TESIS – ME185401

STRATEGI INSPEKSI PERALATAN *PRESSURE VESSEL* PADA *OFFSHORE PLATFORM* DENGAN METODE *RISK BASED INSPECTION*

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Dosen Pembimbing
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INSPECTION STRATEGY PRESSURE VESSEL ON OFFSHORE PLATFORM WITH RISK BASED INSPECTION METHOD

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2024

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Surabaya, 2024

Penulis

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STRATEGI INSPEKSI *PRESSURE VESSEL* PADA *OFFSHORE PLATFORM* DENGAN METODE *RISK BASED INSPECTION*

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ABSTRAK

Dengan adanya risiko dan kerugian yang akan ditimbulkan bila terjadi kegagalan pada setiap *plant* maka seluruh peralatan yang sudah ada perlu dijamin dengan adanya *reliability* sehingga tidak memberikan dampak baik pada pekerja maupun pada lingkungan. RBI merupakan metode yang dapat dilakukan untuk mengantisipasi risiko dengan perencanaan jadwal I&M (inspeksi dan *maintenance*), karena tujuan dari RBI adalah untuk mengoptimasi waktu dan tipe inspeksi. Terhitung dari tahun 2004 hingga 2018 insiden yang terjadi 28% melibatkan kebakaran dan ledakan, kemudian 71% penyumbang insiden ialah zat berbahaya yang keluar tanpa di sertai kebakaran maupun ledakan dan 1% disebabkan oleh pekerja yang memasuki area terbatas (*confined space*) yang mengandung zat berbahaya. Didapatkan hasil dari analisis dengan metode *preliminary screening criticality* pada *pressure vessel* V-001, V-002, V-003 dan V-004 memiliki kategori risiko *medium risk*. Perhitungan lanjutan dengan metode RBI pada *pressure vessel* didapatkan memiliki level risiko *medium risk* pada *pressure vessel* V-001 dan V-002, dan *pressure vessel* V-003 serta V-004 memiliki level risiko *low risk*. Strategi inspeksi yang dapat dilakukan antara lain *visual inspection*, *ultrasonic test* dan *radiography*.

Kata kunci: risiko , *pressure vessel*, RBI

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INSPECTION STRATEGY PRESSURE VESSEL ON OFFSHORE PLATFORM WITH RISK BASED INSPECTION METHOD

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ABSTRACT

With the risk and losses that will be occurred if there is a failure in each plant, all existing equipment needs to be guaranteed with reliability so it does not have an impact both to workers and to environment. RBI is a method that can be used to anticipate risk by planning I&M (inspection and maintenance) schedules, because the purpose of RBI is to optimize time and type of inspection. From 2004 to 2018, 28% of incidents involved fires and explosions, then 71% of the incident contributors were hazardous substances that escaped without fire or explosion and 1% were caused by workers entering confined spaces containing hazardous substances. Analysis obtained from preliminary screening criticality method are pressure vessel V-001, V-002 V-003 and V-004 risk category is medium risk. Advance equation using RBI method on pressure vessels have a risk level of medium risk on pressure vessel V-001,V-002 and V-003 also V-004 pressure vessels have a risk level of low risk. Inspection strategy arranged are visual inspection, ultrasonic test and radiography test.

Kata kunci: risk , *pressure vessel*, RBI

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BAB 1
PENDAHULUAN

1.1 Latar Belakang

Pressure vessel merupakan wadah yang didesain untuk menyimpan fluida baik berupa cair maupun gas pada tekanan substantial yang berbeda dengan tekanan sekitar (*ambient*). Komponen pada *pressure vessel* didesain untuk jangka waktu pemakaian yang lama pada siklus penggunaan yang terus menerus, tetapi tidak menutup kemungkinan untuk terjadinya kegagalan pada umur pemakaian dibawah umur desain awal (Njelle *et al.*, 2020). Terdapat beberapa risiko kegagalan yang umum terjadi seperti degradasi pada material, korosi, erosi, kelelahan pada material, kegagalan pada operasional dan perawatan yang bisa disebabkan saat proses produksi maupun akibat *humam error*. Peralatan dan infrastruktur yang digunakan di industri baik untuk mengangkat, menyimpan, memproduksi, mengepak, memindahkan dan untuk mendistribusikan untuk customer sangat berharga dan cukup mahal (Dabagh *et al.*, 2022).

Kemungkinan risiko yang dapat terjadi dan kerugian yang akan ditimbulkan bila terjadi kegagalan pada setiap *plant* maka seluruh peralatan yang sudah ada perlu dijamin dengan adanya *reliability* sehingga tidak memberikan dampak baik pada pekerja maupun pada lingkungan (Cahyono *et al.*, 2021). Metode RBI merupakan metode yang telah digunakan di banyak *plant* dan kasus yang ada, juga merupakan metode yang populer dan dipercaya untuk menilai dan mengembangkan rencana inspeksi (Abubakirov, Yang and Khakzad, 2020; Dabagh *et al.*, 2022). RBI menyediakan banyak keuntungan seperti meningkatkan *plant availability*, mengurangi jumlah kegagalan yang terjadi, mengurangi level risiko berdasarkan kegagalannya dan mereduksi biaya inspeksi yang ditimbulkan untuk fasilitas produksi (Ratnayake, 2016). Merupakan metode yang dapat dilakukan untuk mengantisipasi risiko dengan perencanaan jadwal I&M (inspeksi dan *maintenance*), karena tujuan dari RBI adalah untuk mengoptimasi waktu dan tipe inspeksi.

Dalam menjalankan prosesnya, tidak dapat menghilangkan sisi keamanan pada saat proses produksi berjalan (*In-Service*). Metode RBI digunakan untuk mereduksi risiko yang ada, karena melihat dari beberapa kecelakaan yang terjadi di beberapa negara yang diakibatkan oleh *pressure vessel*. Berdasarkan (CSB, 2022) pada April 2017 di St. Louis, Missouri terjadi kecelakaan yang menewaskan 4 orang – 1 pekerja pabrik dan 3 orang warga setempat. Kecelakaan ini disebabkan adanya kebocoran yang telah terindikasi saat *break* tetapi tidak ada Tindakan lanjutan yang dilakukan oleh *management*. Pada senin waktu setempat, kebocoran yang semakin membesar mengakibatkan terlepasnya fluida air dan uap bertekanan yang membuat *pressure vessel* melayang. Hal ini terjadi karena *pressure vessel* yang tidak pernah dilakukan inspeksi dan *maintenance* selama 20 tahun semenjak dioperasikan. Meledaknya *boiler* di Algeria pada Januari 2004 berdasarkan (Reuters, 2004) mengakibatkan 27 orang pekerja meninggal dan 72 lainnya cedera. Hal ini terjadi dikarenakan dari pihak *management* lalai terhadap inspeksi dan *maintenance*. Pada Desember 2004 berdasarkan laporan investigasi (CSB, 2006) *pressure vessel* dengan bobot 50,000 *pounds* meledak di Marcus *oil facility*, Houston, Texas. Mengakibatkan 3 orang meninggal dan kerusakan pada sebagian besar *plant* yang berimbas pada hilangnya setengah dari akses listrik negara dan kebakaran yang terjadi selama 7 jam. Indikasi kecelakaan ini karena modifikasi pada *pressure vessel* dan adanya cacat las. Pada Juli 1984 *Union Oil Co. refinery* Illinois, U.S.A. Mengalami kerusakan yang cukup parah diakibatkan oleh ledakan dan kebakaran yang terjadi dari *pressure vessel amine absorber* yang mengalami pecah, 17 orang meninggal dan kerugian yang ditimbulkan mencapai 100 juta dollar. Hal ini disebabkan oleh percikan yang ditimbulkan dari gas percampuran antara *propane* dan *butane* (Hayes, 1996).

Beberapa penelitian terkait RBI. Pada tahun 2014 (Si *et al.*, 2014) melakukan analisa risiko dengan metode RBI pada unit kompresi ethylene yang terdiri dari bagian kompresi gas, bagian penghilangan gas beracun, pengisian gas dan bagian pengeringan kondensat. *Damage mechanism* potensial dan yang telah terjadi antara lain *thinning*, *exiernal corrosion* dan *stress corrosion cracking* (SCC). Sebanyak 303 komponen yang terdiri dari *pressure vessel* dan *pipeline* dikalkulasi dan dianalisa, didapatkan sejumlah 12 *high risk*, 136 *medium high risk*, 127 *medium risk* dan 28 *low risk* komponen. Pada 2021 (Siswantoro *et al.*, 2021) melakukan studi kasus pada separator kondensat 10V2102 dan *storage vessel* 10V2103 dengan mengacu pada API RP 581, didapatkan kedua *vessel* memiliki kategori risiko *low risk*. Mengacu pada standard API 510 untuk menentukan jadwal inspeksi, dimana untuk interval maksimum inspeksi eksternal adalah 5 tahun dan untuk inspeksi internal 10 tahun. Pada 2021 (Cahyono *et al.*, 2021) menjelaskan data-data dan informasi yang dibutuhkan dalam melakukan metode RBI pada *pressure vessel* di bangunan lepas pantai. Begitu juga dengan langkah-langkah dalam perhitungan *proability of failure* (POF) dan *consequence of failure* (COF).

Interval inspeksi dapat mempengaruhi biaya yang dikeluarkan oleh *plant*, hal tersebut dapat bergantung pada pada jenis *equipment* yang dianalisis begitu juga dengan klasifikasi risikonya. Interval inspeksi yang berdekatan cenderung sangat bagus dan membantu dalam mengurangi risiko yang ada. Tetapi hal tersebut akan mempengaruhi dari segi biaya dimana semakin berdekatannya jaraknya maka biaya yang ditimbulkan juga akan semakin besar. Penggunaan RBI dapat membantu dalam penentuan jadwal inspeksi.

