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Evaluation of Manual Radiography Versus Digital Radiography for High-Pressure Pipeline Weld Inspection

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Abstract

This study compares manual film radiography and digital radiography for high-pressure pipeline girth weld inspection. The comparison was based on a representative inspection scenario for API 5L X65 steel pipelines with 30 in outer diameter and 20 mm wall thickness. The evaluated indicators included image sensitivity, probability of detection, false call rate, inspection time, radiation exposure, and relative cost per weld. The results showed that digital radiography improved image sensitivity from 2.5% of wall thickness in film radiography to 2.0% for computed radiography and 1.8% for digital detector array systems. For small defects of 1–3 mm, the probability of detection increased from 78% to 88%. Digital radiography also reduced false calls from 12 to 7 per 100 welds and decreased exposure time by about 40–50%. Overall, digital radiography showed better technical and operational performance, especially for medium and large pipeline inspection projects.

Keywords: Digital radiography, Film radiography, Pipeline weld inspection, Non-destructive testing, Probability of detection.

1. Introduction

Essential infrastructure, high-pressure pipeline systems transport crude oil, refined products, natural gas, and petrochemicals over long distances. These pipelines operate under high internal pressure and variable environmental conditions. Therefore, the structural integrity of girth welds is a major safety requirement. Welds may be defective due to porosity, slag inclusion, lack of fusion, internal undercut, cracks, etc. The performance of welded joints is adversely affected by these defects. Further, these defects may lead to leakage, rupture, or service failure. That is why it is essential to evaluate weld quality before commissioning and during service using non-destructive testing (NDT) techniques. Most importantly, NDT techniques do not damage the inspected structure [1,2].

Radiographic testing is one of the most widely used NDT methods for pipeline weld inspection because it provides visual evidence of internal discontinuities and permanent inspection records. Conventional film radiography has been used for decades in industrial inspection because of its high spatial resolution and its acceptance in established inspection procedures. However, film-based radiography has several limitations, including long exposure and processing times, dependence on chemical processing, high consumable costs, environmental concerns, and limited post-processing capabilities [3–5].

Digital radiography, which includes computed radiography and digital detector arrays, has evolved as an alternative to film radiography. With digital systems, images can be acquired, stored, enhanced, transmitted, and transferred out more quickly. These devices might also limit exposure time and the radiation dose received, since digital detectors usually provide images of adequate quality. In other words, because of these advantages, use of digital radiography is very appropriate for inspection jobs involving large numbers of specimens, where speed, documentation, radiation safety, and workflow efficiency are relevant [6–9].

Previous studies have examined several aspects related to pipeline integrity, weld defect detection, and digital radiographic inspection. Kowalczyk et al. [1] discussed failure and degradation mechanisms in steel pipelines, while Alnaily and Aboalhol [2] evaluated weld defects in petroleum pipelines using X-ray inspection. Vaidya [3] discussed radiographic films and screens, whereas Vaidya [6] addressed filmless radiographic options and image processing. White [7], Dankar and Brzuchac [8], and Khan [9] examined digital detector arrays and their performance in nondestructive evaluation. Other studies also addressed advanced NDT techniques for pipeline integrity, girth weld defect identification, automated ultrasonic inspection, and computed radiography applications [10–15].

Even though studies imply a growing importance of digital technologies for the industrial inspection of pipelines, a direct combined comparison between manual film radiography and digital radiography for high-pressure pipeline girth welds is, however, still lacking, particularly when detecting performance, inspection time, radiation exposure, data management, and also cost-effectiveness are taken into account. Thus, the need for a systematic comparative assessment of manual film radiography and digital radiography, which becomes increasingly important during a representative high-pressure pipeline weld inspection, is the research gap this study addresses.

To inspect the welds of a high-pressure pipeline, the objective of this research is to compare the effectiveness of manual film radiography and digital radiography. The study aims to to compare various characteristics of both procedures. The assessment is conceptual but technically reasonable. The evaluation is supported by industry practices and literature.

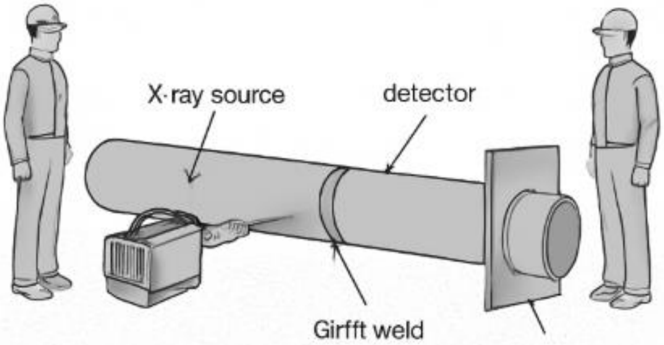

Fig. 1: Field setup for radiographic testing of high-pressure pipeline (Simulation Layout).

