

Recommended Practice No.

SNT-TC-1A

2001



**The American Society for
Nondestructive Testing, Inc.**

This document is intended as a guideline for employers to establish their own written practice for the qualification and certification of nondestructive testing personnel. It is not intended to be used as a strict specification.

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Former editions of *SNT-TC-1A* used a variety of paragraph numbering schemes, and several of those were imported into later editions of the document, including the 1996 edition. The 2001 edition standardizes all paragraph numbering into a single format that is consistent throughout the document.

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FOREWORD

This Recommended Practice establishes the general framework for a qualification and certification program. In addition, the document provides recommended educational, experience and training requirements for the different test methods. Supplementary documents include question and answer lists, which may be used in composing examinations for nondestructive testing personnel.

This recommended practice is not intended to be used as a strict specification. It is recognized, however, that contracts require programs, which meet the intent of this document. For such contracts, purchaser and supplier must agree upon acceptability of an employer's program.

The verb "should" has been used throughout this document to emphasize the recommendation presented herein. It is the employer's responsibility to address specific needs and to modify these guidelines as appropriate in a written practice. In the employer's written practice, the verb "shall" is to be used in place of "should" to emphasize the employer's needs.

The 2001 Edition of *SNT-TC-1A* is annotated so that users of the 1996 Edition can quickly and easily locate new and updated material. The vertical lines in the margins of this document indicate that information in the text has been modified in some way.

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Recommended Practice No. SNT-TC-1A

Personnel Qualification and Certification in

Nondestructive Testing

1.0 Scope

- 1.1 It is recognized that the effectiveness of nondestructive testing (NDT) applications depends upon the capabilities of the personnel who are responsible for and perform, NDT. This Recommended Practice has been prepared to establish guidelines for the qualification and certification of NDT personnel whose specific jobs require appropriate knowledge of the technical principles underlying the nondestructive tests they perform, witness, monitor, or evaluate.
- 1.2 This document provides guidelines for the establishment of a qualification and certification program.
- 1.3 These guidelines have been developed by the American Society for Nondestructive Testing, Inc., to aid employers in recognizing the essential factors to be considered in qualifying personnel engaged in any of the NDT methods listed in Section 3.
- 1.4 It is recognized that these guidelines may not be appropriate for certain employers' circumstances and/or applications. In developing a written practice as required in Section 5, the employer should review the detailed recommendations presented herein and modify them, as necessary, to meet particular needs.

2.0 Definitions

- 2.1 Terms included in this document are defined as follows:
 - 2.1.1 Certification: written testimony of qualification.
 - 2.1.2 Certifying Authority: the person or persons properly designated in the written practice to sign certifications on behalf of the employer.
 - 2.1.3 Certifying Agency: the employer of the personnel being certified.
 - 2.1.4 Closed Book Examination: an examination administered without access to reference material except for materials supplied with or in the examination. (See 8.7.)
 - 2.1.5 Comparable: being at an equivalent or similar level of NDT responsibility and difficulty as determined by the employer's Level III.
 - 2.1.6 Documented: the condition of being in written form.
 - 2.1.7 Employer: the corporate, private, or public entity, which employs personnel for wages, salary, fees, or other considerations.
 - 2.1.8 Experience: work activities accomplished in a specific NDT method under the direction of qualified supervision including the performance of the NDT method and related activities but *not* including time spent in organized training programs.
 - 2.1.9 Nondestructive Testing: a process that involves the inspection, testing, or evaluation of materials, components and assemblies for materials' discontinuities, properties and machine problems without further impairing or destroying the parts serviceability. Throughout this document the term NDT applies equally to the NDT inspection methods used for material inspection, flaw detection or predictive maintenance (PdM) applications.
 - 2.1.10 Outside Agency: a company or individual who provides NDT Level III services and whose qualifications to provide these services have been reviewed and approved by the employer engaging the company or individual.
 - 2.1.11 Qualification: demonstrated skill and knowledge, along with documented training and experience required for personnel to properly perform the duties of a specific job.
 - 2.1.12 Recommended Practice: a set of guidelines to assist the employer in developing uniform procedures for the qualification and certification of NDT personnel to satisfy the employer's specific requirements.
 - 2.1.13 Training: an organized program developed to impart the knowledge and skills necessary for qualification.

- 2.1.14 Written Practice: a written procedure developed by the employer that details the requirements for qualification and certification of their employees.

3.0 Nondestructive Testing Methods

- 3.1 Qualification and certification of NDT personnel in accordance with this Recommended Practice is applicable to each of the following methods:

- Acoustic Emission Testing
- Electromagnetic Testing
- Laser Testing Methods
- Leak Testing
- Liquid Penetrant Testing
- Magnetic Particle Testing
- Neutron Radiographic Testing
- Radiographic Testing
- Thermal/Infrared Testing
- Ultrasonic Testing
- Vibration Analysis
- Visual Testing

4.0 Levels of Qualification

- 4.1 There are three basic levels of qualification. The employer may subdivide these levels for situations where additional levels are deemed necessary for specific skills and responsibilities.
- 4.2 While in the process of being initially trained, qualified and certified, an individual should be considered a trainee. A trainee should work with a certified individual. The trainee shall not independently conduct, interpret, evaluate, or report the results of any NDT test.
- 4.3 The three basic levels of qualification are as follow:
- 4.3.1 NDT Level I. An NDT Level I individual should be qualified to properly perform specific calibrations, specific NDT, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDT Level I should receive the necessary instruction or supervision from a certified NDT Level II or III individual.
 - 4.3.2 NDT Level II. An NDT Level II individual should be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards and specifications. The NDT Level II should be thoroughly familiar with the scope and limitations of the methods for which qualified and should exercise assigned responsibility for on-the-job training and guidance of trainees and NDT Level I personnel. The NDT Level II should be able to organize and report the results of NDT tests.
 - 4.3.3 NDT Level III. An NDT Level III individual should be capable of developing, qualifying, and approving procedures, establishing and approving techniques, interpreting codes, standards, specifications and procedures; and designating the particular NDT methods, techniques and procedures to be used. The NDT Level III should be responsible for the NDT operations for which qualified and assigned and should be capable of interpreting and evaluating results in terms of existing codes, standards and specifications. The NDT Level III should have sufficient practical background in applicable materials, fabrication and product technology to establish techniques and to assist in establishing acceptance criteria when none are otherwise available. The NDT Level III should have general familiarity with other appropriate NDT methods, as demonstrated by an ASNT Level III Basic examination or other means. The NDT Level III, in the methods in which certified, should be capable of training and examining NDT Level I and II personnel for certification in those methods.

5.0 Written Practice

- 5.1 The employer shall establish a written practice for the control and administration of NDT personnel training, examination and certification.
- 5.2 The employer's written practice should describe the responsibility of each level of certification for determining the acceptability of materials or components in accordance with the applicable codes, standards, specifications and procedures.
- 5.3 The employer's written practice shall describe the training, experience and examination requirements for each level of certification.
- 5.4 The employer's written practice shall be reviewed and approved by the employer's NDT Level III.
- 5.5 The employer's written practice shall be maintained on file.

6.0 Education, Training and Experience Requirements for Initial Qualification

- 6.1 Candidates for certification in NDT should have sufficient education, training and experience to ensure qualification in those NDT methods in which they are being considered for certification. Documentation of prior certification may be used by an employer as evidence of qualification for comparable levels of certification.
- 6.2 Documented training and/or experience gained in positions and activities comparable to those of Levels I, II and/or III prior to establishment of the employer's written practice may be considered in satisfying the criteria of Section 6.3.
- 6.3 To be considered for certification, a candidate should satisfy one of the following criteria for the applicable NDT level:
 - 6.3.1 NDT Levels I and II

Table 6.3.1A (page 10) lists the recommended training and experience factors to be considered by the employer in establishing written practices for initial qualification of Level I and Level II individuals.

Table 6.3.1B (page 11) lists alternate training and experience factors which may be considered by the employer in establishing written practices for initial qualification of Level I and Level II individuals.
 - 6.3.2 NDT Level III
 - 6.3.2.1 Have graduated from a minimum four-year college or university curriculum with a degree in engineering or science, plus one additional year of experience beyond the level II requirements in NDT in an assignment comparable to that of an NDT Level II in the applicable NDT method(s), or:
 - 6.3.2.2 Have completed with passing grades at least two years of engineering or science study at a university, college, or technical school, plus two additional years of experience beyond the level II requirements in NDT in an assignment at least comparable to that of NDT Level II in the applicable NDT method(s), or:
 - 6.3.3.3 Have four years of experience beyond the level II requirements in NDT in an assignment at least comparable to that of an NDT Level II in the applicable NDT method(s).

The above Level III requirements may be partially replaced by experience as a certified NDT Level II or by assignments at least comparable to NDT Level as defined in the employer's written practice.

7.0 Training Programs

- 7.1 Personnel being considered for initial certification should complete sufficient organized training to become thoroughly familiar with the principles and practices of the specified NDT method related to the level of certification desired and applicable to the processes to be used and the products to be tested.

- 7.2 The training program should include sufficient examinations to ensure understanding of the necessary information.
- 7.3 Recommended training course outlines and references for NDT Levels I, II and III which may be used as technical source material are contained in the Recommended Training Courses section of this Recommended Practice.
- 7.4 The employer who purchases outside training services is responsible for ensuring that such services meet the requirements of the employer's written practice.

8.0 Examinations

8.1 Administration and Grading

- 8.1.1 An NDT Level III shall be responsible for the administration and grading of examinations specified in Section 8.3 through 8.8 for NDT Level I, II, or other Level III personnel. The administration and grading of examinations may be delegated to a qualified representative of the NDT Level III and so recorded. A qualified representative of the employer may perform the actual administration and grading of Level III examinations specified in 8.8.
- 8.1.2 For Level I and II personnel, a composite grade should be determined by simple averaging of the results of the general, specific and practical examinations described below. For Level III personnel, the composite grade should be determined by simple averaging of the results of the basic, method and specific examinations described below.
- 8.1.3 Examinations administered for qualification should result in a passing composite grade of at least 80 percent, with no individual examination having a passing grade less than 70 percent.
- 8.1.4 When an examination is administered and graded for the employer by an outside agency and the outside agency issues grades of pass or fail only, on a certified report, then the employer may accept the pass grade as 80 percent for that particular examination.
- 8.1.5 The employer who purchases outside services is responsible for ensuring that the examination services meet the requirements of the employer's written practice.

8.2 Vision Examinations

- 8.2.1 Near-Vision Acuity: The examination should ensure natural or corrected near-distance acuity in at least one eye such that the applicant is capable of reading a minimum of Jaeger Number 2 or equivalent type and size letter at the distance designated on the chart but not less than 12 inches (30.5 cm) on a standard Jaeger test chart. The ability to perceive an Ortho-Rater minimum of 8 or similar test pattern is also acceptable. This should be administered annually.
- 8.2.2 Color Contrast Differentiation: The examination should demonstrate the capability of distinguishing and differentiating contrast among colors or shades of gray used in the method as determined by the employer. This should be conducted upon initial certification and at three-year intervals thereafter.

8.3 General (written for NDT Levels I and II)

- 8.3.1 The general examinations should address the basic principles of the applicable method.
- 8.3.2 In preparing the examinations, the NDT Level III should select or devise appropriate questions covering the applicable method to the degree required by the employer's written practice.
- 8.3.3 See the Appendix for example questions.
- 8.3.4 The minimum number of questions that should be given is as follows:

Test Method	Number of Level I Questions	Number of Level II Questions
Acoustic Emission Testing	40	40
Electromagnetic Testing	40	40
Laser Testing	30	30
Leak Testing	20	20
Liquid Penetrant Testing	40	40
Magnetic Particle Testing	40	40
Neutron Radiographic Testing	40	40
Radiographic Testing	40	40
Thermal/Infrared Testing	40	40
Ultrasonic Testing	40	40
Vibration Analysis	40	40
Visual Testing	40	40

8.4 Specific (written for NDT Levels I and II)

- 8.4.1 The specific examination should address the equipment, operating procedures and NDT techniques that the individual may encounter during specific assignments to the degree required by the employer's written practice.
- 8.4.2 The specific examination should also cover the specifications or codes and acceptance criteria used in the employer's NDT procedures.
- 8.4.3 The minimum number of questions that should be given is as follows:

Test Method	Number of Level I Questions	Number of Level II Questions
Acoustic Emission Testing	20	20
Electromagnetic Testing	20	20
Laser Testing:		
1. Profilometry	20	20
2. Holography/Shearography	20	20
Leak Testing:		
1. Bubble Test	15	15
2. Absolute Pressure Leak Test (Pressure Change)	15	15
3. Halogen Diode Leak Test	15	15
4. Mass Spectrometer Leak Test	20	40
Liquid Penetrant Testing	20	20
Magnetic Particle Testing	20	20
Neutron Radiographic Testing	15	15
Radiographic Testing	20	20
Thermal/Infrared Testing	20	20
Ultrasonic Testing	20	20
Vibration Analysis	20	60
Visual Testing	20	20

- 8.5 Practical (for NDT Level I and II)
- 8.5.1 The candidate should demonstrate familiarity with and ability to operate the necessary NDT equipment, record and analyze the resultant information to the degree required.
 - 8.5.2 At least one flawed specimen or component should be tested and the results of the NDT test analyzed by the candidate.
 - 8.5.3 The description of the specimen, the NDT procedure, including check points, and the results of the examination should be documented.
 - 8.5.4 NDT Level I Practical Examination. Proficiency should be demonstrated in performing the applicable NDT on one or more specimens or machine problems approved by the NDT Level III and in evaluating the results to the degree of responsibility as described in the employer's written practice. At least ten (10) different checkpoints requiring an understanding of test variables and the employer's procedural requirements should be included in this practical examination.
 - 8.5.5 NDT Level II Practical Examination. Proficiency should be demonstrated in selecting and performing the applicable NDT technique within the method and interpreting and evaluating the results on one or more specimens or machine problems approved by the NDT Level III. At least ten (10) different checkpoints requiring an understanding of NDT variables and the employer's procedural requirements should be included in this practical examination.
- 8.6 Sample questions for general examinations are presented in the separate question booklets that can be obtained from ASNT Headquarters. These questions are intended as examples only and should not be used verbatim for qualification examinations. The following is a list of the booklets:

Question Test Method	Booklets
Acoustic Emission Testing	G
Electromagnetic Test (Eddy Current and Flux Leakage)	E
Laser Testing	
1. Profilometry	LP*
2. Holography/Shearography	LH*
Leak Testing	
1. Bubble Test	HB
2. Pressure Change Measurement	HP
3. Halogen Diode Leak Test	HH
4. Mass Spectrometer Test	HM
Liquid Penetrant Testing	D
Magnetic Particle Testing	B
Neutron Radiographic Testing	F
Radiographic Testing	A
Thermal/Infrared Testing	J*
Ultrasonic Testing	C
Vibration Analysis	K*
Visual Testing	I

* In course of preparation

- 8.7 Additional Written, Specific and Practical Examination Criteria
- 8.7.1 Level I, II and III Written Examinations
 - 8.7.1.1 All Level I, II and III written examinations should be closed book except that necessary data, such as graphs, tables, specifications, procedures,

- codes, etc., may be provided with or in the examination. Questions utilizing such reference materials should require an understanding of the information rather than merely locating the appropriate answer. All questions used for Level I and Level II examinations should be approved by the responsible Level III.
- 8.7.1.2 A valid endorsement on an ACCP Level I or Level II certificate fulfills the corresponding examination criteria described in paragraphs 8.3 and 8.5 for each applicable NDT method.
 - 8.7.1.3 The employer may delete the specific examination (paragraph 8.4) if the candidate has a valid ACCP certificate, provided the examinations administered meet the technical needs of the employer.
 - 8.7.2 Level I and II Specific Examinations
The employer may delete the specific examination if the candidate has a valid ACCP Level I or Level II certificate in the method and if documented experience exists to permit such.
 - 8.7.3 Practical Examinations
Successful completion of ACCP Level I or Level II general hands-on practical examinations may be considered as fulfilling the requirements of paragraphs 8.3 and 8.5 respectively.
 - 8.8 NDT/PdM Level III Examinations
 - 8.8.1 Basic Examinations
 - 8.8.1.1 NDT Basic Examination (required only once when more than one method examination is taken). The minimum number of questions that should be given is as follows:
 - 8.8.1.1.1 Fifteen (15) questions relating to understanding the *SNT-TC-1A* document.
 - 8.8.1.1.2 Twenty (20) questions relating to applicable materials, fabrication and product technology.
 - 8.8.1.1.3 Twenty (20) questions that are similar to published Level II questions for other appropriate NDT methods.
 - 8.8.1.2 PdM Basic Examination (required only once when more than one method examination is taken). The minimum number of questions that should be given is as follows:
 - 8.8.1.2.1 Fifteen (15) questions relating to understanding the *SNT-TC-1A* document.
 - 8.8.1.2.2 Twenty (20) questions relating to applicable machinery technology.
 - 8.8.1.2.3 Thirty (30) questions that are similar to published Level II questions for other appropriate PdM methods.
 - 8.8.2 Method Examination (for each method)
 - 8.8.2.1 Thirty (30) questions relating to fundamentals and principles that are similar to published ASNT Level III questions for each method, and
 - 8.8.2.2 Fifteen (15) questions relating to application and establishment of techniques and procedures that are similar to the published ASNT Level III questions for each method, and
 - 8.8.2.3 Twenty (20) questions relating to capability for interpreting codes, standards and specifications relating to the method.
 - 8.8.3 Specific Examination (for each method)
 - 8.8.3.1 Twenty (20) questions relating to specifications, equipment, techniques and procedures applicable to the employer's product(s) and methods employed and to the administration of the employer's written practice.
 - 8.8.3.2 The employer may delete the specific examination if the candidate has a valid ASNT Level III certificate in the method and if documented evidence of experience exists, including the preparation of procedures to codes, standards, or specifications and the evaluation of test results.
 - 8.8.4 A valid endorsement on an ASNT Level III certificate fulfills the examination criteria described in 8.8.1 and 8.8.2 for each applicable method.

- 8.8.5 A valid endorsement of an ACCP Professional Level III certificate fulfills the examination criteria described in 8.8.1 and 8.8.2 for each applicable method.
- 8.9 Reexamination
Those failing to attain the required grades should wait at least thirty (30) days or receive suitable additional training as determined by the Level III before reexamination.

9.0 Certification

- 9.1 Certification of all levels of NDT personnel is the responsibility of the employer.
- 9.2 Certification of NDT personnel shall be based on demonstration of satisfactory qualification in accordance with Sections 6, 7 and 8, as described in the employer's written practice.
- 9.3 At the option of the employer, an outside agency may be engaged to provide NDT Level III services. In such instances, the responsibility of certification of the employees shall be retained by the employer.
- 9.4 Personnel certification records shall be maintained on file by the employer for the duration specified in the employers written practice and should include the following:
 - 9.4.1 Name of certified individual.
 - 9.4.2 Level of certification and NDT method.
 - 9.4.3 Educational background and experience of certified individuals.
 - 9.4.4 Statement indicating satisfactory completion of training in accordance with the employer's written practice.
 - 9.4.5 Results of the vision examinations prescribed in 8.2 for the current certification period.
 - 9.4.6 Current examination copy(ies) or evidence of successful completion of examinations.
 - 9.4.7 Other suitable evidence of satisfactory qualifications when such qualifications are used in lieu of the specific examination prescribed in 8.8.3.2 or as prescribed in the employer's written practice.
 - 9.4.8 Composite grade(s) or suitable evidence of grades.
 - 9.4.9 Signature of the Level III that verified qualifications of candidate for certification.
 - 9.4.10 Date of certification and/or recertification and the date of assignments to NDT.
 - 9.4.11 Certification expiration date.
 - 9.4.12 Signature of employer's certifying authority.

10.0 Technical Performance Evaluation

- 10.1 NDT personnel may be reexamined any time at the discretion of the employer and have their certificates extended or revoked.
- 10.2 Periodically, as defined in the employers written practice, the technical performance of Level I and II personnel should be evaluated and documented by an NDT Level III. The evaluation and documentation should follow the format and guidelines described in section 8.5.

11.0 Interrupted Service

- 11.1 The employer's written practice should include rules covering the types and duration of interrupted service.
- 11.2 The written practice should specify the requirements for reexamination and/or recertification for the interrupted service.

12.0 Recertification

- 12.1 All levels of NDT personnel shall be recertified periodically in accordance with one of the following criteria:
 - 12.1.1 Evidence of continuing satisfactory technical performance.
 - 12.1.2 Reexamination in those portions of the examinations in Section 8 deemed necessary by the employer's Level III.
- 12.2 Recommended maximum recertification intervals are:

- 12.2.1 Levels I and II – 3 years
- 12.2.2 Level III – 5 years

13.0 Termination

- 13.1 The employer's certification shall be deemed revoked when employment is terminated.
- 13.2 A Level I, Level II, or Level III whose certification has been terminated may be certified to the former NDT level by a new employer based on examination, as described in Section 8, provided all of the following conditions are met to the new employer's satisfaction:
 - 13.2.1 The employee has proof of prior certification.
 - 13.2.2 The employee was working in the capacity to which certified within six (6) months of termination.
 - 13.2.3 The employee is being recertified within six (6) months of termination.
 - 13.2.4 Prior to being examined for certification, employees not meeting the above requirements should receive additional training as deemed appropriate by the Level III.

14.0 Reinstatement

- 14.1 A Level I, Level II, or Level III whose certification has been terminated may be reinstated to the former NDT level, without a new examination, provided all of the following conditions are met:
 - 14.1.1 The employer has maintained the personnel certification records required in section 9.4.
 - 14.1.2 The employees certification did not expire during termination.
 - 14.1.3 The employee is being reinstated within six (6) months of termination.

Table 6.3.1 A Recommended Initial Training and Experience Levels

Examination Method	Level	Technique	High School graduate or equivalent	Completion with a passing grade of at least 2 years of engineering or science study at a university college or technical school	Minimum Required Work Experience in Method (Hours)	Permitted Time Frame (to obtain required work experience in method) (Months)
Acoustic Emission	I		40	32	210	1.5-9
	II		40	40	630	4.5-27
Electromagnetic	I		40	24	210	1.5-9
	II		40	40	630	4.5-27
Laser Methods	I	Profilometry	8	4	70	0.5-3
	II		24	12	140	1-6
	I	Holography/Shearography	40	36	210	1.5-9
	II		40	36	630	4.5-27
Leak Testing	I	Bubble Testing	2	2	3	4 hours to 3 days
	II		4	2	35	1 week to 6 weeks
	I	Pressure Change	24	16	105	0.75-4.5
	II		16	12	280	2-12
	I	Halogen Diode	12	8	105	0.75-4.5
	II		8	6	280	2-12
	I	Mass Spectrometer	40	28	280	2-12
	II		24	16	420	3-18
Liquid Penetrant	I		4	4	70	0.5-3
	II		8	4	140	1-6
Magnetic Particle	I		12	8	70	0.5-3
	II		8	4	210	1.5-9
Neutron Radiography	I		28	20	420	3-18
	II		40	40	1680	12-72
Radiography	I		40	30	210	1.5-9
	II		40	35	630	4.5-27
Thermal/Infrared	I		32	30	210	1.5-9
	II		34	32	1260	9-27
Ultrasonics	I		40	30	210	1.5-9
	II		40	40	840	4.5-27
Vibration Analysis	I		24	24	420	2-18
	II		72	48	1680	12-72
Visual	I		8	4	70	0.5-3
	II		16	8	140	1-6

Notes:

- 1.0 For Level II certification, the experience shall consist of time at Level I or equivalent. If a person is being qualified directly to Level II with no time at Level I, the required experience shall consist of the sum of the times required for Level I and Level II and the required training shall consist of the sum of the hours required for Level I and Level II.
- 2.0 For Level III certification, the required experience shall consist of the sum of the time required for Level I and Level II, and the additional requirements listed in 6.3.2. The required formal training shall consist of the Level I and Level II training, plus any additional formal training as defined in the employer's written practice.
- 3.0 Listed training hours may be adjusted as described in the employer's written practice depending on the candidate's actual education level, e.g. grammar school, college graduate in engineering, etc.
- 4.0 Training shall be outlined in the employer's written practice.

Table 6.3.1 B Alternate Initial Training and Experience Levels

Examination Method	Level	Technique	High School graduate or equivalent	Completion with a passing grade of at least 2 years of engineering or science study at a university college or technical school	Experience Level** (Months)
Acoustic Emission	I		40	32	3
	II		40	40	9
Electromagnetic	I		40	24	3
	II		40	40	9
Laser Methods	I	Profilometry	8	4	1
	II		24	12	2
	I	Holography/ Shearography	40	36	3
	II		40	36	9
Leak Testing	I	Bubble Testing	2	2	*
	II		4	2	0.5
	I	Pressure Change	24	16	1.5
	II		16	12	4
	I	Halogen Diode	12	8	1.5
	II		8	6	4
	I	Mass Spectrometer	40	28	4
	II		24	16	6
Liquid Penetrant	I		4	4	1
	II		8	4	2
Magnetic Particle	I		12	8	1
	II		8	4	3
Neutron Radiography	I		28	20	6
	II		40	40	24
Radiography	I		40	30	3
	II		40	35	9
Thermal/ Infrared	I		32	30	3
	II		34	32	18
Ultrasonics	I		40	30	3
	II		40	40	9
Vibration Analysis	I		24	24	6
	II		72	48	24
Visual	I		8	4	1
	II		16	8	2

* = 2 hours

** = Work Time Experience

Notes:

- 1.0 For Level II certification, the experience shall consist of time at Level I or equivalent. If a person is being qualified directly to Level II with no time at Level I, the required experience shall consist of the sum of the times required for Level I and Level II and the required training shall consist of the sum of the hours required for Level I and Level II.
- 2.0 For Level III certification, the required experience shall consist of the sum of the time required for Level I and Level II, and the additional requirements listed in 6.3.2. The required formal training shall consist of the Level I and Level II training, plus any additional formal training as defined in the employer's written practice.
- 3.0 Listed training hours may be adjusted as described in the employer's written practice depending on the candidate's actual education level, e.g. grammar school, college graduate in engineering, etc.
- 4.0 Initial experience may be gained simultaneously in two or more methods if the:
 - 4.1 candidate spends a minimum of 25 percent of work time on each method for which certification is sought, and
 - 4.2 remainder of the work time claimed as experience is spent in NDT-related activities defined in the employer's written practice.
- 5.0 Training shall be outlined in the employer's written practice.

RECOMMENDED TRAINING COURSES

Acoustic Emission Testing Method (Training Course Outline TC-8)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Basic acoustic emission physics course	12	10
Basic acoustic emission technique course	28	22
Total	40	32
 Level II		
Acoustic emission physics course	12	12
Acoustic emission technique course	28	28
Total	40	40

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Acoustic Emission Testing

Basic Acoustic Emission Physics Course

1.0 Principles of Acoustic Emission Testing

- 1.1 Characteristics of acoustic emission
 - 1.1.1 Continuous emission
 - 1.1.2 Burst emission
 - 1.1.3 Emission/signal levels and frequencies
- 1.2 Sources of acoustic emission
 - 1.2.1 Sources in crystalline materials – introduction
 - 1.2.2 Sources in nonmetals – introduction
 - 1.2.3 Sources in composites – introduction
 - 1.2.4 Other sources
- 1.3 Wave propagation – introduction
 - 1.3.1 Wave velocity in materials
 - 1.3.2 Attenuation
 - 1.3.3 Reflections, multiple paths
 - 1.3.4 Source input versus signal output
- 1.4 Repeated loadings: Kaiser and Felicity effects and Felicity ratio
 - 1.4.1 In metals
 - 1.4.2 In composites
- 1.5 Terminology (refer to acoustic emission glossary, ASTM E1316)

2.0 Sensing the Acoustic Emission Wave

- 2.1 Sensors
 - 2.1.1 Principles of operation
 - 2.1.2 Construction
 - 2.1.3 Frequency
- 2.2 Sensor attachment
 - 2.2.1 Coupling materials
 - 2.2.2 Attachment devices

Total recommended hours of instruction for this course:

Classification A – 12 hours

Classification B – 10 hours

Basic Acoustic Emission Technique Course

1.0 Instrumentation and Signal Processing

- 1.1 Cables
 - 1.1.1 Coaxial cable
 - 1.1.2 Twisted pair cable
 - 1.1.3 Noise problems in cables
 - 1.1.4 Connectors
- 1.2 Signal conditioning
 - 1.2.1 Preamplifiers
 - 1.2.2 Amplifiers
 - 1.2.3 Filters
 - 1.2.4 Units of gain measurement
- 1.3 Signal detection

- 1.3.1 Threshold comparator
- 1.3.2 Units of threshold measurement
- 1.3.3 Sensitivity determined by gain and/or threshold
- 1.4 Signal processing
 - 1.4.1 Waveform characteristics
 - 1.4.2 Discrimination techniques
 - 1.4.3 Distribution techniques
- 1.5 Source location techniques
 - 1.5.1 Single channel location
 - 1.5.2 Linear location
 - 1.5.3 Planar location
 - 1.5.4 Other location techniques
- 1.6 Acoustic emission test systems
 - 1.6.1 Single channel systems
 - 1.6.2 Multichannel systems
 - 1.6.3 Dedicated industrial systems
- 1.7 Accessory techniques
 - 1.7.1 Audio indicators
 - 1.7.2 X-Y and strip chart recording
 - 1.7.3 Oscilloscopes
 - 1.7.4 Others

2.0 Acoustic Emission Test Techniques

- 2.1 Equipment calibration and setup for test
 - 2.1.1 Calibration signal generation techniques
 - 2.1.2 Calibration procedures
 - 2.1.3 Sensor placement
 - 2.1.4 Adjustment of equipment controls
 - 2.1.5 Discrimination technique adjustments
- 2.2 Loading procedures
 - 2.2.1 Type of loading
 - 2.2.2 Maximum test load
 - 2.2.3 Load holds
 - 2.2.4 Repeated and programmed loadings
 - 2.2.5 Rate of loading
- 2.3 Data display
 - 2.3.1 Selection of display mode
 - 2.3.2 Use and reading of different kinds of display
- 2.4 Noise sources and pre-test identification techniques
 - 2.4.1 Electromagnetic noise
 - 2.4.2 Mechanical noise
- 2.5 Precautions against noise
 - 2.5.1 Electrical shielding
 - 2.5.2 Electronic techniques
 - 2.5.3 Prevention of movement
 - 2.5.4 Attenuating materials and applications
- 2.6 Data interpretation and evaluation: introduction
 - 2.6.1 Separating relevant acoustic emission indications from noise
 - 2.6.2 Accept/reject techniques and evaluation criteria
- 2.7 Reports
 - 2.7.1 Purpose
 - 2.7.2 Content and structure

3.0 Codes, Standards and Procedures

- 3.1 Guidetype standards (glossaries, calibration, etc.)
- 3.2 Standardized/codified acoustic emission test procedures
- 3.3 User-developed test procedures

4.0 Applications of Acoustic Emission Testing (course should include at least 3 categories from 4.1 and at least 4 categories from 4.2)

- 4.1 Laboratory studies (material characterization)
 - 4.1.1 Crack growth and fracture mechanics
 - 4.1.2 Environmentally assisted cracking
 - 4.1.3 Dislocation movement (metals)
 - 4.1.4 Clarifying deformation mechanisms (composites)
 - 4.1.5 Phase transformation and phase stability
 - 4.1.6 Creep
 - 4.1.7 Residual stress
 - 4.1.8 Corrosion
 - 4.1.9 Fatigue
 - 4.1.10 Rupture
 - 4.1.11 Ductile/brittle transition
 - 4.1.12 Other material characterization applications
- 4.2 Structural applications
 - 4.2.1 Pressure vessels (metal)
 - 4.2.2 Storage tanks (metal)
 - 4.2.3 Pressure vessels/storage tanks (composite)
 - 4.2.4 Piping and pipelines
 - 4.2.5 Bucket trucks
 - 4.2.6 Aircraft
 - 4.2.7 Bridges
 - 4.2.8 Mines
 - 4.2.9 Dams, earthen slopes
 - 4.2.10 Pumps, valves, etc.
 - 4.2.11 Rotating plant
 - 4.2.12 In-process weld monitoring
 - 4.2.13 Leak detection and monitoring
 - 4.2.14 Other structural applications

Total recommended hours of instruction for this course:

Classification A – 28 hours

Classification B – 22 hours

Recommended Training for Level II Acoustic Emission Testing

Acoustic Emission Physics Course

1.0 Principles of Acoustic Emission Testing

- 1.1 Characteristics of acoustic emission testing
 - 1.1.1 Introductory concepts of source, propagation, measurement, display, evaluation
 - 1.1.2 Relationships between acoustic emission testing and other NDT methods
 - 1.1.3 Significance of applied load in acoustic emission testing
 - 1.1.4 Basic math review (exponents, graphing, metric units)
- 1.2 Materials and deformation
 - 1.2.1 Constitution of crystalline and noncrystalline materials
 - 1.2.2 Stress and strain
 - 1.2.3 Elastic and plastic deformation; crack growth
- 1.3 Sources of acoustic emission
 - 1.3.1 Burst emission, continuous emission
 - 1.3.2 Emission/signal levels, units of amplitude measurement

- 1.3.3 Sources in crystalline materials
 - 1.3.3.1 Dislocations – plastic deformation
 - 1.3.3.2 Phase transformations
 - 1.3.3.3 Deformation twinning
 - 1.3.3.4 Nonmetallic inclusions
 - 1.3.3.5 Subcritical crack growth
 - 1.3.3.5.1 Subcritical crack growth under increasing load
 - 1.3.3.5.2 Ductile tearing under increasing load
 - 1.3.3.5.3 Fatigue crack initiation and growth
 - 1.3.3.5.4 Hydrogen embrittlement cracking
 - 1.3.3.5.5 Stress corrosion cracking
- 1.3.4 Sources in nonmetals
 - 1.3.4.1. Microcracking
 - 1.3.4.2 Gross cracking
 - 1.3.4.3 Crazeing
 - 1.3.4.4 Other sources in nonmetals
- 1.3.5 Sources in composites
 - 1.3.5.1 Fiber breakage
 - 1.3.5.2 Matrix cracking
 - 1.3.5.3 Fiber-matrix debonding
 - 1.3.5.4 Delamination
 - 1.3.5.5 Fiber pull-out, relaxation
 - 1.3.5.6 Friction
- 1.3.6 Other sources
 - 1.3.6.1 Pressure leaks
 - 1.3.6.2 Oxide and scale cracking
 - 1.3.6.3 Slag cracking
 - 1.3.6.4 Frictional sources
 - 1.3.6.5 Liquefaction and solidification
 - 1.3.6.6 Loose parts, intermittent contact
 - 1.3.6.7 Fluids and nonsolids
 - 1.3.6.8 Crack closure
- 1.4 Wave propagation
 - 1.4.1 Near-field impulse response
 - 1.4.2 Modes of propagation
 - 1.4.3 Mode conversion, reflection and refraction
 - 1.4.4 Wave velocity in material
 - 1.4.5 Anisotropic propagation in composites
 - 1.4.6 Specimen geometry effects
- 1.5 Attenuation
 - 1.5.1 Geometric attenuation
 - 1.5.2 Dispersion
 - 1.5.3 Scattering, diffraction
 - 1.5.4 Attenuation due to energy loss mechanisms
 - 1.5.5 Attenuation versus frequency
- 1.6 Kaiser and Felicity effects, and Felicity Ratio
 - 1.6.1 In metals
 - 1.6.2 In composites
 - 1.6.3 In other materials
- 1.7 Terminology (refer to acoustic emission glossary, ASTM E1316)

2.0 Sensing the Acoustic Emission Wave

- 2.1 Transducing processes (piezoelectricity, etc.)
- 2.2 Sensors
 - 2.2.1 Construction
 - 2.2.2 Conversion efficiencies
 - 2.2.3 Calibration (sensitivity curve)

- 2.3 Sensor attachment
 - 2.3.1 Coupling materials
 - 2.3.2 Attachment devices
 - 2.3.3 Waveguides
- 2.4 Sensor utilization
 - 2.4.1 Flat response sensors
 - 2.4.2 Resonant response sensors
 - 2.4.3 Integral-electronics sensors
 - 2.4.4 Special sensors (directional, mode responsive)
 - 2.4.5 Sensor selection

Total recommended hours of instruction for this course:

Classification A – 12 hours

Classification B – 12 hours

Acoustic Emission Technique Course

1.0 Instrumentation and Signal Processing

- 1.1 Cables
 - 1.1.1 Coaxial cable
 - 1.1.2 Twisted pair cable
 - 1.1.3 Optical fiber cable
 - 1.1.4 Noise problems in cables
 - 1.1.5 Impedance matching
 - 1.1.6 Connectors
- 1.2 Signal conditioning
 - 1.2.1 Preamplifiers
 - 1.2.2 Amplifiers
 - 1.2.3 Filters
 - 1.2.4 Units of gain measurement
- 1.3 Signal detection
 - 1.3.1 Threshold comparator
 - 1.3.2 Units of threshold measurement
 - 1.3.3 Sensitivity determined by gain and/or threshold
- 1.4 Signal processing
 - 1.4.1 Waveform characteristics
 - 1.4.1.1 Amplitude analysis
 - 1.4.1.2 Pulse duration analysis
 - 1.4.1.3 Rise time analysis
 - 1.4.1.4 Event and event rate processing
 - 1.4.1.5 MARSE
 - 1.4.2 Discrimination techniques
 - 1.4.3 Distribution techniques
- 1.5 Source location techniques
 - 1.5.1 Single channel location
 - 1.5.2 Linear location
 - 1.5.3 Planar location
 - 1.5.4 Other location techniques
- 1.6 Acoustic emission test systems
 - 1.6.1 Single channel systems
 - 1.6.2 Multichannel systems
 - 1.6.3 Dedicated industrial systems
- 1.7 Accessory techniques
 - 1.7.1 Audio indicators
 - 1.7.2 X-Y and strip chart recording

