Alberta Energy Regulator

Pace Oil and Gas Ltd.
Wellhead Piping Failure
Licence No. W0057420
May 19, 2012

AER Investigation Report

March 3, 2014

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List of Abbreviations

AB	Alberta
AER	Alberta Energy Regulator
Acuren	Acuren Group Incorporated
AEMA	Alberta Emergency Management Agency
APB	acid-producing bacteria
ASERT	Alberta Environment Support and Emergency Response Team
ASME	American Society of Mechanical Engineers
Broadsword	Broadsword Corrosion Engineering Ltd.
Chmilar	Chmilar and Associates Consulting Ltd.
cm	centimetre
CO_2	carbon dioxide
CP	cathodic protection
EM	electromagnetic (survey)
EPA	Emergency Preparedness and Audit
ERP	emergency response plan
ERCB	Energy Resources Conservation Board
ESRD	Environment and Sustainable Resource Development
Fekete	Fekete Engineering Ltd.
Gushor	Gushor Incorporated
H_2S	hydrogen sulphide
HLFC	High Level Field Centre
Inuvialuit	Inuvialuit Oil and Gas Corporation
km	kilometre
kPa	kilopascal
LSD	Legal Subdivision
m	metre
m^3	cubic metre
MIC	microbially induced corrosion
mKB	metres below kelly bushing
mm	millimetre
NACE	North American Corrosion Engineers

NPS	nominal pipe size
O_2	oxygen
OSCAR	oil spill containment and recovery (trailer)
Pace	Pace Oil and Gas Ltd.
Pacific	Pacific Western Petroleum Ltd.
Parkland GEO	Parkland GEO Ltd.
PIISP	Petroleum Industry Incident Support Plan
Plains	Plains Midstream Canada ULC
POC	provincial operations centre
Provident	Provident Energy Resources Inc.
RCA	root cause analysis
RCMP	Royal Canadian Mounted Police
ROW	right-of-way
Samson	Samson Canada Ltd.
SRB	sulphate-reducing bacteria
SWAT	SWAT Consulting Inc.
WCSS	Western Canadian Spill Services

Executive Summary

On May 19, 2012, at about 17:30 Mountain Daylight Time (MDT), Pace Oil and Gas Ltd. (Pace) was notified by Plains Midstream Canada ULC (Plains) that a spill was occurring at one of its water disposal wells located in the Rainbow Lake Field. The spill location, Legal Subdivision (LSD) 14, Section 21, Township 108, Range 7, West of the 6th Meridian (14-21), was about 20 kilometres (km) east-southeast of the Rainbow Lake town site. The spill was identified while Plains was doing an aerial survey of its pipeline right-of-way, which is close to Pace's disposal well. Pace stopped the release by isolating the pipeline to the disposal well at the originating facility and closing the valves on the wellhead.

The incident occurred on Crown land in an area that is characterized by wetlands with flat to mildly rolling topography and varied vegetation cover, including black spruce, sage leaf, and willow. The closest water bodies in the area are the Hay River (3.8 km south) and a number of small unnamed lakes over 3 km away. There are no ecological reserves, wildlife management areas, parks, First Nation lands, Métis settlements, or residences in the area.

The spill volume estimates initially fluctuated substantially since Pace assumed that a large volume of produced water could be associated with the release given the use of the well at LSD 14-21 (14-21 well) for water disposal. This was later proven incorrect by groundwater monitoring and sampling, which identified the spill as being crude oil only. Once Pace had determined the depth and lateral extent of the contaminated area, it estimated that the spill volume was 800 m^3. The Alberta Energy Regulator (AER)[1] accepted this volume on May 23, 2012.

Initial cleanup operations by Pace consisted of delineating the release and renting recovery equipment, including storage tanks, transfer pumps, hoses, containment booms, and swamp matting. During the first two days of the response, the focus was on accessing the site and constructing infrastructure for an efficient response. Once the environmental impact of the release was more clearly understood, the response by Pace, its contractors, and the relevant regulatory agencies during the emergency phase of the incident was significant. By May 31, 2012, a total of 118 individuals were on site and fully engaged in the response.

The 14-21 well was suspended immediately following the first report of the incident. However, the AER allowed Pace to put the well back in service to dispose of the water used for site clean-up operations once the failed wellhead fittings were replaced. The well remains in operation.

The incident triggered ongoing provincial, national, and international media coverage.

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[1] On June 17, 2013, the *Responsible Energy Development Act* was proclaimed, and the AER was created. Although events may have taken place under its predecessor, the Energy Resources Conservation Board, for simplicity "the AER" will be used throughout.

As of September 2012, the site was showing positive signs of vegetative regrowth and results from initial environmental monitoring were showing that site remediation efforts were working. Soil, water, and vegetation will continue to be monitored once Pace completes remediation activities. Alberta Environment and Sustainable Resource Development (ESRD) will require further sampling for hydrocarbon contaminates in standing water in spring 2014.

The following summarizes the AER's investigation findings:

- The spill occurred within the 15-day time period between May 4 and May 19, 2012, and may have taken place over a two- to four-day period.
- Pace's emergency response and stakeholder communication efforts during the first four days after being notified of the spill were not acceptable for a release of this size. However, once Pace was made aware of the AER and ESRD's concerns with the response, it was fully compliant with agency requests.
- The spill occurred as a result of a hole in the wellhead piping.
- The wellhead piping failed as a result of internal pitting corrosion, originally initiated by stray current interference, that was later influenced by one or a combination of the following:
  - stagnant flow conditions that caused localized corrosion cells to form
  - the acidifying effects of dissolved oxygen, carbon dioxide, and hydrogen sulphide in saline produced water
  - corrosion-inducing bacteria
- The oil recovered from the release location originated from the Bluesky Formation and not the Keg River and Muskeg Formations into which the 14-21 well injects produced water.
- The oil that was released into the environment had been entrained in small quantities in the produced water that was injected over the service life of the disposal well.

The AER requires Pace to take the following seven directed actions:

- Conduct a full cathodic protection audit of its Rainbow Lake pipelines, wells, and facilities, taking into account the potential for stray current interference.
- Assess the water being disposed of down the 14-21 well, considering any and all corrosive agents.
- Conduct and document, at a minimum, monthly inspections of all of its licensed water disposal/injection wells and provide the documentation to the AER upon request.