2. METHODS AND MATERIALS

2.1. Mathematical Modeling of Radiographic Parameters

A sound technical basis was established for comparing manual film radiography and digital radiography by documenting the most important radiographic parameters using mathematical methods influencing imaging quality and exposure conditions. These parameters include geometric unsharpness, variation of radiation intensity with distance, signal-to-noise ratio, exposure time, etc. These equations aim to clarify the physical factors that control the quality of radiographic images and to assist in comparing the two inspection techniques.

2.1.1. Geometric Unsharpness

Geometric unsharpness represents the loss of image sharpness caused by the finite size of the radiation source and the geometric relationship between the source, the inspected object, and the detector. It can be expressed as:

$$U_g = \frac{F \times b}{a}$$

where:

U_g: is the geometric unsharpness (mm)

F: is the effective focal spot size or source size (mm)

b: is the object-to-detector distance (mm) and

a: is the source-to-object distance (mm).

A lower value of geometric unsharpness indicates better image sharpness. Therefore, image quality can be improved by reducing the object-to-detector distance or increasing the source-to-object distance.

2.1.2. Inverse Square Law for Radiation Intensity

Radiation intensity decreases as the distance from the radiation source increases. This relationship is described by the inverse square law:

$$I_2 = I_1 (\frac{d_1}{d_2})^2$$

where:

I_1: is the radiation intensity at the first distance,

I_2: is the radiation intensity at the second distance,

d_1: is the first distance from the radiation source, and

d_2: is the second distance from the radiation source.

This equation is important in radiographic testing because any increase in the source-to-detector distance reduces the radiation intensity reaching the detector. Therefore, a longer exposure time may be required to obtain adequate image quality.

2.1.3. Signal-to-Noise Ratio in Digital Radiography

In digital radiography, image quality can be quantitatively evaluated using the signal-to-noise ratio. The signal-to-noise ratio is expressed as:

$$SNR = \frac{\mu_{ROI}}{\sigma_{BG}}$$

where:

SNR: is the signal-to-noise ratio,

μ_{ROI}: is the mean pixel value in the region of interest, and

σ_{BG}: is the standard deviation of the background pixel values.

A higher signal-to-noise ratio indicates a clearer image with lower noise. This improves the visibility of small weld defects such as fine cracks, small pores, and lack of fusion.

2.1.4. Exposure Time Estimation

The quality of the radiographic image is mainly influenced by exposure time. The source-to-detector distance, radiation source activity, detector sensitivity, material thickness, and the required image quality affect it. A basic exposure time relationship can be written as:

$$t = \frac{K \times D^2}{A}$$

where:

t: is the exposure time (min),

K: is the exposure factor depending on material thickness, detector type, and required image quality,

D: is the source-to-detector distance, and

A: is the radiation source activity or radiation output.

The longer the exposure time, the further away the radiation source is. As the distance decreases and the detector's sensitivity increases, the exposure time decreases. Because digital detectors are more sensitive than ordinary film, digital radiography can usually produce acceptable-quality images with shorter exposure times.

2.1.5. Technical Parameters Used in the Comparison

To maintain a controlled comparison between manual film and digital radiography, the same overall inspection geometry was used for both methods. Table 1 summarizes the key technical parameters used in the comparison.

Table 1: Main technical parameters used for manual film radiography and digital radiography

Parameter	Manual Film Radiography	Digital Radiography
Radiation source	Iridium-192 (Ir-192)	Iridium-192 (Ir-192)
Pipe material	API 5L X65 steel pipe	API 5L X65 steel pipe
Pipe outer diameter	30 *in*	30 *in*
Wall thickness	20 mm	20 mm
Source-to-detector distance	600 mm	600 mm
Detector medium	Industrial radiographic film with lead screens	Computed radiography plate or digital detector array
Typical exposure time per shot	4–6 min	1.5–3 min
Number of exposures per weld	4 overlapping exposures	4 overlapping exposures
Image processing method	Chemical processing	Digital image processing
Image interpretation	Illuminated film viewer	Calibrated high-resolution monitor
Image storage	Physical film archive	Electronic digital archive
Main limitation	Long processing time and chemical consumption	Higher initial equipment cost
Main advantage	High spatial resolution and established use	Faster inspection, digital storage, and lower operating cost

2.2 Inspection Scenario and Weld Specimens

The study compares manual film radiography and digital radiography using a representative, detailed, technically realistic inspection scenario. The objective of this scenario was to provide a controlled basis for comparing the two X-ray techniques under similar inspection conditions, not to conduct a proprietary field trial. Based on the above, image quality, defect detection capability, overall inspection time, effective radiation dose, and relative cost can be evaluated , using parameters commonly reported in the industry/literature [10,14,15].