- 1.7.3 Oscilloscopes
- 1.7.4 Magnetic recorders
- 1.7.5 Others
- 1.8 Advanced signal processing techniques
 - 1.8.1 Signal definition
 - 1.8.2 Signal capture
 - 1.8.3 Frequency analysis
 - 1.8.4 Pattern recognition

2.0 Acoustic Emission Test Techniques

- 2.1 Factors affecting test equipment selection
 - 2.1.1 Material being monitored
 - 2.1.2 Location and nature of emission
 - 2.1.3 Type of information desired
 - 2.1.4 Size and shape of test part
- 2.2 Equipment calibration and set up for test
 - 2.2.1 Calibration signal generation techniques
 - 2.2.2 Calibration procedures
 - 2.2.3 Sensor selection and placement
 - 2.2.4 Adjustment of equipment controls
 - 2.2.5 Discrimination technique adjustments
- 2.3 Loading procedures
 - 2.3.1 Type of loading
 - 2.3.2 Maximum test load
 - 2.3.3 Load holds
 - 2.3.4 Repeated and programmed loadings
 - 2.3.5 Rate of loading
- 2.4 Special test procedures
 - 2.4.1 High temperature/low temperature tests
 - 2.4.2 Interrupted tests (including cyclic fatigue)
 - 2.4.3 Long-term tests
 - 2.4.4 Tests in high noise environments
- 2.5 Data display
 - 2.5.1 Selection of display mode
 - 2.5.2 Use and reading of different kinds of display
- 2.6 Noise sources and pre-test identification techniques
 - 2.6.1 Electromagnetic noise
 - 2.6.2 Mechanical noise
- 2.7 Precautions against noise
 - 2.7.1 Electrical shielding
 - 2.7.2 Electronic techniques
 - 2.7.3 Prevention of movement
 - 2.7.4 Attenuating materials and applications
- 2.8 Data interpretation
 - 2.8.1 Recognizing noise in the recorded data
 - 2.8.2 Noise elimination by data filtering techniques
 - 2.8.3 Relevant and nonrelevant acoustic emission response
- 2.9 Data evaluation
 - 2.9.1 Methods for ranking, grading, accepting/rejecting
 - 2.9.2 Comparison with calibration signals
 - 2.9.3 Source evaluation by complementary NDT methods
- 2.10 Reports
 - 2.10.1 Purpose
 - 2.10.2 Content and structure

3.0 Codes, Standards, Procedures and Societies

- 3.1 Guidetype standards (glossaries, calibration, etc.
- 3.2 Standardized/codified acoustic emission test procedures
- 3.3 User-developed test procedures
- 3.4 Societies active in acoustic emission testing

4.0 Applications of Acoustic Emission Testing (course should include at least 3 categories from 4.1 and at least 4 categories from 4.2)

- 4.1 Laboratory studies (material characterization)
 - 4.1.1 Crack growth and fracture mechanics
 - 4.1.2 Environmentally assisted cracking
 - 4.1.3 Dislocation movement (metals)
 - 4.1.4 Clarifying deformation mechanisms (composites)
 - 4.1.5 Phase transformation and phase stability
 - 4.1.6 Creep
 - 4.1.7 Residual stress
 - 4.1.8 Corrosion
 - 4.1.9 Fatigue
 - 4.1.10 Rupture
 - 4.1.11 Ductile/brittle transition
 - 4.1.12 Other material characterization applications
- 4.2 Structural applications
 - 4.2.1 Pressure vessels (metal)
 - 4.2.2 Storage tanks (metal)
 - 4.2.3 Pressure vessels/storage tanks (composite)
 - 4.2.4 Piping and pipelines
 - 4.2.5 Bucket trucks
 - 4.2.6 Aircraft
 - 4.2.7 Bridges
 - 4.2.8 Mines
 - 4.2.9 Dams, earthen slopes
 - 4.2.10 Pumps, valves, etc.
 - 4.2.11 Rotating plant
 - 4.2.12 In-process weld monitoring
 - 4.2.13 Leak detection and monitoring
 - 4.2.14 Other structural applications

Total recommended hours of instruction for this course

Classification A – 28 hours

Classification B – 28 hours

Acoustic Emission Testing Method Level III Topical Outline

1.0 Principles and Theory

- 1.1 Characteristics of acoustic emission testing
 - 1.1.1 Concepts of source, propagation, loading, measurement, display, evaluation
 - 1.1.2 Proper selection of acoustic emission as technique of choice
 - 1.1.2.1 Differences between acoustic emission testing and other techniques
 - 1.1.2.2 Complementary roles of acoustic emission and other methods
 - 1.1.2.3 Potential or conflicting results between methods
 - 1.1.2.4 Factors that qualify/disqualify the use of acoustic emission testing
 - 1.1.3 Math review (exponents, logarithms, metric units and conversions)
- 1.2 Materials and deformation
 - 1.2.1 Materials constitution

- 1.2.1.1 Crystalline/noncrystalline
 - 1.2.1.2 Isotropic/anisotropic
 - 1.2.1.3 Metals/composites/other
 - 1.2.2 Stress and strain (including triaxial, residual, thermal)
 - 1.2.3 Elastic and plastic deformation; crack growth
 - 1.2.4 Materials properties (strength, toughness, etc.)
- 1.3 Sources of acoustic emission
 - 1.3.1 Broadband nature of source spectra
 - 1.3.2 Emission/signal levels, units of amplitude measurement
 - 1.3.3 Sources in crystalline materials
 - 1.3.3.1 Dislocations – plastic deformation
 - 1.3.3.2 Phase transformations
 - 1.3.3.3 Deformation twinning
 - 1.3.3.4 Nonmetallic inclusions
 - 1.3.3.5 Subcritical crack growth
 - 1.3.3.5.1 Subcritical crack growth under increasing load
 - 1.3.3.5.2 Ductile tearing under increasing load
 - 1.3.3.5.3 Fatigue crack initiation and growth
 - 1.3.3.5.4 Hydrogen embrittlement cracking
 - 1.3.3.5.5 Stress corrosion cracking
 - 1.3.4 Sources in nonmetals
 - 1.3.4.1 Microcracking
 - 1.3.4.2 Gross cracking
 - 1.3.4.3 Crazeing
 - 1.3.4.4 Other sources in nonmetals
 - 1.3.5 Sources in composites
 - 1.3.5.1 Fiber breakage
 - 1.3.5.2 Matrix cracking
 - 1.3.5.3 Fiber-matrix debonding
 - 1.3.5.4 Delamination
 - 1.3.5.5 Fiber pull-out, relaxation
 - 1.3.5.6 Friction
 - 1.3.6 Other sources
 - 1.3.6.1 Pressure leaks; cavitation
 - 1.3.6.2 Oxide and scale cracking
 - 1.3.6.3 Slag cracking
 - 1.3.6.4 Frictional sources
 - 1.3.6.5 Liquefaction and solidification
 - 1.3.6.6 Loose parts, intermittent contact
 - 1.3.6.7 Fluids and nonsolids
 - 1.3.6.8 Crack closure
 - 1.3.6.9 Corrosion
- 1.4 Wave propagation
 - 1.4.1 Near-field impulse response
 - 1.4.2 Modes of propagation (including Lamb waves)
 - 1.4.3 Mode conversion, reflection and refraction
 - 1.4.4 Wave velocity in material (including velocity dispersion)
 - 1.4.5 Anisotropic propagation in composites
 - 1.4.6 Specimen geometry effects
- 1.5 Attenuation
 - 1.5.1 Geometric attenuation
 - 1.5.2 Dispersion
 - 1.5.3 Scattering, diffraction
 - 1.5.4 Effects of contained fluids
 - 1.5.5 Attenuation due to energy loss mechanisms
 - 1.5.6 Attenuation versus frequency
- 1.6 Kaiser and Felicity effects, and Felicity ratio

- 1.6.1 In metals
- 1.6.2 In composites
- 1.6.3 Emission during load holds
- 1.7 Terminology (refer to acoustic emission glossary, ASTM 1316)

2.0 Equipment and Materials

- 2.1 Transducing processes (piezoelectricity, etc.)
- 2.2 Sensors
 - 2.2.1 Construction
 - 2.2.1.1 Single ended
 - 2.2.1.2 Differential
 - 2.2.1.3 Test environment considerations
 - 2.2.1.4 Wave mode sensitivity
 - 2.2.2 Conversion efficiencies; temperature effects
 - 2.2.3 Calibration
 - 2.2.3.1 Methods and significance
 - 2.2.3.2 Calculations from absolute sensitivity curve
 - 2.2.4 Reciprocity
- 2.3 Sensor attachment
 - 2.3.1 Coupling materials: selection and effective use
 - 2.3.2 Attachment devices
 - 2.3.3 Waveguides: design considerations, effect on signal
- 2.4 Sensor utilization
 - 2.4.1 Flat response sensors
 - 2.4.2 Resonant response sensors
 - 2.4.3 Integral-electronics sensors
 - 2.4.4 Special sensors (directional, mode responsive, accelerometers)
 - 2.4.5 Sensor selection
- 2.5 Simulated acoustic emission sources
 - 2.5.1 Hsu-Nielsen Source (lead break)
 - 2.5.2 Piezoelectric transducers and associated electronics
 - 2.5.3 Gas jet
 - 2.5.4 Other devices
- 2.6 Cables
 - 2.6.1 Cable types
 - 2.6.1.1 Coaxial
 - 2.6.1.2 Twisted pair
 - 2.6.1.3 Multiscreened
 - 2.6.1.4 Optical
 - 2.6.1.5 Others
 - 2.6.2 Shielding and other factors governing cable selection
 - 2.6.3 Cable length effects
 - 2.6.4 Noise problems in cables
 - 2.6.5 Cables as transmission lines
 - 2.6.6 Impedance matching
 - 2.6.7 Connectors
- 2.7 Signal conditioning
 - 2.7.1 Preamplifiers (dynamic range, cable drive capability, etc.)
 - 2.7.2 Amplifiers
 - 2.7.3 Filters: selection, roll-off rates
 - 2.7.4 Units of gain measurement
 - 2.7.5 Electronic noise
- 2.8 Signal detection
 - 2.8.1 Threshold comparator
 - 2.8.2 Units of threshold measurement
 - 2.8.3 Sensitivity determined by gain and/or threshold

- 2.8.4 Use of floating threshold
- 2.8.5 Dead time
- 2.9 Signal processing
 - 2.9.1 Waveform characteristics
 - 2.9.1.1 Amplitude
 - 2.9.1.2 Pulse duration
 - 2.9.1.3 Rise time
 - 2.9.1.4 Signal strength (MARSE)
 - 2.9.1.5 Threshold crossing counts
 - 2.9.1.6 Hit versus event processing
- 2.10 Source location
 - 2.10.1 Single channel location
 - 2.10.2 Linear location
 - 2.10.3 Planar location
 - 2.10.4 Hit-sequence zonal location
 - 2.10.5 Other location methods
 - 2.10.6 Guard channels and spatial filtering
- 2.11 Advanced signal processing
 - 2.11.1 Data filtering
 - 2.11.2 Signal definition
 - 2.11.3 Signal capture
 - 2.11.4 Frequency analysis (Fourier theorem, theory of spectrum)
 - 2.11.5 Pattern recognition
 - 2.11.6 Source function determination by deconvolution/Green's function
- 2.12 Acoustic emission test systems
 - 2.12.1 Single channel systems
 - 2.12.2 Multichannel systems
 - 2.12.3 Dedicated industrial systems
 - 2.12.4 Interpreting and writing system specifications
- 2.13 Accessory materials
 - 2.13.1 Audio indicators
 - 2.13.2 X-Y and strip chart recording
 - 2.13.3 Oscilloscopes
 - 2.13.4 Magnetic recorders
 - 2.13.5 Computers and their use
 - 2.13.5.1 Operating systems
 - 2.13.5.2 Data storage and transfer
 - 2.13.5.3 Data output
 - 2.13.6 Others
- 2.14 Factors affecting test equipment selection
 - 2.14.1 Material being monitored
 - 2.14.2 Location and nature of emission
 - 2.14.3 Type of information desired
 - 2.14.4 Size and shape of test part

3.0 Techniques

- 3.1 Equipment calibration and set up for test
 - 3.1.1 Calibration signal generation techniques
 - 3.1.2 Calibration procedures
 - 3.1.3 Sensor selection and placement
 - 3.1.4 Adjustment of equipment controls
 - 3.1.5 Discrimination technique adjustments
- 3.2 Establishing loading procedures
 - 3.2.1 Type of loading
 - 3.2.2 Maximum test load
 - 3.2.3 Load holds

- 3.2.4 Repeated and programmed loadings
 - 3.2.5 Rate of loading
- 3.3 Precautions against noise
 - 3.3.1 Noise identification
 - 3.3.1.1 Electromagnetic noise
 - 3.3.1.2 Mechanical noise
 - 3.3.2 Noise elimination/discrimination before test
 - 3.3.2.1 Electrical shielding
 - 3.3.2.2 Grounding
 - 3.3.2.3 Frequency filtering
 - 3.3.2.4 Gain and/or threshold adjustment
 - 3.3.2.5 Floating threshold
 - 3.3.2.6 Attenuating materials and applications
 - 3.3.2.7 Prevention of movement, friction
 - 3.3.2.8 Guard channels, spatial filtering
 - 3.3.2.9 Timebased and loadbased gating
 - 3.3.2.10 Discrimination based on waveform characteristics
- 3.4 Special test procedures
 - 3.4.1 High temperature/low temperature tests
 - 3.4.2 Interrupted tests (including cyclic fatigue)
 - 3.4.3 Long-term tests, permanent/continuous monitoring
 - 3.4.4 Tests in high noise environments
- 3.5 Data displays
 - 3.5.1 Purpose and value of different displays
 - 3.5.1.1 Timebased and loadbased plots
 - 3.5.1.2 Location displays
 - 3.5.1.3 Distribution functions
 - 3.5.1.4 Crossplots
 - 3.5.1.5 Other displays
 - 3.5.2 Selection of displays

4.0 Interpretation and Evaluation

- 4.1 Data interpretation
 - 4.1.1 Relevant and nonrelevant acoustic emission response
 - 4.1.2 Recognizing noise versus true acoustic emission in the recorded data
 - 4.1.3 Distribution function analysis
 - 4.1.4 Crossplot analysis
 - 4.1.5 Noise elimination – data filtering techniques
 - 4.1.5.1 Spatial filtering
 - 4.1.5.2 Filtering on waveform characteristics
 - 4.1.5.3 Timebased and parametricbased filtering
- 4.2 Data evaluation
 - 4.2.1 Methods for ranking, grading, accepting/rejecting
 - 4.2.2 Comparison with calibration signals
 - 4.2.3 Source evaluation by complementary NDT methods
- 4.3 Reports
 - 4.3.1 Purpose
 - 4.3.2 Content and structure
 - 4.3.3 Developing a standard report format

5.0 Procedures

- 5.1 Guidetype standards (glossaries, calibration, etc.)
- 5.2 Standardized/codified acoustic emission test procedures
- 5.3 User-developed test procedures
- 5.4 Societies active in acoustic emission
- 5.5 Interpretation of codes, standards and procedures

- 5.6 Developing and writing acoustic emission test procedures
- 5.7 Training and examining Level I and II NDT personnel
- 6.0 Safety and Health**
 - 6.1 Hazards associated with structural failure during test
 - 6.2 Other hazards associated with acoustic emission testing
 - 6.3 Importance of local regulations
- 7.0 Applications**
 - 7.1 Laboratory studies (material characterization)
 - 7.1.1 Crack growth and fracture mechanics
 - 7.1.2 Environmentally assisted cracking
 - 7.1.3 Dislocation movement (metals) (strain rate and volume effects)
 - 7.1.4 Clarifying deformation mechanisms (composites)
 - 7.1.5 Phase transformation and phase stability
 - 7.1.6 Creep
 - 7.1.7 Residual stress
 - 7.1.8 Corrosion
 - 7.1.9 Fatigue
 - 7.1.10 Rupture
 - 7.1.11 Ductile/brittle transition
 - 7.1.12 Other material characterization applications
 - 7.2 Structural applications
 - 7.2.1 Pressure vessels (metal)
 - 7.2.2 Storage tanks (metal)
 - 7.2.3 Pressure vessels/storage tanks (composite)
 - 7.2.4 Piping and pipelines
 - 7.2.5 Bucket trucks
 - 7.2.6 Aircraft
 - 7.2.7 Bridges
 - 7.2.8 Mines
 - 7.2.9 Dams, earthen slopes
 - 7.2.10 Pumps, valves, etc.
 - 7.2.11 Rotating plant
 - 7.2.12 In-process weld monitoring
 - 7.2.13 Leak detection and monitoring
 - 7.2.14 Other structural applications

Recommended Training References

- Annual Book of ASTM Standards*, Volume 03.03, *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- Bingham, Ek and Tanner, eds. *Acoustic Emission Testing of Aerial Devices and Associated Equipment used in the Utility Industries* - STP 1139. Philadelphia, PA: American Society for Testing and Materials, 1992.
- Boiler and Pressure Vessel Code*, Section V. Articles 11 and 12. New York, NY: American Society of Mechanical Engineers. Latest edition.
- Drouillard, T. F. *Acoustic Emission: A Bibliography with Abstracts*. New York: Plenum Press, 1978.
- Journal of Acoustic Emission*. Volume 8, Number 1–2. (1989). Los Angeles, CA: Acoustic Emission Group.*
- Mathews, J.R. *Acoustic Emission*. (1983)
- Miller, Ronnie K., and Paul McIntire, eds. *Nondestructive Testing Handbook*, Vol. 5: second edition, *Acoustic Emission Testing*. Columbus, OH: The American Society for Nondestructive Testing, 1987.*
- Nicoll, A. R. *Acoustic Emission*. Germany: DGM Metallurgy Informationsgesellschaft, 1980.

Nondestructive Evaluation and Quality Control: Metals Handbook, Vol. 17, ninth edition, Metals Park, OH: ASM International, 1989.*

Sachse, W., K. Yamaguchi and J. Roget, eds. *Acoustic Emission; Current Practice and Future Directions – STP 1077*, Philadelphia, PA: American Society for Testing and Materials, 1991.*

Spanner, J. C. *Acoustic Emission: Techniques and Applications*. Evanston, IL: Intex Publishing Co., 1974.*

Spanner, J. C., and J. W. McElroy, eds. *Monitoring Structural Integrity by Acoustic Emission B STP 571*. Philadelphia, PA: American Society for Testing and Materials, 1975.

Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book); Acoustic Emission Testing Method, Columbus, OH: The American Society for Nondestructive Testing, Inc., 1995.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

Electromagnetic Testing Methods

(Training Course Outline TC-5)

		Recommended Hours of Instruction	
		A*	B*
Level I			
Basic electromagnetic physics course		24	12
Basic electromagnetic technique course		16	12
Total		40	24
Level II			
Electromagnetic evaluation course			
Total		40	40

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Electromagnetic Testing

Basic Electromagnetic Physics Course

1.0 Introduction to Electromagnetic Testing (Eddy Current/Flux Leakage)

- 1.1 Brief history of testing
- 1.2 Basic principles of testing

2.0 Electromagnetic Theory

- 2.1 Eddy current theory
 - 2.1.1 Generation of eddy currents by means of an alternating current field
 - 2.1.2 Effect of fields created by eddy currents (impedance changes)
 - 2.1.3 Effect of change of impedance on instrumentation
 - 2.1.4 Properties of eddy current
 - 2.1.4.1 Travel in circular direction
 - 2.1.4.2 Strongest on surface of test material
 - 2.1.4.3 Zero value at center of solid conductor placed in an alternating magnetic field
 - 2.1.4.4 Strength, time relationship and orientation as functions of test-system parameters and test-part characteristics
 - 2.1.4.5 Have properties of compressible fluids
 - 2.1.4.6 Small magnitude of current flow
 - 2.1.4.7 Relationship of frequency and plane with current in coil
 - 2.1.4.8 Effective permeability variations when induced in magnetic materials
 - 2.1.4.9 Effect of discontinuity orientation
 - 2.1.4.10 Power losses
- 2.2 Flux leakage theory
 - 2.2.1 Terminology and units
 - 2.2.2 Principles of magnetization
 - 2.2.2.1 B-H curve
 - 2.2.2.2 Magnetic properties
 - 2.2.2.3 Magnetic field
 - 2.2.2.4 Hysteresis loop
 - 2.2.2.5 Magnetic permeability
 - 2.2.2.6 Factors affecting permeability
 - 2.2.3 Magnetization B electromagnetism theory
 - 2.2.3.1 Oersted's law
 - 2.2.3.2 Faraday's law
 - 2.2.3.3 Electromagnetic
 - 2.2.4 Flux leakage theory and principle
 - 2.2.4.1 Residual
 - 2.2.4.2 Active
 - 2.2.4.3 Tangential leakage
 - 2.2.4.4 Normal leakage fields

Total recommended hours of instruction for this course:

Classification A – 24 hours

Classification B – 12 hours

Electromagnetic Technique Course

1.0 Readout Mechanism

- 1.1 Calibrated or uncalibrated meter
- 1.2 Null meter with dial indicator
- 1.3 Oscilloscope and other monitor displays
- 1.4 Alarm, lights, etc.
- 1.5 Numerical counters
- 1.6 Marking system
- 1.7 Sorting gates and tables
- 1.8 Cutoff saw or shears
- 1.9 Automation and feedback
- 1.10 Strip chart recorder

2.0 Types of Eddy Current Sensing Elements

- 2.1 Probes
 - 2.1.1 Types of arrangements
 - 2.1.1.1 Absolute
 - 2.1.1.2 Differential
 - 2.1.2 Lift-off
 - 2.1.3 Theory of operation
 - 2.1.4 Applications
 - 2.1.5 Advantages
 - 2.1.6 Limitations
- 2.2 Through, encircling or annular coils
 - 2.2.1 Types of arrangements
 - 2.2.1.1 Absolute
 - 2.2.1.2 Differential
 - 2.2.2 Fill factor
 - 2.2.3 Theory of operation
 - 2.2.4 Applications
 - 2.2.5 Advantages
 - 2.2.6 Limitations
- 2.3 Factors affecting choice of sensing elements
 - 2.3.1 Type of part to be inspected
 - 2.3.2 Type of discontinuity to be detected
 - 2.3.3 Speed of testing required
 - 2.3.4 Amount of testing (percentage) required
 - 2.3.5 Probable location of discontinuity

3.0 Types of Flux Leakage Sensing Elements

- 3.1 Principles of magnetic-measurement techniques
- 3.2 Inductive-coil sensors
 - 3.2.1 Theory of electromotive force (emf) induced in coil
 - 3.2.2 Various constructions and designs of coils
 - 3.2.3 Coil parameters affecting the flux leakage response
 - 3.2.4 Sensing-coil systems and connections (single- and multi-element probes)
- 3.3 Semiconductor sensing elements
 - 3.3.1 Hall-effect probes
 - 3.3.2 Magnetoresistors
 - 3.3.3 Magnetodiodes
 - 3.3.4 Magnetotransistors
 - 3.3.5 Magnetic and electric characteristics of semiconductor sensing elements
- 3.4 Other methods of magnetic leakage field detection
 - 3.4.1 Magnetic tape system

- 3.4.2 Magnetic powder
- 3.4.3 Magnetic-resonance sensor

Total recommended hours of instruction for this course:

Classification A –16 hours

Classification B –12 hours

Recommended Training for Level II Electromagnetic Testing

Electromagnetic Evaluation Course

1.0 Review of Electromagnetic Theory

- 1.1 Eddy current theory
- 1.2 Flux leakage theory
- 1.3 Types of eddy current sensing probes
- 1.4 Types of flux leakage sensing probes

2.0 Factors That Affect Coil Impedance

- 2.1 Test part
 - 2.1.1 Conductivity
 - 2.1.2 Permeability
 - 2.1.3 Mass
 - 2.1.4 Homogeneity
- 2.2 Test system
 - 2.2.1 Frequency
 - 2.2.2 Coupling
 - 2.2.3 Field strength
 - 2.2.4 Test coil and shape

3.0 Factors That Affect Flux Leakage Fields

- 3.1 Degree of magnetization
- 3.2 Defect geometry
- 3.3 Defect location
- 3.4 Defect orientation
- 3.5 Velocity factor
- 3.6 Distance between adjacent defects

4.0 Signal-to-Noise Ratio

- 4.1 Definition
- 4.2 Relationship to eddy current testing
- 4.3 Relationship to flux leakage testing
- 4.4 Methods of improving signal-to-noise ratio

5.0 Selection of Test Frequency

- 5.1 Relationship of frequency to type of test
- 5.2 Considerations affecting choice of test
 - 5.2.1 Signal-to-noise ratio
 - 5.2.2 Phase discrimination
 - 5.2.3 Response speed
 - 5.2.4 Skin effect

6.0 Selection of Method of Magnetization for Flux Leakage Testing

- 6.1 Magnetization characteristics for various magnetic materials
- 6.2 Magnetization by means of electric fields
 - 6.2.1 Circular field
 - 6.2.2 Longitudinal field
 - 6.2.3 Value of flux density
- 6.3 Magnetization by means of permanent magnets
 - 6.3.1 Permanent magnet relationship and theory
 - 6.3.2 Permanent magnet materials
- 6.4 Selection of proper magnetization method

7.0 Coupling

- 7.1 “Fill factor” in through-coil inspection
- 7.2 “Lift-off” and compensation in probe coil inspection
- 7.3 Flux leakage “fill factor” in flux leakage testing
- 7.4 “Lift-off” in flux leakage testing

8.0 Field Strength and its Selection

- 8.1 Permeability changes
- 8.2 Saturation
- 8.3 Effect of AC field strength on eddy current testing
- 8.4 Effect of field strength in flux leakage testing

9.0 Field Orientation for Flux Leakage Testing

- 9.1 Circular field
- 9.2 Longitudinal field

10.0 Instrument Design Considerations

- 10.1 Amplification
- 10.2 Phase detection
- 10.3 Differentiation of filtering

11.0 Applications

- 11.1 Flaw detection
 - 11.1.1 Eddy current methods
 - 11.1.2 Flux leakage methods
- 11.2 Sorting for properties related to conductivity B eddy current
- 11.3 Sorting for properties related to permeability
 - 11.3.1 Eddy current methods
 - 11.3.2 Flux leakage methods
- 11.4 Thickness evaluation B eddy current
- 11.5 Measurement of magnetic-characteristic values
 - 11.5.1 Eddy current methods
 - 11.5.2 Flux leakage methods

12.0 User Standards and Operating Procedures

- 12.1 Explanation of standards and specifications used in electromagnetic testing
- 12.2 Explanation of operating procedures used in electromagnetic testing

Total recommended hours of instruction for this course:

Classification A – 40 hours

Classification B – 40 hours

Electromagnetic Testing Method

Level III Topical Outline

1.0 Principles/Theory

- 1.1 Eddy Current Theory
 - 1.1.1 Generation of eddy currents
 - 1.1.2 Effect of fields created by eddy currents (impedance changes)
 - 1.1.3 Properties of eddy current
 - 1.1.3.1 Travel mode
 - 1.1.3.2 Depth of penetration
 - 1.1.3.3 Effects of test part characteristics
 - 1.1.3.4 Current flow
 - 1.1.3.5 Frequency and phase
 - 1.1.3.6 Effects of permeability variations
 - 1.1.3.7 Effects of discontinuity orientation

2.0 Equipment/Materials

- 2.1 Probes – general
 - 2.1.1 Advantages/Limitations
- 2.2 Through, encircling or annular coils
 - 2.2.1 Advantages/Limitations
- 2.3 Factors affecting choice of sensing elements
 - 2.3.1 Type of part to be inspected
 - 2.3.2 Type of discontinuity to be detected
 - 2.3.3 Speed of testing required
 - 2.3.4 Amount of testing required
 - 2.3.5 Probable location of discontinuity
 - 2.3.6 Applications other than discontinuity detection
- 2.4 Read out selection
 - 2.4.1 Meter
 - 2.4.2 Oscilloscope and other monitor displays
 - 2.4.3 Alarm, lights, etc.
 - 2.4.4 Strip chart recorder
- 2.5 Instrument design considerations
 - 2.5.1 Amplification
 - 2.5.2 Phase detection
 - 2.5.3 Differentiation or filtering

3.0 Techniques/Calibrations

- 3.1 Factors which affect coil impedance
 - 3.1.1 Test part
 - 3.1.2 Test system
- 3.2 Selection of test frequency
 - 3.2.1 Relation of frequency to type of test
 - 3.2.2 Consideration affecting choice of test
 - 3.2.2.1 Signal/noise ratio
 - 3.2.2.2 Phase discrimination
 - 3.2.2.3 Response speed
 - 3.2.2.4 Skin effect
- 3.3 Coupling
 - 3.3.1 Fill factor
 - 3.3.2 Lift off
- 3.4 Field strength
 - 3.4.1 Permeability changes
 - 3.4.2 Saturation
 - 3.4.3 Effect of AC field strength on eddy current testing

- 3.5 Comparison of techniques
- 3.6 Calibration
 - 3.6.1 Techniques
 - 3.6.2 Reference standards
- 3.7 Techniques – general
 - 3.7.1 Thickness gaging
 - 3.7.2 Sorting
 - 3.7.3 Conductivity
 - 3.7.4 Surface or subsurface flaw detection
 - 3.7.5 Tubing
 - 3.7.6 Remote field
- 4.0 Interpretation/Evaluation**
 - 4.1 Flaw detection
 - 4.2 Sorting for properties
 - 4.3 Thickness gaging
 - 4.4 Process control
 - 4.5 General interpretations
- 5.0 Procedures**

Recommended Training References

Electromagnetic Testing Method, Level I, II and III

- Annual Book of ASTM Standards*, Volume 03.03. *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- ASNT Level III Study Guide – Eddy Current Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1983.*
- Cecco, V. S., G. Van Drunen, and F. L. Sharp. *Eddy Current Testing*. Columbia, MD: GP Courseware, 1987.*
- Eddy Current Testing, Classroom Training Handbook (CT-6-5)*. San Diego, CA: General Dynamics/Convair Division, 1979.†
- Eddy Current Testing, Programmed Instruction Handbook (PI-4-5)*. San Diego, CA: General Dynamics/Convair Division, 1980.†
- Libby, Hugo L. *Introduction to Electromagnetic Nondestructive Test Methods*. Huntington, NY: Robert E. Krieger Publishing Co., 1971.*
- McGonnagle, Warren J. *Nondestructive Testing*, second edition. New York: Gordon and Breach, 1975.*
- McMaster, Robert C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, 1959.*
- Mester, M. L., and Paul McIntire, eds. *Nondestructive Testing Handbook: Electromagnetic Testing*, Vol. 4, second edition. Columbus, OH: The American Society for Nondestructive Testing, 1986.*
- Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*
- Radio Amateur's Handbook*. Neurington, CT: American Radio Relay League. Latest edition.
- Nondestructive Inspection and Quality Control: Metals Handbook*, Volume 11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Eddy Current/Flux Leakage Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1995.*

* Available from the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Laser Testing Methods — Holography/Shearography (Training Course Outline TC-14)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Basic holography/shearography physics course	10	8
Basic holography/shearography operating course	10	8
Basic holography/shearography application course	20	20
Total	40	36
 Level II		
Intermediate holography/shearography physics course	10	8
Intermediate holography/shearography operating course	10	8
Intermediate holography/shearography application course	20	20
Total	40	36

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Laser Method Fundamentals in Holography/Shearography Course

Basic Holography/Shearography Physics Course

Note: It is recommended that the trainee receive instruction in this course, which focuses on laser safety, prior to performing work in holography and shearography.

1.0 Introduction

- 1.1 Definition of speckle interferometry
- 1.2 History of holography and shearography testing
- 1.3 Applications of shearography NDT (SNDT)
- 1.4 Nondestructive testing
- 1.5 Responsibilities of levels of certification
- 1.6 Overview of shearography NDT

2.0 Basic Principles of Light and SNDT

- 2.1 Nature of light
- 2.1 Light as a wave
- 2.3 Definition of coherence
- 2.4 Speckles
- 2.5 Interference
- 2.6 Interferometry
- 2.7 Stress, the application of force
- 2.8 Strain, the resultant deformation
- 2.9 The double lobed fringe pattern

3.0 Lasers

- 3.1 Introduction to lasers
- 3.2 Laser light
- 3.3 Expanded coherent light as a measuring stick
- 3.4 Types of lasers
- 3.5 Ion lasers
- 3.6 Diode lasers

4.0 Laser Safety

- 4.1 Introduction
- 4.2 Do not stare into the beam
- 4.3 Classifications of laser systems
- 4.4 Nature of laser light
- 4.5 The expanded beam
- 4.6 Laser measurements for safety
- 4.7 Safe use of lasers
- 4.8 Laser safety officer
- 4.9 Safety requirements for the laboratory
- 4.10 Safety requirements for production
- 4.11 Safety requirements for the shop or field
- 4.12 Safe system design
- 4.13 Enclosures
- 4.14 Interlocks
- 4.15 Safety during maintenance
- 4.16 Keeping laser systems safe

5.0 Basic Holography/Shearography System

- 5.1. Laser illumination
- 5.2 Shearography camera
- 5.3 Image processor
- 5.4 Stressing methods

Total recommended hours of instruction for this course:

Classification A – 10 hours

Classification B – 8 hours

Recommended Training for Level I Holography/Shearography NDT

Basic Operating Course

1.0 Introduction

- 1.1 Laser holography/shearography NDT
- 1.2 Basic holography/shearography system
- 1.3 Setup and stability

2.0 Laser Safety Review

- 2.1 Do not stare into the beam
- 2.2 Classifications of laser systems
- 2.3 Safe use of lasers
- 2.4 Safe system design
- 2.5 Keeping laser systems safe

3.0 Laser Systems

- 3.1 Types of laser systems
- 3.2 Tuning an ion laser
- 3.3 Tuning a fiber optic cable (optional)
- 3.4 The simplicity of diode lasers
- 3.5 Aligning the illumination beam for the camera

4.0 Holography/Shearography Camera

- 4.1 Clarity (focus)
- 4.2 Iris settings
- 4.3 Shear optics and shear vector
- 4.4 Holography optics (in-plane and out-of-plane)
- 4.5 Phase stepping
- 4.6 Reflections
- 4.7 Illumination versus field of view

5.0 Holography/Shearography Image Processor

- 5.1 The video signal
- 5.2 Processing technique and parameters
- 5.3 Introduction to advanced processing techniques
- 5.4 Data storage and print out

6.0 Operation of the Image Processor

- 6.1 Basic system setup
- 6.2 SNT setup
- 6.3 Strain measurement setup

7.0 Primary Test Methods

- 7.1 Mechanical loading
- 7.2 Thermal stressing
- 7.3 Vacuum stressing (pressure reduction)
- 7.4 Pressurization stressing
- 7.5 Vibration excitation

8.0 Documentation

- 8.1 Introduction to documentation
- 8.2 Digital image file
- 8.3 Video printer
- 8.4 Video tape

9.0 Holography/Shearography Systems

- 9.1 Basic holography/shearography system
- 9.2 Production systems
- 9.3 Field inspection systems

Total recommended hours of instruction for this course:

Classification A – 10 hours

Classification B – 8 hours

Basic Application Course

1.0 Introduction

- 1.1 Overview
- 1.2 Test standards
- 1.3 Inspection documentation

2.0 Basic Fringe Interpretation

- 2.1 Fringe generation
- 2.2 Basic quantitative measurements with fringes
- 2.3 Indication types – true indications repeat
- 2.4 Shear orientation effect
- 2.5 Defect types
- 2.6 Defect measurements
- 2.7 Depth interpretation

3.0 Mechanical Loading

- 3.1 Types of loading
- 3.2 Applications
- 3.3 Interpretations of results

4.0 Thermal Stress

- 4.1 Types of stressing
 - 4.1.1 Heat then test
 - 4.1.2 Test and heat
 - 4.1.3 Time versus temperature
- 4.2 Applications
- 4.3 Interpretation of results

5.0 Vacuum Stress

- 5.1 Types of stressing
 - 5.1.1 Vacuum chamber
 - 5.1.2 Portable inspection head
 - 5.1.3 Depth versus fringes
- 5.2 Applications
- 5.3 Interpretation of results

6.0 Pressurization Stress

- 6.1 Types of stressing
- 6.2 Applications
- 6.3 Interpretation of results

7.0 Vibration Excitation, Mechanical

- 7.1 Types of excitation
 - 7.1.1 Frequency versus material
 - 7.1.2 Frequency versus defect size
 - 7.1.3 Amplitude
- 7.2 Applications
- 7.3 Interpretation of results

8.0 Vibration Excitation, Acoustic

- 8.1 Types of excitation
 - 8.1.1 Frequency versus material
 - 8.1.2 Frequency versus defect size
 - 8.1.3 Amplitude
- 8.2 Applications
- 8.3 Interpretation of results
- 8.4 Safe use of acoustic exciters

9.0 Complex structures

- 9.1 Types of constructions
- 9.2 Interpretation of results

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 2 hours

Recommended Training for Level II Holography/Shearography NDT Intermediate Physics Course

1.0 Physics of Light

- 1.1 Basic wave theory
- 1.2 Coherence and interference
- 1.3 Specular versus diffuse light
- 1.4 Holography optics (in-plane and out-of-plane)
- 1.5 Shearography optics

2.0 Physics of Lasers

- 2.1 Construction of ion lasers
- 2.2 Maintenance of ion lasers

- 2.3 Fiber optic beam delivery systems
- 2.4 Construction of DPY lasers
- 2.5 Logistics and choice of lasers

3.0 Laser Safety Officer

- 3.1 The guide to the safe use of lasers
- 3.2 Developing procedures

4.0 Physics of Materials

- 4.1 Stress/strain, the modulus of elasticity
- 4.2 Plate deformation equation
- 4.3 Deformation versus strain
- 4.4 Specular versus diffuse materials
- 4.5 Mechanical stress/strain
- 4.6 Thermal expansion of materials
- 4.7 Vacuum stress and out-of-plane strain
- 4.8 Pressure and hoop strain
- 4.9 Vibration and resonance
- 4.10 Stress relaxation

Total recommended hours of instruction for this course:

Classification A – 10 hours

Classification B – 8 hours

Intermediate Operating Course

1.0 Holography and Shearography Systems

- 1.1 Automated inspection stations
- 1.2 Tripodbased inspections
- 1.3 On vehicle inspections

2.0 Sources of Noise and Solutions

- 2.1 Stability
- 2.2 Vibration
- 2.3 Thermal gradients
- 2.4 Air currents

3.0 Fixturing

- 3.1 Simple forms
- 3.2 Automated system requirements

4.0 Speckle Interferometry Camera

- 4.1. Field of view (FOV) – zoom
- 4.2 Resolution versus FOV
- 4.3 Focus and iris settings
- 4.4 Sensitivity versus shear angle
- 4.5 Effects of shear orientation
- 4.6 Specular reflections

5.0 Speckle Interferometry Image Processor

- 5.1 Advanced processor adjustment
- 5.2 Advanced post processing techniques
- 5.3 Interface options
- 5.4 Documentation options

6.0 Stressing Systems Setup and Operation

- 6.1 Thermal stressing system
- 6.2 Vacuum inspection station
- 6.3 Pressurization stressing
- 6.4 Vibration excitation

7.0 Method Development

- 7.1 Test standards
- 7.0 Method format

8.0 Documentation

- 8.1 Digital image file management
- 8.2 Reporting
- 8.3 Video prints
- 8.4 Video tapes
- 8.5 Archiving data

Total recommended hours of instruction for this course:

Classification A – 10 hours

Classification B – 10 hours

Intermediate Applications Course

1.0 Materials and Applications

- 1.1 Laminates
- 1.2 Honeycombs
- 1.3 Foam core materials
- 1.4 Advanced materials
- 1.5 Pressure vessel, piping and tubing
- 1.5 Plasma spray and ceramics
- 1.6 Bonded metal

2.0 Fringe Interpretation

- 2.1 Quantitative fringe measurement
- 2.2 Defect measurement and characterization
- 2.3 Strain measurement

3.0 Mechanical Loading

- 3.1 Review of mechanical loading methods
- 3.2 Applications
 - 3.2.1 Cracks
 - 3.2.2 Material weaknesses
- 3.3 Interpretation of results

4.0 Thermal Stress

- 4.1 Review of thermal stressing methods
 - 4.1.1 Time versus Temperature
 - 4.1.2 Time versus depth
- 4.2 Applications
 - 4.2.1 Delamination
 - 4.2.2 Impact damage
 - 4.2.3 Composite repair evaluation
 - 4.2.4 Foreign material

4.3 Interpretation of results

5.0 Vacuum Stress

- 5.1 Review of vacuum stressing methods
 - 5.1.1 The general purpose method
 - 5.1.2 Depth versus fringes
- 5.2 Applications
 - 5.2.1 Near side disbonds
 - 5.2.1 Far side disbonds
 - 5.2.3. Composite repair evaluation
 - 5.2.4 Delaminations
- 5.3 Interpretation of results
 - 5.3.1 Effects of windows

6.0 Pressurization Stress

- 6.1 Review of pressure stressing methods
- 6.2 Applications
 - 6.2.1 Piping and tubing
 - 6.2.2 Pressure vessels
 - 6.2.3 Aircraft fuselage
- 6.3 Interpretation of results

7.0 Vibration Excitation, Mechanical

- 7.1 Review of mechanical vibration excitation methods
 - 7.1.1 Frequency versus material
 - 7.1.2 Frequency versus defect size
 - 7.1.3 Amplitude
 - 7.1.4 Sweep rate
 - 7.1.5 White noise
- 7.2 Applications
- 7.3 Interpretation of results

8.0 Vibration Excitation, Acoustic

- 8.1 Review of acoustic vibration excitation methods
 - 8.1.1 Frequency versus material
 - 8.1.2 Frequency versus defect size
 - 8.1.3 Amplitude
- 8.2 Applications
- 8.3 Interpretation of results
- 8.4 Safe use of acoustic exciters

9.0 Other Stressing Methods

- 9.1 Review of stress relaxation methods
- 9.2 Applications
- 9.3 Interpretation

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 20 hours

Recommended References for Holography/Shearography Training

- ASNT Special Methods Handbook, Holographic Interferometry, pp104–114.
ASNT Special Methods Handbook, Speckle Interferometry, pp115–127.
ASNT Special Methods Handbook, Shearographic Nondestructive Testing, pp128–140.
Spicer, J.W.M., Champion, J.L., Osiander, R., Spicer, J., Thermal Stressing Techniques for Flaw
Characterization with Shearography, SPIE Vol. 2455, pp. 250–259.
Tyson, J. Advances in Evaluation of Composites and Composite Repairs. Proc. SAMPE, 1995, pp. 71–78.
Tyson, J, Wegner, R., Ettemeyer, A, Non-contact Total Strain Measurement for Failure prediction,
Materials Evaluation, Vol. 57, No. 6, June 1999, pp. 576–580.
Tyson, J., Full-field Vibration and Strain Measurement, Sensors, The Journal of Applied Sensing
Technology, Vol. 16, No. 6, June 1999, pp. 16–22.

