



TUGAS AKHIR - ME184834

ANALISIS INSPEKSI BERBASIS RISIKO UNTUK CORROSION UNDER INSULATION (CUI) PIPING DI STORAGE AND LOADING AREA PT X

**BAGUS FYANDIKA
NRP. 04211640000024**

**Dosen Pembimbing
Ir. Dwi Priyanta, M.SE
Nurhadi Siswantoro, S.T, M.T.**

**Departemen Teknik Sistem Perkapalan
Fakultas Teknologi Kelautan
Institut Teknologi Sepuluh Nopember
Surabaya
2020**



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DOSEN PEMBIMBING:

Ir. Dwi Priyanta, M.SE

Nurhadi Siswantoro, S.T, M.T.

DEPARTEMEN TEKNIK SISTEM PERKAPALAN

FAKULTAS TEKNOLOGI KELAUTAN

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

SURABAYA

2020



BACHELOR THESIS - ME184834

RISK BASED INSPECTION ANALYSIS FOR CORROSION UNDER INSULATION (CUI) PIPING AT STORAGE AND LOADING AREA IN PT X

BAGUS FYANDIKA

NRP. 04211640000024

SUPERVISORS:

Ir. Dwi Priyanta, M.SE

Nurhadi Siswantoro, S.T, M.T.

DEPARTMENT OF MARINE ENGINEERING

FACULTY OF MARINE TECHNOLOGY

INSTITUT TEKNOLOGI SEPULUH NOPEMBER

SURABAYA

2020

LEMBAR PENGESAHAN

ANALISIS INSPEKSI BERBASIS RISIKO UNTUK CORROSION UNDER INSULATION (CUI) PIPING DI STORAGE AND LOADING AREA PT X

TUGAS AKHIR

Diajukan Untuk Memenuhi Salah Satu Syarat
Memperoleh Gelar Sarjana Teknik
pada

Bidang Studi Digital Marine Operation and Maintenance (DMOM)
Program Studi S-1 Departemen Teknik Sistem Perkapalan
Fakultas Teknologi Kelautan
Institut Teknologi Sepuluh Nopember

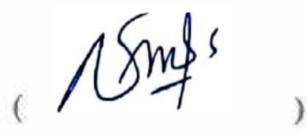
Oleh :
BAGUS FYANDIKA
NRP. 0421 16 4000 0024

Disetujui oleh Pembimbing Tugas Akhir :

Ir. Dwi Privanta, M.S.E.
NIP. 196807031994021001



Nurhadi Siswantoro, S.T., M.T.
NIP. 1992201711049



SURABAYA
JULI, 2020

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Fakultas Teknologi Kelautan

Institut Teknologi Sepuluh Nopember

Penulis:

Bagus Fyandika

NRP. 04211640000024

Disetujui Oleh,

Kepala Departemen Teknik Sistem Perkapalan

Beny Cahyono, S.T., M.T., Ph.D

NIP. 197903192008011008

SURABAYA

AGUSTUS, 2020

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ANALISIS INSPEKSI BERBASIS RISIKO UNTUK CORROSION UNDER INSULATION (CUI) PIPING DI STORAGE AND LOADING AREA PT X

Nama mahasiswa : Bagus Fyandika
NRP : 04211640000024
Departemen : Teknik Sistem Perkapalan d/h Teknik Permesinan Kapal
Pembimbing : 1. Ir. Dwi Priyanta, M.SE
 2. Nurhadi Siswantoro, S.T, M.T.

ABSTRAK

Salah satu korosi yang disebabkan oleh lingkungan adalah *Corrosion Under Insulation* (CUI). CUI didefinisikan sebagai korosi eksternal perpipaan yang terjadi ketika air terjebak di bawah insulasi. CUI terjadi ketika air atau uap air terjebak di dalam insulasi pipa dan menyebabkan terjadinya korosi pada pipa yang terinsulasi. Kerusakan CUI berupa korosi eksternal terlokalisasi pada carbon and low alloy steels. Dampak dari kejadian ini memicu banyak pihak untuk menetapkan beberapa aturan untuk memanajemen kerusakan akiba CUI. PT X melaksanakan inspeksi berkala untuk pemantauan CUI berdasarkan pada dokumen nomor OP / INS / BP-33 / 99-228, dimana survei CUI dilakukan sebagai inspeksi berbasis waktu setiap lima tahun dan setiap sistem perpipaan dilakukan inspeksi dengan cara yang sama. Ini membuat semua peralatan dan sistem perpipaan yang terdaftar rentan terhadap risiko kegagalan CUI dengan diperiksa tanpa mempertimbangkan faktor risiko dari masing-masing objek. Strategi ini dinilai kurang efektif karena risiko kegagalan CUI pada peralatan tertentu dapat berbeda satu sama lain. Maka dari itu diperlukan analisa berbasis resiko agar kegiatan inspeksi bisa lebih terfokus dan sesuai prioritas. Untuk membuat strategi dan kegiatan inspeksi lebih tepat, PT X mulai melakukan inspeksi berdasarkan kondisi dan risiko dari komponen terkait. Metode yang cocok digunakan adalah *Risk-Based Inspection* (RBI), yang telah dijelaskan secara sistematis pada API RP 581. Risiko komponen dihitung dari probabilitas dan konsekuensi kegagalan komponen. Sedangkan, untuk parameter perencanaan inspeksi ditetapkan dengan target risiko sebesar $3.72 \text{ m}^2/\text{tahun}$. Target risiko sendiri berguna untuk mengetahui batas maksimal hasil Analisa risiko dapat diterima atau tidak. Dari hasil analisa yang telah dilakukan menunjukkan 5 dari 10 piping yang dianalisa sudah melebihi target risiko dan disarankan agar dilakukan inspeksi segera mungkin.

Kata kunci: (Corrosion Under Insulation, Piping, Risk Based Inspection)

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RISK BASED INSPECTION ANALYSIS FOR CORROSION UNDER INSULATION (CUI) PIPING AT STORAGE AND LOADING AREA PT X

Name : Bagus Fyandika
NRP : 04211640000024
Department : Marine Engineering
Supervisors : 1. Ir. Dwi Priyanta, M.SE
 2. Nurhadi Siswantoro, S.T, M.T.

ABSTRACT

One of the corrosion caused by the environment is Corrosion Under Insulation (CUI). CUI is defined as external piping corrosion that occurs when water is trapped under insulation. CUI occurs when water or water vapor is trapped inside the pipe insulation and causes corrosion of the insulated pipe. CUI damage in the form of external corrosion is localized to carbon and low alloy steels. The impact of this incident triggered many parties to set some rules for managing the damage to the CUI. PT X conducts periodic inspections for CUI monitoring based on document number OP / INS / BP-33 / 99-228, where the CUI survey is carried out as a time-based inspection every five years and each piping system is inspected in the same manner. This makes all equipment and piping systems listed vulnerable to the risk of failure of the CUI by being checked without considering the risk factors of each object. This strategy is considered ineffective because the risk of CUI failure on certain equipment may differ from one another. Therefore a risk-based inspection analysis is needed so that inspection activities can be more focused and according to priority. To make the inspection strategy and activities more appropriate, PT X began to conduct inspections based on the conditions and risks of the related components. The suitable method used is Risk-Based Inspection (RBI), which has been explained systematically in API RP 581. Component risk is calculated from the probability and consequences of component failure. Meanwhile, the inspection planning parameters are set with a risk target of $3.72 \text{ m}^2 / \text{year}$. The risk target itself is useful to know the maximum limit of the results. Risk analysis is acceptable or not. The analysis shows that 5 out of 10 piped analyzed have exceeded the risk target and it is recommended that inspection be carried out as soon as possible.

Keywords: (Corrosion Under Insulation, Piping, Risk Based Inspection)

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KATA PENGANTAR

Alhamdulillahi Rabbil'alamin, puji syukur saya panjatkan ke hadirat Allah SWT, yang telah melimpahkan rahmat, hidayah serta pertolongannya sehingga saya dapat menyelesaikan tugas akhir ini dengan judul "Analisis Inspeksi Berbasis Risiko untuk *Corrosion Under Insulation (CUI) Piping di Storage and Loading Area PT X*" dengan lancar, tepat waktu dan sebaik-baiknya. Tugas akhir ini diajukan sebagai salah satu persyaratan kelulusan program strata satu teknik di Departemen Teknik Sistem Perkapalan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember Surabaya. Tugas akhir ini sangatlah penting bagi saya selaku mahasiswa Departemen Teknik Sistem Perkapalan. Karena tugas akhir ini mengajarkan saya tentang bagaimana mencintai sebuah proses dalam membaca, belajar, dan memahami salah satu bidang yang semoga bisa saya lanjutkan nanti di dunia kerja. Dimulai dari pemilihan bidang penelitian, pencarian data, pemilihan judul, hingga menjadi tugas tulisan tugas akhir ini.

Dalam proses penulisan tugas akhir ini, penulis banyak mendapat bantuan serta dukungan dari pihak-pihak yang telah melancarkan proses pengeraannya. Dengan mengucap terima kasih sebesar-besarnya, pihak-pihak tersebut adalah :

1. Allah Subhanahu Wata'ala atas segala nikmat dan kuasa-Nya, serta junjungan besar Nabi Muhammad SAW yang telah memberikan kita pedoman ke jalan yang benar.
2. Dina Agustianingsih, Eka Setiabudi, Derby, dan Bagas serta keluarga besar penulis yang selalu memberikan semangat dan doa setiap hari.
3. Bapak Beny Cahyono, S.T., M.T., Ph.D. selaku Kepala Departemen Teknik Sistem Perkapalan FTK - ITS.
4. Bapak Ir. Dwi Priyanta, M.S.E., dan Bapak Nurhadi Siswantoro, S.T, M.T. selaku dosen pembimbing tugas akhir penulis.
5. Bapak Irwin Maulana, Para *Engineer*, Staf, dan Mitra *Inspection Section* di PT X. lainnya yang telah memberikan penulis kesempatan untuk mengambil data serta berdiskusi mengenai tugas akhir yang akan ditulis.
6. Bapak dan Ibu dosen dan karyawan Departemen Teknik Sistem Perkapalan FTK – ITS yang telah memberikan ilmunya dan membantu selama duduk di bangku kuliah.
7. Ir. Amiadji, M.M., M.Sc. selaku dosen wali penulis.
8. Teman-teman EPC Office (Jamal, Teguh, Afa, Nina, Triska, Mas Agung, Mas Tyo, Mas Nanang, Mas Rusdi, Mas Asep, Mas Linggar, Mas Andri, Mas Ipul, Mbak Chika, Mas Sholeh, Jeryco, Bagas, dan Rama) yang telah memberikan motivasi, dukungan, semangat, dan saran selama pengeraaan tugas akhir.
9. Teman- teman Lab MOM yang telah memberikan bantuan kepada penulis dan pengarahan mengenai pengeraaan tugas akhir selama ini.
10. Mas Wildan yang telah memberikan bimbingan dan membantu selama pengeraaan tugas akhir.
11. Sahabat yang telah memberi bantuan selama proses pengeraaan tugas akhir.
12. Dan semua pihak yang telah membantu menyelesaikan tugas akhir ini yang tidak bisa penulis sebutkan satu per satu.

Sebagai akhir dari pengantar ini, penulis mengucapkan terima kasih kepada semua pihak yang telah ikut membantu kelancaran dalam proses penggerjaan tugas akhir ini. Penulis menyadari bahwa banyaknya kendala dan keterbatasan ilmu pengetahuan serta wawasan penulis menjadikan tugas akhir ini masih jauh dari kata sempurna. Oleh karena itu, kritik dan saran yang membangun sangat diharapkan demi penulisan yang lebih baik di kemudian hari. Penulis juga memohon maaf apabila dalam proses penggerjaan tugas akhir ini terdapat banyak kesalahan yang disengaja maupun tidak disengaja. Besar harapan penulis, bahwasannya tugas akhir ini dapat bermanfaat bagi penulis secara khusus sebagai pengalaman studi, bagi pembaca sebagai bahan studi dan referensi tugas akhir, serta nusa dan bangsa.

Surabaya, Juli 2020

Penulis

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BAB I

PENDAHULUAN

1.1 Latar Belakang Masalah

Salah satu negara dengan jumlah pulau terbanyak dan hutan terluas adalah Indonesia. Indonesia memiliki hutan yang sangat luas dan memiliki tingkat curah hujan tinggi. Tak heran berbagai alat yang terbuat dari logam akan sering terkena air dan mendukung proses terjadinya korosi pada logam. Hal itu tidak bisa dihindari termasuk di PT X. Area PT. X memiliki tingkat korosi yang relatif tinggi disebabkan curah hujan rata-rata sebesar 188.47 mm³/tahun, didukung dengan kondisi wilayah yang berada di pesisir laut dan proses produksi dari PT X. Jika tidak dilakukan manajemen perawatan dengan baik dan terstruktur akan menyebabkan banyak biaya. Karena konsekuensi kerusakan dan proses pemeliharaan yang bisa menjadi seperti bom waktu.

Salah satu korosi yang disebabkan oleh lingkungan adalah *Corrosion Under Insulation* (CUI). CUI didefinisikan sebagai korosi eksternal perpipaan yang terjadi ketika air terjebak di bawah insulasi. CUI terjadi ketika air atau uap air terjebak di dalam insulasi pipa dan menyebabkan terjadinya korosi pada pipa yang terinsulasi. [1] Kerusakan CUI berupa korosi eksternal terlokalisasi pada *carbon* dan *low alloy steels*. Dampak dari kejadian ini memicu banyak pihak dalam menetapkan beberapa aturan baru dalam memanajemen kegiatan yang digunakan untuk mencegah, memitigasi, dan bahkan meminimalkan kerusakan kegagalan akibat CUI pada peralatan yang ada di perusahaan mereka.

Masalah terkait CUI juga menjadi perhatian serius PT X. Dalam memanajemen kerusakan kegagalan akibat CUI, perusahaan melaksanakan inspeksi berkala untuk pemantauan CUI berdasarkan pada dokumen nomor OP / INS / BP-33 / 99-228, dimana survei CUI dilakukan sebagai inspeksi berbasis waktu setiap lima tahun dan setiap sistem perpipaan dilakukan inspeksi dengan cara yang sama. Ini membuat semua peralatan dan sistem perpipaan yang terdaftar rentan terhadap risiko kegagalan CUI dengan diperiksa tanpa mempertimbangkan faktor risiko dari masing-masing objek. Strategi ini dinilai kurang efektif karena risiko kegagalan CUI pada peralatan tertentu dapat berbeda satu sama lain. Maka dari itu diperlukan analisa berbasis resiko agar kegiatan inspeksi bisa lebih terfokus dan sesuai prioritas.

Dari penelitian ini, risiko masing-masing peralatan terhadap kegagalan CUI dapat dipetakan dengan baik. Rencana inspeksi untuk setiap kategori risiko juga dapat ditentukan lebih lanjut sesuai dengan level risiko. Hal tersebut memiliki kontribusi positif terhadap strategi manajemen CUI bagi perusahaan. Oleh karena itu, analisis yang lebih lengkap dan intensif dapat dikembangkan guna mengevaluasi kebutuhan untuk memodifikasi strategi inspeksi CUI, dari sebelumnya penerapan inspeksi strategi berbasis waktu dan setiap pipa berinsulasi dilakukan inspeksi yang sama menjadi evaluasi berbasis risiko yang dapat mengukur berbagai tingkat kategori risiko kerusakan akibat CUI dan strategi inspeksi sesuai dengan level risiko dari setiap pipa yang terinsulasi.

1.2 Perumusan Masalah

Berdasarkan latar belakang di atas permasalahan dari penelitian ini adalah:

1. Bagaimana cara menghitung *Probability of Failure* (POF) pada pipa yang terinsulasi menggunakan *Risk Based Inspection* (RBI)?
2. Bagaimana cara menghitung *Consequence of Failure* (COF) pada pipa yang terinsulasi menggunakan *Risk Based Inspection* (RBI)?
3. Bagaimana cara menentukan Analisis Risiko pada pipa yang terinsulasi di *storage & loading area* Kilang PT X?
4. Bagaimana menentukan perencanaan strategi inspeksi dan interval inspeksi yang tepat pada pipa yang terinsulasi sesuai dengan klasifikasi risiko menggunakan metode RBI?

1.3 Batasan Masalah

Batasan masalah dari penelitian ini adalah:

1. Analisis inspeksi berbasis risiko hanya dilakukan pada pipa berinsulasi di *storage and loading area* (*Plant 16: Condensate Stabilization*) PT X
2. Analisis inspeksi berbasis risiko ini berpedoman pada API RP 580 (Risk Based Inspection) dan API RP 581 (Risk Based Inspection Methodology) dan EFC CUI Guidelines (European Federation of Corrosion Publications Number 55 – Corrosion Under Insulation Guidelines)
3. Tidak menghitungkan biaya dalam inspeksi/pengujian ketika menggunakan metode *Risk Based Inspection* (RBI).
4. Kerusakan akibat bencana alam tidak dipertimbangkan.

1.4 Tujuan

Berdasarkan rumusan masalah yang ada tujuan dari penelitian ini adalah:

1. Untuk menentukan *Probability of Failure* (POF) pada pipa yang terinsulasi berdasarkan metode *Risk-Based Inspection* (RBI)
2. Untuk menentukan *Consequence of Failure* (COF) pada pipa yang terinsulasi berdasarkan metode *Risk-Based Inspection* (RBI)
3. Melakukan analisis berbasis risiko untuk kegagalan akibat CUI pada pipa yang terinsulasi di *storage & loading area* Kilang PT X
4. Untuk menentukan perencanaan strategi inspeksi dan interval inspeksi yang tepat pada pipa yang terinsulasi sesuai dengan klasifikasi risiko menggunakan metode RBI

1.5 Manfaat

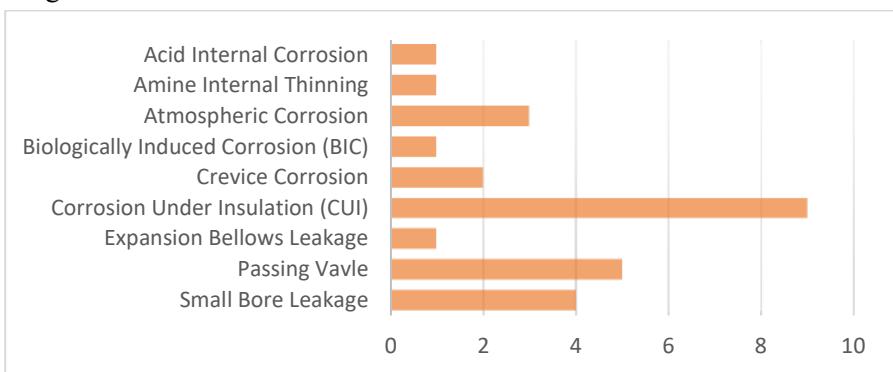
Dapat digunakan sebagai acuan bagi perusahaan dalam menentukan program inspeksi dan interval inspeksi/testing pada sistem perpipaan yang terinsulasi.

BAB II

TINJAUAN PUSTAKA

2.1 Kajian Penelitian Terkait

Sejak tahun 1980an *Corrosion Under Insulation* (CUI) dan *Corrosion Under Fireproofing* (CUF) telah teridentifikasi dalam industri permifyakan sebagai risiko utama terhadap kerusakan mekanis dan operasi peralatan. [2] Pada PT X kerusakan akibat CUI menjadi masalah serius karena mengakibatkan terjadinya *loss of primary containment* (LOPC). Dibandingkan dengan *damage mechanism* yang lain, kerusakan akibat CUI menjadi kasus terbanyak dengan jumlah 9 kasus pada kisaran tahun 2017 sampai 2019. **Gambar 2.1** menunjukkan perbandingan kerusakan akibat CUI dengan *damage mechanism* yang lain. Kerusakan CUI termasuk korosi eksternal perpipaan dan bejana yang terbuat dari *carbon manganese, low alloy, and austenitic stainless steel*. CUI cenderung tidak terdeteksi sampai insulasi dan *cladding/jacketing* dilepas untuk kegiatan inspeksi atau ketika terjadi kebocoran ke lingkungan.



Gambar 2.1 Data kerusakan piping yang menyebabkan LOPC
(sumber: Database PT X)

Karena menyebabkan kerusakan terbanyak yang menyebabkan LOPC, CUI menjadi perhatian khusus PT X. Dalam memanajemen kerusakan kegagalan akibat CUI, perusahaan melaksanakan inspeksi berkala untuk pemantauan CUI berdasarkan pada dokumen nomor OP / INS / BP-33 / 99-228, dimana survei CUI dilakukan sebagai inspeksi berbasis waktu setiap lima tahun dan setiap sistem perpipaan dilakukan inspeksi dengan cara yang sama. Strategi ini dinilai kurang efektif karena risiko kegagalan CUI pada peralatan tertentu dapat berbeda satu sama lain. Maka dari itu untuk mengatasi masalah yang disebabkan oleh CUI perlu menggunakan program inspeksi berbasis risiko sebagai rekomendasi strategi inspeksi. Sehingga rencana inspeksi dapat diprioritaskan pada bagian yang paling berisiko.

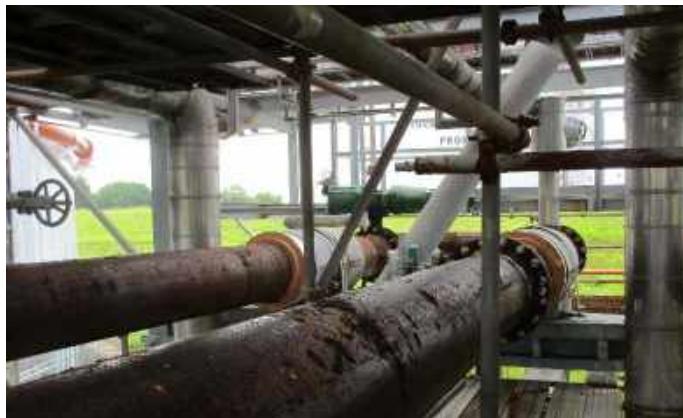
Tujuan dari program inspeksi berbasis risiko adalah mengurangi risiko ke tingkat yang dapat diterima dan kemudian mengelola risiko itu dalam program inspeksi dan pemeliharaan yang sedang berlangsung. Program CUI sering gagal karena mahal untuk dilakukan dan membutuhkan komitmen waktu yang besar.

Pengalaman industri dan *in-house* telah menunjukkan bahwa program CUI yang sukses memiliki dampak positif pada keselamatan, keandalan, lingkungan, dan biaya perawatan.

2.2 *Piping*

Umumnya, pipa digunakan di perusahaan minyak dan gas untuk proses produksi. Pipa adalah media tempat mengalirnya fluida proses dari suatu unit yang ke unit lainnya. [3] Secara umum karakteristiknya ditentukan berdasarkan material (bahan) penyusunnya. Ukuran diameter pipa didasarkan pada diameter "Nominal" antara diameter luar (OD) atau diameter dalam (ID). Tubing adalah pipa dengan ukuran diameter yang lebih kecil dari pipa, kegunaannya (secara umum) adalah untuk penghubung antara alat ukur dengan pipa proses dari instrumen ke sistem kontrol. Ukuran standar untuk tubing selalu diameter luar (OD). Ada beberapa jenis perpipaan, seperti *carbon* dan *stainless steel*. Penggunaan jenis pipa didasarkan pada fluida dan persyaratan setiap perusahaan.

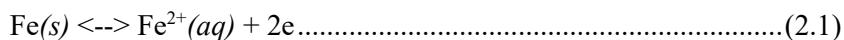
Pada piping PT X yang diteliti pada penelitian ini merupakan jenis *carbon steel*. *Design code* yang digunakan adalah ASME B.31.1 dengan material ASTM A106 Gr B. Kisaran suhu yang bisa di layani antara -29 °C sampai 399 °C dan tekanan maksimal yang bisa dilayani sebesar 5.1 MPa. Gambar 2.2 menunjukan pipa yang yang digunakan oleh PT X.



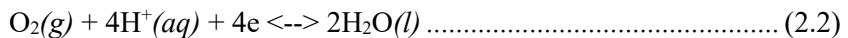
Gambar 2.2 Pipa *carbon steel* di *Plant 16*
(sumber: Dokumen Pribadi)

2.3 Korosi

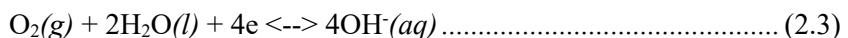
Korosi adalah penghancuran atau degradasi bahan karena bereaksi dengan lingkungan. [3] Contoh korosi yang paling sering terjadi adalah perkaratan besi. Pada peristiwa korosi, logam mengalami oksidasi, sedangkan oksigen (udara) mengalami reduksi. Karat logam umumnya adalah berupa oksida atau karbonat. Rumus kimia karat besi adalah $\text{Fe}_2\text{O}_3 \cdot \text{nH}_2\text{O}$, suatu zat padat yang berwarna coklat-merah. Korosi merupakan proses elektrokimia. Pada korosi besi, bagian tertentu dari besi itu berlaku sebagai anode, di mana besi mengalami oksidasi.



Elektron yang dibebaskan di anode mengalir ke bagian lain dari besi itu yang bertindak sebagai katode, di mana oksigen tereduksi.



atau



Ion besi (II) yang terbentuk pada anode selanjutnya teroksidasi membentuk ion besi(III) yang kemudian membentuk senyawa oksida terhidrasi, yaitu karat besi. Mengenai bagian mana dari besi itu yang bertindak sebagai anode dan bagian mana yang bertindak sebagai katode, bergantung pada berbagai faktor, misalnya zat pengotor atau perbedaan rapatan logam itu. Secara umum, ada dua jenis korosi pada piping:

1. Internal Corrosion

Korosi yang terjadi karena kandungan CO₂ dan H₂S dalam minyak bumi dan gas alam, kemudian terjadi kontak dengan udara dan membentuk asam yang menjadi penyebab korosi. **Gambar 2.3** menunjukkan *internal corrosion* yang terjadi pada bagian dalam pipa.

2. External Corrosion

Korosi yang terjadi pada permukaan yang terjadi kontak dengan udara, baik yang bersentuhan dengan udara bebas dan permukaan tanah. Disebabkan karena adanya kandungan asam di udara dari tanah. **Gambar 2.4** menunjukkan *external corrosion* yang terjadi pada bagian luar pipa.



Gambar 2.3 Internal Corrosion
(sumber: corrosionmaterials.com)



Gambar 2.4 External Corrosion

2.4 Insulation

Insulation adalah metode atau serangkaian proses yang digunakan untuk mengurangi atau meredam energi (Panas/kalor, suara, listrik, dll). Energi tersebut dapat diredam melalui beberapa cara, yaitu konduksi, konveksi maupun radiasi. Pada piping dengan *insulation* bagian luar pipa yang berfungsi untuk melindungi pipa dan mengisolasi panas atau dingin. *Insulation* pipa sering digunakan pada instalasi pipa untuk konstruksi dan properti baik di kilang, pabrik, hotel, rumah sakit, laboratorium

dan lainnya. Selain itu *Insulation* pipa berfungsi sebagai pengontrol kondensasi, proteksi terhadap suhu dan kontak fisik. **Gambar 2.5** menunjukkan *insulation* pada pipa di *Plant* 16. Adapun tiga jenis material insulasi yang dibedakan dari kegunaannya: [4]

1. Cold insulation

Untuk *cold insulation* menggunakan material *cork* (khususnya di instalasi tua), *polyurethane* atau *polystyrene*. Bahan-bahan ini dapat diberikan secara *preformed* (untuk perpipaan) atau sebagai lembaran (untuk seluruh *equipment*).

2. Medium-hot insulation

Pada suhu hingga 350°C *fiberglass* digunakan, baik dalam bentuk serat "wool", atau dalam lembaran.

3. Insulasi untuk cold conservation

Untuk suhu antara 350°C dan 550°C *mineral (or rock) wool* digunakan. *Mineral wool* adalah *spun silica fiber* dan digunakan dengan cara yang sama seperti *fiberglass*.



Gambar 2.5 Insulation Pipa
(sumber: Dokumen Pribadi)

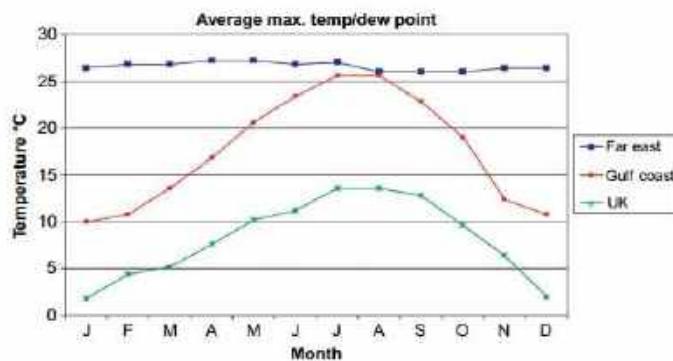
2.5 Corrosion Under Insulation (CUI)

Corrosion Under Insulation termasuk korosi eksternal pipa dan bejana yang terbuat dari *carbon manganese*, *low alloy*, and *austenitic stainless steel*. Terjadi di bawah *insulation* atau *jacketed thermal* atau *acoustic insulation* terutama karena penetrasi air ke dalam *insulation*. Sifat CUI cenderung tidak terdeteksi sampai *insulation* dan *cladding/jacketing* dilepas untuk kegiatan inspeksi atau ketika kebocoran ke atmosfer terjadi. CUI adalah masalah utama di seluruh dunia dan terjadi di semua perusahaan Oil & Gas (baik di darat dan lepas pantai), industri pengolahan kimia (CPI), dan industri terkait. CUI bukan masalah baru, tetapi bisa menjadi masalah serius jika tidak ditangani dengan benar. CUI telah menjadi penyebab atas banyak kebocoran besar yang menyebabkan insiden terkait keselamatan, kesehatan, dan lingkungan (SHE), kehilangan produksi, dan bertanggung jawab atas besarnya

anggaran pemeliharaan yang diperlukan untuk mengurangi masalah kerusakan. Menurut penyebabnya, secara umum CUI diklasifikasikan dalam empat kategori: [1]

1. Low temperature (*cold or cryogenic*)
2. Sweating service (*below dew point*)
3. High temperature
4. Cyclic temperature

Keempat kategori CUI tersebut dipengaruhi oleh lokasi atau geografi dan kondisi iklim setempat. Terutama untuk peralatan yang beroperasi di bawah suhu sekitar atau dalam *sweating service* dengan laju CUI yang dipengaruhi oleh suhu dan kelembaban sekitar rata-rata. Suhu dan kelembaban mengontrol titik embun dan titik embunlah yang mengontrol tingkat basah. **Gambar 2.6** menunjukkan variasi tahunan titik embun di tiga wilayah berbeda.



Gambar 2.6 Variasi tahunan suhu dan titik embun pada tingkat kelembapan
(sumber: EFC CUI Guidelines, 2016)

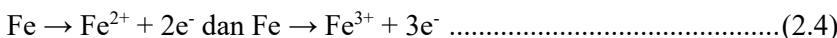
Ada kontaminan yang dapat menyebabkan masalah pada *carbon manganese* dan *low alloy* serta *stainless steel*. Klorida dan sulfida merupakan masalah terbesar dari kontaminasi dan umumnya meningkatkan korosifitas air. Sumber kontaminan dapat berasal dari luar, seperti dari lingkungan yang disebabkan oleh klorida yang terletak di lingkungan laut (mis., Lepas pantai) atau garam yang terbawa angin dari menara pendingin atau dari pengujian berkala sistem banjir air limbah. Kontaminan juga dapat disebabkan karena pencucian dari bahan insulasi. Dengan adanya tegangan yang diterapkan atau residu dan suhu yang melebihi 60 °C (140 °F), kandungan air klorida yang tinggi berkontribusi terhadap *chloride external stress corrosion cracking* (Cl-ESCC).

CUI umumnya terjadi pada kisaran suhu antara -12 °C dan 177 °C dan kisaran suhu 49 °C hingga 93 °C menjadi kisaran suhu yang paling parah. Rentang suhu ini diperkirakan dengan keadaan di lapangan yang ditunjukkan dalam literatur dan digunakan sebagai panduan untuk menjadi pengembangan terhadap prosedur mitigasi. Adapun masalah akibat CUI terjadi melebihi rentang tersebut. Namun kejadian CUI mayoritas berada dalam -12 °C dan 177 °C.

2.5.1 Mekanisme CUI

CUI adalah elektrokimia dan membutuhkan kehadiran empat elemen yaitu anoda, katoda, elektrolit, dan sirkuit atau aliran listrik. Elektrolit dalam bentuknya yang paling sederhana adalah air beroksigen, yang mungkin mengandung kontaminan yang dapat meningkatkan laju korosi. **Gambar 2.7** memberikan gambaran sederhana dari reaksi elektrokimia dari CUI.

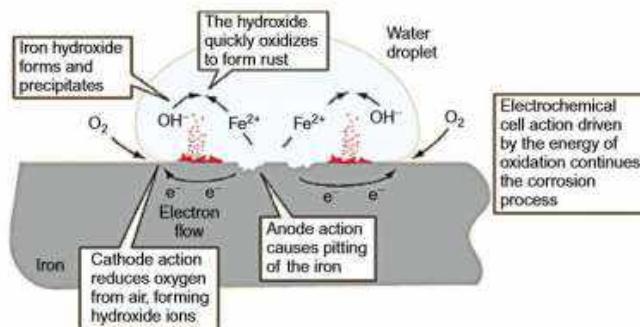
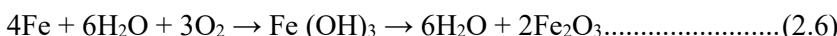
Reaksi oksidasi:



Reaksi Reduksi:



OH^- bereaksi dengan Fe^{2+} dan Fe^{3+} untuk membentuk Fe(OH)_2 / Fe(OH)_3 dan Fe_2O_3 diendapkan, sesuai dengan reaksi berikut:



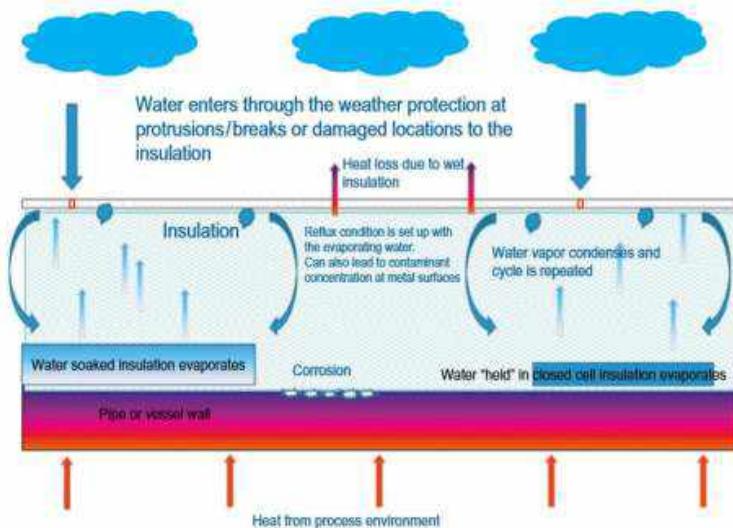
Gambar 2.7 Mekanisme CUI pada carbon steel

(sumber: EFC CUI Guidelines, 2016)

Kontaminan Cl^- meningkatkan oksidasi Fe^{2+} menjadi Fe^{3+} , yang menurunkan pH dan mempercepat korosi (melalui reduksi ion H^+). SO_2 mengasamkan air dan juga membuat reduksi ion H^+ . Dengan mengasumsikan tidak ada atau kerusakan lapisan pelindung yang mungkin telah diterapkan.

Gambar 2.8 menunjukkan bagaimana reaksi elektrokimia terjadi dalam keadaan nyata di bawah insulasi "hot thermal". Air atau kelembaban menembus insulasi dan akan diserap atau terjebak oleh insulasi. Akhirnya, air akan menyentuh permukaan logam yang panas. Penguapan akan terjadi, yang menggerakkan uap air melalui insulasi menuju penghalang eksternal "cold" di mana terjadi kondensasi. Air kemudian akan bermigrasi lagi, kembali ke permukaan logam yang panas. Beberapa proses lain juga terjadi selama proses ini. Kontaminan dapat terkonsentrasi karena sifat siklik atau refluks dari siklus penguapan / kondensasi dan degradasi lapisan dapat terjadi jika ada. Akhirnya, lapisan akan rusak dan cukup untuk memungkinkan terjadinya korosi elektrokimia. Siklus penguapan / kondensasi juga dapat merusak insulasi, mengurangi efektivitas / sifat termal. Proses ini terjadi di semua sistem terisolasi,

yang insulasi sel terbuka dan sel tertutup rentan terhadap CUI. Sistem insulasi yang menampung jumlah uap air dan mengering paling cepat akan menghasilkan paling sedikit kerusakan korosi pada peralatan. Tidak adanya atau adanya lapisan pelindung yang rusak akan memungkinkan kontak langsung antara air dan permukaan pipa atau kapal yang akan memungkinkan terjadinya korosi.



Gambar 2.8 Mekanisme CUI pada kondisi panas
(sumber: EFC CUI Guidelines, 2016)

2.5.2 Lokasi pada Perpipaan yang Rentan terhadap CUI

CUI cenderung terjadi pada area tertentu dari peralatan yang rentan. **Tabel 2.1** di bawah ini menunjukkan lokasi peralatan yang rentan terhadap CUI.

Tabel 2.1 Lokasi Rentan terhadap CUI pada pipa
(sumber: EFC CUI Guidelines, 2016)

| Equipment Type | Critical Locations |
|----------------------------------|--|
| Piping system Higher Priority | Dead-legs, vents, and drains |
| | Pipe hangers and supports |
| | Valves and fittings |
| | Bolted on pipe shoes |
| | Steam-tracing/electric-tracing tubing penetrations |
| | Termination of insulation at flanges and other piping components |
| | Carbon/low alloy steel flanges, bolting, and other components in high alloy piping |
| | Jacketing seams on the top of horizontal piping |
| | Termination of insulation on vertical piping |
| | Areas where smaller branch connections intersect larger diameter lines |
| Priority Lower | Low points in piping with breaches in the insulation |
| | Close proximity to water (e.g. wharf) and/or ground (e.g. increased absorption) |
| | Wet due to flooding or submerging into water |
| | Damage due to foot traffic |

2.5.3 Mitigasi CUI

Untuk memitigasi CUI perlu melibatkan banyak kompetensi di kilang seperti inspeksi korosi, evaluasi nondestruktif, evaluasi risiko dan keselamatan, pemeliharaan, unit operator, dan manajemen perusahaan sangat penting. Strategi-strategi ini membutuhkan identifikasi zona dan peralatan yang paling berisiko.