The chosen case studies a high-pressure cross-country pipeline built from API 5L X65 steel. The nominal external diameter of the pipe was 30 in, and the wall thickness was 20 mm. These measurements are usually used in high-pressure gas and oil transmission pipelines [16]. The reviewed joints were assumed to be circular girth welds made using a multi-pass welding technique. Because defects in the weld zone may impair the pipeline's structural integrity in operation, such welds are critical inspection locations [17].

For the comparative analysis, a sample of 100 girth welds was selected. Of the welds, twenty-five were assumed to contain relevant internal imperfections with known locations and approximate sizes. The defects chosen are typical of pipeline girth welds and include lack of fusion, porosity, slag inclusions, internal undercut, and internal concavity. The defect types considered for selection are those that often occur during radiographic and ultrasonic inspection of welded joints [12,13,18].

Using a fictitious verification procedure based on automated ultrasonic testing and destructive sectioning of selected weld regions, the reference condition of the defects was defined. Reference methods must be available in inspection programs to determine whether the indications detected by radiography are genuine defects or false calls. The so-called reference condition, which wasn’t even a reference, was used solely as a technical basis for computing comparative indicators such as probability of detection and false call rate [17–19].

Both manual film radiography and digital radiography were evaluated under the same inspection geometry to ensure a fair comparison. The inspection was assumed to use an Iridium-192 source and a double-wall single-image technique. The distance from the source to the detector was kept at 600 mm. To ensure full coverage of the weld circumference, four overlapping exposures were used to examine each weld. Both radiographic techniques were subject to the same acceptance criteria, so the differences could be attributed to the inspection method rather than to different evaluation rules.

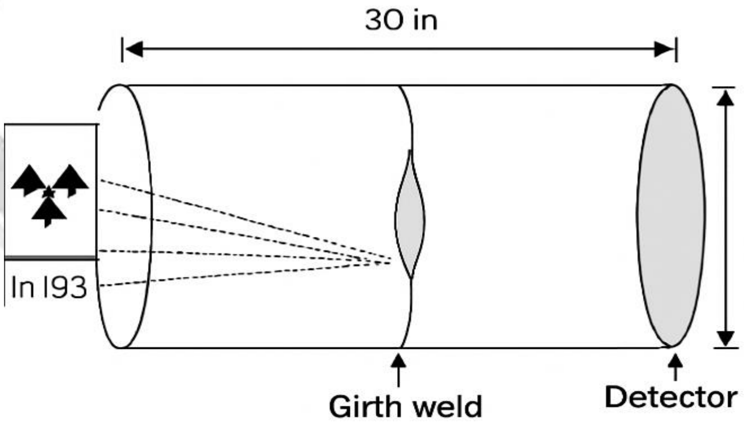

Fig. 2: Schematic representation of X-ray inspection geometry for high-pressure pipeline girth welds.

The main parameters of the inspection scenario are summarized in Table 2.

Table 2: Representative inspection scenario for high-pressure pipeline welds

Parameter	Description
Pipeline type	High-pressure transmission pipeline
Pipe material	API 5L X65 steel
Pipe outer diameter	30 in
Wall thickness	20 mm
Weld type	Circumferential girth weld
Welding configuration	Multi-pass butt weld
Number of welds considered	100 welds
Number of welds with relevant defects	25 welds
Main defect types	Porosity, slag inclusion, lack of fusion, internal undercut, internal concavity
Reference verification method	Automated ultrasonic testing and destructive sectioning of selected regions
Radiation source	Iridium-192
Radiographic technique	Double-wall single-image technique
Source-to-detector distance	600 mm
Number of exposures per weld	Four overlapping exposures
Evaluation basis	Same acceptance criteria for both techniques

2.3 Radiographic Procedures and Performance Indicators

The image receptor used in manual film radiography is the industrial radiographic film. The film was kept in a cassette with a lead screen to improve image contrast and reduce the effect of scattered radiation. The exposure settings were chosen to yield the desired optical density in the weld zone after chemical treatment. After exposure, the films were developed, fixed, washed, and dried, and interpreted by a qualified radiographic interpreter using an illuminated film viewer. Film inspection offers effective spatial resolution and permanent physical records of inspection results. However, it requires chemical processing, consumables, and longer handling time because it depends on offline processing methods [3–5].

Digital detector arrays and computed radiography plates are considered image receptors. In computed radiography, a plate stores a latent image after exposure, which is subsequently scanned by a reader to produce a digital image. A direct digital radiographic detector receives the radiation signal and converts it into an image displayed on a workstation. It was assumed that calibrated high-resolution monitors would be used for image manipulation under controlled viewing conditions [6–9,19,20].