- Develop a sampling procedure for disposal water to aide in minimizing the potential for hydrocarbons to become entrained in the disposal water.
- Conduct an engineering assessment of its disposal systems to aide in minimizing the potential for hydrocarbons to become entrained in the disposal water.
- Assess the feasibility of installing monitoring equipment at the 14-21 well to monitor and regulate line pressures.
- Conduct an emergency response plan (ERP) exercise within 90 days of the release of this report.

As part of the AER's incident investigation, Emergency Preparedness and Audit (EPA) Section staff conducted an audit of Pace's ERP on November 6, 2012. The audit determined that Pace had failed to

1) review the corporate-level ERP with personnel assigned roles and responsibilities and
2) provide training sessions to ensure that response personnel are competent in emergency response procedures

in accordance with *Directive 071: Emergency Preparedness and Response Requirements for the Petroleum Industry*. As a result, the AER issued a High Risk Enforcement Action against Pace on January 9, 2013.

On January 29, 2013, the EPA Section accepted Pace's action plan to address the noncompliances and the audit was closed.

1 Incident Description

On May 19, 2012, at about 17:30 Mountain Daylight Time (MDT),[1] Plains Midstream Canada ULC (Plains) notified Pace Oil and Gas Ltd. (Pace)[2] that a spill was occurring at one of its water disposal wells located in the Rainbow Lake Field. The spill location, Legal Subdivision (LSD) 14, Section 21, Township 108, Range 7, West of the 6th Meridian (14-21), was about 20 kilometres (km) east-southeast of the Rainbow Lake town site (see figure 1). Plains identified the spill while doing routine aerial surveillance of its pipeline in the vicinity of the 14-21 well.

The spill, originating at the disposal well at LSD 14-21 (14-21 well), pooled in an unoccupied beaver dam about 40 metres (m) from the well and migrated almost 500 m downgradient from the source. The area visibly impacted by the spill extended about 475 m from the source and was about 185 m at its widest point. Pace, in consultation with the Alberta Energy Regulator (AER) [3] and Alberta Environment and Sustainable Resource Development (ESRD), estimated the total spill area to be 4.5 hectares (11 acres).

Pace staff had to use all-terrain vehicles to access the spill location as the 14-21 well is located in a wetland area. Due to site-access challenges, the release footprint was not determined until an aerial survey was done by Pace between 17:30 and 19:30, and air monitoring indicated that the area was safe to access. Once the release footprint was determined by Pace and ESRD, initial response efforts focused on accessing the spill perimeter for spill plume monitoring, water sampling, and spill containment.

By about 19:30, Pace had closed the valves at the disposal well and associated flow line from the originating facility located at LSD 15-7-108-6W6M and had identified a hole on the aboveground pipe between the first on-lease control valve and the wellhead master valve as the source of the release.

The initial estimated spill volume reported by Pace to the AER as of 19:30 was 5 to 10 cubic metres (m^3) of an oil-and-water mix. Pace updated this figure to 100 m^3 by about 23:30. Once the depth and lateral extent of the spill were determined, a new volume was estimated at 800 m^3 and accepted

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* This report is accompanied by numerous supporting documents. These documents are available from the report's webpage on the AER website, www.aer.ca. Each document cited is identified by a number (e.g., DOC01) to make it easier to locate.

[1] All times in this report are in MDT.

[2] On March 26, 2013 (during the writing of this report), Pace Oil and Gas Ltd., AvenEx Energy Corp., and Charger Energy Corp. announced a merger of the three companies to form Spyglass Resources Corp. As the incident occurred during Pace's ownership of the subject well and associated facility, this report will refer to Pace as the owner.

[3] On June 17, 2013, the *Responsible Energy Development Act* was proclaimed, and the AER was created. Although events may have taken place under its predecessor, the Energy Resources Conservation Board, for simplicity "the AER" will be used throughout.

by the AER on May 23, 2012. These estimates fluctuated since, according to Pace and based on the use of the well for water disposal, it was possible that a large volume of produced water[4] was associated with the release. This was later proven incorrect by groundwater monitoring and confirmatory sampling conducted by Parkland GEO Ltd. (Parkland GEO), who were contracted by Pace for environmental sampling and monitoring. Chloride levels, used to determine salinity, in water samples obtained from the release location were very close to background levels of around 30 parts per million indicating that the release was oil.

The incident occurred on Crown land where the boreal plains ecozone transitions into the taiga plains ecozone.[5] This area is characterized by flat to mildly rolling topography and varied vegetation cover, including black spruce, sage leaf willow, and graminoids (e.g., low rushes, sedges, reed grasses). With the exception of the unoccupied beaver dam, which was close to the release, the closest water features/bodies in the area are the Hay River (3.8 km south) and a number of small unnamed lakes over 3 km away. There are no ecological reserves, wildlife management areas, parks, First Nation lands, Métis settlements, or residences in the area.

1.1 Well History

The well, known as the Pace Rainbow 14-21 well, was drilled open hole in 1966 by Baily Selburn Oil and Gas Ltd. (a subsidiary of Pacific Western Petroleum Ltd. [Pacific]) to a depth of 1972.1 metres below kelly bushing (mKB) into the Keg River and Muskeg Formations in the Rainbow Lake Field. The well was abandoned after five drillstem tests indicated no measurable quantities of hydrocarbons.

The 14-21 well was re-entered in 1977 when Pacific received AER approval to use the well for water disposal. The re-entry established a 141.0 m open-hole section penetrating both the Keg River and Muskeg Formations. According to the well history supplied by Pace, the well received a total of only 197.1 m^3 of injected water from June 1977 to November 1982 and was suspended from November 1982 to May 1993.

In 1993, Inuvialuit Oil and Gas Corporation (Inuvialuit) acquired the 14-21 well and returned it to service as a water disposal well. AER records dating back to 1997 indicate that the well and associated facilities were operated by Samson Canada Ltd. (Samson) and later sold to Provident Energy Resources Inc. (Provident) on July 1, 2006. Effective June 29, 2010, Pace became a 100 per cent interest holder in the well as a result of a merger between Provident and Midnight Oil Exploration Ltd. The 14-21 well licence transfer from Provident to Pace occurred on June 29, 2011.

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4 Produced water is the water extracted from the subsurface with oil and gas and may contain any chemicals added during the production/treatment process. Produced water is also called “brine” and may contain high mineral or salt content.

5 *Ecological Framework of Canada – Ecoregions of Canada*, accessed July 22, 2013, http://ecozones.ca/english/region/139.html.