Mempertimbangkan waktu dan risiko sebagai objek, rencana inspeksi dapat dioptimasi untuk menyeimbangkan program manajemen asset. *Risk based inspection* dapat diaplikasikan pada banyak objek seperti *pipeline* maupun *pressure vessel* dengan hasil pengamatan yang terukur dan meningkatkan pengurangan risiko yang ada.

Penulis berencana untuk melakukan studi analisis risiko dengan menggunakan metode *Risk based inspection* untuk mengetahui risiko terhadap *pressure vessel* di *plant* beserta komparasi dengan menggunakan metode optimasi untuk mendapatkan perencanaan penjadwalan yang membantu *plant* untuk menentukan jadwal inspeksi yang efisien.

1.2 Rumusan Masalah

Berdasarkan latar belakang yang telah diuraikan, dalam penelitian ini terdapat beberapa rumusan masalah yang akan dianalisis :

1. Bagaimana analisis *probability* dan *consequence* untuk menetukan level risiko peralatan *pressure vessel* pada *offshore platform*?
2. Bagaimana interval dan metode inspeksi yang sesuai berdasarkan *damage mechanism* dan penilaian risiko?

1.3 Tujuan

Tujuan yang akan dicapai pada penelitian ini antara lain:

1. Menganalisis *probability* dan *consequence* untuk menetukan level risiko peralatan *pressure vessel* pada *offshore platform*.
2. Menganalisis interval dan metode inspeksi yang sesuai berdasarkan *damage mechanism* dan penilaian risiko.

1.4 Batasan Masalah

Batasan masalah dalam penelitian ini antara lain:

1. Menggunakan metode RBI yang mengacu pada standard API RP 581
2. Dalam penelitian ini, yang menjadi objek penelitian adalah terbatas pada *pressure vessel*

1.5 Kontribusi

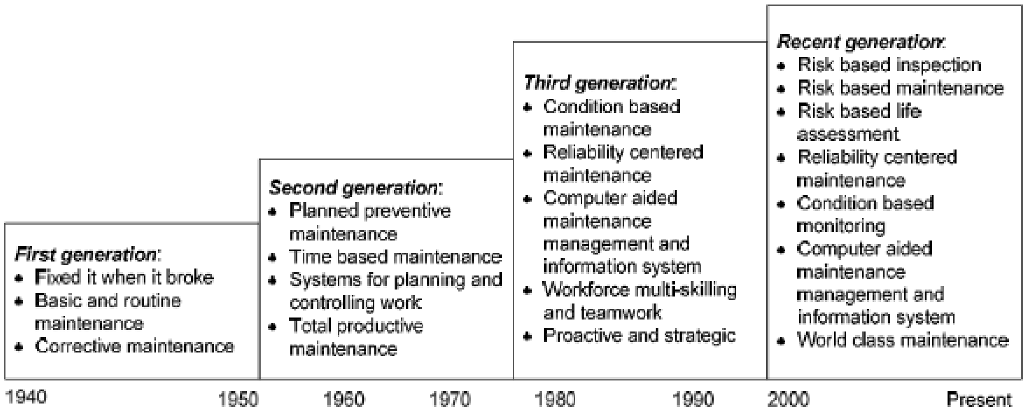
Kontribusi yang diharapkan dari hasil penelitian tesis terkait dengan tujuan penelitian antara lain:

- Membantu *plant* maupun perusahaan dalam menentukan waktu inpeksi maupun maintenance yang tepat
- Menambahkan sudut pandang baru terkait metode perencaanaan inpeksi dengan penggunaan metode RBI bersamaan dengan perbandingannya dari segi finansial.

BAB 2
KAJIAN PUSTAKA

2.1 Kajian Penelitian Terkait

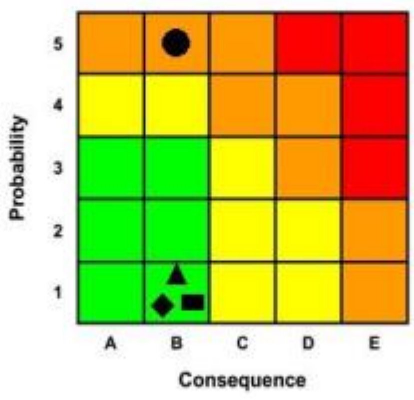
Perkembangan metode inspeksi dan *maintenance* telah mengalami perubahan dari tahun 1940 hingga sekarang. Dimulai dari generasi pertama dengan penanganan ketika rusak, *maintenance* dasar dan rutin hingga terus berkembang sampai sekarang dengan beberapa metode baru yang penggunaannya di bidang *oil & gas* maupun bidang lainnya. Perkembangan inspeksi dan *maintenance* dapat dilihat pada Gambar 2.1. Salah satu dari metode tersebut ialah RBI, metode ini telah digunakan di banyak *plant* dan kasus yang ada, juga merupakan metode yang populer dan dipercaya untuk menilai dan mengembangkan rencana inspeksi (Abubakirov, Yang and Khakzad, 2020; Dabagh *et al.*, 2022). RBI menyediakan banyak keuntungan seperti meningkatkan *plant availability*, mengurangi jumlah kegagalan yang terjadi, mengurangi level risiko berdasarkan kegagalannya dan mereduksi biaya inspeksi yang ditimbulkan untuk fasilitas produksi (Ratnayake, 2016).



Gambar 2.1 Perkembangan Inspeksi dan *Maintenance*

Berdasarkan (Rozie and Adnyana, 2021) horizontal *pressure vessel* dengan kapasitas 50 ton yang difungsikan sebagai LPG *storage tank* dilakukan analisis risiko dengan menggunakan metode RBI 581 dan standard acuan *vessel* ASME sec. VIII div. 1. *Vessel* pada instalasi stasiun pengisian *bulk* elpiji (SPBE) ini memimiliki tingkat risiko *medium-high risk* dengan CA (*consequence area*) sebesar 15430431,8 ft^2 yang mana bila terjadi kelalaian dalam penanganan *equipment* ini akan berdampak baik pada *plant* maupun lingkungan sekitar. Pendekatan berbasis risiko yang dilakukan oleh (Abubakirov, Yang and Khakzad, 2020) selain menggunakan API RP 581, penelitian tersebut juga menggunakan metode *dynamic bayesian* untuk menilai *probability of failure* dari sistem dan untuk mengoptimasi interval inspeksi. DBN (*Dynamic Bayesian Network*) model yang digunakan untuk korosi internal dan eksternal yang kemudian pada *probability of failure* menggunakan *pipeline burst* dengan komparasi 3 standard yaitu ASME B31G, DNV-RP-F101 dan Shell-92. Penentuan akhir untuk inspeksi yang optimal berbeda-beda juga berdasarkan oleh metodologi perhitungan *burst pressure* yang berbeda dengan range 80-88 minggu.

Pada 2018 (Prabowo, Husodo and Arumsari, 2018) melakukan analisis pada *pipeline* pada 4 lokasi. 4 lokasi *pipeline* tersebut antara lain Canal, Bagong, MT14 dan SWO dilakukan uji distribusi data dan didapatkan distibusi, normal, log normal dan weibull2 yang kemudian dilakukan proses simulasi *Monte Carlo* dengan melakukan *random number generate* pada nilai korosi yang ada. Didapatkan hasil analisis pada 3 lokasi yaknik Bagong, MT14 dan SWO merupakan kategori risiko 1B dan Canal memiliki kategori risiko 5B seperti pada Gambar 2.2. Hasil analisis tersebut didapatkan rekomendasi inspeksi antara lain *visual examination, ultrasonic straight beam, eddy current, flux leakage, radiography* dan pengukuran dimensi.



Gambar 2.2 Matriks Risiko pada *Pipeline* Canal, Bagong, MT14 dan SWO (Prabowo, Husodo and Arumsari, 2018)

Pada 2018 (Singh and Pokhrel, 2018) melakukan penelitian metode *risk based inspection* dengan menggunakan *fuzzy logic* untuk mengetahui laju korosi dari pipa yang mengalami korosi yang diakibatkan oleh mikrobiologi. Terdapat beberapa parameter yang digunakan seperti efektifitas mitigasi MIC, *water breakthrough*, *Settlement potential*, suhu, pH, kecepatan fluida, *oxygen ingress*, material yang digunakan dan ketersediaan nutrisi untuk mikrobiologi. Beberapa parameter tersebut merupakan acuan dalam penggunaan *fuzzy* untuk mendapatkan laju korosi terhadap MIC. Didapatkan bahwa setiap kombinasi dari parameter memiliki keluaran terhadap penjadwalan inspeksi yang berbeda-beda. Metode ini dapat digunakan untuk menambah referensi dalam penjadwalan.

Pada 2020 (Eskandari, Charkhand and Gholami, 2020) melakukan penelitian dengan metode *Risk Based Inspection* pada *petrochemical plant* bagian *de-ethanizer* yang terdiri dari 22 peralatan proses seperti *tower, pressure vessel* dan *exchanger*. Pada perhitungan *Consequence of Failure* (COF) terdapat beberapa hal yang diperhatikan seperti *safety consequence, pollution consequence, production consequence* sedangkan pada *Likelihood of Failure* (LOF) *remaining life, damage, inspection, condition, process* dan *mechanical design.* Pada perhitungan COF didapatkan memiliki risiko 13,63% *very high risk*, 22,72% *hish risk*, 54,54% *moderate risk* dan 9,09% *low risk.* Didapatkan level risiko pada *petrochemical plant* bagian *de-ethanizer* pada Gambar 2.3. Metode RBI yang dilakukan secara signifikan mengurangi biaya untuk *major repair,* inspeksi dan tenaga yang dibutuhkan sebesar $69.000.000.

