Practical Field Handbook in Industrial Radiography & Radiograph Interpretation

Authors: George W. Jaques
Dr. Aziz U. Rehman
A Practical Field Handbook

In

INDUSTRIAL RADIOGRAPHY & RADIOGRAPH INTERPRETATION

Authors:

George W. Jaques
Dr. Aziz U. Rehman

Jaques Enterprise Inspection Inc.

George’s River, Nova Scotia, Canada

Engineering Quality & Inspection Professionals+

Brandon, Manitoba, Canada
Industrial radiography is one of the oldest methods in nondestructive testing which has evolved rapidly with the introduction of Cobalt and Iridium after the 2nd World War. The field of industrial radiography covers a broad spectrum of applications with different levels of technician competencies. Though matured, industrial radiography still suffers from inspector subjectivity, interpretation discrepancies and code application variances. Numerous texts, formal trainings, and multitude of specifications are available to cover the training and application aspects of industrial radiography, but still there is a gap, a missing link and a disconnect between the training and the field application of industrial radiography. To increase compliance, improve conformity, decrease subjectivity and reduce interpretation variance, the authors of this handbook with over 40 years of combined industrial radiography field experience, have felt the need to develop a comprehensive text which can serve as a connection between training and application, a bridge between code requirements and correct interpretation, and also a ready reference to guide users in their day-to-day field work when applying their skills in a manner that is safe, reliable, and most importantly, correct.

The handbook is designed with a purposeful scope, covering all levels of inspector competencies, and is configured by taking into consideration all aspects of field industrial radiography (i.e. education & training, qualification & competency, techniques development & application, code compliance & interpretation), and most importantly, will prove to be handy field guide for routine reference.

The handbook contains more than 100 figures, sketches, graphs and illustrations, nearly 100 tables, over 100 industrial radiography techniques with close to 200 radiographs fully interpreted in
compliance with industrial codes, and more than 400 certification questions with numerous calculus examples. It covers in detail the subjects of radiographic film viewing coupled with industrial radiography application techniques, radiograph evaluation and interpretation aligned with prevalent industrial radiography codes and standards. The handbook also presents advancements in industrial radiography.

The handbook not only provides readers with the learning opportunity for attaining industrial radiography certification, but also serves as a field reference where all relevant data (i.e. sensitivity charts, density tolerances, several inspection techniques & other relevant information), are available in one treatise, for a code compliant radiographic inspection and evaluation with correct interpretation.

The handbook, a one of its kind, is aimed at both the practical and field aspects of industrial radiography. It is an effort focused on reducing inspector subjectivity and interpretation variances. The main goal is to give readers, novice or experienced, a structured approach in developing radiographic inspection techniques with a focused understanding on application of different industrial codes with correct interpretation. The handbook also provides readers with a side by side comparison of the use and application of different industrial codes, and will educate users in applying sound judgement while using the acceptance criteria.

This handbook provides readers with some basic understanding in radiation safety, however the main emphasis is to guide the users in correct application of industrial radiography.

George W. Jaques
Dr. Aziz U. Rehman
September 3, 2019

Mr. George Jaques
5 Bedwin Drive
George's River Nova Scotia
Canada B1Y043

Subject: 3rd Revision - Copyrighted Material

Dear Mr. Jaques:

In response to your e-mail dated May 18, 2019, ASME grants you and your Co-author Dr. Aziz U. Rehman permission to use excerpts from the standards and Codes listed below:

**Interpretations from ASME B31.1, B31.3, Section I, Section V, Section VIII-1**

1. B31.1-2010 – Interpretation #17-2529
3. B31.3-2008 – Interpretation #18-1018
4. 2001 Section VIII-1 – Interpretation # VIII-1-01-144
5. B31.3-2002 – Interpretation #20-20
6. B31.3-2002 – Interpretation #20-16
7. Section V – Interpretation # V-77-05
8. Section V – Interpretation # V-83-05
9. B31.3-2004 – Interpretation #20-42
10. 2013 Section I – Interpretation #15-902
11. 2013 Section VIII-1 – Interpretation #15-903
12. Section I – Interpretation #98-13
14. B31.3-1987 – Interpretation #9-04
15. 2013 Section VIII-Div. 1 – Interpretation #1-15-13
16. B31.3 – Interpretation #2-6
17. B31.3-1996 – Interpretation #16-6
19. 2001 Section VIII-1 – Record #16-1302
20. 2013 Section V – Interpretation #V-92-04
21. B31.3-2016 – Interpretation #18-2839
22. 2013 Section V – Record #14-2265
23. B31.3-2008 – Interpretation #19-895
24. 2001 Section VIII-Div. 1 – Interpretation VIII-1-04-18
25. 2017 Section I – Record Number 19-798

