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# How Much Radiography Is Enough? Weld Porosity, Inspection Coverage, and Confidence in Strategic API 650 Potable-Water Storage Tanks for Emergency Preparedness

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## Abstract

# Background

Potable-water tanks built to API 650 are accepted on a package of examinations, but only a sample of the shell welds is radiographed (RT), and the adequacy of that sample is rarely examined with field data.

# Methods

Case study of the inspection records of two nominally identical, field-erected A36 steel tanks (five shell courses, 10–20 mm plate). Rejections were analysed by shell course, RT batch, joint location and listed welder with exact confidence intervals and exact tests, and two sampling scenarios estimated the chance of detecting defective seams.

# Results

Of 86 traceable RT spots listed (122 planned for both tanks), 67 were radiographed and 6 (9.0%; 95% CI 3.4–18.5%) were rejected for porosity. All six were in one tank and one RT batch, in the two 10 mm upper courses, on four joints credited to four different welders; the same joints in the other tank were accepted. In the 10 mm fourth course, rejection was 5/12 versus 0/12 (risk difference 41.7 percentage points, 95% CI 8.7–68.0; Fisher exact p = 0.037). After repair all rejected spots were accepted; all other examinations reported no indications, and both tanks passed the hydrostatic test at the 8 m design liquid level. A 25% random sample would include a single defective seam in 25% of cases, and would hit a cluster of 3 to 6 defective seams in 59–84% of cases, after which extending RT to the whole batch would find all of them.

# Conclusions

Porosity clustered by batch rather than by welder, thickness or joint type. Batch-triggered extension of RT, recording of consumable and ambient conditions, and documentation of any reduction in RT scope are proposed for consideration. The findings come from two tanks and support analytical rather than statistical generalisation.

## Highlights

- Spot RT rejected 6 of 67 shell spots for porosity, all in one tank and one batch.

- Leak and hydrostatic tests complement, but do not replace, volumetric RT.

- A 25% random sample finds an isolated defective seam in only 25% of cases.

- Batch-based extension of RT is proposed alongside the welder-based rule of API 650.

- Anonymised inspection records are analysed with exact statistics and welder codes.

# 1. Introduction

Ground-level welded steel tanks are widely used to store potable water (American Water Works Association (AWWA), 2021), and API 650 is a common basis for their design and construction (API 650, 2018). Field-erected shell seams are made under variable site conditions, and their quality is verified by a package of examinations rather than by any single test. Visual and leak-based methods are applied to all or most welds; volumetric examination, normally radiography, is applied to a defined sample of shell seams and junctions; and the completed tank is filled for a hydrostatic test.

Beyond routine quality assurance, tanks have a strategic role where supply depends on seawater desalination: treated water held in tanks is the buffer when an intake or treatment plant is interrupted, with reserves of roughly 36 hours to seven days reported for Gulf states that obtain 60–90% of their freshwater from desalination (Ben Saad, et al., 2026). Modelling of hypothetical accidents at coastal power plants shows that source-water contamination is a credible disruption pathway (Maderich, et al., 2023). We assess no such scenario; we argue only that confidence in tank integrity, including the adequacy of weld inspection, is part of supply resilience.

In regions that depend heavily on desalinated seawater, potable-water storage tanks constitute a critical component of emergency-response infrastructure. Following industrial accidents, radiological releases, extreme weather events, or disruptions to seawater intake systems, stored potable water may become the primary short-term source of drinking water. Under such circumstances, confidence in tank integrity becomes not only a construction-quality issue but also a matter of water-security resilience and emergency preparedness.

Porosity is one of the most common workmanship discontinuities in manual arc welds, and its main drivers (moisture, contamination, electrode handling, ambient conditions) are well known in general terms (Mascalco & Koltz, 2020; Rofiqie & Fitri, 2024; Cameron, 2022). Weld discontinuities have also been implicated in failures of aboveground liquid storage tanks, including a collapse in which an earlier third-party inspection had not identified the defects (United States Environmental Protection Agency (EPA), 2009; U.S. Chemical Safety and Hazard Investigation Board (CSB), 2008). What is much less documented is how a real sampling-based RT programme behaves on an actual potable-water project: how many spots are taken, where defects appear, whether defects cluster, and what the other examinations in the package add. Although API 650 specifies minimum radiographic examination requirements, we found little published evidence on how often spot radiography detects defects in actual potable-water tank projects, whether defects occur randomly or in clusters, and how RT findings compare with the outcomes of the other mandatory examinations. The closest sources are a case study of weld defects in an oil tank (Syahputra, 2026), a practice-oriented inspection framework (Gunjan, 2026), a textbook chapter on the examination of tank welds (Sotoodeh, 2024) and an in-service defect

analysis (Stoicescu, 2025). To the author's knowledge, no published study was identified that directly relates spot-radiography yield to sampling coverage in potable-water storage tanks.