Laser Testing Methods — Profilometry

(Training Course Outline TC-14)

		Recommended Hours of Instruction	
		A*	B*
Level I			
	Laser based profilometry testing	8	4
	Total	8	4
Level II			
	Laser Based Profilometry Testing	24	12
	Total	24	12

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Laser Methods

Laser Profilometry Testing

1.0 Introduction

- 1.1 Brief history of NDT and laser methods testing.
- 1.2 Purpose for laser profilometry testing
- 1.3 Benefits and limitations of laser profilometry testing

2.0 Lasers and Laser Safety

- 2.1 Introduction to lasers
- 2.2 Laser classifications
- 2.3 Basic laser safety
- 2.4 Precautions for safe laser operation
- 2.5 Definitions

3.0 Theory of Laser Profilometry Testing

- 3.1 Introduction to basic optical triangulation
- 3.2 Photodetectors
- 3.3 Calibration

4.0 Laser Profilometry Testing

- 4.1 Preparation of test parts
- 4.2 Environmental considerations and limitations
- 4.3 System set up
- 4.4 Instrument calibration
- 4.5 Data acquisition
- 4.6 Data storage

5.0 Introduction to data processing and analysis

- 5.1 Confirming quality of inspection results
- 5.2 Basic interpretation of test results
- 5.3 Data storage and archival

Recommended Training for Level II Laser Methods

Laser Profilometry Testing

1.0 Introduction

- 1.1 Purpose for laser methods and laser profilometry testing
- 1.2 Review of basic principles of laser profilometry testing
- 1.3 Benefits and limitations of laser profilometry testing
- 1.4 Responsibilities of Level II laser profilometry examiner
- 1.5 Limitations of Level II laser profilometry examiner

2.0 Laser Safety

- 2.1 Types laser types
- 2.2 Laser classifications
- 2.3 Laser safety equipment
- 2.4 Precautions for safe laser operation
- 2.5 Regulations and governing organizations

3.0 Intermediate Theory of Profilometry Testing

- 3.1 Optical triangulation
- 3.2 Lasers
 - 3.2.1 Gas lasers
 - 3.2.2 Diode lasers
- 3.3 Lenses and optical filters
- 3.4 Photodetectors
 - 3.4.1 Charge couple devices
 - 3.4.2 Lateral effect photodetectors
- 3.5 Basic signal processing
- 3.6 Calibration

4.0 Conducting Laser Profilometry Inspection

- 4.1 Equipment selection and setup
- 4.2 Environmental considerations
 - 4.2.1 Test material
 - 4.2.2 Dust and other contamination
 - 4.2.3 Humidity and moisture
 - 4.2.4 Power considerations
- 4.3 Calibration
 - 4.3.1 When to calibrate
 - 4.3.2 Factors that effect calibration
- 4.4 Acquiring and saving inspection results

5.0 Evaluation of Indications

- 5.1 General
 - 5.1.1 Flaws in various materials
 - 5.1.2 Overview of typical causes of flaws in materials
 - 5.1.3 Appearance of flaws
 - 5.1.4 Nonflaw-related indication
- 5.2 Factors affecting quality of inspection results
 - 5.2.1 Condition/cleanliness of test component surface
 - 5.2.2 Reflectivity of test component surface
 - 5.2.3 Sharp corners/glints
 - 5.2.4 Signal too high/too low

6.0 Inspection Procedures and Standards

- 6.1 Inspection procedures and specifications
- 6.2 Standards
- 6.3 Codes

Recommended Training for Level III Laser Methods

Laser Profilometry Testing

1.0 Introduction

- 1.1 Purpose for laser methods and laser profilometry testing
- 1.2 Responsibilities of Level III laser profilometry examiner
- 1.3 Limitations of Level III laser profilometry examiner

- 2.0 Knowledge of Other Basic NDT Methods**
 - 2.1 Advantages and limitations of each method
 - 2.2 Applications well suited to laser profilometry testing
 - 2.3 Test methods that complement laser profilometry testing
- 3.0 Laser Safety**
 - 3.1 Laser Classifications
 - 3.1.1 Laser power calculation
 - 3.1.2 Calculating laser classification
 - 3.2 Precautions and equipment for safe laser operation
 - 3.3 Regulations and governing organizations
 - 3.3.1 Laser product user
 - 3.3.2 Laser product manufacturer
- 4.0 Codes, standards, specifications and procedures**
 - 4.1 Interpreting codes, standards, specifications
 - 4.2 Establishing techniques, procedures and acceptance criteria
- 5.0 Advanced Theory of Profilometry Testing**
 - 5.1 Basic laser physics
 - 5.2 Diode lasers
 - 5.2.1 CW/pulsed operation
 - 5.2.2 Laser beam “footprint”
 - 5.2.3 Matching lasers and detectors
 - 5.3 Basic optics and optical triangulation
 - 5.3.1 Snell’s law
 - 5.3.2 Scheimpflug condition
 - 5.3.3 Optical design considerations
 - 5.4 Photodetectors
 - 5.4.1 Charge couple devices (CCD)
 - 5.4.2 Lateral effect photodetectors
 - 5.4.3 Benefits and limitations of photodetectors
 - 5.5 Signal processing
 - 5.6 Equipment selection and calibration
 - 5.6.1 Equipment
 - 5.6.2 Calibration equipment
 - 5.6.2.1 When to calibrate
 - 5.6.2.2 Factors that effect calibration quality
- 6.0 Evaluation of Indications**
 - 6.1 General
 - 6.1.1 Flaws in various materials
 - 6.1.2 Overview of typical causes of flaws in materials
 - 6.1.3 Appearance of flaws
 - 6.1.4 Nonflaw-related indication
 - 6.2 Factors affecting quality of inspection results
 - 6.3 Indications
 - 6.3.1 Internal pitting and corrosion
 - 6.3.2 Cracks
 - 6.3.3 Erosion
 - 6.3.4 Other
 - 6.4 False indications
 - 6.5 Interpreting and sizing indications
 - 6.6 Confirming inspection results

7.0 Reporting Inspection Results

8.0 Training Level I and II Personnel for Certification

Recommended Training References

- Doyle, J.L., R.F. Johnson and P.D. Bondurant,. “Laser-Based Profilometry Using Point Triangulation,” The American Society for Nondestructive Testing, second edition vol. 9, *Special Nondestructive Testing Methods*, Section 3 Part 4, pp. 141–157, 1995.
- “American National Standard for Safe Use of Lasers – ANSI Z136.1–1993” American National Standards Institute, Inc., 1986.
- Owen, R.B. and Awscock, M.L., “One and Two Dimensional Position Sensitive Photodetectors.” *IEEE Transactions on Electron Devices*. Vol. ED-21, No. 3, New York, NY: Institute of Electrical and Electronic Engineers (1968) p. 290–297.
- Bickel, G., G.Hausler and M. Maul. “Triangulation with Expanded Range of Depth.” *Optical Engineering*. vol. 24, No. 6, Bellingham, WA: International Society for Optical Engineering (Society of Photo-Optical Engineers)(1985) p.975–977.

Leak Testing Methods

(Training Course Outline TC-7)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Fundamentals in leak testing course	14	8
Safety in leak testing	14	8
Leak testing methods	14	8
Total	42	24
Level II		
Principles of leak testing course	24	12
Pressure and vacuum technology course	12	6
Leak test selection course	12	6
Total	48	24

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Leak Testing

Fundamentals in Leak Testing Course

1.0 Introduction

- 1.1 History of leak testing
- 1.2 Reasons for leak testing
 - 1.2.1 Material loss prevention
 - 1.2.2 Contamination
 - 1.2.3 Component/system reliability
 - 1.2.4 Pressure-differential maintenance
 - 1.2.5 Personnel/public safety
- 1.3 Functions of leak testing
 - 1.3.1 Categories
 - 1.3.2 Applications
- 1.4 Training and certification

2.0 Leak Testing Fundamentals

- 2.1 Terminology
 - 2.1.1 Leakage terms
 - 2.1.2 Leakage tightness
 - 2.1.3 Quantitative/semiquantitative
 - 2.1.4 Sensitivity/calibration terms
- 2.2 Leak testing units
 - 2.2.1 Mathematics in leak testing
 - 2.2.2 Exponential notation
 - 2.2.3 Basic and fundamental units
 - 2.2.4 Système Internationale (SI) units
- 2.3 Physical units in leak testing
 - 2.3.1 Volume and pressure
 - 2.3.2 Time and temperature
 - 2.3.3 Absolute values
 - 2.3.4 Standard or atmospheric conditions
 - 2.3.5 Leakage measurement
- 2.4 Leak testing standards
 - 2.4.1 Capillary or permeation
 - 2.4.2 National Institute of Standards and Technology (NIST) standards
 - 2.4.3 System versus instrument calibration
 - 2.4.4 Inaccuracy of calibration
- 2.5 Flow characteristics
 - 2.5.1 Gas flow
 - 2.5.2 Liquid flow
 - 2.5.3 Correlation of leakage rates
 - 2.5.4 Anomalous leaks
 - 2.5.5 Leak clogging
- 2.6 Vacuum fundamentals
 - 2.6.1 Introduction to vacuum
 - 2.6.1.1 Terminology
 - 2.6.1.1 Principles
 - 2.6.1.1 Units of pressure
 - 2.6.2 Characteristics of gases
 - 2.6.2.1 Kinetic theory
 - 2.6.2.2 Mean free path
 - 2.6.3 Gas laws

- 2.6.4 Quantity, throughput and conductance of gas
 - 2.6.4.1 Quantity
 - 2.6.4.1.1 Comparison with an electric circuit
 - 2.6.4.1.2 Comparison with water flow
 - 2.6.4.2 Conductance analogy with electrical resistance
 - 2.6.4.2.1 Resistance connected in series
 - 2.6.4.2.2 Resistance connected in parallel
- 2.7 Vacuum system operation
 - 2.7.1 Effects of evacuating a vessel
 - 2.7.2 Pump-down time
- 2.8 Vacuum system characteristics
 - 2.8.1 General
 - 2.8.1.1 Operating limits
 - 2.8.1.2 Rate of pressure rise B measurement
 - 2.8.2 Vacuum pumps
 - 2.8.2.1 Mechanical pumps (positive displacement)
 - 2.8.2.1.1 Oil-sealed rotary pumps
 - 2.8.2.1.1.1 Construction
 - 2.8.2.1.1.2 Operation
 - 2.8.2.1.1.3 Pump fluids
 - 2.8.2.1.1.4 Difficulties with rotary pumps
 - 2.8.2.1.1.5 Care of rotary pumps
 - 2.8.2.1.2 Mechanical booster pumps
 - 2.8.2.2 Vapor (diffusion) pumps
 - 2.8.2.2.1 Construction
 - 2.8.2.2.2 Operation
 - 2.8.2.2.3 Pump fluids
 - 2.8.2.2.4 Difficulties with diffusion pumps
 - 2.8.2.2.5 Diagnosis of diffusion pump trouble
 - 2.8.2.3 Sublimation pumps (getter pumps)
 - 2.8.2.4 Ion pumps
 - 2.8.2.5 Turbomolecular pumps
 - 2.8.2.6 Absorption pumps
 - 2.8.2.7 Cryopumps

Total recommended hours of instruction for this course:

Classification A – 14 hours

Classification B – 8 hours

Safety in Leak Testing Course

Note: It is recommended that the trainee, as well as all other leak testing personnel, receive instruction in this course prior to performing work in leak testing.

1.0 Safety Considerations

- 1.1 Personnel and the public
- 1.2 Product serviceability
- 1.3 Test validity
- 1.4 Safe work practices

2.0 Safety Precautions

- 2.1 Explosive/implosive hazards
- 2.2 Flammability, ignitibility, combustibility hazards

- 2.3 Toxicity and asphyxiation hazards
- 2.4 Cleaning and electrical hazards
- 3.0 Pressure Precautions**
 - 3.1 Pressure test versus proof test
 - 3.2 Preliminary leak testing
 - 3.3 Pressurization check
 - 3.4 Design limitations
 - 3.5 Equipment and setup
- 4.0 Safety Devices**
 - 4.1 Pressure control valves and regulators
 - 4.2 Pressure relief valves and vents
 - 4.3 Flow rate of regulator and relief valves
- 5.0 Hazardous and Tracer Gas Safety**
 - 5.1 Combustible gas detection and safety
 - 5.2 Toxic gas detection and safety
 - 5.3 Oxygen-deficiency detectors
 - 5.4 Radioisotope detection
- 6.0 Types of Monitoring Equipment**
 - 6.1 Area monitors
 - 6.2 Personnel monitors
 - 6.3 Leak-locating devices
- 7.0 Safety Regulations**
 - 7.1 State and federal regulations
 - 7.2 Safety codes/standards
 - 7.3 Hazardous gas standards
 - 7.4 Nuclear Regulatory Commission (NRC) radiation requirements

Total recommended hours of instruction for this course:

Classification A – 14 hours

Classification B – 8 hours

Leak Testing Methods Course

- 1.0 The Following Leak Testing Methods may be Incorporated as Applicable**
 - 1.1 Each of these methods can be further divided into major techniques as shown in the following examples.
 - 1.1.1 Bubble testing
 - 1.1.1.1 Immersion
 - 1.1.1.2 Film solution
 - 1.1.2 Ultrasonic testing
 - 1.1.2.1 Sonic/mechanical flow
 - 1.1.2.2 Sound generator
 - 1.1.3 Voltage discharge testing
 - 1.1.3.1 Voltage spark
 - 1.1.3.2 Color change
 - 1.1.4 Pressure leak testing
 - 1.1.4.1 Hydrostatic
 - 1.1.4.2 Pneumatic

- 1.1.5 Ionization
 - 1.1.5.1 Photoionization
 - 1.1.5.2 Flame ionization
- 1.1.6 Conductivity
 - 1.1.6.1 Thermal conductivity
 - 1.1.6.2 Solid state
- 1.1.7 Radiation absorption
 - 1.1.7.1 Infrared
 - 1.1.7.2 Ultraviolet
 - 1.1.7.3 Laser
- 1.1.8 Chemicalbased
 - 1.1.8.1 Chemical penetrants
 - 1.1.8.2 Chemical gas tracer (colorimetric)
- 1.1.9 Halogen detector
 - 1.1.9.1 Halide torch
 - 1.1.9.2 Electron capture
 - 1.1.9.3 Halogen diode
- 1.1.10 Pressure change measurement
 - 1.1.10.1 Absolute
 - 1.1.10.2 Reference
 - 1.1.10.3 Pressure rise
 - 1.1.10.4 Flow
 - 1.1.10.5 Pressure decay
 - 1.1.10.6 Volumetric
- 1.1.11 Mass spectrometer
 - 1.1.11.1 Helium or argon leak detector
 - 1.1.11.2 Residual gas analyzer
- 1.1.12 Radioisotope

2.0 Leak Testing Method Course Outline

- 2.1 The following may be applied to any of the listed methods.
- 2.2 Terminology
- 2.3 Basic techniques and/or units
 - 2.3.1 Leak location B measurement/monitoring
 - 2.3.2 Visual and other sensing devices
 - 2.3.3 Various techniques
- 2.4 Testing materials and equipment
 - 2.4.1 Materials, gases/fluids used
 - 2.4.2 Control devices and operation
 - 2.4.3 Instrument/gages used
 - 2.4.4 Range and calibration of instrument/gages
- 2.5 Testing principles and practices
 - 2.5.1 Pressure/vacuum and control used
 - 2.5.2 Principles of techniques used
 - 2.5.3 Effects of temperature and other atmospheric conditions
 - 2.5.4 Calibration for testing
 - 2.5.5 Probing/scanning or measurement/monitoring
 - 2.5.6 Leak interpretation evaluation
- 2.6 Acceptance and rejection criteria
- 2.7 Safety concerns
- 2.8 Advantages and limitations
- 2.9 Codes/standards

Total recommended hours of instruction for this course:

Classification A – 14 hours

Classification B – 8 hours

Recommended Training for Level II Leak Testing

Principles of Leak Testing Course

1.0 Introduction

- 1.1 Leak testing fundamentals
 - 1.1.1 Reasons for leak testing
 - 1.1.2 Functions of leak testing
 - 1.1.3 Terminology
 - 1.1.4 Leak testing units
 - 1.1.5 Leak conductance
- 1.2 Leak testing standards
 - 1.2.1 Leak standards
 - 1.2.2 National Institute of Standards and Technology (NIST) traceability and calibration
 - 1.2.3 Instrument calibration versus test qualification
 - 1.2.4 System calibration techniques
 - 1.2.5 Inaccuracy of calibration
 - 1.2.6 Tracer-gas leak rate/air-equivalent leak rate
- 1.3 Leak testing safety
 - 1.3.1 Safety considerations
 - 1.3.2 Safety precautions
 - 1.3.3 Pressure precautions
 - 1.3.4 Tracer gas safety and monitoring
 - 1.3.5 Safety devices
 - 1.3.6 Cleaning and electrical hazards
 - 1.3.7 Safe work practices
 - 1.3.8 Safety regulations
- 1.4 Leak testing procedure
 - 1.4.1 Basic categories and techniques
 - 1.4.2 Leak location versus leakage measurement
 - 1.4.3 Pressurization or evacuation
 - 1.4.4 Sealed units with or without tracer gas
 - 1.4.5 Units inaccessible from one or both sides
 - 1.4.6 System at, above, or below atmospheric pressure
- 1.5 Leak testing specifications
 - 1.5.1 Design versus working conditions
 - 1.5.2 Pressure and temperature control
 - 1.5.3 Types of leak testing methods
 - 1.5.4 Sensitivity of leak testing methods
 - 1.5.5 Test method and sensitivity needed
 - 1.5.6 Preparation of a leak testing specification
- 1.6 Detector/instrument performance factors
 - 1.6.1 Design and use
 - 1.6.2 Accuracy and precision
 - 1.6.3 Linearity (straight/logarithmic scale)
 - 1.6.4 Calibration and frequency
 - 1.6.5 Response and recovery time

2.0 Physical Principles in Leak Testing

- 2.1 Physical quantities
 - 2.1.1 Fundamental units
 - 2.1.2 Volume and pressure
 - 2.1.3 Time and temperature
 - 2.1.4 Absolute values

- 2.1.5 Standard versus atmospheric conditions
- 2.1.6 Leakage rates
- 2.2 Structure of matter
 - 2.2.1 Atomic theory
 - 2.2.2 Ionization and ion pairs
 - 2.2.3 States of matter
 - 2.2.4 Molecular structure
 - 2.2.5 Diatomic and monatomic molecules
 - 2.2.5 Molecular weight
- 2.3 Gas principles and laws
 - 2.3.1 Brownian movement
 - 2.3.2 Mean free path
 - 2.3.3 Pressure and temperature effects on gases
 - 2.3.4 Pascal's law of pressure
 - 2.3.5 Charles' and Boyle's gas laws
 - 2.3.6 Ideal gas law
 - 2.3.7 Dalton's law of partial pressure
 - 2.3.8 Vapor pressure and effects in vacuum
- 2.4 Gas properties
 - 2.4.1 Kinetic theory of gases
 - 2.4.2 Graham law of diffusion
 - 2.4.3 Stratification
 - 2.4.4 Avogadro's principle
 - 2.4.5 Gas law relationship
 - 2.4.6 General ideal gas law
 - 2.4.7 Gas mixture and concentration
 - 2.4.8 Gas velocity, density and viscosity

3.0 Principles of Gas Flow

- 3.1 Standard leaks
 - 3.1.1 Capillary
 - 3.1.2 Permeation
- 3.2 Modes of gas flow
 - 3.2.1 Molecular and viscous
 - 3.2.2 Transitional
 - 3.2.3 Laminar, turbulent, sonic
- 3.3 Factors affecting gas flow
- 3.4 Geometry of leakage path
 - 3.4.1 Mean free flow of fluid
 - 3.4.2 Clogging and check valve effects
 - 3.4.3 Irregular aperture size
 - 3.4.4 Leak rate versus cross section of flow
 - 3.4.5 Temperature and atmospheric conditions
 - 3.4.6 Velocity gradient versus viscosity
 - 3.4.7 Reynolds number versus Knudsen number

Total recommended hours of instruction for this course:

Classification A – 24 hours

Classification B – 12 hours

Pressure and Vacuum Technology Course

1.0 Pressure Technology

- 1.1 Properties of a fluid
 - 1.1.1 What is a fluid?
 - 1.1.2 Liquid versus gas
 - 1.1.3 Compressibility
 - 1.1.4 Partial and vapor pressure
 - 1.1.5 Critical pressure and temperature
 - 1.1.6 Viscosity of a liquid
 - 1.1.7 Surface tension and capillarity of a liquid
- 1.2 Gas properties
 - 1.2.1 Review of gas properties
 - 1.2.2 What is a perfect/ideal gas?
 - 1.2.3 Pressure and temperature effects on gases
 - 1.2.4 Viscosity of a gas
 - 1.2.5 Gas flow modes
 - 1.2.6 Gas flow conductance
 - 1.2.7 Dynamic flow measurements
 - 1.2.8 Factors affecting gas flow
- 1.3 Pressurization
 - 1.3.1 Pressure measurements
 - 1.3.2 Types of pressure gages
 - 1.3.2.1 Bourdon or diaphragm
 - 1.3.2.2 Manometers
 - 1.3.3 Pressure control and procedure
 - 1.3.4 Mixing of gases
 - 1.3.5 Tracer gases and concentration
 - 1.3.6 Pressure hold time
 - 1.3.7 Pressure versus sensitivity
 - 1.3.8 Gage calibration
 - 1.3.8.1 Working range
 - 1.3.8.2 Frequency
 - 1.3.8.3 Master gage versus deadweight tester
- 1.4 Leak testing background/noise variables
 - 1.4.1 Atmospheric changes
 - 1.4.2 Liquid/air temperature correction
 - 1.4.3 Vapor pressure (evaporation/ condensation)
 - 1.4.4 Vapor/moisture pockets
 - 1.4.5 Geometry/volume changes
 - 1.4.6 Surface/internal vibration waves
- 1.5 Detector/instrument performance variables
 - 1.5.1 Instrument calibration variables
 - 1.5.2 Limits of accuracy
 - 1.5.3 Intrinsic and inherent safety performance
 - 1.5.4 Protection for electromagnetic interference, radio frequency interference, shock, etc.
 - 1.5.5 Flooding, poisoning, contamination
- 1.6 Measurement and data documentation
 - 1.6.1 Experimental, simulation and/or preliminary testing
 - 1.6.2 Analysis of background/noise variables
 - 1.6.3 Analysis of leakage indications/signals
 - 1.6.4 Validation and error analysis
 - 1.6.5 Interpretation and evaluation of results
 - 1.6.6 Documentation of data and test results

2.0 Vacuum Technology

- 2.1 Nature of vacuum
 - 2.1.1 What is a vacuum?
 - 2.1.2 Vacuum terminology
 - 2.1.3 Degrees of vacuum
 - 2.1.4 Mean free path in a vacuum
 - 2.1.5 Gas flow in a vacuum
- 2.2 Vacuum measurement
 - 2.2.1 Pressure units in a vacuum
 - 2.2.2 Absolute versus gage pressure
 - 2.2.3 Mechanical gages
 - 2.2.3.1 Bourdon or diaphragm
 - 2.2.3.2 Manometer (U-tube or McLeod)
 - 2.2.3.3 Capacitance manometer
 - 2.2.3.4 Electrical gages
 - 2.2.3.4.1 Thermal conductivity
 - 2.2.3.4.2 Ionization
 - 2.2.3.5 Gage calibration B full range
- 2.3 Vacuum pumps
 - 2.3.1 Types of vacuum pumps
 - 2.3.2 Mechanical pumps
 - 2.3.2.1 Reciprocating versus rotary
 - 2.3.2.2 Roots, turbomolecular, drag pumps
 - 2.3.3 Nonmechanical pumps
 - 2.3.3.1 Fluid entrainment or diffusion
 - 2.3.3.2 Condensation or sorption
 - 2.3.4 Pump oils
 - 2.3.5 Pumping speed and pump-down time
- 2.4 Vacuum materials
 - 2.4.1 Outgassing B vapor pressure
 - 2.4.2 Elastomers, gaskets, O-rings
 - 2.4.3 Metals, metal alloys and nonmetals
 - 2.4.3.1 Carbon steel versus stainless steel
 - 2.4.3.2 Aluminum, copper, nickel and alloys
 - 2.4.4 Nonmetals
 - 2.4.4.1 Glass, ceramics
 - 2.4.4.2 Plastics, TygonJ, etc.
 - 2.4.5 Joint design
 - 2.4.5.1 Sealed joint
 - 2.4.5.2 Welded/brazed joint
 - 2.4.5.3 Mechanical joint
 - 2.4.6 Vacuum greases and sealing materials
 - 2.4.7 Tracer gas permeation through materials
- 2.5 Design of a vacuum system
 - 2.5.1 Production of a vacuum
 - 2.5.1.1 Removal of gas molecules
 - 2.5.1.2 Gas quantity or throughput
 - 2.5.1.3 Conductance
 - 2.5.2 Stages of vacuum pumping
 - 2.5.2.1 Various vacuum pumps
 - 2.5.2.2 Various traps and baffles
 - 2.5.2.3 Pumping stages or sequences
 - 2.5.3 Vacuum valve location
 - 2.5.3.1 Vacuum valve design and seat leakage
 - 2.5.3.2 Isolation and protection
 - 2.5.3.3 Automatic versus manual
 - 2.5.3.4 Venting

- 2.6 Maintenance and cleanliness
 - 2.6.1 Maintenance of vacuum equipment
 - 2.6.1.1 Under constant vacuum
 - 2.6.1.2 Dry gas (nitrogen)
 - 2.6.2 Routing oil changes
 - 2.6.3 System cleanliness
 - 2.6.3.1 Initial cleanliness
 - 2.6.3.2 Cleaning procedures and effects on leak location and measurement
 - 2.6.3.3 Continued cleanliness
- 2.7 Analysis and documentation
 - 2.7.1 Analysis of outgassing and background contamination
 - 2.7.2 Instrument/system calibration
 - 2.7.3 Analysis of leakage indications/signals
 - 2.7.4 Interpretation and evaluation
 - 2.7.5 Documentation of calibration and test results

Total recommended hours of instruction for this course:

Classification A – 12 hours

Classification B – 6 hours

Leak Test Selection Course

1.0 Choice of Leak Testing Procedure

- 1.1 Basic categories of leak testing
 - 1.1.1 Leak location
 - 1.1.2 Leakage measurement
 - 1.1.3 Leakage monitoring
- 1.2 Types of leak testing methods
 - 1.2.2 Specifications
 - 1.2.3 Sensitivity
- 1.3 Basic techniques
 - 1.3.1 Pressurization or evacuation
 - 1.3.2 Sealed unit with or without tracer gases
 - 1.3.3 Probing or visual leak location
 - 1.3.4 Tracer or detector probing
 - 1.3.5 Accumulation techniques

Total recommended hours of instruction for this course:

Classification A – 12 hours

Classification B – 6 hours

Leak Testing Method(s) Level III Topical Outline

1.0 Principles/Theory

- 1.1 Physical principles in leak testing
 - 1.1.1 Physical quantities
 - 1.1.1.1 Fundamental units
 - 1.1.1.2 Volume and pressure
 - 1.1.1.3 Time and temperature
 - 1.1.1.4 Absolute values

- 1.1.1.5 Standard versus atmospheric conditions
 - 1.1.1.6 Leakage rates
 - 1.1.2 Structure of matter
 - 1.1.2.1 Atomic theory
 - 1.1.2.2 Ionization and ion pairs
 - 1.1.2.3 States of matter
 - 1.1.2.4 Molecular structure
 - 1.1.2.5 Diatomic and monatomic molecules
 - 1.1.2.6 Molecular weight
 - 1.1.3 Gas principles and law
 - 1.1.3.1 Brownian movement
 - 1.1.3.2 Mean free path
 - 1.1.3.3 Pressure and temperature effects on gases
 - 1.1.3.4 Pascal's law of pressure
 - 1.1.3.5 Charles' and Boyles' laws
 - 1.1.3.6 Ideal gas law
 - 1.1.3.7 Dalton's law of partial pressure
 - 1.1.3.8 Vapor pressure and effects in vacuum
 - 1.1.4 Gas properties
 - 1.1.4.1 Kinetic theory of gases
 - 1.1.4.2 Graham law of diffusion
 - 1.1.4.3 Stratification
 - 1.1.4.4 Avogadro's principle
 - 1.1.4.5 Gas law relationship
 - 1.1.4.6 General ideal gas law
 - 1.1.4.7 Gas mixture and concentration
 - 1.1.4.8 Gas velocity, density and viscosity
- 1.2 Principles of gas flow
 - 1.2.1 Standard leaks
 - 1.2.1.1 Capillary
 - 1.2.1.2 Permeation
 - 1.2.2 Modes of gas flow
 - 1.2.2.1 Molecular and viscous
 - 1.2.2.2 Transitional
 - 1.2.2.3 Laminar, turbulent, sonic
 - 1.2.3 Factors affecting gas flow
 - 1.2.4 Geometry of leakage path
 - 1.2.4.1 Mean free flow of fluid
 - 1.2.4.2 Clogging and check valve effects
 - 1.2.4.3 Irregular aperture size
 - 1.2.4.4 Leak rate versus viscosity
 - 1.2.4.5 Temperature and atmospheric conditions
 - 1.2.4.6 Velocity gradient versus viscosity
 - 1.2.4.7 Reynolds number versus Knudsen number
 - 1.2.5 Principles of mass spectrometer testing
 - 1.2.5.1 Vacuum and pressure technology
 - 1.2.5.2 Outgassing of materials versus pressure
 - 1.2.5.4 Vacuum pumping technology
- 1.3 Proper selection of leak testing as method of choice
 - 1.3.1 Differences between leak testing and other methods
 - 1.3.2 Complementary roles of leak testing and other methods
 - 1.3.3 Potential for conflicting results between methods
 - 1.3.4 Factors that qualify/disqualify the use of leak testing

2.0 Equipment/Material

- 2.1 Leak testing standards

- 2.1.1 Capillary or permeation
- 2.1.2 National Institute of Standards and Technology (NIST) Standards
- 2.1.3 System versus instrument calibration
- 2.1.4 Inaccuracy of calibration
- 2.2 Detector/instrument performance factors
 - 2.2.1 Design and use
 - 2.2.2 Accuracy and precision
 - 2.2.3 Linearity (straight/logarithmic scale)
 - 2.2.4 Calibration and frequency
 - 2.2.5 Response and recovery time
- 2.3 Vacuum pumps
 - 2.3.1 Mechanical pumps (positive displacement)
 - 2.3.1.1 Oil-sealed rotary pumps
 - 2.3.1.1.1 Construction
 - 2.3.1.1.2 Operation
 - 2.3.1.1.3 Pump fluid
 - 2.3.1.1.4 Difficulties with rotary pumps
 - 2.3.1.1.5 Care of rotary pumps
 - 2.3.1.2 Vapor (diffusion) pumps
 - 2.3.1.2.1 Construction
 - 2.3.1.2.2 Operation
 - 2.3.1.2.3 Pump fluid
 - 2.3.1.2.4 Diagnosis of diffusion pump troubles
 - 2.3.1.3 Sublimation pumps (getter pumps)
 - 2.3.1.4 Ion pumps
 - 2.3.1.5 Turbomolecular pumps
 - 2.3.1.6 Absorption pumps
 - 2.3.1.7 Cryopumps
- 2.4 Bubble testing practices and techniques
 - 2.4.1 Solutions
 - 2.4.2 Solution applicators
 - 2.4.3 Vacuum boxes
- 2.5 Absolute pressure testing equipment
 - 2.5.1 Pressure measuring instruments
 - 2.5.2 Temperature measuring instruments
 - 2.5.3 Dew point measuring instruments
 - 2.5.4 Accuracy of equipment
 - 2.5.5 Calibration of equipment
 - 2.5.6 Reference panel instruments
 - 2.5.7 Reference system installation and testing
- 2.6 Absolute pressure hold testing of containers
 - 2.6.1 Equation for determining pressure change
 - 2.6.2 Temperature measuring
- 2.7 Absolute pressure leakage rate testing of containers
 - 2.7.1 Equation(s) for determining percent loss
 - 2.7.2 Positioning of temperature and dew point sensors for mean sampling accuracy
 - 2.7.3 Analysis of temperature and dew point data
- 2.8 Analysis of data for determination of accurate results
- 2.9 Halogen testing equipment
 - 2.9.1 Leak detector control unit
 - 2.9.2 Gun detectors
 - 2.9.3 Standard leaks
 - 2.9.4 Refrigerant tracer gases
- 2.10 Helium mass spectrometer testing equipment
 - 2.10.1 Mechanical vacuum pump systems
 - 2.10.2 Cryogenic pumps
 - 2.10.3 Diffusion pumps

- 2.10.4 Vacuum gauges
- 2.10.5 Vacuum hose
- 2.10.6 Vacuum valves
- 2.10.7 Standard leaks
- 2.10.8 Vacuum sealing compounds
- 2.10.9 Vacuum connectors
- 2.10.10 Detector “sniffer” probes
- 2.10.11 Tracer probes