Both radiographic techniques were conducted with uniform exposure geometry, source type, pipe thickness, and number of exposures. The comparison was performed in a manner that did not allow the inspection setup to influence the image receptor and workflow. The digital imaging process are restricted to acceptable operations such as window-level adjustment, zooming, and noise reduction. The evaluation did not include processes that create a false or hidden defect indication or attribute.

The findings were determined based on six performance metrics. The first metric was assessed on image quality, measured by image sensitivity and visibility of small discontinuities. The second indicator concerns the probability of detection, the percentage of known defects correctly detected by each method. The false-call rate is the third indicator, referring to the number of calls that were not confirmed by the reference condition. Inspectors spent an average of 6.5 hours inspecting and interpreting each weld. The fifth indicator is exposure to radiation, which we assessed based on time spent and source activity [21]. The sixth indicator, economic efficiency, was expressed as a simplified relative cost per weld (equipment, consumables, labor, archiving).

The main performance indicators used in the comparison are summarized in Table 3.

Table 3: Performance indicators used to compare manual film radiography and digital radiography

Indicator	Definition	Purpose in the comparison
Image quality	Visibility and clarity of weld indications	To evaluate the ability of each method to produce interpretable images
IQI sensitivity	Smallest visible image quality indicator value	To compare radiographic sensitivity
Probability of detection	Percentage of known defects correctly detected	To evaluate defect detection capability
False call rate	Number of unconfirmed reported indications	To assess interpretation reliability
Inspection time	Time required for exposure, processing, and interpretation	To compare productivity
Radiation exposure	Relative exposure based on source activity and exposure time	To compare radiation safety
Data management	Method of storing and retrieving inspection records	To compare traceability and documentation
Relative cost per weld	Simplified cost including equipment, labor, consumables, and archiving	To compare economic efficiency

3. Results

3.1 Image Quality and Detection Performance

Given the inspection scenario and the performance characteristics described in the previous section, manual film radiography and digital radiography were compared in terms of image quality, defect detection capability, probability of detection, and false call rate. Both evaluations were performed under the same inspection geometry and pipe thickness, with the same source and evaluation criterion. In this way, any differences observed could be ascribed to the radiographic technique and not the inspection arrangement.

Image quality indicator sensitivity was used to evaluate image quality. In manual film radiography, the minimum visible wire was equivalent to approximately 2.5% of the pipe wall thickness. In weld inspection, a moderate numerical difference in sensitivity is important, as it can enhance visibility of small indications, especially fine cracks, small pores, and lack of fusion at the weld root.

The number of detected weld defects was then compared between the two methods. The detection gain was calculated using the following equation:

$$Detection\ Gain\ (\%) = \frac{N_D - N_F}{N_F} \times 100$$

where:

N_D: is the number of defects detected by digital radiography, and

N_F: is the number of defects detected by manual film radiography.

The comparative results of weld defect detection are presented in Table 4.

Table 4: Comparative results of weld defect detection by manual film radiography and digital radiography

Type of weld defect	Manual film radiography	Digital radiography	Detection gain (%)
Porosity	10	12	20.0
Slag inclusions	7	8	14.3
Lack of fusion	4	5	25.0
Fine cracks	2	6	200.0
Total detected indications	23	31	34.8

The results show that digital radiography detected more indications than manual film radiography. Compared to two readings recorded by film radiography, digital radiography readings of six indicate a huge improvement for oriented strand boards. Contrast adjustments in digital images have improved the production of color and grayscale images. However, the high percentage gain for fine cracks should be interpreted carefully because the number of crack indications was relatively small.

The probability of detection was evaluated for two defect size categories. For defects larger than 3 mm, manual film radiography achieved a probability of detection of approximately 94%, while digital radiography achieved approximately 97%. For smaller defects ranging from 1 to 3 mm, manual film radiography achieved approximately 78%, while digital radiography achieved approximately 88%. These results indicate that the main advantage of digital radiography appears in the detection of smaller defects rather than in the detection of large and clearly visible discontinuities [12,13,15].

The probability of detection behavior for both inspection techniques is presented in Fig. 3.