Analisis risiko harus mempertimbangkan dampak pada keselamatan, lingkungan, dan kinerja (keandalan / ketersediaan) unit.

a. Teknik Pemeriksaan dan Pengujian untuk CUI

Pemeriksaan CUI dapat dilakukan dengan menerapkan teknik nondestructive testing (NDE / NDT). Di bawah ini adalah daftar kemungkinan metode NDT yang dapat digunakan untuk mendeteksi CUI: [1]

1. Inspeksi eksternal / visual (dengan atau tanpa melepas insulasi)
2. Pengukuran ketebalan dengan ultrasonik (dengan dan tanpa melepas insulasi - termasuk melalui bukaan inspeksi)
3. *Flash radiography*
4. *Guided wave ultrasonic*
5. *Profile/flash radiography*
6. *Digital radiography*
7. *Real-time radiography*
8. *Pulsed eddy current*
9. *Digital/real-time radiography*
10. *Infrared*
11. *Neutron backscatter*
12. *Dye penetrant testing*

Setiap teknik memiliki keterbatasan, kelebihan, dan kekurangan yang harus dipertimbangkan sebelum digunakan untuk inspeksi CUI.

b. Metode Pencegahan CUI

Berikut ini adalah beberapa metode yang saat ini diimplementasikan untuk mencegah CUI: [1]

1. Rancang dan pasang sistem isolasi untuk mencegah masuknya air.
2. Menggunakan insulasi organik yang cocok untuk menahan korosi.
3. Lakukan inspeksi visual berkala dan / atau inspeksi *nondestructive*.
4. Buka semua insulasi secara berkala, siapkan permukaan pipa untuk pelapisan, dan melakukan *reinsulate*.
 - Pemeliharaan sistem pelapisan konvensional (cat) adalah satu-satunya mitigasi untuk CUI pada peralatan *carbon steel*
 - Sistem cat konvensional memiliki *lifetime* rata-rata (9-13 tahun) yang sangat bergantung pada persiapan dan pengecatan permukaan yang baik

Metode pencegahan pada peralatan servis dingin pemeliharaan cat konvensional tanpa penghentian unit.

c. Pertimbangan untuk Pencegahan CUI

Pada dasarnya semakin banyak kerusakan yang terjadi pada *weatherproofing* semakin besar kemungkinan air akan memasuki isolasi dan berpotensi menyebabkan CUI. [5] Oleh karena itu, penting untuk meminimalkan jumlah nozel, *support*, dan penahan yang akan menonjol pada *weatherproofing*. Karena kesulitan dalam pengaplikasian *weatherproofing* dan *sealing* pada *support* perlatan, sudah menjadi praktik yang harus dilakukan untuk memotongnya setelah peralatan diangkat ke pabrik dan terpasang dengan aman di posisinya.

Dalam sistem perpipaan, penyangga pipa merupakan penyebab umum CUI karena kesulitan mengisolasi dan menyegel dengan benar di sekitarnya. [1] *Rod hangers* atau klem yang digunakan untuk menopang *piping* dengan "*direct contact*" tidak praktis untuk diisolasi dan disegel secara efektif terhadap pencegahan masuknya air. Lokasi lain yang juga sulit untuk diisolasi adalah *beam support*. Dimana *piping* langsung bersandar pada *beam*. Oleh karena itu, semua pipa berinsulasi harus dirancang dengan penyangga pipa yang sesuai yang memitigasi atau setidaknya meminimalisir masuknya air. Praktik yang dianggap baik adalah menggunakan *high-density insulation* di lokasi penopang dan pas dengan bantalan penyangga yang hanya akan mengenai *weatherproofing*, sehingga memungkinkan sebagai *weather barrier* terus menerus.

2.6 Peraturan Terkait

Perusahaan minyak dan gas wajib menerapkan peraturan keselamatan untuk setiap proses, yang mengacu pada Pemerintah Indonesia, pembuat peraturan, dan memastikan bahwa semuanya berjalan dengan baik di jalur dan di bawah kendali. Setiap pekerja berhak mendapatkan perlindungan dan keselamatan dalam setiap detail pekerjaan. Oleh karena itu, implementasi setiap peraturan yang mengacu pada keselamatan dan kesehatan kerja, perlu untuk mencegah kegagalan atau kecelakaan dalam setiap operasi.

2.6.1 Peraturan No. 1, 1970

Peraturan ini memberikan alasan keamanan. Seperti yang dapat kita lihat dalam Bab III, Pasal 3, paragraf 1, menjelaskan bahwa untuk mewujudkan keselamatan kerja, kita perlu:

1. Mencegah dan kurangi kemungkinan kecelakaan
2. Mencegah, mengurangi, dan memadamkan api
3. Mencegah dan mengurangi bahaya ledakan

2.6.2 Peraturan Pemerintah No.11, 1979

Peraturan ini mengontrol keselamatan kerja dalam proses pemurnian minyak dan gas. Ini terdiri dari 31 bab dan 58 artikel yang mengatur administrasi dan pengawasan keselamatan kerja pada proses pemurnian industri minyak dan gas, wewenang dan tanggung jawab pertambangan menteri, dan dalam pelaksanaan pengawasan disampaikan kepada Direktur Jenderal (Dirjen) dengan

hak substitusi sementara tugas dan pekerjaan pengawasan dilakukan oleh kepala inspeksi. Menurut Bab IV Artikel, 14 dan 15 membahas penggunaan dan program inspeksi yang akan dilakukan untuk mencegah kemungkinan bahaya yang mungkin terjadi selama pemrosesan minyak bumi.

2.6.3 Peraturan Menteri ESDM Republik Indonesia No. 38, 2017

Peraturan ini menetapkan peraturan Menteri Energi dan Sumber Daya Mineral tentang inspeksi instalasi dan peralatan keselamatan dalam bisnis industri minyak dan gas. Beberapa artikel terkait meliputi:

1. **Pasal 5 Ayat 1**

Untuk jaminan desain, konstruksi, operasi dan pemeliharaan, pengujian, inspeksi dan implementasi instalasi dan peralatan, setiap fasilitas dan peralatan yang digunakan dalam kegiatan bisnis minyak dan gas bumi harus memeriksa dan diperiksa dengan baik.

2. **Pasal 11 Ayat 2**

Pemeriksaan dan inspeksi keselamatan pada instalasi dan peralatan yang dioperasikan dapat dilakukan secara berkala berdasarkan periode atau waktu tertentu serta hasil analisis risiko.

3. **Pasal 17 Ayat 1 dan 3**

Persetujuan penggunaan pemeriksaan keamanan berkala berdasarkan periode tertentu berlaku untuk maksimum empat tahun atau kurang dari periode tersebut jika instalasi dan peralatan berubah atau ragu-ragu dengan kemampuannya.

2.6.4 Peraturan Menteri ESDM Republik Indonesia No. 18, 2018

Isi spesifik dari peraturan ini lebih lanjut kemungkinan mengarah pada prosedur tentang bagaimana melakukan inspeksi keselamatan dan pihak-pihak yang bertanggung jawab melaksanakan inspeksi ini, sebagaimana disebutkan di bawah ini:

1. **Bab III Pasal 6 Ayat 1 dan 2**

- (1) Setiap instalasi atau peralatan yang digunakan dalam industri minyak dan gas harus melakukan inspeksi dan pemeriksaan keamanan.

- (2) Jenis peralatan yang bergerak dalam industri minyak dan gas yang harus termasuk dalam inspeksi terdiri dari bejana tekan, peralatan berputar (pompa dan kompresor), pembangkit listrik, transformator daya, panel distribusi, tangki atmosfer, dll.

2. **Bab III Pasal 10 Ayat 1 dan 2**

- (1) Kepala Teknik mengeluarkan informasi tentang hasil inspeksi.

- (2) Perusahaan inspeksi menerbitkan sertifikat inspeksi untuk mengantikan keterangan hasil inspeksi.

- (3) Jika instalasi dan/atau peralatan tidak laya dioperasikan, Kepala Teknik melaporkan kepada Kepala Inspeksi

- (4) Sertifikat inspeksi paling sedikit memuat:
- a. nama pengguna dan pemilik instalasi atau peralatan
 - b. jenis instalasi atau peralatan
 - c. data desain dan operasi
 - d. umur layan desain
 - e. peralatan pengaman
 - f. kesimpulan hasil inspeksi
 - g. masa berlaku
 - h. akurasi sistem alat ukur serah terima (apabila ada)

2.6.5 Pedoman Kerja 041 SKK MIGAS

SKK Migas adalah lembaga yang didirikan oleh pemerintah Republik Indonesia melalui Peraturan Presiden (Perpres) No. 9 tahun 2013 yang membahas implementasi manajemen dalam kegiatan minyak dan gas. SKK Migas adalah tugas dengan menjalankan administrasi bisnis hulu minyak dan gas di bawah kontrak kerja sama dan juga mengeluarkan peraturan dan prosedur sebagai Pedoman Tata Kerja (PTK). Salah satu PTK yang harus diperhatikan oleh perusahaan minyak dan gas di Indonesia adalah tentang "Pemeliharaan Fasilitas Minyak dan Produksi". Menurut PTK-041 / SKKMA000 / 2018 / S0, Bab II "Prinsip Manajemen Pemeliharaan", Setiap data dan dokumen yang terkait dengan program maintenane diperiksa secara berkala oleh KKKS dan disimpan dalam sistem manajemen data yang dapat diperbarui dan diakses kapan saja. Data dan dokumen yang terkait dengan program pemeliharaan termasuk integritas dan keandalan data, termasuk Risk Based Inspection (RBI).

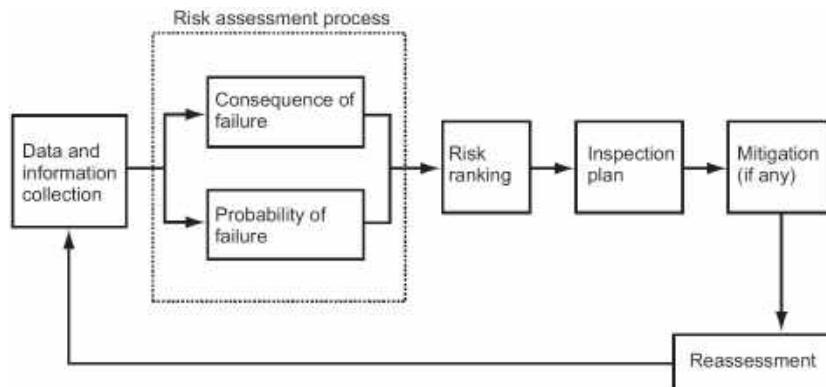
2.7 Risk Based Inspection (RBI)

Risk Based Inspection (RBI) adalah proses pengembangan skema inspeksi berdasarkan pengetahuan tentang risiko kegagalan. Proses penting dari RBI adalah analisis risiko. Analisis risiko dari RBI dilakukan dengan mengalikan antara *probability of failure* (POF) dengan *probability of failure* (COF). Hasil dari analisis *Risk Based Inspection* digunakan untuk membuat rencana dan mengatur usaha untuk menjalankan suatu program inspeksi. Program inspeksi yang memfokuskan sebagian besar program inspeksi pada peralatan yang memiliki risiko kegagalan tertinggi.

Analisis risiko RBI akibat CUI menggunakan data kondisi operasional dan struktural aktual dari sistem yang terisolasi. Sebagai tambahan juga diperlukan data kondisi desain. Untuk mendapatkan informasi yang valid dari analisis RBI perlu dilakukan validasi untuk memastikan bahwa semua data yang diinput benar. Saat melakukan analisis risiko RBI akan mengetahui level risiko dari sistem. Sistem yang terisolasi harus dianalisi untuk menentukan tingkat risiko dan rencana inspeksi yang sesuai dengan level risiko.

Gambar 2.9 menunjukkan proses perencanaan RBI. Mulai dari mengumpulkan data spesifikasi peralatan dan riwayat inspeksi, seperti karakteristik material, riwayat kegagalan, kondisi saat ini, dan data lainnya. [6] Kemudian,

probabilitas kegagalan dan konsekuensi kegagalan dihitung. Keduanya dapat menentukan tingkat risiko masing-masing komponen. Setelah mengetahui risikonya, perencanaan dan mitigasi inspeksi (jika ada) ditetapkan. Mitigasi risiko seperti perubahan konstruksi material dan kondisi operasi, dan penggunaan inhibitor korosi.



Gambar 2.9 Risk based inspection planning method

(sumber: API RP 580 - 3rd Edition)

2.7.1 Kelebihan dari RBI

Hasil utama dari penerapan metode RBI adalah rencana yang membahas pengelolaan risiko pada tingkat equipment. Rencana tersebut memperhatikan risiko dari segi keselamatan/kesehatan/lingkungan dan/atau dari segi ekonomi. [6] Penerapan rencana tersebut dapat menghasilkan:

1. Penurunan risiko dari fasilitas atau equipment yang diteliti.
2. Peningkatan tingkat keselamatan, karena tetap mengikuti pada standar/kode internasional.
3. Dapat menentukan equipment yang tidak memerlukan inspeksi ataupun tindakan mitigasi lainnya.
4. Menghasilkan rencana inspeksi sesuai dengan risiko dari komponen tertentu yang efektif dari segi biaya.

2.7.2 Batasan dari RBI

Meskipun memiliki kelebihan yang menonjol, penerapan metode RBI tidak akan efektif apabila terdapat kekurangan seperti: [6]

1. Data yang tidak akurat atau tidak lengkap
2. Desain yang tidak memadai atau kesalahan pada pemasangan equipment.
3. Pelaksanaan rencana yang tidak efektif.
4. Tim atau personil yang kurang kompeten.

Perlu diperhatikan bahwa RBI tidak dapat menghilangkan risiko. Namun penerapan RBI dapat mengatur risiko pada tingkat yang dapat diterima, tentunya dengan memprioritaskan komponen yang memiliki risiko lebih tinggi.

2.7.3 Hasil dari RBI

Hasil dari penerapan metode RBI adalah rencana inspeksi dari tiap komponen pada sistem/komponen yang dianalisa sesuai dengan level risikonya, dimana menjelaskan:

1. Metode inspeksi yang dapat digunakan
2. Interval waktu hingga inspeksi berikutnya
3. Tindakan mitigasi lainnya seperti penggantian komponen, upgrade komponen, penggantian inhibitor korosi, dan tindakan lainnya sesuai dengan kondisi komponen.
4. Penurunan risiko dari sebelum dan sesudah dilakukannya inspeksi atau mitigasi (jika ada).

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BAB III

METODOLOGI

Bab ini membahas metode yang digunakan oleh penulis dalam menulis dan melakukan penelitian. Metode termasuk studi literatur, pengambilan data, pemodelan analisis risiko menggunakan Microsoft Excel untuk mengetahui posisi level risiko, analisis hasil, kesimpulan dan rekomendasi. **Gambar 3.1** menunjukkan diagram alir dari metodologi penelitian.

3.1 Studi Literatur

Tujuan dilakukan studi literatur adalah untuk mengetahui teori-teori dasar, merangkum informasi pendukung, dan menjadi acuan secara umum dan khusus yang digunakan sebagai acuan penggerjaan penelitian. Studi literatur dilakukan dengan cara mempelajari dan merangkum isi dari buku/*guideline*, skripsi/*thesis*, *standard*, dan jurnal yang berhubungan dengan tugas akhir serta melakukan diskusi dengan dosen pembimbing. Untuk literatur yang digunakan pada penelitian ini adalah:

1. API RP 580 (*Risk Based Inspection*)
2. API RP 581 (*Risk Based Inspection Methodology*)
3. API RP 583 (*Corrosion Under Insulation and Fireproofing*)
4. API 570 (*Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems*)
5. API RP 571 (*Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*)
6. API 579-1/ASME FFS-1 (*Fitness-For-Service*)
7. EFC CUI Guidelines (*European Federation of Corrosion Publications Number 55*) 2016
8. *Database* Perusahaan
9. Jurnal terkait

3.2 Pengumpulan Data dan Informasi

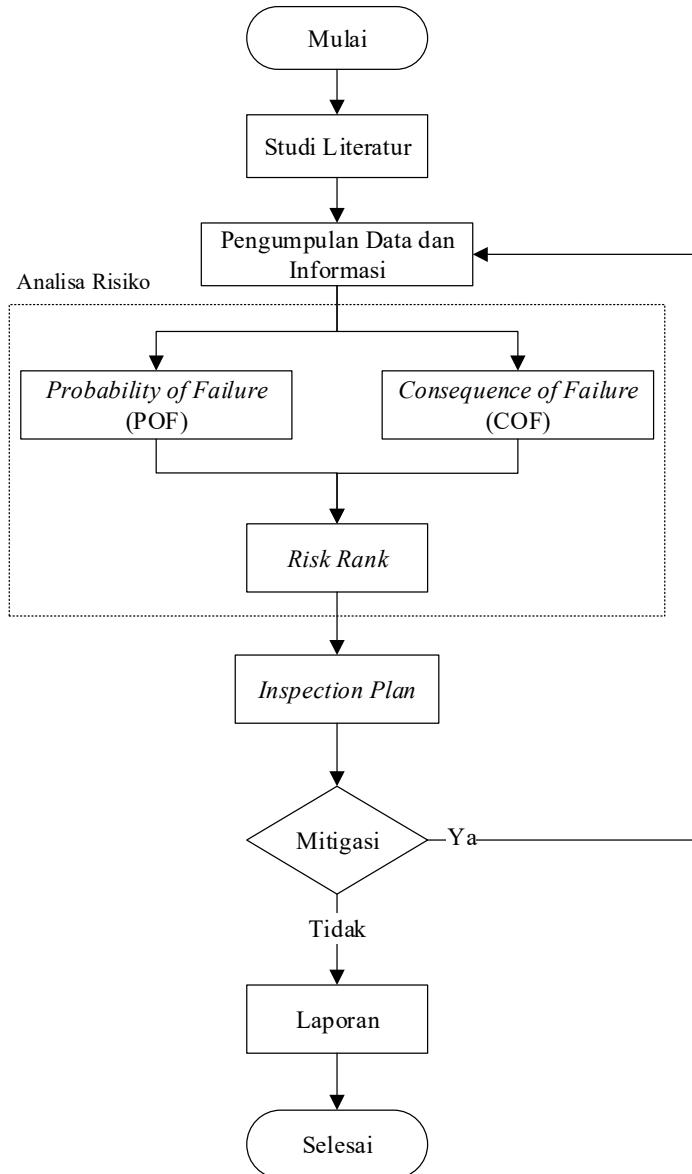
Metode pengumpulan data dilakukan dengan mengumpulkan data konstruksi dan operasional *piping* yang terinsulasi pada *Storage and Loading Area* milik PT X. Data yang dibutuhkan meliputi PFD, P&ID, jenis fluida yang diproses, desain dan operasional dari *piping* yang terinsulasi, laporan interval waktu, dan data-data lain yang mendukung dalam penggerjaan tugas akhir ini.

Salah satu data yang diperlukan adalah laporan inspeksi yang sudah dilakukan. Data tersebut berguna untuk mengetahui apa saja inspeksi yang dilakukan dan bagaimana keefektifitasan dari inspeksi yang telah dilakukan. Data yang diperlukan pada laporan inspeksi meliputi:

- a. Jadwal dan frekuensi inspeksi yang telah dilakukan
- b. Tipe dan metode inspeksi yang dilakukan
- c. Hasil inspeksi

Data-data yang telah didapatkan selanjutnya akan digunakan dalam melakukan *screening damage mechanism*, perhitungan *probability of failure*, perhitungan

consequence of failure, mengetahui level resiko, merencanakan strategi inspeksi, dan penjadwalan program inspeksi.



Gambar 3.1 Metodologi Penelitian

3.3 Analisi Risiko (*Risk Based Inspection*)

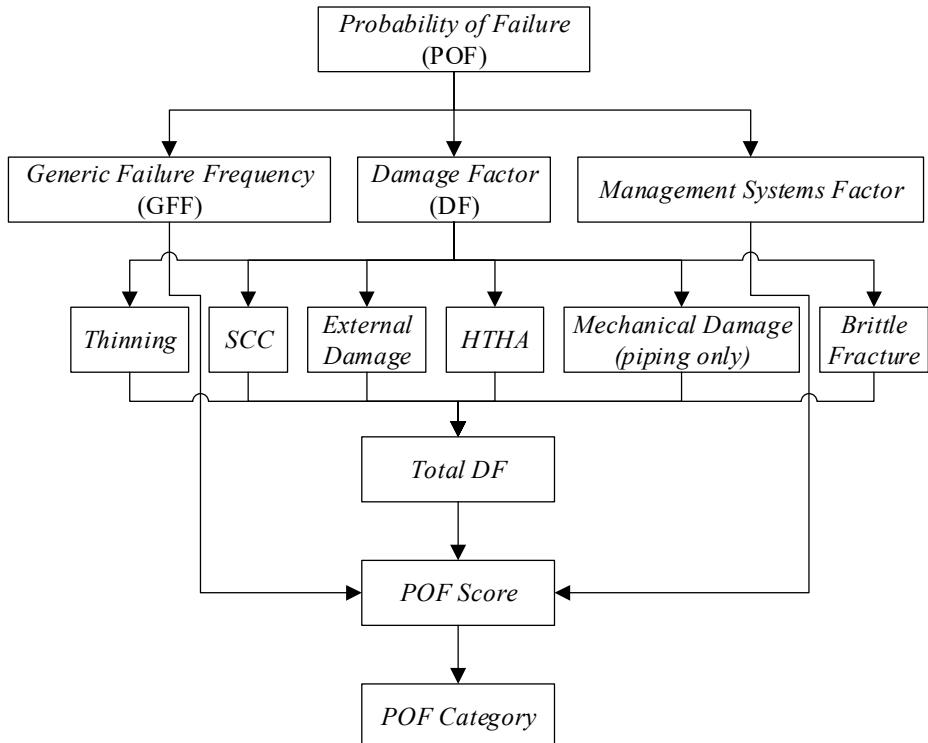
Metodologi RBI menyediakan prosedur kuantitatif untuk menetapkan program inspeksi menggunakan metode berbasis risiko untuk peralatan bertekanan tetap termasuk bajana tekan, perpipaan, tangki, alat pelepas tekanan (PRD), dan bundel heat exchanger. Perhitungan risiko dalam API 581 melibatkan penentuan Probability

of Failure (POF) dan Consequence of Failure (COF). Kegagalan didefinisikan sebagai kehilangan kontainmen dari batas tekanan yang mengakibatkan kebocoran ke lingkungan di atmosfer komponen bertekanan. API 581 ini berisi metodologi untuk menghitung POF dan COF untuk dapat menentukan analisis risiko dan program perencanaan inspeksi untuk peralatan tertentu.

Setelah semua data yang dibutuhkan untuk *assessment* telah dikumpulkan dan divalidasi, maka analisis risiko dapat dilakukan. Dalam penelitian ini, pendekatan semi kuantitatif (*Risk Based Inspection*) diimplementasikan dengan melakukan perhitungan PoF, perhitungan CoF, dan perhitungan *Risk Rank* untuk mengetahui level risiko.

3.3.1 Probability of Failure (POF)

Metode untuk menghitung Probability of Failure (POF) untuk *piping* dicakup dalam API RP 581 Part 2. POF didasarkan pada jenis komponen dan mekanisme kerusakan yang ada seperti karakteristik fluida yang dilayani, kondisi desain, bahan konstruksi, dan kode konstruksi dasarnya.



Gambar 3.2 Perhitungan *Probability of Failure* (POF)

POF adalah sebagai fungsi waktu dan efektivitas inspeksi ditentukan dengan menggunakan frekuensi kegagalan generik, sistem manajemen faktor, dan DF untuk mekanisme kerusakan aktif yang berlaku seperti yang ada pada

Gambar 3.2. Untuk perhitungan POF dapat dirumuskan secara matematis sebagai berikut:

Dimana $P_f(t)$ adalah probabilitas kegagalan yang ditentukan oleh *gff* (*generic failure frequency*), $D_f(t)$ sebagai faktor kerusakan, dan faktor management sistem F_{MS} .

1. Generic Failure Frequency (gff)

Generic failure frequency merupakan sebuah nilai representatif dari data refining dan kegagalan dari tipe tipe komponen yang berbeda seperti pada **Tabel 3.1.** GFF di gunakan sebagai frekuensi kegagalan sebelum terjadinya kerusakan yang di akibatkan oleh lingkungkan terhadap operasi sebuah komponen.

2. Damage Factors

Merupakan faktor yang ditentukan dari detioriasi (*Thinning, SCC, External Damage, HTHA, Mechanical Damage, Brittle Fracture*) yang proposisional terhadap pemeliharaan. Pada API RP 581, terdapat 21 jenis damage factor yaitu: [7]

1. Thinning Damage Factor
 2. Component Lining Damage Factor
 3. SCC Damage Factor – Caustic Cracking
 4. SCC Damage Factor – Amine Cracking
 5. SCC Damage Factor – Sulfide Stress Cracking
 6. SCC Damage Factor – HIC / SOHIC – H2S
 7. SCC Damage Factor – Alkaline Carbonate Cracking
 8. SCC Damage Factor – PTA Cracking
 9. SCC Damage Factor – CLSCC
 10. SCC Damage Factor – HSC-HF
 11. SCC Damage Factor – HIC / SOHIC – HF
 12. External Corrosion Damage Factor – Ferritic Component
 13. External CLSCC Damage Factor Austenitic Component
 14. CUI Damage Factor – Ferritic Component
 15. External CUI CLSCC Damage Factor – Austenitic Component
 16. HTHA Damage Factor
 17. Brittle Damage Factor
 18. Temper Embrittlement Damage Factor
 19. Embrittlement Damage Factor
 20. Sigma Phase Embrittlement Damage Factor
 21. Piping Mechanical Fatigue Damage Factor.

Tabel 3.1 Component Generic Failure Frequencies
 (sumber: API RP 581, 2016)

| Equipment Type | Component Type | GFF As a Function of Hole Size (failures/yr) | | | | <i>gff_{total}</i> (failures/yr) |
|-----------------------|-----------------------|---|---------------|--------------|----------------|---|
| | | Small | Medium | Large | Rupture | |
| Compressor | COMPC | 8.00E-06 | 2.00E-05 | 2.00E-06 | 0 | 3.00E-05 |
| Compressor | COMPR | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Heat Exchanger | HEXSS | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Heat Exchanger | HEXTS | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pipe | PIPE-1 | 2.80E-05 | 0 | 0 | 2.60E-06 | 3.06E-05 |
| Pipe | PIPE-2 | 2.80E-05 | 0 | 0 | 2.60E-06 | 3.06E-05 |
| Pipe | PIPE-4 | 8.00E-06 | 2.00E-05 | 0 | 2.60E-06 | 3.06E-05 |
| Pipe | PIPE-6 | 8.00E-06 | 2.00E-05 | 0 | 2.60E-06 | 3.06E-05 |
| Pipe | PIPE-8 | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pipe | PIPE-10 | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pipe | PIPE-12 | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pipe | PIPE-16 | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pipe | PIPEGT16 | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pump | PUMP2S | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pump | PUMPR | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Pump | PUMP1S | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Tank650 | TANKBOTTOM | 7.20E-04 | 0 | 0 | 2.00E-06 | 7.22E-04 |
| Tank650 | COURSE-1-10 | 7.00E-05 | 2.50E-05 | 5.00E-06 | 1.00E-07 | 1.00E-04 |
| Vessel/FinFan | KODRUM | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | COLBTM | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | FINFAN | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | FILTER | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | DRUM | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | REACTOR | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | COLTOP | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |
| Vessel/FinFan | COLMID | 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

Semua damage factor tersebut memiliki kriterianya masing-masing. Untuk mengawali perhitungan *probability of failure* pada komponen tertentu, dilakukan *screening damage factor* agar dapat mengetahui kerusakan jenis apa saja yang terjadi di komponen tersebut. *Screening* tersebut dapat dilakukan melalui data komponen serta pengamatan di lokasi.

Damage factor ditentukan dengan melakukan tabel screening dari API RP 581, sesuai dengan kondisi equipment terkait. **Tabel 3.2** berikut adalah *Screening criteria* dari beberapa *damage factor*. Selanjutnya akan membahas mekanisme dan langkah perhitungannya.

Tabel 3.2 Damage Factors Selection
(sumber: API RP 581, 2016)

| Damage Factors | Variable | Description | Applies? |
|--|-----------------------|--|-----------------|
| Thinning | D_f^{thin} | <i>This is a required factor that applies to all components.</i> | Yes / No |
| Component Lining | D_f^{elin} | <i>The component includes a lining (either inorganic or organic).</i> | Yes / No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | <i>The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment.</i> | Yes / No |
| SCC - Amine Cracking | D_f^{amine} | <i>The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.).</i> | Yes / No |
| SCC - Sulfide Stress Cracking | D_f^{SSC} | <i>The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H₂S and water.</i> | Yes / No |
| SCC - HIC/SOHC-H ₂ S | $D_f^{HIC/SOHC-H_2S}$ | <i>The component is composed of a carbon or low alloy steel and there is H₂S and water in any concentration in the process environment.</i> | Yes / No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | <i>The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration.</i> | Yes / No |

| Damage Factors | Variable | Description | Applies? |
|--|---------------------|---|-----------------|
| <i>SCC - Polythionic Acid Stress Corrosion Cracking</i> | D_f^{PTA} | <i>The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds.</i> | Yes / No |
| <i>SCC - Chloride Stress Corrosion Cracking</i> | D_f^{CISCC} | <i>The component is composed of an austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C</i> | Yes / No |
| <i>SCC - Hydrogen Stress Cracking in Hydrofluoric Acid</i> | D_f^{HSC-HF} | <i>The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid.</i> | Yes / No |
| <i>SCC - HIC/SOHC-HF</i> | $D_f^{HIC/SOHC-HF}$ | <i>The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid.</i> | Yes / No |
| <i>External Corrosion - Ferritic Component</i> | D_f^{extcor} | <p>Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions:</p> <ul style="list-style-type: none"> • Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays. • Some areas are subject to acid vapors, process spills or the ingress of moisture. • The component is composed of carbon steel and the operating temperature is 23°C - 121°C. • The component has deteriorated wrapping or coatings. • The component is subject to frequent outages. • The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range. • The component consistently operates below the atmospheric dew point. • The component has un-insulated protrusions or nozzles in cold conditions. | Yes / No |

| Damage Factors | Variable | Description | Applies? |
|--|-------------------|--|-----------------|
| <i>Corrosion Under Insulation (CUI) - Ferritic Component</i> | D_f^{CUIF} | <i>Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations.</i> | Yes / No |
| <i>ExtClSCC - Austenitic Component</i> | $D_f^{ext-ClSCC}$ | <i>The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling.</i> | Yes / No |
| <i>External CUI ClSCC-Austenitic Component</i> | $D_f^{CUI-ClSCC}$ | <i>The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling.</i> | Yes / No |
| <i>Brittle Fracture</i> | D_f^{brit} | <i>The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions.</i> | Yes / No |
| <i>Low Alloy Steel Embrittlement</i> | D_f^{tempe} | <i>The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F).</i> | Yes / No |
| <i>High Temperature Hydrogen Attack (HTHA)</i> | D_f^{htha} | <i>The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1¼ Cr-½ Mo, 2¼ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial</i> | Yes / No |

| Damage Factors | Variable | Description | Applies? |
|----------------------------------|-----------------|--|-----------------|
| | | <i>pressure is greater than 0.345 MPa (50 psia).</i> | |
| <i>885 °F Embrittlement</i> | D_f^{885F} | <i>The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F).</i> | Yes / No |
| <i>Sigma Phase Embrittlement</i> | D_f^{σ} | <i>The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F)</i> | Yes / No |
| <i>Piping Mechanical Fatigue</i> | D_f^{mfat} | <p>Select this factor if the component is a pipe and any of the following conditions are true:</p> <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | Yes / No |

A. Thinning Damage Factor

Thinning – merupakan degradasi logam karena lingkungannya yang mengakibatkan penipisan ketebalan logam tersebut, dengan kata lain korosi. Ada beberapa mekanisme thinning yang dapat terjadi, dan masing-masing terjadi pada kondisi yang berbeda. Memahami mekanisme thinning yang terjadi sangatlah penting untuk mengetahui apakah thinning terjadi secara local atau general, dan penentuan tindakan mitigasi kedepannya. Berikut adalah mekanisme thinning yang dapat terjadi sesuai dengan API RP 581 3rd Edition Part 2 – Annex 2.B:

- Korosi asam klorida (HCl)
Mekanisme korosi thinning ini terjadi apabila pada proses terdapat HCl, air dan tingkat keasaman (pH) di bawah 7.0.
- Korosi asam sulfida/naftenat temperatur tinggi
Mekanisme korosi thinning ini terjadi apabila pada prosesnya terdapat minyak dengan senyawa sulphur, dan beroperasi di atas 204°C (400°F).
- Korosi H₂S/H₂ temperatur tinggi
Dapat terjadi apabila pada prosesnya terdapat H₂S dan hydrogen, serta beroperasi di atas 204°C (400°F).

- Korosi asam sulphur (H_2SO_4)
Dapat terjadi apabila pada prosesnya terdapat H_2SO_4 .
- Korosi asam hidroflourik (HF)
Dapat terjadi apabila pada prosesnya terdapat HF.
- Korosi sour water
Korosi sour water harus diperhitungkan apabila terdapat H_2S .
- Korosi amina
Mekanisme thinning ini dapat terjadi apabila equipment terpapar gas amina untuk pengolah gas.
- Oksidasi temperatur tinggi
Mekanisme ini dapat terjadi apabila terdapat oksigen dan beroperasi setidaknya $482^\circ C$ ($900^\circ F$).
- Korosi acid sour water
Dapat terjadi apabila pada prosesnya mengandung klorida di bawah 50 ppm, H_2S , dan pH di bawah 7.0
- Cairan pendingin
Jika equipment terintegrasi dengan cairan pendingin maka, korosi tipe ini harus diperhitungkan.
- Korosi tanah
Mekanisme thinning ini dapat terjadi apabila equipment kontak dengan tanah (terkubur atau terkubur sebagian) dan materi equipment adalah carbon steel.
- Korosi karbon dioksida (CO_2)
Korosi karena karbon dioksida dapat terjadi apabila materi equipment adalah carbon steel dengan kadar Cr < 13%, dan terdapat air dengan H_2S .
- AST Bottom
Mekanisme ini perlu diperhitungkan apabila bottom equipment berbentuk AST tank.

Masing-masing dari mekanisme thinning tersebut haruslah dicocokkan dengan kondisi equipment, agar mengetahui mekanisme thinning apa saja yang terjadi. Sedangkan perhitungan thinning, dijelaskan pada langkah-langkah berikut:

Langkah 1. Tentukan furnished thickness, t , dan usia komponen dari waktu instalasi.

Langkah 2. Tentukan corrosion rate untuk base material, Cr_{bm} , berdasarkan material konstruksi dan lingkungannya, serta cladding/overlay corrosion rate, Cr_{cm} .

Untuk menentukan corrosion rate di thinning damage factor, kita harus mempertimbangkan beberapa skenario berdasarkan data yang tersedia dan kondisi dari equipment itu sendiri, seperti:

- Perhitungan corrosion rate berdasarkan RLA dari perusahaan
- Perhitungan corrosion rate berdasarkan API RP 581 Annex 2B. Corrosion rate ini merupakan gabungan corrosion rate dari mekanisme-mekanisme thinning yang terjadi pada komponen.

- Langkah 3. Menentukan waktu operasi, age_{tk} , sejak inspeksi terakhir, t_{rdi} .
- Langkah 4. Untuk cladding/weld overlay pressure vessel components, hitung usia untuk habisnya ketebalan di inspeksi terakhir (langkah 3) karena korosi, age_{rc} :

$$age_{rc} = \max \left[\left(\frac{t_{rdi} - tbm}{c_{rcm}} \right), 0.0 \right] \quad \dots \dots \dots \quad (3.2)$$

- Langkah 5. Determine the minimum thickness of the component's wall, t_{min} . Minimum thickness didapatkan dari designed pressure equipment, allowable stress, diameter dalam, corrosion allowance dan joint efficiency.

- Langkah 6. Tentukan parameter A_{rt} (*age relating thickness*). Untuk komponen tanpa cladding/weld overlay menggunakan persamaan:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}} \quad \dots \dots \dots \quad (3.3)$$

- Langkah 7. Hitung nilai flowstress, FS^{thin} .

$$FS^{Thin} = \frac{(YS+TS)}{2} \cdot E.1,1 \quad \dots \dots \dots \quad (3.4)$$

- Langkah 8. Hitung parameter strength ratio, SR_P^{thin} .

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{\text{Max}(t_{min}, t_c)}{FS^{Thin}} \quad \dots \dots \dots \quad (3.5)$$

- Langkah 9. Tentukan jumlah dari inspeksi serta efektifitas dari inspeksi tersebut. N_A^{Thin} N_A^{Thin} N_B^{Thin} N_C^{Thin} N_D^{Thin}
didapat dari perusahaan dapat didefinisikan dari tabel berikut.

Tabel 3.3 Inspection Effectiveness
(sumber: API RP 581, 2016)

| <i>Inspection effectiveness category</i> | <i>Inspection effectiveness description</i> | <i>Description</i> |
|--|---|---|
| A | <i>Highly effective</i> | The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence) |

| <i>Inspection effectiveness category</i> | <i>Inspection effectiveness description</i> | <i>Description</i> |
|--|---|---|
| B | <i>Usually effective</i> | The inspection methods will correctly identify the true damage state most of the time case (or 60-80% confidence) |
| C | <i>Fairly effective</i> | The inspection methods will correctly identify the true damage state about half of the time (or 40-60% confidence) |
| D | <i>Poorly effective</i> | The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence) |
| E | <i>Ineffective</i> | The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence) |

Langkah 10. Hitung faktor *inspection effectiveness*, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$, menggunakan persamaan berikut, dan *prior probabilities*, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}, Pr_{p3}^{Thin}$, dari Tabel 4.5 and 4.6 dari API RP 581 Part 2 of POF jumlah inspeksi, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, dari Langkah 9

$$I_1^{Thin} = Pr_{p1}^{Thin} (Co_{p1}^{ThinA})^{N_A^{Thin}} (Co_{p1}^{ThinB})^{N_B^{Thin}} \\ (Co_{p1}^{ThinC})^{N_C^{Thin}} (Co_{p1}^{ThinD})^{N_D^{Thin}} \quad(3.6)$$

$$I_2^{Thin} = Pr_{p2}^{Thin} (Co_{p2}^{ThinA})^{N_A^{Thin}} (Co_{p2}^{ThinB})^{N_B^{Thin}} \\ (Co_{p2}^{ThinC})^{N_C^{Thin}} (Co_{p2}^{ThinD})^{N_A^{Thin}} \quad(3.7)$$

$$I_3^{Thin} = Pr_{p3}^{Thin} (Co_{p3}^{ThinA})^{N_A^{Thin}} (Co_{p3}^{ThinB})^{N_B^{Thin}} \\ (Co_{p3}^{ThinC})^{N_C^{Thin}} (Co_{p3}^{ThinD})^{N_A^{Thin}} \quad(3.8)$$

Untuk nilai *Conditional probability* didapatkan dari tabel berikut.

Tabel 3.4 Nilai *conditional probability*
 (sumber: API RP 581, 2016)

| <i>Conditional probability of inspection</i> | E | D | C | B | A |
|--|------|------|-----|-----|------|
| Co_{P1}^{Thin} | 0.33 | 0.4 | 0.5 | 0.7 | 0.9 |
| Co_{P2}^{Thin} | 0.33 | 0.33 | 0.3 | 0.2 | 0.09 |
| Co_{P3}^{Thin} | 0.33 | 0.27 | 0.2 | 0.1 | 0.01 |

Langkah 11. Hitung Posterior Probability, Po_{p1}^{Thin} , Po_{p2}^{Thin} , Po_{p3}^{Thin}

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \dots \dots \dots (3.9)$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \dots \dots \dots (3.10)$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \dots \dots \dots (3.11)$$

Langkah 12. Hitung parameter, β_1^{Thin} , β_2^{Thin} , β_3^{Thin} , dengan persamaan (3.12), (3.13), dan (3.14) dengan nilai $COV_{\Delta t} = 0.2$, $COV_{sf} = 0.2$, dan $COV_p = 0.05$.

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot Art - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot Art^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot Art)^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}} \dots \dots \dots (3.12)$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot Art - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot Art^2 \cdot COV_{\Delta^2}^2 + (1 - D_{S2} \cdot Art)^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}} \quad \dots \dots \dots (3.13)$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot Art - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot Art^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot Art)^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}} \dots \dots \dots (3.14)$$

Langkah 13. Untuk komponen tank bottom, tentukan base damage factor untuk thinning menggunakan Tabel 4.8 dari API RP 581 Part 2 dan perhitungan A_{rt} parameter dari langkah 6.