3.0 Techniques/Calibration

- 3.1 Bubble test
 - 3.1.1 Bubble testing practices and techniques
 - 3.1.1.1 Vacuum box testing
 - 3.1.1.2 Pipe, nozzle and pad plate testing
 - 3.1.1.3 Vessel testing
 - 3.1.1.4 Weather effects and lighting
- 3.2 Pressure change/measurement test
 - 3.2.1 Absolute pressure leak test and reference system test
 - 3.2.1.1 Principles of absolute pressure testing
 - 3.2.1.1.1 General gas law equation
 - 3.2.1.1.2 Effects of temperature change
 - 3.2.1.1.3 Effects of water vapor pressure change
 - 3.2.1.1.4 Effects of barometric pressure change
 - 3.2.1.2 Terminology related to absolute pressure testing
- 3.3 Halogen diode detector leak test
 - 3.3.1 Principles of halogen diode detector test
 - 3.3.2 Terminology related to halogen diode test
 - 3.3.3 Calibration of detectors for testing
 - 3.3.3.1 Standard leak settings
 - 3.3.3.2 Halogen mixture percentages
 - 3.3.3.3 Detection sensitivity versus test sensitivity
 - 3.3.4 Halogen detector probe “sniffer” testing techniques and practices
 - 3.3.4.1 Detector probe “sniffer” speed
 - 3.3.4.2 Halogen background
 - 3.3.4.3 Effects of heat on refrigerant R-12
 - 3.3.5 Halogen leak detector operation and servicing
 - 3.3.5.2 Operation of the probe
 - 3.3.5.2 Replacing the sensing element
 - 3.3.5.3 Cleaning the sensing element
- 3.4 Mass spectrometer leak testing
 - 3.4.1 Terminology related to mass spectrometer testing
 - 3.4.2 Helium mass spectrometer
 - 3.4.2.1 Operation
 - 3.4.2.2 Calibration
 - 3.4.2.3 Maintenance
 - 3.4.3 Helium mass spectrometer pressure testing
 - 3.4.3.1 Detector probe “sniffer” techniques
 - 3.4.3.2 Mixture percentage
 - 3.4.3.3 Pressure differential techniques
 - 3.4.3.4 Bagging-accumulation techniques
 - 3.4.3.5 Calibration helium mass spectrometer for “sniffer” testing
 - 3.4.4 Helium mass spectrometer vacuum testing by dynamic method
 - 3.4.4.1 Tracer probing
 - 3.4.4.2 Bagging or hooding
 - 3.4.4.3 System calibration
 - 3.4.4.4 Helium mixture
 - 3.4.4.5 Calculation of leakage rate

- 3.4.5 Helium mass spectrometer vacuum testing by static method
 - 3.4.5.1 Static equation
 - 3.4.5.2 System calibration
 - 3.4.5.3 Helium mixture
 - 3.4.5.4 System pressure
 - 3.4.5.5 Calculation of leakage rate

4.0 Interpretation/Evaluation

- 4.1 Basic techniques and/or units
 - 4.1.1 Leak location-measurement/monitoring
 - 4.1.2 Visual and other sensing devices
 - 4.1.3 Various techniques
- 4.2 Test materials and equipment effects
 - 4.2.1 Materials, gases/fluids used
 - 4.2.2 Control devices and responses
 - 4.2.3 Instrumentation/gages used
 - 4.2.4 Range and calibration
- 4.3 Effects of temperature and other atmospheric conditions
- 4.4 Calibration for testing
- 4.5 Probing/scanning or measurement/monitoring
- 4.6 Leak interpretation evaluation
- 4.7 Acceptance and rejection criteria

5.0 Procedures

- 5.1 Leak testing procedures
 - 5.1.1 Basic categories and techniques
 - 5.1.2 Leak location versus leakage measurement
 - 5.1.3 Pressurization or evacuation
 - 5.1.4 Sealed units with or without tracer gas
 - 5.1.5 Units accessible from one or both sides
 - 5.1.6 Systems at, above, or below atmospheric pressure
- 5.2 Leak testing specifications
 - 5.2.1 Design versus working conditions
 - 5.2.2 Pressures and temperature control
 - 5.2.3 Types of leak testing methods
 - 5.2.4 Sensitivity of leak testing methods
 - 5.2.5 Test method and sensitivity needed
 - 5.2.6 Preparation of a leak testing specification

6.0 Safety and Health

- 6.1 Safety considerations
 - 6.1.1 Personnel and the public
 - 6.1.2 Product serviceability
 - 6.1.3 Test validity
 - 6.1.4 Safe work practices
- 6.2 Safety precautions
 - 6.2.1 Explosive/implosive hazards
 - 6.2.2 Flammability, ignitibility, combustibility hazards
 - 6.2.3 Toxicity and asphyxiation hazards
 - 6.2.4 Cleaning and electrical hazards
- 6.3 Pressure precautions
 - 6.3.1 Pressure test versus proof test
 - 6.3.2 Preliminary leak test
 - 6.3.3 Pressurization check
 - 6.3.4 Design limitations
 - 6.3.5 Equipment and setup

- 6.4 Safety devices
 - 6.4.1 Pressure control valves and regulators
 - 6.4.2 Pressure relief valves and vents
 - 6.4.3 Flow rate of regulator and relief valves
- 6.5 Hazardous and tracer gas safety
 - 6.5.1 Combustible gas detection and safety
 - 6.5.2 Toxic gas detection and safety
 - 6.5.3 Oxygen-deficiency detectors
 - 6.5.4 Radioisotope detection
- 6.6 Types of monitoring equipment
 - 6.6.1 Area monitors
 - 6.6.2 Personnel monitors
 - 6.6.3 Leak-locating devices
- 6.7 Safety
 - 6.7.1 State and federal regulations
 - 6.7.2 Safety codes/standards
 - 6.7.3 Hazardous gas standards
 - 6.7.4 Nuclear Regulatory Commission (NRC) radiation requirements

Recommended Training References

Leak Testing Method, Level I, II and III

- Annual Book of ASTM Standards*, Vol. 03.03. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- ASME Boiler and Pressure Vessel Inspection Code B Section V, Article 10, Leak Testing*. New York: American Society of Mechanical Engineers. Latest edition.
- Calibration of Leak Detectors of the Mass Spectrometer Type (2.1)*. New York: American Vacuum Society, 1973.**
- Containment System Leakage Testing Requirements (ANSI/ANS 56.8)*. New York: American National Standards Institute, 1981.
- Drinkwine and Lichlman. *Partial Pressure Analyzer and Analysis*. New York: American Vacuum Society, 1979.**
- Dushman, S. *Scientific Foundation of Vacuum Technique*, Third Printing. Somerset, NJ: John Wiley & Sons, Inc., 1965.
- Guthrie, A. *Vacuum Technology*. Somerset, NJ: John Wiley & Sons, Inc., 1963.**
- Halmshaw, R., ed. *Mathematics and Formulas in NDT*. British Institute of Non-Destructive Testing, 1978.*
- Introduction to Helium Mass Spectrometer Leak Detection*. Lexington, MA: Varian Assn., 1980.
- Introduction to Vacuum and Leak Detection*. Plainview, NY: Veeco Instruments, Inc., 1980.
- Jackson, Charles N., and Charles N. Sherlock, technical eds., Patrick O. Moore, ed. *Nondestructive Testing Handbook: Leak Testing*, Vol. 1, third edition. Columbus, OH: The American Society for Nondestructive Testing, 1998.*
- Leak Detection Manual (Halogen)*, 1D-4816. Shenandoah, GA: General Electric.**
- Leak Detection Manual (Helium)*, 4820-48000. Wilmington, DE: CEC/Du Pont, 1982.**
- Leakage-rate Testing of Containment Structures for Nuclear Reactors (N45.4)*. New York: American National Standards Institute, 1972.
- Leakage Testing Handbook* by General Electric and NASA under contracts CR-952 and NAS7-396, NASA Report #N69-38843, available as report IST-295 from National Technical Information Services, Springfield, VA.
- Light Water Reactor Coolant Pressure Boundary Leak Detection (S67.03)*. Pittsburgh, PA: Instrument Society of America.
- McGonnagle, Warren J. *Nondestructive Testing*, second edition. New York: Gordon and Breach, 1975.**

- Method for Vacuum Leak Detection (2.2)*. New York: American Vacuum Society, 1968.**
- Military Publications†
- Leak Detection Compound, Oxygen Systems (MIL-I-2556C)*.**
- Leak Detector, Refrigerant Gas; Acetylene Burning with Search Hose (MIL-L-3516C)*.**
- Leak Detector, Full System (MIL-L-83774)*.
- Liquid Dye for Leak Detection (MIL-D-81298)*.
- Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, Inc., 1987.*
- Modey and Brown, eds. *History of Vacuum Science and Technology*. New York: American Vacuum Society, 1984.
- Nondestructive Evaluation Criteria for Use of ASME Section III and USASI B31.7. Div., Reactor Dev. and Tech., U.S. Government, Department of Energy.†
- Nondestructive Inspection and Quality Control: Metals Handbook*, Vol. 11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*
- Nondestructive Testing – A Survey*. NASA Report SP-5113, Southwest Research Institute, available as Report N73-28517 from National Technical Information Service, Springfield, VA.
- O'Hanlon, J. *A User's Guide to Vacuum Technology*. New York: John Wiley & Sons, Inc., 1989.*
- Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors (Appendix J Title 10 CFR Part 50). U.S. Government, Department of Energy.**
- Procedure for the Calibration of Gas Analyzers of the Mass Spectrometry Type (2.3)*. New York: American Vacuum Society, 1973.**
- Quality Assurance Provision for Nondestructive Testing Handbook, QE-702-14E*. Alabama: U.S. Army Redstone Arsenal.**
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Bubble Leak Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, 1994.*
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Halogen Diode Method*. Columbus, OH: The American Society for Nondestructive Testing, 1995.*
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Mass Spectrometer Test Method*. Columbus, OH: The American Society for Nondestructive Testing, 1996.*
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Pressure Change Measurement Testing*. Columbus, OH: The American Society for Nondestructive Testing, 1994.*
- Testing of Nuclear Air-Cleaning Systems (ANSI/ASME N510)*. New York: American National Standards Institute.
- Tompkin, H. *Introduction to the Fundamentals of Vacuum Technology*. New York: American Vacuum Society, 1984.
- US Government Federal Test Method Standards†
- Leak Testing (Helium Mass Spectrometer) (#151 b-method 441)*.
- Leak Testing (Pressurized Gas) (#151 b-method 442)*.
- Leak Testing (Vacuum) (#151 b-method 443)*.
- Vacuum Technology – Mass Spectrometer Type Leak Detector (3530)*. Geneva, Switzerland: International Organization for Standardization.
- Vacuum Technology: Its Foundation, Formula, and Tables*. E. Syracuse, NY: Inficon Leybold-Heraeus, 1980.
- Water and Steam in the Power Cycle (Purity and Quality, Leak Detection and Measurement) (PTC 19.11, Part II)*. New York: American Society of Mechanical Engineers, 1970.
- Weast, R. C. *Handbook of Chemistry and Physics*. Boca Raton, FL: CRC Press.
- Wilson, N., and L. Beavis. *Handbook of Vacuum Leak Detection*. New York: American Vacuum Society, 1979.

* Available from the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Available from the Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

Liquid Penetrant Testing Methods

(Training Course Outline TC-4)

	Recommended Hours of Instruction	
	A*	B*
Level I	4	4
Level II	8	4

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended hours of instruction should be considered as a minimum requirement, regardless of training course topic changes.

Recommended Training for Level I Liquid Penetrant Testing

1.0 Introduction

- 1.1 Brief history of nondestructive testing and liquid penetrant testing
- 1.2 Purpose of liquid penetrant testing
- 1.3 Basic principles of liquid penetrant testing
- 1.4 Types of liquid penetrants commercially available
- 1.5 Method of personnel qualification

2.0 Liquid Penetrant Processing

- 2.1 Preparation of parts
- 2.2 Adequate lighting
- 2.3 Application of penetrant to parts
- 2.4 Removal of surface penetrant
- 2.5 Developer application and drying
- 2.6 Inspection and evaluation
- 2.7 Postcleaning

3.0 Various Penetrant Testing Methods

- 3.1 Current ASTM and ASME standard methods – ASTM E1208, 1209, 1210.
- 3.2 Characteristics of each method
- 3.3 General applications of each method

4.0 Liquid Penetrant Testing Equipment

- 4.1 Liquid penetrant testing units
- 4.2 Lighting for liquid penetrant testing equipment and light meters
- 4.3 Materials for liquid penetrant testing
- 4.4 Precautions in liquid penetrant testing

Total recommended hours of instruction for this course:

Classification A – 4 hours

Classification B – 4 hours

Recommended Training for Level II Liquid Penetrant Testing

1.0 Review

- 1.1 Basic principles
- 1.2 Process of various methods
- 1.3 Equipment

2.0 Selection of the Appropriate Penetrant Testing Method

- 2.1 Advantages of various methods
- 2.2 Disadvantages of various methods

3.0 Inspection and Evaluation of Indications

- 3.1 General
 - 3.1.1 Discontinuities inherent in various materials
 - 3.1.2 Reason for indications
 - 3.1.3 Appearance of indications
 - 3.1.4 Time for indications to appear

- 3.1.5 Persistence of indications
- 3.1.6 Effects of temperature and lighting (white to UV)
- 3.1.7 Effects of metal smearing operations (shot peening, machining, etc.)
- 3.1.8 Preferred sequence for penetrant inspection
- 3.1.9 Part preparation (precleaning, stripping, etc.)
- 3.2 Factors affecting indications
 - 3.2.1 Penetrant used
 - 3.2.2 Prior processing
 - 3.2.3 Technique used
- 3.3 Indications from cracks
 - 3.3.1 Cracks occurring during solidification
 - 3.3.2 Cracks occurring during processing
 - 3.3.3 Cracks occurring during service
- 3.4 Indications from porosity
- 3.5 Indications from specific material forms
 - 3.5.1 Forgings
 - 3.5.2 Castings
 - 3.5.3 Plate
 - 3.5.4 Welds
 - 3.5.5 Extrusions
- 3.6 Evaluation of indications
 - 3.6.1 True indications
 - 3.6.2 False indications
 - 3.6.3 Relevant indications
 - 3.6.4 Nonrelevant indications
 - 3.6.5 Process control
 - 3.6.5.1 Controlling process variables
 - 3.6.5.2 Testing and maintenance materials

4.0 Inspection Procedures and Standards

- 4.1 Inspection procedures (minimum requirements)
- 4.2 Standards/codes
 - 4.2.3 Applicable methods/processes
 - 4.2.4 Acceptance criteria

5.0 Basic Methods of Instruction

Total recommended hours of instruction for this course:

Classification A – 8 hours

Classification B – 4 hours

Liquid Penetrant Testing Method Level III Topical Outline

1.0 Principles/Theory

- 1.1 Principles of liquid penetrant process
 - 1.1.1 Process variables
 - 1.1.2 Effects of test object factors on process
- 1.2 Theory
 - 1.2.1 Physics of how penetrants work
 - 1.2.2 Control and measurement of penetrant process variables
 - 1.2.2.1 Surface tension, viscosity and capillary entrapment
 - 1.2.2.2 Measurement of penetrability, washability and emulsification

- 1.2.2.3 Contrast, brightness and fluorescence
 - 1.2.2.4 Contamination of materials
 - 1.2.2.5 Proper selection of penetrant levels for different testing (sensitivity)
 - 1.3 Proper selection of liquid penetrant testing as method of choice
 - 1.3.1 Difference between liquid penetrant testing and other methods
 - 1.3.2 Complementary roles of liquid penetrant testing and other methods
 - 1.3.3 Potential for conflicting results between methods
 - 1.3.4 Factors that qualify/disqualify the use of liquid penetrant testing
 - 1.3.5 Selection of liquid penetrant testing technique
 - 1.4 Liquid penetrant processing
 - 1.4.1 Preparation of parts
 - 1.4.2 Applications of penetrants and emulsifiers to parts
 - 1.4.3 Removal of surface penetrants
 - 1.4.4 Developer application and drying
 - 1.4.5 Evaluation
 - 1.4.6 Post cleaning
 - 1.4.7 Precautions
- 2.0 Equipment/Materials**
 - 2.1 Methods of measurement
 - 2.2 Lighting for liquid penetrant testing
 - 2.2.1 White light intensity
 - 2.2.2 Black (UV fluorescent) light intensity, warm-up time, etc.
 - 2.2.3 Physics and physiological differences
 - 2.3 Materials for liquid penetrant testing
 - 2.3.1 Solvent removable
 - 2.3.2 Water washable
 - 2.3.3 Post emulsifiable
 - 2.3.3.1 Water base (hydrophilic)
 - 2.3.3.2 Oil base (lipophilic)
 - 2.3.4 Dual sensitivity
 - 2.4 Testing and maintenance of materials
- 3.0 Interpretation/Evaluation**
 - 3.1 General
 - 3.1.1 Appearance of penetrant indications
 - 3.1.2 Persistence of indications
 - 3.2 Factors affecting indications
 - 3.2.1 Preferred sequence for penetrant inspection
 - 3.2.2 Part preparation (precleaning, stripping, etc.)
 - 3.2.3 Environment (lighting, temperature, etc.)
 - 3.2.4 Effect of metal smearing operations (shot peening, machining, etc.)
 - 3.3 Indications from discontinuities
 - 3.3.1 Metallic materials
 - 3.3.2 Nonmetallic materials
 - 3.4 Relevant and nonrelevant indications
 - 3.4.1 True indications
 - 3.4.2 False indications
- 4.0 Procedures**
- 5.0 Safety and Health**
 - 5.1 Toxicity
 - 5.2 Flammability

Total recommended hours of instruction for this course:

Classification A – Six months of experience as a Level II

Classification B – Four-year degree and completion of Level I and Level II courses

Recommended Training References Liquid Penetrant Testing Method, Level I, II and III

Annual Book of ASTM Standards, Vol. 03.03, *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*

ASNT Level III Study Guide: Liquid Penetrant Testing. Columbus, OH: The American Society for Nondestructive Testing, 1980.*

Boisvert, Bernie. *Principles and Applications of Liquid Penetrant Testing: A Classroom Training Text*. Columbus, OH: The American Society for Nondestructive Testing, 1993.*

Liquid Penetrant Testing, Classroom Training Handbook (CT-6-2). San Diego, CA: General Dynamics/Convair Division, 1977.†

Liquid Penetrant Testing, Programmed Instruction Handbook (PI-4-2). San Diego, CA: General Dynamics/Convair Division, 1977.†

Lovejoy, David. *Penetrant Testing: A Practical Guide*. New York: Chapman & Hall, 1991.*

Materials Evaluation. Vol. 44, No. 12 (November 1986). Columbus, OH: The American Society for Nondestructive Testing.*

Materials Evaluation. Vol. 45, No. 7 (July 1987). Columbus, OH: The American Society for Nondestructive Testing.*

McGonnagle, Warren J. *Nondestructive Testing*, second edition. New York: Gordon and Breach, 1975.**

Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*

Nondestructive Inspection and Quality Control: Metals Handbook, Vol.11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*

Standard Reference Photographs for Liquid Penetrant Inspection: Adjunct to ASTM E433, Philadelphia, PA: ASTM, 1985.

Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Liquid Penetrant Test Method. Columbus, OH: The American Society for Nondestructive Testing, 1996.*

Tracy Noel, technical ed., and Patrick O. Moore, ed., *Nondestructive Testing Handbook: Liquid Penetrant Testing*, Vol. 2, third edition. Columbus, OH: The American Society for Nondestructive Testing, 1999*

Welding Handbook, Vol. 1. Miami, FL: American Welding Society. Latest edition.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Magnetic Particle Testing Method

(Training Course Outline TC-2)

	Recommended Hours of Instruction	
	A*	B*
Level I	12	8
Level II	8	4

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Magnetic Particle Testing

1.0 Principles of Magnets and Magnetic Fields

- 1.1 Theory of magnetic fields
 - 1.1.1 Earth's magnetic field
 - 1.1.2 Magnetic fields around magnetized materials
- 1.2 Theory of magnetism
 - 1.2.1 Magnetic poles
 - 1.2.2 Law of magnetism
 - 1.2.3 Materials influenced by magnetic fields
 - 1.2.3.1 Ferromagnetic
 - 1.2.3.2 Paramagnetic
 - 1.2.3 Magnetic characteristics of nonferrous materials
- 1.3 Terminology associated with magnetic particle testing

2.0 Characteristics of Magnetic Fields

- 2.1 Bar magnet
- 2.2 Ring magnet

3.0 Effect of Discontinuities of Materials

- 3.1 Surface cracks
- 3.2 Scratches
- 3.3 Subsurface defects

4.0 Magnetization by Means of Electric Current

- 4.1 Circular field
 - 4.1.1 Field around a straight conductor
 - 4.1.2 Right-hand rule
 - 4.1.3 Field in parts through which current flows
 - 4.1.3.1 Long, solid, cylindrical, regular parts
 - 4.1.3.2 Irregularly shaped parts
 - 4.1.3.3 Tubular parts
 - 4.1.3.1 Parts containing machined holes, slots, etc.
 - 4.1.4 Methods of inducing current flow in parts
 - 4.1.4.1 Contact plates
 - 4.1.4.2 Prods
 - 4.1.5 Discontinuities commonly discovered by circular fields
- 4.2 Longitudinal field
 - 4.2.1 Field produced by current flow in a coil
 - 4.2.2 Field direction in a current-carrying coil
 - 4.2.3 Field strength in a current-carrying coil
 - 4.2.4 Discontinuities commonly discovered by longitudinal fields
 - 4.2.5 Advantages of longitudinal magnetization
 - 4.2.6 Disadvantages of longitudinal magnetization

5.0 Selecting the Proper Method of Magnetization

- 5.1 Alloy, shape and condition of part
- 5.2 Type of magnetizing current
- 5.3 Direction of magnetic field
- 5.4 Sequence of operations
- 5.5 Value of flux density

6.0 Inspection Materials

- 6.1 Wet particles
- 6.2 Dry particles

7.0 Principles of Demagnetization

- 7.1 Residual magnetism
- 7.2 Reasons for requiring demagnetization
- 7.3 Longitudinal and circular residual fields
- 7.4 Basic principles of demagnetization
- 7.5 Retentivity and coercive force
- 7.6 Methods of demagnetization

8.0 Magnetic Particle Testing Equipment

- 8.1 Equipment selection considerations
 - 8.1.1 Type of magnetizing current
 - 8.1.2 Location and nature of test
 - 8.1.3 Test materials used
 - 8.1.4 Purpose of test
 - 8.1.5 Area inspected
- 8.2 Manual inspection equipment
- 8.3 Medium- and heavy-duty equipment
- 8.4 Stationary equipment
- 8.5 Mechanized inspection equipment
 - 8.5.1 Semiautomatic inspection equipment
 - 8.5.2 Single-purpose semiautomatic equipment
 - 8.5.3 Multipurpose semiautomatic equipment
 - 8.5.4 Fully automatic equipment

9.0 Types of Discontinuities Detected by Magnetic Particle Testing

- 9.1 Inclusions
- 9.2 Blowholes
- 9.3 Porosity
- 9.4 Flakes
- 9.5 Cracks
- 9.6 Pipes
- 9.6 Laminations
- 9.7 Laps
- 9.8 Forging bursts
- 9.9 Voids

10.0 Magnetic Particle Test Indications and Interpretations

- 10.1 Indications of nonmetallic inclusions
- 10.2 Indications of surface seams
- 10.3 Indications of cracks
- 10.4 Indications of laminations
- 10.5 Indications of laps
- 10.6 Indications of bursts and flakes
- 10.7 Indications of porosity
- 10.8 Nonrelevant indications

Total recommended hours of instruction for this course:

Classification A – 12 hours

Classification B – 8 hours

Recommended Training for Level II Magnetic Particle Testing

1.0 Principles

- 1.1 Theory
 - 1.1.1 Flux patterns
 - 1.1.2 Frequency and voltage factors
 - 1.1.3 Current calculations
 - 1.1.4 Surface flux strength
 - 1.1.5 Subsurface effects
- 1.2 Magnets and magnetism
 - 1.2.1 Distance factors versus strength of flux
 - 1.2.2 Internal and external flux patterns
 - 1.2.3 Phenomenon action at the discontinuity
 - 1.2.4 Heat effects on magnetism
 - 1.2.5 Material hardness versus magnetic retention

2.0 Flux Fields

- 2.1 Direct current
 - 2.1.1 Depth of penetration factors
 - 2.1.2 Source of current
- 2.2 Direct pulsating current
 - 2.2.1 Similarity to direct current
 - 2.2.2 Advantages
 - 2.2.3 Typical fields
- 2.3 Alternating current
 - 2.3.1 Cyclic effects
 - 2.3.2 Surface strength characteristics
 - 2.3.3 Safety precautions
 - 2.3.4 Voltage and current factors
 - 2.3.5 Source of current

3.0 Effects of Discontinuities on Materials

- 3.1 Design factors
 - 3.1.1 Mechanical properties
 - 3.1.2 Part use
- 3.2 Relationship to load-carrying ability

4.0 Magnetization by Means of Electric Current

- 4.1 Circular techniques
 - 4.1.1 Current calculations
 - 4.1.2 Depth-factor considerations
 - 4.1.3 Precautions B safety and overheating
 - 4.1.4 Contact prods and yokes
 - 4.1.4.1 Requirements for prods and yokes
 - 4.1.4.2 Current-carrying capabilities
 - 4.1.5 Discontinuities commonly detected
- 4.2 Longitudinal technique
 - 4.2.1 Principles of induced flux fields
 - 4.2.2 Geometry of part to be inspected
 - 4.2.3 Shapes and sizes of coils
 - 4.2.4 Use of coils and cables
 - 4.2.4.1 Strength of field
 - 4.2.4.2 Current directional flow versus flux field
 - 4.2.4.3 Shapes, sizes and current capacities

- 4.2.5 Current calculations
 - 4.2.5.1 Formulas
 - 4.2.5.2 Types of current required
 - 4.2.5.3 Current demand
- 4.2.6 Discontinuities commonly detected

5.0 Selecting the Proper Method of Magnetization

- 5.1 Alloy, shape and condition of part
- 5.2 Type of magnetizing current
- 5.3 Direction of magnetic field
- 5.4 Sequence of operations
- 5.5 Value of flux density

6.0 Demagnetization Procedures

- 6.1 Need for demagnetization of parts
- 6.2 Current, frequency and field orientation
- 6.3 Heat factors and precautions
- 6.4 Need for collapsing flux fields

7.0 Equipment

- 7.1 Portable type
 - 7.1.1 Reason for portable equipment
 - 7.1.2 Capabilities of portable equipment
 - 7.1.3 Similarity to stationary equipment
- 7.2 Stationary type
 - 7.2.1 Capability of handling large and heavy parts
 - 7.2.2 Flexibility in use
 - 7.2.3 Need for stationary equipment
 - 7.2.4 Use of accessories and attachments
- 7.3 Automatic type
 - 7.3.1 Requirements for automation
 - 7.3.2 Sequential operations
 - 7.3.3 Control and operation factors
 - 7.3.4 Alarm and rejection mechanisms
- 7.4 Liquids and powders
 - 7.4.1 Liquid requirements as a particle vehicle
 - 7.4.2 Safety precautions
 - 7.4.3 Temperature needs
 - 7.4.4 Powder and paste contents
 - 7.4.5 Mixing procedures
 - 7.4.6 Need for accurate proportions
- 7.5 Black light type
 - 7.5.1 Black light and fluorescence
 - 7.5.2 Visible light and black light comparisons
 - 7.5.3 Requirements in the testing cycle
 - 7.5.4 Techniques in use
- 7.6 Light-sensitive instruments
 - 7.6.1 Need for instrumentation
 - 7.6.2 Light characteristics

8.0 Types of Discontinuities

- 8.1 In castings
- 8.2 In ingots
- 8.3 In wrought sections and parts
- 8.4 In welds

9.0 Evaluation Techniques

- 9.1 Use of standards
 - 9.1.1 Need for standards and references
 - 9.1.2 Comparison of known with unknown
 - 9.1.3 Specifications and certifications
 - 9.1.4 Comparison techniques
- 9.2 Defect appraisal
 - 9.2.1 History of part
 - 9.2.2 Manufacturing process
 - 9.2.3 Possible causes of defect
 - 9.2.4 Use of part
 - 9.2.5 Acceptance and rejection criteria
 - 9.2.6 Use of tolerances

10.0 Quality Control of Equipment and Processes

- 10.1 Malfunctioning of equipment
- 10.2 Proper magnetic particles and bath liquid
- 10.3 Bath concentration
 - 10.3.1 Settling test
 - 10.3.2 Other bath-strength tests
- 10.4 Tests for black light intensity

Total recommended hours of instruction for this course:

Classification A – 8 hours

Classification B – 4 hours

Magnetic Particle Testing Method Level III Topical Outline

1.0 Principles/Theory

- 1.1 Principles of magnets and magnetic fields
 - 1.1.1 Theory of magnetic fields
 - 1.1.2 Theory of magnetism
 - 1.1.3 Terminology associated with magnetic particle testing
- 1.2 Characteristics of magnetic fields
 - 1.2.1 Bar magnet
 - 1.2.2 Ring magnet

2.0 Equipment/Materials

- 2.1 Magnetic particle test equipment
 - 2.1.1 Equipment selection considerations
 - 2.1.2 Manual inspection equipment
 - 2.1.3 Medium and heavy duty equipment
 - 2.1.4 Stationary equipment
 - 2.1.5 Mechanized inspection equipment
- 2.2 Inspection materials
 - 2.2.1 Wet particle technique
 - 2.2.2 Dry particle technique

3.0 Technique/Calibrations

- 3.1 Magnetization by means of electric current
 - 3.1.1 Circular field
 - 3.1.1.1 Field around a straight conductor
 - 3.1.1.2 Right hand rule

- 3.1.1.3 Field in parts through which current flows
 - 3.1.1.4 Methods of inducing current flow in parts
 - 3.1.1.5 Discontinuities commonly indicated by circular field
 - 3.1.1.6 Applications of circular magnetization
 - 3.1.2 Longitudinal field
 - 3.1.2.1 Field direction
 - 3.1.2.2 Discontinuities commonly indicated by longitudinal techniques
 - 3.1.2.3 Applications of longitudinal magnetization
 - 3.2 Selecting the proper method of magnetization
 - 3.2.1 Alloy, shape and condition of part
 - 3.2.2 Type of magnetizing field
 - 3.2.3 Direction of magnetic field
 - 3.2.4 Sequence of operation
 - 3.2.5 Value of flux density
 - 3.3 Demagnetization
 - 3.3.1 Reasons for requiring demagnetization
 - 3.3.2 Methods of demagnetization
- 4.0 Interpretation/Evaluation**
- 4.1 Magnetic particle test indications and interpretations
 - 4.2 Effects of discontinuities on materials and types of discontinuities indicated by magnetic particle testing
- 5.0 Procedures**
- 5.1 Magnetic particle procedures, codes, standards and specifications
- 6.0 Safety and Health**

Recommended Training References

Magnetic Particle Testing Method, Level I, II and III

- Annual Book of ASTM Standards*, Vol. 03.03, *Nondestructive Testing*. Philadelphia, PA: The American Society for Testing and Materials. Latest edition.*
- ASNT Level III Study Guide: Magnetic Particle Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, 1980.*
- Betz, Carl E. *Principles of Magnetic Particle Testing*. Chicago: Magnaflux Corp., 1985.
- Nondestructive Inspection and Quality Control: Metals Handbook*, Vol. 11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*
- Magnetic Particle Testing, Classroom Training Handbook (CT-6-3)*. San Diego, CA: General Dynamics/Convair Division, 1977.†
- Magnetic Particle Testing, Programmed Instruction Handbook (PI-4-3)*. San Diego, CA: General Dynamics/Convair Division, 1977.†
- McGonnagle, Warren J. *Nondestructive Testing*, second edition. New York: Gordon and Breach, 1975.**
- McMaster, Robert C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, 1959.*
- Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*
- Schmidt, J. Thomas and Kermit Skeie, technical ed. *Nondestructive Testing Handbook*, Volume 6: second edition, *Magnetic Particle Testing*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1989.*
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Magnetic Particle Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1994.*

Welding Handbook. Vol. 1. Miami, FL: American Welding Society. Latest edition.*

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† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Neutron Radiographic Testing Method

(Training Course Outline TC-6)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Neutron radiographic equipment operating and emergency instructions course	8	8
Basic neutron radiographic physics course	7	4
Basic neutron radiographic technique course	13	8
Total	28	20
 Level II		
Neutron radiographic physics course	14	14
Neutron radiographic technique course	26	26
Total	40	40

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Neutron Radiographic Testing

Neutron Radiographic Equipment Operating and Emergency Instructions Course

Note: It is recommended that the trainee receive instruction in this course prior to performing work in neutron radiography.

1.0 Personnel Monitoring

- 1.1 Personnel monitoring dosimeters
 - 1.1.1 Types
 - 1.1.2 Reading
 - 1.1.3 Recordkeeping
- 1.2 Permissible personnel exposure limits

2.0 Radiation Survey Instruments

- 2.1 Types of instruments
- 2.2 Reading and interpreting meter indications
- 2.3 Calibration frequency
- 2.4 Calibration expiration – actions to be taken
- 2.5 Battery check – importance

3.0 Radiation-Area Surveys

- 3.1 Type and quantity of radiation
- 3.2 Posting
 - 3.2.1 Radiation areas
 - 3.2.2 High radiation areas
- 3.3 Establishment of time limits

4.0 Radioactivity

- 4.1 Radioactive components (fuel, sources, etc.)
- 4.2 Induced radioactivity due to neutron radiography
 - 4.2.1 Handling of radioactive components
 - 4.2.2 Decay of radioactive components
 - 4.2.3 Shipping of radioactive components

5.0 Radiation-Area Work Practices – Safety

- 5.1 Use of time, shielding and distance to reduce personnel radiation exposure
- 5.2 Restricted areas
- 5.3 Radioactive contamination
 - 5.3.1 Clothing requirements
 - 5.3.2 Contamination control
 - 5.3.3 Contamination cleanup
- 5.4 Specific procedures

6.0* Explosive-Device Safety

- 6.1 Static electricity
- 6.2 Grounding devices
- 6.3 Clothing requirements
- 6.4 Handling and storage requirements and procedures
- 6.5 Shipping and receiving procedures

7.0 State and Federal Regulations

- 7.1 Nuclear Regulatory Commission (NRC) and Agreement States authority
- 7.2 Occupational Safety and Health Administration (OSHA)
- 7.3 Department of Transportation (DOT)
- 7.4* State and federal explosive-licensing requirements

*Required only by those personnel who will be involved in neutron radiography of explosive devices.