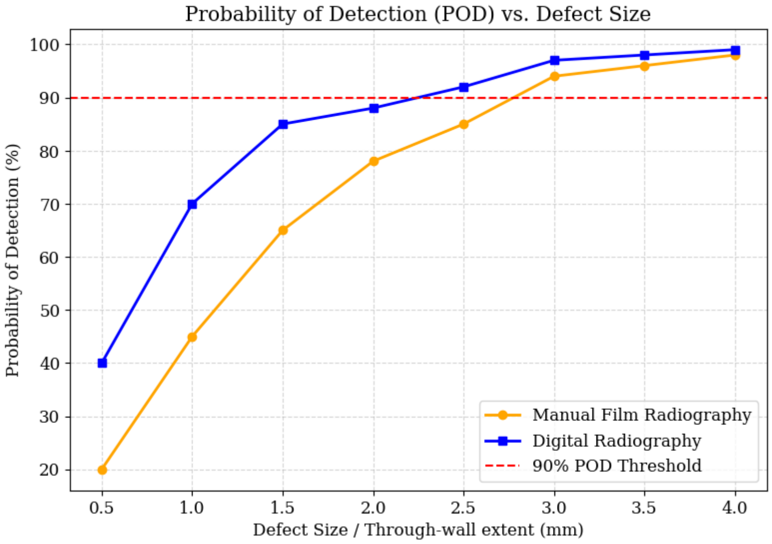

Fig. 3: Probability of detection as a function of defect size for manual film radiography and digital radiography.

False call rate was also considered as an indicator of interpretation reliability. In the assumed 100-weld sample, manual film radiography produced approximately 12 false calls, while digital radiography produced approximately 7 false calls. False calls in film radiography may result from scratches, dust, chemical processing marks, or difficulty in interpretation. In the digital radiographic process, false calls may arise from detector artifacts or over-processing the image. Nevertheless, with zoom, brightness, and contrast controls available, the interpreter can differentiate real defects from unrelated indications [18,20].

The main technical performance indicators are summarized in Table 5.

Table 5: Technical performance indicators for manual film radiography and digital radiography

Indicator	Manual film radiography	Digital radiography
IQI sensitivity	2.5% of wall thickness	2.0% for CR; 1.8% for DDA
POD for defects > 3 mm	94%	97%
POD for defects of 1–3 mm	78%	88%
False calls per 100 welds	12	7
Image stability	Affected by chemical processing	More stable digital response
Image enhancement	Limited after processing	Available under controlled limits
Record format	Physical film	Digital image file

A general comparison of the main technical performance indicators is shown in Fig. 4.

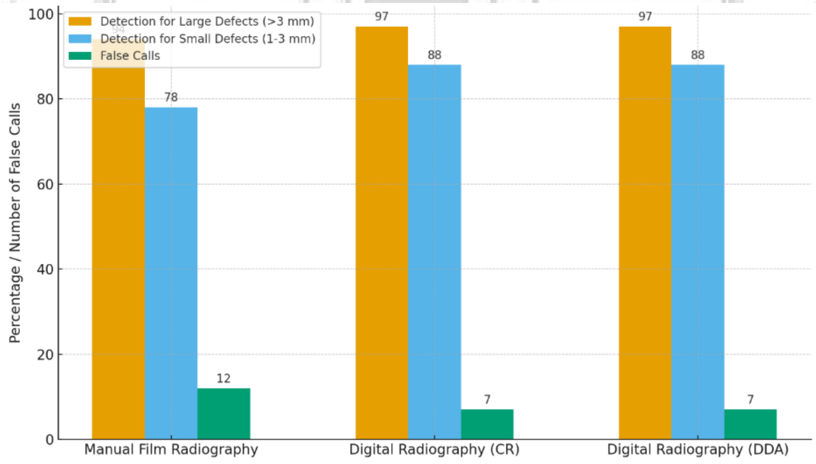

Fig. 4: Comparison of main technical indicators between manual film radiography and digital radiography.

These results indicate that digital radiography provides equal or better technical performance than manual film radiography in the assumed inspection scenario. The strongest advantages of digital radiography are related to improved detection of small defects, reduced false calls, faster image availability, and better image handling. Nevertheless, these results should be interpreted as a comparative analytical evaluation rather than a full field validation, because the inspection scenario was designed as a representative technical model.

3.2 Productivity, Radiation Exposure, and Economic Indicators

Beyond detection performance, productivity and radiation safety are important factors in high-pressure pipeline construction and inspection projects. The total inspection cycle time per weld was shorter for digital radiography than for manual film radiography. In manual film radiography, the average exposure time per weld, considering multiple overlapping exposures, was approximately 20 minutes. When film loading, transport, chemical processing, drying, and waiting time were included, the total time before interpretation usually reached 40–60 minutes per weld.

Digital X-ray systems feature highly sensitive detectors that enable short exposure times. The exposure time was about 10 to 15 minutes per weld, for a total of about 10 to 15 minutes. Due to the extra step of reading out the plate in computed radiography, the images were normally available in about 20–25 minutes. After exposure, images were available almost immediately and could be evaluated soon thereafter for digital detector array systems. Consequently, under similar field and crew-size conditions, digital radiography can improve inspection productivity by minimizing the time required for image acquisition, processing, and interpretation [6–9].