Tabel 2.1 Level Risiko Bagian *De-ethanizer*

No.	Equipment Tag	Risk	Insp. Grade	Interval	No.	Equipment Tag	Risk	Insp. Grade	Interval
1	30-D-406	H	2	48	12	30-R-401A	L	2	90
2	30-E-420	H	2	48	13	30-R-401B	L	2	90
3	30-E-421	M	2	72	14	30-T-402	H	2	48
4	30-E-422A	M	1	48	15	30-D-412	L	2	90
5	30-E-422B	M	1	48	16	C2-P-0001	M	1	72
6	30-E-423	M	2	72	17	C2-P-0002	M	1	72
7	30-E-424	M	2	72	18	C2-P-0003	M	1	72
8	30-E-425	M	2	72	19	C2-P-0004	M	1	72
9	30-E-426	L	1	60	20	C2-P-0005	M	1	72
10	30-E-430	L	2	90	21	C2-P-0006	M	1	72
11	30-E-433	M	2	72	22	C2-P-0007	M	1	72

Sumber: Eskandari, Charkhand and Gholami, 2020

Pada 2020 (Bijay *et al.*, 2020) melakukan penelitian terhadap studi kasus ledakan Macondo menggunakan metode Bayesian yang dikembangkan untuk melakukan perhitungan probabilitas terjadinya kejadian dan *safety barrier*. Metode pendukung lainnya antara lain *fault tree*, *event tree* dan *bow tie* analysis, dengan menggunakan probabilitas kegagalan dari *real-time*. Didapatkan pentingnya memonitor *safety barrier* secara *real-time* untuk mengetahui efek kerusakan yang terjadi dan melakukan tindakan pencegahan dengan adanya observasi yang cukup dan variasi probabilitas.

Pada 2021 (Siswantoro *et al.*, 2021) melakukan studi kasus pada separator kondensat 10V2102 dan *storage vessel* 10V2103 dengan mengacu pada API RP 581, didapatkan kedua *vessel* memiliki kategori risiko *low risk*. Kemudian digunakan standard API 510 untuk menentukan jadwal inspeksi, dimana untuk interval maksimum inspkesi eksternal adalah 5 tahun dan untuk inspeksi internal 10 tahun. Adapun beberapa metode inspeksi yang dipilih antara lain *visual testing*, *ultrasonic testing* (UT), *radiography tesi* (RT), *eddy current test* dan *magnetic particle inspection*.

Pada 2018 (Rohmansyah and Suwarno, 2018) melakukan evaluasi lingkup pekerjaan inspeksi pada HRSG (*Heat Recovery Steam Generator*) 1.1 Muara Karang berdasarkan analisis risiko dengan metode RBI API RP 581, dengan peralatan yang diinspeksi antara lain *pressure vessel*, *heat exchanger*, pipa dan *tube*. Terdapat beberapa *damage factor* yang terjadi pada peralatan yang dinspeksi seperti *thinning*, *SCC Amine Cracking*, HTHA (*High Temperature Hydrogen Attack*), CUI (*Corrosion Under Insulation*) dan FAC (*Flow Accelerated Corrosion*). Didapatkan 16 pelaratan dengan risiko rendah dan 10 peralatan dengan risiko menengah. Dengan 2 peralatan (Risiko Menengah) memiliki interval inspeksi yang cukup pendek yaitu 2 tahun untuk HP SH 1 dan 1 tahun pada HP SH 2, hal ini dikarenakan *remaining life* dari *tube* yang kecil yang juga disebabkan oleh *minimum thickness* dari *tube*. Peralatan lain memiliki waktu inspek > 10 tahun karena melihat dari tingkat risikonya dan dapat menggunakan jadwal inspeksi perusahaan sesuai acuan manufaktur yaitu 4 tahun, kemudian diperoleh jenis inspeksi untuk setiap *damage factor* seperti penggunaan UT dan radiografi pada *thinning*, *Wet fluorescent magnetic particle* pada *SCC Amine Cracking*, AUBT (*Advance Ultrasonic Back*

Scatter Technique) atau *extensive in-situ* metallography pada HTHA, *visual inspection* dan UT pada CUI dan UT pada FAC.

Pada 2022 (Henrique *et al.*, 2022) melakukan penelitian menggunakan *genetic algorithm* sebagai metode optimasi, yang mana metode tersebut dapat diaplikasikan dengan efektif untuk mengoptimasi rencana inspeksi pada peralatan bawah laut pada industry *oil and gas*. Penggunaan GA mampu untuk mempertimbangkan banyak kriteria seperti waktu, biaya dan risiko dalam proses optimasinya juga rencana inspeksi dapat dikembangkan dengan menyeimbangkan sesuai kebutuhan kerusakan yang akurat, optimasi biaya dan mitigasi risiko. Objek yang diteliti dalam hal ini adalah *Christmas-tree*.

Pada 2023 (Yuliati, Yuwono and Asral, 2023) menggunakan kombinasi *risk based inspection* dan *fault tree analysis* pada Pertamina upstream Regional 2 Zona 5. Analisis ini menggunakan 3 interval yang waktu disimbolkan IP1, IP2 dan IP3 yang memiliki interval 2 tahun. Pada *fault tree analysis* terdapat beberapa *basic factor* yang dipertimbangkan seperti *material deficiency, component failure, high fluid velocity, low fluid velocity, turbulent flow, low pH, high internal pressure, High* CO_2 *content, fluid containing sand* dan *inadequate corrosion detection*. *Failure frequency* dihitung dengan menggunakan kebocoran hidrokarbon pada tahun 2001-2022 yang kemudian diverifikasi dengan menggunakan data aktual hidrokarbon yang dilepaskan. Dari perhitungan tersebut didapatkan hasil level risiko 3 *line* merupakan *low risk,* 2 *line medium risk* dan 1 *line high risk* dengan estimasi masa hidup seperti pada Tabel 2.

Tabel 2.2 Level Risiko dan Estimasi Masa Hidup *Pipeline*

Line No.	IP 1	IP 2	IP 3	Estimated life (year)
Line 1	1E	1E	2E	0
Line 2	4D	4D	4D	21,24
Line 4	2D	2D	3D	52,78
Line 5	1D	2D	3D	33,92
Line 6	2D	2D	3D	30,38
Line 7	1D	1D	1D	72,46

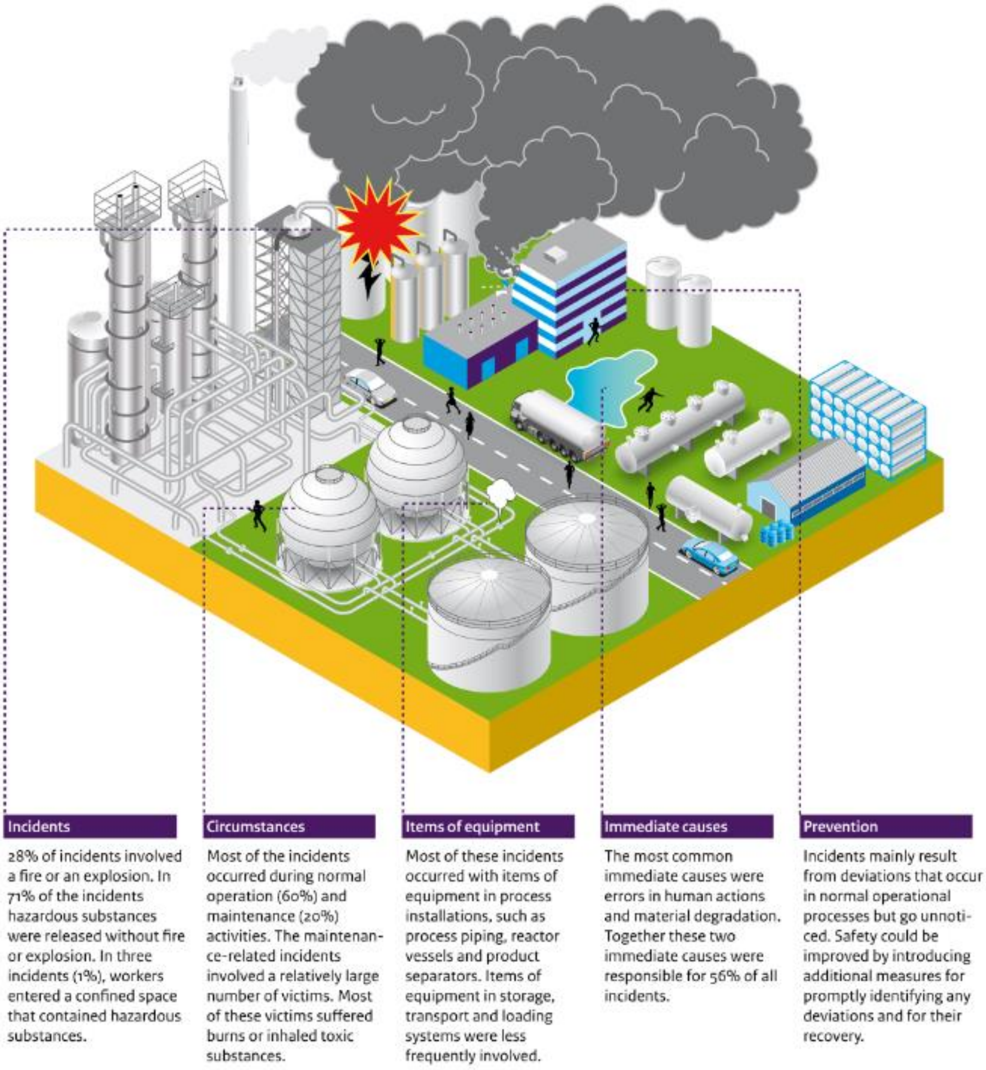
Sumber: Yuliati, Yuwono and Asral, 2023

Pada 2018 (Haladuick and Dann, 2018) menggunakan *genetic algorithm* untuk optimasi rencana inspeksi dan perawatan untuk sistim yang kompleks dengan dikhusukan pada *pressure vessel* yang mengalami korosi. Hasil dari *genetic algorithm* dibandingkan dengan *exhaustive search,* didapatkan bahwa *genetic algorithm* merupakan pendekatan yang lebih efisien dalam mengurangi kebutuhan komputasional untuk mengoptimasi, juga lebih cepat dalam menentukan inspeksi dan perawatan yang kompleks. Pada penelitian ini *genetic algorithm* cukup sukses sebagai metode heuristic untuk secara efisien menentukan inspeksi dan perawatan yang optimal untuk sistim yang kompleks seperti *pressure vessel* dalam *risk based inspection.*

Penjadwalan berdasarkan RBI API 581 bukan merupakan acuan penjadwalan yang harus sertamerta diikuti, tetapi hal tersebut tetap bergantung pada penilaian dan keputusan dari *owner*. Karena pengembangan analisis dan perhitungan yang juga berbasis dengan menggunakan API 581 juga dapat menjadi pertimbangan dalam melakukan penjadwalan baik inspeksi maupun perawatan kedepannya.