Langkah 14. Hitung base damage factor, D_{fB}^{Thin} ,

$$D_{fb}^{Thin} = \left[\frac{\left(Po_{P1}^{Thin} \Phi(-\beta_1^{Thin}) \right) + \left(Po_{P2}^{Thin} \Phi(-\beta_2^{Thin}) \right) + \left(Po_{P3}^{Thin} \Phi(-\beta_3^{Thin}) \right)}{1.56E - 0.4} \right] (3.15)$$

Langkah 15. Tentukan DF untuk thinning, D_f^{Thin} .

$$D_f^{Thin} = \text{Max}\left[\left(\frac{(D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM})}{F_{OM}}\right), 0.1\right] \quad \dots \dots \dots \quad (3.16)$$

B. Corrosion Under Insulation Damage Factor

CUI disebabkan oleh pengumpulan air di ruang uap (atau ruang annulus) antara insulasi dan permukaan logam. Sumber air dapat mencakup hujan, kebocoran air, kondensasi, *drift* menara air pendingin, sistem banjir, dan *steam tracing leaks*. [8] CUI menyebabkan menipisnya dinding dalam bentuk korosi lokal. CUI umumnya terjadi pada kisaran suhu antara -12 °C dan 175 °C (10 °F dan 350 °F), dengan kisaran suhu 77 °C hingga 110 °C (170 °F hingga 230 °F) adalah rentang yang paling parah.

Sebagai aturan umum, kilang yang berlokasi di daerah dengan curah hujan tahunan tinggi, di iklim lembab yang hangat, atau di lokasi laut lebih rentan terhadap CUI daripada kilang yang berlokasi di lokasi yang lebih dingin, lebih kering, dan di *mid-continent*. Variabel yang dapat mempengaruhi laju korosi CUI termasuk curah hujan tahunan, kelembaban, kadar klorida dalam curah hujan, kedekatan dengan *ocean spray*, dan kadar berbagai polutan industri. Laju korosi juga dapat bervariasi menurut lokasi di dalam fasilitas. Misalnya, unit yang terletak di dekat menara pendingin dan lubang uap sangat rentan terhadap CUI, seperti juga unit yang suhu operasinya *cyclic* melalui titik embun secara teratur. Inspeksi eksternal sistem terisolasi harus mencakup peninjauan integritas sistem isolasi untuk kondisi yang dapat menyebabkan CUI dan tanda-tanda CUI yang sedang berlangsung seperti *rust stains or bulging*. Namun, indikator eksternal CUI tidak selalu ada.

Mitigasi CUI dilakukan melalui praktik insulasi yang baik dan pelapisan yang tepat. Pemasangan dan pemeliharaan isolasi yang tepat hanya mencegah masuknya air dalam jumlah besar. Dalam beberapa tahun terakhir, sistem pelapisan sering ditentukan untuk operasi komponen dalam kisaran suhu CUI dan di mana CUI telah menjadi masalah. Direkomendasikan untuk menggunakan pelapis dengan tingkat perendaman berkualitas tinggi, seperti yang digunakan dalam tangki air panas. Untuk panduan, lihat NACE 6H189. Sistem pelapisan yang baik harus berlangsung minimal 15 tahun.

Inspeksi diperlukan berdasarkan efektifitas yang diharapkan dalam mendeteksi mekanisme kerusakan yang spesifik. Contoh-contoh kegiatan inspeksi yang mengganggu (memerlukan masuk ke dalam peralatan) dan nonintrusif (dapat dilakukan secara eksternal) disediakan dalam Lampiran 2.C, Tabel 2.C.10.3. Prosedur berikut dapat digunakan untuk menentukan DF untuk CUI:

Langkah 1. Tentukan ketebalan, t , dan usia komponen dari tanggal pemasangan.

Langkah 2. Tentukan laju korosi dasar, C_{rB} , berdasarkan driver dan suhu pengoperasian menggunakan **Tabel 3.5**.

Tabel 3.5 Laju Korosi untuk Perhitungan CUI DF
(sumber: API RP 581, 2016)

| <i>Operating Temperature (°C)</i> | <i>Corrosion Rate as a Function of Driver¹ (mm/y)</i> | | | |
|-----------------------------------|--|-----------------|-------------|------------|
| | <i>Severe</i> | <i>Moderate</i> | <i>Mild</i> | <i>Dry</i> |
| -12 | 0 | 0 | 0 | 0 |
| -8 | 0.076 | 0.025 | 0 | 0 |
| 6 | 0.254 | 0.127 | 0.076 | 0.025 |
| 32 | 0.254 | 0.127 | 0.076 | 0.025 |
| 71 | 0.508 | 0.254 | 0.127 | 0.051 |
| 107 | 0.254 | 0.127 | 0.025 | 0.025 |
| 135 | 0.254 | 0.051 | 0.025 | 0 |
| 162 | 0.127 | 0.025 | 0 | 0 |
| 176 | 0 | 0 | 0 | 0 |

Note 1:
Driver is defined as the CUI condition causing the corrosion rate.
See Part 2, Section 15.6.2 for explanation of drivers.

Note 2:
Interpolation may be used for intermediate values of temperature.

Note 3:
A time-weighted average corrosion rate may be used for systems that are in intermittent service or that operate at 2 or more temperatures

Langkah 3. Hitung laju korosi akhir menggunakan rumus (3.17)

$$C_r = C_{rB} \cdot F_{IN} \cdot F_{CM} \cdot F_{IC} \cdot \max [F_{EQ} \cdot F_{IF}] \dots \dots \dots \quad (3.17)$$

Dimana,

- Untuk jenis isolasi; F_{IN} , berdasarkan **Tabel 3.6**

Tabel 3.6 Faktor Laju Korosi karena Jenis Isolasi
(sumber: API RP 581, 2016)

| <i>Insulation Type</i> | <i>F_{IN}</i> |
|------------------------|----------------------------|
| Unknown/unspecified | 1.25 |
| Foamglass | 0.75 |
| Pearlite | 1.0 |
| Fiberglass | 1.25 |
| Mineral wool | 1.25 |
| Calcium silicate | 1.25 |
| Asbestos | 1.25 |

- Untuk Kompleksitas, F_{CM} - Ditentukan berdasarkan kriteria berikut.
 - Jika *Below Average*, maka $F_{CM}=0,75$.
 - Jika *Average*, maka $F_{CM}=1.0$.

- Jika *Above Average*, maka $F_{CM} = 1,25$.

3. Untuk *Insulation Condition*, F_{IC} - Ditentukan berdasarkan kriteria berikut.

 - Jika *Below Average*, maka $F_{IC} = 1,25$.
 - Jika *Average*, maka $F_{IC} = 1,0$.
 - Jika *Above Average*, maka $F_{IC} = 0,75$.

4. Untuk Desain atau Pabrikasi Peralatan, F_{EQ}

Jika peralatan memiliki desain yang memungkinkan air menggenang dan meningkatkan tingkat korosi logam, seperti perpipaan yang *di-support* langsung pada *beams*, *vessel external stiffening rings* atau penyangga insulasi, atau konfigurasi lain yang tidak memungkinkan jalan keluar air dan / atau tidak memungkinkan untuk tepat perawatan pelapisan, maka $F_{EQ} = 2$; jika tidak, $F_{EQ} = 1$.

5. Untuk *Interface*, F_{IF}

Jika piping memiliki *interface* tempat menempel pada tanah atau masuknya air, maka $F_{IF} = 2$; jika tidak, $F_{IF} = 1$.

Langkah 4. Menentukan lama waktu dalam pelayanan age_{tk}, sejak inspeksi terakhir, t_{rde}

Langkah 5. Menentukan waktu in-service, age_{coat} , sejak *coating* telah diaplikasikan

$$age_{coat} = \text{Calc. Date} - \text{Coating Installation Date} \dots\dots(3.19)$$

Langkah 6. Menentukan penyesuaian pelapisan, Coat_{adj}

Jika $age_{tke} \geq age_{coat}$

- No Coating or Poor Coating Quality

- Medium Coating Quality

- High Coating Quality

Jika $age_{tke} < age_{coat}$

- No Coating or Poor Coating Quality

$$\text{Coat}_{\text{adj}}=0 \dots \quad (3.23)$$

- Medium Coating Quality

$$\text{Coat}_{\text{adj}} = \min [5, \text{age}_{\text{coat}}] - \min [5, \text{age}_{\text{coat}} - \text{age}_{\text{ik}}] \dots\dots\dots (3.24)$$

- High Coating Quality

$$\text{Coat}_{\text{adj}} = \min [15, \text{age}_{\text{coat}}] - \min [15, \text{age}_{\text{coat}} - \text{age}_{\text{ik}}] \dots\dots\dots (3.25)$$

Langkah 7. Menentukan waktu dalam layanan, age

$$\text{age} = \text{age}_{\text{ike}} - \text{Coat}_{\text{adj}} \dots\dots\dots (3.26)$$

Langkah 8. Determine the allowable stress per the original construction code or API 579-1/ASME FFS-1

Langkah 9. Tentukan parameter A_{rt} (age relating thickness). Menggunakan persamaan:

$$A_{rt} = \frac{C_r \cdot \text{age}}{t_{rde}} \dots\dots\dots (3.27)$$

Langkah 10. Hitung nilai flowstress, FS^{CUIF} .

$$FS^{\text{CUIF}} = \frac{(YS+TS)}{2} \cdot E.1,1 \dots\dots\dots (3.28)$$

Langkah 11. Hitung parameter strength ratio, SR_P^{CUIF} .

$$SR_P^{\text{CUIF}} = \frac{S.E}{FS^{\text{CUIF}}} \cdot \frac{\min(t_{\text{min}}, t_c)}{t_{rde}} \dots\dots\dots (3.29)$$

Langkah 12. Tentukan jumlah dari inspeksi serta efektifitas dari inspeksi tersebut. N_A^{CUIF} N_B^{CUIF} N_C^{CUIF} N_D^{CUIF} didapat dari perusahaan dapat didefinisikan dari tabel berikut.

Tabel 3.7 Inspection Effectiveness
(sumber: API RP 581, 2016)

| <i>Inspection effectiveness category</i> | <i>Inspection effectiveness description</i> | <i>Description</i> |
|--|---|---|
| A | <i>Highly effective</i> | The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence) |
| B | <i>Usually effective</i> | The inspection methods will correctly identify the true damage state most of the time case (or 60-80% confidence) |
| C | <i>Fairly effective</i> | The inspection methods will correctly identify the true damage |

| <i>Inspection effectiveness category</i> | <i>Inspection effectiveness description</i> | <i>Description</i> |
|--|---|---|
| | | state about half of the time (or 40-60% confidence) |
| D | <i>Poorly effective</i> | The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence) |
| E | <i>Ineffective</i> | The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence) |

Langkah 13. Hitung faktor *inspection effectiveness*, $I_1^{CUIF}, I_2^{CUIF}, I_3^{CUIF}$, menggunakan persamaan berikut, dan *prior probabilities*, $Pr_{p1}^{CUIF}, Pr_{p2}^{CUIF}, Pr_{p3}^{CUIF}$, dari Tabel 5.6 dari API RP 581 Part 2 of POF jumlah inspeksi, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, dari Langkah 12.

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \left(Co_{P1}^{CUIFA} \right)^{N_A^{CUIF}} \left(Co_{P1}^{CUIFB} \right)^{N_B^{CUIF}} \\ \left(Co_{P1}^{CUIFC} \right)^{N_C^{CUIF}} \left(Co_{P1}^{CUIFD} \right)^{N_D^{CUIF}} \quad \dots\dots\dots (3.30)$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \left(Co_{P2}^{CUIFA} \right)^{N_A^{CUIF}} \left(Co_{P2}^{CUIFB} \right)^{N_B^{CUIF}} \\ \left(Co_{P2}^{CUIFC} \right)^{N_C^{CUIF}} \left(Co_{P2}^{CUIFD} \right)^{N_A^{CUIF}} \quad \dots\dots\dots (3.31)$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \left(Co_{P3}^{CUIFA} \right)^{N_A^{CUIF}} \left(Co_{P3}^{CUIFB} \right)^{N_B^{CUIF}} \\ \left(Co_{P3}^{CUIFC} \right)^{N_C^{CUIF}} \left(Co_{P3}^{CUIFD} \right)^{N_A^{CUIF}} \quad \dots\dots\dots (3.32)$$

Untuk nilai *Conditional probability* didapatkan dari tabel Tabel 5.7 dari API RP 581 Part 2

Langkah 14. Hitung *Posterior Probability*, $Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}$

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} \quad \dots\dots\dots (3.33)$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} \quad \dots\dots\dots (3.34)$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} \quad \dots\dots\dots (3.35)$$

Langkah 15. Hitung parameter, β_1^{CUIF} , β_2^{CUIF} , β_3^{CUIF} , dengan persamaan (3.35), (3.36), dan (3.37) dengan nilai $COV_{\Delta t} = 0.2$, $COV_{sf} = 0.2$, dan $COV_P = 0.05$.

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}} \quad \dots \dots \dots \quad (3.35)$$

$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}} \quad \dots \dots \dots \quad (3.36)$$

$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{thin})^2 \cdot (COV_P)^2}} \quad \dots \dots \dots \quad (3.37)$$

Langkah 16. Hitung damage factor, D_f^{CUIF} ,

$$D_f^{CUIF} = \left[\frac{\left(Po_{P1}^{CUIF} \phi(-\beta_1^{CUIF}) \right) + \left(Po_{P2}^{CUIF} \phi(-\beta_2^{CUIF}) \right) + \left(Po_{P3}^{CUIF} \phi(-\beta_3^{CUIF}) \right)}{1.56E-0.4} \right] \quad \dots \dots \quad (3.38)$$

C. Damage Factors Total

Pada kasus damage mechanisms jamak, kombinasinya terdiri di section 3.4.2 API RP 581 Part 2 3rd Edition. Jika ada lebih dari satu damage mechanisms, aturan berikut digunakan untuk menggabungkan DF. Total DF diberikan oleh persamaan (3.39) ketika damage eksternal dan / atau thinning diklasifikasikan sebagai lokal dan karenanya, tidak mungkin terjadi di lokasi yang sama. Jika damage eksternal dan thinning terjadi secara general, maka damage kemungkinan terjadi di lokasi yang sama dan total DF diberikan oleh Persamaan (3.40).

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad \dots \dots \quad (3.39)$$

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad \dots \dots \quad (3.40)$$

Dimana,

$$D_{f-gov}^{thin} = \min | D_f^{thin}, D_f^{elin} | \text{ (lining present)} \quad \dots \dots \quad (3.41)$$

$$D_{f-gov}^{thin} = D_f^{thin} \text{ (lining not present)} \quad \dots \dots \quad (3.42)$$

$$D_{f-gov}^{SCC} = \max | D_f^{PTA}, D_f^{CLSSC}, D_f^{HSC-HF}, D_f^{HIC/SOHCIC-HF} | \quad \dots \dots \quad (3.43)$$

$$D_{f-gov}^{extd} = \max | D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSSC}, D_f^{CUI-CLSSC} | \quad \dots \dots \quad (3.44)$$

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| (3.45)$$

$$D_f^{htha} = D_f^{htha} (3.46)$$

$$D_f^{mfat} = D_f^{mfat} (3.47)$$

3. Management System Factor

Management system factor merupakan faktor dari pengaruh manajemen sistem terhadap integritas mekanik dari komponen. Faktor ini dipengaruhi probabilitas kerusakan yang terakumulasi pada waktu lama dan proporsional terhadap kualitas dari integritas program mekanik sebuah fasilitas. Dimana *pscore* adalah skor dari manajemen perusahaan.

$$FMS = 10^{(-0.02.pscore+1)} (3.48)$$

3.3.2 Consequence of Failure (COF)

Metodologi untuk menghitung *Consequence of Failure* (COF) piping dicakup dalam API RP 581 Bagian 3. Metodologi COF dilakukan untuk membantu dalam menetapkan level risiko item peralatan berdasarkan risiko dan juga dimaksudkan untuk digunakan untuk menetapkan prioritas untuk program inspeksi. Metodologi COF akan dilakukan untuk membantu dalam menetapkan peringkat equipment berdasarkan risiko dan juga dimaksudkan untuk digunakan untuk menetapkan prioritas untuk program inspeksi. Sesuai dengan API 581 RP, ada dua jenis level COF yaitu Level 1 dan Level 2 yang memiliki aplikasi karakteristik fluida yang berbeda satu sama lain. Metodologi COF Level 1 digunakan untuk daftar cairan berbahaya yang ditentukan. Metodologi COF Tingkat 2 dimaksudkan untuk lebih ketat dan dapat diterapkan pada kisaran yang lebih luas.

1. Kategori dari consequences

Terdapat beberapa kategori consequences yang dianalisa, sebagaimana dijelaskan sebagai berikut.

- Flammable and explosive consequences

Flammable and explosive consequence dihitung dengan menggunakan event tree untuk menentukan probabilitas dari berbagai hasil (cth. Kebakaran kolam, kebakaran kilat, ledakan awan uap), dikombinasikan dengan pemodelan komputer untuk menentukan besarnya konsekuensi. Area konsekuensi dapat ditentukan berdasarkan cedera personil yang serius dan kerusakan komponen akibat radiasi dan ledakan termal. Kerugian finansial ditentukan berdasarkan area yang terkena dampak rilis.

- Toxic consequences

Toxic consequence dihitung dengan menggunakan pemodelan komputer untuk menentukan besarnya area konsekuensi sebagai akibat dari paparan berlebih kepada personel terhadap konsentrasi racun dalam uap. Jika cairan mudah terbakar dan beracun, probabilitas kejadian toksik mengasumsikan bahwa pelepasannya dinyalakan, konsekuensi toksik dapat diabaikan (mis. Racun terbakar oleh api). Kerugian finansial ditentukan

berdasarkan area yang terkena dampak.

- Non-flammable, non-toxic consequences

Non-flammable, non-toxic consequences dipertimbangkan karena masih dapat menimbulkan dampak serius. Konsekuensi dari percikan kimiawi dan luka bakar uap suhu tinggi ditentukan berdasarkan cedera serius pada personel. Ledakan fisik dan Ledakan Mendidih Cairan Uap (BLEVE) juga dapat menyebabkan cedera serius pada personil dan kerusakan komponen.

- Financial consequences

Financial consequences termasuk kerugian diakibatkan gangguan bisnis dan biaya yang terkait dengan pelepasan ke lingkungan. Konsekuensi gangguan bisnis diperkirakan sebagai fungsi dari hasil area konsekuensi yang mudah terbakar dan tidak mudah terbakar. Konsekuensi lingkungan ditentukan secara langsung dari massa yang tersedia untuk rilis atau dari laju rilis.

2. Perhitungan consequence of failures

API RP 581 mencantumkan langkah-langkah perhitungan dari consequence of failures yang mana dikutip pada **Table 3.8** berikut:

Tabel 3.8 Consequence of failures analysis steps
(sumber: API RP 581, 2016)

| Step | Description |
|------|---|
| 1 | Determine the released fluid and its properties, including the release phase. |
| 2 | Select a set of release hole sizes to determine the possible range of consequence in the risk calculation |
| 3 | Calculate the theoretical release rate |
| 4 | Estimate the total amount of fluid available for release |
| 5 | Determine the type of release, continuous or instantaneous, to determine the method used for modelling the dispersion and consequence |
| 6 | Estimate the impact of detection and isolation systems on release magnitude. |
| 7 | Determine the release rate and mass for the consequence analysis |
| 8 | Calculate flammable/explosive consequence |
| 9 | Calculate toxic consequence |
| 10 | Calculate non-flammable, non-toxic consequence |
| 11 | Determine the final probability weighted component damage and personnel injury consequence areas |
| 12 | Calculate financial consequence |

Perlu diperhatikan bahwa analisa segi ekonomis tidak dilakukan, maka perhitungan konsekuensi yang berkaitan dengan segi ekonomis pun dilewat. Dalam perhitungan consequence area dari steam scrubber dan steam ejector (gas removal system) ini menggunakan Level 1 COF karena cairan utama yang

terkandung di dalam pressure vessel telah ditentukan dalam daftar cairan representatif yang disediakan oleh API RP 581 sendiri. Langkah-langkah untuk perhitungan consequence tanpa memperhatikan segi ekonomis dijelaskan sebagai berikut:

Langkah 1. Tentukan fluida yang dikeluarkan serta karakteristiknya.

1.1. Tentukan fluida representatif mengacu ke API RP 581 Part 3.

Fluida representatif ditentukan berdasarkan komposisi kimia dari fluida, fluida paling dominan lah yang dipilih menjadi representatif. Namun, apabila berupa campuran ada pertimbangan yang perlu diperhatikan. Tercantum pada API RP 581 Annex 3.A, yaitu

“If a mixture contains inert materials such as CO₂ or water, the choice of representative fluid should be based on the flammable/toxic materials of concern, excluding these materials. This is a conservative assumption that will result in higher CoF results, but it is sufficient for risk prioritization“.

Paragraf tersebut menjelaskan bahwa pada kasus fluida campuran, pemilihan fluida representatif disarankan fluida yang memiliki karakter *flammable* dan/atau *toxic* dimana diasumsikan memiliki nilai CoF lebih tinggi.

Tabel 3.9 Beberapa pilihan fluida representatif

(sumber: API RP 581, 2016)

| | | |
|------------------|--------|------------------|
| H ₂ S | Type 0 | Hydrogen Sulfide |
| Steam | Type 0 | Steam |
| Water | Type 0 | Water |

1.2. Tentukan fase fluida yang tersimpan

Penentuan jenis fluida yang dilayani di *piping* apakah gas atau cairan.

Fase fluida yang melewati *piping* adalah *liquid*.

1.3. Tentukan karakter dari fluida yang tersimpan

Parameter yang ditentukan adalah sebagai berikut:

- MW : Molecular Weight (kg/kg-mol)
- k : Ideal gas specific heat ratio
- AIT : Auto-ignition Temperature (K)

Nilai dari parameter tersebut tercantum di tabel 4.2 API RP 581 Part 3.

1.4. Tentukan fase tetap fluida setelah terlepas ke atmosfer dan fase saat masih tersimpan seperti pada langkah 1.2.

Tabel 3.10 Fase fluida
(sumber: API RP 581, 2016)

| Phase of Fluid at Normal Operating (Storage) | Phase of Fluid at Ambient (after release) | Final Phase of Consequence Calculation |
|--|---|--|
| Gas | Gas | Model as gas |
| Gas | Liquid | Model as gas |

| | | |
|--------|--------|--|
| Liquid | Gas | Model as gas unless the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid |
| Liquid | Liquid | Model as liquid |

Langkah 2. Pilih ukuran lubang (release hole size) untuk menentukan rentang nilai konsekuensi di perhitungan.

2.1. Calculate of release hole sizes by determining each diameter (d_n)

Berdasarkan API RP 581 Part 3 Annex 3.A menunjukkan bahwa untuk peralatan bejana tekan, ukuran empat lubang pelepasan standar diasumsikan untuk semua ukuran dan semua jenis bejana tekan. Jadi, mulai dari ukuran lubang rilis kecil, ukuran lubang rilis menengah, ukuran lubang rilis besar, dan sampai ukuran lubang rilis pecah harus dihitung masing-masing.

Tabel 3.11 Release Hole Size

(sumber: API RP 581, 2016)

| Release hole no. | Sizes | Range of diameter | Release hole diameter |
|------------------|---------|-------------------|-----------------------|
| 1 | Small | 0 – ¼ | $d_1 = 0.25$ |
| 2 | Medium | > 1/4 – 2 | $d_2 = 1$ |
| 3 | Large | > 2 – 6 | $d_3 = 4$ |
| 4 | Rupture | > 6 | $d_4 = 16$ |

2.2. Tentukan nilai gff_n , untuk tiap n^{th} ukuran release hole.

Nilai dari generic failure frequencies untuk tiap ukuran release hole.

Langkah 3. Hitung theoretical release rate

3.1. Memilih persamaan release rate berdasarkan fase fluida di langkah 1.2.

Karena fase fluida yang ditentukan di langkah 1.2. adalah gas atau vapour dan storage pressure dari equipment P_s lebih besar dari transition pressure P_{trans} . Maka, menggunakan

$$W_n = \frac{Cd}{C^2} \times A_n \times P_s \sqrt{\left(\frac{k \times MW \times gc}{R \times T_S}\right)} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}} \quad \dots \quad (3.49)$$

3.2. Hitung luasan release hole size, A_n , di tiap release hole dengan,

$$A_n = \frac{\pi d n^2}{4} \quad \dots \quad (3.50)$$

3.3. Untuk *liquid releases*, hitung viscosity correction factor untuk setiap lubang keluaran ($K_{v,n}$).

3.4. Hitung *release rate* untuk setiap lubang keluaran, W_n , untuk setiap luasan A_n . Hitung theoretical release rate (W_n) untuk setiap lubang keluaran berdasarkan luasan (A_n) yang sudah ditentukan di langkah 3.2.

Langkah 4. Estimasi total fluida yang dapat dikeluarkan

4.1. Menentukan grup komponen and equipment menjadi inven.

API RP 581 memberikan deskripsi apa pun untuk Konsekuensi Kegagalan (COF) untuk item peralatan yang dinilai adalah untuk digabungkan dengan komponen lain yang dapat berkontribusi untuk menambah jumlah rilis inventaris.

4.2. Menghitung massa fluida, massa_{comp},

Estimasi volume untuk tipe komponen tersedia di API RP 581, Part 3 – Annex 3.A.

4.3. Menghitung massa fluida di masing-masing komponen lain yang termasuk dalam kelompok inventaris, massa_{comp}, i.

4.4. Menghitung massa fluida dalam grup inventaris, $\text{massa}_{\text{inv}}$, menggunakan persamaan ini di bawah ini.

4.5. Hitung laju aliran dari lubang diameter 203 mm (8 inci), W_{max} .

Hitung laju aliran dari lubang 203 mm (8 inci) diameter, Wmax8, menggunakan persamaan 5 seperti yang berlaku dengan $A_n = A_8 = 32,450 \text{ mm}^2 (50,3 \text{ inch}^2)$. Ini adalah laju aliran maksimum yang dapat ditambahkan ke massa cairan peralatan dari peralatan di sekitarnya dalam grup inventory.

$$W_{max8} = \frac{Cd}{C2} \times An \times Ps \sqrt{\left(\frac{k \times MW \times gc}{R \times Ts}\right)} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}} \dots \dots \dots (3.53)$$

4.6. Menghitung laju massa fluida $m_{\text{add},n}$ di tiap lubang keluaran

Menentukan massa fluida tambahan untuk setiap ukuran lubang pelepasan yang dihasilkan dari tiga menit aliran dari kelompok persediaan menggunakan persamaan di bawah ini di bawah ini.

4.7. Calculate the available mass for release for each hole size

Untuk setiap ukurang lubang keluaran, calculate the available mass for release using this below equation below.

$$Mass_{avail,n} = \min [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad \dots \quad (3.55)$$

Langkah 5. Tentukan tipe keluaran (continuous, atau instantaneous).

- INSTANTANEOUS RELEASE

Instantaneous release atau pelepasan sesaat adalah pelepasan yang terjadi begitu cepat sehingga fluida menyebar sebagai satu awan atau kumpulan besar.

- CONTINOUS RELEASE

Continous release atau pelepasan menerus adalah pelepasan yang terjadi dalam periode waktu yang lebih lama, memungkinkan cairan untuk membubarkan dalam bentuk elips memanjang (tergantung pada kondisi

cuaca).

5.1. Hitung waktu yang dibutuhkan untuk melepaskan 4536 kg (10.000 lbs) cairan untuk setiap ukuran lubang. Untuk menentukan waktu yang dibutuhkan untuk melepaskan 4536 kg (10.000 lbs) cairan untuk setiap ukuran lubang dapat diadopsi dari persamaan di bawah ini

5.2. Menentukan apakah tipe rilisnya instan atau berkelanjutan menggunakan kriteria berikut ini.

- Jika ukuran lubang pelepasan adalah 6,35 mm (0,25 inci) atau kurang, maka jenis pelepasan secara kontinu.
 - If $t_n \leq 180$ sec dan massa pelepasan lebih dari 4536 kgs (10000 lbs.), maka itu adalah isntan; jika tidak maka itu kontinu.

Langkah 6. Estimasi dampak dari system deteksi dan isolasi pada setiap keluaran

Setiap perusahaan energi umumnya memiliki seperti sistem deteksi, sistem isolasi, dan juga sistem mitigasi dirancang untuk mengurangi kemungkinan besarnya dari komposisi atau cairan berbahaya. Berdasarkan Tabel 4.5 API RP 581 Bagian 3 tercantum tentang skenario sistem deteksi dan isolasi yang mungkin milik perusahaan minyak dan gas tertentu sebagai sistem keselamatannya setiap kali magnitude terjadi.

6.1. Menentukan sistem deteksi dan isolasi yang ada di unit

Jenis dukungan keselamatan yang tersedia di unit adalah SDV yang berfungsi untuk mendeteksi segala perubahan tekanan, baik tekanan berlebih maupun kebocoran. Di sisi lain, sistem isolasi diaktifkan langsung dari instrumentasi proses dengan detektor, tanpa intervensi operator.

6.2. Memilih klasifikasi yang sesuai (A, B, atau C) untuk sistem deteksi menggunakan tabel berikut.

Tabel 3.12 Klasifikasi tipe system deteksi
(sumber: API RP 581, 2016)

| Type of Detection System | Classification |
|--|----------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |
| Suitably located detectors to determine when the material is present outside the pressure-containing envelop | B |
| Visual detection, cameras, or detectors with marginal coverage | C |

6.3. Memilih klasifikasi yang sesuai (A, B, atau C) untuk sistem isolasi menggunakan tabel berikut.

Tabel 3.13 Klasifikasi tipe system insulasi

(sumber: API RP 581, 2016)

| Type of Isolation System | Classification |
|---|----------------|
| Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention | A |
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |
| Isolation dependent on manually operated valves | C |

6.4. Menentukan faktor reduksi pelepasan, $f_{act_{di}}$, tipe dari sistem isolasi dan deteksi sebagaimana dipilih dalam Langkah 6.2 dan 6.3

6.5. Menentukan total durasi kebocoran untuk setiap ukuran lubang rilis yang dipilih, $ld_{max,n}$, menggunakan klasifikasi dari langkah 6.2 dan 6.3 dan tabel berikut.

Tabel 3.14 Durasi kebocoran berdasarkan sistem deteksi dan isolasi

(sumber: API RP 581, 2016)

| Detection System Rating | Isolation System Rating | Maximum Leak Duration, ld_{max} |
|-------------------------|-------------------------|-----------------------------------|
| A | A | 20 minutes for 1/4 inch leaks |
| | | 10 minutes for 1 inch leaks |
| | | 5 minutes for 4 inch leaks |
| A | B | 30 minutes for 1/4 inch leaks |
| | | 20 minutes for 1 inch leaks |
| | | 10 minutes for 4 inch leaks |
| A | C | 40 minutes for 1/4 inch leaks |
| | | 30 minutes for 1 inch leaks |
| | | 20 minutes for 4 inch leaks |
| B | A or B | 40 minutes for 1/4 inch leaks |
| | | 30 minutes for 1 inch leaks |
| | | 20 minutes for 4 inch leaks |
| B | C | 1 hour for 1/4 inch leaks |
| | | 30 minutes for 1 inch leaks |
| | | 20 minutes for 4 inch leaks |
| C | A, B, or C | 1 hour for 1/4 inch leaks |
| | | 40 minutes for 1 inch leaks |
| | | 20 minutes for 4 inch leaks |

Langkah 7. Tentukan release rate dan mass untuk analisa consequence

- CONTINOUS RELEASE RATE

Untuk rilis yang berkelanjutan, rilis dimodelkan sebagai kondisi keadaan stabil: oleh karena itu, release rate digunakan sebagai input untuk analisis konsekuensi. Laju pelepasan yang digunakan dalam analisis adalah pelepasan teoritis yang disesuaikan dengan keberadaan unit deteksi dan isolasi sebagaimana dirumuskan dalam persamaan di bawah ini:

$$Rate_n = W_n (1 - fact_{di}) \quad \dots \dots \dots \quad (3.57)$$

- INSTANTANEOUS RELEASE RATE

Untuk pelepasan instan, laju pelapasan massa diperlukan untuk analisa lebih lanjut. Laju pelepasan massa, $mass_{avail,n}$, digunakan sebagai batas atas laju pelepasan massa, $mass_n$, as shown in the equation below:

$$mass_n = min[\{rate_n \cdot Id_n\}, mass_{avail,n}] \quad \dots \dots \dots \quad (3.58)$$

1.1. Hitung adjusted release rate, $rate_n$, menggunakan persamaan (3.57)

1.2. Hitung waktu kebocoran, Id_n , untuk setiap release hole dengan,

$$Id_n = min \left[\left\{ \frac{Mass_{avail,n}}{Rate_n} \right\}, \{60 \cdot Id_{max,n}\} \right] \quad \dots \dots \dots \quad (3.59)$$

1.3. Hitung release mass, $mass_n$, untuk setiap ukuran release hole.

Untuk setiap ukuran release hole, hitung release mass, $mass_n$, menggunakan rumus 2.10 berdasarkan release rate, $rate_n$, durasi kebocoran, Id_n , dan, $mass_{avail,n}$

Langkah 8. Hitung flammable/explosive consequence

Consequence of Area (CA) diestimasi dengan release rate ($Rate_n$) untuk continuous release type dan Mass rate ($Mass_n$) untuk tipe instantaneous release.

1.1. Memilih faktor reduksi mitigasi konsekuensi area, $fact_{mit}$, dari tabel berikut.

Tabel 3.15 Faktor reduksi mitigasi konsekuensi area
(sumber: API RP 581, 2016)

| Mitigation System | Consequence Area Adjustment | Fact _{mit} |
|---|---------------------------------|---------------------|
| Inventory blowdown, couple with isolation system classification B or higher | Reduce consequence area by 25 % | 0.25 |
| Fire water deluge system and monitor | Reduce consequence area by 20% | 0.2 |
| Firewater monitor only | Reduce consequence area by 5% | 0.05 |
| Foam spray system | Reduce consequence area by 15% | 0.15 |

1.2. Hitung efisiensi energi, $eneff_n$, untuk setiap ukuran lubang menggunakan persamaan yang disebutkan di bawah ini.

$$eneff_4 = 4 \cdot \log_{10}[C_4 \cdot mass_n] - 15 \quad \dots \dots \dots \quad (3.60)$$

- 1.3. Menentukan tipe fluida, baik tipe 0 atau tipe 1 dari tabel 4.1 API 581
 - 1.4. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Not Likely, Continuous Release (AINL-CONT), CA^{AINL-CONT}.

Consequence area untuk Component Damage Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{cmd,n}^{AINL-CONT} = \alpha (rate_n)^b \cdot (1 - fact_{mit}) \quad \dots \dots \dots (3.61)$$

- 1.5. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Likely, Continuous Release (AIT-CONT), CA^{AIL-CONT}.

Consequence area untuk Component Damage Auto-Ignition Likely untuk continuous release dapat dihitung dengan:

$$CA_{cmd,n}^{AIL-CONT} = \alpha (rate_n)^b \cdot (1 - fact_{mit}) \quad \dots \quad (3.62)$$

- 1.6. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Not Likely, Instantaneous Release (AINT-INST), CA^{AINT-INST}.

Consequence area untuk Component Damage Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{cmd,n}^{AINL-INST} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n} \right) \quad \dots \quad (3.63)$$

- 1.7. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Likely, Instantaneous Release (AIT-INST), CA^{AIL-INST}.

Consequence area untuk Component Damage Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{cmd,n}^{ALL-INST} = \alpha(mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad \dots \quad (3.64)$$

- 1.8. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk Auto-Ignition Not Likely, Continuous Release (AJNL-CONT), CA^{AJNL-CONT}.

Consequence area untuk Personnel Injury Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{inj,n}^{AINL-CONT} = [\alpha \cdot (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad \dots \dots (3.65)$$

- 1.9. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk Auto-Ignition Likely, Continuous Release (AIT-CONT), CA_{AIL-CONT}.

Consequence area untuk Personnel Injury Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{inj,n}^{AIL-CONT} = [\alpha \cdot (rate_n^{AIL-CONT})^b] \cdot (1 - fact_{mit}) \quad \dots \dots \dots \quad (3.66)$$

1.10.Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk r Auto-Ignition Not Likely, Instantaneous Release (AINL-INST), CA^{AINL-INST}.

Consequence area for Personnel Injury Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{inj,n}^{AINL-INST} = [\alpha \cdot (mass_n^{AINL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad \dots \dots \dots \quad (3.67)$$

1.11.Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas for Auto-Ignition Likely, Instantaneous Release (AIL-INST), CA^{AIL-INST}.

Consequence area for Personnel Injury Auto-Ignition Likely untuk instantaneous release dapat dihitung dengan::

$$CA_{inj,n}^{AIL-INST} = [\alpha \cdot (mass_n^{AIL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad \dots \dots \dots \quad (3.68)$$

1.12. Hitung instantaneous/continuous blending factor, fact_n, untuk setiap lubang keluaran yang sesuai dengan tipe keluaran pada tiap lubang.

a. For continuous release type

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad \dots \dots \dots \quad (3.69)$$

b. For instantaneous release type

For instantaneous releases, blending factor tidak dihitung. Karena definisi instantaneous release adalah satu keluaran besar, rate_n, lebih besar (4356 kgs (10000 lbs.) dalam 3 menit), the blending factor sama dengan to 1.0.

$$fact_n^{IC} = 1.0 \quad \dots \dots \dots \quad (3.70)$$

1.13. Hitung AIT blending factor, fact^{AIT}, menggunakan persamaan (3.71), (3.72), or (3.73) as applicable.

$$fact^{AIT} = 0 \quad \text{if } T_s + C_6 \leq AIT \quad (3.71)$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2 \times C_6} \quad \text{if } T_s + C_6 > AIT > T_s - C_6 \quad (3.72)$$

$$fact^{AIT} = 1 \quad \text{if } T_s - C_6 \geq AIT \quad (3.73)$$

1.14. Hitung continuous/instantaneous blended consequence area untuk komponen dan personil using equation (3.74) through (3.78) based on the consequence area that have been calculated in the previous steps.

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \times fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \times (1 - fact_n^{IC}) \quad \dots \dots \dots \quad (3.74)$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC}) \quad (3.75)$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC}) \quad \dots\dots(3.76)$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC}) \quad \dots\dots(3.78)$$

1.15. Hitung AIT blended consequence areas untuk komponen menggunakan persamaan (2.54) dan (2.55).

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT}) \quad \dots\dots(3.79)$$

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL-CONT} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad \dots\dots(3.80)$$

1.16. Hitung consequence areas final untuk kerusakan komponen dan personil menggunakan persamaan (2.56) and (2.57).

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}} \right) \quad \dots\dots(3.81)$$

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) \quad \dots\dots(3.82)$$

Langkah 9. Hitung toxic consequence

1.1. Untuk setiap lubang keluaran, hitung durasi efektif penyebaran toxic menggunakan persamaan:

$$ld_n^{tox} = \min \left(3000, \left\{ \frac{mass_n}{W_n} \right\}, \{60 \cdot ld_{max,n}\} \right) \quad \dots\dots(3.83)$$

1.2. Menentukan persentase toksik dari komponen toksik, dalam bahan rilis. Fluida lepas adalah fluida murni, = 1.0. perhatikan bahwa jika ada lebih dari satu komponen toksik dalam campuran cairan pelepasan, prosedur ini dapat diulang untuk setiap komponen toksik.