This paper analyses the complete inspection record of two nominally identical tanks built in the same project. We ask:

- RQ1. What were the RT outcomes, and how were rejections distributed by tank, shell course (plate thickness), RT batch, joint location and listed welder?
- RQ2. What did the other examinations (visual, vacuum box, oil penetration, penetrant testing, hydrostatic test) report?
- RQ3. What probability does a spot-RT sample have of detecting defective seams, and what does this imply for sampling practice in potable-water tanks?

The objective is not statistical generalisation to all API 650 tanks but analytical generalisation (Yin, 2018): a detailed examination of inspection behaviour under real project conditions, from which mechanisms (clustering of defects, sample coverage, complementarity of methods) can be proposed and tested in other projects.

Although the present study does not address radiological contamination directly, the findings are relevant to emergency water-security planning because inspection reliability influences confidence in the integrity of strategic potable-water reserves.

## 2. Background

# 2.1 Porosity in shielded-metal-arc welds

Practitioner and experimental sources associate porosity with moisture in or on the electrode and the joint, condensation, contamination and improper parameters (Mascalco & Koltz, 2020; Rofiqie & Fitri, 2024; Cameron, 2022). One field-oriented study of A106 Grade B pipe, using RT and penetrant testing, reported that higher relative humidity was associated with more porosity (Rofiqie & Fitri, 2024). Evidence is not unanimous: a laboratory study on low-carbon steel found that electrode humidity did not change the defects as long as the electrode flux was not damaged (Hafni, 2021). We therefore treat any causal explanation for our data as a hypothesis, not a finding.

# 2.2 What each method can detect

RT is sensitive to volumetric discontinuities such as porosity and slag and leaves a permanent record (US NRC, 2015). Phased-array ultrasonic testing (PAUT) is an increasingly used alternative: in carbon-steel welds it detected all but very small volumetric flaws and was better than RT for planar flaws, although flaw characterisation depended on operator experience (US NRC, 2015); a recent laboratory comparison on welded plates with embedded defects addressed the same question (Herceg, et al., 2023). Surface and leak-based methods reveal only discontinuities open to the surface or connected to a

leak path (ASTM E515, 2022); a nuclear-piping case documented welds accepted by magnetic-particle and penetrant testing that showed unacceptable indications on radiography (United States Nuclear Regulatory Commission (NRC), 1990). Historically, radiography was adopted for storage-tank welds after a tank failure in which a significant defect had been missed by the earlier inspection method (The Welding Institute (TWI), 2024). API 650 itself allows ultrasonic examination in place of radiography by agreement between purchaser and manufacturer (Annex U) (API 650, 2018). PAUT has been evaluated as a replacement for RT in carbon-steel welds (US NRC, 2015; Moran, et al., 2014), and automated interpretation of radiographs is an active field with several recent reviews (Purnomo, et al., 2023; Wang, et al., 2025).

## 2.3 Why leak and hydrostatic tests may fail to detect porosity

Leak-based tests answer a different question from volumetric examination. The bubble (vacuum-box) method creates a pressure difference across a leak and looks for bubbles on the low-pressure side; its normal sensitivity limit is of the order of $1 \times 10^{-5}$ std $cm^3/s$, and surface contamination such as grease, rust or weld slag is listed among its interferences (ASTM E515, 2022). A bubble test with a vacuum cap is described as not replacing a pressure leaktightness test or a structural strength test (Czuchryj & Pilarczyk, 2013). Four mechanisms follow. (i) Isolated pores: a single gas pore inside the weld metal is connected to neither surface and offers no leak path. (ii) Non-through porosity: pores or clusters open to only one surface, or separated from the other by sound metal, pass neither air nor water. (iii) Subsurface porosity: discontinuities below the surface are invisible to visual, penetrant and bubble methods, which respond only to surface-breaking or through-wall paths (Section 2.2). (iv) Small discontinuities below the leakage threshold: through-wall paths narrower than the sensitivity of the test, or partly sealed by contamination or corrosion product, may not leak at test pressure; a pipeline-integrity study noted that short through-wall seam flaws may not leak during a hydrostatic test (Kolovich & Kiefner, 2013). The hydrostatic test adds a proof load on the wetted part of the shell, but it does not image the weld volume and, alone, does not show that porosity is absent (API 650, 2018; ASTM E515, 2022). For a storage tank the hydrostatic test is therefore best read as a strength and tightness check of the wetted shell that complements, and does not replace, volumetric examination. These are mechanisms from detection principles; our own data cannot demonstrate them directly because the leak tests followed the RT-based repairs (Section 4.5).