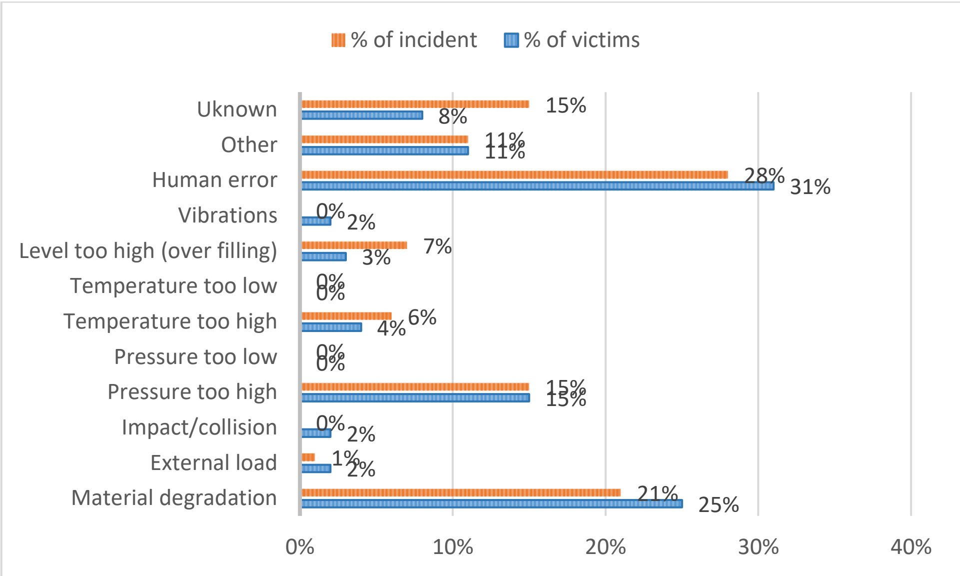
2.2 Kecelakaan pada Industri Minyak dan Gas

Manajemen integritas asset merupakan salah satu hal terpenting dalam menjalankan suatu proses dalam industri minyak dan gas. Selain untuk menjaga agar peralatan dapat bekerja dengan baik juga membawahi beberapa aspek seperti manajemen dalam suatu industri minyak dan gas dan data-data serta runtutan kejadian baik dalam maintenance maupun aktivitas lainnya yang berhubungan dengan objek yang ada pada industri. Terhitung dari tahun 2004 hingga 2018 insiden yang terjadi 28% melibatkan kebakaran dan ledakan, kemudian 71% penyumbang insiden ialah zat berbahaya yang keluar tanpa di sertai kebakaran maupun ledakan dan 1% disebabkan oleh pekerja yang memasuki area terbatas (*confined space*) yang mengandung zat berbahaya (Kooi *et al.*, 2020). Pada Gambar 2.3 dijelaskan bahwa insiden yang terjadi kerapkali disebabkan oleh suatu objek *equipment* seperti pipa, *pressure* vessel, tangki pada instalasi proses saat proses berjalan seperti biasanya maupun saat adanya aktivitas perawatan .



Gambar 2.3 Gambaran Insiden pada Industri (Kooi *et al.*, 2020)

Penyebab terjadinya insiden tidak selalu terjadi secara langsung atau tiba-tiba. Seperti kesalahan dalam desain maupun terjadinya korosi yang menyebabkan dapat terjadi kebocoran di kemudian hari. Terdapat beberapa penyebab terjadinya insiden seperti degradasi terhadap material seperti korosi, beban eksternal, tekanan yang terlalu tinggi, suhu yang terlalu tinggi dan beberapa penyebab lainnya. Penyebab insiden yang paling besar ialah *human error* dan degradasi material yang dapat dilihat seperti pada Gambar 2.4.



Gambar 2.4 Penyebab Kecelakaan pada Industri (Kooi *et al.*, 2020)

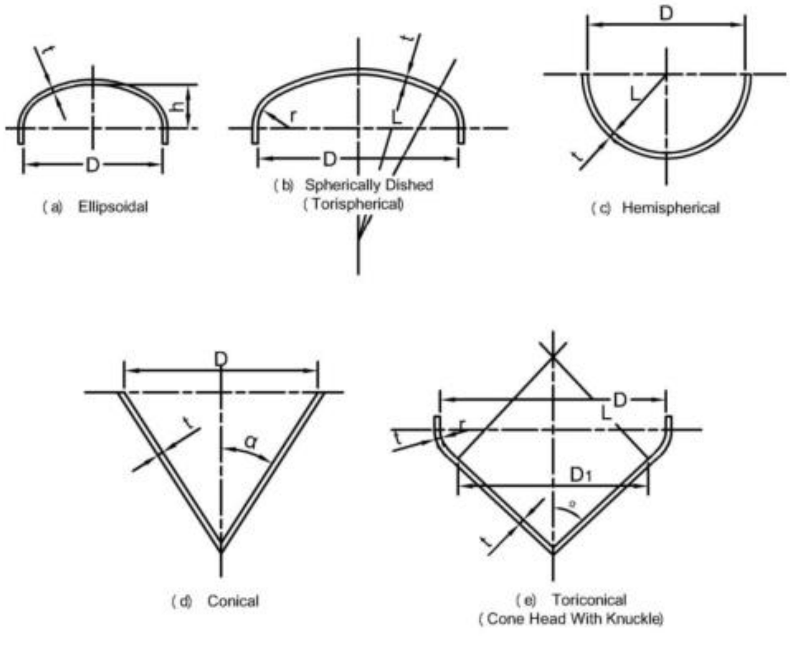
2.3 *Pressure Vessel*

Pressure vessel atau bejana tekan merupakan wadah yang didesain untuk menyimpan fluida baik berupa cair maupun gas pada tekanan substantial yang berbeda dengan tekanan sekitar (*ambient*) yang juga merupakan salah satu *equipment* penting dalam suatu industri baik pada *oil* & *gas*, proses maupun industri - industri lainnya dan seringkali digunakan untuk menyimpan fluida mudah terbakar dan mudah meledak (Qingfeng *et al.*, 2011). Dalam mendesain hingga melakukan konstruksi terhadap *pressure vessel* terdapat beberapa *code and standard* yang diperlukan seperti ASME Sec. VIII, selain untuk membantu dari segi kalkuklasi dan analisis, juga untuk meminimalisir adanya cacat maupun kecelakaan kerja. *Pressure vessel* merupakansalah satu *equipment* khusus yang dapat menampung fluida dalam bentuk, cair, gas maupun uap juga merupakan tempat penyimpanan yang didesain untuk tahan terhadap tekanan internal maupun eksternal dengan tidak kurang dari 15 psi (API RP 572, 2016; Hu *et al.*, 2022), yang penggunaannya luas dan sering digunakan saat ini pada industri kimia, aviasi, transportasi bawah tanah maupun laut, *oil* & *gas* dan lain-lain. Fungsi dari *pressure vessel* juga beragam seperti menjadi *reactor thermal* dan katalis yang mana mengandung perbahan kimia yang dibutuhkan oleh proses yang sedang berjalan, sebagai tempat penyimpanan, fraksinansi untuk memisahkan berbagai macam jenis produk yang di hasilkan oleh reactor, *separator* untuk memisahkan baik gas, bahan kimia, maupun katalis dari suatu produk, sebagai *heat exchanger,* kondensat, pendingin dan berbagai macam fungsi dan kegunaan lainnya.

Pressure vessel dibagi menjadi beberapa tipe, diantaranya berdasarkan ketebalan dan orientasi.

2.3.1 Klasifikasi *pressure vessel* berdasarkan bentuk *head*

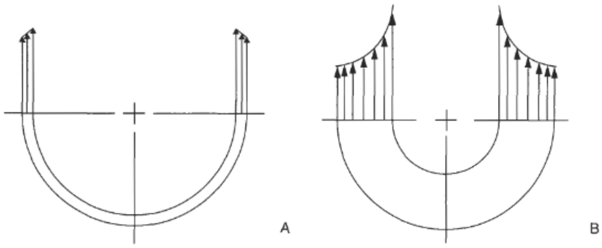
Head pada *pressure vessel* merupakan salah satu komponen penting yang dibtuhkan untuk menutup sisi ujung dari *pressure vessel*. Bentuk dari *head* sendiri khususnya memiliki bentuk melengkung, tetapi tidak menutup kemungkinan untuk berbentuk datar. *Head* pada p*pressure vessel* biasanya dikategorikan berdasarkan bentuknya seperti pada Gambar 2.5. Berdasarkan pada (ASME Sec. VIII, 2017) terdapat beberapa jenis bentuk *head* seperti *ellipsoidal, spherical, hemispherical, conical* dan *toriconical*. Salah satu persyaratan penting dalam *head* sendiri antara lain desain ketabalan yang ada dan material yang digunakan. Adapun material yang digunakan dapat menggunakan material yang sama maupun berbeda dari *shell*.