The difference in total inspection cycle time between the two techniques is illustrated in Fig. 5.

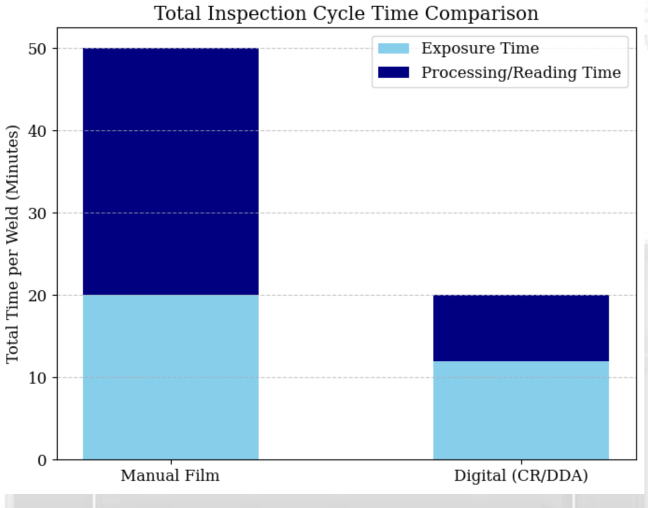

Fig. 5: Comparison of total inspection cycle time per weld for manual film radiography and digital radiography.

This means that if all other factors are kept constant, and the exposure time is kept to a minimum, the collective radiation dose received by the radiographers and other nearby workers can be reduced. In the situation considered, digital radiography reduced the total exposure time per weld by about 40-50%. This is particularly important in field radiography, as a shorter exposure time results in a smaller controlled radiation zone, thereby enhancing site safety management. Moreover, the use of digital detectors may allow lower source activity while maintaining acceptable image quality.

There was also a marked difference in data management. Manual film radiography uses physical films, which take up space, require manual labeling, and require environmental control. Films deteriorate over time, and taking them out for viewing or revision is tiresome. Electronically capturing an image of the specimen to which the X-rays have been applied is the principle of digital radiography. Digital data can be stored with metadata such as weld number, date, operator, location, exposure conditions, acceptance status, etc. It helps monitor and maintain quality standards and assurance going forward [6,9,19].

The economics comparison relied on a simplified relative cost model. The initial cost of manual film radiography equipment might not be too high, but the recurring costs of films, chemicals, film processing, waste disposal, labor and physical archiving are significant. While investment in digital radiography costs more upfront due to the use of digital detector arrays, lower consumable costs and faster inspection workflow may enable less hourly labor costs per weld.

A simplified relative cost estimation for the 100-weld sample is presented in Table 6.

Table 6: Simplified relative cost per weld for manual film radiography and digital radiography

Cost component	Manual film radiography	Digital radiography
Capital equipment, annualized per weld	0.20	0.35
Consumables (films, plates, and chemicals)	0.40	0.10
Labor (operators and interpreters)	0.30	0.25
Archiving and logistics	0.10	0.10
Total relative cost per weld	1.00	0.80

The simplified model indicates that digital radiography has a higher capital cost but a lower total relative cost per weld when the inspection volume is sufficient to spread the equipment cost across many welds. For low-volume operations or infrequent inspections, manual film radiography may be economically justified despite the lower capital costs. Digital radiography can become cost-effective for medium- and large-scale pipeline projects when consumable quantities are reduced, inspection time is shorter, and data handling is more efficient.

Operational feasibility was further evaluated in terms of time, consumables, environmental impact, and archiving. The comparison is summarized in Table 7.

Table 7: Operational time and workflow efficiency comparison

Activity / metric	Manual film radiography	Digital radiography
Preparation and exposure time	15–20 min	3–5 min
Developing / imaging time	Approximately 12 min for chemical development	Instant or near real-time image display
Consumables	High, films and chemicals required	Low, reusable detector or imaging plate
Environmental impact	Chemical waste generated	Reduced chemical waste
Storage and archiving	Physical storage required	Digital storage and electronic retrieval
Field reporting	Slower due to film processing	Faster due to direct image availability

The simplified cost distribution for both radiographic methods is shown in Fig. 6.