The 14-21 well is an approved Class II water disposal well and is tied in to the Basset Lake gas plant (LSD 15-7-108-6W6M [15-7 facility]) via a pipeline with an outside diameter of 114.3 millimetres (mm) (4 inches). The 15-7 facility and the pipeline to the 14-21 well are licensed to Pace. The pipeline is carbon steel and is internally coated with cement. This well disposes produced water into the sour (2–5 per cent hydrogen sulphide [H_2S]) Keg River and Muskeg Formations. External pipeline corrosion is managed with a polyethylene tape outer coating and cathodic protection[6] (CP). The most recent CP survey was completed by Corrosion Technologies Ltd. in February 2012. There are no recorded operational issues with this pipeline.

2 Pace Response

Pace's initial response to being notified of a potential spill at the 14-21 well was to notify its Rainbow Lake field production foreman, then deploy operations staff to the release location. Because of the potential for sour gas, operations staff used self-contained breathing apparatus and personal gas detection monitors to access the site. Once operations staff had confirmed that the release location was safe, they were able to close the master valves on the disposal well and isolate the flow line. The associated valves at the 15-7 facility had previously been closed by operations staff. On May 20 at 09:07, Pace initiated its emergency response plan (ERP).

Pace's initial cleanup operations consisted of delineating the release and renting recovery equipment, including storage tanks, transfer pumps, hoses, containment booms, and swamp matting. During the first two days of the response, Pace focused on accessing the site and constructing infrastructure for an efficient response. By May 21, 2012, Pace contracted Parkland GEO to do environmental sampling, surveying, and a site evaluation to determine if an electromagnetic (EM)[7] survey would be appropriate. Due to very low (almost background) chloride levels, no EM survey was conducted.

On May 22 and 23, Pace began recovering fluid from the spill location. Installation of the storage tank was finished and skimmers from Western Canadian Spill Services' oil spill containment and recovery (OSCAR) trailer were used. Although Pace had access to soaker booms, containment booms were in limited supply in the OSCAR trailer. Containment booms had to be ordered and delivered from Prince Rupert, British Columbia. By May 24, 2012, Pace was using several contracting and consulting companies to assist with spill response.

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6 AER *Directive 055*, appendix 1, defines cathodic protection as "a method of preventing corrosion to a metal surface by introducing another metal (anode) into the ground to create a corrosion cell in which the surface to be protected becomes a cathode. If deterioration or corrosion occurs at the anode (introduced metal), the cathodic protection may be of a sacrificial type or impressed current design."

7 An EM survey in this application is used to measure the electrical conductivity of the soils within and near to a salt/produced water spill. The EM survey is affected by the soil's salt content and type, clay content and type, mineralogy, depth to bedrock, soil moisture, organic matter, and temperature. The EM survey provides an accurate picture of the area of salt water–impacted soils.

By the first week of June, aggressive spill remediation efforts were underway on site and Pace had developed a communications plan, an air monitoring plan, a water monitoring plan, a wildlife management plan, a waste management plan, and a product containment and remediation plan. As of June 7, 2012, all plans had been reviewed and approved by the AER and ESRD. At this time, Pace downgraded its incident command structure as the incident had moved from the emergency phase to the recovery and remediation phase. Pace continued to lead the cleanup operation with support from ESRD.

On June 8, 2012, ESRD approved a controlled remedial burn of the site to remove light hydrocarbons from the spill footprint. The site was ignited at 17:50 on June 9, 2012, and a second burn was done on June 15, 2012.

As of September 2012, the site was showing positive signs of vegetative regrowth and results from initial environmental monitoring results were showing that site remediation efforts were working. Soil, water, and vegetation monitoring will continue to take place once remediation activities are completed by Pace. Water samples will be analyzed and compared to baseline parameters (i.e., nearby water features) and soil samples will be compared with the guidelines for fine-grained surface soils set out in *Alberta Tier 1 Soil and Groundwater Remediation Guidelines*. ESRD will require further sampling for hydrocarbon contaminates in standing water in spring 2014.

3 Regulatory Response

Pace initially notified the AER High Level Field Centre (HLFC) and ESRD of the spill on May 19 between 19:30 and 20:00 and indicated that the spill volume was about 5–10 m^3. This volume was increased to 100 m^3 at about 22:30 after Pace staff conducted an aerial survey of the site and ERP personnel in Pace’s Calgary head office and Peace River regional office had reviewed the aerial surveillance photos. The AER and ESRD were informed of the revised volume at 23:19. Based on its aerial surveillance photos and map sketches provided by ESRD, Pace determined, in consultation with the AER and ESRD, that the spill footprint was about 4.54 hectares (11.22 acres).

By May 21, Pace had notified the following regulatory agencies of the incident: ESRD, the AER, Alberta Emergency Management Agency (AEMA), which coordinates provincial support operations from the provincial operations centre (POC), Occupational Health and Safety, Environment Canada, Alberta Health, and Health Canada.

By May 23, Pace had notified the following of the incident: Royal Canadian Mounted Police (Rainbow detachment), County of McKenzie, Dene Tha’ First Nation, and the Town of Rainbow Lake. The AER’s Community and Aboriginal Relations Team was engaged early in the incident and helped Pace with stakeholder communications. The AER issued a news release about the incident on May 22. Pace issued its first press release about the incident on May 23.

The HLFC used the Assessment Matrix for Classifying Incidents in *Directive 071*: *Emergency Preparedness and Response Requirements for the Petroleum Industry* to classify this incident as an alert. At 09:07 on May 20, Pace implemented its ERP and obtained ESRD permission to begin constructing an on-site command post and to install swamp matting around the release perimeter. ESRD sent a regional responder from its High Level office to the release location on May 20. The regional responder assisted until a duty officer from the Alberta Environment Support and Emergency Response Team (ASERT) arrived to support the incident response.

As a result of the updated spill volume of 100 m^3 and the aerial view of the spill, the HLFC elevated the incident from an alert to a level-1 emergency on May 23 at about 15:00.

Because of the reclassification of the incident as a level-1 emergency, the AER sent an HLFC inspector, an incident investigator, an incident response coordinator, and staff from the AER Office of Public Affairs to the site on May 23, 2012. The AER also activated an emergency situation room in the Calgary head office and used the HLFC as an emergency operations centre to help coordinate site activities.

On May 24, the ESRD duty officer and the AER incident response coordinator jointly released situation reports under a unified response structure. Based on the dynamic nature of the incident and potential access issues, the AER activated the Petroleum Industry Incident Support Plan (PIISP).[8] The AER also requested AEMA to elevate the POC's operational level from the normal operational level 1 to an emergency level 2.[9] Additionally, the AER directed Pace to develop and submit for approval a communications and stakeholder engagement plan to ensure that all stakeholders were kept informed about the incident. This plan was received and approved by May 29.