1.3. Untuk setiap ukuran lubang pelepasan, hitung laju pelepasan, dan lepaskan massa yang akan digunakan dalam analisis toksik menggunakan persamaan (3.84) and (3.85).

a. For continuous release type

$$rate_n^{tox} = mfrac^{tox} \cdot W_n \quad \dots\dots(3.84)$$

b. For instantaneous release type

$$mass_n^{tox} = mfrac^{tox} \cdot mass_n \quad \dots\dots(3.86)$$

1.4. Untuk setiap ukuran lubang pelepasan, hitung area konsekuensi toksik untuk setiap ukuran lubang pelepasan.

Langkah ini diperlukan apabila komposisi kimia dalam aliran fluida mengandung H₂S dan/atau HF. Menggunakan (3.87) untuk continuous release dan (3.88) untuk instantaneous release type.

a. For continuous release type

$$CA_{inj,n}^{toxCONT} = e(Rate_n^{tox})^f \quad \dots\dots(3.87)$$

- b. For instantaneous release type

$$CA_{inj,n}^{tox-INST} = e(Mass_n^{tox})^{\gamma_1} f \quad \dots \quad (3.88)$$

1.5. Jika ada komponen toxic tambahan di campuran fluida keluaran, langkah 1.2 hingga 1.4 harus diulang. Jika tidak ada, langkah 1.5 dapat dilewat.

1.6. Tentukan konsekuensi area toxic untuk injuri personil sesuai rumus (3.89)

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) \quad \dots \quad (3.89)$$

Langkah 10. Hitung non-flammable, non-toxic consequence

Non-flammable dan non-toxic difokuskan terhadap uap, serta konten acid dan caustic. Uap terbentuk pada suhu 100°C, namun pada jarak beberapa meter uap akan bercampur dengan udara dan menjadi lebih dingin. Untuk pendekatan ini, injury terjadi diatas suhu 60°C.

1.1. Untuk setiap ukurang lubang keluaran, hitung non-flammable dan non-toxic consequence are menggunakan persamaan (3.90) and (3.91)

Untuk proses yang tidak mengandung acid dan caustic content, maka menghitung the stream non-flammable dan non-toxic menggunakan:

a. For continuous release type

b. For instantaneous release type

$$CA_{inj,n}^{INST} = (C_{10} \cdot \text{Mass}_n)^{0.6384} \quad \dots \quad (3.91)$$

1.2. Untuk setiap ukuran lubang pelepasan, hitung faktor blending kontinyu / instan, $fact_{id}$, untuk steam menggunakan persamaan 3.92 berikut. Sedangkan untuk acid atau caustic, $fact_n^{IC} = 0$.

1.3. Untuk setiap ukuran lubang keluaran, hitung consequence area untuk non-flammable dan non-toxic personnel injury dari langkah 1.1 dan 1.2.

$$CA_{cmd,n}^{leak} = 0 \quad \dots \quad (3.93)$$

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} \cdot fact_n^{IC} + CA_{inj,n}^{CONT} \cdot (1 - fact_n^{IC}) \quad \dots \quad (3.94)$$

1.4. Tentukan non-flammable, non-toxic consequence areas final untuk personnel injury menggunakan (3.95)

$$CA_{inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) \quad (3.95)$$

Langkah 11. Hitung consequence untuk kerusakan komponen dan personil, untuk menghitung total consequence

- 1.1. Hitung component damage consequence area final, CA_{cmd} , menggunakan persamaan (3.96)

- 1.2. Hitung personnel injury consequence area final, CA_{inj} , menggunakan persamaan (3.97)

$$CA_{inj} = \max [CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}] \quad \dots \quad (3.97)$$

- 1.3. Calculate the final consequence rea, CA, menggunakan persamaan (3.98)

$$CA = \max[CA_{cmd}, CA_{ini}] \quad (3.98)$$

3.3.3 Risk Rank

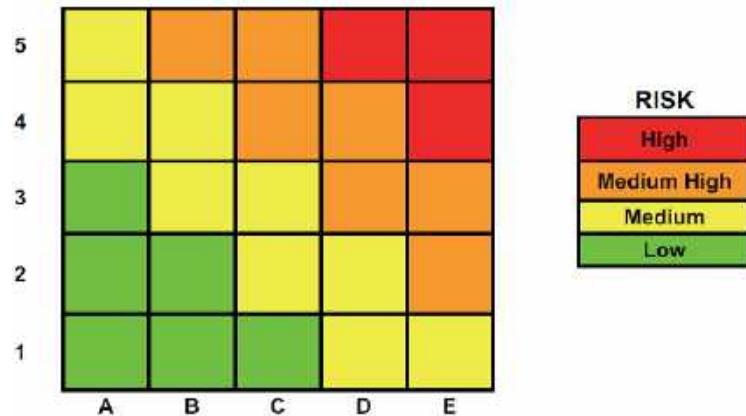
Risiko didefinisikan sebagai kombinasi dari probabilitas suatu kejadian pada kurun waktu tertentu dan konsekuensinya (umumnya negatif) dari kejadian terkait. [7] Sebuah sistem terdiri dari beberapa atau banyak komponen, dimana masing-masing komponen memiliki risikonya masing-masing. Tentunya, karena komponen tersebut merupakan bagian dari sistem maka kegagalan pada komponen dapat berdampak pada sistem baik dari performa ataupun usianya. Maka probabilitas dari risiko komponen harus dipertahankan pada tingkat yang dapat diterima dengan cara melakukan testing ataupun inspeksi.

Secara matematika, risiko dapat didefinisikan sebagai:

Dimana $P_f(t)$ adalah probabilitas kegagalan, $C_f(t)$ adalah konsekuensi dari kegagalannya. Dari persamaan tersebut dapat disimpulkan bahwa sebuah risk assessment yang efektif harus rasional, logis, terstruktur dan mengandung seberapa signifikan dampak dari risiko tersebut, apakah risiko tersebut dapat diterima dan seberapa tinggi probabilitas risiko tersebut terjadi.

Setelah menghitung *Probability of Failure* (POF) dan *Consequence of Failure* (COF), hasil dari level risiko diketahui. Selanjutnya dilakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat sesuai dengan hasil level risiko yang diketahui. Jika hasilnya diterima, dapat terus melakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat. Di sisi lain, jika hasilnya ditolak, maka, kita harus melakukan beberapa langkah mitigasi yang mengharuskan untuk menghitung kembali POF dan COF hingga hasilnya diterima sepenuhnya.

Matriks risiko adalah cara untuk menentukan tingkat risiko dari komponen-komponen terkait. Merah menunjukkan risiko yang tinggi, jingga menunjukkan tingkat risiko yang menengah-tinggi, kuning menunjukkan bahwa risiko kegagalan komponen tersebut pada tingkat menengah, hijau menunjukkan risiko pada tingkat rendah. Contoh gambar matriks risiko ditunjukkan pada **Gambar 3.3** berikut.



Gambar 3.3 Risk Matrix
(sumber: API RP 581, 2016)

Pada **Gambar 3.3**, di sumbu horizontal adalah tingkatan dari *consequence of failure*, dan sumbu vertical adalah tingkatan dari *probability of failure* atau damage factor. Untuk pengklasifikasian nilai dapat dilihat pada **Tabel 3.16**.

Tabel 3.16 Faktor reduksi mitigasi konsekuensi area
(sumber: API RP 581, 2016)

| Probability Category | | | Consequence Category | |
|----------------------|--|-------------------------------|----------------------|-----------------------|
| Cat. | Probability range | DF range | Cat. | Range (m^2) |
| 1 | $P_f(t, I_E) \leq 3.06E-05$ | $D_{f-total} \leq 1$ | A | $CA \leq 9.29$ |
| 2 | $3.06E-05 < P_f(t, I_E) \leq 3.06E-04$ | $1 < D_{f-total} \leq 10$ | B | $9.29 < CA \leq 92.9$ |
| 3 | $3.06E-04 < P_f(t, I_E) \leq 3.06E-03$ | $10 < D_{f-total} \leq 100$ | C | $92.9 < CA \leq 929$ |
| 4 | $3.06E-03 < P_f(t, I_E) \leq 3.06E-02$ | $100 < D_{f-total} \leq 1000$ | D | $929 < CA \leq 9290$ |
| 5 | $P_f(t, I_E) > 3.06E-02$ | $D_{f-total} > 1000$ | E | $CA > 9290$ |

3.4 Inspection Plan

Setelah level risiko diketahui dilanjutkan untuk membuat strategi inspeksi sesuai dengan level risiko. Jika hasilnya diterima, dapat terus melakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat. Di sisi lain, jika hasilnya ditolak, maka, kita harus melakukan beberapa langkah mitigasi yang mengharuskan untuk menghitung kembali POF dan COF hingga hasilnya diterima sepenuhnya.

Inspeksi dirancang berdasarkan level risiko dari sebuah equipment sesuai dari analisa risiko menggunakan RBI. Equipment dengan level risiko yang lebih tinggi akan diprioritaskan untuk diinspeksi. Inspeksi dilaksanakan ketika risiko atau kondisi equipment sudah melebihi target yang dipasang oleh perusahaan. Target-target yang dapat ditentukan dengan RBI untuk tindakan mitigasi adalah¹⁴:

- Target Risiko – tingkat risiko minimum untuk mengadakan perencanaan inspeksi. Dapat berupa unit area ($m^2/tahun$) atau finansial ($$/tahun$).
- Target POF – Batas maksimum dari frekuensi kegagalan/kebocoran yang dapat diterima (#/tahun) atau dapat memicu perencanaan inspeksi.

- Target DF – Batas maksimum nilai kerusakan (merupakan faktor dari PoF) yang dapat diterima atau dapat memicu perencanaan inspeksi.
- Target CoF – Tingkatan consequence area (CA) atau financial consequence (FA) yang tidak dapat diterima.
- Target Thickness – Ketebalan minimum yang dapat diterima atau dapat memicu perencanaan inspeksi.
- Target Interval – Interval maksimum untuk waktu pelaksanaan inspeksi.

Dalam menentukan target, API RP 581 tidak menyediakan panduan spesifik dalam penentuannya dan harus ditentukan berdasarkan keputusan owner. Untuk kegiatan *inspeksi* sendiri, ada 3 yaitu inspeksi internal, on-stream dan eksternal. Inspeksi internal adalah inspeksi harus dilakukan pada saat alat tidak beroperasi. Sedangkan inspeksi onstream dilakukan pada saat peralatan sedang beroperasi. Inspeksi eksternal dilakukan hanya menggunakan visual untuk mengecek apakah kondisi struktural atau eksternal dari alat dalam kondisi yang baik.

Inspeksi dilaksanakan dengan tujuan mengurangi risiko dari *equipment* tersebut dan mendapatkan informasi terkini mengenai kondisi *equipment* tersebut (pelaksanaan inspeksi hanya akan mengurangi *probability of failure* sedangkan untuk mengurangi *consequence*, desain harus ditinjau ulang). Akurasi dari metode inspeksi itulah yang disebut dengan *inspection effectiveness*. Setiap jenis damage factor memiliki *inspection effectiveness* sendiri yang dijelaskan pada API RP 581 3rd Edition – Annex 2.C. Dalam hal thinning pun, untuk general dan local memiliki effectivenessnya masing-masing. Berikut adalah *inspection effectiveness* untuk thinning dan CUI.

Tabel 3.17 Inspection effectiveness untuk local thinning
(sumber: API RP 581, 2016)

| Kategori | Kategori | Inspeksi Intrusif | Inspeksi Non-Intrusif |
|----------|-------------------|---|--|
| A | Highly effective | Untuk area permukaan total: • 100% pemeriksaan visual. • 100% follow up di area local thinning. | Untuk total area yang dicurigai: Cakupan 100% dari CML menggunakan ultrasonic scanning atau profile radiography. |
| B | Usually effective | Untuk area permukaan total: • >75% pemeriksaan visual. • 100% follow up di area local thinning. | Untuk total area yang dicurigai: > cakupan 75% dari CML menggunakan ultrasonic scanning atau profile radiography. |
| C | Fairly effective | Untuk area permukaan total: • >50% pemeriksaan visual. • 100% follow up di area local thinning. | Untuk total area yang dicurigai: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography. |

| Kategori | Kategori | Inspeksi Intrusif | Inspeksi Non-Intrusif |
|----------|------------------|---|--|
| D | Poorly effective | Untuk area permukaan total: • >20% pemeriksaan visual. • 100% follow up di area local thinning. | Untuk total area yang dicurigai: > cakupan 20% dari CML menggunakan ultrasonic scanning atau profile radiography. |
| E | Ineffective | Teknik inspeksi yang tidak efektif | Teknik inspeksi yang tidak efektif |

Tabel 3.18 Inspection effectiveness untuk general thinning
(sumber: API RP 581, 2016)

| Kategori | Kategori | Inspeksi Intrusif | Inspeksi Non-Intrusif |
|----------|--------------------------|---|--|
| A | <i>Highly effective</i> | <i>For the total surface area:</i> <i>>50 % visual examination (partial internals removed)</i> <i>AND</i> <i>>50 % of the spot ultrasonic thickness measurements</i> | <i>For the total surface area:</i> <i>100 % UT/RT of CMLs</i> <i>OR</i> <i>For selected areas:</i> <i>10 % UT scanning</i> <i>OR</i> <i>10 % profile radiography</i> |
| B | <i>Usually effective</i> | <i>For the total surface area:</i> <i>>25 % visual examination</i> <i>AND</i> <i>>25 % of the spot ultrasonic thickness measurements</i> | <i>For the total surface area:</i> <i>>75 % spot UT</i> <i>OR</i> <i>>5 % UT scanning, automated or manual</i> <i>OR</i> <i>>5 % profile radiography of the selected area(s)</i> |
| C | <i>Fairly effective</i> | <i>For the total surface area:</i> <i>>5 % visual examination</i> <i>AND</i> <i>>5 % of the spot ultrasonic thickness measurements</i> | <i>For the total surface area:</i> <i>>50 % spot UT or random UT scans (automated or manual)</i> <i>OR</i> <i>random profile radiography of the selected area(s)</i> |
| D | <i>Poorly effective</i> | <i>For the total surface area:</i> <i><5 % visual examination without thickness measurements</i> | <i>For the total surface area:</i> <i>>25 % spot UT</i> |
| E | <i>Ineffective</i> | <i>Ineffective inspection technique/plan was utilized</i> | <i>Ineffective inspection technique/plan was utilized</i> |

Tabel 3.19 Inspection effectiveness untuk CUI
 (sumber: API RP 581, 2016)

| Kategori | Kategori | Inspeksi Intrusif | Inspeksi Non-Intrusif |
|----------|--------------------------|--|---|
| A | <i>Highly effective</i> | <p><i>For the total surface area:</i> <i>100 % external visual inspection prior to removal of insulation</i> <i>AND</i> <i>Remove 100 % of the insulation for damaged or suspected areas</i> <i>AND</i> <i>100 % visual inspection of the exposed surface area with UT, RT, or pit gauge follow-up of the selected corroded areas</i></p> | <p><i>For the total surface area:</i> <i>100 % external visual inspection</i> <i>AND</i> <i>100 % profile or real-time radiography of damaged or suspect area</i> <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge</i></p> |
| B | <i>Usually effective</i> | <p><i>For the total surface area:</i> <i>100 % external visual inspection prior to removal of insulation</i> <i>AND</i> <i>Remove >50 % of suspect areas</i> <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge</i></p> | <p><i>For the total surface area:</i> <i>100 % external visual inspection</i> <i>AND</i> <i>Follow-up with profile or real-time radiography of >65% of suspect areas</i> <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge</i></p> |
| C | <i>Fairly effective</i> | <p><i>For the total surface area:</i> <i>100 % external visual inspection prior to removal of insulation</i> <i>AND</i> <i>Remove >25 % of suspect areas</i> <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge</i></p> | <p><i>For the total surface area:</i> <i>100 % external visual inspection</i> <i>AND</i> <i>Follow-up with profile or real-time radiography of >35 % of suspect areas</i> <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge</i></p> |
| D | <i>Poorly effective</i> | <p><i>For the total surface area:</i> <i>100 % external visual inspection prior to removal of insulation</i> <i>AND</i> <i>Remove >5 % of total surface area of insulation including suspect areas</i> <i>AND</i></p> | <p><i>For the total surface area:</i> <i>100 % external visual inspection</i> <i>AND</i> <i>Follow-up with profile or real-time radiography of >5 % of total surface area of insulation including suspect areas</i></p> |

| Kategori | Kategori | Inspeksi Intrusif | Inspeksi Non-Intrusif |
|----------|--------------------|---|--|
| | | <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge</i> | <i>AND</i> <i>Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge</i> |
| E | <i>Ineffective</i> | <i>Ineffective inspection technique/plan was utilized</i> | <i>Ineffective inspection technique/plan was utilized</i> |

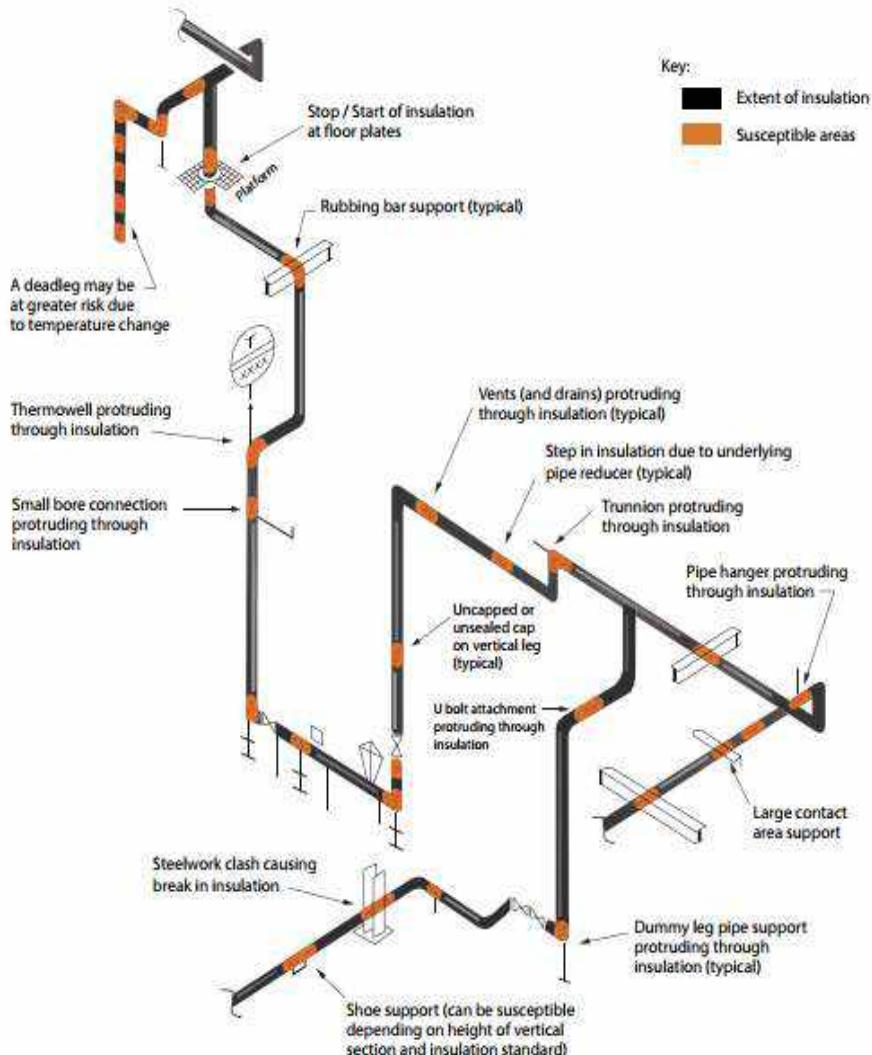
Jika tingkat inspeksi diperlukan dalam mitigasi, maka kategori inspeksi harus ditingkatkan levelnya menjadi lebih tinggi. Hal itu berguna agar mitigasi bisa membantu dalam perencanaan inspeksi sebelumnya. Selain itu penentuan strategi inspeksi sesuai dengan level risiko sangat berperan dalam mengurangi biaya dan membuat strategi inspeksi lebih efektif dan strategis. Seperti dijelaskan pada **Tabel 3.20**, rekomendasi inspeksi berdasarkan level risiko. Pada **Gambar 3.4** juga dijelaskan lokasi yang rentan terjadi CUI dan **Tabel 2.21** dijelaskan lokasi mana saja yang paling sering terjadinya CUI.

Tabel 3.20 Rekomendasi inspeksi sesuai dengan level risiko

(sumber: EFC CUI Guidelines, 2016)

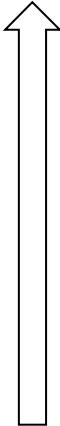
| Level Risiko | Rekomendasi Inspeksi |
|--------------------|---|
| <i>High</i> | <ul style="list-style-type: none"> • <i>100% removal of thermal insulation</i> • <i>Complete visual inspection of exposed areas for corr. and condition of coating as applicable</i> • <i>Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.</i> • <i>Reevaluate the risk</i> |
| <i>Medium High</i> | <ul style="list-style-type: none"> • <i>>40% removal of thermal insulation including all critical points and damaged areas</i> • <i>Complete visual inspection of exposed areas for corr. and condition of coating as applicable</i> • <i>Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.</i> • <i>Reevaluate the risk</i> |
| <i>Medium</i> | <ul style="list-style-type: none"> • <i>>20% removal of thermal insulation including all critical points and damaged areas</i> • <i>Complete visual inspection of exposed areas for corr. and condition of coating as applicable</i> • <i>Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.</i> • <i>Reevaluate the risk</i> |

| Level Risiko | Rekomendasi Inspeksi |
|--------------|--|
| Low | <ul style="list-style-type: none"> • Remove thermal insulation at all critical points with evidence of damage • Complete visual inspection of exposed areas for corr. and condition of coating as applicable • Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography. • Reevaluate the risk |



Gambar 3.4 Lokasi yang rentan terhadap CUI
(sumber: EFC CUI Guidelines, 2016)

Tabel 3.21 Prioritas lokasi inspeksi
 (sumber: EFC CUI Guidelines, 2016)

| Prioritas | Lokasi Kritis |
|---|---|
| Higher  | <i>Dead-legs, vents, and drains</i> |
| | <i>Pipe hangers and supports</i> |
| | <i>Valves and fittings</i> |
| | <i>Bolted on pipe shoes</i> |
| | <i>Steam-tracing/electric-tracing tubing penetrations</i> |
| | <i>Termination of insulation at flanges and other piping components</i> |
| | <i>Carbon/low alloy steel flanges, bolting, and other components in high alloy piping</i> |
| | <i>Jacketing seams on the top of horizontal piping</i> |
| | <i>Termination of insulation on vertical piping</i> |
| | <i>Areas where smaller branch connections intersect larger diameter lines</i> |
| | <i>Low points in piping with breaches in the insulation</i> |
| | <i>Close proximity to water (e.g. wharf) and/or ground (e.g. increased absorption)</i> |
| | <i>Wet due to flooding or submerging into water</i> |
| Lower | <i>Damage due to foot traffic</i> |

3.5 Selesai

Tahap terakhir dari metodologi ini adalah pengambilan keputusan dari hasil inspeksi komparatif yang telah diterapkan pada perusahaan terkait. Pada langkah terakhir, kesimpulan akan diambil dari analisis tugas akhir ini. Pada tahap ini saran untuk perusahaan dicantumkan agar dapat menjadi bahan pertimbangan ke kebijakan selanjutnya.

Halaman ini sengaja dikosongkan

BAB IV

ANALISIS DATA DAN PEMBAHASAN

4.1 Data

Data-data yang lengkap dibutuhkan dalam perhitungan *risk-based inspection* (RBI). Data-data tersebut meliputi desain dan konstruksi *piping*, data operasional *piping*, data fluida yang dilayani oleh *piping*, data inspeksi dan data-data lain yang mendukung dalam tugas akhir ini.

Data-data tersebut akan diolah sesuai dengan rumusan perhitungan yang terdapat pada API 581 baik dalam perhitungan *probability of failure* maupun *consequence of failure*. Di bawah ini merupakan penjelasan lebih detail mengenai data-data yang akan di analisis: Data-data yang dibutuhkan meliputi:

a. *Start date*

Merupakan identitas mengenai waktu operasional pertama baik tanggal, bulan, maupun tahun awal.

b. *Component Geometry*

Component geometry merupakan data ukuran *piping* baik berupa *code* yang digunakan.

c. *Design code*

Standart design yang digunakan oleh PT X adalah ASME B 31.3. *Design code* ini nantinya akan digunakan dalam perhitungan *wall thickness piping*.

d. *Design pressure*

Merupakan tekanan maksimum yang dapat ditahan oleh *piping*. Selama pengoperasian tekanan yang dihasilkan tidak boleh melebihi tekanan maksimumnya. Apabila tekanan operasional melebihi tekanan maksimum maka akan terjadi disintegritas *piping* berupa ledakan. Data *design pressure* dibutuhkan sebagai acuan dalam menentukan besarnya tekanan maksimum yang dibutuhkan.

e. *Design temperature*

Sama dengan *design pressure*, *design temperature* merupakan batas suhu maksimal yang dapat ditahan oleh *piping*. Suhu operasional juga tidak boleh melebihi suhu maksimalnya.

f. *Cladding*

Cladding ialah pelapisan tambahan pada peralatan. Adanya *cladding* akan mempengaruhi hasil perhitungan analisis *probability*. *Piping* milik PT X yang dianalisa tidak memiliki *cladding* sehingga tidak perlu diperhitungkan.

g. *Coating*

Coating merupakan pelapisan luar pada peralatan yang dapat berupa *painting* maupun *wrapping*.

Data-data yang digunakan dalam penelitian ini terlampir di **Lampiran A**.

4.2 Analisis Resiko (*Risk Based Inspection*)

Sebelum melakukan analisis risiko perlu melakukan *screening damage mechanism*. *Screening damage mechanism* berguna untuk pengelompokan *corrosion loop* setiap lokasi. *Damage mechanism* atau mekanisme kerusakan merupakan penyebab suatu peralatan mengalami kerusakan atau disintegritas. API 581 memberikan 21 jenis *damage mechanism* seperti yang ditunjukkan pada **Tabel 3.2**. Pemilihan tipe *damage mechanism* dilakukan dengan elakukan *screening* terhadap komposisi material penyusun *piping*, fluida yang dilayani oleh *piping*, lingkungan proses sekitar *piping*, dan kondisi lain yang turut mempengaruhi pada *screening damage mechanism*.

Tipe *damage mechanism* yang dipilih merupakan penyebab kerusakan tertinggi yang paling mempengaruhi kinerja *piping*. *Piping* yang dianalisis tersusun dari material *carbon steel* ASTM A106 Gr B. Fluida yang dilayani adalah *Gasoline*. Perlindungan *coating* berupa *painting* dan kondisi *wrapping* masih cukup baik.

Dilihat dari kondisi di atas, maka tipe *damage mechanism* yang paling sesuai adalah *thinning*. Namun apabila ditinjau dari kondisi eksternal lokasi sekitar yang berada pada daerah laut dengan curah hujan yang cukup tinggi, maka *external damage mechanism* juga turut mempengaruhi kondisi *piping*. Sehingga tipe *damage mechanism* adalah *multiple damage mechanism* antara *thinning* dan *CUI*. Hasil *screening damage mechanism* dapat dilihat pada **Tabel C-1.1 Lampiran C**.

4.2.1 Probability of Failure (POF)

Probability of failure didapatkan dari nilai *generic failure frequency*, *damage factor*, dan *factor management system*. *Damage factor* harus terlebih dahulu dihitung untuk mengetahui total dari *damage factor*. Setelah total DF diketahui, dilakukan perhitungan dengan mengkalikan nilai *generic failure frequency*, *damage factor*, dan *factor management system*.

1. Generic Failure Frequency (gff)

Generic Failure Frequency (gff) merupakan sebuah nilai representatif dari data refining dan kegagalan dari tipe-tipe komponen yang berbeda. Pada penelitian ini nilai gff yang digunakan dapat dilihat di **Tabel 4.1**. Nilai gff ditentukan sesuai dengan tipe komponen yang akan diteliti. Nilai gff digunakan sebagai frekuensi kegagalan sebelum terjadinya kerusakan yang diakibatkan oleh lingkungan terhadap operasi sebuah komponen. Pemilihan nilai gff yang digunakan di penelitian ini terlampir di **Lampiran C**.

Tabel 4.1 Summary of Generic Failure Frequency

| <i>Tag Number</i> | <i>Type</i> | <i>As a Function of Hole Size (failures/yr)</i> | | | | <i>gff_{total} (failures/yr)</i> |
|-------------------|-------------|---|---------------|--------------|----------------|--|
| | | <i>Small</i> | <i>Medium</i> | <i>Large</i> | <i>Rupture</i> | |
| 16LF37-12"-CB2D | PIPE-12 | 8.0E-06 | 2.0E-05 | 2.0E-06 | 6.0E-07 | 3.06E-05 |
| 16LF31-10"-CB2D | PIPE-10 | 8.0E-06 | 2.0E-05 | 2.0E-06 | 6.0E-07 | 3.06E-05 |
| 16LF36-8"-CB2D | PIPE-8 | 8.0E-06 | 2.0E-05 | 2.0E-06 | 6.0E-07 | 3.06E-05 |
| 16LF22-6"-CB2D | PIPE-6 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |
| 16LF40-6"-CB2D | PIPE-6 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |
| 16LF29-6"-CB2D | PIPE-6 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |
| 16LF30-6"-CB2D | PIPE-6 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |

| <i>Tag Number</i> | <i>Type</i> | <i>As a Function of Hole Size (failures/yr)</i> | | | | <i>gff_{total}</i> <i>(failures/yr)</i> |
|--------------------------|--------------------|--|----------------------|---------------------|-----------------------|--|
| | | <i>Small</i> | <i>Medium</i> | <i>Large</i> | <i>Rupture</i> | |
| 16LF38-6"-CB2D | PIPE-6 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |
| 16LF59-3"-CB2D | PIPE-4 | 8.0E-06 | 2.0E-05 | 0 | 2.6E-06 | 3.06E-05 |
| 16LF44-2"-CB2D | PIPE-2 | 2.8E-05 | 0 | 0 | 2.6E-06 | 3.06E-05 |

2. Damage Factor

Perhitungan *damage factor* menentukan nilai dari *Probability of Failure*. *Damage factor* harus terlebih dahulu dihitung untuk mengetahui total dari *damage factor*. Pada penelitian ini nilai total DF dari setiap komponen dijelaskan di **Tabel 4.2**. Perhitungan DF lebih lanjut dizpenelitian ini terlampir di **Lampiran C**.

Tabel 4.2 Summary of Total Damage Factor

| <i>Tag Number</i> | <i>Type</i> | <i>Total Damage Factor</i> |
|--------------------------|--------------------------|-----------------------------------|
| 16LF37-12"-CB2D | <i>General Corrosion</i> | 1.60E+01 |
| 16LF31-10"-CB2D | <i>General Corrosion</i> | 1.94E+00 |
| 16LF36-8"-CB2D | <i>General Corrosion</i> | 2.69E+01 |
| 16LF22-6"-CB2D | <i>General Corrosion</i> | 1.95E+00 |
| 16LF40-6"-CB2D | <i>General Corrosion</i> | 2.41E+00 |
| 16LF29-6"-CB2D | <i>General Corrosion</i> | 3.01E+00 |
| 16LF30-6"-CB2D | <i>General Corrosion</i> | 3.22E+00 |
| 16LF38-6"-CB2D | <i>General Corrosion</i> | 5.30E+00 |
| 16LF59-3"-CB2D | <i>General Corrosion</i> | 3.07E+01 |
| 16LF44-2"-CB2D | <i>General Corrosion</i> | 4.32E+02 |

A. Thinning Damage Factor

Thinning – merupakan degradasi logam karena lingkungannya yang mengakibatkan penipisan ketebalan logam tersebut, dengan kata lain korosi. Ada beberapa mekanisme thinning yang dapat terjadi, dan masing-masing terjadi pada kondisi yang berbeda. Pada penelitian ini nilai total DF dari setiap komponen dijelaskan di **Tabel 4.3**. Perhitungan *Thinning DF* lebih lanjut di penelitian ini terlampir di **Lampiran C**.

Tabel 4.3 Summary of Thinning Damage Factor

| <i>Tag Number</i> | <i>Liner</i> | <i>Thinning Damage Factor</i> |
|--------------------------|---------------------|--------------------------------------|
| 16LF37-12"-CB2D | <i>Not Present</i> | 6.72E+00 |
| 16LF31-10"-CB2D | <i>Not Present</i> | 9.78E-01 |
| 16LF36-8"-CB2D | <i>Not Present</i> | 9.64E-01 |
| 16LF22-6"-CB2D | <i>Not Present</i> | 9.77E-01 |
| 16LF40-6"-CB2D | <i>Not Present</i> | 1.21E+00 |
| 16LF29-6"-CB2D | <i>Not Present</i> | 1.52E+00 |
| 16LF30-6"-CB2D | <i>Not Present</i> | 1.71E+00 |
| 16LF38-6"-CB2D | <i>Not Present</i> | 2.95E+00 |
| 16LF59-3"-CB2D | <i>Not Present</i> | 2.93E+01 |
| 16LF44-2"-CB2D | <i>Not Present</i> | 4.30E+02 |

B. Corrosion Under Insulation Damage Factor

CUI disebabkan oleh pengumpulan air di ruang uap (atau ruang annulus) antara insulasi dan permukaan logam. Sumber air dapat mencakup hujan, kebocoran air, kondensasi, *drift* menara air pendingin, sistem banjir, dan *steam tracing leaks*. CUI menyebabkan menipisnya dinding dalam bentuk korosi lokal. CUI umumnya terjadi pada kisaran suhu antara -12 ° C dan 175 ° C (10 ° F dan 350 ° F), dengan kisaran suhu 77 ° C hingga 110 ° C (170 ° F hingga 230 ° F) adalah rentang yang paling parah. Hasil perhitungan *corrosion under insulation damage factor* pada penelitian ini dijelaskan di **Tabel 4.4**. Perhitungan *Corrosion Under Insulation DF* lebih lanjut di penelitian ini terlampir di **Lampiran C**.

Tabel 4.4 Summary of Corrosion Under Insulation Damage Factor

| Tag Number | Insulation Type | CUI Damage Factor |
|-----------------|------------------|-------------------|
| 16LF37-12"-CB2D | Calcium Silicate | 9.24E+00 |
| 16LF31-10"-CB2D | Calcium Silicate | 9.60E-01 |
| 16LF36-8"-CB2D | Calcium Silicate | 2.59E+01 |
| 16LF22-6"-CB2D | Calcium Silicate | 9.72E-01 |
| 16LF40-6"-CB2D | Calcium Silicate | 1.21E+00 |
| 16LF29-6"-CB2D | Calcium Silicate | 1.49E+00 |
| 16LF30-6"-CB2D | Calcium Silicate | 1.51E+00 |
| 16LF38-6"-CB2D | Calcium Silicate | 2.35E+00 |
| 16LF59-3"-CB2D | Calcium Silicate | 1.34E+00 |
| 16LF44-2"-CB2D | Calcium Silicate | 2.39E+00 |

3. Management System Factor

Management system factor merupakan faktor dari pengaruh manajemen sistem terhadap integritas mekanik dari komponen. Faktor ini dipengaruhi probabilitas kerusakan yang terakumulasi pada waktu lama dan proporsional terhadap kualitas dari integritas program mekanik sebuah fasilitas. Karena pada penelitian ini tidak sempat untuk melakukan penilaian *pscore* dengan kuisione, maka nilai *pscore* mengikuti rekomendasi dari API 581 sebesar 500. Dimana hasil dari F_{ms} sebesar 1. Hasil perhitungan terlampir di **Lampiran C**.

POF adalah sebagai fungsi waktu dan efektivitas inspeksi ditentukan dengan menggunakan frekuensi kegagalan generik, sistem manajemen faktor, dan DF untuk mekanisme kerusakan aktif yang berlaku. Untuk perhitungan POF dapat dirumuskan secara matematis sesuai dengan persamaan 3.1. Pada penelitian ini hasil perhitungan POF dari setiap komponen dijelaskan di **Tabel 4.5**. Perhitungan POF lebih lanjut di penelitian ini terlampir di **Lampiran C**.

Tabel 4.5 Summary of Probability of Failure

| Tag Number | Score | Category | Damage Factors |
|-----------------|----------|----------|----------------|
| 16LF37-12"-CB2D | 4.89E-04 | 3 | Possible |
| 16LF31-10"-CB2D | 5.93E-05 | 2 | Unlikely |
| 16LF36-8"-CB2D | 8.23E-04 | 3 | Possible |

| <i>Tag Number</i> | <i>Score</i> | <i>Category</i> | <i>Damage Factors</i> |
|-------------------|--------------|-----------------|-----------------------|
| 16LF22-6"-CB2D | 5.97E-05 | 2 | <i>Unlikely</i> |
| 16LF40-6"-CB2D | 7.39E-05 | 2 | <i>Unlikely</i> |
| 16LF29-6"-CB2D | 9.20E-05 | 2 | <i>Unlikely</i> |
| 16LF30-6"-CB2D | 9.85E-05 | 2 | <i>Unlikely</i> |
| 16LF38-6"-CB2D | 1.62E-04 | 2 | <i>Unlikely</i> |
| 16LF59-3"-CB2D | 9.38E-04 | 3 | <i>Possible</i> |
| 16LF44-2"-CB2D | 1.32E-02 | 4 | <i>Likely</i> |

4.2.2 Consequence of Failure (COF)

Perhitungan *Consequence of Failure* (COF) piping pada penelitian ini terlampir pada **Lampiran C**. Perhitungan COF dilakukan untuk menentukan level risiko item peralatan berdasarkan risiko dan juga dimaksudkan untuk digunakan untuk menetapkan prioritas untuk program inspeksi. Perhitungan COF akan dilakukan untuk membantu dalam menetapkan peringkat equipment berdasarkan risiko dan juga dimaksudkan untuk digunakan untuk menetapkan prioritas untuk program inspeksi. Sesuai dengan API 581 RP, ada dua jenis level COF yaitu Level 1 dan Level 2 yang memiliki aplikasi karakteristik fluida yang berbeda satu sama lain. Pada penelitian ini COF Level 1 digunakan untuk melakukan perhitungan. Pada **Tabel 4.6** dijelaskan hasil dari setiap perhitungan COF dari setiap komponen.