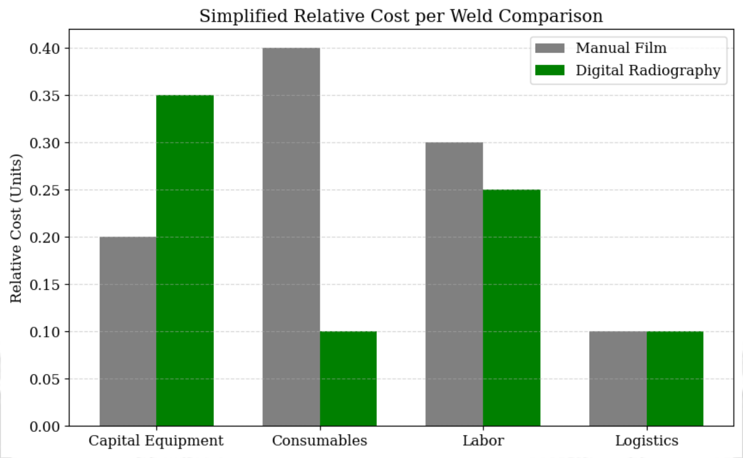

Fig. 6: Simplified relative cost per weld for manual film radiography and digital radiography.

To sum up, the main advantages of digital radiography over manual film radiography for the inspection of welds on high-pressure pipelines are many. All these factors lead to better detection of small defects, a reduced false-call rate, shorter inspection cycle time, shorter exposure time, better data management, and reduced relative cost per weld in large inspection projects. Proper calibration of the system is essential for competent professionals, control of image processing, and compliance with inspection standards.

4. Discussion

This study shows that weld inspection of high-pressure pipelines can be improved using digital radiography. Digital radiography has lower physical, operational, and technical limitations than manual film radiography. A noticeable advancement was in the detection of defects at lower levels. Digital radiography's ability to detect flaws is superior to that of film radiography. What earlier studies have said about the transformative power of digital image processing, imaging quality assessment, and similar aspects seems to be true [6–9,20].

Reading digital images with the ability to modify contrast, brightness, and enlarge them would logically lead to enhanced detection performance. Thanks to these technologies, the radiographer can detect fine cracks, small pores, and lack of fusion more effectively than with traditional film imagers. Nonetheless, the advantage afforded by screening inspection procedures has to be weighed, as over-processing of images will undermine the reliability of interpretation. Consequently, the study investigating digital image quality control and proper viewing conditions for digital radiographic inspection is consistent [20].

Digital radiography is believed to save time and reduce the total inspection cycle time per weld. Digital radiography provides more immediate access to inspection records and images without requiring an additional exposure, unlike film radiography. Similar work on filmless radiography and digital detector arrays is already becoming common, and the results fits this. As per the studies and literature mentioned above, digital systems improve workflow and reduce delays in industrial inspection [6–9].

A significant factor in pipeline radiography is radiation exposure. Digital radiography reduces exposure time and, consequently, the potential collective dose to employees under the same shielding and field conditions. Optimizing doses and detector performance in digital radiography is important, as shown by various studies [19,21]. Nevertheless, radiation safety still depends on proper source handling, controlled areas, shielding, distance, and compliance with radiographic safety procedures.

manual film radiography could be an option for low-volume inspection due to its low equipment cost. In medium- and large-scale pipeline projects, digital radiography is viable due to lower consumables, chemical processing, labor time, and physical archiving costs. When there are many inspected welds, the higher initial price of digital ten is broken down to be more palatable.

The present study corroborates assessment studies on pipeline integrity and weld defects. The most recent studies on the corrosion of steel pipelines and weld defects underscore the need to inspect welded joints to prevent leaks, failures, and service interruptions [1,2,16,17]. Advanced NDT processes and automated defect detection studies indicate the acceptance of more digital orautomated inspection technologies for better defect identification and greater inspection reliability [10–15].

Before it can be considered a simple replacement for film radiography, digital radiography has its drawbacks. Film radiography remains a popular choice for applications that require very high spatial resolution, simple field equipment, and older inspection techniques. To establish an acceptable and qualifying relationship, the partner must be evaluated and approved to continue. The method adopted will depend on the above factors, as well as the required inspection level, pipe geometry, required sensitivity, cost, safety conditions, and the standard to comply with.

The main limitation of this study is that the comparison was based not on a full experimental field campaign but on a representative technical scenario. As a result, the numerical values should be interpreted as comparative indicators supported by the literature and industrial practice. However, they should not be regarded as ‘universal’ values for every pipeline project. Further investigation should include validation in actual sites with real pipeline welds, varying wall thicknesses and defect sizes, and multiple digital detectors.

In total, the discussion concurs that, considering productivity and radiation exposure, data management, and long-term costs, digital radiography is more appropriate for high-volume pipeline weld inspection. While manual film radiography remains technically valid for pipeline inspection systems, digital radiography offers far greater practical advantages.

5. Conclusion

A systematic comparison between manual film radiography and digital radiography for high-pressure pipeline girth weld inspection has been presented. The study addressed the gap in the limited combined comparison of the two methods regarding detection performance, inspection time, radiation dose, data management, and economic efficiency. Recent studies that focus on a single aspect of the inspection often fail to address other specifications or method evaluations. This paper evaluates both methods in a representative pipeline inspection scenario conducted in the field, using a set of technical, operational, safety, and economic indicators.