Total recommended hours of instruction for this course:

Classification A – 8 hours

Classification B – 8 hours

Basic Neutron Radiographic Physics Course

1.0 Introduction

- 1.1 History of industrial neutron radiography
- 1.2 General principles of examination of materials by penetrating radiation
- 1.3 Relationship of penetrating neutron radiation, radiography and radiometry
- 1.4 Comparison with other NDT methods, particularly with X-rays and gamma rays
- 1.5 General areas of application
 - 1.5.1 Imaging
 - 1.5.2 Metrology
 - 1.5.3 Product

2.0 Physical Principles

- 2.1 Sources for neutron radiography (general description)
 - 2.1.1 Isotopes
 - 2.1.2 Nuclear reactors
 - 2.1.3 Accelerators
- 2.2 Interaction between neutrons and matter
 - 2.2.1 Absorption
 - 2.2.1.1 Thermal neutrons
 - 2.2.1.2 Resonance neutrons
 - 2.2.1.3 Fast neutrons
 - 2.2.2 Scatter
 - 2.2.2.1 Elastic
 - 2.2.2.2 Inelastic
- 2.3 Neutron radiography techniques
 - 2.3.1 Film imaging techniques
 - 2.3.2 Nonfilm imaging techniques
- 2.4 Glossary of terms and units of measure

3.0 Radiation Sources for Neutrons (Specific Description)

- 3.1 Reactors
 - 3.1.1 Principle of fission chain reactions
 - 3.1.2 Neutron thermalization (slowing down)
 - 3.1.3 Thermal neutron flux
- 3.2 Accelerators
 - 3.2.1 Types of accelerators
 - 3.2.2 Neutron-producing reactions
- 3.3 Isotopic sources
 - 3.3.1 Radioisotope + Be
 - 3.3.1.1 α - Be
 - 3.3.1.2 γ - Be

- 3.3.2 Radioisotope + D
 - 3.3.2.1 γ - D
- 3.3.3 Spontaneous fission
 - 3.3.3.1 ^{252}Cf

4.0 Personnel Safety and Radiation Protection

- 4.1 Hazards of excessive exposure
 - 4.1.1 General – beta radiation, gamma radiation
 - 4.1.2 Specific neutron hazards
 - 4.1.2.1 Relative biological effectiveness
 - 4.1.2.2 Neutron activation
- 4.2 Methods of controlling radiation dose
 - 4.2.1 Time
 - 4.2.2 Distance
 - 4.2.3 Shielding
- 4.3 Specific equipment requirements
 - 4.3.1 Neutron monitoring dosimeters
 - 4.3.2 Gamma ray monitoring dosimeters
 - 4.3.3 Radiation survey equipment
 - 4.3.3.1 Beta/gamma
 - 4.3.3.2 Neutron
 - 4.3.4 Recording/recordkeeping
- 4.4 Radiation work procedures
- 4.5 Federal, state and local regulations

Total recommended hours of instruction for this course:

Classification A – 7 hours

Classification B – 4 hours

Basic Neutron Radiographic Technique Course

1.0 Radiation Detection Imaging

- 1.1 Converter screens
 - 1.1.1 Principles of operation
 - 1.1.2 Direct-imaging screens
 - 1.1.3 Transfer-imaging screens
- 1.2 Film – principles, properties and uses with neutron converter screens
 - 1.2.1 Radiation response
 - 1.2.2 Vacuum/contact considerations
 - 1.2.3 Radiographic speed
 - 1.2.4 Radiographic contrast
- 1.3 Track-etch
 - 1.3.1 Radiation response
 - 1.3.2 Vacuum/contact considerations
 - 1.3.3 Radiographic speed
 - 1.3.4 Radiographic contrast

2.0 Neutron Radiographic Process: Basic Imaging Considerations

- 2.1 Definition of sensitivity (including penetrameters)
- 2.2 Contrast and definition
 - 2.2.1 Neutron energy and neutron screen relationship
 - 2.2.2 Effect of scattering in object
- 2.3 Geometric principles
- 2.4 Generation and control of scatter
- 2.5 Choice of neutron source

- 2.6 Choice of film
- 2.7 Use of exposure curves
- 2.8 Cause of correction of unsatisfactory radiographs
 - 2.8.1 High film density
 - 2.8.2 Low film density
 - 2.8.3 High contrast
 - 2.8.4 Low contrast
 - 2.8.5 Poor definition
 - 2.8.6 Excessive film fog
 - 2.8.7 Light leaks
 - 2.8.8 Artifacts
- 2.9 Arithmetic of exposure

3.0 Test Result Interpretation

- 3.1 Relationship between X-ray and n-ray
- 3.2 Effects on measurement and interpretation of test
- 3.3 Administrative control of test quality by interpreter
- 3.4 Familiarization with image

Total recommended hours of instruction for this course:

Classification A – 13 hours

Classification B – 8 hours

Recommended Training for Level II Neutron Radiographic Testing

Neutron Radiographic Physics Course

1.0 Introduction

- 1.1 General principles of examination of materials by penetrating radiation
- 1.2 Relationship of penetrating neutron radiation, radiography and radiometry
- 1.3 Comparison with other methods, particularly with X-rays and gamma rays
- 1.4 Specific areas of application in industry

2.0 Review of Physical Principles

- 2.1 Nature of penetrating radiation (all types)
 - 2.1.1 Particles
 - 2.1.2 Wave properties
 - 2.1.3 Electromagnetic waves
 - 2.1.4 Fundamentals of radiation physics
 - 2.1.5 Sources of radiation
 - 2.1.5.1 Electronic sources
 - 2.1.5.2 Isotopic sources
 - 2.1.5.3 Nuclear reactors
 - 2.1.5.4 Accelerators
- 2.2 Interaction between penetrating radiation and matter (neutron and gamma ray)
 - 2.2.1 Absorption
 - 2.2.2 Scatter
 - 2.2.3 Other interactions
- 2.3 Glossary of terms and units of measure

3.0 Radiation Sources for Neutrons

- 3.1 Neutron sources – general
 - 3.1.1 Reactors
 - 3.1.1.1 Principle of fission chain reactions
 - 3.1.1.2 Fast neutron flux B energy and spatial distribution
 - 3.1.1.3 Neutron thermalization
 - 3.1.1.4 Thermal-neutron flux B energy and spatial distribution
- 3.2 Accelerators
 - 3.2.1 Types of accelerators
 - 3.2.2 Neutron-producing reactions
 - 3.2.3 Available yields and energy spectra
- 3.3 Isotopic sources
 - 3.3.1 Radioisotope + Be
 - 3.3.2 Radioisotope + D
 - 3.3.3 Spontaneous fission – ^{252}Cf
- 3.4 Beam design
 - 3.4.1 Source placement
 - 3.4.2 Collimation
 - 3.4.3 Filtering
 - 3.4.4 Shielding

4.0 Radiation Detection

- 4.1 Imaging
 - 4.1.1 Converter screens
 - 4.1.1.1 Principles of operations
 - 4.1.1.2 Types of screens
 - 4.1.1.2.1 Direct exposure
 - 4.1.1.2.2 Transfer exposure
 - 4.1.1.2.3 Track-etch process
 - 4.1.1.2.4 Spectral sensitivity (each process)
 - 4.1.2 Film – principles, properties, use with neutron converter screens
 - 4.1.2.1 Material examination
 - 4.1.2.2 Monitoring
 - 4.1.3 Fluoroscopy
 - 4.1.3.1 Fluorescent screen
 - 4.1.3.2 Image amplification
 - 4.1.3.3 Cine techniques
 - 4.1.4 Direct TV viewing
 - 4.1.5 Special instrumentation associated with above techniques
- 4.2 Nonimaging devices
 - 4.2.1 Solidstate
 - 4.2.1.1 Scintillometer
 - 4.2.1.2 Photoresistive devices
 - 4.2.1.3 Other
 - 4.2.2 Gaseous
 - 4.2.2.1 Proportional counters
 - 4.2.2.2 Geiger counters
 - 4.2.2.3 Ionization chambers
 - 4.2.2.4 Other
 - 4.2.3 Neutron detectors
 - 4.2.3.1 Boron-based gas counters
 - 4.2.3.2 Fission counters
 - 4.2.3.3 Helium-3 detectors
 - 4.2.3.4 Lithiumbased scintillator
 - 4.2.3.5 Instrumentation
 - 4.2.3.5.1 Rate meters
 - 4.2.3.5.2 Counters

- 4.2.3.5.3 Amplifiers and preamplifiers
- 4.2.3.5.4 Recording readouts
- 4.2.3.5.5 Other

5.0 Personnel Safety and Radiation Protection

- 5.1 Hazards of excessive exposure
 - 5.1.1 General – beta ray, gamma ray
 - 5.1.2 Specific neutron hazards
 - 5.1.2.1 Relative biological effectiveness (RBE)
 - 5.1.2.2 Neutron activation of components
- 5.2 Methods of controlling accumulated radiation dose
 - 5.2.1 Time
 - 5.2.2 Distance
 - 5.2.3 Shielding
- 5.3 Specific equipment requirements
 - 5.3.1 Neutron monitoring equipment
 - 5.3.2 Gamma ray monitoring equipment
 - 5.3.3 Survey
 - 5.3.4 Recording
 - 5.3.5 Exposure shields and/or rooms
 - 5.3.5.1 Operation
 - 5.3.5.2 Alarms
- 5.4 Operation and emergency procedures
- 5.5 Federal, state and local regulations

Total recommended hours of instruction for this course:

Classification A – 14 hours

Classification B – 14 hours

Neutron Radiographic Technique Course

1.0 Neutron Radiographic Process

- 1.1 Basic neutron-imaging considerations
 - 1.1.1 Definition of sensitivity (including penetrameters)
 - 1.1.2 Contrast and definition
 - 1.1.2.1 Neutron energy and neutron screen relationship
 - 1.1.2.2 Effect of scattering in object
 - 1.1.2.3 Exposure versus foil thickness
 - 1.1.3 Geometric principles
 - 1.1.4 Intensifying screens
 - 1.1.4.1 Fluorescent (neutron sensitive)
 - 1.1.4.2 Metallic (neutron sensitive)
 - 1.1.5 Generation and control of scatter
 - 1.1.6 Choice of source
 - 1.1.7 Choice of film/detector
 - 1.1.8 Use of exposure curves and process by which they are generated
 - 1.1.9 Fluoroscopic inspection
 - 1.1.9.1 Theory of operation
 - 1.1.9.2 Applications
 - 1.1.9.3 Limitations
 - 1.1.10 Film processing
 - 1.1.10.1 Darkroom procedures
 - 1.1.10.2 Darkroom equipment and chemicals
 - 1.1.10.3 Film processing do's and don'ts

- 1.1.11 Viewing of radiographs
 - 1.1.11.1 Illuminator requirements (intensity)
 - 1.1.11.2 Background lighting
 - 1.1.11.3 Judging quality of neutron radiographs
- 1.1.12 Causes and correction of unsatisfactory radiographs
 - 1.1.12.1 High film density
 - 1.1.12.2 Insufficient film density
 - 1.1.12.3 High contrast
 - 1.1.12.4 Low contrast
 - 1.1.12.5 Poor definition
 - 1.1.12.6 Excessive neutron scatter
 - 1.1.12.7 Fog
 - 1.1.12.8 Light leaks
 - 1.1.12.9 Artifacts
- 1.1.13 Arithmetic of exposure and of other factors affecting neutron radiographs
- 1.2 Miscellaneous applications
 - 1.2.1 Blocking and filtering
 - 1.2.2 Multifilm techniques
 - 1.2.3 Enlargement and projection
 - 1.2.4 Stereoradiography
 - 1.2.5 Triangulation methods
 - 1.2.6 Autoradiography
 - 1.2.7 Flash neutron radiography
 - 1.2.8 “In-motion” radiography and fluoroscopy
 - 1.2.9 Backscatter neutron radiography
 - 1.2.10 Neutron tomography
 - 1.2.11 Microneutron radiography
 - 1.2.12 Causes of “diffraction” effects and minimization of interference with test
 - 1.2.13 Determination of focal-spot size
 - 1.2.14 Panoramic techniques
 - 1.2.15 Altering film contrast and density
 - 1.2.16 Gaging and control processes

2.0 Test Result Interpretation

- 2.1 Basic factors
 - 2.1.1 General aspects (relationship between X-ray and neutron radiographs)
 - 2.1.2 Effects on measurement and interpretation of test
 - 2.1.3 Administrative control of test quality by interpreter
 - 2.1.4 Familiarization with image
- 2.2 Material considerations
 - 2.2.1 Metallurgy or other material consideration as it affects use of item and test results
 - 2.2.2 Materials-processing effects on use of item and test results
 - 2.2.3 Discontinuities – their causes and effects
 - 2.2.4 Radiographic appearance of discontinuities
- 2.3 Codes, standards, specifications and procedures
 - 2.3.1 Thermal neutron radiography
 - 2.3.2 Resonance neutron radiography
 - 2.3.3 Other applicable codes, etc.

Total recommended hours of instruction for this course:

Classification A – 26 hours

Classification B – 26 hours

Neutron Radiographic Testing Method

Level III Topical Outline

1.0 Principles/Theory

- 1.1 Nature of penetrating radiation
- 1.2 Interaction between penetrating radiation and matter
- 1.3 Neutron radiography
 - 1.3.1 Imaging by film
 - 1.3.2 Imaging by fluorescent materials
 - 1.3.3 Imaging by electronic devices
- 1.4 Radiometry

2.0 Equipment/Materials

- 2.1 Sources of neutrons
 - 2.1.1 Reactors
 - 2.1.2 Accelerators
 - 2.1.3 Isotopic sources
 - 2.1.4 Beam control factors
- 2.2 Radiation detectors
 - 2.2.1 Imaging
 - 2.2.1.1 Converter screens
 - 2.2.1.2 Film-principles, properties, use with neutron converter screens
 - 2.2.1.3 Fluoroscopy
 - 2.2.1.4 TV and optical systems
- 2.3 Nonimaging devices
 - 2.3.1 Solid state detectors
 - 2.3.2 Gaseous ionization detectors
 - 2.3.3 Neutron detectors
 - 2.3.4 Instrumentation
 - 2.3.5 Gaging and control processes

3.0 Techniques/Calibrations

- 3.1 Blocking and filtering
- 3.2 Multifilm technique
- 3.3 Enlargement and projection
- 3.4 Stereoradiography
- 3.5 Triangulation methods
- 3.6 Autoradiography
- 3.7 Flash radiography
- 3.8 In-motion radiography
- 3.9 Fluoroscopy
- 3.10 Electron emission radiography
- 3.11 Microradiography
- 3.12 Laminography (tomography)
- 3.13 Control of diffraction effects
- 3.14 Panoramic exposures
- 3.15 Gaging
- 3.16 Real time imaging
- 3.17 Image analysis techniques

4.0 Interpretation/Evaluation

- 4.1 Radiographic interpretation
 - 4.1.1 Image-object relationships
 - 4.1.2 Material considerations

- 4.1.2.1 Material processing as it affects use of item and test results
- 4.1.2.2 Discontinuities, their cause and effects
- 4.1.2.3 Radiographic appearance of discontinuities
- 4.1.3 Codes, standards and specifications

5.0 Procedures

- 5.1 The radiographic process
 - 5.1.1 Imaging considerations
 - 5.1.1.1 Sensitivity
 - 5.1.1.2 Contrast and definition
 - 5.1.1.3 Geometric factors
 - 5.1.1.4 Intensifying screens
 - 5.1.1.5 Scattered radiation
 - 5.1.1.6 Source factors
 - 5.1.1.7 Detection media
 - 5.1.1.8 Exposure curves
- 5.2 Film processing
 - 5.2.1 Darkroom procedures
 - 5.2.2 Darkroom equipment and chemicals
 - 5.2.3 Film processing
- 5.3 Viewing of radiographs
 - 5.3.1 Illuminator requirements
 - 5.3.2 Background lighting
 - 5.3.3 Optical aids
- 5.4 Judging radiographic quality
 - 5.4.1 Density
 - 5.4.2 Contrast
 - 5.4.3 Definition
 - 5.4.4 Artifacts
 - 5.4.5 IQIs
 - 5.4.6 Causes and corrections of unsatisfactory radiographs

6.0 Safety and Health

- 6.1 Personnel safety and radiation hazards
 - 6.1.1 Exposure hazards
 - 6.1.1.1 General – beta radiation, gamma radiation
 - 6.1.1.2 Specific neutron hazards
 - 6.1.2 Methods of controlling radiation exposure
 - 6.1.3 Operation and emergency procedures

Recommended Training References Neutron Radiographic Testing, Level I, II and III

- Annual Book of ASTM Standards*, Vol. 03.03, *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- Atomic Energy Review*, Vol. 15, No. 2, June 1977.**
- Berger, H. *Neutron Radiography*. Amsterdam, Netherlands: Elsevier Publishing Co., 1965.*
- Berger, H. "Neutron Radiography," *Annual Reviews of Nuclear Science*, Vol. 21. Palo Alto, CA: Annual Review, Inc., 1971.**
- Berger, H. *Neutron Radiography and Gaging – STP 586*. Philadelphia, PA: American Society for Testing and Materials, 1967.
- Bryant, Lawrence A., and Paul McIntire, eds. *Nondestructive Testing Handbook: Radiography and Radiation Testing*, Vol. 3, second edition. Columbus, OH: The American Society for Nondestructive Testing, 1985.*

Code of Federal Regulations, Title 10: Part 0-5. Washington D.C.: U.S. Government Printing Office, 1993.

Code of Federal Regulations, Title 10: Part 20. Washington D.C.: U.S. Government Printing Office, 1996.

Domanus, J.C. *Collimators for Thermal Neutron Radiography, An Overview*. D. Reidel Publishing Co., 1987.

Herz, R. *The Photographic Action of Ionizing Radiations*. New York: Wiley-Interscience, 1969.**

Horns, A. A. and D. R. Wyman. *Mathematics and Physics of Neutron Radiography*. Reidel Publishing Co., 1986.

Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*

Neutron Radiography Handbook. Holland and Boston: D. Reidel Publishing Co., 1981.**

Neutron Radiography: Proceedings of the First World Conference. D. Reidel Publishing Co., 1981.

Neutron Radiography: Proceedings of the Second World Conference. D. Reidel Publishing Co., 1981.

Neutron Radiography: Proceedings of the Third World Conference. Kluwer Academic Publishers, 1989.

Neutron Radiography: Proceedings of the Fourth World Conference. Gordon & Breach Science Publishers, 1992.

Nondestructive Inspection and Quality Control: Metals Handbook, Vol. 11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*

Radiographic Testing, Classroom Training Handbook (CT-6-6). San Diego, CA: General Dynamics/Convair Division, 1967.†

Radiographic Testing, Programmed Instruction Handbook (PI-4-6). San Diego, CA: General Dynamics/Convair Division, 1983.†

Radiography in Modern Industry, fourth edition. Rochester, NY: Eastman Kodak Co., 1980.*

Sensitometric Properties of X-Ray Films. Rochester, NY: Eastman Kodak Co., 1974.**

Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Neutron Radiographic Test Method. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1994.*

Tyufakov, N. D., and A. S. Shtan. *Principles of Neutron Radiography*, TT76-52048. New Delhi, India: Amerind Publishing Co., 1979.**

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Radiographic Testing Method (Training Course Outline TC-1)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Radiographic equipment operating and emergency instructions course	5	5
Basic radiographic physics course	20	15
Radiographic technique course	15	10
Total	40	30
Level II		
Film quality and manufacturing processes course	20	15
Radiographic evaluation and interpretation course	20	20
Total	40	35

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Radiographic Testing

Radiographic Equipment Operating and Emergency Instructions Course

Note: It is recommended that the trainee receive instruction in this course prior to performing work in radiography.

1.0 Personnel Monitoring

- 1.1 Wearing of monitoring badges
- 1.2 Reading of pocket dosimeters
- 1.3 Recording of daily dosimeter readings
- 1.4 “Off-scale” dosimeter – action required
- 1.5 Permissible exposure limits

2.0 Survey Instruments

- 2.1 Types of radiation instruments
- 2.2 Reading and interpreting meter indications
- 2.3 Calibration frequency
- 2.4 Calibration expiration – action
- 2.5 Battery check – importance

3.0 Leak Testing of Sealed Radioactive Sources

- 3.1 Requirements for leak testing
- 3.2 Purpose of leak testing
- 3.3 Performance of leak testing

4.0 Radiation Survey Reports

- 4.1 Requirements for completion
- 4.2 Description of report format

5.0 Radiographic Work Practices

- 5.1 Establishment of restricted areas
- 5.2 Posting and surveillance of restricted areas
- 5.3 Use of time, distance and shielding to reduce personnel radiation exposure
- 5.4 Applicable regulatory requirements for surveys, posting and control of radiation and high-radiation areas

6.0 Exposure Devices

- 6.1 Daily inspection and maintenance
- 6.2* Radiation exposure limits for gamma ray exposure devices
- 6.3 Labeling
- 6.4 Use
- 6.5 Use of collimators to reduce personnel exposure
- 6.6* Use of “source changers” for gamma ray sources

7.0 Emergency Procedures

- 7.1* Vehicle accidents with radioactive sealed sources
- 7.2* Fire involving sealed sources
- 7.3* “Source out” – failure to return to safe shielded conditions
- 7.4* Emergency call list

8.0 Storage and Shipment of Exposed Devices and Sources

- 8.1* Vehicle storage
- 8.2* Storage vault – permanent
- 8.3* Shipping instructions – sources
- 8.4* Receiving instructions – radioactive material

9.0 State and Federal Regulations

- 9.1 Nuclear Regulatory Commission (NRC) and agreement states authority
- 9.2 License reciprocity
- 9.3* Radioactive materials license requirements for industrial radiography
- 9.4 Qualification requirements for radiography personnel
- 9.5 Regulations for the control of radiation (state or NRC as applicable)
- 9.6* Department of Transportation regulations for radiographic-source shipment
- 9.7 Regulatory requirements for X-ray machines (state and federal as applicable)

*Topics may be deleted if the radiography is limited to X-ray exposure devices.

Total recommended hours of instruction for this course:

Classification A – 5 hours

Classification B – 5 hours

Basic Radiographic Physics Course

1.0 Introduction

- 1.1 History and discovery of radioactive materials
- 1.2 Definition of industrial radiography
- 1.3 Radiation protection – why?
- 1.4 Basic math review: exponents, square root, etc.

2.0 Fundamental Properties of Matter

- 2.1 Elements and atoms
- 2.2 Molecules and compounds
- 2.3 Atomic particles – properties of protons, electrons and neutrons
- 2.4 Atomic structure
- 2.5 Atomic number and weight
- 2.6 Isotope versus radioisotope

3.0 Radioactive Materials

- 3.1 Production
 - 3.1.1 Neutron activation
 - 3.1.2 Nuclear fission
- 3.2 Stable versus unstable (radioactive) atoms
- 3.3 Curie – the unit of activity
- 3.4 Half-life of radioactive materials
- 3.5 Plotting of radioactive decay
- 3.6 Specific activity – curies/gram

4.0 Types of Radiation

- 4.1 Particulate radiation – properties: alpha, beta, neutron
- 4.2 Electromagnetic radiation – X-ray, gamma ray
- 4.3 X-ray production
- 4.4 Gamma ray production
- 4.6 Gamma ray energy

- 4.7 Energy characteristics of common radioisotope sources
- 4.8 Energy characteristics of X-ray machines
- 5.0 Interaction of Radiation with Matter**
 - 5.1 Ionization
 - 5.2 Radiation interaction with matter
 - 5.2.1 Photoelectric effect
 - 5.2.2 Compton scattering
 - 5.2.3 Pair production
 - 5.3 Unit of radiation exposure – the roentgen
 - 5.4 Emissivity of commonly used radiographic sources
 - 5.5 Emissivity of X-ray exposure devices
 - 5.6 Attenuation of electromagnetic radiation – shielding
 - 5.7 Half-value layers; tenth-value layers
 - 5.8 Inverse square law
- 6.0 Biological Effects of Radiation**
 - 6.1 “Natural” background radiation
 - 6.2 Unit of radiation dose – rem
 - 6.3 Difference between radiation and contamination
 - 6.4 Allowable personnel exposure limits and the banking concept
 - 6.5 Theory of allowable dose
 - 6.6 Radiation damage – repair concept
 - 6.7 Symptoms of radiation injury
 - 6.8 Acute radiation exposure and somatic injury
 - 6.9 Personnel monitoring for tracking exposure
 - 6.10 Organ radiosensitivity
- 7.0 Radiation Detection**
 - 7.1. Pocket dosimeter
 - 7.2 Difference between dose and dose rate
 - 7.3 Survey instruments
 - 7.3.1 Geiger-Müller tube
 - 7.3.2 Ionization chambers
 - 7.3.3 Scintillation chambers, counters
 - 7.4 Film badge – radiation detector
 - 7.5 TLDs (thermoluminescent dosimeters)
 - 7.6 Calibration
- 8.0 Exposure Devices and Radiation Sources**
 - 8.1 Radioisotope sources
 - 8.1.1 Sealed-source design and fabrication
 - 8.1.2 Gamma ray sources
 - 8.1.3 Beta and bremsstrahlung sources
 - 8.1.4 Neutron sources
 - 8.2 Radioisotope exposure device characteristics
 - 8.3 Electronic radiation sources – 500 keV and less, low energy
 - 8.3.1 Generator – high voltage rectifiers
 - 8.3.2 X-ray tube design and fabrication
 - 8.3.3 X-ray control circuits
 - 8.3.4 Accelerating potential
 - 8.3.5 Target material and configuration
 - 8.3.6 Heat dissipation
 - 8.3.7 Duty cycle
 - 8.3.8 Beam filtration

- 8.4* Electronic radiation sources – medium and high energy
 - 8.4.1* Resonance transformer
 - 8.4.2* Van de Graaff accelerator
 - 8.4.3* Linac
 - 8.4.4* Betatron
 - 8.4.5* Roentgen output
 - 8.4.6* Equipment design and fabrication
 - 8.4.7* Beam filtration
- 8.5* Fluoroscopic radiation sources
 - 8.5.1* Fluoroscopic equipment design
 - 8.5.2* Direct viewing screens
 - 8.5.3* Image amplification
 - 8.5.4* Special X-ray tube considerations and duty cycle
 - 8.5.5* Screen unsharpness
 - 8.5.6* Screen conversion efficiency

9.0 Special Radiographic Sources and Techniques

- 9.1* Flash radiography
- 9.2* Stereo radiography
- 9.3* In-motion radiography
- 9.4* Autoradiography

*Topics may be deleted if the employer does not use these methods and techniques.

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 15 hours

Radiographic Technique Course

1.0 Introduction

- 1.1 Process of radiography
- 1.2 Types of electromagnetic radiation sources
- 1.3 Electromagnetic spectrum
- 1.4 Penetrating ability or “quality” of X-rays and gamma rays
- 1.5 Spectrum of X-ray tube source
- 1.6 Spectrum of gamma radioisotope source
- 1.7 X-ray tube – change of mA or kVp effect on “quality” and intensity

2.0 Basic Principles of Radiography

- 2.1 Geometric exposure principles
 - 2.1.1 “Shadow” formation and distortion
 - 2.1.2 Shadow enlargement calculation
 - 2.1.3 Shadow sharpness
 - 2.1.4 Geometric unsharpness
 - 2.1.5 Finding discontinuity depth
- 2.2 Radiographic screens
 - 2.2.1 Lead intensifying screens
 - 2.2.2 Fluorescent intensifying screens
 - 2.2.3 Intensifying factors
 - 2.2.4 Importance of screen-to-film contact
 - 2.2.5 Importance of screen cleanliness and care
 - 2.2.6 Techniques for cleaning screens

- 2.3 Radiographic cassettes
- 2.4 Composition of industrial radiographic film
- 2.5 The “heel effect” with X-ray tubes
- 3.0 Radiographs**
 - 3.1 Formation of the latent image on film
 - 3.2 Inherent unsharpness
 - 3.3 Arithmetic of radiographic exposure
 - 3.3.1 Milliamperage – distance-time relationship
 - 3.3.2 Reciprocity law
 - 3.3.3 Photographic density
 - 3.3.4 X-ray exposure charts – material thickness, kV and exposure
 - 3.3.5 Gamma ray exposure chart
 - 3.3.6 Inverse square law considerations
 - 3.3.7 Calculation of exposure time for gamma ray and X-ray sources
 - 3.4 Characteristic Hurter and Driffield (H-D) curve
 - 3.5 Film speed and class descriptions
 - 3.6 Selection of film for particular purpose
- 4.0 Radiographic Image Quality**
 - 4.1 Radiographic sensitivity
 - 4.2 Radiographic contrast
 - 4.3 Film contrast
 - 4.4 Subject contrast
 - 4.5 Definition
 - 4.6 Film graininess and screen mottle effects
 - 4.7 Penetrameters or image quality indicators
- 5.0 Film Handling, Loading and Processing**
 - 5.1 Safe light and darkroom practices
 - 5.2 Loading bench and cleanliness
 - 5.3 Opening of film boxes and packets
 - 5.4 Loading of film and sealing cassettes
 - 5.5 Handling techniques for “green film”
 - 5.6 Elements of manual film processing
- 6.0 Exposure Techniques – Radiography**
 - 6.1 Singlewall radiography
 - 6.2 Doublewall radiography
 - 6.2.1 Viewing two walls simultaneously
 - 6.2.2 Offset doublewall exposure singlewall viewing
 - 6.2.3 Elliptical techniques
 - 6.3 Panoramic radiography
 - 6.4. Use of multiplefilm loading
 - 6.5 Specimen configuration
- 7.0 Fluoroscopic Techniques**
 - 7.1 Dark adaptation and eye sensitivity
 - 7.2 Special scattered radiation techniques
 - 7.3 Personnel protection
 - 7.4 Sensitivity
 - 7.5 Limitations
 - 7.6 Direct screen viewing
 - 7.7 Indirect and remote screen viewing

Total recommended hours of instruction for the course:

Classification A – 15 hours

Classification B – 10 hours

Recommended Training for Level II Radiographic Testing Film Quality and Manufacturing Processes Course

1.0 Review of Basic Radiographic Principles

- 1.1 Interaction of radiation with matter
- 1.2 Math review
- 1.3 Exposure calculations
- 1.4 Geometric exposure principles
- 1.5 Radiographic-image quality parameters

2.0 Darkroom Facilities, Techniques and Processing

- 2.1 Facilities and equipment
 - 2.1.1 Automatic film processor versus manual processing
 - 2.1.2 Safe lights
 - 2.1.3 Viewer lights
 - 2.1.4 Loading bench
 - 2.1.5 Miscellaneous equipment
- 2.2 Film loading
 - 2.2.1 General rules for handling unprocessed film
 - 2.2.2 Types of film packaging
 - 2.2.3 Cassette loading techniques for sheet and roll
- 2.3 Protection of radiographic film in storage
- 2.4 Processing of film – manual
 - 2.4.1 Developer and replenishment
 - 2.4.2 Stop bath
 - 2.4.3 Fixer and replenishment
 - 2.4.4 Washing
 - 2.4.5 Prevention of water spots
 - 2.4.6 Drying
- 2.5 Automatic film processing
- 2.6 Film filing and storage
 - 2.6.1 Retention-life measurements
 - 2.6.2 Long-term storage
 - 2.6.3 Filing and separation techniques
- 2.7 Unsatisfactory radiographs – causes and cures
 - 2.7.1 High film density
 - 2.7.2 Insufficient film density
 - 2.7.3 High contrast
 - 2.7.4 Low contrast
 - 2.7.5 Poor definition
 - 2.7.6 Fog
 - 2.7.7 Light leaks
 - 2.7.8 Artifacts
- 2.8 Film density
 - 2.8.1 Step-wedge comparison film
 - 2.8.2 Densitometers

3.0 Indications, Discontinuities and Defects

- 3.1 Indications
- 3.2 Discontinuities
 - 3.2.1 Inherent
 - 3.2.2 Processing
 - 3.2.3 Service
- 3.3 Defects

4.0 Manufacturing Processes and Associated Discontinuities

- 4.1 Casting processes and associated discontinuities
 - 4.1.1 Ingots, blooms and billets
 - 4.1.2 Sand casting
 - 4.1.3 Centrifugal casting
 - 4.1.4 Investment casting
- 4.2 Wrought processes and associated discontinuities
 - 4.2.1 Forgings
 - 4.2.2 Rolled products
 - 4.2.3 Extruded products
- 4.3 Welding processes and associated discontinuities
 - 4.3.1 Submerged arc welding (SAW)
 - 4.3.2 Shielded metal arc welding (SMAW)
 - 4.3.3 Gas metal arc welding (GMAW)
 - 4.3.4 Flux cored arc welding (FCAW)
 - 4.3.5 Gas tungsten arc welding (GTAW)
 - 4.3.6 Resistance welding
 - 4.3.7 Special welding processes – electron beam, electroslag, electrogas, etc.

5.0 Radiological Safety Principles Review

- 5.1 Controlling personnel exposure
- 5.2 Time, distance, shielding concepts
- 5.3 ALARA (as low as reasonably achievable) concept
- 5.4 Radiation-detection equipment
- 5.5 Exposure-device operating characteristics

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 15 hours

Radiographic Evaluation and Interpretation Course

1.0 Radiographic Viewing

- 1.1 Film-illuminator requirements
- 1.2 Background lighting
- 1.3 Multiple-composite viewing
- 1.4 Penetrameter placement
- 1.5 Personnel dark adaptation and visual acuity
- 1.6 Film identification
- 1.7 Location markers
- 1.8 Film-density measurement
- 1.9 Film artifacts

2.0 Application Techniques

- 2.1 Multiple-film techniques

- 2.1.1 Thickness variation parameters
 - 2.1.2 Film speed
 - 2.1.3 Film latitude
- 2.2 Enlargement and projection
- 2.3 Geometrical relationships
 - 2.3.1 Geometrical unsharpness
 - 2.3.2 Penetrameter sensitivity
 - 2.3.3 Source-to-film distance
 - 2.3.4 Focal-spot size
- 2.4 Triangulation methods for discontinuity location
- 2.5 Localized magnification
- 2.6 Film handling techniques
- 3.0 Evaluation of Castings**
 - 3.1 Casting method review
 - 3.2 Casting discontinuities
 - 3.3 Origin and typical orientation of discontinuities
 - 3.4 Radiographic appearance
 - 3.5 Casting codes/standards – applicable acceptance criteria
 - 3.6 Reference radiographs
- 4.0 Evaluation of Weldments**
 - 4.1 Welding method review
 - 4.2 Welding discontinuities
 - 4.3 Origin and typical orientation of discontinuities
 - 4.4 Radiographic appearance
 - 4.5 Welding codes/standards – applicable acceptance criteria
 - 4.6 Reference radiographs or pictograms
- 5.0 Standards, Codes and Procedures for Radiography**
 - 5.1 ASTM E94/E142
 - 5.2 Acceptable radiographic techniques and setups
 - 5.3 Applicable employer procedures
 - 5.4 Procedure for radiograph parameter verification
 - 5.5 Radiographic reports

Recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 20 hours

Radiographic Testing Method Level III Topical Outline

- 1.0 Principles/Theory**
 - 1.1 Nature of penetrating radiation
 - 1.2 Interaction between penetrating radiation and matter
 - 1.3 Radiography
 - 1.3.1 Imaging by film
 - 1.3.2 Imaging by fluorescent materials
 - 1.3.3 Imaging by electronic devices
 - 1.4 Radiometry

2.0 Equipment/Materials

- 2.1 Electrically generated sources
 - 2.1.1 X-ray sources
 - 2.1.1.1 Generators and tubes as an integrated system
 - 2.1.1.2 Sources of electrons
 - 2.1.1.3 Electron accelerating methods
 - 2.1.1.4 Target materials and characteristics
 - 2.1.1.5 Equipment design considerations
- 2.2 Particulate radiation sources
- 2.3 Radiation detectors
 - 2.3.1 Imaging
 - 2.3.1.1 Film principles properties
 - 2.3.1.2 Fluoroscopy
 - 2.3.1.3 TV and optical systems
 - 2.3.1.4 Other nonfilm devices
 - 2.3.2 Nonimaging devices
 - 2.3.2.1 Solid state detectors
 - 2.3.2.2 Gaseous ionization detectors
 - 2.3.2.3 Instrumentation
 - 2.3.2.4 Gaging and control processes
- 2.4 Gamma
 - 2.4.1 Exposure devices
 - 2.4.2 Source changers
 - 2.4.3 Remote handling equipment
 - 2.4.4 Collimators
 - 2.4.5 Specific characteristics
 - 2.4.5.1 Half lives
 - 2.4.5.2 Energy levels
 - 2.4.5.3 Half value layers
 - 2.4.5.4 Tenth value layers

3.0 Techniques/Calibration

- 3.1 Imaging considerations
 - 3.1.1 Sensitivity
 - 3.1.2 Contrast and definition
 - 3.1.3 Geometric factors
 - 3.1.4 Intensifying screens
 - 3.1.5 Scattered radiation
 - 3.1.6 Source factors
 - 3.1.7 Detection media
 - 3.1.8 Exposures curves
- 3.2 Film processing
 - 3.2.1 Darkroom procedures
 - 3.2.2 Darkroom equipment and chemicals
 - 3.2.3 Film processing
- 3.3 Viewing of radiographs
 - 3.3.1 Illuminator requirements
 - 3.3.2 Background lighting
 - 3.3.3 Optical aids
- 3.4 Judging radiographic quality
 - 3.4.1 Density
 - 3.4.2 Contrast
 - 3.4.3 Definition
 - 3.4.4 Artifacts
 - 3.4.5 IQIs
 - 3.4.6 Causes and correction of unsatisfactory radiographs
- 3.5 Exposure calculations

- 3.6 Radiographic techniques
 - 3.6.1 Blocking and filtering
 - 3.6.2 Multifilm techniques
 - 3.6.3 Enlargement and projection
 - 3.6.4 Stereoradiography
 - 3.6.5 Triangulation methods
 - 3.6.6 Autoradiography
 - 3.6.7 Flash radiography
 - 3.6.8 In-motion radiography
 - 3.6.9 Fluoroscopy
 - 3.6.10 Electron emission radiography
 - 3.6.11 Microradiography
 - 3.6.12 Neutron radiography
 - 3.6.13 Laminography (tomography)
 - 3.6.14 Control of diffraction effects
 - 3.6.15 Pipe welding exposures
 - 3.6.15.1 Contact
 - 3.6.15.2 Elliptical
 - 3.6.15.3 Panoramic
 - 3.6.16 Gaging
 - 3.6.17 Real time imaging
 - 3.6.18 Image analysis techniques
 - 3.6.19 Image-object relationship
- 4.0 Interpretation/Evaluation**
 - 4.1 Material considerations
 - 4.1.1 Materials processing as it affects use of item and test results
 - 4.1.2 Discontinuities, their causes and effects
 - 4.1.3 Radiographic appearance of discontinuities
 - 4.1.4 Nonrelevant indications
 - 4.1.5 Film artifacts
- 5.0 Procedures**
- 6.0 Safety and Health**
 - 6.1 Exposure hazards
 - 6.1.1 Occupational dose limits
 - 6.2 Methods of controlling radiation exposure
 - 6.2.1 Time
 - 6.2.2 Distance
 - 6.2.2.1 Inverse square law
 - 6.2.3 Shielding
 - 6.2.3.1 Half-value layers
 - 6.2.3.2 Tenth-value layers
 - 6.3 Operational and emergency procedures
 - 6.4 Dosimetry and film badges
 - 6.5 Gamma leak testing
 - 6.6 Transportation regulations

Recommended Training References

Radiographic Testing Method

- Annual Book of ASTM Standards*, Volume 03.03, *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- Basic Metallurgy for Nondestructive Testing*, revised edition. Essex, England: W.H. Houldershaw, Ltd (British Institute of Nondestructive Testing), 1988.*
- Bryant, Lawrence A., and Paul McIntire, eds. *Nondestructive Testing Handbook*, Volume 3: second edition, *Radiography and Radiation Testing*. Columbus, OH: The American Society for Nondestructive Testing, 1985.*
- Clark, G. L., *Applied X-rays*. New York: McGraw Hill Book Co., 1955.**
- Halmshaw, R. *Industrial Radiology Techniques*. London: Wykeharn Publications; Ltd., New York: Springer-Verlag, Inc., 1971.**
- Halmshaw, R. *Industrial Radiology: Theory and Practice*. Englewood, New Jersey: Applied Science Publishers, 1982.*
- Halmshaw, R. *Nondestructive Testing: Metallurgy and Materials Science*. London: Edward Arnold, 1987.*
- Halmshaw, R. *Physics of Industrial Radiology*. New York: American Elsevier Publishing Co., 1966.*
- Hartford Steam Boiler's Complete Radiography Workbook*, first edition, Hartford, CT: The Hartford Steam Boiler Inspection and Insurance Co., 1983.
- Industrial Radiography/Holography*. Ridgefield Park, NJ: Agfa-Gevaert, Inc., 1986.*
- McGonnagle, Warren J. *Nondestructive Testing*, second edition, New York: Gordon and Breach, 1975.
- McGuire, Stephen A., and Carol A. Peabody. *Working Safely in Gamma Radiography*. NUREG/BR-0024. Washington, DC: U.S. Government Printing Office, 1982.*
- McMaster, Robert C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, 1959.*
- Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*
- Moore, Harry D., ed. *Materials and Processes for NDT Technology*. Columbus, OH: The American Society for Nondestructive Testing, 1981.*
- Munro, John J., III, and Francis E. Roy, Jr. *Gamma Radiography Radiation Safety Handbook*. Burlington, MA: Amersham Corp., 1986.*
- NDT Terminology*. Wilmington, DE: E. I. du Pont de Nemours and Co., 1981.
- Nondestructive Inspection and Quality Control: Metals Handbook*, Vol. 11, eighth edition Metals Park, OH: American Society for Metals, 1976.*
- Radiographs of Welds*. International Institute of Welding. Latest edition.*
- Radiographic Testing, Classroom Training Handbook (CT-6-6)*. San Diego, CA: General Dynamics/Convair Division, 1967.†
- Radiographic Testing, Programmed Instruction Handbook (PI-4-6)*. San Diego, CA: General Dynamics/Convair Division, 1983.†
- Radiography in Modern Industry*, fourth edition, Rochester, NY: Eastman Kodak Co., 1980.*
- Richardson, Harry D. *NDT Radiography Training Manual*. Wilmington, DE: E. I. du Pont de Nemours and Co., 1968 reprint.*
- Schneeman, J. G. *Industrial X-ray Interpretation*. Evanston, IL: Intex Publishing Co., 1985.*
- Sensitometric Properties of X-Ray Films*. Rochester, NY: Eastman Kodak Co., 1974.**
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Radiographic Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1996.*
- The Sense and Nonsense of Weld Defects*. Morton Grove, IL: Monticello Books, 1967.*
- Thielsch, Helmut. *Defects and Failures in Pressure Vessels and Piping*. New York: Reinhold Publishing Corp., 1966.*
- Welding Handbook*, Volume 1. Miami, FL: American Welding Society. Latest edition.*
- Welding Inspection*. Miami, FL: American Welding Society. Latest edition.