## 2.4 Sampling

When less than 100% of welds is examined, the programme is a sampling plan whose effectiveness can be modelled probabilistically, including the common practice of extending inspection when defects are found (Heasler & Simonen, 1990). In API 650 (12th edition, Addendum 3, 2018) (API 650, 2018), the extent of shell radiography depends on joint type and plate thickness: for vertical joints, one spot radiograph is required in the first 3 m of completed joint of each type and thickness, then one in each further 30 m, with at least a quarter of the spots at vertical–horizontal intersections; every vertical joint in the lowest course receives two spots; and all intersections in plates over 10 mm are radiographed

(clauses 8.1.2.2 to 8.1.2.4 and Fig. 8 – 1). Spots are distributed in proportion to each welder's work (8.1.2.6) and, when a radiograph is rejected, additional spots adjacent to the defective section are required until its limits are determined, with further spots on other joints made by the same welder if that welder's work is replaced (8.1.6). These are welder- and location-based extension rules. Comparable progressive-examination rules exist in piping codes, where a rejected weld triggers examination of further welds of the same kind by the same welder (ASME B31.3). Rational sampling schemes are founded on the principle that inspection effort should be commensurate with the anticipated defect occurrence, thereby balancing inspection costs against the probability of detecting unacceptable discontinuities (Berens, 1989), and the effect of the sampling method on failure probability has been studied for nuclear piping (Mano, et al., 2020).

## 2.5 Surface condition and decontamination (context)

Surface condition also matters in emergency contexts because it affects how easily a surface can be decontaminated. A laboratory study of surfaces similar to those of storage containers found that the ease of removing contamination was significantly affected by surface roughness, with polished stainless steel performing well and raw cast iron proving almost impossible to decontaminate (Zwicky, et al., 1983). Work on stainless steel found roughness to be the most influential parameter on labile contamination and removal factor for dried-liquid contamination (Agullo, et al., 2023). These studies concern stainless steel and containers, not welded carbon-steel water tanks, so whether weld zones in potable-water tanks behave differently from plate is an open question. We raise it as a hypothesis and a research agenda (Section 5.6), not as a result of this study.

# 3. Case and Methods

## 3.1 Tanks

The two tanks were erected in the field in parallel, between August and October 2024 for potable-water storage. Both are cylindrical, of ASTM A36 steel, with five shell courses of nominal plate thickness 20, 18, 14, 10 and 10 mm (courses 1 to 5), 12 vertical seams per course. Vertical seams were made by shielded-metal-arc welding (SMAW) in a single-V groove (60°) with a 3 mm root gap; horizontal seams by SMAW plus submerged-arc welding (SAW) in a single-J groove (45° to 54°). Bottom plates are 8 mm lap-welded; annular plates (16 and 20 mm) are butt-welded with a permanent backing strip. Shell courses are 2.48 m high except course 4 (2.08 m), which gives a shell height of 12.0 m from the plate widths, in line with the 12 m height reported by the project team. The weld-visual report for course 3 lists 18 mm, whereas the fit-up report (plates 12000 × 2480 × 14) and the adjacent course report list 14 mm; we use 14 mm.

## 3.2 Inspection programme

The project procedure specified: visual and dimensional inspection of all joints; vacuum-box testing of 100% of bottom welds (3 to 5 psi) and nozzle-cleanout welds; oil-penetration (diesel and chalk) testing of

shell and annular-plate seams; liquid-penetrant testing of 100% of nozzle, manway and sump welds; RT of shell spots (122 points planned for both tanks together in the project inspection procedure; the contract itself gave only general requirements and no detailed point schedule, and the spots of each request were confirmed by the consultant; RT or UT of 50% of annular-plate radial joints (single-welded butt joints with a permanent backing strip, for which clause 8.1.2.9 requires one spot radiograph on 50% of the radial joints, at least 150 mm long and at the outer edge of the joint) (API 650, 2018); a pneumatic test of reinforcing plates; and a hydrostatic test. The annular-plate examination and the reinforcing-plate test were reported as performed and accepted, but their reports were not available for this analysis.