Total of 5 pages

as requested to be use in a publication titled “A Practical Field Handbook in Industrial Radiography & Radiograph Interpretation”. As is customary, we ask that the source document and ASME be fully acknowledged. “Reprinted from all the standards and codes listed above by permission of The American Society of Mechanical Engineers. All rights reserved”. No further copies can be made without written permission. Permission is for these editions only. If you have any questions do not hesitate to contact me.

Sincerely,

[Signature]

Ivette Esteviez
Manager, Standards IPR
(212) 591-8482
# Table of Contents

## SECTION 1

### Principles & Theory of Industrial Radiography

#### UNIT 1

Industrial Radiography

- What is Industrial Radiography: 3
- Limitations of Industrial Radiography: 3
- Alpha and Beta Particles: 3
- Gamma Rays: 3
- Radiation Decay: 5
- X – Radiation: 5
- X – Ray Tube: 7
- High Energy X – Ray Units: 9
- Ionization: 10
- Radiation Energy Hardness: 10

#### UNIT 2

Radiography Definitions, Terminologies & Equations

#### UNIT 3

Mathematical Applications in Industrial Radiography

### UNIT 4

Units of Industrial Radiography

#### UNIT 5

Mathematical Equations

- Activity: 11
- Becquerel & Curie: 11
- Electron Volt: 11
- Inverse Square Law: 11
- Linear Attenuation Coefficient (μ): 12
- Half Value Layer: 13
- Half Life: 13
- Geometric Unsharpness (Penumbra): 13
- Factor of Radiographic Equivalency: 14

#### UNIT 6

Application of Mathematics in Industrial Radiography

- Mathematical Equations: 17
- Application of Mathematics in Industrial Radiography: 19
- Advanced Mathematics in Industrial Radiography: 23
# Table of Contents

## Section 2: Radiation Safety

### Unit 4: Radiation Safety & Regulations
- Canadian Nuclear Safety Commission (CNSC) & US Nuclear Regulatory Commission (NRC) (Page 29)
- As Low As Reasonably Achievable (ALARA) (Page 30)
- Work Area is an Exclusion Zone for Non-Radiation Workers (Page 30)
- Radiation Protection Regulations of Canada (Page 30)
- Radiation Protection Regulations of USA (Page 31)
- Radiation and Human Cell Interaction (Page 31)
- Effects of Radiation (Page 31)
- Acute and Chronic Exposure (Page 32)
- Radiation Monitoring Equipment (Page 32)
- Emergency & Other Safety Equipment (Page 34)

### Unit 5: Industrial Field Radiography
- Planning for Industrial Field Radiography (Page 35)
- Preliminary Radiation Safety Performance Checks (Page 35)
- Setting Up Controlled Area (Page 36)
- Radiographer Dose Monitoring (Page 36)
- Investigation of Dose Incidence (Page 37)
- Radiation Emergency (Page 38)
- Minimizing Radiation Emergencies (Page 38)
- Requirements for Radiation Source Storage Facility (Page 38)

## Section 3: Radiographic Viewing

### Unit 6: Radiographic Film Properties
- Radiographic Films (Page 43)
- Characteristics & Properties of Films (Page 44)
- Film Characteristic Curves (Page 48)
- Radiographic Film Density (Page 48)
- Film Latitude (Page 51)
- Film Speed (Page 52)
- Film Characteristics Table (Page 53)
- AGFA Film Types and Comparison with other Brands (Page 54)
- Pipe-Film Class Comparison & Recommendations (Page 54)
- Signal-to-Noise Ratio of Films (Page 54)
- Film Packaging Types (Page 55)
- Intensifying Screens (Page 56)
- Storage of Unexposed Films (Page 57)

### Unit 7: Radiographic Image Quality

---

**Table of Contents**
Table of Contents

Film Exposure Setup 117
Weld Increments 119
Radiographic Identification 122
Exposure Time Calculations 123
Development of an Exposure Chart 124
Exposure Factors 125
Exposure Corrections 126
Exposure Setup Application 127