Note: Technical papers on much of the subject material can be found in the journal of ASNT, *Materials Evaluation*. For specific topics, see the 40-year index of *Materials Evaluation*, published in *Materials Evaluation*, December 1982, Vol. 40, No. 13. For papers published subsequently, see the December issues of *Materials Evaluation* for yearly indexes.

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Thermal/Infrared Testing Method

(Training Course Outline TC-10)

	Recommended Hours of Instruction	
	A*	B*
Level I		
Basic thermal/infrared physics course	12	10
Basic thermal/infrared operating course	10	10
Basic thermal/infrared applications course	10	10
Total	32	30
Level II		
Intermediate thermal/infrared physics course	12	10
Intermediate thermal/infrared operating course	10	10
Intermediate thermal/infrared applications course	12	12
Total	34	32

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Thermal/Infrared Testing

Basic Thermal/Infrared Physics Course

- 1.0 The nature of heat – what is it and how is it measured/expressed?**
 - 1.1 Instrumentation
 - 1.2 Scales and conversions
- 2.0 Temperature – what is it and how is it measured/expressed?**
 - 2.1 Instrumentation
 - 2.2 Scales and conversions
- 3.0 Heat Transfer Modes Familiarization**
 - 3.1 Heat conduction fundamentals
 - 3.1.1 Fourier’s law of heat conduction (concept)
 - 3.1.2 Conductivity/resistance basics
 - 3.2 Heat convection fundamentals
 - 3.2.1 Newton’s law of cooling (concept)
 - 3.2.2 Film coefficient/film resistance basics
 - 3.3 Heat radiation fundamentals
 - 3.3.1 Stefan-Boltzmann law (concept)
 - 3.3.2 Emissivity/absorptivity/reflectivity/transmissivity basics (Kirchhoff’s Law)
- 4.0 Radiosity Concepts Familiarization**
 - 4.1 Reflectivity
 - 4.2 Transmissivity
 - 4.3 Absorptivity
 - 4.4 Emissivity
 - 4.5 Infrared radiometry and imaging
 - 4.6 Spatial resolution concepts
 - 4.6.1 Field of view (FOV)
 - 4.6.2 Instantaneous field of view (IFOV) – ref. ASTM E-1149
 - 4.6.3 Spatial resolution for temperature measurement – the Split Response Function (SRF)
 - 4.6.4 Measurement Instantaneous Field of View (MIFOV)
 - 4.7 Error potential in radiant measurements (an overview)

Basic Thermal/Infrared Operating Course

- 1.0 Introduction**
 - 1.1 Thermography defined
 - 1.2 How infrared imagers work
 - 1.3 Differences among imagers and alternative equipment
 - 1.4 Operation of infrared thermal imager
 - 1.4.1 Selecting the best perspective
 - 1.4.2 Image area and lens selection for required details
 - 1.4.3 Optimizing the image
 - 1.4.4 Basic temperature measurement
 - 1.4.5 Basic emissivity measurement
 - 1.5 Operation of support equipment for infrared surveys

2.0 Checking Equipment Calibration with Blackbody References

3.0 Infrared Image and Documentation Quality

- 3.1 Elements of a good infrared image
 - 3.1.1 Clarity (focus)
 - 3.1.2 Dynamic range of the image
 - 3.1.3 Recognizing and dealing with reflections
 - 3.1.4 Recognizing and dealing with spurious convection
- 3.2 Recording
 - 3.2.1 Video tape
 - 3.2.2 Photographic images
 - 3.2.3 Video photo cameras
 - 3.2.4 Digital recording
 - 3.2.5 Videoprinters

4.0 Support Data Collection

- 4.1 Environmental data
- 4.2 Emissivity
 - 4.2.1 Measurement
 - 4.2.2 Estimation
 - 4.2.3 Surface modification
- 4.3 Surface reference temperatures
- 4.4 Identification and other

Basic Thermal/Infrared Applications Course

1.0 Detecting Thermal Anomalies Resulting from Differences in Thermal Resistance (Quasi-steady-state Heat Flow)

- 1.1 Large surface-to-ambient temperature difference
- 1.2 Small surface-to-ambient temperature difference

2.0 Detecting Thermal Anomalies Resulting from Differences in Thermal Capacitance, Using System or Environmental Heat Cycles

3.0 Detecting Thermal Anomalies Resulting from Differences in Physical State

4.0 Detecting Thermal Anomalies Resulting from Fluid Flow Problems

5.0 Detecting Thermal Anomalies Resulting from Friction

6.0 Detecting Thermal Anomalies Resulting from Nonhomogeneous Exothermic or Endothermic Conditions

7.0 Field Quantification of Point Temperatures

- 7.1 Simple techniques for emissivity
- 7.2 Typical (high emissivity) applications
- 7.3 Special problem of low emissivity applications

Recommended Training for Level II Thermal/Infrared Testing

Intermediate Thermal/Infrared Physics Course

1.0 Basic Calculations in the Three Modes of Heat Transfer

- 1.1 Conduction – principles and elementary calculation
 - 1.1.1 Thermal resistance – principles and elementary calculations
 - 1.1.2 Heat capacitance – principles and elementary calculations
- 1.2 Convection – principles and elementary calculations
- 1.3 Radiation – principles and elementary calculations

2.0 The Infrared Spectrum

- 2.1 Planck's law/curves
 - 2.1.1 Typical detected bands
 - 2.1.2 Spectral emissivities of real surfaces
- 2.2 Effects due to semitransparent windows and/or gasses
- 2.3 Filters

3.0 Radiosity Problems

- 3.1 Blackbodies – theory and concepts
- 3.2 Emissivity problems
 - 3.2.1 Blackbody emissivity
 - 3.2.2 The graybody and the nongraybody
 - 3.2.3 Broadband and narrowband emitter targets
 - 3.2.4 Specular and diffuse emitters
 - 3.2.5 Lambertian and non-Lambertian emitters (the angular sensitivity of emissivity)
 - 3.2.6 Effects of emissivity errors
- 3.3 Calculation of emissivity, reflectivity and transmissivity (practical use of Kirchhoff's law)
- 3.4 Reflectivity problem
 - 3.4.1 Quantifying effects of unavoidable reflections
 - 3.4.2 Theoretical corrections
- 3.5 Transmissivity problem
 - 3.5.1 Quantified effects of partial transmittance
 - 3.5.2 Theoretical corrections

4.0 Resolution Tests and Calculations

- 4.1 IFOV, FOV and MIFOV measurements and calculations
- 4.2 MRTD measurements and calculations
- 4.3 Slit response function – measurement, calculations, interpretations and comparisons
- 4.4 Resolution versus lens and distance
- 4.5 Dynamic range
- 4.6 Data acquisition rate/data density
- 4.7 Frame rate and field rate
- 4.8 Image data density
 - 4.8.1 Lines of resolution
 - 4.8.2 IFOVs/line
 - 4.8.3 Computer pixels/line

Intermediate Thermal/Infrared Operating Course

1.0 Operating for Infrared Measurements (Quantification)

- 1.1 Simple infrared energy measurement

- 1.2 Quantifying the emissivity of the target surface
 - 1.3 Quantifying temperature profiles
 - 1.3.1 Use of blackbody temperature references in the image
 - 1.3.2 Use of temperature measurement devices for reference surface temperatures
 - 1.3.3 Common sources of temperature measurement errors
 - 1.4 Computer processing to enhance imager data
- 2.0 Operating for High Speed Data Collection**
- 2.1 Producing accurate images of transient processes
 - 2.2 Recording accurate images of transient processes
 - 2.3 Equipment selection and operation for imaging from moving vehicles
- 3.0 Operating Special Equipment for “Active” Techniques**
- 3.1 Hot or cold fluid energy sources
 - 3.2 Heat lamp energy sources
 - 3.3 Flash-lamp energy sources
 - 3.4 Electromagnetic induction
 - 3.5 Laser energy sources
- 4.0 Reports and Documentation**
- 4.1 Calibration requirements and records
 - 4.2 Report data requirements
 - 4.3 Preparing reports

Intermediate Thermal/Infrared Applications Course

- 1.0 Temperature Measurement Applications**
- 1.1 Isotherms/alarm levels – personnel safety audits, etc.
 - 1.2 Profiles
- 2.0 Energy Loss Analysis Applications**
- 2.1 Conduction losses through envelopes
 - 2.1.1 Basic envelope heat-flow quantification
 - 2.1.2 Recognizing and dealing with wind effects
 - 2.2 Mass transfer heat exchange (air or other flows into or out of the system)
 - 2.2.1 Location
 - 2.2.2 Quantification
- 3.0 “Active” Applications**
- 3.1 Insulation flaws
 - 3.2 De-Lamination of composites
 - 3.3 Bond quality of coatings
 - 3.4 Location of high heat-capacity components
- 4.0 Filtered Applications**
- 4.1 Sunlight
 - 4.2 Furnace interiors
 - 4.3 Semitransparent targets
- 5.0 Transient Applications**
- 5.1 Imaging a rapidly moving process
 - 5.2 Imaging from a vehicle

Thermal/Infrared Testing Method

Level III Topical Outline

1.0 Principles/Theory

- 1.1 Conduction
- 1.2 Convection
- 1.3 Radiation
- 1.4 The nature of heat and flow
 - 1.4.1 Exothermic or endothermic conditions
 - 1.4.2 Friction
 - 1.4.3 Variations in fluid flow
 - 1.4.4 Variations in thermal resistance
 - 1.4.5 Thermal capacitance
- 1.5 Temperature measurement principles
- 1.6 Proper selection of thermal/infrared testing as technique of choice
 - 1.6.1 Differences between thermal/infrared testing and other techniques
 - 1.6.2 Complementary roles of thermal/infrared testing and other methods
 - 1.6.3 Potential for conflicting results between methods
 - 1.6.4 Factors that qualify/disqualify the use of thermal/infrared testing

2.0 Equipment/Materials

- 2.1 Temperature measurement equipment
 - 2.1.1 Liquid-in-glass thermometers
 - 2.1.2 Vapor – pressure thermometers
 - 2.1.3 Bourdon – tube thermometers
 - 2.1.4 Bimetallic thermometers
 - 2.1.5 Melting point indicators
 - 2.1.6 Thermochromic liquid crystal materials
 - 2.1.7 (Irreversible) Thermochromic change materials
 - 2.1.8 Thermocouples
 - 2.1.9 Resistance thermometers
 - 2.1.9.1 RTDs
 - 2.1.9.2 Thermistors
 - 2.1.10 Optical pyrometers
 - 2.1.11 Infrared pyrometers
 - 2.1.12 Two color infrared pyrometers
 - 2.1.13 Laser/infrared pyrometers
 - 2.1.14 Integrating hemisphere radiation pyrometers
 - 2.1.15 Fiberoptic thermometers
 - 2.1.16 Infrared photographic films and cameras
 - 2.1.17 Infrared line – scanners
 - 2.1.18 Thermal/infrared imagers
 - 2.1.18.1 Pyroelectric vidicons
 - 2.1.18.2 Singledetector scanners
 - 2.1.18.3 Multidetector scanners
 - 2.1.18.4 Staring arrays
- 2.2 Heat flux indicators
- 2.3 Performance parameters of noncontact devices
 - 2.3.1 Absolute precision and accuracy
 - 2.3.2 Repeatability
 - 2.3.2 Repeatability
 - 2.3.3 Sensitivity
 - 2.3.4 Spectral response limits
 - 2.3.5 Response time
 - 2.3.6 Drift

- 2.3.7 Spot size ratio
- 2.3.8 Instantaneous field of view
- 2.3.9 Minimum resolvable temperature difference
- 2.3.10 Slit response function

3.0 Techniques

- 3.1 Contact temperature indicators
 - 3.1.1 Calibration
- 3.2 Noncontact pyrometers
 - 3.2.1 Calibration of equipment
 - 3.2.2 Quantifying emissivity
 - 3.2.3 Evaluating background radiation
 - 3.2.4 Measuring (or mapping) radiant energy
 - 3.2.5 Measuring (or mapping) surface temperatures
 - 3.2.6 Measuring (or mapping) surface heat flows
 - 3.2.7 Use in high temperature environments
 - 3.2.8 Use in high magnetic field environments
 - 3.2.9 Measurements on small targets
 - 3.2.10 Measurements through semitransparent materials
- 3.3 Infrared line scanners
 - 3.3.1 Calibration of equipment
 - 3.3.2 Quantifying emissivity
 - 3.3.3 Evaluating background radiation
 - 3.3.4 Measuring (or mapping) surface radiant energy
 - 3.3.5 Measuring (or mapping) surface temperatures
 - 3.3.6 Measuring (or mapping) surface heat flows
 - 3.3.7 Use in high temperature environments
 - 3.3.8 Use in high magnetic field environments
 - 3.3.9 Measurements on small targets
 - 3.3.10 Measurements through semitransparent materials
- 3.4 Thermal/Infrared imaging
 - 3.4.1 Calibration of equipment
 - 3.4.2 Quantifying emissivity
 - 3.4.3 Evaluating background radiation
 - 3.4.4 Measuring (or mapping) surface radiant energy
 - 3.4.5 Measuring (or mapping) surface temperatures
 - 3.4.6 Measuring (or mapping) surface heat flows
 - 3.4.7 Use in high temperature environments
 - 3.4.8 Use in high magnetic field environments
 - 3.4.9 Measurements on small targets
 - 3.4.10 Measurements through semitransparent materials
- 3.5 Heat flux indicators
 - 3.5.1 Calibration of equipment
 - 3.5.2 Measurement of heat flow
- 3.6 Exothermic or endothermic investigations: typical examples may include, but are not limited to, the following:
 - 3.6.1 Power distribution systems
 - 3.6.1.1 Exposed electrical switchgear
 - 3.6.1.2 Enclosed electrical switchgear
 - 3.6.1.3 Exposed electrical busses
 - 3.6.1.4 Enclosed electrical busses
 - 3.6.1.5 Transformers
 - 3.6.1.6 Electric rotating equipment
 - 3.6.1.7 Overhead power lines
 - 3.6.1.8 Coils
 - 3.6.1.9 Capacitors

- 3.6.1.10 Circuit breakers
 - 3.6.1.11 Indoor wiring
 - 3.6.1.12 Motor control center starters
 - 3.6.1.13 Lighter arrestors
 - 3.6.2 Chemical processes
 - 3.6.3 Foam-in-place insulation
 - 3.6.4 Fire fighting
 - 3.6.4.1 Building investigations
 - 3.6.4.2 Outside ground base investigations
 - 3.6.4.3 Outside airborne investigations
 - 3.6.5 Moisture in airframes
 - 3.6.6 Underground investigations
 - 3.6.6.1 Airborne coal mine fires
 - 3.6.6.2 Utility locating
 - 3.6.6.3 Utility pipe leak detection
 - 3.6.6.4 Void detection
 - 3.6.7 Locating and mapping utilities concealed in structures
 - 3.6.8 Mammal location and monitoring
 - 3.6.8.1 Ground investigations
 - 3.6.8.2 Airborne investigations
 - 3.6.8.3 Sorting mammals according to stress levels
 - 3.6.9 Fracture dynamics
 - 3.6.10 Process heating or cooling
 - 3.6.10.1 Rate
 - 3.6.10.2 Uniformity
 - 3.6.11 Heat tracing or channelized cooling
 - 3.6.12 Radiant heating
 - 3.6.13 Electronic components
 - 3.6.13.1 Assembled circuit boards
 - 3.6.13.2 Bare printed circuit boards
 - 3.6.13.3 Semiconductor microcircuits
 - 3.6.14 Welding
 - 3.6.14.1 Welding technique parameters
 - 3.6.14.2 Material parameters
 - 3.6.15 Mapping of energy fields
 - 3.6.15.1 Electromagnetic fields
 - 3.6.15.2 Electromagnetic heating processes
 - 3.6.15.3 Radiant heat flux distribution
 - 3.6.15.4 Acoustic fields
 - 3.6.16 Gaseous plumes
 - 3.6.16.1 Monitoring
 - 3.6.16.2 Mapping
 - 3.6.17 Ground frostline mapping
- 3.7 Friction investigations: typical examples may include, but are not limited to, the following:
 - 3.7.1 Bearings
 - 3.7.2 Seals
 - 3.7.3 Drive belts
 - 3.7.4 Drive couplings
 - 3.7.5 Exposed gears
 - 3.7.6 Gearboxes
 - 3.7.7 Machining processes
 - 3.7.8 Aerodynamic heating
- 3.8 Fluid flow investigations: typical examples may include, but are not limited to, the following:
 - 3.8.1 Fluid piping
 - 3.8.2 Valves

- 3.8.3 Heat exchangers
- 3.8.4 Fin fans
- 3.8.5 Cooling ponds
- 3.8.6 Cooling towers
- 3.8.7 Distillation towers
 - 3.8.7.1 Packed
 - 3.8.7.2 Trays
- 3.8.8 HVAC systems
- 3.8.9 Lake and ocean current mapping
- 3.8.10 Mapping civil and industrial outflows into waterways
- 3.8.11 Locating leaks in pressure systems
- 3.8.12 Filters
- 3.9 Thermal resistance (steady state heat flow) investigations: typical examples may include, but are not limited to, the following:
 - 3.9.1 Thermal safety audits
 - 3.9.2 Low temperature insulating systems
 - 3.9.4 Industrial insulation systems
 - 3.9.5 Refractory systems
 - 3.9.6 Semitransparent walls
 - 3.9.7 Furnace interiors
 - 3.9.8 Disbonds in lined process equipment
- 3.10 Thermal capacitance investigations: typical examples may include, but are not limited to, the following:
 - 3.10.1 Tank levels
 - 3.10.2 Rigid injection molding
 - 3.10.3 Thermal laminating processes
 - 3.10.4 Building envelopes
 - 3.10.5 Roof moisture
 - 3.10.5.1 Roof level investigations
 - 3.10.5.2 Airborne investigations
 - 3.10.6 Underground voids
 - 3.10.7 Bridge deck laminations
 - 3.10.8 Steam traps
 - 3.10.9 Paper manufacturing moisture profiles
 - 3.10.10 Subsurface discontinuity detection in materials
 - 3.10.11 Coating disbond
 - 3.10.12 Structural materials
 - 3.10.12.1 Subsurface discontinuity detection
 - 3.10.12.2 Thickness variations
 - 3.10.12.3 Disbonding

4.0 Interpretation/Evaluation

- 4.1 Exothermic or endothermic investigation: typical examples may include, but are not limited to, the examples shown in Section 3.6.
- 4.2 Friction investigations: typical examples may include, but are not limited to, the examples shown in Section 3.7.
- 4.3 Fluid flow investigations: typical examples may include, but are not limited to, the examples shown in Section 3.8.
- 4.4 Differences in thermal resistance (stead state heat flow) investigations: typical examples may include, but are not limited to, the examples shown in Section 3.9.
- 4.5 Thermal capacitance investigations: typical examples may include, but are not limited to, the examples shown in Section 3.10.

5.0 Procedures

- 5.1 Existing codes and standards
- 5.2 Elements of thermal/infrared testing job procedure development

6.0 Safety and Health

- 6.1 Safety responsibility and authority
- 6.2 Safety for personnel
 - 6.2.1 Liquefied nitrogen handling
 - 6.2.2 Compressed gas handling
 - 6.2.3 Battery handling
 - 6.2.4 Safety clothing
 - 6.2.5 Safety ropes and harnesses
 - 6.2.6 Ladders
 - 6.2.7 Safety backup personnel
- 6.3 Safety for client and facilities
- 6.4 Safety for testing equipment

Recommended Training References Thermal/Infrared Testing Method, Level I, II and III

Applied Infrared Photography. Eastman Kodak Company, 1987.

Asimov, Isaac. *Understanding Physics*. Three volumes in one, Dorset Press, 1988.

ASNT's Infrared Thermography Topical Conference 1997 Paper Summaries Book. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1997.*

Bernard, Bertram. *The ABC's of Infrared*. Howard W. Sams & Co., Inc., 1970.

Buckely, Robert E. and Gene D. Nutter. *Handbook of Applied Thermal Design*. New York: McGraw Hill, 1988.

Burnay, S. G., et. al., eds. *Application of Thermal Imaging*. Bristol, UK: Adam Hilger, 1988.

Cohen, Julius. (1983, May). *Elements of Thermography for Nondestructive Testing*, NBS Technical Note, V1177 GPO S/N 83020123.

Colwell, Robert N., ed. *Manual of Remote Sensing*, second edition, Volumes I and II. American Society of Photogrammetry, 1983.

DeWit, D. P. *Theory and Practice of Radiation Thermometry*. New York: John Wiley & Sons, Inc., 1989.*

Electro-Optics Handbook. Burle Industries, 1974.

Falk, David S., Dieter R. Brill, and David G. Stork. *Seeing the Light*. New York: John Wiley and Sons, 1977.

Gaussorgues, G. *Infrared Thermography* (Original French Title: *La Thermographie Infrarouge*). Translated by S. Chomet. Microwave Technology Series 5. English Language Edition. Chapman & Hall, 1994.**

Geankoplis, Christie J. *Transport Processes and Unit Operations*. Boston, MA: Allyn & Bacon, 1978.**

Guyer, Eric C. *Handbook of Applied Thermal Design*. New York: McGraw-Hill, 1989.

Hackforth, Henry L. *Infrared Radiation*. McGraw-Hill, 1960.**

Holman, J. P. *Experimental Methods for Engineers*, seventh edition. New York: McGraw-Hill, 2000.

Holman, J. P. *Heat Transfer*. New York: McGraw-Hill, 1997.

Holst, Gerald C. *Testing and Evaluation of Infrared Imaging Systems*, second edition. JCD Publishing Co., 1998.

Holst, Gerald C. *Common Sense Approach to Thermal Imaging*. JCD Publishing Co., SPIE – The International Society for Optical Engineering, 2000.

Hougan, O. A., K. M. Watson, and R.A. Ragatz. *Chemical Process Principles*, third edition. New York: John Wiley & Sons, Inc., 1985.

Incopera, Frank P. and David P. DeWitt. *Fundamentals of Heat and Mass Transfer*, fourth edition. New York: John Wiley & Sons, Inc., 1996.*

Kaplan, Herbert. *Practical Applications of Infrared Thermal Sensing and Imaging Equipment*, Vol. TT13. Bellingham, WA: SPIE Press, 1993.

Kerlin, Thomas W. and Robert L. Shepard. *Industrial Temperature Measurement*. Research Triangle Park, NC: Instrument Society of America, 1982.

Kreith, Frank and Mark S. Bohn. *Principles of Heat Transfer*. New York: Harper & Row, 1986.

Lloyd, J. M. *Thermal Imaging Systems*. New York: Harper and Row, 1986.

Lucier, Ronald D., ed. *Selected Papers on Temperature Sensing: Optical Methods*, volume MS 116, Milestone Series. SPIE Optical Engineering Press, 1995.

- Madding, Robert P. *Thermographic Instruments and Systems*. University of Wisconsin-Extension, Department of Engineering and Applied Science, 423 North Lake Street, Madison, WI 53706.**
- Magnum, B. W. and G.T. Furukawa. *Guidelines for Realizing the International Temperature Scale of 1990*. Washington D.C.: U.S. Government Printing Office, 1990.
- Maldague, Xavier P. V. *Nondestructive Evaluation of Materials by Infrared Thermography*. London: Springer-Verlag, 1993.*
- Maldague, Xavier P.V., editor. *Infrared Methodology and Technology*. Gordon and Breach Science Publishers, 1994.
- Manual for Thermographic Analysis of Building Enclosures. 149-GP-2MP*, Committee on Thermography. Canadian General Standards Board, 1986.
- MIL-HDBK-728 Vol. 1 "Nondestructive Testing."
- Pettersson, Bertil. *Thermography, Testing of the Thermal Insulation and Airtightness of Building*. Swedish Council for Building Research, 1980.
- Rohsenow, Warren M. and James P. Hartnett, eds. *Handbook of Heat Transfer*. McGraw-Hill, 1973.
- Schlessinger, Monroe. *Infrared Technology Fundamentals*, Optical Engineering Series/46. second edition, revised and expanded. Dekker, Marcel Inc., 1994.
- Simon, Ivan. *Infrared Radiation*. D. Van Nostrand Company, Inc., Van Nostrand Momentum Book #12, 1966.**
- Standards, Tentative Standards, and Special Technical Publications (STP) Relating to Infrared Imaging Applications*. Philadelphia, PA: American Society for Testing and Materials. Latest issue.
- Stanley, Roderick K., technical ed.; Paul McIntire and Patrick O. Moore, eds. *Nondestructive Testing Handbook*, volume 9: second edition, *Special Nondestructive Testing Methods*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1995.*
- Thomas, Roderick A. *The Thermography Monitoring Handbook*, first edition. Coxmoor Publishing Company, 1999.
- Tipler, Paul A. *Modern Physics*. second edition. Worth Publishers, Inc., 1978.
- Turner, William C. and John F. Malloy. *Thermal Insulation Handbook*. New York: McGraw-Hill, 1981.**
- Va_ko, Antonín, D. Sc., *Infra-red Radiation*. English translation edited by P.S. Allen, B.Sc., PhD., Lecturer, Department of Physics, University of Nottingham. Translated by Sylvia E. Myhre-Finková and Karel Fink 1967. English edition © Iliffe Books Ltd., 1968.**
- von Baeyer, Hans Christian. *Warmth Disperses and Time Passes – The History of Heat*. Random House, 1999.
- Walder, Jearl. *The Flying Circus of Physics*. John Wiley & Sons, 1977.
- Wolfe, William L. and George J. Ziessis, eds. *The Infrared Handbook*. The Environmental Research Institute of Michigan (prepared for The Department of Navy), 1985.
- Zemansky, Mark W. *Temperatures: Very Low and Very High*. Dover Publications, 1981.
- Ziessis, George J., ed. *The Infrared & Electro-Optical Systems Handbook*, Volumes 1-8. Bellington, WA: SPIE Press, 1993.

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

Ultrasonic Testing Method

(Training Course Outline TC-3)

		Recommended Hours of Instruction	
		A*	B*
Level I			
Basic ultrasonic course		20	15
Ultrasonic technique course		20	15
Total		40	30
Level II			
Ultrasonic evaluation course		40	40
Total		40	40

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Ultrasonic Testing

Basic Ultrasonic Course

Note: It is recommended that the trainee receive instruction in this course prior to performing work in ultrasonics.

1.0 Introduction

- 1.1 Definition of ultrasonics
- 1.2 History of ultrasonic testing
- 1.3 Applications of ultrasonic energy
- 1.4 Basic math review
- 1.5 Responsibilities of levels of certification

2.0 Basic Principles of Acoustics

- 2.1 Nature of sound waves
- 2.2 Modes of sound-wave generation
- 2.3 Velocity, frequency and wavelength of sound waves
- 2.4 Attenuation of sound waves
- 2.5 Acoustic impedance
- 2.6 Reflection
- 2.7 Refraction and mode conversion
- 2.8 Snell's law and critical angles
- 2.9 Fresnel and Fraunhofer effects

3.0 Equipment

- 3.1 Basic pulse-echo instrumentation (A scan, B scan, C scan and computerized systems)
 - 3.1.1 Electronics – time base, pulser, receiver and various monitor displays
 - 3.1.2 Control functions
 - 3.1.3 Calibration
 - 3.3.3.1 Basic instrument calibration
 - 3.3.3.2 Calibration blocks (types and use)
- 3.2 Digital thickness instrumentation
- 3.3 Transducer operation and theory
 - 3.3.1 Piezoelectric effect
 - 3.3.2 Types of transducer elements
 - 3.3.3 Frequency (transducer elements, thickness relationships)
 - 3.3.4 Near field and far field
 - 3.3.5 Beam spread
 - 3.3.6 Construction, materials and shapes
 - 3.3.7 Types (straight, angle, dual, etc.)
 - 3.3.8 Beam-intensity characteristics
 - 3.3.9 Sensitivity, resolution and damping
 - 3.3.10 Mechanical vibration into part
 - 3.3.11 Other type of transducers (laser UT, EMAT, etc.)
- 3.4 Couplants
 - 3.4.1 Purpose and principles
 - 3.4.2 Materials and their efficiency

4.0 Basic Testing Methods

- 4.1 Contact
- 4.2 Immersion
- 4.3 Air coupling

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 15 hours

Ultrasonic Technique Course

1.0 Testing Methods

- 1.1 Contact
 - 1.1.1 Straight beam
 - 1.1.2 Angle beam
 - 1.1.3 Surface wave and plate waves
 - 1.1.4 Pulse-echo transmission
 - 1.1.5 Multiple transducer
 - 1.1.6 Curved surfaces
 - 1.1.6.1 Flat entry surfaces
 - 1.1.6.2 Cylindrical and tubular shapes
- 1.2 Immersion
 - 1.2.1 Transducer in water
 - 1.2.2 Water column, wheels, etc.
 - 1.2.3 Submerged test part
 - 1.2.4 Sound-beam path B transducer to part
 - 1.2.5 Focused transducers
 - 1.2.6 Curved surfaces
 - 1.2.7 Plate waves
 - 1.2.8 Pulse-echo and through-transmission
- 1.3 Comparison of contact and immersion methods

2.0 Calibration (Electronic and Functional)

- 2.1 Equipment
 - 2.1.1 Monitor displays (amplitude, sweep, etc.)
 - 2.1.2 Recorders
 - 2.1.3 Alarms
 - 2.1.4 Automatic and semiautomatic systems
 - 2.1.5 Electronic distance/amplitude correction
 - 2.1.6 Transducers
- 2.2 Calibration of equipment electronics
 - 2.2.1 Variable effects
 - 2.2.2 Transmission accuracy
 - 2.2.3 Calibration requirements
 - 2.2.4 Calibration reflectors
- 2.3 Inspection calibration
 - 2.3.1 Comparison with reference blocks
 - 2.3.2 Pulse-echo variables
 - 2.3.3 Reference for planned tests (straight beam, angle beam, etc.)
 - 2.3.4 Transmission factors
 - 2.3.5 Transducer
 - 2.3.6 Couplants
 - 2.3.7 Materials

3.0 Straight Beam Examination to Specific Procedures

- 3.1 Selection of parameters
- 3.2 Test standards
- 3.3 Evaluation of results
- 3.4 Test reports

4.0 Angle Beam Examination to Specific Procedures

- 4.1 Selection of parameters
- 4.2 Test standards
- 4.3 Evaluation of results
- 4.4 Test reports

Total recommended hours of instruction for this course:

Classification A – 20 hours

Classification B – 15 hours

Recommended Training for Level II Ultrasonic Testing

Ultrasonic Evaluation Course

1.0 Review of Ultrasonic Technique Course

- 1.1 Principles of ultrasonics
- 1.2 Equipment
 - 1.2.1 A scan
 - 1.2.2 B scan
 - 1.2.3 C scan
 - 1.2.4 Computerized systems
- 1.3 Testing techniques
- 1.4 Calibration
 - 1.4.1 Straight beam
 - 1.4.2 Angle beam
 - 1.4.3 Resonance
 - 1.4.4 Special applications

2.0 Evaluation of Base Material Product Forms

- 2.1 Ingots
 - 2.1.1 Process review
 - 2.1.2 Types, origin and typical orientation of discontinuities
 - 2.1.3 Response of discontinuities to ultrasound
 - 2.1.4 Applicable codes/standards
- 2.2 Plate and sheet
 - 2.2.1 Rolling process
 - 2.2.2 Types, origin and typical orientation of discontinuities
 - 2.2.3 Response of discontinuities to ultrasound
 - 2.2.4 Applicable codes/standards
- 2.3 Bar and rod
 - 2.3.1 Forming process
 - 2.3.2 Types, origin and typical orientation of discontinuities
 - 2.3.3 Response of discontinuities to ultrasound
 - 2.3.4 Applicable codes/standards
- 2.4 Pipe and tubular products
 - 2.4.1 Manufacturing process
 - 2.4.2 Types, origin and typical orientation of discontinuities
 - 2.4.3 Response of discontinuities to ultrasound
 - 2.4.4 Applicable codes/standards
- 2.5 Forgings
 - 2.5.1 Process review
 - 2.5.2 Types, origin and typical orientation of discontinuities

- 2.5.3 Response of discontinuities to ultrasound
 - 2.5.4 Applicable codes/standards
 - 2.6 Castings
 - 2.6.1 Process review
 - 2.6.2 Types, origin and typical orientation of discontinuities
 - 2.6.3 Response of ultrasound to discontinuities
 - 2.6.4 Applicable codes/standards
 - 2.7 Composite structures
 - 2.7.1 Process review
 - 2.7.2 Types, origin and typical orientation of discontinuities
 - 2.7.3 Response of ultrasound to discontinuities
 - 2.7.4 Applicable codes/standards
 - 2.8 Other product forms as applicable B rubber, glass, etc.
- 3.0 Evaluation of Weldments**
- 3.1 Welding processes
 - 3.2 Weld geometries
 - 3.3 Welding discontinuities
 - 3.4 Origin and typical orientation of discontinuities
 - 3.5 Response of discontinuities to ultrasound
 - 3.6 Applicable codes/standards
- 4.0 Evaluation of Bonded Structures**
- 4.1 Manufacturing processes
 - 4.2 Types of discontinuities
 - 4.3 Origin and typical orientation of discontinuities
 - 4.4 Response of discontinuities to ultrasound
 - 4.5 Applicable codes/standards
- 5.0 Discontinuity Detection**
- 5.1 Sensitivity to reflections
 - 5.1.1 Size, type and location of discontinuities
 - 5.1.2 Techniques used in detection
 - 5.1.3 Wave characteristics
 - 5.1.4 Material and velocity
 - 5.2 Resolution
 - 5.2.1 Standard reference comparisons
 - 5.2.2 History of part
 - 5.2.3 Probability of type of discontinuity
 - 5.2.4 Degrees of operator discrimination
 - 5.2.5 Effects of ultrasonic frequency
 - 5.2.6 Damping effects
 - 5.3 Determination of discontinuity size
 - 5.3.1 Various monitor displays and meter indications
 - 5.3.2 Transducer movement versus display
 - 5.3.3 Two-dimensional testing techniques
 - 5.3.4 Signal patterns
 - 5.4 Location of discontinuity
 - 5.4.1 Various monitor displays
 - 5.4.2 Amplitude and linear time
 - 5.4.3 Search technique

6.0 Evaluation

- 6.1 Comparison procedures
 - 6.1.1 Standards and references
 - 6.1.2 Amplitude, area and distance relationship
 - 6.1.3 Application of results of other NDT methods
- 6.2 Object appraisal
 - 6.2.1 History of part
 - 6.2.2 Intended use of part
 - 6.2.3 Existing and applicable code interpretation
 - 6.2.4 Type of discontinuity and location

Total recommended hours of instruction for this course:

Classification A – 40 hours

Classification B – 40 hours

Ultrasonic Testing Method Level III Topical Outline

1.0 Principles/Theory

- 1.1 General
- 1.2 Principles of acoustics
 - 1.2.1 Nature of sound waves
 - 1.2.2 Modes of sound wave generation
 - 1.2.3 Velocity, frequency and wavelength of sound waves
 - 1.2.4 Attenuation of sound waves
 - 1.2.5 Acoustic impedance
 - 1.2.6 Reflection
 - 1.2.7 Refraction and mode conversion
 - 1.2.8 Snell's law and critical angles
 - 1.2.9 Fresnel and Fraunhofer effects

2.0 Equipment/Materials

- 2.1 Equipment
 - 2.1.1 Pulse-echo instrumentation
 - 2.1.1.1 Controls and circuits
 - 2.1.1.2 Pulse generation (spike, square wave and toneburst pulsers)
 - 2.1.1.3 Signal detection
 - 2.1.1.4 Display and recording methods, A scan, B scan, C scan and digital
 - 2.1.1.5 Sensitivity and resolution
 - 2.1.1.6 Gates, alarms and attenuators
 - 2.1.1.6.1 Basic instrument calibration
 - 2.1.1.6.2 Calibration blocks
 - 2.1.2 Digital thickness instrumentation
 - 2.1.3 Transducer operation and theory
 - 2.1.3.1 Piezoelectric effect
 - 2.1.3.2 Types of transducer elements
 - 2.1.3.3 Frequency (transducer elements – thickness relationships)
 - 2.1.3.4 Near field and far field
 - 2.1.3.5 Beam spread
 - 2.1.3.6 Construction, materials and shapes
 - 2.1.3.7 Types (straight, angle, dual, etc.)
 - 2.1.3.8 Beam intensity characteristics
 - 2.1.3.9 Sensitivity, resolution and damping