Tabel 4.6 Summary of Consequence of Failure

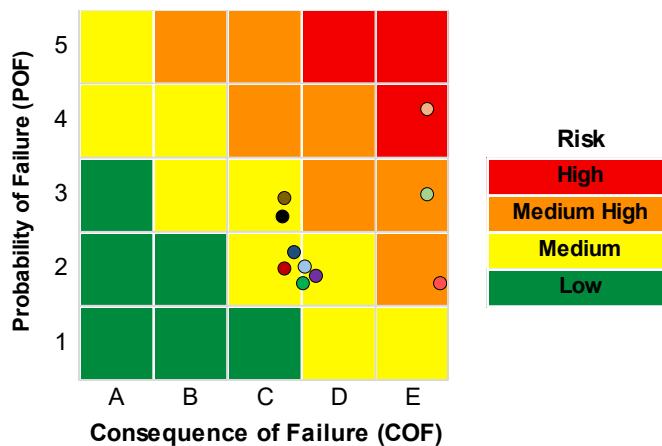
| <i>Tag Number</i> | <i>Rep. Fluid</i> | <i>Fluid Phase</i> | <i>Score (m²)</i> | <i>Category</i> | |
|-------------------|-------------------|--------------------|------------------------------|-----------------|---------------------|
| 16LF37-12"-CB2D | C6-C8 | <i>Liquid</i> | 5.47E+02 | C | <i>Serious</i> |
| 16LF31-10"-CB2D | C6-C8 | <i>Liquid</i> | 6.99E+04 | E | <i>Catastrophic</i> |
| 16LF36-8"-CB2D | C6-C8 | <i>Liquid</i> | 5.66E+02 | C | <i>Serious</i> |
| 16LF22-6"-CB2D | C6-C8 | <i>Liquid</i> | 9.80E+02 | D | <i>Major</i> |
| 16LF40-6"-CB2D | C6-C8 | <i>Liquid</i> | 1.48E+03 | D | <i>Major</i> |
| 16LF29-6"-CB2D | C6-C8 | <i>Liquid</i> | 5.62E+02 | C | <i>Serious</i> |
| 16LF30-6"-CB2D | C6-C8 | <i>Liquid</i> | 1.07E+03 | D | <i>Major</i> |
| 16LF38-6"-CB2D | C6-C8 | <i>Liquid</i> | 7.50E+02 | C | <i>Serious</i> |
| 16LF59-3"-CB2D | C6-C8 | <i>Liquid</i> | 4.79E+04 | E | <i>Catastrophic</i> |
| 16LF44-2"-CB2D | C6-C8 | <i>Liquid</i> | 4.67E+04 | E | <i>Catastrophic</i> |

4.2.3 Risk Rank

Setelah menghitung *Probability of Failure* (POF) dan *Consequence of Failure* (COF), hasil dari level risiko diketahui seperti dijelaskan di **Gambar 4.1** dan **Tabel 4.7**. Perhitungan *Risk Rank* lebih lanjut dijelaskan di **Lampiran C**. Selanjutnya dilakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat sesuai dengan hasil level risiko yang diketahui. Jika hasilnya diterima, dapat terus melakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat. Di sisi lain, jika hasilnya ditolak, maka, kita harus melakukan beberapa langkah mitigasi yang mengharuskan untuk menghitung kembali POF dan COF hingga hasilnya diterima sepenuhnya.

Tabel 4.7 Summary of Risk Based Inspection Result

| No | Tag Number | Score ($m^2/year$) | Category | | Code |
|----|-----------------|----------------------|----------|-------------|------|
| 1 | 16LF37-12"-CB2D | 2.67E-01 | 3C | Medium | ● |
| 2 | 16LF31-10"-CB2D | 4.15E+00 | 2E | Medium High | ● |
| 3 | 16LF36-8"-CB2D | 4.66E-01 | 3C | Medium | ● |
| 4 | 16LF22-6"-CB2D | 5.85E-02 | 2D | Medium | ● |
| 5 | 16LF40-6"-CB2D | 1.10E-01 | 2D | Medium | ● |
| 6 | 16LF29-6"-CB2D | 5.17E-02 | 2C | Medium | ● |
| 7 | 16LF30-6"-CB2D | 1.06E-01 | 2D | Medium | ● |
| 8 | 16LF38-6"-CB2D | 1.22E-01 | 2C | Medium | ● |
| 9 | 16LF59-3"-CB2D | 4.49E+01 | 3E | Medium High | ● |
| 10 | 16LF44-2"-CB2D | 6.17E+02 | 4E | High | ● |

**Gambar 4.1 Level Risiko Setiap Piping**

4.3 Inspection Plan

Setelah level risiko diketahui dilanjutkan untuk membuat strategi inspeksi sesuai dengan level risiko. *Risk target* ditentukan sebesar $3.72 m^2/year$ sebagai batas diterimanya level risiko. Jika hasilnya diterima, dapat terus melakukan perencanaan inspeksi menggunakan metodologi perawatan yang tepat. Di sisi lain, jika hasilnya ditolak, maka, kita harus melakukan beberapa langkah mitigasi yang mengharuskan untuk menghitung kembali POF dan COF hingga hasilnya diterima sepenuhnya atau menggunakan *date* dari *risk target* sebagai acuan perencanaan inspeksi selanjutnya. Rekomendasi *Inspection Plan* lebih lanjut dijelaskan di **Lampiran D**.

Pada penelitian ini rekomendasi *inspection effectiveness* yang digunakan adalah kategori C (*fairly effective*). Rekomendasi tersebut digunakan karena pertimbangan historis inspeksi sebelumnya. Jika tingkat inspeksi diperlukan dalam mitigasi, maka kategori inspeksi harus ditingkatkan levelnya menjadi lebih tinggi. Hal itu berguna agar mitigasi bisa membantu dalam perencanaan inspeksi sebelumnya. Selain itu penentuan strategi inspeksi sesuai dengan level risiko sangat berperan dalam mengurangi biaya dan membuat strategi inspeksi lebih efektif dan strategis. Seperti dijelaskan pada **Tabel 3.20**, rekomendasi inspeksi berdasarkan level risiko. Pada **Gambar 3.4** juga dijelaskan lokasi yang rentan terjadi CUI dan **Tabel 2.21** dijelaskan lokasi mana saja yang paling sering terjadinya CUI.

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BAB V

KESIMPULAN DAN SARAN

5.1 Kesimpulan

Kesimpulan yang dapat diambil dari hasil penelitian dalam tugas akhir ini adalah:

- Nilai dari *probability of failure* dari setiap komponen yang diteliti seperti dijelaskan pada **Tabel 5.1** di bawah.

Tabel 5.1 Probability of Failure

| <i>Tag Number</i> | <i>Score</i> | <i>Category</i> | | <i>Total DF</i> | <i>gff_{total} (failures/yr)</i> | <i>F_{MS}</i> |
|-------------------|--------------|-----------------|-----------------|-----------------|--|-----------------------|
| 16LF37-12"-CB2D | 4.89E-04 | 3 | <i>Possible</i> | 1.60E+01 | 3.06E-05 | 1 |
| 16LF31-10"-CB2D | 5.93E-05 | 2 | <i>Unlikely</i> | 1.94E+00 | 3.06E-05 | 1 |
| 16LF36-8"-CB2D | 8.23E-04 | 3 | <i>Possible</i> | 2.69E+01 | 3.06E-05 | 1 |
| 16LF22-6"-CB2D | 5.97E-05 | 2 | <i>Unlikely</i> | 1.95E+00 | 3.06E-05 | 1 |
| 16LF40-6"-CB2D | 7.39E-05 | 2 | <i>Unlikely</i> | 2.41E+00 | 3.06E-05 | 1 |
| 16LF29-6"-CB2D | 9.20E-05 | 2 | <i>Unlikely</i> | 3.01E+00 | 3.06E-05 | 1 |
| 16LF30-6"-CB2D | 9.85E-05 | 2 | <i>Unlikely</i> | 3.22E+00 | 3.06E-05 | 1 |
| 16LF38-6"-CB2D | 1.62E-04 | 2 | <i>Unlikely</i> | 5.30E+00 | 3.06E-05 | 1 |
| 16LF59-3"-CB2D | 9.38E-04 | 3 | <i>Possible</i> | 3.07E+01 | 3.06E-05 | 1 |
| 16LF44-2"-CB2D | 1.32E-02 | 4 | <i>Likely</i> | 4.32E+02 | 3.06E-05 | 1 |

- Nilai dari *Consequence of failure* dari setiap komponen yang diteliti seperti dijelaskan pada **Tabel 5.2** di bawah.

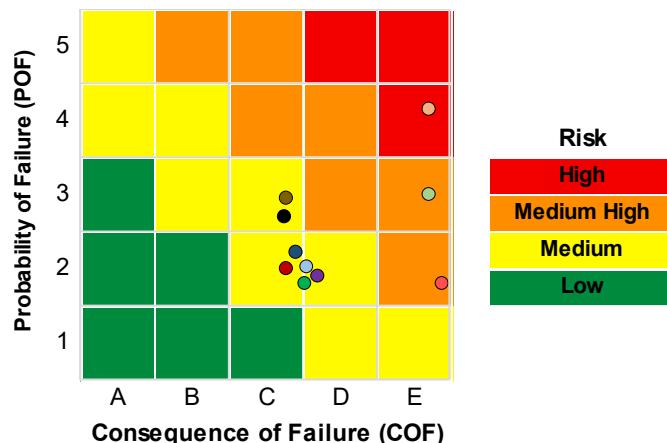
Tabel 5.2 Consequence of Failure

| <i>Tag Number</i> | <i>Rep. Fluid</i> | <i>Fluid Phase</i> | <i>Score (m²)</i> | <i>Category</i> | |
|-------------------|-------------------|--------------------|------------------------------|-----------------|---------------------|
| 16LF37-12"-CB2D | C6-C8 | <i>Liquid</i> | 5.47E+02 | C | <i>Serious</i> |
| 16LF31-10"-CB2D | C6-C8 | <i>Liquid</i> | 6.99E+04 | E | <i>Catastrophic</i> |
| 16LF36-8"-CB2D | C6-C8 | <i>Liquid</i> | 5.66E+02 | C | <i>Serious</i> |
| 16LF22-6"-CB2D | C6-C8 | <i>Liquid</i> | 9.80E+02 | D | <i>Major</i> |
| 16LF40-6"-CB2D | C6-C8 | <i>Liquid</i> | 1.48E+03 | D | <i>Major</i> |
| 16LF29-6"-CB2D | C6-C8 | <i>Liquid</i> | 5.62E+02 | C | <i>Serious</i> |
| 16LF30-6"-CB2D | C6-C8 | <i>Liquid</i> | 1.07E+03 | D | <i>Major</i> |
| 16LF38-6"-CB2D | C6-C8 | <i>Liquid</i> | 7.50E+02 | C | <i>Serious</i> |
| 16LF59-3"-CB2D | C6-C8 | <i>Liquid</i> | 4.79E+04 | E | <i>Catastrophic</i> |
| 16LF44-2"-CB2D | C6-C8 | <i>Liquid</i> | 4.67E+04 | E | <i>Catastrophic</i> |

3. Hasil dari analisis risiko (RBI) dari setiap komponen yang diteliti seperti dijelaskan pada **Tabel 5.3** dan **Gambar 5.1** di bawah.

Tabel 5.3 Risk Based Inspection Result

| No | Tag Number | Score ($m^2/year$) | Category | Code |
|----|-----------------|----------------------|----------|-------------|
| 1 | 16LF37-12"-CB2D | 2.67E-01 | 3C | Medium |
| 2 | 16LF31-10"-CB2D | 4.15E+00 | 2E | Medium High |
| 3 | 16LF36-8"-CB2D | 4.66E-01 | 3C | Medium |
| 4 | 16LF22-6"-CB2D | 5.85E-02 | 2D | Medium |
| 5 | 16LF40-6"-CB2D | 1.10E-01 | 2D | Medium |
| 6 | 16LF29-6"-CB2D | 5.17E-02 | 2C | Medium |
| 7 | 16LF30-6"-CB2D | 1.06E-01 | 2D | Medium |
| 8 | 16LF38-6"-CB2D | 1.22E-01 | 2C | Medium |
| 9 | 16LF59-3"-CB2D | 4.49E+01 | 3E | Medium High |
| 10 | 16LF44-2"-CB2D | 6.17E+02 | 4E | High |



Gambar 5.1 Level Risiko Setiap Komponen

4. Rekomendasi tahun inspeksi selanjutnya untuk setiap komponen dijelaskan pada **Tabel 5.4** dan untuk *inspection plan* setiap komponen dijelaskan lebih lanjut di **Lampiran D**. Interval inspeksi setiap komponen direkomendasikan setiap 5 tahun sesuai dengan rekomendasi API 570. Adapun setelah dilakukan analisis risiko, pada beberapa komponen melebihi batas maksimal dari *risk target*. Maka dari itu untuk mitigasi, tahun inspeksi selanjutnya menggunakan tahun dimana komponen tersebut mencapai *risk target*.

Tabel 5.4 Recommendation Inspection Date

| No | Tag Number | Date |
|----|-----------------|------------|
| 1 | 16LF37-12"-CB2D | 01-06-2022 |
| 2 | 16LF31-10"-CB2D | 07-03-2020 |
| 3 | 16LF36-8"-CB2D | 16-01-2021 |
| 4 | 16LF22-6"-CB2D | 01-06-2022 |
| 5 | 16LF40-6"-CB2D | 01-06-2022 |
| 6 | 16LF29-6"-CB2D | 01-06-2022 |
| 7 | 16LF30-6"-CB2D | 01-06-2022 |
| 8 | 16LF38-6"-CB2D | 25-11-2021 |
| 9 | 16LF59-3"-CB2D | 24-05-2020 |
| 10 | 16LF44-2"-CB2D | 18-04-2020 |

Strategi inspeksi yang digunakan lebih jelas terlampir di **Lampiran D** dapat digunakan sebagai rekomendasi agar bisa digunakan sebagai acuan strategi inspeksi selanjutnya dan metode inspeksi yang dipakai. Metode inspeksi yang digunakan sesuai dengan level risiko seperti **Tabel 5.5**. Untuk *inspection effectiveness* yang digunakan adalah kategori C dengan pertimbangan inspeksi yang digunakan sebelumnya. Metode inspeksi yang digunakan yaitu *Visual Testing* (VT) dan *Ultrasonic Testing* (UT) atau *Radiographic Testing* (RT).

Tabel 5.5 Rekomendasi inspeksi sesuai dengan level risiko

(sumber: EFC CUI Guidelines, 2016)

| Level Risiko | Rekomendasi Inspeksi |
|--------------|---|
| High | <ul style="list-style-type: none"> • 100% removal of thermal insulation • Complete visual inspection of exposed areas for corr. and condition of coating as applicable • Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography. • Reevaluate the risk |
| Medium High | <ul style="list-style-type: none"> • >40% removal of thermal insulation including all critical points and damaged areas • Complete visual inspection of exposed areas for corr. and condition of coating as applicable • Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography. • Reevaluate the risk |
| Medium | <ul style="list-style-type: none"> • >20% removal of thermal insulation including all critical points and damaged areas • Complete visual inspection of exposed areas for corr. and condition of coating as applicable • Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography. • Reevaluate the risk |

| Level Risiko | Rekomendasi Inspeksi |
|--------------|--|
| <i>Low</i> | <ul style="list-style-type: none"> • <i>Remove thermal insulation at all critical points with evidence of damage</i> • <i>Complete visual inspection of exposed areas for corr. and condition of coating as applicable</i> • <i>Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.</i> • <i>Reevaluate the risk</i> |

5.2 Saran

1. Data yang digunakan dalam analisis RBI seharusnya data beberapa inspeksi terakhir, sehingga hasil analisis diharapkan lebih akurat.
2. Pembuatan CML pada bagian *piping* yang rentan terjadi CUI agar memudahkan dalam inspeksi dan tidak harus melepas semua *insulation* pada pipa ketika melakukan inspeksi.
3. Perlu dilakukan mitigasi pada pipa dengan *tag number*: 16LF31-10"-CB2D, 16LF36-8"-CB2D, 16LF38-6"-CB2D, 16LF59-3"-CB2D, dan 16LF44-2"-CB2D. Salah satu Langkah mitigasi adalah melakukan inspeksi lebih awal sebagai langkah *preventive* agar tidak terjadi kerusakan.

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Attachment A
Assets Data



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Asset Data

Attach. A-1
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 112.00 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 7.77 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 122 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-12 |
| Diameter (in) | 12 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-2
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 174.00 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 9.15 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 174 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-10 |
| Diameter (in) | 10 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-3
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 8" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 70.51 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 7.99 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 70.51 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-8 |
| Diameter (in) | 8 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-4
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16E-11 |
| Material | Carbon Steel | To | Vessel 16E-5 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 131.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 6.9 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 131 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Diameter (in) | 6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-5
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF22-6"-CB2D |
| Material | Carbon Steel | To | 16LF39-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 129.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 6.7 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 129 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Diameter (in) | 6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-6
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 128.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 6.5 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 128 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Diameter (in) | 6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-7
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 131.50 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 6.4 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 131.5 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Diameter (in) | 6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-8
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | 16LF22-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 130.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 6 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 130 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Diameter (in) | 6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-9
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 3" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 197.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 4.2 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 197 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-4 |
| Diameter (in) | 3 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |



Asset Data

Attach. A-10
Rev. No. 0
Year 2020

1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 2" | From | 16LF36-8"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 197.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |

3 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Last Inspection | 01-06-2017 |
| Thickness (mm) | 3.18 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 197 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-4 |
| Diameter (in) | 2 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

Attachment B
Piping & Instrumentation Diagram

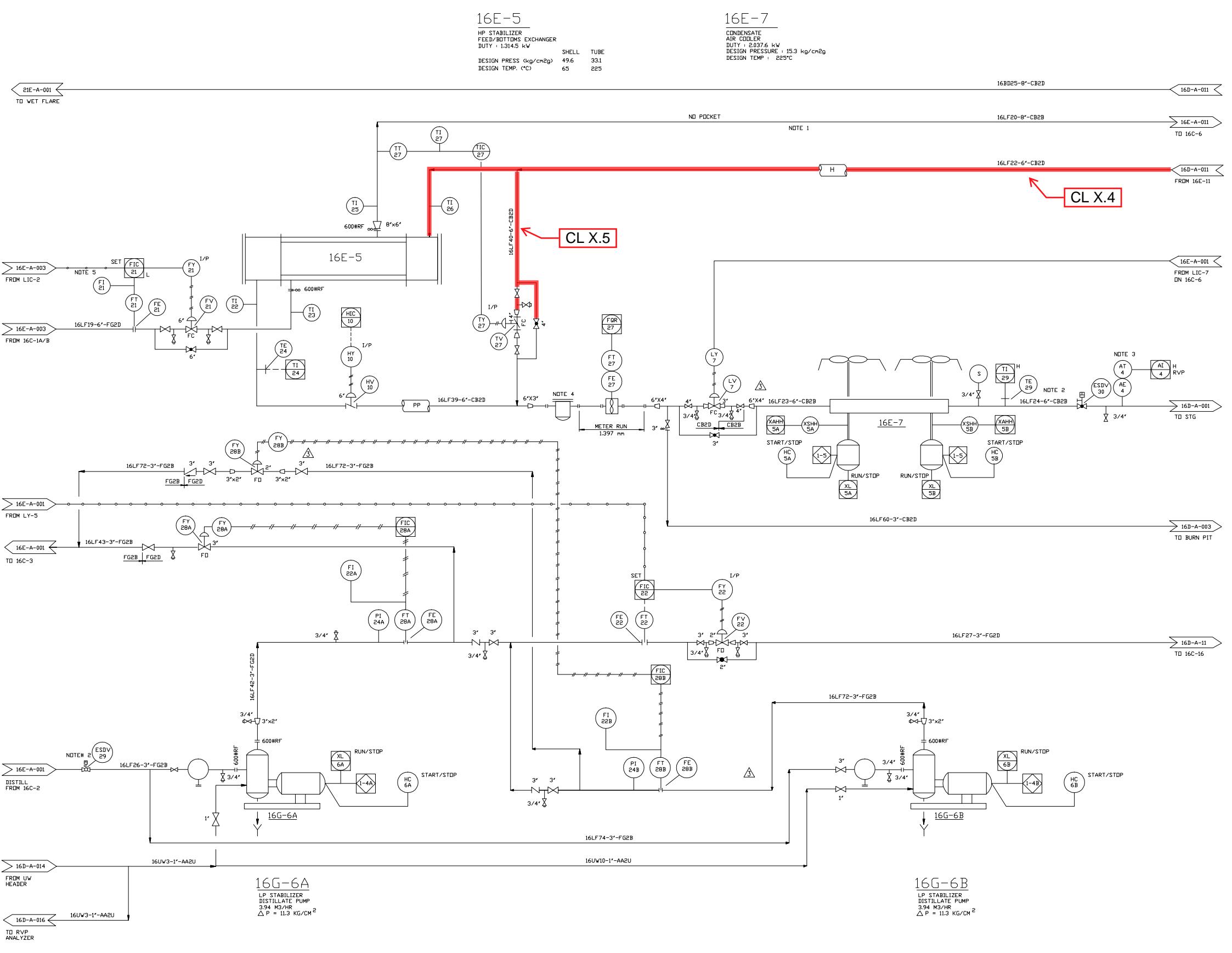


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NOTES

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 2. FDR ESR DETAILS, SEE DIAGRAM "A" ON PBD 16D-A-016
 3. FDR RVP ANALYSIS DETAILS, SEE DIAGRAM C ON PBD 16D-A-016
 4. STRAINER PART OF TURBINE METER VENDOR SUPPLY
DUPLEX STRAINER TO BE PROVIDED
 5. THE CONTROL SIGNAL TO FDV-21 WILL BE SET BY DIFFERENT BAND OF THE SPLIT RANGE OUTPUT OF LIC-2 DEPENDING ON WHICH OF THREE OPERATING CASES IS SELECTED IN LY-2

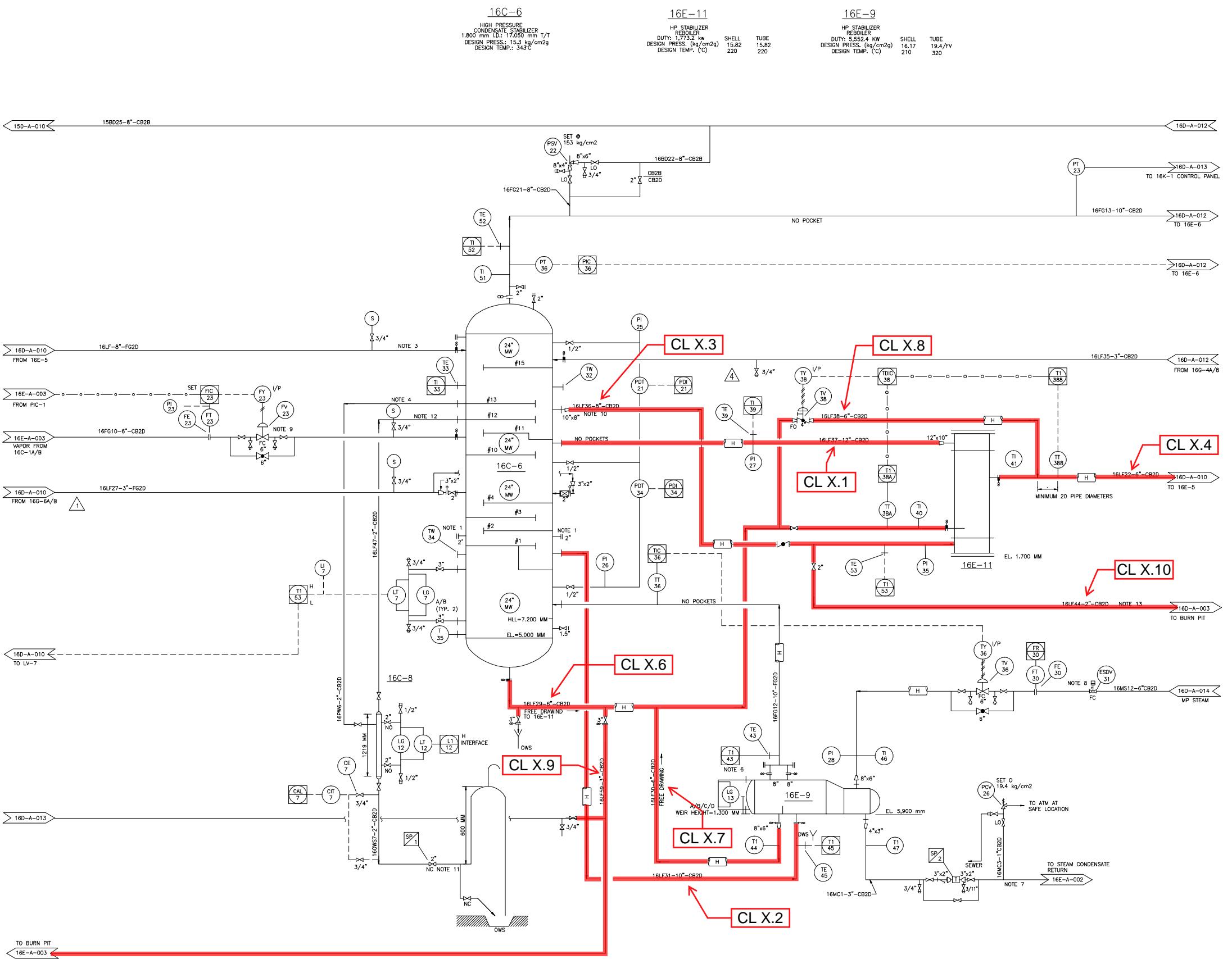
REFERENCE DRAWINGS

PLANT 16 REVAMP PROJECT
PIPING & INSTRUMENTATION DIAGRAM
HP CONDENSATE STABILIZER

| | PROJECT NO. | DRAWING NO | REV. |
|--|-------------|------------------|------|
| | 72912 | 16D-A-010 | 3 |

NOTES

1. NOZZLES ARE PROVIDED FOR POSSIBLE FUTURE PROCESSING OF TRAINS A-D DEBUONIZER BOTTOMS STREAMS. NOZZLES ARE ON TRAY #14.
2. DELETED.
3. BRACE PIPING FOR SLUG FLOW.
4. WATER DRAW PAN IS ON TRAY 13.
5. DELETED.
6. AVAILABLE FOR USE IN REBOILER TEMPERATURE CONTROL IF REQUIRED.
7. BRACE PIPING FOR TWO-PHASE FLOW.
8. FOR ESDV DETAILS, SEE DIAGRAM "A" ON P & ID 16D-A-016.
9. CONTROL VALVE TO LIMIT FLOW TO MAXIMUM SHOWN ON MATERIAL BALANCE.
10. MINIMUM 6 METERS REQUIRED VERTICAL ELEVATION BETWEEN 16C-11 DRAW-OFF AND 16E-11 INLET.
11. INVIEW OF INTERFACE LEVEL GAUGE GLASS.
12. RETURN ON TRAY 12
13. EPS CONTRACTOR TO CONFIRM ROUTING.



Attachment C
Risk Based Inspection Calculation



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- C-6 16LF29-6"-CB2D
- C-7 16LF30-6"-CB2D
- C-8 16LF38-6"-CB2D
- C-9 16LF59-3"-CB2D
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**Attachment C-1
16LF37-12"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 112.00 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-1.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



Probability of Failure

Attach. C-1
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Table C-1.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



Probability of Failure

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Table C-1.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



Probability of Failure

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Table C-1.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-12
Diameter 12 in

Table C-1.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-1.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-1.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 6.72\text{E+00}$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-1.3})$$

$$D_{f-gov}^{SCC} = 0.00\text{E+00}$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-1.4})$$

$$D_{f-gov}^{extd} = 9.24\text{E+00}$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-1.5})$$

$$D_{f-gov}^{brit} = 0.00\text{E+00}$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00\text{E+00}$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00\text{E+00}$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-1.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-1.7})$$

$$D_{f-total} = 1.60\text{E+01} \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-1.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-1.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 4.89E-04 \quad (\text{C-1.10})$$

Table C-1.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 3 | <i>Possible</i> |



Thinning Damage Factor

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6 Date |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 7.77 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 122 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-12 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 7.77 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.052 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 7.77 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (RBI date \quad 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-1.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-1.12})$$

$$t_{min} = \frac{5.1 \times 323.8}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 7.49 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-1.13})$$

$$A_{rt} = \frac{0.052 \times 3.00}{7.77}$$

$$A_{rt} = 0.020177$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-1.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-1.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{7.49}{7.77}$$

$$SR_P^{Thin} = 0.3689$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-1.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-1.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-1.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-1.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.1032$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.0612$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 2.9674$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 12"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-1.19})$$

$$D_{fb}^{Thin} = 6.72E+00$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-1.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{6.7234 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 6.72E+00$$



1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6 Date |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.052 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | Fairly Effective |
| Thickness Reading (mm) | 1 |
| Thickness Reading Date | 7.77 |
| | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 7.77 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 122 \text{ }^{\circ}\text{C} \\ Cr_b &= 0.086 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.11 \text{ mm/year} \end{aligned} \quad (\text{C-1.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 7.77 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-1.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-1.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-1.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 7.49 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-1.25})$$

$$A_{rt} = \frac{0.108 \times 3.00}{7.77}$$

$$A_{rt} = 0.041644$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-1.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-1.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{7.77} \times \frac{7.49}{7.77}$$

$$SR_P^{CUIF} = 0.368888$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-1.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-1.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-1.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-1.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.0584$$



CUI Damage Factor

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$$\begin{aligned}\beta_2^{CUIF} &= \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}} \\ \beta_2^{CUIF} &= 2.9609 \\ \beta_3^{CUIF} &= \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}} \\ \beta_3^{CUIF} &= 2.7169\end{aligned}$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (\text{C-1.31})$$
$$D_f^{CUIF} = 9.24E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-1.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-1.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 12 in = 304.8 mm



Consequence of Failure

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Table C-1.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 304.8$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-12

Table C-1.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-1.32})$$

Table C-1.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 72995.25 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-1.33})$$

Table C-1.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 1.8E+03 kg/s |



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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 2261.27 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-1.34})$$

$$W_8 = 7.85E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-1.35})$$

Table C-1.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.40E+02 kg/s | 2.14E+03 kg/s | 3.56E+04 kg/s | 1.41E+05 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-1.36})$$

Table C-1.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 2.40E+03 kg/s | 4.40E+03 kg/s | 3.78E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-1.37})$$

Table C-1.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.83E+03 s | 3.82E+02 s | 2.29E+01 s | 2.57E+00 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-1.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-1.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-1.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-1.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-1.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-1.38)$$

Table C-1.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.23E-01 kg/s | 9.50E+00 kg/s | 1.58E+02 kg/s | 1.41E+03 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\frac{Mass_{avail,n}}{Rate_n} , \{ 60 . Id_{max,n} \}] \quad (C-1.39)$$

Table C-1.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.80E+03 s | 4.63E+02 s | 2.39E+02 s | 4.25E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \} , Mass_{avail,n}] \quad (C-1.40)$$

Table C-1.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.12E+03 kg | 4.40E+03 kg | 3.78E+04 kg | 6.01E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-1.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (C-1.41)$$

Table C-1.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.43E+00 | 9.47E-01 | 4.69E+00 | 5.49E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-1.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-1.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-1.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | | b | | a | | b | | a | |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-1.42)$$

Table C-1.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.68E+01 m ² | 1.90E+02 m ² | 2.32E+03 m ² | 1.63E+04 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-1.43)$$



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Table C-1.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.94E+01 m ² | 2.24E+05 m ² | 1.73E+06 m ² | 2.69E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-1.44})$$

Table C-1.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.40E+01 m ² | 4.12E+02 m ² | 4.46E+02 m ² | 5.46E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-1.45})$$

Table C-1.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.04E+02 m ² | 3.08E+02 m ² | 4.31E+02 m ² | 4.75E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-1.46})$$

Table C-1.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.77E+01 m ² | 5.39E+02 m ² | 6.58E+03 m ² | 4.62E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-1.47)$$

Table C-1.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.23E+02 m ² | 1.50E+03 m ² | 2.00E+04 m ² | 1.50E+05 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-1.48)$$

Table C-1.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.74E+02 m ² | 4.14E+02 m ² | 1.30E+03 m ² | 1.59E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-1.49)$$

Table C-1.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.42E+02 m ² | 1.12E+03 m ² | 1.51E+03 m ² | 1.66E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-1.50)$$

Table C-1.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.47E-02 | 3.77E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-1.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 395.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-1.52)

Table C-1.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.56E+02 m ² | 1.40E+05 m ² | 4.31E+02 m ² | 4.75E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-1.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.23E+02 m ² | 2.06E+03 m ² | 1.51E+03 m ² | 1.66E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-1.54)

Table C-1.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.76E+01 m ² | 5.31E+02 m ² | 4.46E+02 m ² | 5.46E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-1.55)

Table C-1.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.28E+02 m ² | 7.50E+02 m ² | 1.30E+03 m ² | 1.59E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-1.56)



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Table C-1.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.76E+01 m ² | 5.31E+02 m ² | 4.46E+02 m ² | 5.46E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-1.57)$$

Table C-1.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.28E+02 m ² | 7.50E+02 m ² | 1.30E+03 m ² | 1.59E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 3.66E+02 \text{ m}^2 \quad (C-1.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 5.47E+02 \text{ m}^2 \quad (C-1.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 3.66E+02 \text{ m}^2 \quad (C-1.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 5.47E+02 \text{ m}^2 \quad (C-1.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 5.47E+02 \text{ m}^2 \quad (\text{C-1.64})$$

Table C-1.42 Consequence of Failure Category

| COF Category | |
|--------------|---------|
| C | Serious |



Result

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A. EQUIPMENT SPECIFICATION

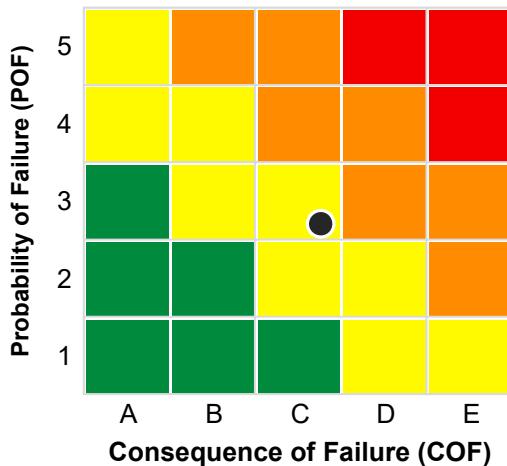
| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 1.60E+01$
 - POF Score
 $P_f(t) = 4.89E-04$
 - Category
3 - Possible
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 5.47E+02 \text{ m}^2$
 - Category
C - Serious

- c. Risk Ranking
 - Risk Score
 $R(t) = 2.67E-01 \text{ m}^2/\text{year}$
 - Risk Ranking
3C Medium
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-1.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

Attachment C-2
16LF31-10"-CB2D



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 174.00 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-2.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-2.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|---|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | <p>Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions:</p> <ul style="list-style-type: none"> • Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays. • Some areas are subject to acid vapors, process spills or the ingress of moisture. • The component is composed of carbon steel and the operating temperature is 23°C - 121°C. • The component has deteriorated wrapping or coatings. • The component is subject to frequent outages. | No |



Probability of Failure

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Table C-2.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



Probability of Failure

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Table C-2.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-10
Diameter 10 in

Table C-2.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-2.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-2.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 9.78E-01$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-2.3})$$

$$D_{f-gov}^{SCC} = 0.00E+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-2.4})$$

$$D_{f-gov}^{extd} = 9.60E-01$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-2.5})$$

$$D_{f-gov}^{brit} = 0.00E+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00E+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00E+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-2.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-2.7})$$

$$D_{f-total} = 1.94E+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-2.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-2.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 5.93E-05 \quad (\text{C-2.10})$$

Table C-2.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6 Date |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 9.15 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 174 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-10 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 9.15 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.011 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 9.15 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-2.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-2.12})$$

$$t_{min} = \frac{5.1 \times 273}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 6.56 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-2.13})$$

$$A_{rt} = \frac{0.011 \times 3.00}{9.15}$$

$$A_{rt} = 0.003661$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-2.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-2.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{6.56}{9.15}$$

$$SR_P^{Thin} = 0.2745$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-2.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-2.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-2.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-2.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.6137$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.6085$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.5979$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 10"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-2.19})$$

$$D_{fb}^{Thin} = 9.78E-01$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-2.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{0.9784 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 9.78E-01$$



1 Asset

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6 Date |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.011 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 9.15 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 9.15 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 174 \text{ }^{\circ}\text{C} \\ Cr_b &= 0.004 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.00 \text{ mm/year} \end{aligned} \quad (\text{C-2.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 9.15 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-2.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-2.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-2.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 6.56 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-2.25})$$

$$A_{rt} = \frac{0.004 \times 3.00}{9.15}$$

$$A_{rt} = 0.001464$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-2.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-2.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{9.15} \times \frac{6.56}{9.15}$$

$$SR_P^{CUIF} = 0.274526$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-2.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-2.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-2.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-2.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.6168$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.6148$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.6106$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-2.31)$$
$$D_f^{CUIF} = 9.60E-01$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-2.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-2.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 10 in = 254.0 mm



Consequence of Failure

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Table C-2.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 254.0$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-10

Table C-2.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-2.32})$$

Table C-2.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 50691.14 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-2.33})$$

Table C-2.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 1.2E+03 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 1160.29 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-2.34})$$

$$W_8 = 7.85E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-2.35})$$

Table C-2.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.40E+02 kg/s | 2.14E+03 kg/s | 3.56E+04 kg/s | 1.41E+05 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-2.36})$$

Table C-2.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.30E+03 kg/s | 3.30E+03 kg/s | 3.67E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-2.37})$$

Table C-2.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.83E+03 s | 3.82E+02 s | 2.29E+01 s | 3.70E+00 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-2.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-2.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-2.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-2.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-2.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |
| | | | | | |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-2.38)$$

Table C-2.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.23E-01 kg/s | 9.50E+00 kg/s | 1.58E+02 kg/s | 9.81E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\frac{Mass_{avail,n}}{Rate_n} , \{ 60 . Id_{max,n} \}] \quad (C-2.39)$$

Table C-2.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.80E+03 s | 3.47E+02 s | 2.32E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \} , Mass_{avail,n}] \quad (C-2.40)$$

Table C-2.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.12E+03 kg | 3.30E+03 kg | 3.67E+04 kg | 5.88E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-2.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (C-2.41)$$

Table C-2.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.43E+00 | 4.46E-01 | 4.63E+00 | 5.45E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-2.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-2.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-2.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | | b | | a | | b | | a | |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-2.42)$$

Table C-2.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.68E+01 m ² | 1.90E+02 m ² | 2.32E+03 m ² | 1.18E+04 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-2.43)$$



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Table C-2.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.94E+01 m ² | 1.71E+05 m ² | 1.68E+06 m ² | 2.63E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-2.44})$$

Table C-2.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.40E+01 m ² | 6.98E+02 m ² | 4.41E+02 m ² | 5.41E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-2.45})$$

Table C-2.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.04E+02 m ² | 6.53E+02 m ² | 4.29E+02 m ² | 4.73E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-2.46})$$

Table C-2.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.77E+01 m ² | 5.39E+02 m ² | 6.58E+03 m ² | 3.34E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-2.47)$$

Table C-2.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.23E+02 m ² | 1.50E+03 m ² | 2.00E+04 m ² | 1.07E+05 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-2.48)$$

Table C-2.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.74E+02 m ² | 8.78E+02 m ² | 1.29E+03 m ² | 1.58E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-2.49)$$

Table C-2.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.42E+02 m ² | 2.37E+03 m ² | 1.51E+03 m ² | 1.65E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-2.50)$$

Table C-2.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.47E-02 | 3.77E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-2.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 447.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 1$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-2.52)

Table C-2.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.56E+02 m ² | 1.07E+05 m ² | 4.29E+02 m ² | 4.73E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-2.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.23E+02 m ² | 3.31E+03 m ² | 1.51E+03 m ² | 1.65E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-2.54)

Table C-2.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.76E+01 m ² | 8.17E+02 m ² | 4.41E+02 m ² | 5.41E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-2.55)

Table C-2.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.28E+02 m ² | 1.21E+03 m ² | 1.29E+03 m ² | 1.58E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-2.56)



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Table C-2.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.56E+02 m ² | 1.07E+05 m ² | 8.70E+02 m ² | 1.01E+03 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-2.57)$$

Table C-2.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.23E+02 m ² | 3.31E+03 m ² | 1.51E+03 m ² | 1.65E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 6.99E+04 \text{ m}^2 \quad (C-2.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 2.13E+03 \text{ m}^2 \quad (C-2.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-2.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 6.99E+04 \text{ m}^2 \quad (C-2.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 2.13E+03 \text{ m}^2 \quad (C-2.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 6.99E+04 \text{ m}^2 \quad (\text{C-2.64})$$

Table C-2.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| E | Catastrophic |