UNIT 13 Geometric Unsharpness & Magnification 133
Geometric Unsharpness (Ug) 133
Improving Geometric Unsharpness 133
Geometric Principles 133
Geometric Magnification 135
Light, X- and Gamma Ray Characteristics 136
Geometric Unsharpness – ASME Limits 136

UNIT 14 Scattered Radiation & Detection 137
Scattered Radiation 137
Lead Screens 138
Detection & Analysis of Backscatter 138

UNIT 15 Failed Film Exposures 141
Common Causes for Failed Exposures 141
Limiting Darkroom Reshots 142
Limiting Reshots for Exposure Device Operators 143
X-Ray Operating Window 143

SECTION 5 Radiographic Evaluation, Interpretation & Reporting 145

UNIT 16 General 147
Radiographic Indications 147
Codes and Standards 147
Radiograph Interpretation and Reporting 148
General Reporting 149
Evaluation and Interpretation 149
Radiographic Viewing 150
Radiographic Technique Evaluation 151
Marking Repairs 152
Reporting False Indications 153
Reporting Calculations for OFD and SOD 154

UNIT 17 Radiographic Film Artifacts 159
Radiographic Film Artifacts 159
Film Artifacts – Example Radiographs 162
Automatic Processing Film Artifacts 162

UNIT 18 Welding Radiography 167
Common Welding Discontinuities 167
Welding Discontinuity Illustrations 168

UNIT 19 Forging & Casting Radiography 187
Forging 187
Forging Discontinuities 188
Casting 188
Casting Discontinuities 191
Casting Interpretations 196

Table of Contents
# Table of Contents

## American Society of Mechanical Engineers

- **UNIT 20**
  - Various ASME Codes Acceptance Criteria
  - Rounded and Linear Indications
  - ASME Rounded Indication Criteria
  - Density Requirements
  - ASME B31.3 Normal Fluid Service Welds > ¼ in. (6 mm)
  - ASME Unit Discrepancies
  - Field Work Practical Questions (General)
  - ASME B31.3N Interpretation and Evaluation Practices
  - ASME B31.3 Severe Cyclic Interpretation and Evaluation Practices
  - ASME Code Inquiries & Interpretations

## Canadian Standards Association (CSA)

- **UNIT 22**
  - CSA Z662 Code Evaluation & Acceptance Criteria
  - CSA Z662 Density Requirements

## CSA Z662 Code Evaluation & Acceptance Criteria

- **UNIT 23**
  - Placement of IQIs
  - CSA Z662 Practical Code Questions
  - CSA Z662 Field Work Practical Questions
  - CSA W59 Welded Steel Construction
  - CSA W59 Density Requirements
  - CSA W59 Image Quality Indicators (IQIs)
  - CSA W59 Code Evaluation & Tolerances

## American Petroleum Institute (API) 1104

- **UNIT 24**
  - API 1104 Selection of IQIs
  - API 1104 Placement of IQIs
  - API 1104 Film Density
  - API 1104 Discontinuities & Acceptance Criteria

## Additional Standards & Norms

- **UNIT 25**
  - ASTM International
  - European Norms (EN)
SECTION 7

Industrial Radiography & Professional Certifications

UNIT 26  Professional Certification in Industrial Radiography  283
Industrial Radiography Certification  283
The Certification Process  284
The Recertification Process  287
Level III Certification in Industrial Radiography  288
Suggestions for Competency & Skills Improvements  288
Recertification through Re – Examination  288

UNIT 27  Sample Certification Questions – Level I & II  289
Sample Theoretical Questions – Level I & II  289

UNIT 28  Sample Certification Questions – Level III  305
Sample Theoretical Questions – Level III  305
Sample Certification Code Questions  313

UNIT 29  Industrial Radiography Examples  315
Film Artifacts  315
Casting Radiographs  318
Welding Radiographs  321
Uncommon Concepts in Industrial Radiography  348

UNIT 30  Development of an Inspection Procedure  351
Industrial Radiography Procedure  351
Development  351
Industrial Radiography Procedure Example  352
Example Procedure  353
Table of Contents  354
1. Introduction  355
2. Scope  355
3. References  356
4. Personnel Qualification  356
5. Safety  356
6. Radiation Safety and Monitoring Equipment  357
7. Surface Preparation  357
8. Equipment & Materials  357
9. Equipment Calibration  359
10. Radiographic Testing Examination Technique  360
11. Essential Parameters  362
12. Acceptance Criteria  363
13. Disposition  363
14. Documentation and Reporting  363
15. Appendix  364
Inspection Report Template  365