Gambar 2.5 Jenis Bentuk *Head* (Ghanbari *et al.*, 2011)

2.3.2 Klasifikasi *pressure vessel* berdasarkan ketebalan

Berdasarkan ketebalan dibagi manjadi dua yakni *thin walled* dan *thick walled*. Perbedaan mendasar dari kedua tipe ini adalah dari sisi ketebalan dan pada distribusi tegangannya. Pada Gambar 2.6 terlihat distribusi tegangan antar kedua jenis ketebalan. Dimana pada *thin walled* tegangan dianggap seragam karena antara permukaan bagian dalam dan permukaan bagian luar tidak terkait jauh perbedaannya. Pada *thick walled* bagian dalam *vessel* mendapat *internal pressure* dimana tegangan *circumferential* dan *radial* berada pada puncaknya (Moss, 2004).



Gambar 2.6 (A) *thin walled vessel* dan (B) *thick walled vessel* (Moss, 2004)

2.3.3 Klasifikasi berdasarkan orientasi

Menurut (Megyesy, 2008) berdasarkan orientasinya *pressure vessel* dibagi menjadi dua yaitu *horizontal* dan *vertical*:

1. *Horizontal vessel*

   Horizontal vessel merupakan suatu *equipment* yang memanjang kearah horizontal dengan berbagai macam fungsi. Diantaranya sebagai *storage tank* untuk bentuk cair maupun gas dan separator. Tidak memiliki komponen yang bergerak di bagian dalam *vessel* dan umumnya menggunakan tipe *support* berupa *saddle*.

Gambar 2.7 Horizontal *Vessel* (Parisher and Rhea Robert A., 2002)

2. *Vertical vessel*

   Merupakan *vessel* dengan garis panjang tegak lurus dengan *horizontal*. Memiliki berbagai macam fungsi dari fraksinansi, distilasi, *storage tank* dan lain sebagainya. *Support* yang digunakan juga beragam seperti *skirt¸lug* dan *leg support*.

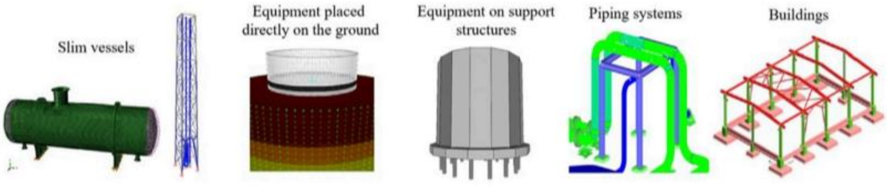
Gambar 2.8 Vertikal *Vessel* (Parisher and Rhea Robert A., 2002)

2.4 *Preliminary Screening Criticality*

Preliminary screening criticality merupakan metode awal yang digunakan untuk menentukan risiko pada pada suatu objek yang akan dianalisis. Penentuan peringkat untuk seluruh peralatan yang memiliki kecenderungan *critical equipment* dibuat untuk dilakukan *preliminary screening*. *Preliminary screening* penting untuk dilakukan pada *plant* dengan instalasi dan *equipment* yang banyak untuk mengurangi pertimbangan terhadap objek yang dianalisis dan mengurangi waktu analisis (Corritore, Paolacci and Caprinozzi, 2021). Berdasarkan (Paolacci, Giannini and De Angelis, 2013) *equipment* utama pada *plant process* terbagi menjadi beberapa kategori, antara lain:

1. *Pressure Vessel* yang terbagi menjadi vertikal *vessel* dengan *leg, skirt atau lug support* dan horizontal vessel dengan menggunakan *saddle support*. Peralatan pada komponen ini seperti *columns, stacks,* reaktor dan horizontal *pressure vessel*.
2. *Above ground equipment* merupakan peralatan yang diletakkan di atas tanah dan terbagi menjadi *storage tank* dan peralatan proses yang memiliki ukuran besar seperti *storage tank*.
3. *Equipment supported by column* merupakan peralatan yang disangga oleh kolom seperti *furnace*, *spherical tank*, kompresor, *air cooler* atau peralatan pada ketinggian tertentu yang diletakkan pada kerangka logam.

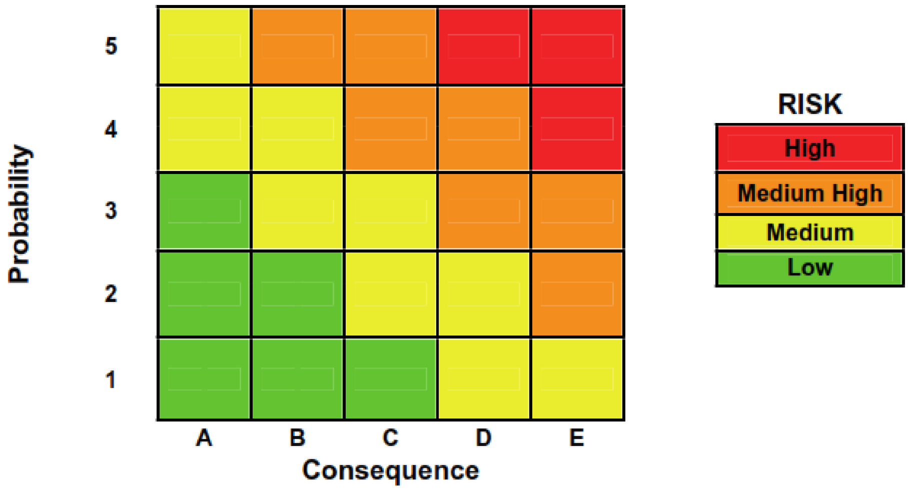
4. Sistem perpipaan terdapat pada banyak jenis *pkant* dan memiliki banyak komponen dan struktur pendukung yang terpasang. Beroperasi dalam berbagai macam kondisi lingkungan dan dirancang untuk bekerja dalam berbagai macam suhu dan tekanan.
5. *Support structure* atau bangunan penyangga merupakan area yang digunakan banyak peralatan dan pipa sebagai tempat penyangga.



Gambar 2.9 Jenis Peralatan dan Struktur (Corritore, Paolacci and Aprinozzi,2021)

Berdasarkan (Droyner and Veith, 2002; Eskandari, Charkhand and Gholami, 2020) *Preliminary screening criticality* mempertimbangkan *consequence of failure* dan *probability of failure* dengan beberapa faktor yang diperhitungkan pada setiap kegagalan yang ada. Terdapat beberapa faktor pada *Consequence of failure* yang terdiri dari *safety consequence factor* (C_{saf}), *pollution consequence factor* ($C_{pol.}$), *production consequence factor* ($C_{prod.}$). C_{saf} merupakan faktor yang mempertimbangkan *loss of containment* atau cedera pada personal yang diakibatkan oleh *loss of containment*. *Pollution consequence factor* merupakan konsekuensi yang berhubungan dengan polusi yang terjadi akibat dari *loss of containment* yang terlepas, Ketika fluida yang memiliki potensi sebagai polusi bocor dengan tanpa disengaja dipertimbangkawn sebagai polusi yang dapat membahayakan manusia maupun lingkungan sekitar dan *production consequence factor* mengacu pada efek kegagalan yang ditimbulkan dari sebuah proses produksi yang terdiri dari dua parameter *repair factor* (Frep) dan *operability factor* (Fop).

Probability of failure terdiri dari *remaining life factor* (RLF), *damage factor* (DF), *inspection factor* (IF), *condition factor* (CCF), *process factor* (PF) dan *mechanical design factor* (MDF). *Remaining life factor* merupakan perkiraan pengukuran dari risiko yang berhubungan dengan umur hidup peralatan atau perpipaan yang memperhitungkan pengurangan ketebalan, keretakan atau mekenisme kerusakan lainnya yang dapat menyebabkan peralatan tersebut berhenti beroperasi. *Damage factor* merupakan pengukuran risiko yang berhubungan dengan mekanisme kerusakan yang telah terjadi atau yang kemungkinan dapat terjadi. *Inspection factor* bertujuan untuk mengukur efektifitas inpeksi untuk mengidentifikasi mekanisme kerusakan yang terjadi atapun untuk mengantisipasi mekanisme kerusakan. *Condition factor* dimaksudkan untuk mengukur efektifitas dari perawatan. *Process factor* merupakan pengukuran untuk mendapatkan indikasi pengoperasian abnormal atau kondisi yang rawan untuk terjadi *loss of containment* dan *Mechanical design factor* mengacu pada beberapa aspek desain pada pengoperasi peralatan.



Gambar 2.10 *Risk Matrix Preliminary Screening Criticallity* (API 581, 2016)

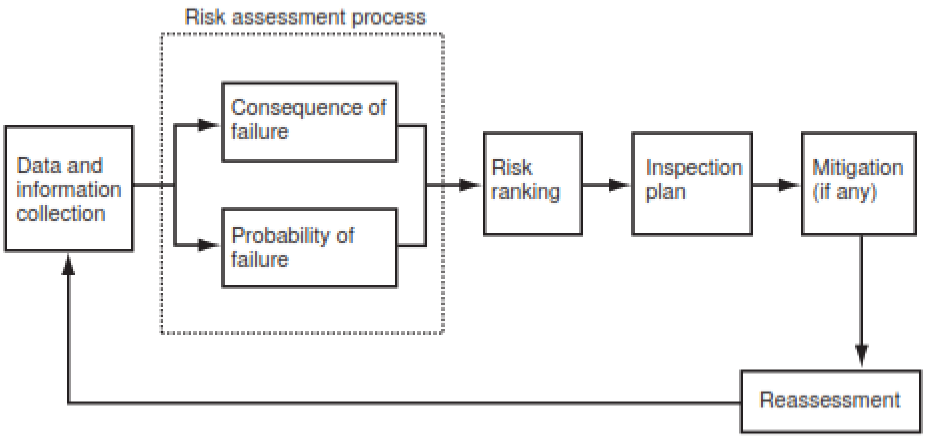
Tabel 2.3 *Risk Category Preliminary Screening Criticallity*

Cat.	Probability Category	Consequence Category	
	Probability Range	Cat.	Range
1	0 - 15	A	0 – 0,2
2	6 - 25	B	0,2 – 0,4
3	26 - 35	C	0,4 – 0,6
4	36 - 50	D	0,6 – 0,8
5	52 - 75	E	0,8 – 1

Sumber: (Eskandari, Charkhand and Gholami, 2020)

2.5 *Risk Based Inspection*

Risk based inspection (RBI) merupakan analisis risiko berfokus pada *loss of containment equipment* bertekanan pada *process plant*, yang disebabkan kerusakan yang terjadi pada material. Risiko-risiko tersebut ditangani melalui inspeksi equipment (API 581, 2016) dan metode yang menggunakan risiko sebagai dasar dalam memprioritaskan dan mengatur program inspeksi (Droyner and Veith, 2002). RBI merupakan pendekatan dengan metodologi untuk menilai, memonitor dan memitigasi risiko yang perlu diperhitungkan karena kompleksitas dari aspek bahan kimia maupun fisik. RBI berurusan dengan konsekuensi dari lubang dan *rupture* yang terjadi pada *equipment* bertekanan dalam hal area yang terdampak dari fluida berbahaya yang mungkin dikeluarkan oleh *equipment* dan biaya yang diperlukan untuk melakukan mitigasi dari masalah yang ditimbulkan dari kejadian tersebut (Moura *et al.*, 2015). Perhitungan metode inspeksi yang paling tepat untuk melakukan pengecak maupun evaluasi di lapangan. Gambar 2.11 di bawah merupakan blok diagram dari alur pengerjaan RBI.