Result

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A. EQUIPMENT SPECIFICATION

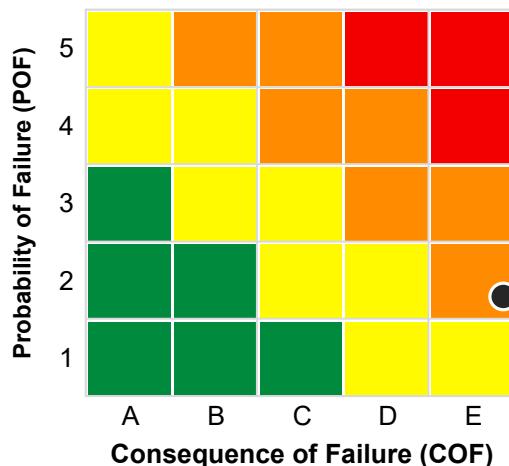
| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 1.94E+00$
 - POF Score
 $P_f(t) = 5.93E-05$
 - Category
2 - Unlikely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 6.99E+04 \text{ m}^2$
 - Category
E - Catastrophic

- c. Risk Ranking
 - Risk Score
 $R(t) = 4.15E+00 \text{ m}^2/\text{year}$
 - Risk Ranking
2E Medium High
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-2.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

**Attachment C-3
16LF36-8"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 8" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 70.51 |
| Operating Pressure (MPa) | 1.25 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-3.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-3.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-3.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-3.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-8
Diameter 8 in

Table C-3.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-3.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-3.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 9.64E-01$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-3.3})$$

$$D_{f-gov}^{SCC} = 0.00E+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-3.4})$$

$$D_{f-gov}^{extd} = 2.59E+01$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-3.5})$$

$$D_{f-gov}^{brit} = 0.00E+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00E+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00E+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-3.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-3.7})$$

$$D_{f-total} = 2.69E+01 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-3.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-3.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 8.23E-04 \quad (\text{C-3.10})$$

Table C-3.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 3 | <i>Possible</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|-----------|--------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 8" | From | Vessel | 16C-6 |
| Material | Carbon Steel | To | Vessel | 16E-11 |
| | ASTM A106 Gr B | Unit | Plant | 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 7.99 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 70.51 |
| Operating Pressure (MPa) | 1.25 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-8 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 7.99 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.046 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 7.99 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-3.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-3.12})$$

$$t_{min} = \frac{5.1 \times 219.1}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 5.58 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-3.13})$$

$$A_{rt} = \frac{0.046 \times 3.00}{7.99}$$

$$A_{rt} = 0.017162$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-3.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-3.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{5.58}{7.99}$$

$$SR_P^{Thin} = 0.2673$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-3.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-3.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-3.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-3.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.6311$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.6050$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.5461$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 8"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-3.19})$$

$$D_{fb}^{Thin} = 9.64E-01$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-3.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{0.9640 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 9.64E-01$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|-----------|--------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 8" | From | Vessel | 16C-6 |
| Material | Carbon Steel | To | Vessel | 16E-11 |
| | ASTM A106 Gr B | Unit | Plant | 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.046 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | Fairly Effective |
| Thickness Reading (mm) | 1 |
| Thickness Reading Date | 7.99 |
| | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 7.99 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 70.51^\circ\text{C} \\ Cr_b &= 0.252 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.32 \text{ mm/year} \end{aligned} \quad (\text{C-3.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 7.99 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

$$\text{If } age_{tk} \geq age_{coat}$$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-3.22})$$

$$\text{If } age_{tk} < age_{coat}$$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-3.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-3.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 5.58 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-3.25})$$

$$A_{rt} = \frac{0.316 \times 3.00}{7.99}$$

$$A_{rt} = 0.118463$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-3.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-3.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{7.99} \times \frac{5.58}{5.58}$$

$$SR_P^{CUIF} = 0.267328$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-3.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-3.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-3.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-3.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.4430$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.0915$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 1.8196$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-3.31)$$
$$D_f^{CUIF} = 2.59E+01$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 8" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-3.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-3.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 8 in = 203.2 mm



Consequence of Failure

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Table C-3.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 203.2$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-8

Table C-3.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 2.00E-06 | 6.00E-07 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-3.32})$$

Table C-3.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 32442.33 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-3.33})$$

Table C-3.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 7.8E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 2063.22 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-3.34})$$

$$W_8 = 7.85E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-3.35})$$

Table C-3.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.40E+02 kg/s | 2.14E+03 kg/s | 3.56E+04 kg/s | 1.41E+05 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-3.36})$$

Table C-3.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 2.20E+03 kg/s | 4.20E+03 kg/s | 3.76E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-3.37})$$

Table C-3.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.83E+03 s | 3.82E+02 s | 2.29E+01 s | 5.78E+00 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-3.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-3.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-3.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-3.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-3.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-3.38)$$

Table C-3.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.23E-01 kg/s | 9.50E+00 kg/s | 1.58E+02 kg/s | 6.28E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (\text{C-3.39})$$

Table C-3.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.80E+03 s | 4.42E+02 s | 2.38E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (\text{C-3.40})$$

Table C-3.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.12E+03 kg | 4.20E+03 kg | 3.76E+04 kg | 3.77E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-3.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-3.41})$$

Table C-3.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.43E+00 | 8.67E-01 | 4.68E+00 | 4.68E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-3.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-3.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-3.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | | b | | a | | b | | a | |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-3.42)$$

Table C-3.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.68E+01 m ² | 1.90E+02 m ² | 2.32E+03 m ² | 7.92E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-3.43)$$



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Table C-3.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.94E+01 m ² | 2.15E+05 m ² | 1.72E+06 m ² | 1.72E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-3.44})$$

Table C-3.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.40E+01 m ² | 4.34E+02 m ² | 4.45E+02 m ² | 4.45E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-3.45})$$

Table C-3.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.04E+02 m ² | 3.37E+02 m ² | 4.31E+02 m ² | 4.31E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-3.46})$$

Table C-3.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.77E+01 m ² | 5.39E+02 m ² | 6.58E+03 m ² | 2.25E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-3.47)$$

Table C-3.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.23E+02 m ² | 1.50E+03 m ² | 2.00E+04 m ² | 7.11E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-3.48)$$

Table C-3.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.74E+02 m ² | 4.52E+02 m ² | 1.30E+03 m ² | 1.30E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-3.49)$$

Table C-3.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.42E+02 m ² | 1.22E+03 m ² | 1.51E+03 m ² | 1.51E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-3.50)$$

Table C-3.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.47E-02 | 3.77E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-3.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 343.66 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-3.52)

Table C-3.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.56E+02 m ² | 1.34E+05 m ² | 4.31E+02 m ² | 4.31E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-3.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.23E+02 m ² | 2.16E+03 m ² | 1.51E+03 m ² | 1.51E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-3.54)

Table C-3.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.76E+01 m ² | 5.53E+02 m ² | 4.45E+02 m ² | 4.45E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-3.55)

Table C-3.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.28E+02 m ² | 7.88E+02 m ² | 1.30E+03 m ² | 1.30E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-3.56)



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Table C-3.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.76E+01 m ² | 5.53E+02 m ² | 4.45E+02 m ² | 4.45E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-3.57)$$

Table C-3.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.28E+02 m ² | 7.88E+02 m ² | 1.30E+03 m ² | 1.30E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 3.79E+02 \text{ m}^2 \quad (C-3.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 5.66E+02 \text{ m}^2 \quad (C-3.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-3.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 3.79E+02 \text{ m}^2 \quad (C-3.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 5.66E+02 \text{ m}^2 \quad (C-3.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 5.66E+02 \text{ m}^2 \quad (\text{C-3.64})$$

Table C-3.42 Consequence of Failure Category

| COF Category | |
|--------------|---------|
| C | Serious |



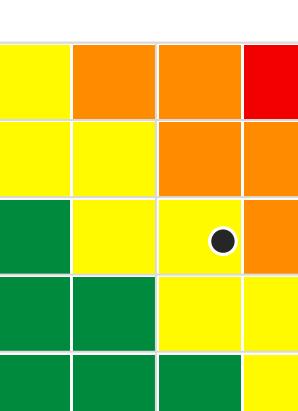
Result

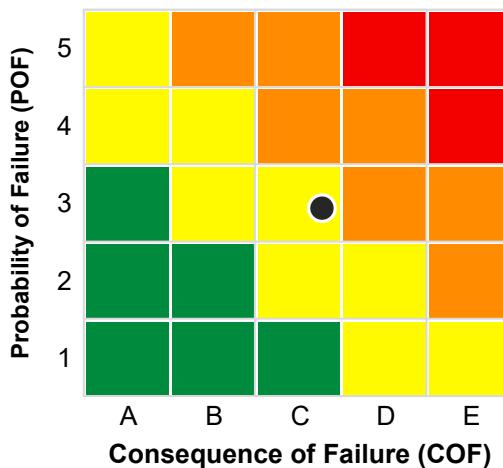
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A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 8" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- | <p>a. Probability of Failure (POF)</p> <ul style="list-style-type: none"> Total Damage Factor
 $D_{f-total} = 2.69E+01$ POF Score
 $P_f(t) = 8.23E-04$ Category
 3 - Possible Damage Factors Selection
 Thinning, Corrosion Under Insulation (CUI) | | <p>c. Risk Ranking</p> <ul style="list-style-type: none"> Risk Score
 $R(t) = 4.66E-01 \text{ m}^2/\text{year}$ Risk Ranking
 3C Medium Date
 RBI Date : 01-06-2020 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|------------|---|------------------------------|--------|-----|---|---|---|---|------------|------------|------------|--------|-----|---|------------|------------|--------|--------|-----|---|------------|--------|-----------|--------|-----|---|--------|--------|--------|--------|-----|---|--------|--------|--------|-----|-----|---|-----|-----|-----|-----|-----|
| <p>b. Consequence of Failure (COF)</p> <ul style="list-style-type: none"> Representative Fluid C6-C8 Fluid Phase Model as liquid COF Score $CA_f = 5.66E+02 \text{ m}^2$ Category C - Serious | |  <table border="1"> <thead> <tr> <th>Probability of Failure (POF)</th> <th>A</th> <th>B</th> <th>C</th> <th>D</th> <th>E</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Dark Green</td> <td>Dark Green</td> <td>Dark Green</td> <td>Yellow</td> <td>Red</td> </tr> <tr> <td>2</td> <td>Dark Green</td> <td>Dark Green</td> <td>Yellow</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>3</td> <td>Dark Green</td> <td>Yellow</td> <td>Black Dot</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>4</td> <td>Yellow</td> <td>Yellow</td> <td>Yellow</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>5</td> <td>Yellow</td> <td>Yellow</td> <td>Yellow</td> <td>Red</td> <td>Red</td> </tr> <tr> <td>6</td> <td>Red</td> <td>Red</td> <td>Red</td> <td>Red</td> <td>Red</td> </tr> </tbody> </table> <p>Probability of Failure (POF)</p> <p>Consequence of Failure (COF)</p> | Probability of Failure (POF) | A | B | C | D | E | 1 | Dark Green | Dark Green | Dark Green | Yellow | Red | 2 | Dark Green | Dark Green | Yellow | Orange | Red | 3 | Dark Green | Yellow | Black Dot | Orange | Red | 4 | Yellow | Yellow | Yellow | Orange | Red | 5 | Yellow | Yellow | Yellow | Red | Red | 6 | Red | Red | Red | Red | Red |
| Probability of Failure (POF) | A | B | C | D | E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Dark Green | Dark Green | Dark Green | Yellow | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Dark Green | Dark Green | Yellow | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Dark Green | Yellow | Black Dot | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Yellow | Yellow | Yellow | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Yellow | Yellow | Yellow | Red | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Red | Red | Red | Red | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |



C. INSPECTION ACTIVITIES

Table C-3.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

**Attachment C-4
16LF22-6"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16E-11 |
| Material | Carbon Steel | To | Vessel 16E-5 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 131.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-4.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-4.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



Probability of Failure

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Table C-4.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



Probability of Failure

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Table C-4.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-6
Diameter 6 in

Table C-4.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-4.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-4.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 9.77E-01$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-4.3})$$

$$D_{f-gov}^{SCC} = 0.00E+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-4.4})$$

$$D_{f-gov}^{extd} = 9.72E-01$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-4.5})$$

$$D_{f-gov}^{brit} = 0.00E+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00E+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00E+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-4.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-4.7})$$

$$D_{f-total} = 1.95E+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-4.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-4.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 5.97E-05 \quad (\text{C-4.10})$$

Table C-4.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|-----------|--------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | Vessel | 16E-11 |
| Material | Carbon Steel | To | Vessel | 16E-5 |
| | ASTM A106 Gr B | Unit | Plant | 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 6.9 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 131 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.9 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.078 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 6.9 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-4.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-4.12})$$

$$t_{min} = \frac{5.1 \times 168.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 4.65 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-4.13})$$

$$A_{rt} = \frac{0.078 \times 3.00}{6.9}$$

$$A_{rt} = 0.033984$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-4.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-4.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{4.65}{6.9}$$

$$SR_P^{Thin} = 0.2582$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-4.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-4.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-4.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-4.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.6532$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.5967$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.4539$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 6"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-4.19})$$

$$D_{fb}^{Thin} = 9.77E-01$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-4.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{0.9773 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 9.77\text{E-}01$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|-----------|--------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | Vessel | 16E-11 |
| Material | Carbon Steel | To | Vessel | 16E-5 |
| | ASTM A106 Gr B | Unit | Plant | 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.078 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 6.9 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.9 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 131^\circ\text{C} \\ Cr_b &= 0.062 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.08 \text{ mm/year} \end{aligned} \quad (\text{C-4.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 6.9 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-4.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-4.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-4.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 4.65 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-4.25})$$

$$A_{rt} = \frac{0.077 \times 3.00}{6.9}$$

$$A_{rt} = 0.033618$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-4.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-4.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{6.9} \times \frac{4.65}{6.9}$$

$$SR_P^{CUIF} = 0.258204$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-4.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-4.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-4.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-4.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.6537$$



**CUI
Damage Factor**

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$$\begin{aligned}\beta_2^{CUIF} &= \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}} \\ \beta_2^{CUIF} &= 3.5980 \\ \beta_3^{CUIF} &= \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}} \\ \beta_3^{CUIF} &= 3.4574\end{aligned}$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-4.31)$$
$$D_f^{CUIF} = 9.72E-01$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16E-11 |
| Material | Carbon Steel | To | Vessel 16E-5 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-4.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-4.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 6 in = 152.4 mm



Consequence of Failure

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Table C-4.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 152.4$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-6

Table C-4.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-4.32})$$

Table C-4.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 18248.81 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-4.33})$$

Table C-4.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 4.5E+02 kg/s |



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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 958.90 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-4.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-4.35})$$

Table C-4.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 3.59E+04 kg/s | 8.01E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-4.36})$$

Table C-4.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.10E+03 kg/s | 3.11E+03 kg/s | 3.68E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-4.37})$$

Table C-4.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 2.28E+01 s | 1.02E+01 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-4.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-4.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-4.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-4.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-4.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-4.38)$$

Table C-4.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 1.60E+02 kg/s | 3.56E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\frac{Mass_{avail,n}}{Rate_n} , \{ 60 . Id_{max,n} \}] \quad (\text{C-4.39})$$

Table C-4.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.75E+03 s | 3.25E+02 s | 2.31E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \} , Mass_{avail,n}] \quad (\text{C-4.40})$$

Table C-4.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.10E+03 kg | 3.11E+03 kg | 3.68E+04 kg | 2.14E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-4.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-4.41})$$

Table C-4.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.46E+00 | 3.47E-01 | 4.64E+00 | 3.69E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-4.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-4.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-4.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | b | a | b | a | b | a | b | a | b |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-4.42)$$

Table C-4.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 2.34E+03 m ² | 4.78E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-4.43)$$



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Table C-4.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.62E+05 m ² | 1.69E+06 m ² | 1.01E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-4.44})$$

Table C-4.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.07E+01 m ² | 8.58E+02 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-4.45})$$

Table C-4.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.98E+02 m ² | 8.31E+02 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-4.46})$$

Table C-4.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 6.63E+03 m ² | 1.36E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-4.47)$$

Table C-4.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 2.02E+04 m ² | 4.22E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-4.48)$$

Table C-4.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.65E+02 m ² | 1.11E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-4.49)$$

Table C-4.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.19E+02 m ² | 3.02E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-4.50)$$

Table C-4.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-4.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 404.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-4.52)

Table C-4.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.49E+02 m ² | 1.01E+05 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-4.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -5.98E+02 m ² | 3.96E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-4.54)

Table C-4.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.41E+01 m ² | 9.77E+02 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-4.55)

Table C-4.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.18E+02 m ² | 1.45E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-4.56)



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Table C-4.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.41E+01 m ² | 9.77E+02 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-4.57)$$

Table C-4.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.18E+02 m ² | 1.45E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 6.50E+02 \text{ m}^2 \quad (C-4.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 9.80E+02 \text{ m}^2 \quad (C-4.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-4.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-4.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 6.50E+02 \text{ m}^2 \quad (C-4.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 9.80E+02 \text{ m}^2 \quad (C-4.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 9.80E+02 \text{ m}^2 \quad (\text{C-4.64})$$

Table C-4.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| <i>D</i> | <i>Major</i> |



Result

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A. EQUIPMENT SPECIFICATION

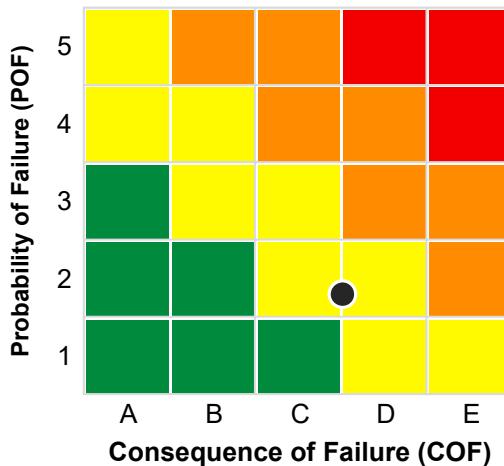
| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16E-11 |
| Material | Carbon Steel | To | Vessel 16E-5 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 1.95E+00$
 - POF Score
 $P_f(t) = 5.97E-05$
 - Category
2 - Unlikely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 9.80E+02 \text{ m}^2$
 - Category
D - Major

- c. Risk Ranking
 - Risk Score
 $R(t) = 5.85E-02 \text{ m}^2/\text{year}$
 - Risk Ranking
2D Medium
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-4.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

Attachment C-5
16LF40-6"-CB2D



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF22-6"-CB2D |
| Material | Carbon Steel | To | 16LF39-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 129.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-5.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-5.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|---|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | <p>Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions:</p> <ul style="list-style-type: none"> • Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays. • Some areas are subject to acid vapors, process spills or the ingress of moisture. • The component is composed of carbon steel and the operating temperature is 23°C - 121°C. • The component has deteriorated wrapping or coatings. • The component is subject to frequent outages. | No |



Probability of Failure

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Table C-5.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-5.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-6
Diameter 6 in

Table C-5.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-5.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-5.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 1.21\text{E}+00$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-5.3})$$

$$D_{f-gov}^{SCC} = 0.00\text{E}+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-5.4})$$

$$D_{f-gov}^{extd} = 1.21\text{E}+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-5.5})$$

$$D_{f-gov}^{brit} = 0.00\text{E}+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00\text{E}+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00\text{E}+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-5.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-5.7})$$

$$D_{f-total} = 2.41\text{E}+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-5.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-5.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 7.39E-05 \quad (\text{C-5.10})$$

Table C-5.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF22-6"-CB2D | |
| Material | Carbon Steel | To | 16LF39-6"-CB2D | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 6.7 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 129 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.7 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.084 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 6.7 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-5.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-5.12})$$

$$t_{min} = \frac{5.1 \times 168.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 4.65 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-5.13})$$

$$A_{rt} = \frac{0.084 \times 3.00}{6.7}$$

$$A_{rt} = 0.037665$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times I.1 \quad (\text{C-5.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-5.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{4.65}{6.7}$$

$$SR_P^{Thin} = 0.2659$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-5.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-5.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-5.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-5.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.6071$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.5413$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.3718$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 6"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-5.19})$$

$$D_{fb}^{Thin} = 1.21E+00$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-5.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{1.2073 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 1.21\text{E+00}$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF22-6"-CB2D | |
| Material | Carbon Steel | To | 16LF39-6"-CB2D | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.084 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 6.7 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.7 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 129^\circ\text{C} \\ Cr_b &= 0.067 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.08 \text{ mm/year} \end{aligned} \quad (\text{C-5.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$\begin{aligned} t_{rde} &= 6.7 \text{ mm} & (\text{inspected on } & 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} & (\text{RBI date } & 01-06-2020) \end{aligned}$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$\begin{aligned} age_{tk} &= 3.00 \text{ years} & \text{Medium - single coat epoxy} \\ age_{coat} &= 31.58 \text{ years} \end{aligned}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-5.22})$$

If $age_{tk} < age_{coat}$

$$\begin{aligned} Coat_{adj} &= \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}] \\ Coat_{adj} &= 0.00 \end{aligned} \quad (\text{C-5.23})$$

Step 7 : Determine the in-service time

$$\begin{aligned} age &= age_{tk} - Coat_{adj} \quad (\text{C-5.24}) \\ &= 3.00 - 0.00 \\ &= 3.00 \text{ years} \end{aligned}$$

Step 8 : Determine the allowable stress

$$\begin{aligned} P &= 5.1 \text{ mpa} \\ S &= 137.9 \text{ mpa} \\ E &= 1 \\ Y &= 0.4 \\ t_{min} &= 4.65 \text{ mm} \end{aligned}$$

Step 9 : Determine Art parameter

$$\begin{aligned} A_{rt} &= \frac{C_r \times age}{t_{rde}} \quad (\text{C-5.25}) \\ A_{rt} &= \frac{0.084 \times 3.00}{6.7} \\ A_{rt} &= 0.037660 \end{aligned}$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-5.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-5.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{6.7} \times \frac{4.65}{6.7}$$

$$SR_P^{CUIF} = 0.265912$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-5.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-5.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-5.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-5.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.6071$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.5413$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.3719$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-5.31)$$
$$D_f^{CUIF} = 1.21E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF22-6"-CB2D |
| Material | Carbon Steel | To | 16LF39-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-5.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-5.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 6 in = 152.4 mm



Consequence of Failure

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Table C-5.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 152.4$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-6

Table C-5.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-5.32})$$

Table C-5.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 18248.81 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-5.33})$$

Table C-5.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 4.5E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 643.30 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-5.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-5.35})$$

Table C-5.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 3.59E+04 kg/s | 8.01E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-5.36})$$

Table C-5.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 7.85E+02 kg/s | 2.80E+03 kg/s | 3.65E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-5.37})$$

Table C-5.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 2.28E+01 s | 1.02E+01 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-5.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-5.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-5.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-5.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-5.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-5.38)$$

Table C-5.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 1.60E+02 kg/s | 3.56E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (\text{C-5.39})$$

Table C-5.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.25E+03 s | 2.92E+02 s | 2.29E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (\text{C-5.40})$$

Table C-5.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 7.85E+02 kg | 2.80E+03 kg | 3.65E+04 kg | 2.14E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-5.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-5.41})$$

Table C-5.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -2.05E+00 | 1.62E-01 | 4.62E+00 | 3.69E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-5.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-5.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-5.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | | b | | a | | b | | a | |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-5.42)$$

Table C-5.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 2.34E+03 m ² | 4.78E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-5.43)$$



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Table C-5.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.46E+05 m ² | 1.68E+06 m ² | 1.01E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-5.44)$$

Table C-5.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -4.97E+01 m ² | 1.70E+03 m ² | 4.40E+02 m ² | 3.63E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-5.45)$$

Table C-5.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.17E+02 m ² | 1.48E+03 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (C-5.46)$$

Table C-5.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 6.63E+03 m ² | 1.36E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-5.47)$$

Table C-5.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 2.02E+04 m ² | 4.22E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-5.48)$$

Table C-5.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.45E+02 m ² | 1.83E+03 m ² | 1.28E+03 m ² | 1.06E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-5.49)$$

Table C-5.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -4.27E+02 m ² | 5.41E+03 m ² | 1.50E+03 m ² | 1.41E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-5.50)$$

Table C-5.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-5.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 402.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-5.52)

Table C-5.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.85E+01 m ² | 9.20E+04 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-5.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -3.07E+02 m ² | 6.35E+03 m ² | 1.50E+03 m ² | 1.41E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-5.54)

Table C-5.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -3.32E+01 m ² | 1.81E+03 m ² | 4.40E+02 m ² | 3.63E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-5.55)

Table C-5.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.81E+01 m ² | 2.17E+03 m ² | 1.28E+03 m ² | 1.06E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-5.56)



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Table C-5.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -3.32E+01 m ² | 1.81E+03 m ² | 4.40E+02 m ² | 3.63E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-5.57)$$

Table C-5.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.81E+01 m ² | 2.17E+03 m ² | 1.28E+03 m ² | 1.06E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 1.21E+03 \text{ m}^2 \quad (C-5.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 1.48E+03 \text{ m}^2 \quad (C-5.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-5.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 1.21E+03 \text{ m}^2 \quad (C-5.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 1.48E+03 \text{ m}^2 \quad (C-5.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 1.48E+03 \text{ m}^2 \quad (\text{C-5.64})$$

Table C-5.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| <i>D</i> | <i>Major</i> |



Result

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A. EQUIPMENT SPECIFICATION

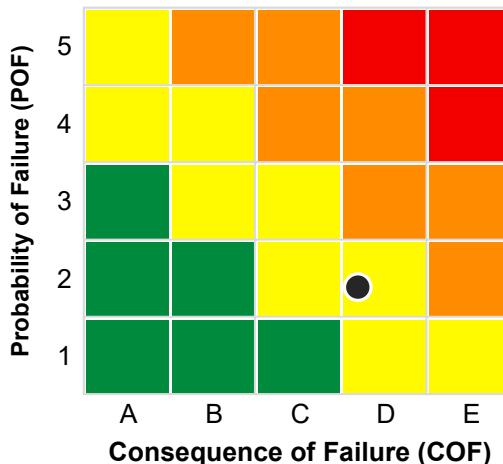
| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF22-6"-CB2D |
| Material | Carbon Steel | To | 16LF39-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 2.41E+00$
 - POF Score
 $P_f(t) = 7.39E-05$
 - Category
2 - Unlikely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 1.48E+03 \text{ m}^2$
 - Category
D - Major

- c. Risk Ranking
 - Risk Score
 $R(t) = 1.10E-01 \text{ m}^2/\text{year}$
 - Risk Ranking
2D Medium
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-5.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

**Attachment C-6
16LF29-6"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 128.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-6.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-6.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-6.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-6.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-6
Diameter 6 in

Table C-6.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-6.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-6.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 1.52\text{E}+00$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-6.3})$$

$$D_{f-gov}^{SCC} = 0.00\text{E}+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-6.4})$$

$$D_{f-gov}^{extd} = 1.49\text{E}+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-6.5})$$

$$D_{f-gov}^{brit} = 0.00\text{E}+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00\text{E}+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00\text{E}+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-6.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-6.7})$$

$$D_{f-total} = 3.01\text{E}+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-6.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-6.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 9.20E-05 \quad (\text{C-6.10})$$

Table C-6.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6 Date |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 6.5 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 128 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.5 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.090 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 6.5 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-6.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-6.12})$$

$$t_{min} = \frac{5.1 \times 168.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 4.65 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-6.13})$$

$$A_{rt} = \frac{0.090 \times 3.00}{6.5}$$

$$A_{rt} = 0.041573$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-6.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-6.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{4.65}{6.5}$$

$$SR_P^{Thin} = 0.2741$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-6.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-6.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-6.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-6.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.5577$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.4813$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.2807$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 6"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-6.19})$$

$$D_{fb}^{Thin} = 1.52E+00$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-6.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{1.5171 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 1.52E+00$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|-----------|--------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | Vessel | 16C-6 |
| Material | Carbon Steel | To | Vessel | 16E-11 |
| | ASTM A106 Gr B | Unit | Plant | 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.090 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 6.5 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.5 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 128^\circ\text{C} \\ Cr_b &= 0.070 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.09 \text{ mm/year} \end{aligned} \quad (\text{C-6.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 6.5 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-6.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-6.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-6.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 4.65 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-6.25})$$

$$A_{rt} = \frac{0.087 \times 3.00}{6.5}$$

$$A_{rt} = 0.040385$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-6.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-6.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{6.5} \times \frac{4.65}{6.5}$$

$$SR_P^{CUIF} = 0.274094$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-6.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-6.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-6.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-6.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.5596$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.4860$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.2941$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-6.31)$$
$$D_f^{CUIF} = 1.49E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-6.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-6.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 6 in = 152.4 mm



Consequence of Failure

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Table C-6.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 152.4$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-6

Table C-6.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-6.32})$$

Table C-6.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 18248.81 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-6.33})$$

Table C-6.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 4.5E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 1943.63 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-6.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-6.35})$$

Table C-6.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 3.59E+04 kg/s | 8.01E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-6.36})$$

Table C-6.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 2.08E+03 kg/s | 4.10E+03 kg/s | 3.78E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-6.37})$$

Table C-6.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 2.28E+01 s | 1.02E+01 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-6.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-6.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-6.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-6.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-6.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |
| | | | | | |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-6.38)$$

Table C-6.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 1.60E+02 kg/s | 3.56E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (\text{C-6.39})$$

Table C-6.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.80E+03 s | 4.28E+02 s | 2.37E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (\text{C-6.40})$$

Table C-6.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.13E+03 kg | 4.10E+03 kg | 3.78E+04 kg | 2.14E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-6.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-6.41})$$

Table C-6.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.41E+00 | 8.25E-01 | 4.69E+00 | 3.69E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-6.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-6.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-6.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | b | a | b | a | b | a | b | a | b |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-6.42)$$

Table C-6.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 2.34E+03 m ² | 4.78E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-6.43)$$



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Table C-6.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 2.10E+05 m ² | 1.73E+06 m ² | 1.01E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-6.44})$$

Table C-6.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.57E+01 m ² | 4.48E+02 m ² | 4.46E+02 m ² | 3.63E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-6.45})$$

Table C-6.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.07E+02 m ² | 3.56E+02 m ² | 4.31E+02 m ² | 4.00E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-6.46})$$

Table C-6.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 6.63E+03 m ² | 1.36E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-6.47)$$

Table C-6.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 2.02E+04 m ² | 4.22E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-6.48)$$

Table C-6.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.79E+02 m ² | 4.79E+02 m ² | 1.30E+03 m ² | 1.06E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-6.49)$$

Table C-6.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.54E+02 m ² | 1.29E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-6.50)$$

Table C-6.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-6.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 401.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-6.52)

Table C-6.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.59E+02 m ² | 1.30E+05 m ² | 4.31E+02 m ² | 4.00E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-6.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.33E+02 m ² | 2.23E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-6.54)

Table C-6.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.91E+01 m ² | 5.67E+02 m ² | 4.46E+02 m ² | 3.63E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-6.55)

Table C-6.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.32E+02 m ² | 8.15E+02 m ² | 1.30E+03 m ² | 1.06E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-6.56)



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Table C-6.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.91E+01 m ² | 5.67E+02 m ² | 4.46E+02 m ² | 3.63E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-6.57)$$

Table C-6.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.32E+02 m ² | 8.15E+02 m ² | 1.30E+03 m ² | 1.06E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 3.80E+02 \text{ m}^2 \quad (C-6.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 5.62E+02 \text{ m}^2 \quad (C-6.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-6.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-6.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 3.80E+02 \text{ m}^2 \quad (C-6.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 5.62E+02 \text{ m}^2 \quad (C-6.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 5.62E+02 \text{ m}^2 \quad (\text{C-6.64})$$

Table C-6.42 Consequence of Failure Category

| COF Category | |
|--------------|---------|
| C | Serious |



Result

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A. EQUIPMENT SPECIFICATION

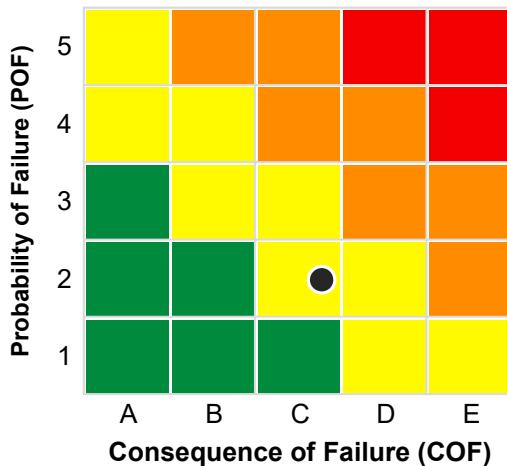
| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 3.01E+00$
 - POF Score
 $P_f(t) = 9.20E-05$
 - Category
2 - Unlikely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 5.62E+02 \text{ m}^2$
 - Category
C - Serious

- c. Risk Ranking
 - Risk Score
 $R(t) = 5.17E-02 \text{ m}^2/\text{year}$
 - Risk Ranking
2C Medium
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-6.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

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16LF30-6"-CB2D



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 131.50 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-7.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-7.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-7.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-7.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-6
Diameter 6 in

Table C-7.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-7.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-7.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 1.71\text{E}+00$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-7.3})$$

$$D_{f-gov}^{SCC} = 0.00\text{E}+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-7.4})$$

$$D_{f-gov}^{extd} = 1.51\text{E}+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-7.5})$$

$$D_{f-gov}^{brit} = 0.00\text{E}+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00\text{E}+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00\text{E}+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-7.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-7.7})$$

$$D_{f-total} = 3.22\text{E}+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-7.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-7.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 9.85E-05 \quad (\text{C-7.10})$$

Table C-7.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | Vessel 16E-9 | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 6.4 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 131.5 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.4 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.093 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 6.4 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-7.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-7.12})$$

$$t_{min} = \frac{5.1 \times 168.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 4.65 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-7.13})$$

$$A_{rt} = \frac{0.093 \times 3.00}{6.4}$$

$$A_{rt} = 0.043618$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-7.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-7.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{4.65}{6.4}$$

$$SR_P^{Thin} = 0.2784$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-7.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-7.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-7.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-7.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.5316$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.4494$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.2314$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 6"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-7.19})$$

$$D_{fb}^{Thin} = 1.71E+00$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-7.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{1.7130 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 1.71\text{E+00}$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | Vessel 16E-9 | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.093 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 6.4 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6.4 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 131.5 \text{ }^{\circ}\text{C} \\ Cr_b &= 0.060 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.08 \text{ mm/year} \end{aligned} \quad (\text{C-7.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 6.4 \text{ mm} \quad (\text{inspected on } 01-06-2017) \\ age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy} \\ age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-7.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}] \\ Coat_{adj} = 0.00 \quad (\text{C-7.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-7.24}) \\ = 3.00 - 0.00 \\ = 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa} \\ S = 137.9 \text{ mpa} \\ E = 1 \\ Y = 0.4 \\ t_{min} = 4.65 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-7.25}) \\ A_{rt} = \frac{0.076 \times 3.00}{6.4} \\ A_{rt} = 0.035449$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-7.26}) \\ FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1 \\ FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-7.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{6.4} \times \frac{4.65}{6.4}$$

$$SR_P^{CUIF} = 0.278377$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-7.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-7.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-7.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-7.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.5454$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.4821$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.3223$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-7.31)$$
$$D_f^{CUIF} = 1.51E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-7.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-7.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 6 in = 152.4 mm



Consequence of Failure

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Table C-7.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 152.4$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-6

Table C-7.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-7.32})$$

Table C-7.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 18248.81 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-7.33})$$

Table C-7.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 4.5E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 857.60 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-7.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-7.35})$$

Table C-7.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 3.59E+04 kg/s | 8.01E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-7.36})$$

Table C-7.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 9.99E+02 kg/s | 3.01E+03 kg/s | 3.67E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-7.37})$$

Table C-7.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 2.28E+01 s | 1.02E+01 s |



Consequence of Failure

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Step 2 : Determine release type is instantaneous or continuous

Table C-7.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-7.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-7.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-7.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-7.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-7.38)$$

Table C-7.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 1.60E+02 kg/s | 3.56E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (C-7.39)$$

Table C-7.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.59E+03 s | 3.15E+02 s | 2.30E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (C-7.40)$$

Table C-7.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 9.99E+02 kg | 3.01E+03 kg | 3.67E+04 kg | 2.14E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-7.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (C-7.41)$$

Table C-7.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.63E+00 | 2.90E-01 | 4.63E+00 | 3.69E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-7.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-7.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-7.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | b | a | b | a | b | a | b | a | b |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-7.42)$$

Table C-7.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 2.34E+03 m ² | 4.78E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-7.43)$$



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Table C-7.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.57E+05 m ² | 1.68E+06 m ² | 1.01E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-7.44})$$

Table C-7.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.54E+01 m ² | 1.00E+03 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-7.45})$$

Table C-7.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.68E+02 m ² | 9.45E+02 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-7.46})$$

Table C-7.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 6.63E+03 m ² | 1.36E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b] \cdot (1 - fact_{mit}) \quad (C-7.47)$$

Table C-7.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 2.02E+04 m ² | 4.22E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-7.48)$$

Table C-7.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.20E+02 m ² | 1.24E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-7.49)$$

Table C-7.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.12E+02 m ² | 3.44E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-7.50)$$

Table C-7.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-7.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 404.65 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-7.52)

Table C-7.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.20E+02 m ² | 9.80E+04 m ² | 4.29E+02 m ² | 4.00E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-7.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -4.91E+02 m ² | 4.38E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-7.54)

Table C-7.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -5.89E+01 m ² | 1.12E+03 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-7.55)

Table C-7.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.73E+02 m ² | 1.57E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-7.56)



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Table C-7.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -5.89E+01 m ² | 1.12E+03 m ² | 4.41E+02 m ² | 3.63E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-7.57)$$

Table C-7.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.73E+02 m ² | 1.57E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 7.48E+02 \text{ m}^2 \quad (C-7.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 1.07E+03 \text{ m}^2 \quad (C-7.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-7.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 7.48E+02 \text{ m}^2 \quad (C-7.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 1.07E+03 \text{ m}^2 \quad (C-7.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 1.07E+03 \text{ m}^2 \quad (\text{C-7.64})$$

Table C-7.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| <i>D</i> | <i>Major</i> |