Table of Contents
## Advancements in Industrial Radiography

### UNIT 31: Digital & Computed Radiography
- Digital Radiography 369
- Pros & Cons of Digital Radiography 370
- Computed Radiography 370
- Advantages of Computed Radiography 371
- Digital & Computed Radiography Comparison 371
- Conventional Radiography Compared with Digital and Computed Radiography 371
- Field Applications 371
- Digital Information Radiography 372
- Computed Radiography Applications 375

### UNIT 32: Industrial Radiography with Selenium 75 (\(^{75}\text{Se}\))
- Properties of Selenium 75 377
- \(^{75}\text{Se}\) Energy Information 378

### UNIT 33: Small Controlled Area Radiography (SCAR)
- SCAR 959M 379
- Baby SCAR 989 380
- SCAR Pro 382
- Summary 382

### UNIT 34: Real Time Radiography (RTR)
- Applications of RTR 383
- Advantages of Real Time Radiography 383
- Disadvantages of Real Time Radiography 385

### UNIT 35: Field Radiography Pipeline Crawlers
- Principle of X-Ray Field Radiography 387
- Pipeline Crawler 387
- X-Ray Position (Control) Devices 387
- Pipeline X-Ray Crawlers, Advantages & Disadvantages 388
## Sensitivity & Reinforcement Charts for Field Use

<table>
<thead>
<tr>
<th>APP A</th>
<th>Sensitivity &amp; Reinforcement Charts for Field Use</th>
<th>391</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASME B31.3 Sensitivity Tables</td>
<td>391</td>
<td></td>
</tr>
<tr>
<td>ASME B31.1 Sensitivity Tables</td>
<td>394</td>
<td></td>
</tr>
<tr>
<td>ASME Sec. I Sensitivity Tables</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>ASME Sec. III Sensitivity Tables</td>
<td>406</td>
<td></td>
</tr>
<tr>
<td>ASME Sec. VIII Sensitivity Tables</td>
<td>418</td>
<td></td>
</tr>
<tr>
<td>CSA Z662 Sensitivity Tables</td>
<td>424</td>
<td></td>
</tr>
<tr>
<td>ASME Sec. V, Density Tolerance</td>
<td>430</td>
<td></td>
</tr>
<tr>
<td>IQI Reinforcement Reference</td>
<td>432</td>
<td></td>
</tr>
<tr>
<td>IQI References from ASME Sec. III</td>
<td>439</td>
<td></td>
</tr>
<tr>
<td>Tables From Different Sections for Ready Reference</td>
<td>441</td>
<td></td>
</tr>
</tbody>
</table>

## Answers to Questions from Different Sections

<table>
<thead>
<tr>
<th>APP C</th>
<th>Answers to Questions from Different Sections</th>
<th>459</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 6, Unit 20</td>
<td>459</td>
<td></td>
</tr>
<tr>
<td>Section 6, Unit 22</td>
<td>463</td>
<td></td>
</tr>
<tr>
<td>Section 7, Unit 27</td>
<td>464</td>
<td></td>
</tr>
<tr>
<td>Section 7, Unit 28</td>
<td>465</td>
<td></td>
</tr>
</tbody>
</table>

## Glossary of Terminologies

<table>
<thead>
<tr>
<th>APP D</th>
<th>Glossary of Terminologies</th>
<th>467</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition &amp; Terminologies</td>
<td>467</td>
<td></td>
</tr>
</tbody>
</table>