Gambar 2.11 Blok Diagram Alur Pengerjaan RBI (API RP 580, 2008)

2.5.1 Risk

Risiko selalu berhubungan dengan apa yang akan terjadi kedepannya, berada dimanapun, baik secara sadar maupun tidak sadar keputusan cenderung berdasarkan risikonya. Beberapa pernyataan mengatakan bahwa *risk* dapat diganti dengan *chance*, *likelihood* atau *possibility*, dalam beberapa kasus dapat berarti *hazard*, *threat*, atau *danger* (Rausand, 2011). *Risk* atau risiko pada RBI merupakan kombinasi dari kemungkinan (*Probability*) suatu *event* pada periode waktu tertentu dan *consequences* atau konsekuensi.

$$\text{Risk} = \textit{probability} \times \textit{consequences} \tag{2.1}$$

2.5.2 Probability of Failure (POF)

*M*erupakan perkiraan kemungkinan terjadinya konsekuensi tertentu akibat dari *loss of containment* yang terjadi karena *damage mechanism* pada komponen tertentu. Berdasarkan (API 581, 2016), POF dapat ditentukan dengan persamaan berikut:

$$P_f(t) = gff . D_f\ (t) . F_{MS} \qquad (2.2)$$

Dimana :

P_f (t) = Probabilitas kegagalan (*Probability of Failure*)

Gff = Frekuensi kegagalan suatu komponen (*Total Generic Failure Frequency*)

D_f (t) = Faktor kerusakan (*Damage Factor*)

F_{MS} = Faktor sistem manajemen (*Management System Factor*)

2.5.2.1 *Generic Failure Frequency* (GFF)

GFF merupakan frekuensi kegagalan yang dimiliki oleh masing-masing *equipment* untuk mekanisme kerusakan tertentu yang disebabkan oleh lingkungan operasional dari peralatan yang sedang dianalisis. Nilai GFF dapat mewakili industri secara umum karena terdiri dari Kumpulan-kumpulan data dari berbagai macam *plant* dan berupa nilai frekuensi kegagalan yang sebenarnya dari *equipment* tertentu.

2.5.2.2 *Damage factor* (DF)

DF didefinisikan berdasarkan mekanisme kerusakan relevan yang berlaku pada konstruksi material dan servis pada proses yang berljalan, kondisi fisik dari komponen dan teknik inspeksi yang digunakan untuk mengukur kerusakan. Fungsi dasar dari DF adalah untuk mengevaluasi secara statistic jumlah kerusakan yang mungkin terjadi

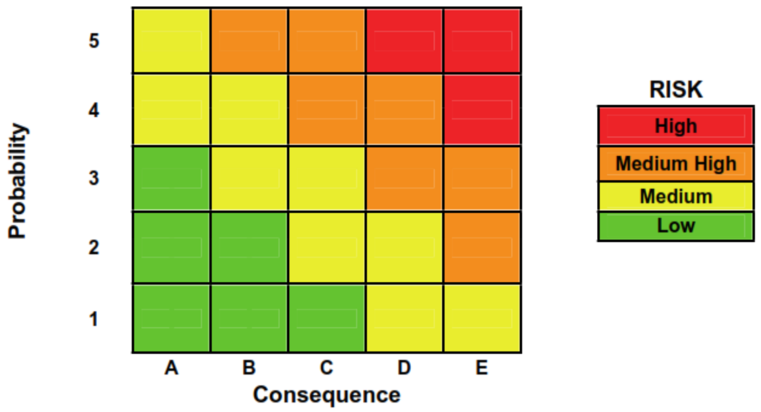
2.5.3 *Consequence of Failure* (COF)

Perhitungan *consequence of failure* dilakukan untuk mengetahui dan memperkirakan dampak dari konsekuensi yang mungkin terjadi, perhitungan CoF juga digunakan untuk menentukan prioritas program inspeksi untuk *equipment*.

Analisis konsekuensi kegagalan pada API 581 dibagi menjadi 2 level berdasarkan jenis fluidanya, yaitu level 1 dan level 2. Pada analisis konsekuensi level 1 terdiri dari beberapa tahapan untuk mendapatkan nilai akhir konsekuensi dan Sebagian besar data yang dibutuhkan terkait data-data fluida sudah tersedia pada API 581, berbeda dengan analisis konsekuensi level 2

2.6 Level Risiko

Hasil dari analisis dan perhitungan RBI adalah level risiko yang bisa dilanjutkan dengan penggunaan *risk matrix* atau *risk plot*. Dengan menggabungkan POF dan COF sesuai dengan rumus pada Persamaan 2.3. Gambar 2.12 Berikut merupakan matriks risiko berdasarkan pada API RP 581.



Gambar 2.12 *Risk Matrix* (API 581, 2016)

Menentukan kategori untuk POF dan COF *risk matrix* dapat menggunakan Tabel 2.4 berdasarkan standar API 581.

Tabel 2.4 *Risk Category*

Cat.	Probability Category		Consequence Category	
	Probability Range	Damage Factor Range	Cat.	Range (m^2)
1	$P_f(t,I_E) \leq 3.06E-05$	$D_{f-total} \leq 1$	A	CA ≤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 ≤ 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 ≤ 929
4	$3.06E-03 < P_f(t,I_E) \leq 3.06E-02$	$100 < D_{f-total} \leq 1000$	D	929 < CA ≤ 9,290
5	$P_f(t,I_E) > 3.06E-02$	$D_{f-total} > 1000$	E	CA > 9,290

Sumber: API 581, 2016

2.7 *Inspection Plan*

Inspeksi merupakan aktivitas yang dilakukan untuk memverifikasi material, fabrikasi, ereksi, eksaminasi, testing, repair dan lain-lain, untuk mengkonfirmasi sesuai dengan *code*, *engineer* atau prosedur tertulis dari *owner*. Sedangkan *inspection plan* merupakan strategi untuk menentukan bagaimana dan kapan inspeksi, *repair* ataupun pemeliharaan (dalam hal ini *pressure vessel*) dilakukan. Dalam penyusunan program inspeksi perlu mempertimbangkan beberapa kriteria untuk menyusun rencana inspeksi yang efektif. Tujuan utama penyusunan inspeksi ini untuk membantu dalam menilai kondisi *pressure vessel* dan mendapatkan data maupun informasi yang dibutuhkan untuk dilakukan adanya analisis, secara tepat waktu tanpa memaksakan suatu kondisi dimana hal tersebut akan merugikan *equipment*. Terdapat beberapa faktor yang dapat dipertimbangkan dalam melakukan penyusunan rencana inspeksi antara lain :

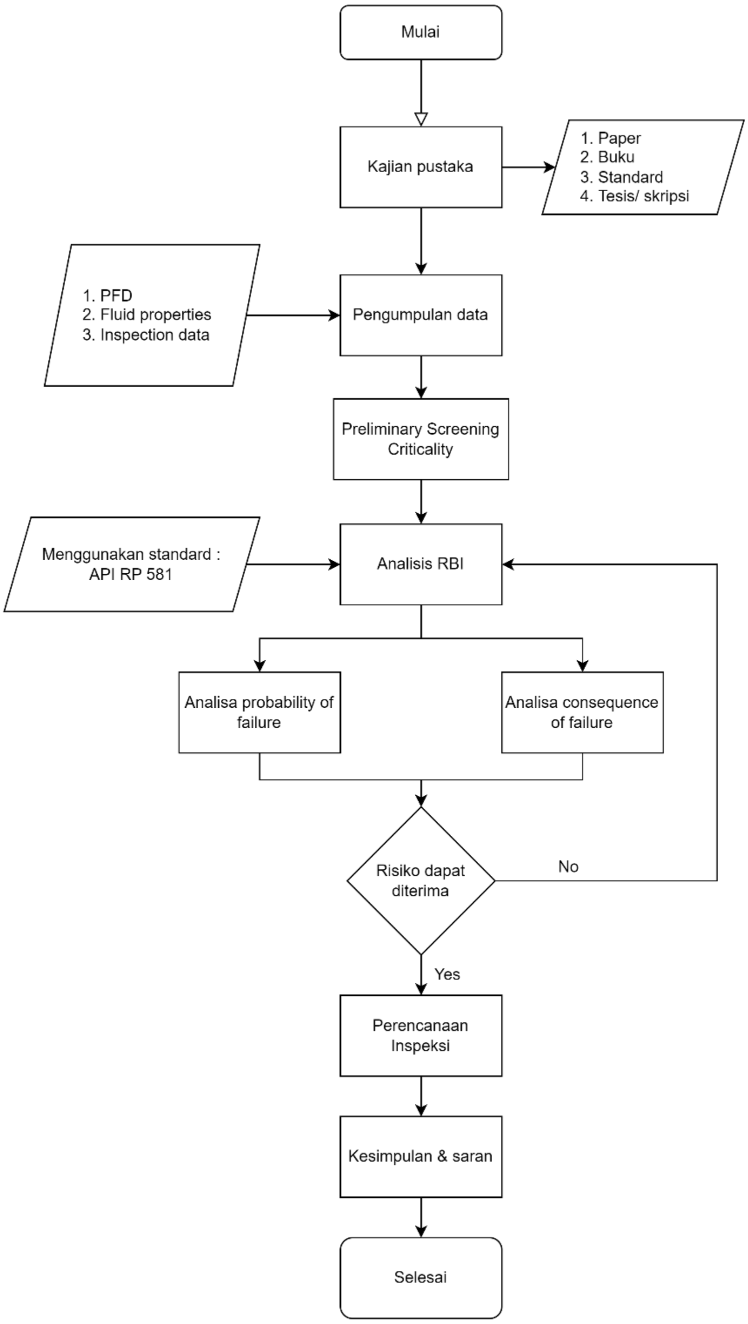
a) Mengetahui atau mengantisipasi jenis-jenis kerusakan
b) Area-area utama terjadinya kerusakan
c) Menduga kecepatan atau waktu terjadinya kerusakan/ kerentanan
d) Sisa hidup dari *equipment*
e) Teknik atau jenis inspeksi yang secara efektif mengarah ke jenis kerusakan yang sudah teridentifikasi
f) Aksesibilitas *equipment* yang aman maupun bagian dari *equipment*
g) Dampak negatif dari dilakukannya inspeksi terhadap keutuhan dan *damage mechanism*, seperti melepas la pisan pelindung, *stress* pada *equipment* akibat dari *start-up* dan *shutdown* atau terpapar oleh udara dan kelembaban yang memungkinkan untuk mempercepat adanya retak akibat dari lingkungan
h) Risiko yang mungkin terjadi pada personil yang melakukan aktivitas inspeksi