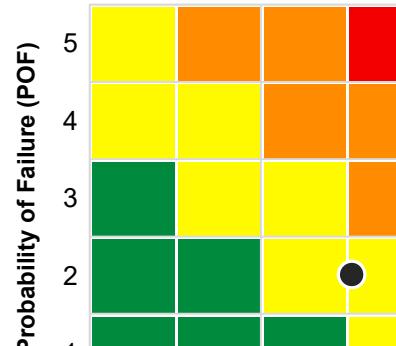
Result

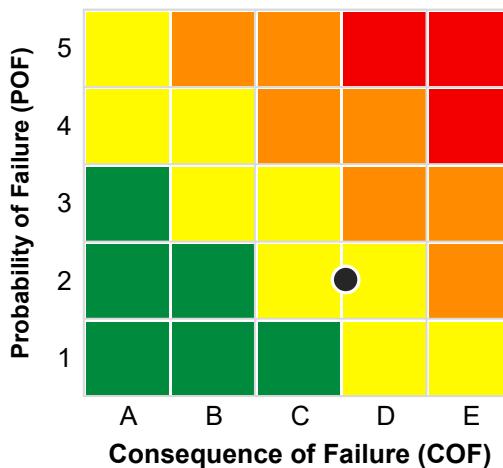
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A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- | <p>a. Probability of Failure (POF)</p> <ul style="list-style-type: none"> Total Damage Factor
 $D_{f-total} = 3.22E+00$ POF Score
 $P_f(t) = 9.85E-05$ Category
 2 - Unlikely Damage Factors Selection
 Thinning, Corrosion Under Insulation (CUI) | | <p>c. Risk Ranking</p> <ul style="list-style-type: none"> Risk Score
 $R(t) = 1.06E-01 \text{ m}^2/\text{year}$ Risk Ranking
 2D Medium Date
 RBI Date : 01-06-2020 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|--------------|--|------------------------------|--------|--------|---|---|---|---|------------|------------|------------|--------|--------|---|--------------|--------------|--------|--------|-----|---|--------|--------|--------|--------|-----|---|--------|--------|--------|--------|-----|---|--------|--------|--------|-----|-----|
| <p>b. Consequence of Failure (COF)</p> <ul style="list-style-type: none"> Representative Fluid C6-C8 Fluid Phase Model as liquid COF Score $CA_f = 1.07E+03 \text{ m}^2$ Category D - Major | |  <table border="1" data-bbox="682 786 1078 1132"> <thead> <tr> <th>Probability of Failure (POF)</th> <th>A</th> <th>B</th> <th>C</th> <th>D</th> <th>E</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Dark Green</td> <td>Dark Green</td> <td>Dark Green</td> <td>Yellow</td> <td>Yellow</td> </tr> <tr> <td>2</td> <td>Medium Green</td> <td>Medium Green</td> <td>Yellow</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>3</td> <td>Yellow</td> <td>Yellow</td> <td>Yellow</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>4</td> <td>Yellow</td> <td>Yellow</td> <td>Yellow</td> <td>Orange</td> <td>Red</td> </tr> <tr> <td>5</td> <td>Yellow</td> <td>Yellow</td> <td>Yellow</td> <td>Red</td> <td>Red</td> </tr> </tbody> </table> <p>Probability of Failure (POF)</p> <p>Consequence of Failure (COF)</p> | Probability of Failure (POF) | A | B | C | D | E | 1 | Dark Green | Dark Green | Dark Green | Yellow | Yellow | 2 | Medium Green | Medium Green | Yellow | Orange | Red | 3 | Yellow | Yellow | Yellow | Orange | Red | 4 | Yellow | Yellow | Yellow | Orange | Red | 5 | Yellow | Yellow | Yellow | Red | Red |
| Probability of Failure (POF) | A | B | C | D | E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Dark Green | Dark Green | Dark Green | Yellow | Yellow | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Medium Green | Medium Green | Yellow | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Yellow | Yellow | Yellow | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Yellow | Yellow | Yellow | Orange | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Yellow | Yellow | Yellow | Red | Red | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |



C. INSPECTION ACTIVITIES

Table C-7.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

Attachment C-8
16LF38-6"-CB2D



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | 16LF22-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 130.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-8.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-8.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-8.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-8.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-6
Diameter 6 in

Table C-8.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-8.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-8.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 2.95\text{E}+00$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-8.3})$$

$$D_{f-gov}^{SCC} = 0.00\text{E}+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-8.4})$$

$$D_{f-gov}^{extd} = 2.35\text{E}+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-8.5})$$

$$D_{f-gov}^{brit} = 0.00\text{E}+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00\text{E}+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00\text{E}+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-8.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-8.7})$$

$$D_{f-total} = 5.30\text{E}+00 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-8.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-8.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 1.62E-04 \quad (\text{C-8.10})$$

Table C-8.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 2 | <i>Unlikely</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | 16LF22-6"-CB2D | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 6 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 130 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-6 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.105 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 6 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-8.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-8.12})$$

$$t_{min} = \frac{5.1 \times 168.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 4.65 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-8.13})$$

$$A_{rt} = \frac{0.105 \times 3.00}{6}$$

$$A_{rt} = 0.052481$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-8.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-8.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{4.65}{6}$$

$$SR_P^{Thin} = 0.2969$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-8.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-8.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-8.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-8.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.4174$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 3.3073$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 3.0038$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 6"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-8.19})$$

$$D_{fb}^{Thin} = 2.95E+00$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-8.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{2.9478 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 2.95E+00$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 6" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | 16LF22-6"-CB2D | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.105 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 6 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 6 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 130 \text{ }^{\circ}\text{C} \\ Cr_b &= 0.065 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.08 \text{ mm/year} \end{aligned} \quad (\text{C-8.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 6 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-8.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-8.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-8.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 4.65 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-8.25})$$

$$A_{rt} = \frac{0.081 \times 3.00}{6}$$

$$A_{rt} = 0.040357$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-8.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-8.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{6} \times \frac{4.65}{6}$$

$$SR_P^{CUIF} = 0.296935$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-8.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-8.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-8.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-8.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.4396$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.3611$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.1594$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-8.31)$$
$$D_f^{CUIF} = 2.35E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | 16LF22-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-8.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-8.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 6 in = 152.4 mm



Consequence of Failure

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Table C-8.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 102.0$ |
| 4 | Rupture | >152 | $d_4 = 152.4$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-6

Table C-8.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-8.32})$$

Table C-8.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|--------------------------|
| 32.18 mm ² | 491.07 mm ² | 8174.57 mm ² | 18248.81 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-8.33})$$

Table C-8.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 2.0E+02 kg/s | 4.5E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 1274.01 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-8.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-8.35})$$

Table C-8.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 3.59E+04 kg/s | 8.01E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-8.36})$$

Table C-8.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.42E+03 kg/s | 3.43E+03 kg/s | 3.72E+04 kg/s | 6.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-8.37})$$

Table C-8.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 2.28E+01 s | 1.02E+01 s |



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Step 2 : Determine release type is instantaneous or continuous

Table C-8.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-8.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-8.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-8.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-8.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-8.38)$$

Table C-8.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 1.60E+02 kg/s | 3.56E+02 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (\text{C-8.39})$$

Table C-8.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 1.80E+03 s | 3.58E+02 s | 2.33E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (\text{C-8.40})$$

Table C-8.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 1.13E+03 kg | 3.43E+03 kg | 3.72E+04 kg | 2.14E+04 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-8.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-8.41})$$

Table C-8.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|----------|----------|----------|
| -1.41E+00 | 5.15E-01 | 4.65E+00 | 3.69E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-8.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-8.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-8.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | b | a | b | a | b | a | b | a | b |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-8.42)$$

Table C-8.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 2.34E+03 m ² | 4.78E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-8.43)$$



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Table C-8.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.77E+05 m ² | 1.70E+06 m ² | 1.01E+06 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-8.44})$$

Table C-8.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -9.57E+01 m ² | 6.24E+02 m ² | 4.43E+02 m ² | 3.63E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-8.45})$$

Table C-8.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.07E+02 m ² | 5.69E+02 m ² | 4.30E+02 m ² | 4.00E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-8.46})$$

Table C-8.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 6.63E+03 m ² | 1.36E+04 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b] \cdot (1 - fact_{mit}) \quad (C-8.47)$$

Table C-8.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 2.02E+04 m ² | 4.22E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-8.48)$$

Table C-8.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.79E+02 m ² | 7.67E+02 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-8.49)$$

Table C-8.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.54E+02 m ² | 2.07E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-8.50)$$

Table C-8.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-8.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 403.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 0$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-8.52)

Table C-8.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -1.59E+02 m ² | 1.10E+05 m ² | 4.30E+02 m ² | 4.00E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-8.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -6.33E+02 m ² | 3.01E+03 m ² | 1.51E+03 m ² | 1.41E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-8.54)

Table C-8.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.91E+01 m ² | 7.43E+02 m ² | 4.43E+02 m ² | 3.63E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-8.55)

Table C-8.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.32E+02 m ² | 1.10E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-8.56)



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Table C-8.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -7.91E+01 m ² | 7.43E+02 m ² | 4.43E+02 m ² | 3.63E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-8.57)$$

Table C-8.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|--------------------------|-------------------------|-------------------------|-------------------------|
| -2.32E+02 m ² | 1.10E+03 m ² | 1.29E+03 m ² | 1.06E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 4.96E+02 \text{ m}^2 \quad (C-8.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = 7.50E+02 \text{ m}^2 \quad (C-8.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-8.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 4.96E+02 \text{ m}^2 \quad (C-8.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 7.50E+02 \text{ m}^2 \quad (C-8.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 7.50E+02 \text{ m}^2 \quad (\text{C-8.64})$$

Table C-8.42 Consequence of Failure Category

| COF Category | |
|--------------|---------|
| C | Serious |



Result

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A. EQUIPMENT SPECIFICATION

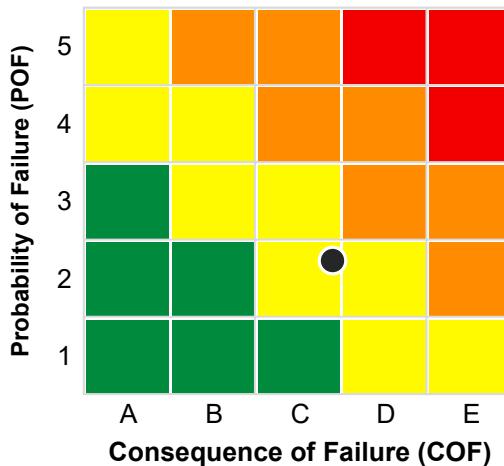
| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | 16LF22-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 5.30E+00$
 - POF Score
 $P_f(t) = 1.62E-04$
 - Category
2 - Unlikely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 7.50E+02 \text{ m}^2$
 - Category
C - Serious

- c. Risk Ranking
 - Risk Score
 $R(t) = 1.22E-01 \text{ m}^2/\text{year}$
 - Risk Ranking
2C Medium
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-8.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

**Attachment C-9
16LF59-3"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 3" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 197.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-9.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-9.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|--|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions: <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-9.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-9.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-4
Diameter 3 in

Table C-9.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-9.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-9.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 2.93E+01$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-9.3})$$

$$D_{f-gov}^{SCC} = 0.00E+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-9.4})$$

$$D_{f-gov}^{extd} = 1.34E+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-9.5})$$

$$D_{f-gov}^{brit} = 0.00E+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00E+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00E+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-9.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-9.7})$$

$$D_{f-total} = 3.07E+01 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-9.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-9.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 9.38E-04 \quad (\text{C-9.10})$$

Table C-9.3 Probability of Failure Category

| POF Category | |
|--------------|-----------------|
| 3 | <i>Possible</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 3" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | Burn Pit | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 4.2 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 197 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-4 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 4.2 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.159 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 4.2 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-9.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-9.12})$$

$$t_{min} = \frac{5.1 \times 88.9}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 3.21 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-9.13})$$

$$A_{rt} = \frac{0.159 \times 3.00}{4.2}$$

$$A_{rt} = 0.113258$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-9.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-9.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{3.21}{4.2}$$

$$SR_P^{Thin} = 0.2923$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-9.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-9.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-9.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-9.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 3.3136$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 2.9728$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = 1.7833$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 3"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-9.19})$$

$$D_{fb}^{Thin} = 2.93E+01$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-9.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{29.3313 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 2.93E+01$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 3" | From | 16LF29-6"-CB2D | |
| Material | Carbon Steel | To | Burn Pit | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.159 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 4.2 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 4.2 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 197^\circ\text{C} \\ Cr_b &= 0.000 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.00 \text{ mm/year} \end{aligned} \quad (\text{C-9.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 4.2 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

If $age_{tk} \geq age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-9.22})$$

If $age_{tk} < age_{coat}$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-9.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-9.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 3.21 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-9.25})$$

$$A_{rt} = \frac{0.000 \times 3.00}{4.2}$$

$$A_{rt} = 0.000000$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-9.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-9.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{4.2} \times \frac{3.21}{4.2}$$

$$SR_P^{CUIF} = 0.292328$$

Step 12 : Determine the number of inspections

| | | | |
|--------------|---|---|-------------------------------------|
| N_A^{CUIF} | = | 0 | Table C-9.5 CUI Inspection Category |
| N_B^{CUIF} | = | 0 | Inspection Category |
| N_C^{CUIF} | = | 1 | C Fairly Effective |
| N_D^{CUIF} | = | 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-9.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-9.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-9.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.5289$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.5289$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.5289$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-9.31)$$
$$D_f^{CUIF} = 1.34E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 3" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-9.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-9.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 3 in = 76.2 mm



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Table C-9.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 76.2$ |
| 4 | Rupture | >152 | $d_4 = 76.2$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-4

Table C-9.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-9.32})$$

Table C-9.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|-------------------------|
| 32.18 mm ² | 491.07 mm ² | 4562.20 mm ² | 4562.20 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-9.33})$$

Table C-9.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 1.1E+02 kg/s | 1.1E+02 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 100.28 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-9.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-9.35})$$

Table C-9.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 2.00E+04 kg/s | 2.00E+04 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-9.36})$$

Table C-9.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 2.42E+02 kg/s | 2.26E+03 kg/s | 2.01E+04 kg/s | 2.01E+04 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-9.37})$$

Table C-9.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 4.08E+01 s | 4.08E+01 s |



Consequence of Failure

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Step 2 : Determine release type is instantaneous or continuous

Table C-9.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-9.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-9.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-9.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-9.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-9.38)$$

Table C-9.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 8.90E+01 kg/s | 8.90E+01 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (\text{C-9.39})$$

Table C-9.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 3.85E+02 s | 2.35E+02 s | 2.26E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (\text{C-9.40})$$

Table C-9.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 2.42E+02 kg | 2.26E+03 kg | 2.01E+04 kg | 5.34E+03 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-9.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (\text{C-9.41})$$

Table C-9.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|-----------|----------|----------|
| -4.09E+00 | -2.13E-01 | 3.59E+00 | 1.28E+00 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-9.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



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Table C-9.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-9.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | | b | | a | | b | | a | |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-9.42)$$

Table C-9.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 1.39E+03 m ² | 1.39E+03 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-9.43)$$



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Table C-9.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.19E+05 m ² | 9.51E+05 m ² | 2.70E+05 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-9.44)$$

Table C-9.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|-------------------------|
| -9.91E+00 m ² | -1.09E+03 m ² | 3.56E+02 m ² | 3.54E+02 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-9.45)$$

Table C-9.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|-------------------------|
| -3.06E+01 m ² | -5.89E+02 m ² | 3.98E+02 m ² | 5.36E+02 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (C-9.46)$$

Table C-9.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 3.95E+03 m ² | 3.95E+03 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (C-9.47)$$

Table C-9.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 1.18E+04 m ² | 1.18E+04 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-9.48)$$

Table C-9.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|-------------------------|
| -2.89E+01 m ² | -5.56E+02 m ² | 1.04E+03 m ² | 1.03E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (C-9.49)$$

Table C-9.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|-------------------------|
| -1.13E+02 m ² | -2.18E+03 m ² | 1.41E+03 m ² | 1.92E+03 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-9.50)$$

Table C-9.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-9.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 470.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 1$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-9.52)

Table C-9.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.80E+01 m ² | 7.31E+04 m ² | 3.98E+02 m ² | 5.36E+02 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-9.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|-------------------------|
| 7.42E+00 m ² | -1.24E+03 m ² | 1.41E+03 m ² | 1.92E+03 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-9.54)

Table C-9.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|-------------------------|
| 6.60E+00 m ² | -9.71E+02 m ² | 3.56E+02 m ² | 3.54E+02 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-9.55)

Table C-9.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|-------------------------|
| 1.79E+01 m ² | -2.20E+02 m ² | 1.04E+03 m ² | 1.03E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-9.56)



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Table C-9.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.80E+01 m ² | 7.31E+04 m ² | 7.54E+02 m ² | 8.90E+02 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-9.57)$$

Table C-9.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|-------------------------|
| 7.42E+00 m ² | -1.24E+03 m ² | 1.41E+03 m ² | 1.92E+03 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 4.79E+04 \text{ m}^2 \quad (C-9.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = -6.43E+02 \text{ m}^2 \quad (C-9.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-9.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 4.79E+04 \text{ m}^2 \quad (C-9.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 0.00E+00 \text{ m}^2 \quad (C-9.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 4.79E+04 \text{ m}^2 \quad (\text{C-9.64})$$

Table C-9.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| E | Catastrophic |



Result

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A. EQUIPMENT SPECIFICATION

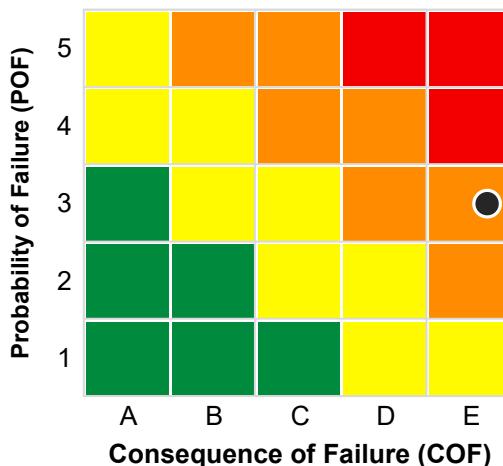
| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 3" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 3.07E+01$
 - POF Score
 $P_f(t) = 9.38E-04$
 - Category
3 - Possible
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 4.79E+04 \text{ m}^2$
 - Category
E - Catastrophic

- c. Risk Ranking
 - Risk Score
 $R(t) = 4.49E+01 \text{ m}^2/\text{year}$
 - Risk Ranking
3E Medium High
 - Date
RBI Date : 01-06-2020 ●



C. INSPECTION ACTIVITIES

Table C-9.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

**Attachment C-10
16LF44-2"-CB2D**



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Probability of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 2" | From | 16LF36-8"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 General Properties

| | |
|--------------------------------|---------------------|
| Material of Construction | Carbon or Low Alloy |
| Lining Present | No |
| Insulation Present | Yes |
| Exposed to Chloride and Water | Yes |
| Operating Temperature (°C) | 197.00 |
| Operating Pressure (MPa) | 1.27 |
| Date of Component Installation | 24-10-1983 |
| Risk Based Inspection Date | 01-06-2020 |

3 Damage Factors Selection

Table C-10.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|-------------------------------|-----------------|---|----------|
| Thinning | D_f^{thin} | This is a required factor that applies to all components. | Yes |
| Component Lining | D_f^{elin} | The component includes a lining (either inorganic or organic). | No |
| SCC - Caustic Cracking | $D_f^{caustic}$ | The Component is composed of a carbon or low alloy steel and there are any concentrations of caustic elements in the process environment. | No |
| SCC - Amine Cracking | D_f^{amine} | The component is composed of a carbon or low alloy steel and the process environment has any concentration present of acid gas treating amines (e.g., DIPA, MEA, etc.). | No |
| SCC - Sulfide Stress Cracking | D_f^{ssc} | The component is composed of carbon or low alloy steel and it operates in an environment that contains any concentration of H2S and water. | No |



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Table C-10.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|----------------------|---|----------|
| SCC - HIC/SOHC-H2S | $D_f^{HIC/SOHC-H2S}$ | The component is composed of a carbon or low alloy steel and there is H2S and water in any concentration in the process environment. | No |
| SCC - Alkaline Carbonate Stress Corrosion Cracking | D_f^{ACSCC} | The component is composed of a carbon or low alloy steel and there is sour water with pH > 7.5 in the process environment in any concentration. | No |
| SCC - Polythionic Acid Stress Corrosion Cracking | D_f^{PTA} | The component is composed of a nickel-based alloy or an austenitic stainless steel and it is exposed to sulfur bearing compounds. | No |
| SCC - Chloride Stress Corrosion Cracking | D_f^{CISCC} | The component is composed of a austenitic stainless steel and it is exposed to water and chlorides with the operating temperature being above 38 °C | No |
| SCC - Hydrogen Stress Cracking in Hydrofluoric Acid | D_f^{HSC-HF} | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| SCC - HIC/SOHC-HF | $D_f^{HIC/SOHC-HF}$ | The component is composed of a carbon or low alloy steel and it is exposed to any concentration of hydrofluoric acid. | No |
| External Corrosion - Ferritic Component | D_f^{extcor} | <p>Select this factor if the component is <u>un-insulated</u> and subject to any of the following conditions:</p> <ul style="list-style-type: none">• Some areas are exposed to steam vents, deluge systems or cooling tower mist overlays.• Some areas are subject to acid vapors, process spills or the ingress of moisture.• The component is composed of carbon steel and the operating temperature is 23°C - 121°C.• The component has deteriorated wrapping or coatings.• The component is subject to frequent outages. | No |



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Table C-10.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|-------------------|--|----------|
| External Corrosion - Ferritic Component | D_f^{extcor} | <ul style="list-style-type: none">The component does not normally operate 12°C - 177°C, but does periodically heat or cool in this range.The component consistently operates below the atmospheric dew point.The component has un-insulated protrusions or nozzles in cold conditions. | No |
| Corrosion Under Insulation (CUI) - Ferritic Component | D_f^{CUIF} | Component and/or locations are suspect. i.e., visually damaged insulation areas or penetrations. | Yes |
| ExtClSCC - Austenitic Component | $D_f^{ext-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| External CUI ClSCC-Austenitic Component | $D_f^{CUI-ClSCC}$ | The component is composed of austenitic stainless steel and its external surface is exposed to fluids, mists or solids containing chloride and either the operating temperature is 50°C - 150°C or the component is intermittently in this range due to heating or cooling. | No |
| Brittle Fracture | D_f^{brit} | The material is composed of carbon steel or low-alloy steel (see the table in the help file for the available steel types) and the Minimum Design Metal Temperature is either unknown or known but the component may operate below it under normal conditions. | No |
| Low Alloy Steel Embrittlement | D_f^{temp} | The material is composed of 1Cr-0.5Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, or 3Cr-1 Mo low alloy steel. The operating temperature is 343 °C - 577 °C (650 °F - 1070 °F). | No |



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Table C-10.1 Damage Factors Selection

| Damage Factors | Variable | Description | Applies? |
|---|---------------|--|----------|
| High Temperature Hydrogen Attack (HTHA) | D_f^{htha} | The component is composed of carbon steel, C-½ Mo, or a Cr-Mo low alloy steel (such as ½ Cr-½ Mo, 1 Cr-½ Mo, 1½ Cr-½ Mo, 2½ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-½ Mo, 7 Cr-1 Mo, and 9 Cr-1 Mo). The operating temperature is greater than 177 °C (350 °F). The operating hydrogen partial pressure is greater than 0.345 MPa (50 psia). | No |
| 885 °F Embrittlement | D_f^{885F} | The material is composed of high chromium (>12 % Cr) ferritic steel. The operating temperature is 371 °C - 566 °C (700 °F - 1050 °F). | No |
| Sigma Phase Embrittlement | D_f^{sigma} | The material is composed of austenitic stainless steel. The operating temperature is 593 °C - 927 °C (1100 °F - 1700 °F) | No |
| Piping Mechanical Fatigue | D_f^{mfat} | Select this factor if the component is a pipe and any of the following conditions are true: <ul style="list-style-type: none"> • The pipe system has had previous fatigue failures. • There is audible and/or visible shaking (continuous or intermittent) in the pipe system. • The pipe system is connected (directly or indirectly) to a cyclic vibration source within 15.24 meters. | No |

4 Calculation

A. Total Generic Failure Frequency

Equip. Type Pipe Comp. Type PIPE-4
Diameter 2 in

Table C-10.2 Total Generic Failure Frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|--------------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

(API 581, 2016)



Probability of Failure

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B. Damage Factor

D_{f-gov}^{thin} : Thinning

$$D_{f-gov}^{thin} = \min |D_f^{thin}, D_f^{elin}| \quad (\text{C-10.1}) \quad \text{when an internal liner is present}$$

$$D_{f-gov}^{thin} = D_f^{thin} \quad (\text{C-10.2}) \quad \text{when an internal liner is not present}$$

$$D_{f-gov}^{thin} = 4.30E+02$$

D_{f-gov}^{SCC} : Stress Corrosion Cracking

$$D_{f-gov}^{SCC} = \max \left| \begin{array}{l} D_f^{caustic}, D_f^{amine}, D_f^{SSC}, D_f^{HIC/SOHC-H2S}, \\ D_f^{ACSCC}, D_f^{PTA}, D_f^{CLSCC}, D_f^{HSC-HF}, \\ D_f^{HIC/SOHC-HF} \end{array} \right| \quad (\text{C-10.3})$$

$$D_{f-gov}^{SCC} = 0.00E+00$$

D_{f-gov}^{extd} : External

$$D_{f-gov}^{extd} = \max |D_f^{extcor}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}| \quad (\text{C-10.4})$$

$$D_{f-gov}^{extd} = 2.39E+00$$

D_{f-gov}^{brit} : Brittle fracture

$$D_{f-gov}^{brit} = \max |(D_f^{brit} + D_f^{tempe}), D_f^{885F}, D_f^{sigma}| \quad (\text{C-10.5})$$

$$D_{f-gov}^{brit} = 0.00E+00$$

D_f^{htha} : High Temperature Hydrogen Attack

$$D_f^{htha} = 0.00E+00$$

D_f^{mfat} : Piping Mechanical Fatigue

$$D_f^{mfat} = 0.00E+00$$

Total DF:

- Localized corrosion

$$D_{f-total} = \max [D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-10.6})$$

- General corrosion

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_{f-gov}^{htha} + D_{f-gov}^{brit} + D_{f-gov}^{mfat} \quad (\text{C-10.7})$$

$$D_{f-total} = 4.32E+02 \quad (\text{General corrosion})$$

C. Management Systems Factor

To determine the value of Fms, use a series of question and survey given by API RBI 581 to determine Fms value. But in this calculation the score is 500 from 1000.

$$pscore = \frac{\text{score}}{1000} \times 100\% = \frac{500}{1000} \times 100 = 50 \% \quad (\text{C-10.8})$$

$$F_{MS} = 10^{(-0.02 \times pscore + 1)} = 1 \quad (\text{C-10.9})$$



Probability of Failure

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D. Calculate The Probability of Failure (POF)

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} = 1.32E-02 \quad (\text{C-10.10})$$

Table C-10.3 Probability of Failure Category

| POF Category | |
|--------------|---------------|
| 4 | <i>Likely</i> |



Thinning Damage Factor

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1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 2" | From | 16LF36-8"-CB2D | |
| Material | Carbon Steel | To | Burn Pit | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|------------------------------|----------------|
| Start date | 24-10-1983 |
| Thickness (mm) | 3.18 |
| Corrosion Allowance (in) | 0.0625 |
| Max. Design Temperature (°C) | 399 |
| Min. Design Temperature (°C) | -29 |
| Max. Design Pressure (MPa) | 5.1 |
| Operating Temperature (°C) | 197 |
| Operating Pressure (MPa) | 1.27 |
| Design Code | ASME B.31.3 |
| Equipment Type | Pipe |
| Component Type | PIPE-4 |
| Component Geometry Data | CYL, ELB |
| Material Specification | ASTM A106 Gr B |
| Yield Strength (MPa) | 241.32 |
| Tensile Strength (MPa) | 413.68 |
| Weld Joint Efficiency | 1 |
| Heat tracing | No |

3 Calculation of Thinning

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 3.18 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the corrosion rate for the base material

$$Cr = 0.189 \text{ mm/year} \quad (\text{measured})$$

Step 3 : Determine the time in service

$$\begin{aligned} t_{rdi} &= 3.18 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age_{tk} &= 3.00 \text{ years} && (\text{RBI date } 01-06-2020) \end{aligned}$$



Thinning Damage Factor

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Step 4 : Determine the age of cladding

$$age_{rc} = - \quad \text{years} \quad (cladding \text{ not applicable})$$

Step 5 : Determine t_{min}

$$t_{min} = t + c \quad (\text{C-10.11})$$

$$t_{min} = \frac{PD}{2(SE + PY)} + c \quad (\text{C-10.12})$$

$$t_{min} = \frac{5.1 \times 60.3}{2(137.9 \times 1 + 5.1 \times 0.4)} + 1.5875$$

$$t_{min} = 2.69 \text{ mm}$$

Step 6 : Determine A_{rt} parameter

$$A_{rt} = \frac{C_{r,bm} \times age_{tk}}{t_{rdi}} \quad (\text{C-10.13})$$

$$A_{rt} = \frac{0.189 \times 3.00}{3.18}$$

$$A_{rt} = 0.178239$$

Step 7 : Calculate the flow stress

$$FS^{Thin} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-10.14})$$

$$FS^{Thin} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{Thin} = 360.25$$

Step 8 : Calculate the strength ratio parameter

$$SR_P^{Thin} = \frac{S \times E}{FS^{Thin}} \times \frac{t_{min}}{t_{rdi}} \quad (\text{C-10.15})$$

$$SR_P^{Thin} = \frac{137.9 \times 1}{360.25} \times \frac{2.69}{3.18}$$

$$SR_P^{Thin} = 0.3234$$

Step 9 : Determine the number of inspections

$$N_A^{Thin} = 0 \quad \text{Table C-10.4 Thinning Inspection Category}$$

$$N_B^{Thin} = 0$$

| Inspection Category | |
|---------------------|------------------|
| C | Fairly Effective |

$$N_C^{Thin} = 1$$

$$N_D^{Thin} = 0$$

Step 10 : Calculate the inspection effectiveness factors

(C-10.16)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective



Thinning Damage Factor

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$$I_1^{Thin} = Pr_{p1}^{Thin} \times (Co_{p1}^{ThinC})^{N_C^{Thin}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{Thin} = Pr_{p2}^{Thin} \times (Co_{p2}^{ThinC})^{N_C^{Thin}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{Thin} = Pr_{p3}^{Thin} \times (Co_{p3}^{ThinC})^{N_C^{Thin}} = 0.2 \times 0.2 = 0.04$$

Step 11 : Calculate the posterior probabilities (C-10.17)

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 12 : Calculate the parameters β reliability indices (C-10.18)

$$\text{Assigning } COV_{\Delta t} = 0.20 \quad \text{Where} \quad D_{S1} = 1$$

$$COV_{sf} = 0.20 \quad D_{S2} = 2$$

$$COV_p = 0.05 \quad D_{S3} = 4$$

$$\beta_1^{Thin} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{Thin} = 2.9500$$

$$\beta_2^{Thin} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_2^{Thin} = 2.1630$$

$$\beta_3^{Thin} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_p)^2}}$$

$$\beta_3^{Thin} = -0.2350$$

**Step 13 : Determine the base DF for thinning for tank bottom comp.
Comp. Type Pipe 2"**

Step 14 : Calculate the base DF for all components

$$D_{fb}^{Thin} = \left[\frac{(Po_{p1}^{Thin} \Phi(-\beta_1^{Thin})) + (Po_{p2}^{Thin} \Phi(-\beta_2^{Thin})) + (Po_{p3}^{Thin} \Phi(-\beta_3^{Thin}))}{1.56E-0.4} \right] \quad (\text{C-10.19})$$

$$D_{fb}^{Thin} = 4.30E+02$$



Thinning Damage Factor

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Step 15 : Determine the DF for thinning (C-10.20)

$$D_f^{Thin} = \text{Max} \left[\left(\frac{D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \right), 0.1 \right]$$

$$D_f^{Thin} = \text{Max} \left[\left(\frac{429.9370 \cdot 1 \cdot 1 \cdot 0 \cdot 0 \cdot 0}{1} \right), 0.1 \right]$$

$$D_f^{Thin} = 4.30\text{E+02}$$



1 Asset

| | | | | |
|-----------------|------------------|--------------|----------------|------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6 | Date |
| Type | Pipe 2" | From | 16LF36-8"-CB2D | |
| Material | Carbon Steel | To | Burn Pit | |
| | ASTM A106 Gr B | Unit | Plant 16 | |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 | |

2 Component Data

| | |
|--------------------------------------|----------------------------|
| Insulation Type | Calcium Silicate |
| Driver | Moderate - Frequently wet |
| Corrosion Rate (mm/yr) | 0.189 |
| Coating Installation Date | 24-10-1988 |
| Coating Quality | Medium - single coat epoxy |
| Equipment Design/Fabrication Penalty | No |
| Complexity | Average |
| Insulation Condition | Average |
| Pipe Support Penalty | No |
| Interface Penalty | No |
| Inspection Effectiveness Category | C |
| Number of Inspections | 1 |
| Thickness Reading (mm) | 3.18 |
| Thickness Reading Date | 01-06-2017 |

3 Calculation of Corrosion Under Insulation

Step 1 : Determine the furnished thickness

$$\begin{aligned} t &= 3.18 \text{ mm} && (\text{inspected on } 01-06-2017) \\ age &= 33.58 \text{ years} \\ t_{cm} &= - \text{ mm} && (\text{cladding not applicable}) \end{aligned}$$

Step 2 : Determine the base corrosion rate

$$\begin{aligned} \text{Operating Temperature} &= 197 \text{ }^{\circ}\text{C} \\ Cr_b &= 0.000 \text{ mm/year} && (\text{Driver: Moderate}) \end{aligned}$$

Step 3 : Compute the final corrosion rate

$$\begin{aligned} F_{INS} &= 1.25 & F_{CM} &= 1.00 & F_{IC} &= 1.00 \\ F_{EQ} &= 1 & F_{IF} &= 1 \end{aligned}$$

$$\begin{aligned} Cr &= C_{rb} \times F_{INS} \times F_{CM} \times F_{IC} \times \max [F_{EQ}, F_{IF}] \\ Cr &= 0.00 \text{ mm/year} \end{aligned} \quad (\text{C-10.21})$$



**CUI
Damage Factor**

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Step 4 : Determine the time in service

$$t_{rde} = 3.18 \text{ mm} \quad (\text{inspected on } 01-06-2017)$$

$$age_{tk} = 3.00 \text{ years} \quad (\text{RBI date } 01-06-2020)$$

Step 5 : Determine the age of coating

$$age_{coat} = 31.58 \text{ years}$$

Step 6 : Determine the coating adjustment

$$age_{tk} = 3.00 \text{ years} \quad \text{Medium - single coat epoxy}$$

$$age_{coat} = 31.58 \text{ years}$$

$$\text{If } age_{tk} \geq age_{coat}$$

$$Coat_{adj} = \min [5, age_{coat}] \quad (\text{C-10.22})$$

$$\text{If } age_{tk} < age_{coat}$$

$$Coat_{adj} = \min [5, age_{coat}] - \min [5, age_{coat} - age_{tk}]$$

$$Coat_{adj} = 0.00 \quad (\text{C-10.23})$$

Step 7 : Determine the in-service time

$$age = age_{tk} - Coat_{adj} \quad (\text{C-10.24})$$

$$= 3.00 - 0.00$$

$$= 3.00 \text{ years}$$

Step 8 : Determine the allowable stress

$$P = 5.1 \text{ mpa}$$

$$S = 137.9 \text{ mpa}$$

$$E = 1$$

$$Y = 0.4$$

$$t_{min} = 2.69 \text{ mm}$$

Step 9 : Determine Art parameter

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \quad (\text{C-10.25})$$

$$A_{rt} = \frac{0.000 \times 3.00}{3.18}$$

$$A_{rt} = 0.000000$$

Step 10 : Calculate the flow stress

$$FS^{CUIF} = \frac{YS + TS}{2} \times E \times 1.1 \quad (\text{C-10.26})$$

$$FS^{CUIF} = \frac{241.32 + 413.68}{2} \times 1 \times 1.1$$

$$FS^{CUIF} = 360$$



CUI Damage Factor

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Step 11 : Calculate the flow stress

$$SR_P^{CUIF} = \frac{S \times E}{FS^{CUIF}} \times \frac{t_{min}}{t_{rde}} \quad (C-10.27)$$

$$SR_P^{CUIF} = \frac{138}{360} \times \frac{1}{3.18} \times \frac{2.69}{2.69}$$

$$SR_P^{CUIF} = 0.323360$$

Step 12 : Determine the number of inspections

| | | |
|--------------|-----|--------------------------------------|
| N_A^{CUIF} | = 0 | Table C-10.5 CUI Inspection Category |
| N_B^{CUIF} | = 0 | Inspection Category |
| N_C^{CUIF} | = 1 | C Fairly Effective |
| N_D^{CUIF} | = 0 | |

Step 13 : Calculate the inspection effectiveness factors (C-10.28)

Prior Probability Low Confidence Data

Conditional Probability C - Fairly Effective

$$I_1^{CUIF} = Pr_{p1}^{CUIF} \times (Co_{p1}^{CUIFC})^{N_C^{CUIF}} = 0.5 \times 0.5 = 0.25$$

$$I_2^{CUIF} = Pr_{p2}^{CUIF} \times (Co_{p2}^{CUIFC})^{N_C^{CUIF}} = 0.3 \times 0.3 = 0.09$$

$$I_3^{CUIF} = Pr_{p3}^{CUIF} \times (Co_{p3}^{CUIFC})^{N_C^{CUIF}} = 0.2 \times 0.2 = 0.04$$

Step 14 : Calculate the posterior probabilities (C-10.29)

$$Po_{p1}^{CUIF} = \frac{I_1^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.25}{0.25 + 0.09 + 0.04} = 0.658$$

$$Po_{p2}^{CUIF} = \frac{I_2^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.09}{0.25 + 0.09 + 0.04} = 0.237$$

$$Po_{p3}^{CUIF} = \frac{I_3^{CUIF}}{I_1^{CUIF} + I_2^{CUIF} + I_3^{CUIF}} = \frac{0.04}{0.25 + 0.09 + 0.04} = 0.105$$

Step 15 : Calculate the parameters β reliability indices (C-10.30)

Assigning $COV_{\Delta t} = 0.20$ Where $D_{S1} = 1$

$COV_{sf} = 0.20$ $D_{S2} = 2$

$COV_p = 0.05$ $D_{S3} = 4$

$$\beta_1^{CUIF} = \frac{1 - D_{S1} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_p)^2}}$$

$$\beta_1^{CUIF} = 3.3722$$



CUI Damage Factor

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$$\beta_2^{CUIF} = \frac{1 - D_{S2} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{CUIF})^2 \cdot (COV_P)^2}}$$
$$\beta_2^{CUIF} = 3.3722$$
$$\beta_3^{CUIF} = \frac{1 - D_{S3} \cdot A_{rt} - SR_P^{CUIF}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2 + (1 - D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2 + (SR_P^{Thin})^2 \cdot (COV_P)^2}}$$
$$\beta_3^{CUIF} = 3.3722$$

Step 16 : Determine the DF for CUIF

$$D_f^{CUIF} = \left[\frac{(Po_{P1}^{CUIF} \Phi(-\beta_1^{CUIF})) + (Po_{P2}^{CUIF} \Phi(-\beta_2^{CUIF})) + (Po_{P3}^{CUIF} \Phi(-\beta_3^{CUIF}))}{1.56E-0.4} \right] \quad (C-10.31)$$
$$D_f^{CUIF} = 2.39E+00$$



Consequence of Failure

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1 Asset

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 2" | From | 16LF36-8"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

2 Determine the Representative Fluid and Associated Properties

Step 1 : Select a representative fluid group

Representative Fluids = C6-C8

Table C-10.6 Representative Fluid

| Fluid | Fluid Type | Examples of Applicable Materials |
|-------|------------|--|
| C6-C8 | TYPE 0 | Gasoline, naphtha, light straight run, heptane |

Step 2 : Determine the stored fluid phase

Fluid phase = Liquid

Step 3 : Determine the stored fluid properties

- For a stored liquid

Liquid density = 684.018 kg/m³

Autoignition temperature = 223 C = 496.15 K

- For a stored vapor

Molecular weight = - kg/kg-mol

Ideal gas specific heat ratio = - J/(kg-mol-K)

Autoignition temperature = - C = - K

Step 4 : Determine the steady state phase of the fluid after release to the atm

Table C-10.7 Final phase of the fluid after release to the atm

| Phase of Fluid at Normal Operating (Storage) Conditions | Phase of Fluid at Ambient (after release) Conditions | Determination of Final Phase of Consequence Calculation |
|---|--|---|
| Liquid | Liquid | Model as liquid |

3 Release Hole Size Selection

Step 1 : Determine the release hole size diameters

Component Diameter = 2 in = 50.8 mm



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Table C-10.8 Release hole size

| Release Hole Number | Release Hole Size | Diameters (mm) | Release Hole Diameter, d_n (mm) |
|---------------------|-------------------|----------------|-----------------------------------|
| 1 | Small | 0 to 6.4 | $d_1 = 6.4$ |
| 2 | Medium | >6.4 to 51 | $d_2 = 25.0$ |
| 3 | Large | >51 to 152 | $d_3 = 50.8$ |
| 4 | Rupture | >152 | $d_4 = 50.8$ |