The AER and ESRD noted that Pace's response during the first four days after being notified of the spill by Plains was inadequate in relation to the spill size. The response-related activities by day five should have occurred by day two or three. However, once Pace was made aware of the regulators' expectations, it fully complied with agency requests.

By June 5, Pace had contained the spill and its ongoing spill recovery operations (e.g., water, soil, and air monitoring) were meeting the regulators' expectations. Pace submitted all relevant technical

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[8] PIISP is a provincial-level plan that directs Government of Alberta operations in supporting a local authority, a licensee, or an operator during an emergency.

[9] The POC has duty officers employed by AEMA who operate the POC 24 hours a day, seven days per week. During normal, nonemergency operations, the POC operates at a level 1. During emergency operations, the POC can elevate the operational status to a level 4. The level is not based on the emergency level of the incident, but is dictated by the resources required to manage the provincial response to the emergency.

and environmental plans to the AER and ESRD and implemented them following regulatory approval.

Also by June 5, the AER, in consultation with ESRD and AEMA, had developed a transition plan that set out the conditions for each agency to meet in order to transition this incident from the emergency phase to the remediation phase. In addition, the first stages of the transition plan were implemented: the AER downgraded the incident from a level-1 emergency to an alert and, in consultation with AEMA, deactivated the PIISP, and the POC reduced its operational level to a level 1.

As of June 7, the incident moved from the emergency phase into the recovery and remediation phase and ESRD took over from the AER as the lead agency.

The AER suspended the 14-21 well immediately following the first report of the incident. However, the AER allowed Pace to put the well back in service to dispose of the water used for site cleanup operations once the failed wellhead fittings were replaced.

4 Root Cause Analysis

Root cause analysis (RCA) addresses what happened, how the event occurred, and why conditions leading up to the event existed. Root causes are defined as

- specific underlying causes that can be reasonably identified,
- those over which responsible parties (licensees) have control, and
- those for which effective mitigation measures can be established.

The AER used RCA to explore three significant issues that contributed to this incident and to provide recommendations to prevent a recurrence:

- Why the wellhead piping failed
- Why a produced-water disposal well released primarily hydrocarbons to the environment
- Why a water disposal well injecting an average of only 6 m^3/day spilled fluid at a significantly higher rate

Pace retained five consulting firms to provide technical reports to assist with the RCA:[10]

- Acuren Group Incorporated performed a materials failure analysis of the wellhead piping and produced a report dated June 8, 2012 (the Acuren report; DOC01).

[10] The technical reports refer to the failed wellhead piping on the 14-21 well as nominal pipe size (NPS) 2.

- Broadsword Corrosion Engineering Ltd. performed a failure analysis, engineering assessment, and RCA of the subject piping and produced a report dated July 2, 2012 (the Broadsword report; DOC02).
- Chmilar and Associates Consulting Ltd. provided technical advice about the possibility of stray current interference having been the failure mechanism on the subject piping and produced a report dated June 15, 2012 (the Chmilar report).
- Fekete Engineering Ltd. evaluated the disposal well's potential release rate over the estimated time the release occurred and the theoretical spill volume and produced a report dated July 5, 2012 (the Fekete report; DOC03).
- Gushor Incorporated characterized and compared the geochemistry of the released oil and oil from two separate sources through carbon fingerprinting and produced a report dated July 7, 2012 (the Gushor report).

In its RCA, the AER evaluated documents from its site investigation, the five technical reports, and Pace's own summary of the incident and recommendations. The AER used Sologic's RCA[11] method, which included using a comprehensive cause-and-effect chart that considered the three main incident issues.

4.1 Lease Piping Failure

The 14-21 wellhead pipe failure occurred on a threaded, 58 centimetre (cm), vertically oriented segment of pipe (figure 2). The through-wall perforation (hole) was about 13 mm in diameter (figure 3) and about 15 cm downstream (towards the wellhead) of an electrical isolating union.[12] Documentation supplied by Pace indicated that there were no piping modifications to the wellhead until 2009 when Provident replaced the isolating union with a non-isolating hammer union. Provident made this replacement because of a recommendation from a CP adjustive survey.[13] The failed pipe segment appears to have been originally installed in 1977 by Pacific when the well was approved for disposal operations. Produced water (about 14 000 to 18 000 ppm chlorides) is disposed of on an intermittent basis at a maximum pressure of 700 kilopascals (kPa) and a temperature of 38°C.

[11] Sologic® RCA is a method of conducting an RCA to identify reactive solutions that prevent problem recurrence and uncover proactive solutions that preempt future problems.

[12] The isolating union in this case is composed of two union halves, a connection nut, and a plastic (dielectric) sleeve that encapsulates one of the union halves creating an electrically isolated joint.

[13] CP adjustive surveys are required on a yearly basis in Alberta. They involve function testing CP systems and determining appropriate CP coverage by testing structure-to-soil potentials and adjusting CP rectifiers as needed.

4.1.1 Acuren Findings

The Acuren report detailed a number of possible incident scenarios. The report identified sudden anomalous corrosion damage to the piping about 15 cm towards the wellhead of an isolating union downstream of the first control valve after the vertically oriented pipe. The isolating union on the 14-21 wellhead piping was installed to eliminate the impressed current applied to the pipeline from being applied to the well casing. Acuren found indications that at some point during the operating life of the system, stray current corrosion[14, 15] may have occurred on the pipe area immediately downstream of the isolating union (figure 3) and could have contributed to the pipe failure. Black scale found within the internal corrosion pitting was chemically analyzed using X-ray diffraction supplemented by energy dispersive spectroscopy technology. The analysis revealed a high percentage of iron-based corrosion products, suggesting a complex array of corrosive agents affecting the corrosion process. The Acuren report detailed the following potentially interactive factors:

- dissolved carbon dioxide (CO_2) and H_2S in the produced water contributing to the formation of under-deposit occluded corrosion cells
- high iron oxide/hydroxide concentrations, indicating dissolved oxygen may have been a factor in the corrosion rate
- corrosion-inducing bacteria causing microbiologically induced corrosion (MIC)
- stagnant flow conditions associated with disposal operations specific to the 14-21 well. Stagnant water encourages the formation of sessile (deposited) corrosion-inducing bacteria colonies on the interior surface of the pipe, resulting in localized corrosion.