## 3.3 Data and coding

Data were transcribed from scanned site reports (quality-inspection files for each tank and a two-page RT results sheet). Each RT spot was coded for tank, report page, batch, date, course, thickness, vertical-joint number, joint location (T-junction where a vertical meets a horizontal seam, otherwise mid-seam), initial result and defect type. Defect type follows the legend written on the report: single porosity (Pore) or cluster porosity (CP). The listed vertical-seam welder for each spot was taken from the weld-visual tables and replaced by an anonymous code (W1 to W20). The two pages of the RT sheet were assigned to tanks from acceptance dates of the shell courses and confirmed by the project team. Rejected spots were repaired by grinding and re-radiographed; the acceptance of repaired spots is as reported by the project team.

## 3.4 Analysis

Proportions are given with exact (Clopper–Pearson) 95% confidence intervals (Clopper & Pearson, 1934). Tanks and courses were compared with Fisher's exact test. Because one group had zero events, risk ratios and odds ratios are undefined or unbounded; we therefore report the risk difference with a Newcombe hybrid-score 95% confidence interval (Newcombe, 1998), the lower bound of the exact conditional odds ratio, and a risk ratio with a Haldane–Anscombe correction (0.5 added to each cell), labelled as such. All comparisons other than the overall rejection rate are exploratory, and no correction for multiple comparisons was applied. For RQ3 we used a hypergeometric model, in the spirit of probabilistic evaluations of weld sampling plans (Heasler & Simonen, 1990): each tank has 60 vertical seams (5 courses × 12); if d seams are defective and n seams are sampled at random, the probability of sampling at least one defective seam is $1 - C(60 - d,\ n)/C(60,\ n)$. We considered two scenarios. In scenario A, defective seams are isolated and no follow-up is possible, so the expected share of defective seams found equals the sampling fraction. In scenario B, the defective seams form one cluster within a batch of 12 seams and a hit triggers extension of RT to the whole batch; the cluster is discovered with the probability of sampling at least one of its defective seams, and all of them are then found. Both scenarios assume equal selection probability and perfect detection when a defective seam is sampled, so they give upper bounds on detection; they are illustrations built from the observed pattern, not fitted models.

# 4. Results

# 4.1 Programme planned, listed and executed

Each tank contained 60 vertical shell seams distributed across five shell courses.

Only 86 RT locations were traceable in the available project records, although the inspection procedure specified 122 planned RT spots for the two tanks combined.

Table 1
Planned, Traceable, and Executed RT Examination of the Two Tanks

| Status | Tank 1 | Tank 2 | Total |
|---|---|---|---|
| RT spots listed | 42 | 44 | 86 |
| Radiographed | 23 | 44 | 67 |
| Not radiographed (judged visually excellent) | 19 | 0 | 19 |
| Accepted at first exposure | 21 | 37 | 58 |
| Rejected for porosity (repaired) | 0 | 6 | 6 |
| Re-shoot requested | 2 | 1 | 3 |

The execution status of the RT programme is summarised in Table 1.

The procedure planned 122 RT spots for both tanks; 67 were radiographed (55% of the plan). The 19 spots not radiographed were all in Tank 1 (spots 68 to 86) and were omitted because the welds were judged visually excellent.

# 4.2 RT rejections

Six spots were rejected: spots 21 and 24 (cluster porosity) and spots 23, 25, 26 and 27 (single porosity; two indications each at spots 23 and 27). All were in Tank 2. Overall rejection was 6/67 = 9.0% (95% CI 3.4–18.5%); Tank 2 6/44 = 13.6% (5.2–27.4%); Tank 1 0/23 (0–14.8%). The difference between tanks is not significant (Fisher p = 0.087; risk difference 13.6 percentage points, 95% CI − 2.4 to 26.7).

# 4.3 Distribution by course, batch and joint location

Table 2
Distribution of RT Results by Shell Course and Tank

| Course | Thickness (mm) | Tank 1 radiographed / rejected | Tank 2 radiographed / rejected | Total |
|---|---|---|---|---|
| 1 | 20 | 3 / 0 | 15 / 0 | 18 / 0 |
| 2 | 18 | 2 / 0 | 5 / 0 | 7 / 0 |
| 3 | 14 | 6 / 0 | 6 / 0 | 12 / 0 |
| 4 | 10 | 12 / 0 | 12 / 5 | 24 / 5 |
| 5 | 10 | 0 / 0 | 6 / 1 | 6 / 1 |
| All | | 23 / 0 | 44 / 6 | 67 / 6 |

The distribution of rejections by shell course is presented in Table 2.