Step 2 : Determine the generic failure frequency

Equip. Type Pipe Comp. Type PIPE-4

Table C-10.9 The generic failure frequency

| GFF As a Function of Hole Size (failures/yr) | | | | gff_{total} (failures/yr) |
|--|----------|----------|----------|-----------------------------|
| Small | Medium | Large | Rupture | |
| 8.00E-06 | 2.00E-05 | 0.00E+00 | 2.60E-06 | 3.06E-05 |

4 Release Rate Calculation

Step 1 : Determine the fluid phase

Fluid phase = Liquid

Step 2 : Calculate the release hole size area

$$A_n = \frac{\pi d_n^2}{4} \quad (\text{C-10.32})$$

Table C-10.10 The release hole size area

| Small | Medium | Large | Rupture |
|-----------------------|------------------------|-------------------------|-------------------------|
| 32.18 mm ² | 491.07 mm ² | 2027.65 mm ² | 2027.65 mm ² |

Step 3 : Viscosity correction factor

$K_{v,n} = 1$ (*conservative assumption*)

Step 4 : Calculate the release rate for each release area

$C_d = 0.61$

$$W_n = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_n}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-10.33})$$

Table C-10.11 The release rate for each release area

| Small | Medium | Large | Rupture |
|--------------|--------------|--------------|--------------|
| 7.8E-01 kg/s | 1.2E+01 kg/s | 4.9E+01 kg/s | 4.9E+01 kg/s |



Consequence of Failure

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5 Estimate the Fluid Inventory Available for Release

Step 1 : Group comp. and eq. items into inventory groups

Equip. Type Pipe 100 % full, calculated for Level 2 methodology

Step 2 : Determine the fluid mass

$$mass_{comp} = 63.30 \text{ kg}$$

Step 3 : Determine the fluid mass in the inventory group

$$mass_{comp,i} = 60059.46 \text{ kg}$$

Step 4 : Determine the fluid mass in the inventory group

$$mass_{inv} = 60059.46 \text{ kg}$$

Step 5 : Calculate the flow rate a 203 mm (8 in) diameter hole

$$A_8 = 32450 \text{ mm}^2$$

$$W_8 = C_d \cdot K_{v,n} \cdot \rho_l \cdot \frac{A_8}{C_1} \cdot \sqrt{\frac{2 \cdot g_c \cdot (P_s - P_{atm})}{\rho_l}} \quad (\text{C-10.34})$$

$$W_8 = 7.91E+02 \text{ kg/s}$$

Step 6 : For each release hole size, Calculate the added fluid mass

$$mass_{add,n} = 180 \cdot \min[W_n; W_{max8}] \quad (\text{C-10.35})$$

Table C-10.12 The added fluid mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 1.41E+02 kg/s | 2.16E+03 kg/s | 8.90E+03 kg/s | 8.90E+03 kg/s |

Step 7 : For each release hole size, calculate the available mass

$$Mass_{avail,n} = \min. [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \quad (\text{C-10.36})$$

Table C-10.13 The available mass

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 2.05E+02 kg/s | 2.22E+03 kg/s | 8.97E+03 kg/s | 8.97E+03 kg/s |

6 Determine the Release Type (Continuous or Instantaneous)

Step 1 : Calculate the time required to release 4,536 kg

$$t_n = \frac{C_3}{W_n} \quad (\text{C-10.37})$$

Table C-10.14 The time required to release 4,536 kg

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 5.78E+03 s | 3.79E+02 s | 9.17E+01 s | 9.17E+01 s |



Consequence of Failure

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Step 2 : Determine release type is instantaneous or continuous

Table C-10.15 Release type

| Small | Medium | Large | Rupture |
|--------------------|--------------------|-----------------------|-----------------------|
| Continuous Release | Continuous Release | Instantaneous Release | Instantaneous Release |

7 Assess the Impact of Detection and Isolation Systems

Step 1 : Detection and isolation systems present in the unit

Table C-10.16 Type of Detection System

| Type of Detection System | Detection Classification |
|--|--------------------------|
| Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system | A |

Table C-10.17 Type of Isolation System

| Type of Isolation System | Isolation Classification |
|--|--------------------------|
| Isolation or shutdown systems activated by operators in the control room or other suitable location remote from the leak | B |

Step 2 : The release reduction factor

Table C-10.18 The release reduction factor

| System Classifications | | Release Magnitude Adjustment | Reduction Factor |
|------------------------|-----------|------------------------------------|------------------|
| Detection | Isolation | | |
| A | B | Reduce release rate or mass by 20% | 0.20 |

Step 3 : The total leak durations

Table C-10.19 The total leak durations

| System Classifications | | Maximum Leak Duration, ld_{max} | | | |
|------------------------|-----------|-----------------------------------|-------------|-----|----------|
| Detection | Isolation | 30 | minutes for | 6.4 | mm leaks |
| A | B | 20 | minutes for | 25 | mm leaks |
| | | 10 | minutes for | 102 | mm leaks |

8 Determine the Release Rate and Mass for COF

Step 1 : Calculate the adjusted release rate

$$Rate_n = W_n (1 - fact_{di}) \quad (C-10.38)$$

Table C-10.20 The adjusted release rate

| Small | Medium | Large | Rupture |
|---------------|---------------|---------------|---------------|
| 6.28E-01 kg/s | 9.58E+00 kg/s | 3.96E+01 kg/s | 3.96E+01 kg/s |



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Step 2 : Calculate the leak duration

$$Id_n = \min . [\{ \frac{Mass_{avail,n}}{Rate_n} \}, \{ 60 . Id_{max,n} \}] \quad (C-10.39)$$

Table C-10.21 The leak duration

| Small | Medium | Large | Rupture |
|------------|------------|------------|------------|
| 3.26E+02 s | 2.32E+02 s | 2.27E+02 s | 6.00E+01 s |

Step 3 : Calculate the release mass

$$mass_n = \min . [\{ Rate_n . Id_n \}, Mass_{avail,n}] \quad (C-10.40)$$

Table C-10.22 The release mass

| Small | Medium | Large | Rupture |
|-------------|-------------|-------------|---------------|
| 2.05E+02 kg | 2.22E+03 kg | 8.97E+03 kg | 2.37E+03 kg/s |

9 Determine Flammable and Explosive Consequence

Step 1 : Select the consequence area mitigation reduction factor

Table C-10.23 The consequence area mitigation reduction factor

| Mitigation System | Consequence Area Adjustment | Reduction Factor |
|---|--------------------------------|------------------|
| Inventory blowdown and coupled with isolation system classification B or higher | Reduce consequence area by 25% | 0.25 |

Step 2 : Calculate the energy efficiency correction factor

$$eneff_n = 4 . \log_{10} [C_{4A} . mass_n] - 15 \quad (C-10.41)$$

Table C-10.24 The energy efficiency correction factor

| Small | Medium | Large | Rupture |
|-----------|-----------|----------|-----------|
| -4.38E+00 | -2.42E-01 | 2.18E+00 | -1.25E-01 |

Step 3 : Determine the fluid type

A. Component Damage

Table C-10.25 Component Damage

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|-------|--------|-------------------------------------|------|--------|------|--------------------------------|---|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 5.846 | 0.98 | 34.17 | 0.89 | 63.98 | 1 | 103.4 | 0.95 |



Consequence of Failure

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Table C-10.25 Component Damage

| Fluid | Type | Instantaneous Releases Constants | | | | | | | |
|-------|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-INST) | | | | Autoignition Likely (AIL-INST) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 2.188 | 0.66 | 0.749 | 0.78 | 41.49 | 0.61 | 8.18 | 0.55 |

B. Personnel Injury

Table C-10.26 Personnel Injury

| Fluid | Type | Continuous Releases Constants | | | | | | | |
|--|--------|--|------|--------|------|-----------------------------------|------|--------|------|
| | | Autoignition Not Likely (AINL-CONT) | | | | Autoignition Likely (AIL-CONT) | | | |
| | | Gas | | Liquid | | Gas | | Liquid | |
| | | a | b | a | b | a | b | a | b |
| C6-C8 | TYPE 0 | 13.49 | 0.96 | 96.88 | 0.89 | 169.7 | 1 | 252.8 | 0.92 |
| Instantaneous Releases Constants | | | | | | | | | |
| Autoignition Not Likely (AINL-INST) | | | | | | | | | |
| Gas | | Liquid | | Gas | | Liquid | | | |
| a | b | a | b | a | b | a | b | a | b |
| | | 4.216 | 0.67 | 2.186 | 0.78 | 147.2 | 0.63 | 31.89 | 0.54 |

Step 4 : The component damage consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{cmd}^{AINL-CONT} = 34.17 \quad b = b_{cmd}^{AINL-CONT} = 0.89$$

$$CA_{cmd,n}^{AINL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-10.42)$$

Table C-10.27 The component damage consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.69E+01 m ² | 1.92E+02 m ² | 6.77E+02 m ² | 6.77E+02 m ² |

Step 5 : The component damage consequence areas for Autoignition Likely - Continuous Release

$$a = a_{cmd}^{AIL-CONT} = 103.4 \quad b = b_{cmd}^{AIL-CONT} = 0.95$$

$$CA_{cmd,n}^{AIL-CONT} = a (rate_n)^b \cdot (1 - fact_{mit}) \quad (C-10.43)$$



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Table C-10.28 The component damage consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.98E+01 m ² | 1.17E+05 m ² | 4.41E+05 m ² | 1.25E+05 m ² |

Step 6 : The component damage consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{cmd}^{AINL-INST} = 0.749 \quad b = b_{cmd}^{AINL-INST} = 0.78$$

$$CA_{cmd,n}^{AINL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-10.44})$$

Table C-10.29 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|--------------------------|
| -8.13E+00 m ² | -9.48E+02 m ² | 3.11E+02 m ² | -1.94E+03 m ² |

Step 7 : The component damage consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{cmd}^{AIL-INST} = 8.18 \quad b = b_{cmd}^{AIL-INST} = 0.55$$

$$CA_{cmd,n}^{AIL-INST} = \alpha (mass_n)^b \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (\text{C-10.45})$$

Table C-10.30 The component damage consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|--------------------------|
| -2.61E+01 m ² | -4.74E+02 m ² | 4.19E+02 m ² | -3.54E+03 m ² |

Step 8 : The personnel injury consequence areas for Autoignition Not Likely - Continuous Release

$$a = a_{inj}^{AINL-CONT} = 96.88 \quad b = b_{inj}^{AINL-CONT} = 0.89$$

$$CA_{inj,n}^{AINL-CONT} = [a (rate_n^{AINL-CONT})^b] \cdot (1 - fact_{mit}) \quad (\text{C-10.46})$$

Table C-10.31 The personnel injury consequence areas for AINL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 4.80E+01 m ² | 5.43E+02 m ² | 1.92E+03 m ² | 1.92E+03 m ² |

Step 9 : The personnel injury consequence areas for Autoignition Likely - Continuous Release

$$a = a_{inj}^{AIL-CONT} = 252.8 \quad b = b_{inj}^{AIL-CONT} = 0.92$$



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$$CA_{inj,n}^{AIL-CONT} = [a (rate_n^{AIL-CONT})^b] \cdot (1 - fact_{mit}) \quad (C-10.47)$$

Table C-10.32 The personnel injury consequence areas for AIL - Cont.

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|-------------------------|
| 1.24E+02 m ² | 1.52E+03 m ² | 5.59E+03 m ² | 5.59E+03 m ² |

Step 10 : The personnel injury consequence areas for Autoignition Not Likely - Instantaneous Release

$$a = a_{inj}^{AINL-INST} = 2.186 \quad b = b_{inj}^{AINL-INST} = 0.78$$

$$CA_{inj,n}^{AINL-INST} = [\alpha (mass_n^{AINL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-10.48)$$

Table C-10.33 The personnel injury consequence areas for AINL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|--------------------------|
| -2.37E+01 m ² | -4.31E+02 m ² | 9.09E+02 m ² | -5.65E+03 m ² |

Step 11 : The personnel injury consequence areas for Autoignition Likely - Instantaneous Release

$$a = a_{inj}^{AIL-INST} = 31.89 \quad b = b_{inj}^{AIL-INST} = 0.54$$

$$CA_{inj,n}^{AIL-INST} = [\alpha (mass_n^{AIL-INST})^b] \cdot \left(\frac{1 - fact_{mit}}{eneff_n} \right) \quad (C-10.49)$$

Table C-10.34 The personnel injury consequence areas for AIL - Inst.

| Small | Medium | Large | Rupture |
|--------------------------|--------------------------|-------------------------|--------------------------|
| -9.66E+01 m ² | -1.75E+03 m ² | 1.49E+03 m ² | -1.28E+04 m ² |

Step 12 : Calculate the instantaneous/continuous blending factor

- Continuous Releases

$$fact_n^{IC} = \min \left[\left\{ \frac{rate_n}{C_5} \right\}, 1.0 \right] \quad (C-10.50)$$

Table C-10.35 The instantaneous/continuous blending factor

| Small | Medium | Large | Rupture |
|----------|----------|----------|----------|
| 2.49E-02 | 3.80E-01 | 1.00E+00 | 1.00E+00 |

- Instantaneous Releases

$$fact_n^{IC} = 1.0$$



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Step 13 : Calculate the AIT blending factor, $fact^{AIT}$ (C-10.51)

$$fact^{AIT} = 0 \quad \text{for } T_S + C_6 \leq AIT$$

$$fact^{AIT} = \frac{(T_S - AIT + C_6)}{2 \cdot C_6} \quad \text{for } T_S + C_6 > AIT > T_S - C_6$$

$$fact^{AIT} = 1 \quad \text{for } T_S + C_6 \geq AIT$$

$$T_S = 470.15 \text{ K} \quad AIT = 496.15 \text{ K} \quad C_6 = 55.6 \text{ K}$$

$$fact^{AIT} = 1$$

Step 14 : Calculate the continuous / instantaneous blended consequence areas (Type 0)

- $CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-10.52)

Table C-10.36 The inst./cont. blended consequence areas (AIL-CMD)

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|--------------------------|
| 2.25E+01 m ² | 7.21E+04 m ² | 4.19E+02 m ² | -3.54E+03 m ² |

- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AIL-CONT} \cdot (1 - fact_n^{IC})$ (C-10.53)

Table C-1.37 The inst./cont. blended consequence areas (AIL-INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|--------------------------|
| 2.39E+01 m ² | -8.13E+02 m ² | 1.49E+03 m ² | -1.28E+04 m ² |

- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-10.54)

Table C-10.38 The inst./cont. blended consequence areas (AINL-CMD)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|--------------------------|
| 8.38E+00 m ² | -8.29E+02 m ² | 3.11E+02 m ² | -1.94E+03 m ² |

- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} \cdot fact_n^{IC} + CA_{inj,n}^{AINL-CONT} \cdot (1 - fact_n^{IC})$ (C-10.55)

Table C-10.39 The inst./cont. blended consequence areas (AINL-INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|--------------------------|
| 2.31E+01 m ² | -9.42E+01 m ² | 9.09E+02 m ² | -5.65E+03 m ² |

Step 15 : Calculate the AIT blended consequence areas

- $CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \cdot fact^{AIT} + CA_{cmd,n}^{AINL} \cdot (1 - fact^{AIT})$ (C-10.56)



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Table C-10.40 The AIT blended consequence areas (CMD)

| Small | Medium | Large | Rupture |
|-------------------------|-------------------------|-------------------------|--------------------------|
| 2.25E+01 m ² | 7.21E+04 m ² | 7.31E+02 m ² | -5.48E+03 m ² |

$$\bullet CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \cdot fact^{AIT} + CA_{inj,n}^{AINL} \cdot (1 - fact^{AIT}) \quad (C-10.57)$$

Table C-10.41 The AIT blended consequence areas (INJ)

| Small | Medium | Large | Rupture |
|-------------------------|--------------------------|-------------------------|--------------------------|
| 2.39E+01 m ² | -8.13E+02 m ² | 1.49E+03 m ² | -1.28E+04 m ² |

Step 16 : Determine the final consequence areas

$$CA_{f,cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd.n}^{flam}}{gff_{total}} \right) = 4.67E+04 \text{ m}^2 \quad (C-10.58)$$

$$CA_{f,inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) = -1.61E+03 \text{ m}^2 \quad (C-10.59)$$

10 Determine Toxic Consequence

There are no toxic chemicals release

$$CA_{f,inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-1.60)$$

11 Determine Nonflammable, Nontoxic Consequence

There are no steam, caustic, or acid releases in the equipment

$$CA_{f,inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}} \right) = 0.00E+00 \text{ m}^2 \quad (C-10.61)$$

12 Determine the Final Consequence Area

Step 1 : Calculate the final component damage consequence area

$$CA_{f,cmd} = CA_{f,cmd}^{flam} = 4.67E+04 \text{ m}^2 \quad (C-10.62)$$

Step 2 : Calculate the final personnel injury consequence area

$$CA_{inj} = \max [CA_{f,inj}^{flam}, CA_{f,inj}^{tox}, CA_{f,inj}^{nfnt}] = 0.00E+00 \text{ m}^2 \quad (C-10.63)$$



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Step 3 : Final Consequence Area

$$CA_f = \max [CA_{f,cmd}, CA_{inj}] = 4.67E+04 \text{ m}^2 \quad (\text{C-10.64})$$

Table C-10.42 Consequence of Failure Category

| COF Category | |
|--------------|--------------|
| E | Catastrophic |



Result

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A. EQUIPMENT SPECIFICATION

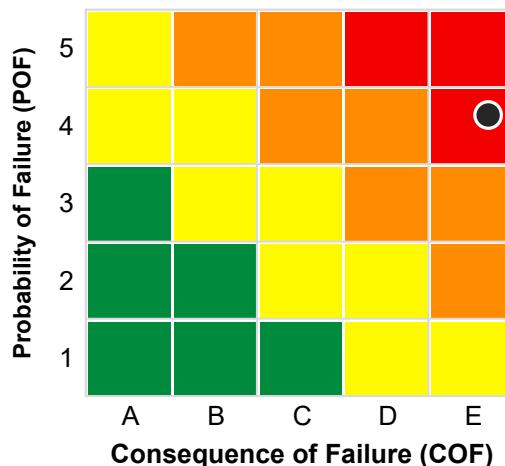
| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 2" | From | 16LF36-8"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 4.32E+02$
 - POF Score
 $P_f(t) = 1.32E-02$
 - Category
4 - Likely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 4.67E+04 \text{ m}^2$
 - Category
E - Catastrophic

- c. Risk Ranking
 - Risk Score
 $R(t) = 6.17E+02 \text{ m}^2/\text{year}$
 - Risk Ranking
4E High
 - Date
RBI Date : 01-06-2020



C. INSPECTION ACTIVITIES

Table C-10.43 Inspection Activities

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2017 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2017 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

Attachment D
Inspection Plan



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A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF37-12"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 12" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 2.24E+01$$

- POF Score

$$P_f(t) = 6.85E-04$$

- Category

3 - Possible

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 5.47E+02 \text{ m}^2$$

- Category

C - Serious

c. Risk Ranking

- Risk Score

$$R(t) = 3.75E-01 \text{ m}^2/\text{year}$$

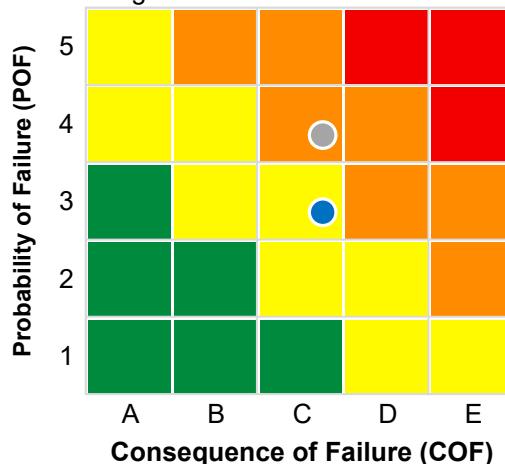
- Risk Ranking

3C Medium

- Date

Plan Date : 01-06-2022

Target Date : 04-07-2084



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 2.67E-01 | 4.89E-04 | 5.47E+02 | m^2 |
| Plan Date | 01-06-2022 | 3.75E-01 | 6.85E-04 | 5.47E+02 | m^2 |
| Target Date | 04-07-2084 | 3.72E+00 | 6.80E-03 | 5.47E+02 | m^2 |

D. REMARK

- >20% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



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E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2022 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2022 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| etc. | | | | | | | |



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A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|--------------|
| Tag Number | 16LF31-10"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 10" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 3.66E+00$$

- POF Score

$$P_f(t) = 1.12E-04$$

- Category

2 - Unlikely

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 6.99E+04 \text{ m}^2$$

- Category

E - Catastrophic

c. Risk Ranking

- Risk Score

$$R(t) = 7.84E+00 \text{ m}^2/\text{year}$$

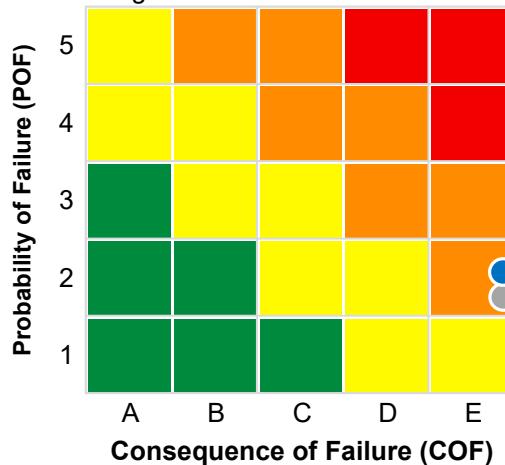
- Risk Ranking

2E Medium High

- Date

Plan Date : 01-06-2022

Target Date : 07-03-2020



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 4.15E+00 | 5.93E-05 | 6.99E+04 | m^2 |
| Plan Date | 01-06-2022 | 7.84E+00 | 1.12E-04 | 6.99E+04 | m^2 |
| Target Date | 07-03-2020 | 3.72E+00 | 5.31E-05 | 6.99E+04 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



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E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 07-03-2020 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 07-03-2020 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| etc. | | | | | | | |



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A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF36-8"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 8" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 6.24E+02$$

- POF Score

$$P_f(t) = 1.91E-02$$

- Category

4 - Likely

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 5.66E+02 \text{ m}^2$$

- Category

C - Serious

c. Risk Ranking

- Risk Score

$$R(t) = 1.08E+01 \text{ m}^2/\text{year}$$

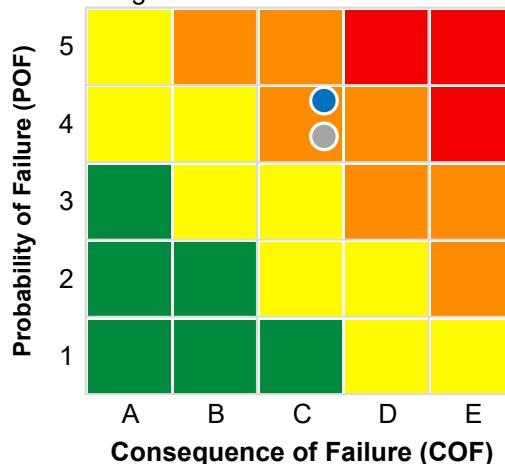
- Risk Ranking

4C Medium High

- Date

Plan Date : 01-06-2022

Target Date : 16-01-2021



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 4.66E-01 | 8.23E-04 | 5.66E+02 | m^2 |
| Plan Date | 01-06-2022 | 1.08E+01 | 1.91E-02 | 5.66E+02 | m^2 |
| Target Date | 16-01-2021 | 3.72E+00 | 6.57E-03 | 5.66E+02 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-3
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 16-01-2021 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 16-01-2021 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-4
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF22-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16E-11 |
| Material | Carbon Steel | To | Vessel 16E-5 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 4.77E+01$$

- POF Score

$$P_f(t) = 1.46E-03$$

- Category

3 - Possible

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 9.80E+02 \text{ m}^2$$

- Category

D - Major

c. Risk Ranking

- Risk Score

$$R(t) = 1.43E+00 \text{ m}^2/\text{year}$$

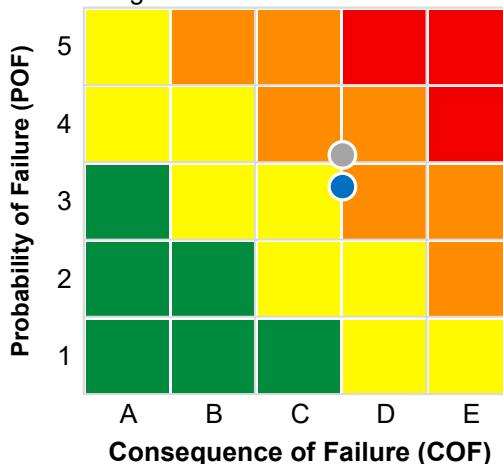
- Risk Ranking

3D Medium High

- Date

Plan Date : 01-06-2022

Target Date : 29-09-2025



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 5.85E-02 | 5.97E-05 | 9.80E+02 | m^2 |
| Plan Date | 01-06-2022 | 1.43E+00 | 1.46E-03 | 9.80E+02 | m^2 |
| Target Date | 29-09-2025 | 3.72E+00 | 3.79E-03 | 9.80E+02 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-4
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2022 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2022 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-5
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF40-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF22-6"-CB2D |
| Material | Carbon Steel | To | 16LF39-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-010 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 6.77E+01$$

- POF Score

$$P_f(t) = 2.07E-03$$

- Category

3 - Possible

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 1.48E+03 \text{ m}^2$$

- Category

D - Major

c. Risk Ranking

- Risk Score

$$R(t) = 3.07E+00 \text{ m}^2/\text{year}$$

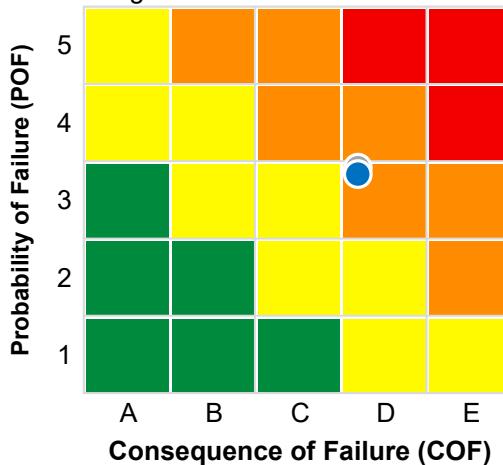
- Risk Ranking

3D Medium High

- Date

Plan Date : 01-06-2022

Target Date : 06-11-2022



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 1.10E-01 | 7.39E-05 | 1.48E+03 | m^2 |
| Plan Date | 01-06-2022 | 3.07E+00 | 2.07E-03 | 1.48E+03 | m^2 |
| Target Date | 06-11-2022 | 3.72E+00 | 2.51E-03 | 1.48E+03 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-5
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2022 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2022 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
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| 9 | | | | | | | |
| etc. | | | | | | | |



Inspection Plan

Attach. D-6
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|---------------|
| Tag Number | 16LF29-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | Vessel 16C-6 |
| Material | Carbon Steel | To | Vessel 16E-11 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 9.56E+01$$

- POF Score

$$P_f(t) = 2.92E-03$$

- Category

3 - Possible

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 5.62E+02 \text{ m}^2$$

- Category

C - Serious

c. Risk Ranking

- Risk Score

$$R(t) = 1.64E+00 \text{ m}^2/\text{year}$$

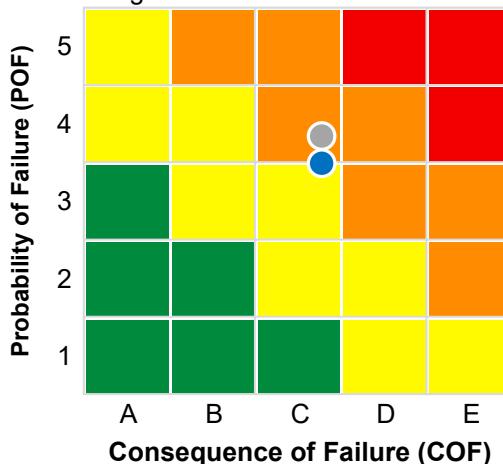
- Risk Ranking

3C Medium

- Date

Plan Date : 01-06-2022

Target Date : 06-01-2025



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 5.17E-02 | 9.20E-05 | 5.62E+02 | m^2 |
| Plan Date | 01-06-2022 | 1.64E+00 | 2.92E-03 | 5.62E+02 | m^2 |
| Target Date | 06-01-2025 | 3.72E+00 | 6.61E-03 | 5.62E+02 | m^2 |

D. REMARK

- >20% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-6
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2022 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2022 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-7
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF30-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Vessel 16E-9 |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

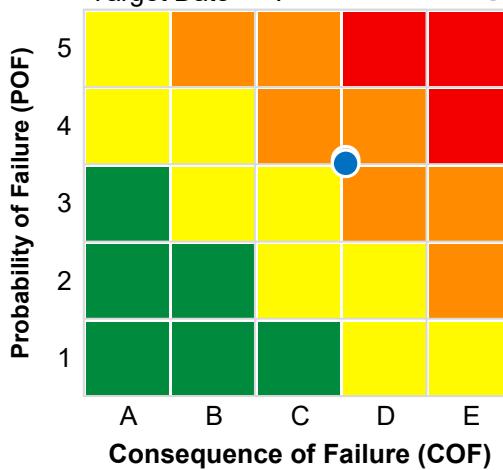
- a. Probability of Failure (POF)
 - Total Damage Factor
 $D_{f-total} = 1.02E+02$
 - POF Score
 $P_f(t) = 3.12E-03$
 - Category
4 - Likely
 - Damage Factors Selection
Thinning, Corrosion Under Insulation (CUI)

- b. Consequence of Failure (COF)
 - Representative Fluid
C6-C8
 - Fluid Phase
Model as liquid
 - COF Score
 $CA_f = 1.07E+03 \text{ m}^2$
 - Category
D - Major

- c. Risk Ranking
 - Risk Score
 $R(t) = 3.34E+00 \text{ m}^2/\text{year}$
 - Risk Ranking
4D Medium High

- Date

| | | |
|---------------|------------|-------------------------------------|
| Plan Date : | 01-06-2022 | ● |
| Target Date : | 24-08-2022 | ● |



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 1.06E-01 | 9.85E-05 | 1.07E+03 | m^2 |
| Plan Date | 01-06-2022 | 3.34E+00 | 3.12E-03 | 1.07E+03 | m^2 |
| Target Date | 24-08-2022 | 3.72E+00 | 3.47E-03 | 1.07E+03 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-7
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 01-06-2022 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 01-06-2022 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-8
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF38-6"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 6" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | 16LF22-6"-CB2D |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 2.16E+02$$

- POF Score

$$P_f(t) = 6.61E-03$$

- Category

4 - Likely

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 7.50E+02 \text{ m}^2$$

- Category

C - Serious

c. Risk Ranking

- Risk Score

$$R(t) = 4.96E+00 \text{ m}^2/\text{year}$$

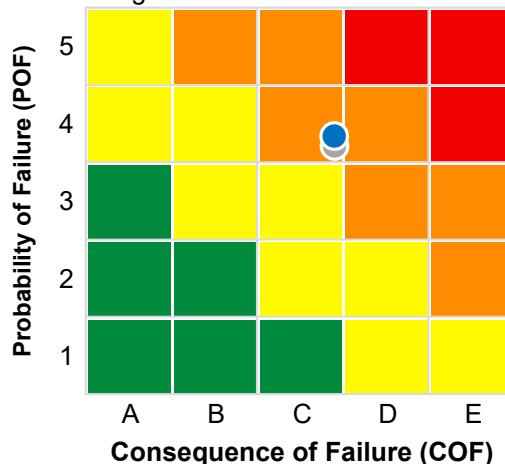
- Risk Ranking

4C Medium High

- Date

Plan Date : 01-06-2022

Target Date : 25-11-2021



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 1.22E-01 | 1.62E-04 | 7.50E+02 | m^2 |
| Plan Date | 01-06-2022 | 4.96E+00 | 6.61E-03 | 7.50E+02 | m^2 |
| Target Date | 25-11-2021 | 3.72E+00 | 4.95E-03 | 7.50E+02 | m^2 |

D. REMARK

- >40% removal of thermal insulation including all critical points and damaged areas
- Complete visual inspection of exposed areas for corr. and condition of coating as applicable
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-8
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 25-11-2021 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 25-11-2021 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-9
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF59-3"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 3" | From | 16LF29-6"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 2.79E+03$$

- POF Score

$$P_f(t) = 8.53E-02$$

- Category

5 - Very Likely

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 4.79E+04 \text{ m}^2$$

- Category

E - Catastrophic

c. Risk Ranking

- Risk Score

$$R(t) = 4.08E+03 \text{ m}^2/\text{year}$$

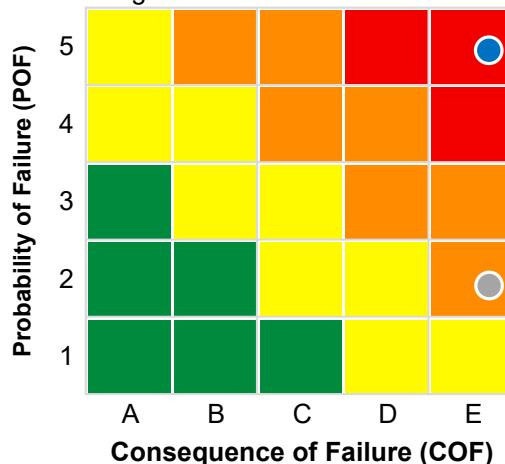
- Risk Ranking

5E High

- Date

Plan Date : 01-06-2022 ●

Target Date : 24-05-2020 ●



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 4.49E+01 | 9.38E-04 | 4.79E+04 | m^2 |
| Plan Date | 01-06-2022 | 4.08E+03 | 8.53E-02 | 4.79E+04 | m^2 |
| Target Date | 24-05-2020 | 3.72E+00 | 7.76E-05 | 4.79E+04 | m^2 |

D. REMARK

- 100% removal of thermal insulation
- Complete visual inspection for corr. and condition of coating
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-9
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 24-05-2020 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 24-05-2020 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
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| etc. | | | | | | | |



Inspection Plan

Attach. D-10
Rev. No. 0
Year 2020

A. EQUIPMENT SPECIFICATION

| | | | |
|-----------------|------------------|--------------|----------------|
| Tag Number | 16LF44-2"-CB2D | Fluid Handle | C6-C8 |
| Type | Pipe 2" | From | 16LF36-8"-CB2D |
| Material | Carbon Steel | To | Burn Pit |
| | ASTM A106 Gr B | Unit | Plant 16 |
| Insulation Type | Calcium Silicate | Drawing No. | 16D-A-011 |

B. RISK BASED INSPECTION

a. Probability of Failure (POF)

- Total Damage Factor

$$D_{f-total} = 7.69E+03$$

- POF Score

$$P_f(t) = 2.35E-01$$

- Category

5 - Very Likely

- Damage Factors Selection

Thinning, Corrosion Under Insulation (CUI)

b. Consequence of Failure (COF)

- Representative Fluid

C6-C8

- Fluid Phase

Model as liquid

- COF Score

$$CA_f = 4.67E+04 \text{ m}^2$$

- Category

E - Catastrophic

c. Risk Ranking

- Risk Score

$$R(t) = 1.10E+04 \text{ m}^2/\text{year}$$

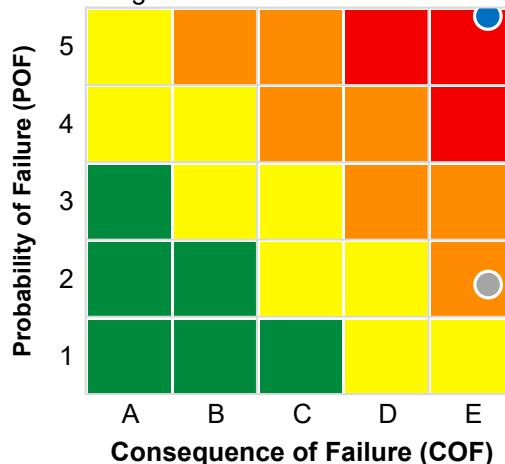
- Risk Ranking

5E High

- Date

Plan Date : 01-06-2022

Target Date : 18-04-2020



C. TARGET DATE

| Category | Date | Risk (m^2/year) | POF | COF | |
|-------------|------------|-----------------------------------|----------|----------|--------------|
| RBI Date | 01-06-2020 | 6.17E+02 | 1.32E-02 | 4.67E+04 | m^2 |
| Plan Date | 01-06-2022 | 1.10E+04 | 2.35E-01 | 4.67E+04 | m^2 |
| Target Date | 18-04-2020 | 3.72E+00 | 7.96E-05 | 4.67E+04 | m^2 |

D. REMARK

- 100% removal of thermal insulation
- Complete visual inspection for corr. and condition of coating
- Evaluate corroded areas by pit gauge, ultrasonic testing, or radiography.
- Reevaluate the risk



Inspection Plan

Attach. D-10
Rev. No. 0
Year 2020

E. RECOMMENDATION

| Damage Factors | Effectiveness | Date | Description |
|----------------------------------|------------------|------------|---|
| Thinning | C | 18-04-2020 | >50 % spot UT or random UT scans |
| | Fairly Effective | | |
| Corrosion Under Insulation (CUI) | C | 18-04-2020 | 100% ext. visual insp., Follow-up with profile or real-time radiography of >35 % of suspect areas, Follow-up of corroded areas with 100 % visual insp. of the exposed surface with UT, RT, or pit gauge |
| | Fairly Effective | | |

F. INSPECTION STRATEGY

a. Validation Check List

- Insulation system present? : Y / N
- In service? : Y / N
- Cyclic Service? : Y / N
- Intermittent service? : Y / N
- Insulation Type :
- Op Temperature (C) :

b. Visual Inspection

- Insulation Condition :
- Support Condition :
- Bolt & Nut :
- Coating/Painting Condition :
- Corrosion/Pitting :

c. Inspection Point (CML)

| No. | Code | Prev. Thick. | Measured Thickness | | | | Min. Thick. |
|------|------|-----------------|--------------------|---|---|---|----------------|
| | | | 12 | 3 | 6 | 9 | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| etc. | | | | | | | |

BIOGRAFI



Penulis bernama Bagus Fyandika lahir di Blitar pada tanggal 7 Maret 1998. Penulis merupakan anak pertama dari tiga bersaudara dari pasangan Bapak Eka Setiabudi dan Ibu Dina Agustianingsih. Pendidikan formal yang telah ditempuh oleh penulis, yaitu TK Dharma Wanita Tambakan (2002-2004), SDN Tambakan 02 (2004-2010), SMPN 1 Wlingi (2010-2013), dan SMAN 1 Talun (2013-2016). Pada tahun 2016 penulis diterima di Departemen Teknik Sistem Perkapalan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember melalui jalur SNMPTN dengan NRP 04211640000024. Penulis aktif di Divisi Sosbud (Sosial Budaya) UKM Maritime Challenge ITS 2017/2018. Semester 3 penulis masuk ke ruang lingkup Proyek Bapak Ir. Dwi Priyanta, M.SE. Kerja Praktek penulis yang ke-1 di PT. Dok dan Perkapalan Surabaya (DPS) dan Kerja Praktek penulis yang ke-2 di PT. Badak NGL. Penulis mengambil laboratorium Digital Marine Operation and Maintenance. Penulis mengerjakan Tugas Akhir yang berjudul "**Analisis Inspeksi Berbasis Risiko Untuk Corrosion Under Insulation (CUI) Piping di Storage and Loading Area PT X**". Apabila ada kritik dan saran dapat dikirim ke bagusfyandika@gmail.com.