4.1.2 Broadsword Findings

The Broadsword report identified stray current corrosion as the primary factor contributing to the wellhead piping failure. According to CP surveys conducted while Samson owned the well, stray current interference was first detected in 2002 and reached 50 millivolts in 2006. Prudent operating practices should have been adopted to mitigate stray current interference when first detected in 2002; however, based on information submitted by Pace, it appears that no action was taken by previous operators. Pace acquired the 14-21 well in June 2011, and a CP adjustive survey was done by Pace's CP contractor in February 2012. The survey did not indicate the need for any follow-up

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[14] "Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth." (A.W. Peabody, Control of Pipeline Corrosion, ed. Ronald Bianchetti, 2nd ed. [Houston: North American Corrosion Engineers, 2001]).

[15] The Acuren report, page 18, indicates that "stray current corrosion is known to occur inside pipes at electrical isolation joints when the combination of potential difference in the electrolytic strength of the water in the pipe are [sic] high enough to permit electrical current migration from one side of the connection through the water to the pipe on the other side of the connection. Corrosion will take place where the current leaves the pipe and there will be no corrosion on the opposite side of the union where the current enters the pipe."

actions. This may have been due to the survey having been done during an "off" cycle when the well was not operating and no measurable current was flowing. According to the Broadsword report, disposal operations for this well are cyclical and occur only about 37.5 per cent, or one-third, of the time.

The report indicated that the undiagnosed stray currents were detected at the 14-21 well casing, flowed through the wellhead piping that was isolated from the pipeline, and were discharged or "bridged" across the isolating union through the lower resistivity salt water (electrolyte). Broadsword observed elevated metal loss and pitting where the current left the pipe wall and entered the electrolyte.

The Broadsword report indicated that the source of the stray currents could have been from

- stray currents from other CP systems close to the 14-21 well (Pace, Husky Energy, and Plains operate other pipelines in this area),
- anomalous telluric earth currents[16] (a rare possibility), or
- a combination of both.

The Broadsword report also indicated that one or both of the following secondary or tertiary corrosion mechanisms potentially contributed to the corrosion rate and severity:

- The acidifying effect of dissolved oxygen (O_2), H_2S, CO_2, and chlorides in the saline disposal water—This finding was supported by chemical analysis of the black-scale product from the secondary corrosion pits that revealed iron-based corrosion products such as iron hydroxide, iron oxide, and iron sulphide.
- Microbiologically induced corrosion—Microbiological testing[17] of the sessile bacteria in proximity to the failure site revealed acid-producing bacteria (APB) and sulphate-reducing bacteria (SRB) at levels as high as 10 000 colonies per millilitre of water. Both APBs and SRBs are corrosion-inducing.

The Broadsword report concluded that, based on the water and bacterial analyses and the corrosion modelling of the carbon steel piping specific to this system, the combination of oxygenated brine and bacterial contamination may have contributed to, but was not the primary factor in, the wellhead piping failure.

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[16] "Natural electric current flowing on and beneath the surface of the Earth and generally following a direction parallel to the Earth's surface." (Encyclopaedia Britannica Online, s.v. "telluric current," accessed July 22, 2013, http://www.britannica.com/EBchecked/topic/586372/telluric-current.)

[17] North American Corrosion Engineers (NACE) International Standard Practice TM0194.

4.1.3 Pace Findings

Pace filed a report of the incident dated July 9, 2012 (the Pace report). The executive summary (DOC04), page 1, states that "the hole was caused by internal pit corrosion accelerated through stray electrical currents in the surrounding area." A CP adjustive survey done by Pace's CP contractor in February 2012 indicated abnormal voltage potential. The contractor did not include comments in the remarks column of the survey report to recommend corrective actions. As a result, Pace did not make any modifications to the wellhead piping or CP system at that time. Pace is currently investigating the source of the stray current at the 14-21 well.

4.1.4 AER Findings

The AER has reviewed the metallurgical analysis and supporting documents submitted by Pace in the reports noted above relating to the failed wellhead piping on the 14-21 well. The AER concludes that the Schedule 80,[18] 60.3 mm wellhead piping failed as a result of internal pitting corrosion initiated by stray current interference that could have been later influenced by one or a combination of the following:

- stagnant flow conditions that cause localized corrosion cells to form
- the acidifying effects of dissolved oxygen, CO_2, and H_2S in saline produced water
- corrosion-inducing bacteria

The AER agrees with the analyses submitted by Pace and its consultants, which indicate that at some point during the operating history of the 14-21 well, stray current interference initiated the corrosion process, ultimately contributing to the wellhead pipe failure. This finding is supported by the obvious and abrupt internal corrosion pitting in the transition area immediately downstream of the CP isolating union.

According to volumetric reporting by Pace from January 2011 to June 2012, water disposal down the 14-21 well was intermittent, as disposal operations do not occur regularly. Because of the frequent non-flow conditions within this piping, localized corrosion cells could have formed or corrosive agents could have exacerbated the already initiated corrosion pits that were the result of stray current interference. As a result, stagnant flow conditions cannot be ruled out as a contributing factor to the observed corrosion.

A combination of other factors, such as corrosion-inducing bacteria and the acidifying effects of O_2, CO_2, H_2S, and dissolved chlorides in saline water, could also have played a significant role in the corrosion process. These factors are supported by analysis of the

[18] The schedule of a pipe is designated based on 1000 times the internal pressure per square inch the pipe can withstand before deformation or burst.

- corrosion pit morphology,
- chemical and x-ray diffraction,
- black scale deposited within pits immediately adjacent to the through wall perforation, and
- disposal water from the 15-7 facility.

4.2 Spill Fluid Composition

Pace's initial reports indicated that the spill consisted of a 50 per cent water-and-oil emulsion, with an estimated 1750 m^3 being oil and 1750 m^3 being water. Water volumes were assumed based on the use of the well for water disposal; however, analysis of the water recovered from the site during cleanup operations indicated chloride levels comparable to background levels, suggesting that it was fresh surface water. After reviewing further data of the site and the spill—including rate of vapourization, spill depth and breadth, recovery volumes, and oil remaining at the location—Pace reduced the total spill volume to 800 m^3.

The fluid that spilled as a result of the hole in the 14-21 wellhead piping was oil. Oil analysis performed by Gushor indicated that the spilled oil was produced from the sweet Bluesky production zone in the Rainbow Lake Field. The 14-21 well injects saline produced water into the Keg River and Muskeg Formations. The formations are capable of flowing; however, they typically produce oil consisting of 1–3 per cent H_2S, which is inconsistent with the oil that spilled from the 14-21 well.