- 2.1.3.10 Mechanical vibration into parts
 - 2.1.3.11 Other types of transducers (Laser UT, EMAT, etc.)
 - 2.1.4 Transducer operation/manipulations
 - 2.1.4.1 Tanks, bridges, manipulators and squirters
 - 2.1.4.2 Wheels and special hand devices
 - 2.1.4.3 Transfer devices for materials
 - 2.1.4.4 Manual manipulation
 - 2.1.5 Resonance testing equipment
 - 2.1.5.1 Bond testing
 - 2.1.5.2 Thickness testing
- 2.2 Materials
 - 2.2.1 Couplants
 - 2.2.1.1 Contact
 - 2.2.1.1.1 Purpose and principles
 - 2.2.1.1.2 Materials and their efficiency
 - 2.2.1.2 Immersion
 - 2.2.1.2.1 Purpose and principles
 - 2.2.1.2.2 Materials and their efficiency
 - 2.2.1.2.3 Air coupling
 - 2.2.2 Calibration blocks
 - 2.2.3 Cables/connectors
 - 2.2.4 Test specimen
 - 2.2.5 Miscellaneous materials

3.0 Techniques/Calibrations

- 3.1 Contact
 - 3.1.1 Straight beam
 - 3.1.2 Angle beam
 - 3.1.3 Surface wave and plate waves
 - 3.1.4 Pulse-echo transmission
 - 3.1.5 Multiple transducer
 - 3.1.6 Curved surfaces
- 3.2 Immersion
 - 3.2.1 Transducer in water
 - 3.2.2 Water column, wheels, etc.
 - 3.2.3 Submerged test part
 - 3.2.4 Sound beam path – transducer to part
 - 3.2.5 Focused transducers
 - 3.2.6 Curved surfaces
 - 3.2.7 Plate waves
 - 3.2.8 Pulse-echo and through-transmission
- 3.3 Comparison of contact and immersion methods
- 3.4 Remote monitoring
- 3.5 Calibration (electronic and functional)
 - 3.5.1 General
 - 3.5.2 Reference reflectors for calibration
 - 3.5.2.1 Balls and flat bottom holes
 - 3.5.2.2 Area amplitude blocks
 - 3.5.2.3 Distance amplitude blocks
 - 3.5.2.4 Notches
 - 3.5.2.5 Side-drilled holes
 - 3.5.2.6 Special blocks – IIW and others
 - 3.5.3 Equipment
 - 3.5.3.1 Various monitor displays (amplitude, sweep, etc.)
 - 3.5.3.2 Recorders
 - 3.5.3.3 Alarms
 - 3.5.3.4 Automatic and semiautomatic systems

- 3.5.3.5 Electronic distance amplitude correction
- 3.5.3.6 Transducers
- 3.5.4 Calibration of equipment electronics
 - 3.5.4.1 Variable effects
 - 3.5.4.2 Transmission accuracy
 - 3.5.4.3 Calibration requirements
 - 3.5.4.4 Calibration reflectors
- 3.5.5 Inspection calibration
 - 3.5.5.1 Comparison with reference blocks
 - 3.5.5.2 Pulse-echo variables
 - 3.5.5.3 Reference for planned tests (straight beam, angle beam, etc.)
 - 3.5.5.4 Transmission factors
 - 3.5.5.5 Transducers
 - 3.5.5.6 Couplants
 - 3.5.5.7 Materials

4.0 Interpretations/Evaluations

- 4.1 Evaluation of base material product forms
 - 4.1.1 Ingots
 - 4.1.1.1 Process review
 - 4.1.1.2 Types, origin and typical orientation of discontinuities
 - 4.1.1.3 Response of discontinuities to ultrasound
 - 4.1.1.4 Applicable codes, standards, specs
 - 4.1.2 Plate and sheet
 - 4.1.2.1 Process review
 - 4.1.2.2 Types, origin and typical orientation of discontinuities
 - 4.1.2.3 Response of discontinuities to ultrasound
 - 4.1.2.4 Applicable codes, standards, specs
 - 4.1.3 Bar and rod
 - 4.1.3.1 Process review
 - 4.1.3.2 Types, origin and typical orientation of discontinuities
 - 4.1.3.3 Response of discontinuities to ultrasound
 - 4.1.3.4 Applicable codes, standards, specs
 - 4.1.4 Pipe and tubular products
 - 4.1.4.1 Process review
 - 4.1.4.2 Types, origin and typical orientation of discontinuities
 - 4.1.4.3 Response of discontinuities to ultrasound
 - 4.1.4.4 Applicable codes, standards, specs
 - 4.1.5 Forgings
 - 4.1.5.1 Process review
 - 4.1.5.2 Types, origin and typical orientation of discontinuities
 - 4.1.5.3 Response of discontinuities to ultrasound
 - 4.1.5.4 Applicable codes, standards, specs
 - 4.1.6 Castings
 - 4.1.6.1 Process review
 - 4.1.6.2 Types, origin and typical orientation of discontinuities
 - 4.1.6.3 Response of discontinuities to ultrasound
 - 4.1.6.4 Applicable codes, standards, specs
 - 4.1.7 Composite Structures
 - 4.1.7.1 Process review
 - 4.1.7.2 Types, origin and typical orientation of discontinuities
 - 4.1.7.3 Response of discontinuities to ultrasound
 - 4.1.7.4 Applicable codes standards, specs
 - 4.1.8 Miscellaneous product forms as applicable (rubber, glass, etc.)
 - 4.1.8.1 Process review
 - 4.1.8.2 Types, origin and typical orientation of discontinuities

- 4.1.8.3 Response of discontinuities to ultrasound
 - 4.1.8.4 Applicable codes standards, specs
 - 4.2 Evaluation of weldments
 - 4.2.1 Process review
 - 4.2.2 Weld geometries
 - 4.2.3 Types, origin and typical orientation of discontinuities
 - 4.2.4 Response of discontinuities to ultrasound
 - 4.2.5 Applicable codes, standards, specs
 - 4.3 Evaluation of bonded structures
 - 4.3.1 Manufacturing process
 - 4.3.2 Types origin and typical orientation of discontinuities
 - 4.3.3 Response of discontinuities to ultrasound
 - 4.3.4 Applicable codes/standards/specs
 - 4.4 Variables affecting test results
 - 4.4.1 Instrument performance variations
 - 4.4.2 Transducer performance variations
 - 4.4.3 Test specimen variations
 - 4.4.3.1 Surface condition
 - 4.4.3.2 Part geometry
 - 4.4.3.3 Material structure
 - 4.4.4 Discontinuity variations
 - 4.4.4.1 Size and geometry
 - 4.4.4.2 Relation to entry surface
 - 4.4.4.3 Type of discontinuity
 - 4.4.5 Procedure variations
 - 4.4.5.1 Recording criteria
 - 4.4.5.2 Acceptance criteria
 - 4.4.6 Personnel variations
 - 4.4.6.1 Skill level in interpretation of results
 - 4.4.6.2 Knowledge level in interpretation of results
 - 4.5 Evaluation (General)
 - 4.5.1 Comparison procedures
 - 4.5.1.1 Standards and references
 - 4.5.1.2 Amplitude, area and distance relationship
 - 4.5.1.3 Application of results of other NDT methods
 - 4.5.2 Object appraisal
 - 4.5.2.1 History of part
 - 4.5.2.2 Intended use of part
 - 4.5.2.3 Existing and applicable code interpretation
 - 4.5.2.4 Type of discontinuity and location

5.0 Procedures

- 5.1 Specific applications
 - 5.1.1 General
 - 5.1.2 Flaw detection
 - 5.1.3 Thickness measurement
 - 5.1.4 Bond evaluation
 - 5.1.5 Fluid flow measurement
 - 5.1.6 Material properties measurements
 - 5.1.7 Computer control and defect analysis
 - 5.1.8 Liquid level sensing
 - 5.1.9 Process control
 - 5.1.10 Field inspection
- 5.2 Codes/standards/specifications

Recommended Training References

Ultrasonic Testing Method, Level I, II and III

- Annual Book of ASTM Standards*, Volume 03.03, *Nondestructive Testing*. Philadelphia, PA: American Society for Testing and Materials. Latest edition.*
- ASNT Level III Study Guide – Ultrasonic Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1992.*
- Birks, Albert S. and Robert E. Green, Jr., technical eds; Paul McIntire, ed. *Nondestructive Testing Handbook*, Volume 7: second edition, *Ultrasonic Testing*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1991.*
- Ensminger, D. *Ultrasonics: Fundamentals Technology Applications*, second edition. New York and Basel: Marcel Dekker, Inc., 1988.*
- Ensminger, D. *Ultrasonics: The Low and High Intensity Applications*. New York: Marcel Dekker, Inc., 1973.
- Halmshaw, R. *Nondestructive Testing: Metallurgy and Materials Science Series*. London: Edward Arnold, 1987.
- Handbook for Standardization of Nondestructive Testing Methods, MJL-HDBK-333 (USAF)*, Volume 2. Washington, DC: U.S. Government Printing Office, 1974.
- Krautkramer, Josef, and Herbert Krautkramer. *Ultrasonic Testing of Materials*, third edition. New York: Springer-Verlag, 1983.*
- McGonnagle, Warren J. *Nondestructive Testing*, second edition. New York: Gordon & Breach, 1975.*
- McMaster, Robert C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1959.*
- Mix, Paul E. *Introduction to Nondestructive Testing: A Training Guide*. New York: John Wiley & Sons, 1987.*
- Nondestructive Inspection and Quality Control: Metals Handbook*, Volume 17, ninth edition. Metals Park, OH: American Society for Metals, 1976.*
- Procedures and Recommendations for the Ultrasonic Testing of Butt Welds*, second edition. London: The Welding Institute, 1972.*
- Rose, J. L., and B. B. Goldberg. *Basic Physics in Diagnostic Ultrasound*. New York: John Wiley & Sons, 1979.**
- Silvus, H. S., Jr. *Advanced Ultrasonic Testing Systems: A State of the Art Survey*. San Antonio, TX: Nondestructive Testing Information Analysis Center (NTIAC), 1977.**
- Supplement to Recommended Practice No. SNT-TC-1A (Q&A Book): Ultrasonic Testing Method*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1994.*
- Ultrasonic Method Training Program: Instructor's Package*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1981.*
- Ultrasonic Method Training Program: Student's Package*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1981.*
- Ultrasonic Testing, Classroom Training Handbook (CT-6-4)*. San Diego, CA: General Dynamics/Convair Division, 1967.†
- Ultrasonic Testing, Programmed Instruction Handbook (PI-4-4)*, Vols. 1, 2, and 3. San Diego, CA: General Dynamics/Convair Division, 1967.†
- Welding Handbook*. Volume 1. Miami, FL: American Welding Society. Latest edition.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

† Currently published by the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Vibration Analysis Method

(Training Course Outline TC-11)

	Recommended Hours of Instruction	
	A*	B*
Level I	24	24
Level II	72	48

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Vibration Analysis

Basic Vibration Analysis Physics Course

1.0 Introduction

- 1.1 Brief history of NDT/PdM and vibration analysis
- 1.2 The purpose of vibration analysis
- 1.3 Basic principles of vibration analysis
- 1.4 Basic terminology of vibration analysis to include:
 - 1.4.1 Measurement units
 - 1.4.2 Measurement orientation
 - 1.4.3 Hardware
 - 1.4.4 Software
 - 1.4.5 Machine components
 - 1.4.6 Data presentation

2.0 Transducers

- 2.1. Types
- 2.2 Applications
- 2.3 Mounting
- 2.4 Limitations

3.0 Instrumentation

- 3.1 Types
- 3.2 Applications
- 3.3 Limitations

Basic Vibration Analysis Operating Course

1.0 Machinery Basics

- 1.1 Machine types to include:
 - 1.1.1 Motors
 - 1.1.2 Pumps
 - 1.1.3 Gearbox
 - 1.1.4 Air handlers
 - 1.1.5 Compressors
 - 1.1.6 Turbines
- 1.2 Machine components to include:
 - 1.2.1 Bearings
 - 1.2.2 Couplings
 - 1.2.3 Rotors
 - 1.2.4 Gears
 - 1.2.5 Impellers
- 1.3 Machine orientations

2.0 Data Collection Procedures

- 2.1 Upload/download route
- 2.2 Following a route
- 2.3 Data acquisition
 - 2.3.1 Recognize good versus bad data
 - 2.3.2 Perform machine observations
 - 2.3.3 Recognize abnormal conditions (exceptions data)

3.0 Safety and Health

- 3.1 Mechanical
- 3.2 Electrical
- 3.3 Environmental
- 3.4 Regulations
 - 3.4.1 Federal
 - 3.4.2 Local
- 3.5. Equipment

Recommended Training for Level II Vibration Analysis

Intermediate Vibration Analysis Physics Course

1.0 Review

- 1.1 Basic principles
- 1.2 Basic terminology
- 1.3 Transducers
- 1.4 Instrumentation

2.0 Additional Terminology

- 2.1 Data acquisition
- 2.2 Signal processing
- 2.3 Data presentation

3.0 Diagnostic Tools

- 3.1 Phase
- 3.2 FFT
- 3.3 Time waveform
- 3.4 Orbit analysis
- 3.5 Bode/Nyquist
- 3.6 Trend analysis

Intermediate Vibration Analysis Techniques Course

1.0 Data Acquisition

- 1.1 Units
- 1.2 Analysis parameters
- 1.3 Alarm levels
- 1.4 Time constant (minimum/maximum)
- 1.5 Speed consideration
- 1.6 Lines of resolution
- 1.7 Number of averages (specifications)
- 1.8 Averaging types and applications
- 1.9 Route (data collection) and online systems
- 1.10 Types of data collection
- 1.11 Transducer sensitivity
- 1.12 Special transducers
- 1.13 Transducer selections
- 1.14 Transducer location
- 1.15 Resonance testing

- 1.16 Check (instrument) calibration
- 1.17 Codes, standards and specifications
- 2.0 Signal Processing**
 - 2.1 Windows/weighting
 - 2.1.1 Hanning
 - 2.1.2 Uniform
 - 2.1.3 Flat top
 - 2.2 Overlap processing
 - 2.3 Filters
 - 2.3.1 High pass
 - 2.3.2 Low pass
 - 2.3.3 Bandpass
 - 2.4 Sampling rate and size
 - 2.5 Digital versus analog
- 3.0 Data Presentation**
 - 3.1 Scope and limitations of different testing methods
 - 3.2 Waterfall/cascade plots
 - 3.3 Linear versus Logarithmic
 - 3.4 Trends
 - 3.5 Changing units
 - 3.6 True zoom and frequency expansion
 - 3.7 Order CPM or hertz
- 4.0 Problem Identification**
 - 4.1 Unbalance
 - 4.2 Misalignment
 - 4.3 Resonance
 - 4.4 Bearing defects
 - 4.5 Looseness
 - 4.6 Bent shafts
 - 4.7 Gear defects
 - 4.8 Electrical defects
 - 4.9 Hydraulic/flow dynamics
 - 4.10 Rubs
 - 4.11 Belts and couplings
 - 4.12 Eccentricity
 - 4.13 Beats
 - 4.14 Soft foot
- 5.0 Reporting Methodology**
 - 5.1 Technical reports
 - 5.2 Management oriented reports
 - 5.3 Oral reports
- 6.0 Safety and Health**

Vibration Analysis Testing Method

Level III Topical Outline

1.0 Principles/Theory

The vibration data provides detailed information about the condition of a machine and its components. Data can be processed and presented in different ways to help the analyst in diagnosing specific problems. The section on principles and theory and provides the concepts of vibration analysis.

- 1.1 Physical concepts
 - 1.1.1 Sources of vibration
 - 1.1.2 Stiffness
 - 1.1.3 Mass
 - 1.1.4 Damping
 - 1.1.5 Phase
 - 1.1.6 Modes of vibration
 - 1.1.7 Resonance
- 1.2 Data Presentation
 - 1.2.1 Units of measurement of spectrum
 - 1.2.2 Waveform
 - 1.2.3 Phase analysis
- 1.3 Sources of Vibration
 - 1.3.1 Reciprocating machinery analysis
 - 1.3.2 Specialty machine concepts
 - 1.3.2.1 Nonlinear behavior
- 1.4 Correction Methods
 - 1.4.1 Absorbers
 - 1.4.1.1 Damping treatments
 - 1.4.1.2 Isolators
 - 1.4.1.3 Natural frequency modification

2.0 Equipment

This section under equipment includes instrumentation, sensors and cabling used in vibration analysis.

- 2.1 Sensors
 - 2.1.1 Attachments (brackets, connectors, sensor mounting)
 - 2.1.2 Cabling
 - 2.1.3 Specifications
- 2.2 Signal conditioning
- 2.3 Instruments
 - 2.3.1 Recorders
 - 2.3.2 Analyzers
 - 2.3.3 Oscilloscopes
 - 2.3.4 Multichannel
- 2.4 Online monitoring
- 2.5 Equipment response to environments performance based
 - 2.5.1 Temperature gradients
 - 2.5.2 Moisture

3.0 Techniques/Calibration

Description of ways in which vibration analysis equipment can be used to perform vibration measurements and to analyze the results. This includes routine field calibration and correction of measured data due to effects of test equipment.

- 3.1 Calibration
 - 3.1.1 Point sensor calibration/verification
 - 3.1.2 Instrument calibration/verification
 - 3.1.3 Test instrument calibration/verification
- 3.2 Measurement and techniques
 - 3.2.1 Low speed
 - 3.2.2 High speed
 - 3.2.3 Variable speed
 - 3.2.4 Order tracking
 - 3.2.5 Time synchronous analysis
 - 3.2.6 Cross channel measurements
 - 3.2.7 Transient analysis
 - 3.2.8 Model analysis fundamentals (notice that)
 - 3.2.9 Operating deflection shape analysis
 - 3.2.10 Natural frequency tests
 - 3.2.11 Torsional vibration techniques
 - 3.2.12 Specialized vibration analysis techniques (demodulated spectrum, spike energy spectrum, etc.)
- 3.3 Correction Techniques
 - 3.3.1 Vibration Correction Techniques
 - 3.3.1.1 Add mass
 - 3.3.1.2 Alignment
 - 3.3.1.3 Clearances on journal bearings
 - 3.3.1.4 Correct beats
 - 3.3.1.5 Damping treatments
 - 3.3.1.6 Dynamic absorber
 - 3.3.1.7 Eliminate looseness
 - 3.3.1.8 Isolation treatments
 - 3.3.1.9 Speed change
 - 3.3.1.10 Stiffening

4.0 Analysis/Evaluation

Ability to analyze test data, perform an evaluation and recommend remedial action.

- 4.1 Data Analysis
 - 4.1.1 Operational effects
 - 4.1.2 Correlation of test data
 - 4.1.3 Transient analysis
 - 4.1.4 In-depth time waveform analysis
 - 4.1.5 Cross channel analysis
 - 4.1.6 Multichannel analysis
 - 4.1.7 Machinery specific analysis
- 4.2 Data evaluation
 - 4.2.1 Evaluation of data to standards codes
 - 4.2.2 Specifications or acceptance criteria
 - 4.2.3 Failure mode and effects analysis
 - 4.2.4 Root cause analysis
 - 4.2.5 Cost justification or return on investment analysis

5.0 Procedures

To be able to develop procedures for performing the various types of testing techniques needed to determine equipment condition.

6.0 Safety and Health

Working in close proximity to operating equipment containing a great deal of energy, special care must be taken to avoid injury in addition to using specific personal protective equipment.

Recommended Training References

Vibration Analysis Testing Method, Level I, II and III

American Petroleum Institute, *API 610,630*.
Bloch, Heinz. *Practical Machinery Management Series*, Volumes 1-4. Gulf Publishing Co.
Crawford, Arthur R. *The Simplified Handbook of Vibration Analysis*, Volume I, *Introduction to Vibration Analysis*. Knoxville, TN: CSI, 1992.
Crawford, Arthur R. *The Simplified Handbook of Vibration Analysis*, Volume II, *Applied Vibration Analysis*. Knoxville, TN: CSI, 1992.
Eisenmann, Robert C., Sr, and Eisenmann, Robert C., Jr., *Machinery Malfunction Diagnosis and Correction*, Prentice Hall Printers, 1998.
Goldman, Steve. *Vibration Spectrum Analysis – A Practical Approach*. Industrial Press.
Harris, Cyril, M. *Shock & Vibration Handbook*. McGraw-Hill Inc., 1988.
Jackson, Charlie. *The Practical Vibration Primer*. Gulf Publishing Co.
Mitchell, John S. *An Introduction to Machinery Analysis and Monitoring*. Penwell Publishing Co., 1993.
Mitchell, John S. *Machinery Analysis and Monitoring*, first edition. Penwell Publishing Co., 1981.
Schneider, Hatto. *Schenk Balancing Technology*. Schenk Trebel Corporation.
Taylor, James. *The Vibration Analysis Handbook*, 1994.*
White, Glen D. *Introduction to Machine Vibration*.
Wowk, Victor. *Machinery Vibration Measurement and Analysis*. McGraw-Hill, 1991.

* Available from the American Society for Nondestructive Testing, Inc., Columbus, Ohio.

Vendor/Trainer – Training Guide Materials

Computational Systems, Inc., Knoxville, TN

Vibration Analysis I– IV
Slow Speed Analysis
Modal Analysis

Entek, Inc., Cincinnati, OH (1993)

Dynamic Balancing
Introduction to Vibration Technology Predictive Maintenance and Vibration Signature Analysis I – III

SKF Condition Monitoring, San Diego, CA (1994)

Predictive Maintenance and Vibration Signature Analysis I– III

Technical Associates of Charlotte, Inc., Charlotte, NC (1993)

Predictive Maintenance and Vibration Signature Analysis I– III

Update International, Inc., Denver, CO (1994)

Practical Solutions to Machinery and Maintenance Vibration Problems

Schenck Trebel Corporation Deer Park, NY (1983)

Fundamentals of Balancing

Vibration Institute, Willowbrook, IL (1991– 19935)

Machinery Vibration Analysis I– III

Vitec, Inc., Cleveland, OH

Vibration Primer

Visual Testing Method (Training Course Outline TC-9)

	Recommended Hours of Instruction	
	A*	B*
Level I	8	4
Level II	16	8

***A** High school graduate or equivalent.

***B** Completion with passing grades of at least two years of engineering or science study at a university, college or technical school.

This is a progressive training course. Consideration as Level I is based on satisfactory completion of the Level I training course. Consideration as Level II is based on satisfactory completion of both Level I and Level II training courses.

Topics in the training outline may be deleted or expanded to meet the employer's specific applications or for limited certification and may be accompanied by a corresponding change in training hours.

Recommended Training for Level I Visual Testing

Note: The guidelines listed below should be implemented using equipment and procedures relevant to the employer's industry. No times are given for a specific subject; this should be specified in the employer's written practice. Based upon the employer's product, not all of the referenced subcategories need apply.

1.0 Introduction

- 1.1 Definition of visual testing
- 1.2 History of visual testing
- 1.3 Overview of visual testing applications

2.0 Definitions

- 2.1 Standard terms and their meanings in the employer's industry

3.0 Fundamentals

- 3.1 Vision
- 3.2 Lighting
- 3.3 Material attributes
- 3.4 Environmental factors
- 3.5 Visual perception
- 3.6 Direct and indirect methods

4.0 Equipment (as applicable)

- 4.1 Mirrors
- 4.2 Magnifiers
- 4.3 Borescopes
- 4.4 Fiberscopes
- 4.5 Closedcircuit television
- 4.6 Remote visual inspection systems
- 4.7 Light sources and special lighting
- 4.8 Gages (welding, go no-go, etc.), templates, scales, micrometers, calipers, special tools, etc.
- 4.9 Automated systems
- 4.10 Computer-enhanced systems

5.0 Employer-Defined Applications (Includes a description of inherent, processing and service discontinuities)

- 5.1 Mineralbased material
- 5.2 Metallic materials, including welds
- 5.3 Organicbased materials
- 5.4 Other materials (employer defined)

6.0 Visual Testing to Specific Procedures

- 6.1 Selection of parameters
 - 6.1.1 Inspection objectives
 - 6.1.2 Inspection checkpoints
 - 6.1.3 Sampling plans
 - 6.1.4 Inspection patterns
 - 6.1.5 Documented procedures
- 6.2 Test standards/calibration
- 6.3 Classification of indications per acceptance criteria
- 6.4 Reports and documentation

Total recommended hours of instruction for this course:

Classification A – 8 hours

Classification B – 4 hours

Recommended Training for Level II Visual Testing

The guidelines listed below should be implemented using equipment and procedures relevant to the employer's industry. The employer should tailor the program to the company's particular application area. Discontinuity cause, appearance and how to best visually detect and identify these discontinuities should be emphasized. No times are given for a specific subject; this should be specified in the employer's written practice. Depending upon the employer's product, not all the referenced subcategories need apply.

1.0 Review of Level I

- 1.1 Definitions
- 1.2 Fundamentals of visual testing
- 1.3 Equipment
- 1.4 Applications

2.0 Vision

- 2.1 The eye
- 2.2 Vision limitations
- 2.3 Disorders
- 2.4 Employer's vision examination methods

3.0 Lighting

- 3.1 Fundamentals of light
- 3.2 Lighting measurements
- 3.3 Recommended lighting levels
- 3.4 Lighting techniques for inspection

4.0 Material attributes

- 4.1 Cleanliness
- 4.2 Color
- 4.3 Condition
- 4.4 Shape
- 4.5 Size
- 4.6 Temperature
- 4.7 Texture
- 4.8 Type

5.0 Environmental and Physiological Factors

- 5.1 Atmosphere
- 5.2 Cleanliness
- 5.3 Comfort
- 5.4 Distance
- 5.5 Elevation
- 5.6 Fatigue
- 5.7 Health
- 5.8 Humidity
- 5.9 Mental attitude
- 5.10 Position
- 5.11 Safety
- 5.12 Temperature

6.0 Visual Perception

- 6.1 What your eyes see
- 6.2 What your mind sees
- 6.3 What others perceive
- 6.4 What the designer, engineer, etc., wants you to see

7.0 Equipment

- 7.1 Automated systems
- 7.2 Borescopes
- 7.3 Closedcircuit television
- 7.4 Computerbased systems
- 7.5 Fiberscopes
- 7.6 Gages, micrometers, calipers, templates, scales, etc.
- 7.7 Imaging systems
- 7.8 Light sources and special lighting
- 7.9. Magnifiers
- 7.10 Mirrors
- 7.11 Special optical systems
- 7.12 Standard lighting
- 7.13 Remote visual inspection systems

8.0 Employer-Defined Applications

- 8.1 Mineralbased material
- 8.2 Metallic materials (including welds)
- 8.3 Organicbased materials
- 8.4 Other materials and products (employer-defined)

9.0 Acceptance/Rejection Criteria

- 9.1 Subjective basis (qualitative)
- 9.2 Objective basis (quantitative)
- 9.3 Evaluation of results per acceptance criteria

10.0 Recording and Reports

- 10.1 Subjective method
- 10.2 Objective method
- 10.3 Recording methods

Total recommended hours of instruction for this course:

Classification A – 16 hours

Classification B – 8 hours

Visual Testing Method Level III Topical Outline

1.0 Principles/Theory

- 1.1 Vision and light
 - 1.1.1 Physiology of sight
 - 1.1.2 Visual acuity
 - 1.1.3 Visual angle and distance
 - 1.1.4 Color vision
 - 1.1.5 Physics and measurement of light
- 1.2 Environmental factors
 - 1.2.1 Lighting
 - 1.2.2 Cleanliness
 - 1.2.3 Distance
 - 1.2.4 Air contamination
- 1.3 Test object characteristics
 - 1.3.1 Texture
 - 1.3.2 Color
 - 1.3.3 Cleanliness
 - 1.3.4 Geometry

2.0 Equipment Accessories

- 2.1 Magnifiers
- 2.2 Mirrors
- 2.3 Dimensional
 - 2.3.1 Linear measurement
 - 2.3.2 Micrometers/calipers
 - 2.3.3 Optical comparators
 - 2.3.4 Dial indicators
 - 2.3.5 Gages
- 2.4 Borescopes
 - 2.4.1 Rigid
 - 2.4.2 Fiberoptic
 - 2.4.3 Special purpose
- 2.5 Video systems (robotics)
 - 2.5.1 Photoelectric devices
 - 2.5.2 Electron microscopy
 - 2.5.3 Video borescopes
 - 2.5.4 Video imaging/resolution/image processing (enhancement)
 - 2.5.5 Charge coupled devices (CCDs)
- 2.6 Automated systems
 - 2.6.1 Lighting techniques
 - 2.6.2 Optical filtering
 - 2.6.3 Image sensors
 - 2.6.4 Signal processing
- 2.7 Video technologies
- 2.8 Machine vision
- 2.9 Replication
- 2.10 Temperature sensitive markers and surface comparators
- 2.11 Chemical aids
- 2.12 Photography
- 2.13 Eye

3.0 Techniques/Calibration

- 3.1 Diagrams and drawings
- 3.2 Raw materials
 - 3.2.1 Ingots
 - 3.2.2 Blooms/billets/slabs
- 3.3 Primary process materials
 - 3.3.1 Plates/sheets
 - 3.3.2 Forgings
 - 3.3.3 Castings
 - 3.3.4 Bars
 - 3.3.5 Tubing
 - 3.3.6 Extrusions
 - 3.3.7 Wire
- 3.4 Joining processes
 - 3.4.1 Joint configuration
 - 3.4.2 Welding
 - 3.4.3 Brazing
 - 3.4.4 Soldering
 - 3.4.5 Bonding
- 3.5 Fabricated components
 - 3.5.1 Pressure vessels
 - 3.5.2 Pumps
 - 3.5.3 Valves
 - 3.5.4 Fasteners
 - 3.5.5 Piping systems

- 3.6 In-service materials
 - 3.6.1 Wear
 - 3.6.2 Corrosion/erosion
 - 3.6.3 Microscopy
- 3.7 Coatings
 - 3.7.1 Paint
 - 3.7.2 Insulation
 - 3.7.3 Cathodic protection (conversion coatings)
 - 3.7.4 Anodizing
- 3.8 Other applications
 - 3.8.1 Ceramics
 - 3.8.2 Composites
 - 3.8.3 Glasses
 - 3.8.4 Plastics
 - 3.8.5 Electronics
 - 3.8.6 Bearings
- 3.9 Requirements
 - 3.9.1 Codes
 - 3.9.2 Standards
 - 3.9.3 Specifications
 - 3.9.4 Techniques (direct, indirect, video, etc.)
 - 3.9.5 Personnel qualification and certification

4.0 Interpretation/Evaluation

- 4.1 Equipment variables affecting test results including type and intensity of light
- 4.2 Material variables affecting test results including the variations of surface finish
- 4.3 Discontinuity variables affecting test results
- 4.4 Determination of dimensions (i.e., depth, width, length, etc.)
- 4.5 Sampling/scanning procedure variables affecting test results
- 4.6 Process for reporting visual discontinuities
- 4.7 Personnel (human factors) variables affecting test results
- 4.8 Detection
 - 4.8.1 Interpretation
 - 4.8.2 Evaluation

5.0 Procedures and Documentation

- 5.1 Hard copy – general applications
 - 5.1.1 Mineral based materials
 - 5.1.2 Organic based materials
 - 5.1.3 Composite materials
 - 5.1.4 Metallic materials
- 5.2 Photography – specific applications
 - 5.2.1 Metal joining processes
 - 5.2.2 Pressure vessels
 - 5.2.3 Pumps
 - 5.2.4 Valves
 - 5.2.5 Bolting
 - 5.2.6 Castings
 - 5.2.7 Forgings
 - 5.2.8 Extrusions
 - 5.2.9 Microcircuits
- 5.3 Audio/video – requirements
 - 5.3.1 Codes (AWS, ASME, etc.)
 - 5.3.2 Standards (MIL-STD-, NAVSEA, etc.)
 - 5.3.3 Specifications
 - 5.3.4 Procedures (Level III exam specific)

- 5.4 Electronic and magnetic media
- 5.5 Personnel qualification and certification

6.0 Safety and Health

- 6.1 Electrical shock
- 6.2 Mechanical hazards
- 6.3 Lighting hazards physiological deleterious effects of light
- 6.4 Chemicals contamination
- 6.5 Radioactive materials
- 6.6 Explosive environments

Recommended Training References Visual Testing Method, Level I, II and III

- Allgaier, Michael W. and Stanley Ness, technical eds.; Paul McIntire and Patrick Moore, eds.
Nondestructive Testing Handbook, Volume 8, second edition, *Visual and Optical Testing*. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1993.*
- Anderson, R. C. *Visual Examination: Inspection of Metals*, Volume 1. Metals Park, OH: ASM International, 1983.**
- Berger, Harold, ed. *Nondestructive Testing Standards – A Review – STP 624*, “Considerations and Standards for Visual Inspection Techniques.” Philadelphia, PA: American Society for Testing and Materials, 1977.
- Cary, H. B. *Modern Welding Technology*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1979.
- Hobart Welding Guide*. Troy, OH: Hobart School of Welding Technology, 1980.
- McMaster, Robert C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, Inc., 1959.*
- Megaw, E. D. “Factors Affecting Visual Inspection Accuracy,” *Applied Ergonomics*, Cleveland, OH: IPC Business Press. March, 1979.**
- Nondestructive Inspection and Quality Control: Metals Handbook*, Volume 11, eighth edition. Metals Park, OH: American Society for Metals, 1976.*
- Schoonard, J. W., et al. “Studies of Visual Inspection,” *Ergonomics*, Vol. 16, No. 4. Philadelphia, PA: Taylor & Francis, Inc., 1973.**
- The Tools and Rules of Precision Measuring*. Athol, MA: L. S. Starret Co., 1982.
- Visual Examination Technology – 101, 102, and 103*. Charlotte, NC: EPRI NDE Center, 1983.
- Welding and Fabrication Data Book*. Cleveland, OH: Welding Design and Fabrication, 1984.**
- Welding Handbook*, Volume 1. Miami, FL: American Welding Society. Latest edition.*
- Welding Inspection*. Miami, FL: American Welding Society. Latest edition.

* Available from The American Society for Nondestructive Testing, Inc., Columbus, Ohio.

** This book is a Recommended Reference because of the valuable data it contains. This title is currently out of print, however, and is not available from ASNT.

Basic Examination

General Level III Requirements

The Basic Examination will cover three main topical areas:

- 1.0 Personnel Qualification and Certification Programs
 - 1.1 SNT-TC-1A
 - 1.2 ANSI/ASNT-CP-189
 - 1.3 ASNT Level III Program
- 2.0 General Familiarity with Other NDT Methods
- 3.0 General Knowledge of Materials, Fabrication and Product Technology.

Separate Method examinations will be given to cover each of the following NDT Methods:

- Acoustic Emission Testing
- Electromagnetic Testing
- Leak Testing
- Liquid Penetrant Testing
- Magnetic Particle Testing
- Neutron Radiographic Testing
- Radiographic Testing
- Thermal/Infrared Testing
- Ultrasonic Testing
- Visual Testing

Each of the ten Method examinations are divided into three main topical areas:

- 1. Method fundamentals and principles
- 2. General knowledge of techniques within the Methods
- 3. General interpretation of codes, standards and specifications relating to the Method

The Basic examination and one or more Method examinations must be taken and passed to qualify for an ASNT Level III Certificate. The endorsements on the ASNT Certificate will list the various Methods, which the applicant passed.

The following topical outlines further subdivide the main topical areas of both Basic and Method examinations, cite literature references and have sample questions typical of those in the examinations.