Courses 1 to 3 produced no rejection (0 of 37; upper 95% bound about 9.5%). In course 4, the only course with spots in both tanks at 10 mm, rejection was 5/12 in Tank 2 versus 0/12 in Tank 1 (Fisher p = 0.037; risk difference 41.7 percentage points, 95% CI 8.7 to 68.0; exact conditional odds ratio at least 1.1, with no upper bound because of the zero cell; Haldane–Anscombe-corrected risk ratio 11.0, 95% CI 0.7 to 179, which includes 1). The evidence is therefore suggestive but imprecise, and the comparison is exploratory. Course 5 was not radiographed in Tank 1.

All six rejections fell in one RT batch (30 September 2024): 6 of 12 spots (50%; 95% CI 21–79%), whereas the other batches produced none (0 of 55). The rejected joints were 4V9, 4V10, 4V12 and 5V11. By joint location, 4 of 44 T-junction spots (9.1%) and 2 of 23 mid-seam spots (8.7%) were rejected, i.e. no location effect was apparent.

Spot-level RT dataset; 67 radiographed spots in two tanks

The rejections sit in the two 10 mm courses of Tank 2, whereas the same courses in Tank 1 (course 4) and all thicker courses in both tanks show none; the dashed line marks the overall rate for reference.

# 4.4 Welders and tanks

Twenty distinct welders are listed for the vertical seams, and the weld-visual tables of the two tanks list the same welder for each joint. The four rejected joints are credited to four different welders (codes W2, W3, W12, W16). The same joint positions in Tank 1 (4V9, 4V10, 4V12 at T-junctions) were radiographed and accepted. Per-welder rates are not interpretable (1 to 10 spots per welder).

# 4.5 Other examinations

In the reports reviewed, all visual and fit-up inspections, all vacuum-box tests of bottom seams (one report records 16 inHg), all oil-penetration tests of shell and annular seams, and all penetrant tests of nozzles, sumps and pipe were accepted with no indication. Both tanks passed the hydrostatic test, filled to a water level of 8 m as reported by the project team, about two thirds of the 12 m shell height; 8 m is the overflow level, i.e. the maximum design liquid level. Chronology matters: RT of the shell (30 September to 7 October 2024) preceded the shell oil-penetration tests (25 October for Tank 1 and 17 November for Tank 2), so those tests were applied after the RT-based repairs. The hydrostatic test of both tanks was carried out on 15 January 2025. The project team states that every spot rejected by RT was repaired, re-radiographed and accepted before any of these later tests. Visual and fit-up inspections, and the oil-penetration test of the annular-plate seams (September 2024), necessarily preceded the shell RT. According to the project team, the upper courses were repaired, re-examined and tested in the same way as the rest of the tank and were accepted before handover.

# 4.6 Probability of detecting defective seams

Table 3
Probability of Sampling at Least One Defective Seam

| Defective seams per tank | Sample of 15 seams (25%) | Sample of 21 seams (35%) |
|---|---|---|
| 1 | 25% | 35% |
| 2 | 44% | 58% |
| 3 | 59% | 73% |
| 5 | 78% | 89% |
| 8 | 92% | 98% |

Probabilities of sampling at least one defective seam are presented in Table 3.

Probability of at least one defective seam being sampled (hypergeometric model, 60 vertical seams per tank).

Expected share of defective seams found, by scenario (60 vertical seams per tank; random samples of 25% and 35%).

Table 4
Expected Share of Defective Seams Detected Under Alternative Sampling Scenarios

| Defective seams | Scenario A: isolated (25% / 35% sample) | Scenario B: one cluster, discovered with 25% sample | Scenario B: one cluster, discovered with 35% sample |
|---|---|---|---|
| 1 | 25% / 35% | 25% | 35% |
| 3 | 25% / 35% | 59% | 73% |
| 6 | 25% / 35% | 84% | 93% |
| 12 | 25% / 35% | 98% | 100% |

Expected detection performance under the two sampling scenarios is summarised in Table 4.