4.2.1 Gushor Report Findings

The Gushor report discussed the geochemical comparison of produced oils taken from the 14-21 well, the Husky-owned 08-28-108-7W6M well (8-28 well), 15-7 facility (condensate/oil produced from Bluesky gas production wells that provide plant feedstock), as well as the 14-21 spill oil (referred to as seep oil in the Gushor report). The 8-28 well is an offsetting well that is close to the 14-21 disposal well. Pace acquired from Husky an analysis of the oil from the 8-28 well since the analysis was done very recently and the 8-28 well is the closest well to the 14-21 well and was completed in the same Keg River and Muskeg Formations.

Gas chromatography-mass spectrometry analyses of the 14-21 spill oil, oil from the 15-7 facility, and oil from within the 14-21 wellbore indicated matching carbon fingerprints. However, produced oil from the 8-28 well did not match. These analyses indicate that oil recovered from the spill location was produced oil from the Bluesky Formation and did not originate from the Keg River and Muskeg Formations where the 14-21 well was completed.

4.2.2 Pace Findings

The Pace report indicated the following:

- During a work-over performed by Inuvialuit in 1993, the 14-21 well was capable of flowing; however, oil recovered from the spill location and oil samples taken from the 14-21 wellbore close to the time of the incident were not consistent with the oil recovered during work-over flowback operations performed in 1993.
- A successful packer isolation test was done by Pace on May 31, 2012, proving wellbore integrity. This indicated that there was no communication with the 14-21 wellbore from any zone other than the Keg River and Muskeg Formations into which the well disposes produced water.
- Oil carbon fingerprinting, discussed in the Gushor report, confirms that the spilled fluid originated from the Bluesky Formation.

Pace concluded that over the service life of the well oil released from the 14-21 wellhead piping had been injected into the Keg River and Muskeg Formations as carryover with the produced water being disposed of.

Produced water tank levels are manually controlled. To drain the tank without pumping skim oil into the well, the injection water is checked during injection by periodically sampling the fluid in the transfer pump discharge. Sampling identifies the possibility of oil entrained in the disposal water. The injection fluid also passes through a 25-micron filter to remove any hydrocarbon particulate that may be entrained in the water. This process has been used since the property was acquired on July 1, 2006, by Provident (Pace's predecessor).

Sampling and disposal procedures for produced water before July 1, 2006, are not known. Pace indicated that oil carryover in the disposal water that caused an accumulation of oil in the reservoir of the 14-21 well was the source of the oil that spilled on May 19, 2012.

4.2.3 AER Findings

The AER has reviewed the Gushor and Pace reports. Based on the carbon fingerprint of oil recovered from the release location, the oil released to surface as a result of the incident originated from the Bluesky Formation and not the Keg River and Muskeg Formations.

A total of 166 wells produce sweet natural gas and a small amount of liquid hydrocarbon and water that is ultimately piped to the 15-7 facility. All produced gas (with oil and water entrained) passes through an inlet separator that removes the oil and water. The liquid components removed during the inlet separation process are stored in two 63 m^3 on-site storage tanks at the 15-7 facility. While in the tanks, the oil and water are atmospherically separated through stratification. Periodically, as dictated by tank levels, the separated water is pumped to the 14-21 well for disposal through a 114.3 mm cement-lined pipeline for disposal.

Any estimate of the volume of hydrocarbon liquids that may have been disposed of in the Keg River and Muskeg Formations over the service life of the 14-21 well would be speculative and could not be confirmed by production accounting records. The AER believes that a significant volume of liquid hydrocarbon, in the form of wastewater with liquid hydrocarbon carryover, has been injected into the formations during operation of the 14-21 well. This assumption is based on the volume and composition of the spill fluid and that standard operating practices for managing hydrocarbon liquids entrained in disposal water were unknown or nonexistent before July 1, 2006, when Provident purchased the facility from Samson.

4.3 Spill Volume

Spill volumes reported by Pace fluctuated significantly over the span of five days. The spill volume initially reported on May 19, 2012, was between 5 m^3 and 10 m^3. This volume was increased to 100 m^3 by 23:00 that evening. The spill volume then went from 100 m^3 to 3500 m^3 (50 per cent water cut), then back down to 800 m^3, at which point the AER accepted Pace's estimate of 800 m^3 on May 23, 2012.

The estimated spill volume of 3500 m^3 at 50 per cent water cut was reported once Pace had determined the depth and breadth of the spill. This volume was based on the 14-21 well's use as a water disposal well. An analysis of the water recovered at the spill location, however, revealed that little or no produced water had been released to the environment. Once Pace had gathered further information about recovered volumes, vapourization, and absorption/non-absorption into an already water-saturated environment, it revised the estimated spill volume to 800 m^3 of oil.

Based on the AER's examination of the vents, windows, and doors on the building that housed the disposal well as well as the surface area in the vicinity of the well, the release appeared to be of relatively high velocity and short duration.

4.3.1 Fekete Findings

The Fekete report considered two issues: the volumetric flow rate from the well and the sustained duration of the flow rate.

Pace performed a static gradient[19] on the 14-21 well on June 2, 2012. The gradient indicated dead (gas free, stabilized) oil from the midpoint of well perforations to 56 m below surface in the

[19] A static gradient is a pressure survey done during well shutdown periods. A pressure gauge is run into the well and stopped at several depths to measure the pressure at each interval. The pressure increase (considering fluid column weight) with depth is a measure of oil density and potential well deliverability.

wellbore. The wellhead pressure was recorded at about 540 kPa. Considering oil column height, the static reservoir pressure of 15 656 kPa was consistent with the static gradient test of June 2.

The Fekete report indicated that the well was capable of flowing anywhere from 232 m^3/day to about 550 m^3/day. This was based on flow modelling scenarios, pressure gradient information, and fluid samples taken at 100 m down the well annulus and at intervals near the total depth of the well.

