate number for each stage of the practical and theory exams. Be aware that the candidate number for the General, Specific and Practical exams are not the same.
3) The registration letter should advise what reference material you are allowed during your exam. If not, then this will be clarified by the invigilator. Normally reference material is limited to the published ISO/ Australia/New Zealand NDT specification relating to the technique
4) \Clarify with CBIP prior to the exam if you are allowed to use your company reporting documents for the practical exams

The Exam

1) Ensure that you write your candidate number on all exam papers and notes
2) Do not sign your name or identify yourself or your employer on any exam papers or reports
3) **All** notes should be handed in with your exam package. These may be used, on occasion, to award marks where the candidate has incorrectly transposed information to their exam paper.
4) Cell phones are not allowed in the examination venue.
5) Photographing of practical test pieces is not allowed.
6) Do not discuss practical test results with other candidates during the exam.
7) There will be an invigilator supervising your practical exam. The invigilator has a marking sheet and you may be asked questions relating to the technique you are being examined on. The marks allocated by the invigilator contribute to the final total mark.
8) If there are issues with the test pieces, equipment or the test venue, discuss with the invigilator.
9) Test reports/test record should contain all of the information specified in the relevant test specification.
10) Your report should contain a test summary stating how many defects have been found. The location and lengths of defects should also be shown on sketches.
11) Where appropriate, e.g. defects in welds, the preferred way to record defects is the start location followed by the defect length, e.g. Defect #1 at datum +55mm, length 24mm.
12) Defects should be identified, e.g. lack of fusion, transverse crack. Marks are deducted for incorrect defect identification.
13) There are fixed rules for the exam markers regarding allocating marks for defect position and length. There is a set allowance for variations in measurement but outside these there are marks deducted up to a maximum of -5 marks.
14) Reports with company letterheads are not allowed.
15) If there is a written work instruction component to your exam then this instruction should contain all the information required for a level 1 technician to carry out and report on the inspection of the specified item(s) without having to refer to any other documents or test specifications.

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What to Bring to the Exam.

1) Pen, pencil, ruler, measuring tape, torch/flashlight. (10x magnifier)
2) Prescription spectacles if required.
3) Your own test equipment.
4) PPE – overalls, safety footwear, gloves, safety glasses etc.

What to Expect at the Examination Venue

Penetrant Inspection

1) You will be given 3 test samples. Normally a welded sample, a forging and a casting.
2) Confirm each sample's identification number with the invigilator and record this on the exam paperwork that accompanies each test item.
3) You will be required to use both colour contrast and fluorescent test techniques. The choice of technique to be used and whether it is appropriate will be discussed with the invigilator prior to applying penetrant and marks will be allocated relating to the choice of technique. To avoid contamination there are specific test pieces for colour contrast and fluorescent techniques.
4) The exam venue will have penetrant consumables, a dedicated wash station and a darkened test area for fluorescent test techniques with a calibrated UV inspection lamp.

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