Recommended Practice No. SNT-TC-1A

- 1.0 Scope
- 2.0 Definitions
- 3.0 Nondestructive Testing Methods
- 4.0 Levels of Qualification
- 5.0 Written Practice
- 6.0 Education, Training and Experience
- 7.0 Training Programs
- 8.0 Examinations
- 9.0 Certification
- 10.0 Termination

ASNT Standard ANSI/ASNT-CP-189

- 1.0 Scope
- 2.0 Definitions

- 3.0 Levels of qualification
- 4.0 Qualification requirements
- 5.0 Qualification and certification
- 6.0 Examinations
- 7.0 Expiration, suspension, revocation and reinstatement of employee's certification
- 8.0 Employer recertification
- 9.0 Records
- 10.0 Referenced publications
 - 10.1 ASNT Level III Certification Program
 - 10.2 ASNT Document Numbers
 - 10.3 CP-3-89
 - 10.4 CP-4-86
 - 10.5 CP-5-87
 - 10.6 CP-6-86

References

Recommended Practice No. SNT-TC-1A contains numerous technical references.*

"General Information, ASNT Level III Program: A Review of the ASNT Personnel Certification Program,"

Materials Evaluation, Vol. 43, No. 3, (Redi Reference Guide/1984), pp 566.*

Hardison, R. R. (1991, June). ASNT Standard. *Materials Evaluation*. Vol. 49, No. 6, pp 798-806.*

Hardison, R. R. (1991, February). Position Paper on ASNT Certifications, Standards, and Recommended Practices. *Materials Evaluation*. Vol. 49, No. 2, pp 286-289.*

Wheeler, G. C. *A Guide to Personnel Qualification and Certification*. Columbus, OH: The American Society for Nondestructive Testing, 1991.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

Basics of Common NDT Methods

1.0 Acoustic Emission Testing

- 1.1 Fundamentals
 - 1.1.1 Principles/theory of acoustic emission testing
 - 1.1.2 Sources of acoustic emissions
 - 1.1.3 Equipment and material
- 1.2 Proper selection of acoustic emission technique
 - 1.2.1 Instrumentation and signal processing
 - 1.2.1.1 Cables (types)
 - 1.2.1.2 Signal conditioning
 - 1.2.1.3 Signal detection
 - 1.2.1.4 Noise discrimination
 - 1.2.1.5 Electronic technique
 - 1.2.1.6 Attenuation materials
 - 1.2.1.7 Data filtering techniques
- 1.3 Interpretation and evaluation of test results

2.0 Electromagnetic Testing

- 2.1 Fundamentals
 - 2.1.1 Electromagnetic field generation
 - 2.1.2 Properties of eddy current
 - 2.1.3 Effects of varying frequency
 - 2.1.4 Phase discrimination

- 2.2 Electromagnetic testing
 - 2.2.1 Sensors
 - 2.2.2 Basic types of equipment; types of read out
 - 2.2.3 Reference standards
 - 2.2.4 Applications and test result interpretation
 - 2.2.4.1 Flaw detection
 - 2.2.4.2 Conductivity and permeability sorting
 - 2.2.4.3 Thickness gaging
 - 2.2.4.4 Process control
- 3.0 Leak Testing**
 - 3.1 Fundamentals
 - 3.1.1 Bubble detection
 - 3.1.2 Pressure change
 - 3.1.3 Halogen diode detector
 - 3.1.4 Mass Spectrometer
 - 3.2 Leak testing
 - 3.2.1 Systems factors
 - 3.2.1.1 Relative sensitivity
 - 3.2.1.2 Evacuated systems
 - 3.2.1.3 Pressurized systems; ambient fluids, tracer fluids
 - 3.2.1.4 Locating leaks
 - 3.2.1.5 Calibration
 - 3.2.2 Test result interpretation
 - 3.2.3 Essentials of safety
 - 3.2.4 Test equipment
 - 3.2.5 Applications
 - 3.2.5.1 Piping and pressure vessels
 - 3.2.5.2 Evacuated systems
 - 3.2.5.3 Low pressure fluid containment vessels, pipes and tubing
 - 3.2.5.4 Hermetic seals
 - 3.2.5.5 Electrical and electronic components
- 4.0 Liquid Penetrant Testing**
 - 4.1 Fundamentals
 - 4.1.1 Interaction of penetrants and discontinuity openings
 - 4.1.2 Fluorescence and contrast
 - 4.2 Liquid penetrant tenting
 - 4.2.1 Penetrant processes
 - 4.2.2 Test equipment and systems factors
 - 4.2.3 Test result interpretation; discontinuity indications
 - 4.2.4 Applications
 - 4.2.4.1 Castings
 - 4.2.4.2 Welds
 - 4.2.4.3 Wrought metals
 - 4.2.4.4 Machined parts
 - 4.2.4.5 Leaks
 - 4.2.4.6 Field inspections
- 5.0 Magnetic Particle Testing**
 - 5.1 Fundamentals
 - 5.1.1 Magnetic field principles
 - 5.1.2 Magnetization by means of electric current
 - 5.1.3 Demagnetization
 - 5.2 Magnetic particle inspection

- 5.2.1 Basic types of equipment and inspection materials
- 5.2.2 Test results interpretation; discontinuity indications
- 5.2.3 Applications
 - 5.2.3.1 Welds
 - 5.2.3.2 Castings
 - 5.2.3.3 Wrought metals
 - 5.2.3.4 Machined parts
 - 5.2.3.5 Field applications

6.0 Neutron Radiographic Testing

- 6.1 Fundamentals
 - 6.1.1 Sources
 - 6.1.1.1 X-ray
 - 6.1.1.2 Isotopic
 - 6.1.1.3 Neutron
 - 6.1.2 Detectors
 - 6.1.2.1 Imaging
 - 6.1.2.2 Nonimaging
 - 6.1.3 Nature of penetrating radiation and interactions with matter
 - 6.1.4 Essentials of safety
- 6.2 Neutron radiographic testing
 - 6.2.1 Basic imaging considerations
 - 6.2.2 Test result interpretation; discontinuity indications
 - 6.2.3 Systems factors (source/test object/detector interactions)
 - 6.2.4 Applications
 - 6.2.4.1 Explosives and pyrotechnic devices
 - 6.2.4.2 Assembled components
 - 6.2.4.3 Bonded components
 - 6.2.4.4 Corrosion detection
 - 6.2.4.5 Nonmetallic materials

7.0 Radiographic Testing

- 7.1 Fundamentals
 - 7.1.1 Sources
 - 7.1.1.1 Castings
 - 7.1.1.2 Welds
 - 7.1.1.3 Assemblies
 - 7.1.1.4 Electronic components
 - 7.1.1.5 Field inspections
 - 7.1.2 Detectors
 - 7.1.2.1 Imaging
 - 7.1.2.2 Nonimaging
 - 7.1.3 Nature of penetrating radiation and interactions with matter
 - 7.1.4 Essentials of safety
- 7.2 Radiographic testing
 - 7.2.1 Basic imaging considerations
 - 7.2.2 Test result interpretation; discontinuity indications
 - 7.2.3 Systems factors (source/test object/detector interactions)
 - 7.2.4 Applications
 - 7.2.4.1 Castings
 - 7.2.4.2 Welds
 - 7.2.4.3 Assemblies
 - 7.2.4.4 Electronic components
 - 7.2.4.5 Field inspections

8.0 Thermal/Infrared Testing

- 8.1 Fundamentals
 - 8.1.1 Principles and theory of thermal/infrared testing
 - 8.1.2 Temperature measurement principles
 - 8.1.3 Proper selection of thermal/infrared technique
- 8.2 Equipment/materials
 - 8.2.1 Temperature measurement equipment
 - 8.2.2 Heat flux indicators
 - 8.2.3 Noncontact devices
- 8.3 Applications
 - 8.3.1 Contact temperature indicators
 - 8.3.2 Noncontact pyrometers
 - 8.3.3 Linescanners
 - 8.3.4 Thermal imaging
 - 8.3.5 Heat flux indicators
 - 8.3.6 Erothermic or endothermic investigations
 - 8.3.7 Friction investigations
 - 8.3.8 Fluid flow investigations
 - 8.3.9 Thermal resistance investigations
 - 8.3.10 Thermal capacitance investigations
- 8.4 Interpretation and evaluation

9.0 Ultrasonic Testing

- 9.1 Fundamentals
 - 9.1.1 Ultrasonic sound beams
 - 9.1.1.1 Wave travel modes
 - 9.1.1.2 Refraction, reflection, scattering and attenuation
 - 9.1.2 Transducers and sound beam coupling
- 9.2 Ultrasonic testing
 - 9.2.1 Basic types of equipment
 - 9.2.2 Reference standards
 - 9.2.3 Test result interpretation; discontinuity indications
 - 9.2.4 System factors
 - 9.2.5 Applications
 - 9.2.5.1 Flaw detection
 - 9.2.5.2 Thickness measurement
 - 9.2.5.3 Bond evaluation
 - 9.2.5.4 Process control
 - 9.2.5.5 Field inspection

10.0 Visual Testing

- 10.1 Fundamentals
 - 10.1.1 Principles and theory of visual testing
 - 10.1.2 Selection of correct visual technique
 - 10.1.3 Equipment and materials
- 10.2 Specific applications
 - 10.2.1 Metal joining processes
 - 10.2.2 Pressure vessels
 - 10.2.3 Pumps
 - 10.2.4 Valves
 - 10.2.5 Bolting
 - 10.2.6 Castings
 - 10.2.7 Forgings
 - 10.2.8 Extrusions
 - 10.2.9 Microcircuits

- 10.3 Interpretation and evaluation
 - 10.3.1 Codes and standards
 - 10.3.2 Environmental factors

References

- Berger, H. *Neutron Radiography*. Amsterdam, Netherlands: Elsevier Publishing Co., 1965.*
- Marr, J. William. *Leakage Testing Handbook*. US Government Printing Office, Clearinghouse: Springfield, VA.
- McMaster, R. C., ed. *Nondestructive Testing Handbook*, first edition. Columbus, OH: The American Society for Nondestructive Testing, 1959.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

Basic Materials, Fabrication and Product Technology

1.0 Fundamentals of Material Technology

- 1.1 Properties of materials
 - 1.1.1 Strength and elastic properties
 - 1.1.2 Physical properties
 - 1.1.3 Material properties testing
- 1.2 Origin of discontinuities and failure modes
 - 1.2.1 Inherent discontinuities
 - 1.2.2 Process-induced discontinuities
 - 1.2.3 Service-induced discontinuities
 - 1.2.4 Failures in metallic materials
 - 1.2.5 Failures in nonmetallic materials
- 1.3 Statistical nature of detecting and characterizing discontinuities

2.0 Fundamentals of Fabrication and Product Technology

- 2.1 Raw materials processing
- 2.2 Metals processing
 - 2.2.1 Primary metals
 - 2.2.1.1 Metal ingot production
 - 2.2.1.2 Wrought primary metals
 - 2.2.2 Castings
 - 2.2.2.1 Green sand molded
 - 2.2.2.2 Metal molded
 - 2.2.2.3 Investment molded
 - 2.2.3 Welding
 - 2.2.3.1 Common processes
 - 2.2.3.2 Hard-surfacing
 - 2.2.3.3 Solid State
 - 2.2.4 Brazing
 - 2.2.5 Soldering
 - 2.2.6 Machining and material removal
 - 2.2.6.1 Turning, boring and drilling
 - 2.2.6.2 Milling
 - 2.2.6.3 Grinding
 - 2.2.6.4 Electrochemical
 - 2.2.6.5 Chemical
 - 2.2.6.6 Gears and bearings

- 2.2.7 Forming
 - 2.2.7.1 Cold-working processes
 - 2.2.7.2 Hot-working processes
- 2.2.8 Powdered metal processes
- 2.2.9 Heat treatment
- 2.2.10 Surface finishing and corrosion protection
 - 2.2.10.1 Shot peening and grit blasting
 - 2.2.10.2 Painting
 - 2.2.10.3 Plating
 - 2.2.10.4 Chemical conversion coatings
- 2.2.11 Adhesive joining
- 2.3 Nonmetals and composite materials processing
 - 2.3.1 Basic materials processing and process control
 - 2.3.2 Nonmetals and composites fabrication
 - 2.3.3 Adhesive joining
- 2.4 Dimensional metrology
 - 2.4.1 Fundamental units and standards
 - 2.4.2 Gaging
 - 2.4.3 Interferometry

References

Materials & Processes for NDT Technology. Columbus, OH: The American Society for Nondestructive Testing, 1981.*

Source Book in Failure Analysis. Metals Park, OH: American Society for Metals, 1974.*

Welding Inspection. Miami, FL; American Welding Society. Latest edition.*

Barer, R. D., and Peters, B. F. *Why Metals Fail*. New York: Gordon and Breach, Science Publishers, 1970.*

Dallas, Daniel B., ed. *Tool and Manufacturing Engineers Handbook*, third edition. New York: Society of Manufacturing Engineers, McGraw-Hill Book Co., 1976.*

Taylor, J. L., ed. *Basic Metallurgy for Nondestructive Testing*. Essex, England: The Nondestructive Testing Society of Great Britain, 1974.*

* Available from the American Society for Nondestructive Testing, Columbus, Ohio.

PdM Basic Examination Predictive Maintenance (PdM) Examination Specification

The PdM Basic Examination, composed of 90 questions, will cover three main topical areas:

- 1.0 Personnel Qualification and Certification Programs – 40 questions
 - 1.1 SNT-TC-1A
 - 1.2 ANSI/ASNT-CP-189
 - 1.3 ASNT Level III Programs
- 2.0 General familiarity with other PdM Methods – 30 questions
- 3.0 General knowledge of machinery – 20 questions

The PdM Basic examination and one or more PdM Method examinations (either Thermal/Infrared Testing or vibration analysis) must be taken and passed to qualify for an ASNT PdM Level III Certificate. The endorsements on the ASNT Certificate will list the various Methods that were passed by the applicant.

1.0 Personnel Qualification and Certification Programs

- 1.1 Recommended Practice No. SNT-TC-1A
 - 1.1.1 Scope
 - 1.1.2 Definitions
 - 1.1.3 Nondestructive testing methods
 - 1.1.4 Levels of qualification
 - 1.1.5 Written practice
 - 1.1.6 Education, training and experience
 - 1.1.7 Training programs
 - 1.1.8 Examinations
 - 1.1.9 Certification
 - 1.1.10 Termination
- 1.2 ASNT Standard ANSI/ASNT-CP-189
 - 1.2.1 Scope
 - 1.2.2 Definitions
 - 1.2.3 Levels of qualification
 - 1.2.4 Qualification requirements
 - 1.2.5 Qualification and certification
 - 1.2.6 Examinations
 - 1.2.7 Expiration, suspension, revocation and reinstatement of employee's certification
 - 1.2.8 Employer recertification
 - 1.2.9 Records
 - 1.2.10 Referenced publications
- 1.3 ASNT Level III Certification Programs

2.0 Basics of Common PdM Methods

- 2.1 Infrared Testing
- 2.2 Vibration Analysis
- 2.3 Oil/Lube Analysis
- 2.4 Motor Circuit Analysis
- 2.5 Alignment
- 2.6 Thermal Testing
- 2.7 System Performance

3.0 Machinery Technology

- 3.1 Machine Design
- 3.2 Electrical Components
- 3.3 Maintenance Concerns
- 3.4 Machine Components
- 3.5 Engineering Mechanics
- 3.6 Lubrication

Appendix

Example Questions Level I and Level II

The purpose of this appendix is to provide a guideline for the preparation of the General, Level I and Level II written examinations. Extensive examples of representative questions for degree of difficulty, type, etc. are provided in separate question booklets, which can be obtained from ASNT Headquarters. These questions are intended as examples only and should not be used verbatim for qualification examinations.

Note: All questions and answers should be referenced to a recognized source.

Acoustic Emission Testing Method

Level I

1. A qualitative description of the sustained signal level produced by rapidly occurring acoustic emission events is the accepted definition for:
 - a. burst emission.
 - b. acoustic emission signature.
 - c. acoustic emission signal.
 - d. continuous emission.
 - e. none of the above.
2. Attenuation of a wave is best defined by which statement?
 - a. a decrease in frequency with distance traveled
 - b. a decrease in amplitude with distance traveled
 - c. a decrease in wave speed with distance traveled
 - d. a change in direction as a function of time
3. The number of times the acoustic emission signal exceeds a preset threshold during any selected portion of a test is called the:
 - a. acoustic emission response.
 - b. acoustic emission count.
 - c. acoustic emission count rate.
 - d. acoustic emission energy.
 - e. none of the above.

Level II

1. When detecting impulsive acoustic emission signals on large objects, the peak of the signals normally decreases with increasing distance from the source. This alteration, dependent on distance, must be explained by:
 - a. absorption: i.e., the elastic pulse gradually converts into heat.
 - b. dispersion: i.e., the pulse gradually spreads out in time because the different waves involved travel with different velocities.
 - c. the geometric factors: i.e., the energy in the pulse is distributed into ever-larger volumes.
 - d. all of the above.

2. Which of the following factors will tend to produce low-amplitude acoustic emission response during a tensile test?
 - a. low temperature
 - b. high strain rate
 - c. plastic deformation
 - d. crack propagation
3. The Kaiser effect is:
 - a. valid only when testing composites.
 - b. a physical law of nature that is never violated.
 - c. not applicable when an rms recording is being made.
 - d. the absence of detectable acoustic emission until previously applied stress levels are exceeded.

Electromagnetic Testing Method

Eddy Current Testing Method

Level I

1. The impedance of an eddy current test coil will increase if the:
 - a. test frequency increases.
 - b. inductive reactance of the coil decreases.
 - c. inductance of the coil decreases.
 - d. resistance of the coil decreases.
2. Which of the following test frequencies would produce eddy currents with the largest depth of penetration?
 - a. 100 Hz
 - b. 10 kHz
 - c. 1 MHz
 - d. 10 MHz
3. To generate measurable eddy currents in a test specimen, the specimen must be:
 - a. a conductor.
 - b. an insulator.
 - c. either a conductor or an insulator.
 - d. a ferromagnetic material.

Level II

1. The fill factor when a 0.5 in. diameter bar is inserted in a 1 in. diameter coil is:
 - a. 0.5 (50 percent).
 - b. 0.75 (75 percent).
 - c. 1.0 (100 percent).
 - d. 0.25 (25 percent).
2. If the characteristic frequency (f_g) of a material is 125 Hz, the test frequency required to give an f/f_g ratio of 10 would be:
 - a. 1.25 Hz.
 - b. 12.5 Hz.
 - c. 1.25 kHz.
 - d. 12.5 kHz.

3. For age-hardened aluminum and titanium alloys, changes in hardness are indicated by changes in:
 - a. retentivity.
 - b. permeability.
 - c. conductivity.
 - d. magnetostriction.

Flux Leakage Testing Method

Level I

1. Flux leakage inspection can normally be applied to:
 - a. ferromagnetic and nonmagnetic material.
 - b. nonmagnetic materials only.
 - c. ferromagnetic materials only.
 - d. nonconductors only.
2. The ratio B/H is equivalent to a material's:
 - a. field strength.
 - b. reluctance.
 - c. permittivity.
 - d. permeability.
 - e. relative permeability.
3. In the flux leakage examination of tubular products, which of the following discontinuities can be detected?
 - a. longitudinally oriented
 - b. transversely oriented
 - c. slivers
 - d. all of the above

Level II

1. The highest sensitivity of a Hall generator is obtained when the direction of the magnetic field in relation to the largest surface of the Hall probe is:
 - a. parallel.
 - b. at an angle of 45 degrees.
 - c. at an angle of 30 or 60 degrees.
 - d. perpendicular.
 - e. none of the above.
2. What particular type of defect is not indicated by flux leakage techniques?
 - a. overlap
 - b. grain-boundary crack
 - c. slag inclusion with crack
 - d. surface contamination
 - e. longitudinal seam
3. In the examination of tubular products where the flux sensor measures the leakage field at the outside surface of the tube:
 - a. outside-diameter discontinuities are detected.
 - b. both outside-diameter and inside-diameter discontinuities may be detected.
 - c. both outside-diameter and inside-diameter discontinuities can be detected but generally cannot be distinguished from each other.
 - d. both outside-diameter and inside-diameter discontinuities can be detected and generally can be distinguished from each other.

Leak Testing Method

Bubble Leak Testing Method

Level I

1. Before performing a vacuum box leak test, which of the following should be checked for required calibration?
 - a. leak-detector solution
 - b. evacuation device or equipment
 - c. lighting equipment
 - d. pressure (or vacuum) gage
2. Which factor can most affect the sensitivity attainable by a pressure bubble leak test?
 - a. operator alertness and technique
 - b. size and shape of the test specimen
 - c. time of day testing is performed
 - d. number of test technicians
3. The letters “psia” mean:
 - a. pressure referred to National Institute of Standards and Technology’s absolute pressure.
 - b. pascals per square inch absolute.
 - c. pressure standard in absolute units.
 - d. pounds per square inch absolute.

Level II

1. Which of the following directly determines the size of the bubble formation when testing using the bubble test method?
 - a. method of application of bubble solution
 - b. ambient temperature and barometric pressure
 - c. amount of leakage from a defect or leak
 - d. size of the test specimen
2. When a vacuum gage is marked with a range of 0-30 with the notation “vacuum” on the face, the units of measurement are:
 - a. inches of mercury.
 - b. pounds per square inch.
 - c. centimeters of vacuum.
 - d. feet of water.
3. The type of leaks that are most likely to go undetected during a bubble leak test are:
 - a. very small leaks and very large leaks.
 - b. leaks occurring at welded joints.
 - c. corner-configuration joints.
 - d. all of the above.

Halogen Diode Detector Leak Testing Method

Level I

1. Good operating practice dictates that the period of time to allow for warm-up of the halogen diode detector prior to calibrating is:
 - a. 30 minutes.
 - b. 15 minutes.
 - c. 1 hour.
 - d. as recommended by the manufacturer.
2. While adjusting a reservoirtype variable-halogen standard leak, the operator accidentally vents the gas from the only standard leak available. Which of the following actions would quickly resolve the problem?
 - a. replace the standard leak
 - b. replace the cylinder in the standard leak
 - c. recharge the standard leak
 - d. send the standard leak to the manufacturer for recharging
3. While performing a halogen-diode detector test, the leak detector becomes difficult to zero, and the pointer on the leak rate meter repeatedly swings up scale. The most likely cause of the problem could be the use of too high a sensitivity range, a shorted element, an excessive heater voltage, or:
 - a. poor airflow.
 - b. a sensing element that is too new.
 - c. a high halogen background.
 - d. a faulty leak-rate meter.

Level II

1. Most leaks detected during a halogen sniffer test could have been detected and usually can be verified by:
 - a. a bubble leak test.
 - b. an ultrasonic examination.
 - c. a visual examination.
 - d. a pressure change test.
2. The presence of small traces of halogen vapors in the halogen diode detector:
 - a. increases the emission of negative ions.
 - b. decreases the emission of positive ions.
 - c. increases the emission of positive ions.
 - d. decreases the emission of negative ions.
3. A halogen standard leak of a certain size produces a known signal on a halogen leak detector. To receive this same intensity signal on the instrument during the test of an object containing a 2 percent by volume halogen-air mixture, the size of the leak in the object causing the signal would theoretically have to be at least ____ times larger than the standard leak.
 - a. 20
 - b. 50
 - c. 40
 - d. 10

Mass Spectrometer Leak Testing Method

Level I

1. The sensitivity of a mass spectrometer leak-detection system is the mass flow rate of tracer gas:
 - a. that gives a maximum measurable signal.
 - b. that gives a minimum measurable signal.
 - c. at standard temperature and pressure.
 - d. in a leak.
2. The diffusion pump and mechanical forepump in a mass spectrometer leak-detection system:
 - a. use the same type of oil.
 - b. use different types of oil.
 - c. operate using the same motor.
 - d. use the same principle of operation.
3. The helium mass spectrometer detector-probe pressure-test technique is:
 - a. a quantitative test.
 - b. a qualitative test.
 - c. a semiautomatic test.
 - d. none of the above.

Level II

1. A torr is defined as:
 - a. 14.7 psia.
 - b. 1 mm of Hg.
 - c. 1/760 of a standard atmosphere.
 - d. 760 mm of Hg.
2. When conducting a helium mass-spectrometer test of a vacuum vessel in the pressure range of 10^{-4} to 10^{-8} mm Hg, which type gage could be used to measure the pressure?
 - a. alphanatron gage
 - b. thermionic ionization gage
 - c. Pirani gage
 - d. thermocouple gage
3. Helium standard leaks in the range of 10^{-6} to 10^{-10} atm. cc/s are known in general terms as:
 - a. reservoir standard leaks.
 - b. capillary standard leaks.
 - c. permeation standard leaks.
 - d. adjustable standard leaks.

Pressure Change Measurement Leak Testing Method

Level I

1. A pressure of 66.0 psig, in terms of absolute pressure at sea level and standard temperature, would be approximately:
 - a. 96.0 psia.
 - b. 80.7 psia.
 - c. 51.3 psia.
 - d. 36.0 psia.

2. When conducting a long-duration pressure change test, it is necessary to measure either absolute pressure or gage pressure plus barometric pressure because the barometric pressure will:
 - a. always fall.
 - b. always rise.
 - c. remain constant.
 - d. tend to vary.
3. Which one of the following is the correct relationship for converting temperature in degrees Rankine (1R) to temperature in degrees Kelvin (1K)?
 - a. $1K = (5/9) 1R$
 - b. $1K = (5/9) 1R + 273$
 - c. $1K = 460 + 1R$
 - d. $1K = 273 1R$

Level II

1. When a system's internal dry bulb's internal temperature and, in turn, total pressure, increase during a pressure change leakage-rate test, the water vapor pressure in the system under test would normally:
 - a. increase.
 - b. remain the same.
 - c. decrease.
 - d. oscillate.
2. For a pneumatically pressurized constant-volume system at an internal temperature of 27 1C, what approximate percentage change in the system absolute pressure can be expected for a system internal temperature change of 1 1C?
 - a. 3 percent
 - b. 6 percent
 - c. 0.3 percent
 - d. 10 percent
3. One set of internal dry bulb temperature data for a pressure change leakage rate test is:
 $(T1 + T2 + T3)/3 = 71.87 \text{ 1F}$
 $(T4 + T5)/2 = 72.32 \text{ 1F}$
 $(T6 + T7)/2 = 72.68 \text{ 1F}$
 $(T8 + T9 + T10)/3 = 73.07 \text{ 1F}$

For each of these four sections of this system, the respective weighting factors are 0.27, 0.18, 0.22 and 0.33. The mean absolute dry bulb temperature of system air for this test data point is:

- a. 532.53 1R.
- b. 345.53 1K.
- c. 532.48 1R.
- d. 532.48 1K.

Liquid Penetrant Testing Method

Level I

1. Which of the following is generally the more acceptable method for cleaning parts prior to penetrant testing?
 - a. sand blasting
 - b. wire brushing
 - c. grinding
 - d. vapor degreasing

2. The term used to define the tendency of certain liquids to penetrate into small openings such as cracks or fissures is:
 - a. saturation.
 - b. capillary action.
 - c. blotting.
 - d. wetting agent.
3. Which of the following is the most commonly used method for removing nonwater-washable visible dye penetrant from the surface of a test specimen?
 - a. dipping in a solvent
 - b. spraying
 - c. hand wiping
 - d. blowing

Level II

1. When conducting a penetrant test, spherical indications on the surface of a part could be indicative of:
 - a. fatigue cracks.
 - b. porosity.
 - c. weld laps.
 - d. hot tears.
2. A commonly used method of checking on the overall performance of a penetrant material system is by:
 - a. determining the viscosity of the penetrant.
 - b. measuring the wettability of the penetrant.
 - c. comparing two sections of artificially cracked specimens.
 - d. all of the above.
3. Which of the following is a discontinuity that might be found in a forging?
 - a. shrinkage crack
 - b. lap
 - c. hot tear
 - d. lamination

Magnetic Particle Testing Method

Level I

1. Which type of current has a “skin effect?”
 - a. AC
 - b. DC
 - c. half-wave rectified
 - d. full-wave rectified
2. The best type of magnetic field to use to inspect a tubular product for surface defects along its length is a:
 - a. longitudinal field.
 - b. circular field.
 - c. swinging field.
 - d. yoke magnetization.

3. Which of the following is most often used for dry magnetic particle inspection?
- full-cycle DC
 - half-wave AC
 - high-voltage, low-amperage current
 - DC from electrolytic cells

Level II

1. When testing a bar with an L/D ratio of four in a ten-turn coil, the required current would be:
- 45,000 A.
 - unknown; more information is needed.
 - 18,000 A.
 - 1,125 A.
2. Which of these cracks may appear as an irregular, checked, or scattered pattern of fine lines usually caused by local overheating?
- fatigue cracks
 - grinding cracks
 - crater cracks
 - HAZ cracks
3. If a copper conductor is placed through a ferrous cylinder and a current is passed through the conductor, then the magnetic field (flux density) in the cylinder will be:
- the same intensity and pattern as in the conductor.
 - greater than in the conductor.
 - less than in the conductor.
 - the same regardless of its proximity to the cylinder wall.

Neutron Radiographic Testing Method

Level I

1. Neutron penetration is greatest in which of the following materials?
- hydrogenous material
 - water
 - lead
 - boron carbide
2. Gadolinium conversion screens are usually mounted in rigid holders called:
- film racks.
 - cassettes.
 - emulsifiers.
 - diaphragms.
3. Which element is commonly used for direct neutron radiography?
- Cd
 - In
 - Dy
 - Gd

Level II

1. Which of the following conversion screens has the longest half-life?
 - a. dysprosium
 - b. indium
 - c. cadmium
 - d. gadolinium
2. Neutron radiography can be used for inspecting which of the following applications?
 - a. presence of explosives in a metal device
 - b. presence of foreign materials such as oil
 - c. lubricants in metal systems
 - d. hydrogen content in metals
 - e. all of the above
3. Real-time imaging of thermal neutron radiography can be performed with which of the following detectors?
 - a. gadolinium
 - b. dysprosium
 - c. zinc sulfide + lithium fluoride
 - d. europium

Radiographic Testing Method

Level I

1. The most widely used unit of measurement for measuring the rate at which the output of a gamma ray source decays is the:
 - a. curie.
 - b. roentgen.
 - c. half-life.
 - d. MeV.
2. If an exposure time of 60 seconds were necessary using a 4 ft source-to-film distance for a particular exposure, what time would be necessary if a 2 ft source-to-film distance is used and all other variables remain the same?
 - a. 120 seconds
 - b. 30 seconds
 - c. 15 seconds
 - d. 240 seconds
3. The sharpness of the outline in the image of the radiograph is a measure of:
 - a. subject contrast.
 - b. radiographic definition.
 - c. radiographic contrast.
 - d. film contrast.

Level II

1. When radiographing to the 2-2T quality level, an ASTM penetrameter for 2.5-in. steel has a thickness of:
 - a. 0.5 in.
 - b. 2.5 mils.
 - c. 5 mils.
 - d. 50 mils.

2. The approximate radiographic equivalence factors for steel and copper at 220 kV are 1.0 and 1.4, respectively. If it is desirable to radiograph a 0.5 in. plate of copper, what thickness of steel would require about the same exposure characteristics?
 - a. 0.7 in. of steel
 - b. 0.35 in. of steel
 - c. 1.4 in. of steel
 - d. 1.0 in. of steel
3. If a specimen were radiographed at 40 kV and again at 50 kV, with time compensation to give the radiographs the same density, which of the following statements would be true?
 - a. The 40 kV exposure would have lower contrast and greater latitude than the 50 kV exposure.
 - b. The 40 kV exposure would have higher contrast and greater latitude than the 50 kV exposure.
 - c. The 50 kV exposure would have lower contrast and greater latitude than the 40 kV exposure.
 - d. The 50 kV exposure would have higher contrast and greater latitude than the 40 kV exposure.

Thermal/Infrared Testing Method

Level I

1. As the temperature of an object increases, the wavelength of its peak radiant emittance:
 - a. increases.
 - b. remains the same.
 - c. varies up and down.
 - d. decreases.
2. The uncorrected temperature readings obtained from an object using an infrared sensor is referred to as the:
 - a. apparent temperature.
 - b. actual temperature.
 - c. absolute temperature.
 - d. temperature resolution.
3. Which is an example of a problem that can be detected through nondestructive infrared methods based on the heat capacity of the subject?
 - a. moisture in roof systems
 - b. high resistance in electric circuits
 - c. blockages in fluid flows
 - d. leaks in negative-pressure systems

Level II

1. A material is being evaluated for response to IR radiation in a specific narrow wavelength band. It is found to have an absorptivity of 0.85 and a reflectivity of 0.11. What is likely to be the transmissivity of the material in that wavelength band?
 - a. 0.96
 - b. 0.04
 - c. 0.106
 - d. 0.74

2. Infrared thermography active testing applies:
 - a. primarily to metals.
 - b. primarily to nonmetals.
 - c. to almost all types of materials.
 - d. primarily to bonded structures.
3. Transient temperature differences over discontinuities in materials having higher thermal diffusivities are _____ in duration and _____ in magnitude than in materials with lower thermal diffusivities.
 - a. shorter, lower
 - b. longer, lower
 - c. longer, greater
 - d. shorter, greater

Ultrasonic Testing

Level I

1. The amount of beam divergence from a transducer element is primarily dependent on the:
 - a. type of test.
 - b. tightness of the transducer element backing in the search unit.
 - c. frequency and transducer element size.
 - d. refraction.
2. On the area-amplitude ultrasonic-standard test blocks, the flat-bottomed holes in the blocks are:
 - a. all of the same diameter.
 - b. different in diameter, increasing by 1/64 in. increments from the No. 1 block to the No. 8 block.
 - c. largest in the No. 1 block and smallest in the No. 8 block.
 - d. drilled to different depths from the front surface of the test block.
3. On many ultrasonic testing instruments, an operator conducting an immersion test can remove that portion of the screen presentation that represents water distance by adjusting a:
 - a. pulse-length control.
 - b. reject control.
 - c. sweep-delay control.
 - d. sweep-length control.

Level II

1. If a contact angle beam transducer produces a 45 degree shear wave in steel ($V_S = 0.323$ cm/s), the angle produced by the same transducer in an aluminum specimen ($V_S = 0.310$ cm/s) would be:
 - a. less than 45 degrees.
 - b. greater than 45 degrees.
 - c. 45 degrees.
 - d. more information is required.
2. A discontinuity is located having an orientation such that its long axis is parallel to the sound beam. The indication from such a discontinuity will be:
 - a. large in proportion to the length of the discontinuity.
 - b. small in proportion to the length of the discontinuity.
 - c. representative of the length of the discontinuity.
 - d. such that complete loss of back-reflection will result.

3. An ultrasonic longitudinal wave travels in aluminum with a velocity of 635,000 cm/s and has a frequency of 1 MHz. The wavelength of this ultrasonic wave is:
 - a. 6.35 ft.
 - b. 3.10 in.
 - c. 6.35 mm.
 - d. 30,000 Å.

Vibration Analysis Testing Method

Level I

1. The vibration amplitude is really a response that is:
 - a. inversely proportional to the dynamic resistance in the system.
 - b. proportional to the amount of displacement in the signal.
 - c. not related at all to the dynamic forces in the system.
 - d. meaningless unless it has been initially taken in acceleration units.
2. If a magnetic base is attached to an accelerometer, it will:
 - a. lower the frequency range capability of the accelerator.
 - b. increase the frequency range capability of the accelerator.
 - c. not allow the accelerometer to read in acceleration units anymore.
 - d. increase the amplitude range of the accelerometer.
3. The enter or store key on a programmable FFT-Analyzer/Data collector should be pressed:
 - a. as soon as the accelerator is attached to the mounting surface.
 - b. after a pause of 30 seconds from the time the accelerometer is mounted.
 - c. after the readings have settled down (usually 3 seconds or longer).
 - d. immediately when a display appears on the screen (to save time).

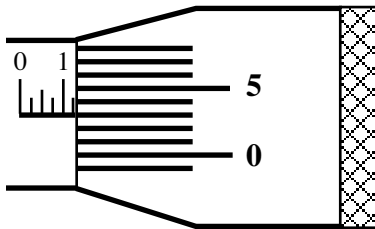
Level II

1. A Lissajous orbit that has a long elliptical (cigar shape) appearance is an indication of:
 - a. unbalance.
 - b. misalignment.
 - c. an oil whirl.
 - d. a rub event.
2. The purpose of a Bode or Polar (Nyquist) Plot is to verify the presence of:
 - a. an eccentricity.
 - b. a defective bearing.
 - c. a resonance.
 - d. a bent shaft.
3. The two most common problems that will produce a higher amplitude at 2X RPM than at 1X RPM in a vibration spectrum are:
 - a. an eccentric pulley and mechanical looseness (Type A).
 - b. offset misalignment and mechanical looseness (Type B).
 - c. a shaft bent between its bearings and worn gear teeth.
 - d. an unbalanced shaft and mechanical looseness (Type C).

Visual Testing Method

Level I

1. Which of the following is true?
 - a. all discontinuities are defects
 - b. defects that affect the product's usefulness are called discontinuities
 - c. discontinuities that affect the product's usefulness are called defects
 - d. all discontinuities are unacceptable
2. The dimension indicated on the sketch of a micrometer is:
 - a. 0.128 in.
 - b. 0.235 in.
 - c. 0.126 in.
 - d. 0.328 in.



3. As a visual examiner, you shall have your eyes checked at least:
 - a. every 3 months.
 - b. every 6 months.
 - c. every year.
 - d. every 3 years.

Level II

1. Hand held magnifiers should fall into which of the following ranges?
 - a. 2X to 4X
 - b. 5X to 10X
 - c. 10X to 20X
 - d. 20X to 30X
2. Visual examiners who perform visual exams using borescopes and fiberscopes must be:
 - a. color blind.
 - b. able to meet far-vision requirements (Snellen 20/30).
 - c. competent in their use.
 - d. ambidextrous.
3. A narrow field of view produces:
 - a. higher magnification and a greater depth of field.
 - b. higher magnification and a shorter depth of field.
 - c. less magnification and a greater depth of field.
 - d. less magnification and a shorter depth of field.

Answers to Example Questions

Acoustic Emission Testing Method

Level I	Level II
1. d	1. d
2. b	2. c
3. b	3. d

Electromagnetic Testing Method Eddy Current Testing Method

Level I	Level II
1. a	1. d
2. a	2. c
3. a	3. c

Electromagnetic Testing Method Flux Leakage Testing Method

Level I	Level II
1. c	1. d
2. d	2. d
3. d	3. d

Leak Testing Method Bubble Leak Testing Method

Level I	Level II
1. d	1. c
2. a	2. a
3. d	3. a

Leak Testing Method Halogen Diode Detector

Level I	Level II
1. d	1. a
2. c	2. c
3. c	3. b

Leak Testing Method Mass Spectrometer

Level I	Level II
1. b	1. c
2. b	2. b
3. b	3. c

Leak Testing Method Pressure Change Measurement

Level I	Level II
1. b	1. a
2. d	2. c
3. a	3. a

Liquid Penetrant Testing Method

Level I	Level II
1. d	1. b
2. b	2. c
3. c	3. b

Magnetic Particle Testing Method

Level I	Level II
1. a	1. d
2. b	2. b
3. b	3. b

Neutron Radiographic Testing Method

Level I	Level II
1. c	1. a
2. b	2. e
3. d	3. c

Radiographic Testing Method

Level I	Level II
1. a	1. d
2. c	2. a
3. b	3. c

Thermal/Infrared Testing

Level I	Level II
1. d	1. b
2. a	2. c
3. a	3. a

Ultrasonic Testing Method

Level I	Level II
1. c	1. a
2. b	2. b
3. c	3. c

Vibration Analysis Testing Method

Level I	Level II
1. a	1. b
2. a	2. c
3. c	3. b

Visual Testing Method

Level I	Level II
1. c	1. b
2. a	2. c
3. c	3. b