4.3.2 Pace Findings

The static gradient that was done by Pace on June 2, 2012, indicated the following:

- initial tubing pressure: 543 kPa
- fluid level: 56 m from surface
- pressure at midpoint of the perforations: 15 656 kPa (1902.4 m into well)
- bottomhole temperature: 87^{o}C
- fluid gradient: 8.2 kPa/m

Positive tubing pressure, observed by Fekete after a short shut-in period, proves that the well was capable of flowing. The June 2 static gradient indicated that the reservoir was under pressured, meaning that the well would be capable of flowing for only a short duration. This, coupled with the introduction of a small amount of water, would ensure that the fluid column (with water entrained) would be too heavy for the under-pressured formation to overcome, causing the well to “kill” itself (cease flowing). This would also explain why little or no saline produced water spilled as a result of this incident.

4.3.3 AER Findings

The AER reviewed the Fekete and Pace reports about the volume of oil released. Based on its investigation and the information submitted, the AER believes that the large-volume release from the 14-21 well occurred over two to four days sometime during the 15-day period from May 4 to May 19, 2012.

The Fekete report indicated a maximum deliverability anywhere from 232 m^3 to about 550 m^3 of oil per day, with a gas-oil ratio of 10 to 1. As part of its report, Fekete modelled a number of possible release scenarios. The Fekete report also supported Pace’s claim that the release was of short duration with a high flow rate. The latter was supported by photographs taken on site by the AER that showed oil seeping through cracks, vents, and windows in the building housing the well.

Alta Flight Charters Inc., under contract with Plains, regularly does aerial patrols of Plains’s pipeline, which crosses about 100 m to the east of the 14-21 well. The well is easily visible from the air and any anomalies along the pipeline right-of-way (ROW) are reported immediately. The last flight before May 19 was on May 4, 2012, and nothing unusual was reported at that time. There were no flights between May 4 and May 19 because of poor weather.

According to operator log books, Pace checked the 14-21 well on April 2, 2012. The ROW was patrolled five times between April 9 and May 4, 2012, with no spill reported. The AER has concluded that the spill occurred between May 4 and May 19, 2012.

5 AER Conclusions

- Pace's response during the first four days after being notified of the spill was inadequate for a release of this size, according to both the AER and ESRD. However, once the environmental impact of the release was more clearly understood, Pace's response during the emergency phase of the incident was significant. By May 31, 2012, a total of 118 individuals were on site and fully engaged in the response.
- The wellhead piping failed as a result of internal pitting corrosion, originally initiated by stray current interference, which was later influenced by one or a combination of the following:
  - stagnant flow conditions that cause localized corrosion cells to form
  - the acidifying effects of dissolved O_2, CO_2, and H_2S in saline produced water
  - corrosion-inducing bacteria
- Based on its carbon fingerprint, the oil recovered from the release location originated from the Bluesky Formation and not the Keg River and Muskeg Formations into which the 14-21 well injects produced water.
- The oil that was released into the environment was injected in small volumes as carryover with the injected water over the service life of the 14-21 well. It is not clear what (if any) oil conservation procedures were in place before Provident purchased the well and water disposal system in July 2006.
- Based on operator logs and aerial patrols near the 14-21 well, the spill occurred between May 4 and May 19, 2012.
- The large-volume release from the 14-21 well took place over two to four days. This is supported by photos of oil that seeped into roof vents, building seams, and windows in the building housing the disposal well, indicating a high-velocity release.

6 Audit Findings of Pace's ERP

As part of the AER's incident investigation, Emergency Preparedness and Audit (EPA) Section staff audited Pace's emergency response plan (ERP) on November 6, 2012. The audit determined that Pace had failed to comply with *Directive 071*. In accordance with *Directive 019: Compliance Assurance*, the AER issued Pace with a High Risk Enforcement Action (DOC05) on January 9, 2013, for the following noncompliances:

1) Failure to review the corporate-level ERP with personnel assigned roles and responsibilities in accordance with section 11.1 of *Directive 071*.

2) Failure to provide training sessions to ensure that response personnel are competent in emergency response procedures in accordance with section 14.9 of *Directive 071*.

On January 29, 2013, the EPA Section accepted Pace's action plan to address these noncompliances and the audit was closed.

7 AER-Directed Actions

1) Pace must retain an independent third-party, CP-certified consultant or company to perform a full CP system audit of the Rainbow Lake system. The results must be submitted to the HLFC no later than 90 days from the release of this report. If an audit has been done between the date of the incident and the release of this report, Pace may submit those results.

2) Pace must assess the produced water being injected into the 14-21 well and monitor for and, where feasible, reduce the following:

    - stagnant flow conditions that cause localized corrosion cells to form
    - corrosion-inducing bacteria suggesting MIC
    - oxygen ingress due to fluid being injected from storage tanks at atmospheric pressure.

    Assessment results must be submitted to the HLFC within 90 days of the release of this report

3) Pace must, at a minimum, conduct and document monthly inspections of its water disposal/injection wells. The documentation must be stored at the producing facility and provided to the AER upon request. Pace must submit an action plan for this directed action and the well inspection recording sheet to the HLFC within 90 days of the release of this report.

4) Pace must assess the feasibility of installing engineering controls and/or telemetry to monitor and regulate line pressures and volume imbalances (e.g., supervisory control and data acquisition systems) at the 14-21 well. This assessment must be submitted to the HLFC within 90 days of the release of this report.

5) Pace must develop a procedure to conduct routine sampling (e.g., during each disposal operation, daily, etc.) of disposal water in accordance with *Directive 017: Measurement Requirements for Oil and Gas Operations,* appendix 4, category 3, for fluid with a sediment

and water cut of 80–100 per cent. The samples must be representative of the disposal fluid (e.g., spot sample from the flow line after the water disposal pump). The procedure must be incorporated into Pace's site-specific standard operating practices with the revisions submitted to the HLFC within 90 days of the release of this report.

6) Pace must perform an engineering assessment of the 15-7 facility to determine the feasibility of

   - configuring water storage tanks to incorporate gas blanketing to aid in reducing oxygen ingress into disposal water,
   - installing an automated start/stop control system with a high- and low-level alarm to ensure that water tank levels are not pumped to below a specified level (this will help ensure that skim oil remains in the tank and does not get pumped into the system), and
   - using one tank as a disposal water tank and the other as a skim oil tank. Sampling results will determine when skim oil from the water tank should be floated over to the skim oil tank.

   This assessment must be submitted in writing to the HLFC within 90 days of the release of this report.

7) Pace must conduct an ERP exercise within 90 days of the release of this report.

8 AER Follow-up

The AER Field Incident Response Support Team and EPA staff will supervise Pace's mandatory ERP exercise.

The HLFC will follow up with Pace to ensure that all AER-directed actions have been completed within 90 days of the release of this report.