Masing-masing objek dari RBI memiliki penyusunan dan standard tersendiri untuk mentukan baik rencana inspeksi maupun jenis-jenis inspeksi yang perlu dilakukan. Beberapa diantaranya telah disebutkan pada API RP 581 seperti pada *equipment pressure relief device*, *heat exchanger* dan *asmopheric storage tank*. Untuk *pressure vessel* dijelaskakan pada API 572 (*Inspection practices for pressure vessel*). Adapun beberapa inspeksi umum yang dapat dilakukan berdasarkan pada ASME PCC-3 yang juga dibagi menjadi 3 yakni pada permukaan (*surface*), *subsurface* dan metode lainnya. Pada 3 lokasi dan cara inspeknya sendiri terdapat beberapa macam antara lain seperti:

1. *Surface*
   a) Visual Test – VT
   b) Liquid Penetrant – PT
   c) Fluorescent Liquid Penetrant
   d) Magnetic Particle Test – MT
   e) Wet Fluorescent Magnetic Particle - WFMT
2. *Surface*
   a) Ultrasonic for Thickness – UTT
   b) Ultrasonic – Straight Beam – UTS
   c) Ultrasonic – Shear Wave – UTSW
   d) Ultrasonic – Shear Wave Adv. Techniques – UTSWA
   e) Radiography – RT
3. *Surface*
   a) Eddy Current – ET
   b) Accoustic Emission – AE
   c) Dimensional Measurement
   d) Hardness Tests
   e) In – Place Metallography (Replication)
   f) Boat/ Plug Sample

BAB 3
METODOLOGI PENELITIAN

Dalam bab 3 ini berisi skema penelitian untuk pengerjaan tesis dengan *risk based inspection*.



Gambar 3.1 Diagram Alir Penelitian

3.1 Studi Literatur

Studi literatur dilakukan untuk membantu dalam pengerjaan tesis, baik dari segi teori, analisis maupun data-data penunjang yang bisa didapatkan dari literatur-literatur. Adapun literatur yang dibaca antara lain seperti penelitian sebelumnya yang membahas *pressure vessel* dengan metode RBI yang mengacu pada API RP 581, jurnal-jurnal terkait, standard pendukung yang dijadikan sebagai acuan dalam pengerjaan tesis API RP 580 dan 581, API 510, API 571, ASME PCC-3, ASME Sec. VIII dan ASME Sec. V.

API RP 580 dan 581 berisi penjelasan dan teori dasar terkait dengan RBI (*Risk Based Inspection*) juga langkah-langkah pengerjaannya, API 510 merupakan API *Certified Pressure Vessel Inspector* dengan penjelasan dasar *pressure vessel*, API 572 merupakan *pressure vessel inspection* dan ASME PCC-3 *Inspection Planning Using Pressure Vessel*.

3.2 Pengumpulan Data

Tracing data-data yang berkaitan dengan metode pengerjaan RBI. Data-data yang sudah terkumpul akan diolah menjadi analisis *risk based analysis*, terdapat beberapa data yang dibutuhkan antara lain:

- *Heat material balance*
- PFD & PID
- *Material data sheet*
- Hasil, kuantitas serta interval inspeksi yang dilakukan pada *pressure vessel*

3.3 *Preliminary Screening Criticality*

Setelah dilakukan pengumpulan data, dilakukan skrining untuk mendapat risiko awal pada *pressure vessel* dengan menggunakan tahap-tahap sebagai berikut untuk mendapatkan POF dan COF:

a) Menentukan COF

Dalam menentukan COF pada metode skrining terdapat beberapa tahap sebagai berikut:

1. *Safety consequence factor* (C_{saf}). Merupakan faktor yang terdiri dari empat parameter yaitu temperatur (Ft), tekanan (Fp), *inventory hazard element* (Fi) dan *inventory size element* (Fis) yang dapat ditentukan dengan menggunakan Tabel 3.1.

Tabel 3.1 Parameter *Safety Consequence Factor*

Faktor	Value	*Consequence*
Temperatur (Ft)	-10 ≤ T ≤ 70 ℃	1
	T < -10, T > 70 ℃	2
Pressure (Fp)	P < 0,5 barg	1
	0,5 ≤ P < 5 barg	2
	5 ≤ P < 10 barg	3
	10 ≤ P ≤ 30 barg	4
	P ≥ 30 barg	5
Inventory hazard element (Fi)	Udara dan air	1
	Asam dan kaustik	3
	Gas proses	5
Inventory size element (Fis)	V = 0	1
	V < 20 liter	1,4
	20 ≤ V < 50 liter	1,6
	50 ≤ V < 500 liter	1,8
	500 ≤ V < 5000	1,9
	V ≥ 5000	2

Sumber: Eskandari, Charkhand and Gholami, 2020

Parameter yang telah ditentukan dapat dihitung dengan menggunakan persamaan C_{saf} sebagai berikut :

$$Csaf = \frac{Ft\ x\ Fp\ x\ Fi\ x\ Fis}{25} \quad (3.1)$$

2. *Pollution consequence factor* ($C_{pol.}$), ditentukan berdasarkan fluida pada penyimpanan yang akan terlepas ke atmosfer. Air dan udara bernilai 0, *acid* dan *caustic* bernilai 2 dan gas bernilai 1.

3. *Production consequence factor* ($C_{prod.}$), terdiri dari 2 parameter yang berhubungan dengan perbaikan *equipment* (*Repair factor*) dan pengoperasiannya (*Operability factor*). Parameter perbaikan *equipment* dapat ditentukan dengan menggunakan Tabel 3.2.

Tabel 3.2 *Repair Factor*

Description	*Characteristic*	*Repair factor* (F_{rep})
Pressure vessel	*PWHT*	2
	Not PWHT	1,8
Pipe	*PWHT – all diameters*	2
	Not PWHT – D > 12"	1,8
	Not PWHT – 2" < D < 12"	1,6
	D ≤ 2"	1,3
Transmission flow line	*As welded or PWHT all diameter*	2

Sumber: Eskandari, Charkhand and Gholami, 2020

Parameter pengoperasian berkaitan dengan kondisi selama proses berjalan dan dapat ditentukan dengan menggunakan Tabel 3.3.

Tabel 3.3 *Operability Factor*

Effect on production	*Operability factor* (F_{op})
No production possible (any event leading to a total shutdown)	3
Loss in production (partial or system shutdown involving some deferment)	2
No effect (events which do not result in deferment)	1

Sumber: Eskandari, Charkhand and Gholami, 2020

C_{prod} dapat dihitung dengan menggunakan persamaan sebagai berikut:

$$Cprod = Frep \ x \ Fop \qquad (3.2)$$

b) Menentukan *probability of failure*

Dalam menentukan *probability of failure* pada metode skrining terdapat beberapa tahap sebagai berikut:

1. *Remaining life factor* (RLF)

   RLF dapat ditentukan dengan menghitung *corrosion rate* menggunakan persamaan sebagai berikut:

   $$CR = \frac{(t_n - t_a)}{T} \quad (3.3)$$

   $$RL = \frac{(t_a - t_{min})}{CR} \quad (3.4)$$

   Dimana:

   CR = Laju korosi (mm/y)

   t_n = Ketebalan nominal (inch)

   t_a = Ketebalan aktual (inch)

   T = Waktu (*year*)

   RL = *Remaining life* (*year*)

   t_{min} = Ketebalan minimal (inch)

2. *Damage factor* (DF)

   Damage factor merupakan segala jenis bentuk kerusakan yang telah terjadi dan berpotensi dapat terjadi. Dapat ditentukan dengan menggunakan Tabel pada Lampiran A.

3. *Inspection factor* (IF)

   Inspection factor untuk menentukan efektfitas inspek pada *pressure vessel* dalam mengetahui kerusakan yang terjadi. Dapat ditentukan dengan menggunakan Tabel pada Lampiran A.

4. *Condition factor* (CCF)

   Condition factor untuk menentukan efektifitas dari perawatan pada *pressure vessel*. Dapat ditentukan dengan menggunakan Lampiran A.