In scenario A the expected share found equals the sample fraction, whatever the number of defective seams. In scenario B the cluster is discovered with the probabilities shown, and extension to the whole batch then finds all of its defective seams, so these probabilities are also the expected share found. The observed pattern (6 of 12 spots rejected in one batch, none elsewhere, four defective joints) resembles scenario B with 3 to 6 defective seams, for which a 25% random sample would discover the problem in 59 to 84% of cases, whereas without extension it would find only a quarter of the defective seams on average.

Hypergeometric calculation for 60 vertical seams per tank, 15 sampled; scenarios as defined in Section 3.4

The figure restates the 25% column of the scenario table: a cluster becomes likely to be discovered as soon as several of its seams are defective, whereas isolated defects are found only in proportion to the sample fraction.

## 5. Discussion

# 5.1 Clustering points to a common cause

The rejections were concentrated in one batch and one tank, spread over four welders, and absent from the same joints (same listed welders) in the other tank. Thickness alone does not explain this, because course 4 has the same thickness in both tanks, and joint location did not differ. The pattern is more consistent with a cause acting on a particular day or period than with an individual welder or a plate property. A welder-level analysis can single out one substandard welder, as in a nuclear-piping case (United States Nuclear Regulatory Commission (NRC), 1990), but that is not the pattern here. Candidate causes include electrode storage or drying, moisture or condensation on the joint, contamination, and ambient humidity (Mascalco & Koltz, 2020; Rofiqie & Fitri, 2024; Hafni, 2021; Cameron, 2022); none of these was recorded in the files, so none can be tested here. Thickness and batch are partly confounded

(the rejected spots are in 10 mm courses welded in the same period), which we flag as a limitation rather than resolve.

## 5.2 What the other examinations can and cannot show

RT was the only examination in the programme that reported rejectable indications. We caution against reading this as direct proof that the other methods would have missed the same porosity: the shell oil-penetration and hydrostatic tests were carried out after the RT repairs, so the data cannot show what they would have found on the unrepaired welds. The argument for complementarity therefore rests on detection principles: leak and penetrant methods respond to surface-breaking or through-wall paths, whereas gas porosity inside the weld is volumetric (Section 2.3) (Herceg, et al., 2023; United States Nuclear Regulatory Commission (NRC), 1990; ASTM E515, 2022; Kolovich & Kiefner, 2013). Practically, a successful hydrostatic test shows that the tank holds water and the loaded welds do not leak; it does not certify that the weld volume is free of porosity. The 8 m test level equals the overflow level, i.e. the maximum design liquid level, so the fill met the usual requirement of testing to the design level (API 650, 2018). With cumulative course tops at 2.48, 4.96, 7.44, 9.52 and 12.0 m, courses 1 to 3 were fully wetted, course 4 only in its lowest 0.56 m, and course 5 not at all. All six rejections occurred in courses 4 and 5, the two 10 mm courses, i.e. largely above the design liquid level, where the hydrostatic test does not load the welds; these welds were examined by oil penetration, and their only volumetric check was the RT sample. The shell welds that are in contact with the stored water in service (courses 1 to 3, 20 to 14 mm) produced no rejection in 37 radiographed spots.

## 5.3 Sampling adequacy

The programme radiographed 55% of the planned spots. Because the contract gave only general requirements for the RT points, the extent of RT was governed by the API 650 minimum as applied by the project team. Under random sampling, a single defective seam per tank has only a 25–35% chance of being included in a 25–35% sample (Table in 4.6), and detection becomes likely only when several seams are defective. Defect clustering by batch makes the sampling question concrete: if a problematic batch is not hit, its defects are not seen, and if it is hit, the sample should trigger extension to neighbouring seams made in the same period, as is usual practice in sampling plans (Heasler & Simonen, 1990). In our data, no further spots were radiographed beside the rejected joints in the same tank (the following batch covered joints V1 to V7 of courses 3 and 4), whereas the sister tank was radiographed on 1 October, one day after the rejections, mostly in courses 3 and 4 (V7 to V12 of course 3 and V1 to V12 of course 4); whether this represented an extension triggered by previous rejections could not be determined from the available project records.

API 650 extension requirements are primarily based on the location of the detected defect and the welder responsible for the work (API 650, 2018). Although this approach has proven effective for localized quality control, it may not fully capture systematic factors affecting multiple welds simultaneously. Process-related variables such as consumable batches, production periods, and

environmental conditions have the potential to influence defect occurrence across groups of welds, suggesting opportunities for more data-driven and risk-based inspection planning (Berens, 1989).