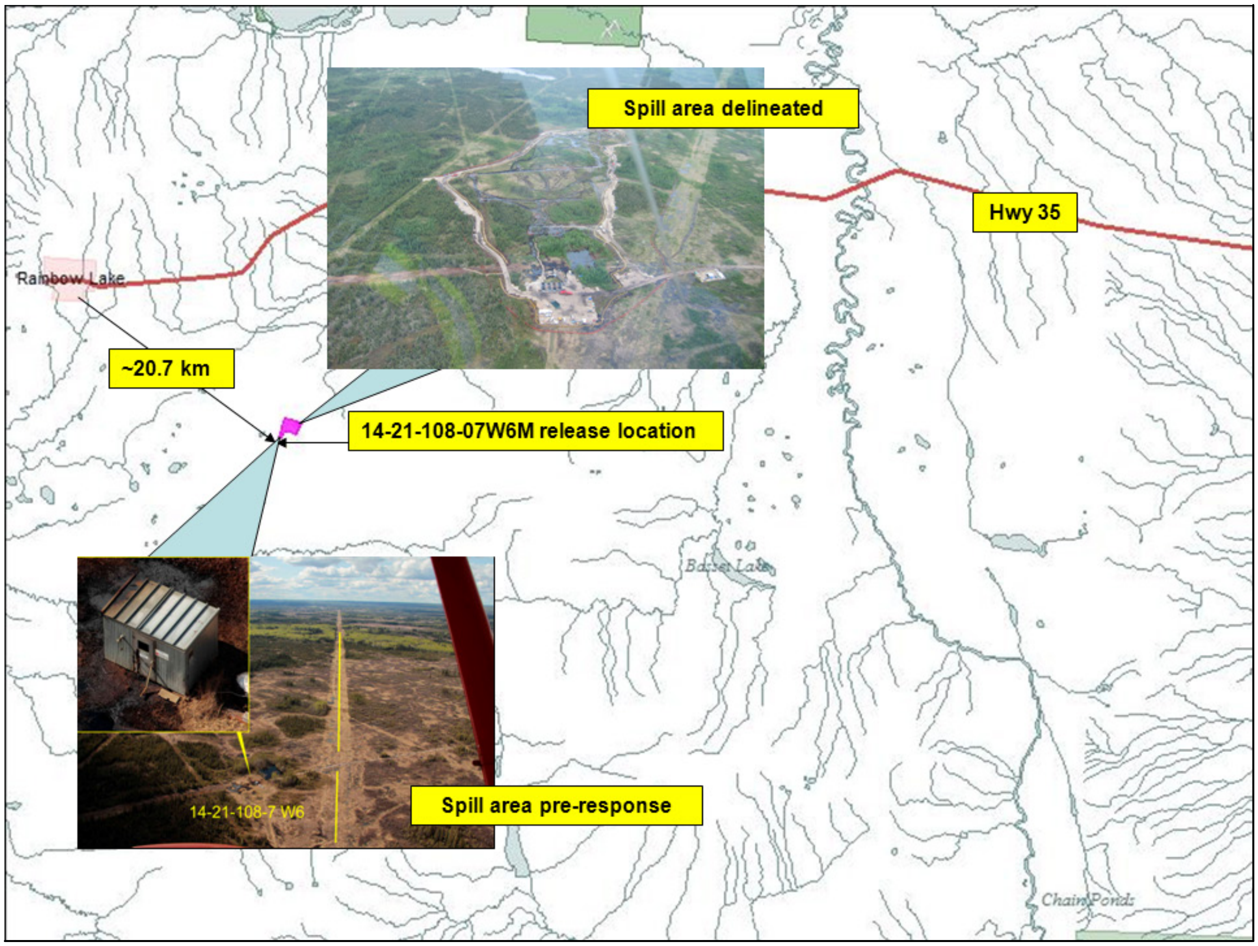

Figure 1. Pace Rainbow Lake Field spill. (Source: AER)

Figure 2. Lease piping prior to removal for analysis. (Source: AER)

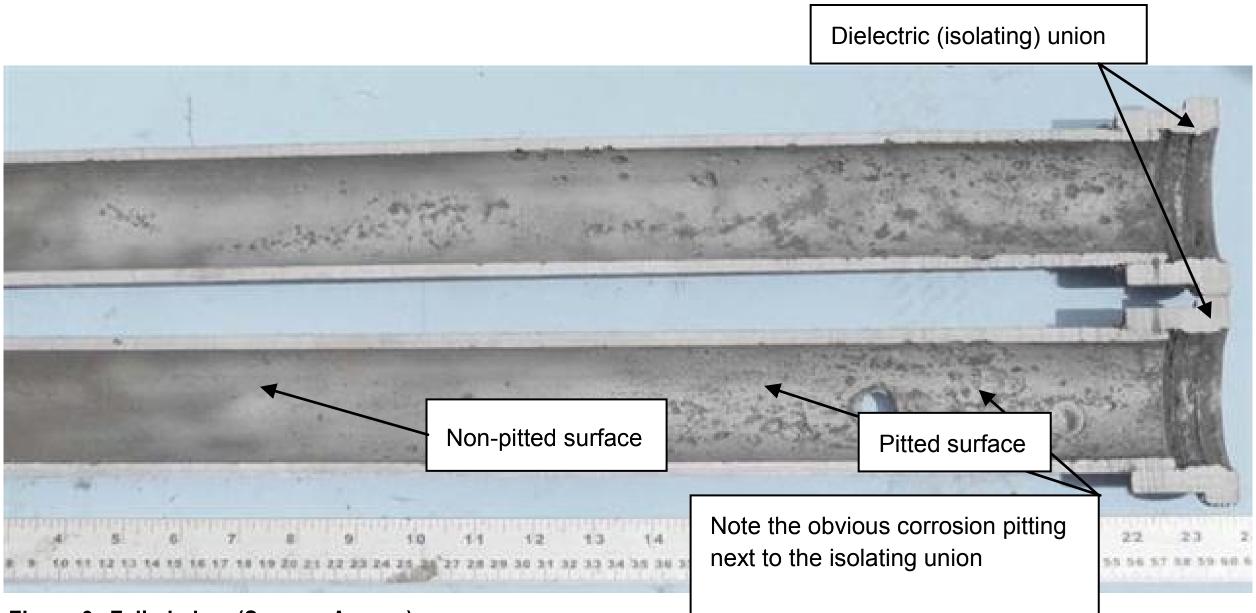

Figure 3. Failed pipe. (Source: Acuren)