Digital radiography had superior image sensitivity compared with film radiography, as indicated by the results. The sensitivity of IQI has increased from about 2.5% of wall thickness for film radiography to about 2.0% for computed radiography and to 1.8% for digital detector array systems. The likelihood of detecting a defect is even greater with digital radiography. This is especially true for defects with a diameter of about 1-3 mm. More specifically, for the 1-3 mm defect, the likelihood of detection increased from 78% for film radiography to 88% for digital radiography. For defects larger than 3 mm, both film and digital radiography showed high detection capability of 94% and 97%, respectively.

According to the results of comparative defect-detection tests, digital radiography detected 31 indications, while manual film radiography detected 23, yielding an overall detection gain of 34.8%. The biggest enhancement was recorded for fine crack detection; nevertheless, this result should be interpreted with caution, as the number of crack indications was small. The number of false calls was reduced from 12 to 7 per 100 welds with digital radiography, primarily due to improved image stability, digital control over contrast, and better viewing tools.

Digital radiography provides a clear advantage over film radiography in both productivity and radiation safety. The findings indicate that, due to shorter exposure times in digital systems and the discharge of chemical file processing, the total inspection cycle time is reduced. Under firmly similar shielding and field conditions, it lowers the probability of collective exposure to radiation by 40-50%. According to previous literature, it is expected that digital radiography is superior to conventional radiography in terms of image quality, workflow, dose, and digital image processing [6–9,20,21].

As economic comparisons reveal, manual film radiography is an economically sound solution for smaller inspection tasks due to its lower initial equipment cost. The Eddy current test is widely accepted for small pipelines. However, for medium and large pipelines, digital radiography is more cost-effective. This is due to a significant reduction in costs for consumables, chemical processing, labor time, and physical archiving. The simplified costing model applied in this work shows that film radiography has a value of 1.00 and digital radiography has a value of 0.80, relative to the cost per welds.

In sum, if detection performance, productivity, radiation exposure, data traceability, and long-term cost are considered together, then digital radiography can be viewed as a more efficient inspection option for welds of high-pressure pipelines. Even so, for a few special applications that require very high spatial resolution, employ very simple equipment, or must comply with an established inspection procedure, manual film radiography still remains technically valid. Essentially, the individual or organization implementing digital radiography must have qualified personnel, calibrated equipment, an approved methodology, and a relevant standard.

The study's primary limitation was that the comparison was not based on a complete experimental field campaign but a representative analytical scenario. It would be useful for future work to support the current findings by providing real pipeline welds with various diameters and wall thicknesses, various defect sizes, and various digital detector configurations. To enhance the assurance of welding inspection decisions, future research employed a combination of digital radiography, automated ultrasonic testing, and machine learning-based defect recognition.

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Conflict of Interest

There is no conflict to disclose

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تقييم التصوير الإشعاعي اليدوي مقابل التصوير الإشعاعي الرقمي لفحص لحامات الأنابيب ذات الضغط العالي

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الخلاصة

تقارن هذه الدراسة بين التصوير الشعاعي التقليدي المعتمد على الفيلم والتصوير الشعاعي الرقمي في فحص لحامات الأنابيب ذات الضغط العالي. اعتمدت المقارنة على سيناريو فحص تمثيلي لأنابيب فولاذية من نوع API 5L X65 بقطر خارجي 30 بوصة وسماكة جدار 20 ملم. شملت مؤشرات التقييم حساسية الصورة، واحتمالية اكتشاف العيوب، ومعدل الإشارات الكاذبة، وزمن الفحص، والتعرض الإشعاعي، والكلفة النسبية لكل لحام. أظهرت النتائج أن التصوير الشعاعي الرقمي حسّن حساسية الصورة من 2.5% من سماكة الجدار في التصوير بالفيلم إلى 2.0% في التصوير الشعاعي المحوسب و1.8% في أنظمة الكواشف الرقمية. كما ارتفعت احتمالية اكتشاف العيوب الصغيرة التي يتراوح حجمها بين 1–3 ملم من 78% إلى 88%. كذلك خفّض التصوير الشعاعي الرقمي الإشارات الكاذبة من 12 إلى 7 لكل 100 لحام، وقلّل زمن التعرض الإشعاعي بنحو 40–50%. وبصورة عامة، أظهر التصوير الشعاعي الرقمي أداءً فنياً وتشغيلياً أفضل، ولا سيما في مشاريع فحص الأنابيب المتوسطة والكبيرة.

الكلمات الدالة: التصوير الشعاعي الرقمي، التصوير الشعاعي بالفيلم، فحص لحامات الأنابيب، الفحص غير التدميري، احتمالية اكتشاف العيوب.