## 5.4 Relevance for potable-water service

The porosity found was repaired and did not cause leakage; it lay in courses above the 8 m overflow level, which the stored water does not reach in service, so its consequence for water quality is expected to be low. However, discontinuities in welded regions may still be relevant to coating performance and localized corrosion processes in headspace environments and therefore may influence long-term durability considerations. Its significance for service life (coating integrity and corrosion at weld surfaces) was not evaluated in the present study and warrants dedicated investigation. From an inspection-assurance perspective, sample-based RT cannot completely exclude the presence of undetected defective seams because confidence depends on both sampling coverage and defect detectability (Berens, 1989). The cost of increased examination coverage, including advanced ultrasonic techniques that may provide higher probabilities of detection than conventional RT in some applications, should therefore be balanced against the potential consequences of in-service repair (Herceg, et al., 2023; US NRC, 2015; Moran, et al., 2014).

## 5.5 Documentation quality

We noted inconsistencies that affect traceability: material designations A37 to A40 in some rows of an A36 project, a thickness mismatch for course 3, a tank number in the body of a report that differs from its header, repeated report numbers across the two tanks' files, and identical welder tables. These do not change the RT results but would weaken any audit and are worth reporting as findings.

## 5.6 Implications for supply resilience and research agenda

Because treated water stored in tanks is the buffer in supply-disruption scenarios (Ben Saad, et al., 2026; Maderich, et al., 2023), quality assurance of tank welds is part of supply resilience as well as of construction quality. Strategic water-storage tanks serve as a critical buffer during disruption scenarios, including industrial accidents, radiological emergencies, contamination events, and temporary interruptions of desalination facilities. In such circumstances, confidence in storage integrity becomes an essential component of emergency preparedness. The present findings therefore have implications beyond construction quality, extending to the reliability of strategic potable-water reserves during crisis conditions.

Our data support three narrow statements: (i) in these tanks only RT reported rejectable porosity, in courses above the liquid level; (ii) the RT sample is small relative to the number of seams, so isolated defects can pass unnoticed; and (iii) clustering by batch makes extension rules effective. They do not show that the tanks are more or less vulnerable to any particular hazard. Two questions remain open. First, whether weld zones, with a different roughness and profile from plate, retain or release surface contamination differently (Zwicky, et al., 1983; Agullo, et al., 2023); this can be tested by measuring weld-cap and plate roughness and by decontamination trials with non-radioactive surrogates. Second, which

inspection level is justified for tanks designated as strategic reserves, for example 100% RT or PAUT of shell seams, in view of the probabilities in Section 4.6. The argument concerns any disruption of seawater intake or treatment, whatever its cause.

# 6. Limitations

The sample is small (67 spots, 6 rejections), so intervals are wide and the between-tank difference is not significant overall. Batch, day and thickness are confounded. The unit of analysis is the spot rather than the seam; four seams account for the six rejections. The welder attribution rests on tables that are identical across tanks. Repair outcomes, the omission of 19 spots, the hydrostatic test and the annular-plate and reinforcing-plate results are reported by the project team and not yet documented in the files. Film interpretation was not reviewed, and the contract did not specify the RT points in detail, so the executed spots cannot be compared with a contractual schedule. The sampling scenarios are idealisations built from a small number of observed events. The findings come from two tanks of one project and are not statistically generalisable (Section 1); all comparisons beyond the overall rejection rate are exploratory.

# 7. Conclusions and recommendations

1. In two nominally identical potable-water tanks, RT rejected 6 of 67 spots (9.0%) for porosity, all in one tank and one batch; the same joints in the other tank were accepted.
2. Rejections were not explained by welder, joint location or thickness alone, and suggest a batch-level cause that should be investigated and recorded.
3. The other examinations reported no indications, but because they followed RT-based repairs, their sensitivity to this porosity cannot be inferred from the data; detection principles indicate that leak and penetrant methods are not substitutes for volumetric examination.
4. With 55% of the planned RT spots executed and a sample fraction of 25–35% of seams, the probability of detecting an isolated defective seam is low.
5. The findings suggest that consideration should be given to (a) extending RT after a rejection to seams produced during the same period and with the same consumable lot, in addition to the welder- and location-based extension already required by API 650, (b) incorporating batch information, consumable lots, and ambient conditions into inspection records to improve traceability and support risk-informed inspection planning, (c) documenting any reduction in the planned RT scope, (d) evaluating PAUT as a complement to sampled RT and (e) considering enhanced inspection requirements and recording of weld surface condition for tanks designated as strategic water reserves.