## Industrial Radiography Additional Techniques

<table>
<thead>
<tr>
<th>APP B</th>
<th>Industrial Radiography Additional Techniques</th>
<th>447</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection Technique for Nozzle Welds</td>
<td>447</td>
<td></td>
</tr>
<tr>
<td>Inspection of Backing Plate or Annular Ring</td>
<td>447</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of Valve Bevel Ends</td>
<td>449</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of Valve Body</td>
<td>449</td>
<td></td>
</tr>
<tr>
<td>Inspection of Valve Bonnet</td>
<td>451</td>
<td></td>
</tr>
<tr>
<td>Inspection of Production Casting</td>
<td>451</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of Concrete</td>
<td>451</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of Light Casting</td>
<td>452</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of T – Weld Joints</td>
<td>453</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of Y – Lateral Weld Joints</td>
<td>453</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of 3 – Way Lateral Weld Joints</td>
<td>454</td>
<td></td>
</tr>
<tr>
<td>Radiographic Inspection of K – Weld Joints</td>
<td>454</td>
<td></td>
</tr>
<tr>
<td>Fillet Weld Inspection with No Internal Source Placement Access</td>
<td>454</td>
<td></td>
</tr>
<tr>
<td>Radiography of Spheres</td>
<td>456</td>
<td></td>
</tr>
</tbody>
</table>
Principles & Theory of Industrial Radiography

Units

1. Industrial Radiography
2. Radiography Definitions, Terminologies & Equations
3. Mathematical Applications in Industrial Radiography
Radiographic Viewing

### Units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Radiographic Film Properties</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>Radiographic Image Quality</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>Radiographic Film Development</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>Radiographic Film Quality</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>Field Equipment &amp; Accessories</td>
<td>89</td>
</tr>
</tbody>
</table>
Industrial Radiography Application Techniques
Industrial Radiography Codes, Standards & Procedures

<table>
<thead>
<tr>
<th>Units</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>America Society of Mechanical Engineers</td>
<td>201</td>
</tr>
<tr>
<td>21</td>
<td>ASME Placement of IQIs &amp; Location Markers</td>
<td>235</td>
</tr>
<tr>
<td>22</td>
<td>Canadian Standards Association (CSA)</td>
<td>249</td>
</tr>
<tr>
<td>23</td>
<td>CSA Z662 Placement of IQIs</td>
<td>263</td>
</tr>
<tr>
<td>24</td>
<td>American Petroleum Institute (API) 1104</td>
<td>273</td>
</tr>
<tr>
<td>25</td>
<td>Additional Standards &amp; Norms</td>
<td>279</td>
</tr>
</tbody>
</table>
Industrial Radiography & Professional Certifications

Units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Professional Certification in Industrial Radiography</td>
<td>283</td>
</tr>
<tr>
<td>27</td>
<td>Sample Certification Questions – Level I &amp; II</td>
<td>289</td>
</tr>
<tr>
<td>28</td>
<td>Sample Certification Questions – Level III</td>
<td>305</td>
</tr>
<tr>
<td>29</td>
<td>Industrial Radiograph Examples</td>
<td>315</td>
</tr>
<tr>
<td>30</td>
<td>Development of an Inspection Procedure</td>
<td>351</td>
</tr>
</tbody>
</table>
Advancements in Industrial Radiography

<table>
<thead>
<tr>
<th>Units</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Digital &amp; Computed Radiography</td>
<td>369</td>
</tr>
<tr>
<td>32</td>
<td>Industrial Radiography with Selenium 75 (Se\textsubscript{75})</td>
<td>377</td>
</tr>
<tr>
<td>33</td>
<td>Small Controlled Area Radiography (SCAR)</td>
<td>379</td>
</tr>
<tr>
<td>34</td>
<td>Real Time Radiography (RTR)</td>
<td>383</td>
</tr>
<tr>
<td>35</td>
<td>Field Radiography Pipeline Crawlers</td>
<td>387</td>
</tr>
</tbody>
</table>
## Appendices

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>App.</strong></td>
<td><strong>Sensitivity &amp; Reinforcement Charts for Field Use</strong></td>
<td>391</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td><strong>Industrial Radiography Additional Techniques</strong></td>
<td>447</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td><strong>Answers to Questions from Different Sections</strong></td>
<td>459</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td><strong>Glossary of Terminologies</strong></td>
<td>467</td>
</tr>
</tbody>
</table>
This handbook is the first and only text book which is aimed at the practical and field aspect of industrial radiography which contains more than 100 sketches, graphs & illustrations. In addition, it contains nearly 100 tables, over 100 industrial radiography techniques, 400 certification questions and close to 200 radiographs which are fully interpreted in compliance with industrial codes. It covers in detail the subjects of radiographic film viewing coupled with industrial radiography application techniques, radiograph evaluation & interpretation aligned with prevalent codes and standards, and also the advancements in industrial radiography.