Beyond routine construction quality assurance, the findings highlight the importance of inspection reliability for strategic potable-water storage infrastructure that may be relied upon during emergency-response and supply-disruption scenarios.

# Declarations

### Conflict of Interest

The author declares no conflict of interest.

### Data Availability Statement

The data supporting the findings of this study were derived from project inspection records that contain confidential project information and are therefore not publicly available. Anonymized data may be made available by the author upon reasonable request, subject to project-owner approval.

### AI Usage Statement

Artificial intelligence tools were used to support language refinement, editing assistance, and manuscript development. All technical concepts, methodologies, interpretations, and conclusions remain the responsibility of the author.

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Conceptualization, Methodology, Formal Analysis, Framework Development, Writing – Original Draft, Writing – Review and Editing.

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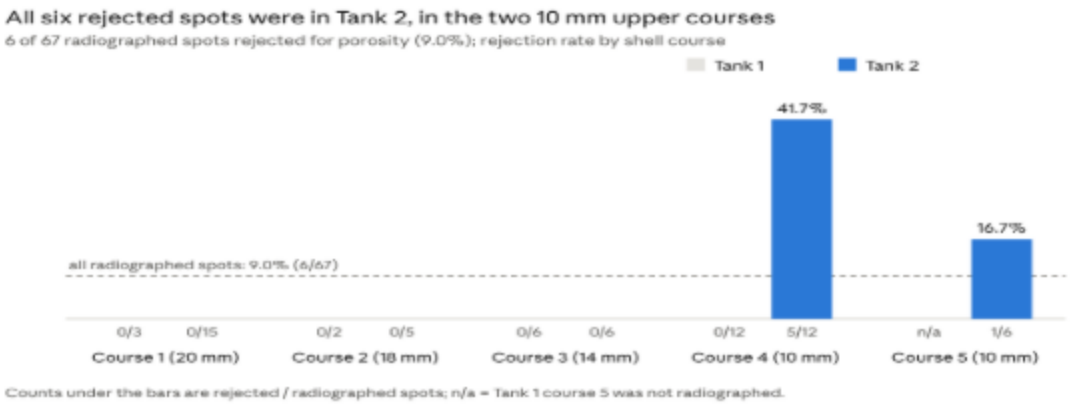
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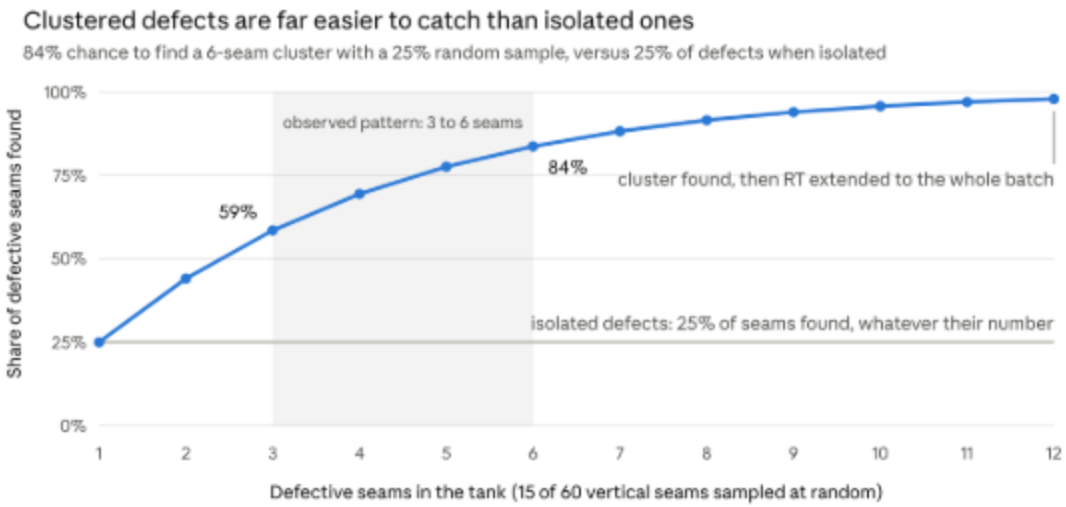
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# Figures



## Figure 1

**RT Rejection Rate by Shell Course and Tank.**




## Figure 2

**Expected Detection Performance of a 25% Random Sample Under Alternative Defect Distributions.**