5. *Process factor* (PF)

   Processs factor untuk menentukan kondisi pengoperasian *pressure vessel*. Dapat ditentukan dengan menggunakan tabel pada Lampiran A.

6. *Mechanical design factor* (MDF)

   Mechanical design factor untuk menentukan kondisi desain *pressure vessel* terhadap *maximum allowable working pressure* (MAWP). Penentuan tersebut dapat ditentukan dengan menggunakan Tabel 3.4.

Tabel 3.4 Kategori *Design Factor*

Mechanical Design factor	*Value*
Parameter 1- Does Operating Pressure (OP) over Maximum Allowable Working Pressure (MAWP) ?	
Operating Pressure (OP) < Max. Allowable Working Pressure (MAWP)	0
Operating Pressure (OP) ≥ Max. Allowable Working Pressure (MAWP)	5
Parameter 2- The possibility of exceeding Maximum Allowable Working Pressure (MAWP)	
Extremely Unlikely - Overpressure is theoretically possible (sufficient source pressure), but only through an extremely unlikely chain of events including errors, omissions, and safety device failures at more than two levels of redundancy.	0
Impossible - The pressure source cannot, under any conceivable chain of events, overpressure the equipment.	1
Possible - Where overpressure can occur through a combination of procedural errors or omissions, and failure of safety devices (at least two levels of safety).	3
Routine - Operations could allow the system to reach MAWP. Overpressure is prevented only by procedure or single-level safety device.	5

Sumber: Eskandari, Charkhand and Gholami, 2020

Kemudian seluruh nilai dari setiap faktor yang ada dilanjutkan menggunakan persamaan sebagai berikut untuk menentukan nilai POF. Kategori POF dapat dilihat pada Tabel 2.3.

$$POF = RLF + DF + IF + CCF + PF + MDF \qquad (3.5)$$

Kemudian nilai POF dan COF yang sudah didapat dapat menggunakan Persamaan 2.1 untuk menentukan risikonya. kategori risiko dapat dilihat pada Gambar 2.10.

3.4 Analisis RBI

Skema proses pengerjaan RBI dapat dilihat pada Gambar 2.7 dimana diawali dengan pengumpulan data dan informasi yang dibutuhkan, baik dari literatur maupun data-data dari *equipment* yang dianalisis. Kemudian dilakukan perhitungan POF dan COF yang akan menghasilkan *risk level* dari *equipment*.

Risk level dari *equipment* akan memengaruhi dari sisi penentuan rencana jadwal inspeksi yang akan dibuat, semakin berisiko *equipment* tersebut makan akan semakin pendek pula jadwal inspeksi begitu juga interval inspeksinya. Hal ini ditujukan untuk mengindari ada kegagalan akibat jadwal inspeksi yang terlalu lama dibandingkan dengan level risiko *equipment*.

3.4.1 *Probability of failure* API 581

Perhitungan *probability of failure* (POF) atau probabilitas kegagalan dengan standard API 581 dilakukan dengan menggunakan beberapa parameter seperti GFF, *damage factor* dan *management system factor* merupakan beberapa parameter yang dibutuhkan dalam menghitung POF. Berdasarkan dari jenis *damage factor*, dapat disesuaikan dengan faktor kerusakan yang ada:

1. *Thinning*
2. *SCC-SSC*
3. *SCC-HIC/ SOHIC-*H_2S
4. *SCC-ACSCC*
5. *External Corrosion*

a) Menentukan mekanisme *damage factor thinning*

Berdasarkan API RP 581 seluruh komponen perlu dilakukan perhitungan terhadap *thinning. Corrosion rate* dihitung menggunakan data ketebalan yang tersedia berdasarkan hasil dari inspeksi. Perhitungan faktor kerusakan akibat *thinning* dapat dilakukan sebagai berikut:

1. Menentukan *furnished thickness* dan umur komponen terhitung dari awal instalasi
2. Menentukan laju korosi logam dasar, $C_{r,bm}$,
3. Menentukan waktu *in-service*, age_{tk}, begitu juga *equipment thickness* berdasarkan *last inspection* yang dilakukan, t_{rdi}.

4. Menentukan, age_{rc}, dapat menggunakan persamaan:

$$age_{rc} = max\left[\left(\frac{t_{rdi} - t_{bm}}{c_{r.cm}}\right), 0.0\right] \quad (3.6)$$

5. Menentukan t_{min} menggunakan persamaan berdasarkan ASME sec. VIII sebagai berikut:

$$t_{min} = \frac{P\ x\ D\ X\ K}{((2\ x\ S\ x\ E) - (0.2P))} \quad (3.7)$$

6. Menghitung A_{rt} tanpa *cladding/ overlay* dapat menggunakan persamaan berikut:

$$A_{rt} = \frac{C_{r.bm} . age_{tk}}{t_{rdi}} \quad (3.8)$$

7. Menghitung *flow stress*, FS^{thin}, dengan persamaan:

$$FS^{Thin} = \frac{(YS + TS)}{2} . E . 1{,}1 \quad (3.9)$$

8. Menghitung SR_P^{Thin} , menggunakan persamaan:

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max(t_{min}, t_c)}{t_{rdi}} \quad (3.10)$$

9. Menentukan jumlah inspeksi untuk setiap efektivitas inspeksi, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}
10. Menentukan faktor efektivitas inspeksi, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}, menggunakan persamaan sebagai berikut, *prior probabilities* Pr_{p1}^{Thin}, Pr_{p2}^{Thin}, Pr_{p3}^{Thin}, dengan Tabel 3.1 kemudian Co_{p1}^{Thin}, Co_{p2}^{Thin}, Co_{p3}^{Thin}, dengan Tabel 3.2 dan jumlah inspeksi N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}

Tabel 3.5 *Prior Probabilities for Thinning Corrosion Rate*

Damage State	*Low Confidence Data*	*Medium Confidence Data*	*High Confidence Data*
Pr_{p1}^{Thin}	0.5	0.7	0.8
Pr_{p2}^{Thin}	0.3	0.2	0.15
Pr_{p3}^{Thin}	0.2	0.1	0.05

Sumber: API 581, 2016

Tabel 3.6 *Conditional Probability for Inspection Effectiveness*

Conditional Probability of Inspection	*E- None or Ineffective*	*D – Poorly Effective*	*C – Fairly Effective*	*B – Usually Efective*	*A – Highly Effective*
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

Sumber: API 581, 2016

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinD}\right)^{N_D^{Thin}} \quad (3.11)$$

$$I_2^{Thin} = Pr_{p2}^{Thin}\left(Co_{p2}^{ThinA}\right)^{N_A^{Thin}} Pr_{p2}^{Thin}\left(Co_{p2}^{ThinB}\right)^{N_B^{Thin}} Pr_{p2}^{Thin}\left(Co_{p2}^{ThinC}\right)^{N_C^{Thin}} Pr_{p2}^{Thin}\left(Co_{p2}^{ThinD}\right)^{N_D^{Thin}} \quad (3.12)$$

$$I_3^{Thin} = Pr_{p3}^{Thin}\left(Co_{p3}^{ThinA}\right)^{N_A^{Thin}} Pr_{p3}^{Thin}\left(Co_{p3}^{ThinB}\right)^{N_B^{Thin}} Pr_{p3}^{Thin}\left(Co_{p3}^{ThinC}\right)^{N_C^{Thin}} Pr_{p3}^{Thin}\left(Co_{p3}^{ThinD}\right)^{N_D^{Thin}} \quad (3.13)$$

11. Menghitung *posterior probabilities* $Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}$ menggunakan persamaan:

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (3.14)$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (3.15)$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (3.16)$$

12. Menghitung parameter, β_1^{Thin}, β_2^{Thin}, β_3^{Thin} menggunakan persamaan di bawah dengan beberapa parameter pendukung $COV_{\Delta t} = 0.20$, $COV_{S_f} = 0.20$, $COV_P = 0.05$ dan $D_{S_1} = 1$, $D_{S_2} = 2$, $D_{S_3} = 4$.

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}} \quad (3.17)$$

$$\beta_2^{Thin} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}} \quad (3.18)$$

$$\beta_3^{Thin} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}} \quad (3.19)$$

13. Melakukan perhitungan *base damage factor*, D_{fB}^{Thin} , menggunakan persamaan:

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04}\right] \quad (3.20)$$

14. Menentukan DF untuk *thinning*, D_f^{Thin} , menggunakan persamaan berikut:

$$D_f^{Thin} = max\ \left[\left(\frac{D_{fB}^{Thin}.F_{IP}.F_{DL}F_{WD}F_{AM}F_{SM}}{F_{OM}}\right),\ 0.1\right] \quad (3.21)$$

b) Menentukan mekanisme faktor kerusakan *sulfide stress cracking*

Perhitungan faktor kerusakan akibat *sulfide stress cracking* dapat dilakukan sebagai berikut:

1. Menentukan kondisi keparahan lingkungan (tingkat potensi dari hydrogen *flux*) untuk dasar keretakan untuk kandungan H_2S pada air dan pH dengan menggunakan Tabel 3.7 Sebagai berikut

Tabel 3.7 *Environmental Severity as Function of H2S Content of Water*

pH of Water	Environmental Severity as Function of H_2S content of water			
	< 50 ppm	50 to 1.000 ppm	1000 to 10.000 ppm	> 10.000 ppm
< 5,5	Low	Moderate	High	High
5,5 to 7,5	Low	Low	Low	Moderate
7,6 to 8,3	Low	Moderate	Moderate	Moderate
8,4 to 8,9	Low	Moderate	Moderate*	High*
> 9,0	Low	Moderate	High*	High*

Sumber: API 581, 2016

2. Menentukan kerawanan untuk keretakan menggunakan Tabel 3.8 Berdasarkan kondisi keparahan lingkungan, *hardness Brinnel* maksimum dari pengelasan dan penggunaan PWHT.

Tabel 3.8 *Susceptibility to SSC as a Function of Heat Treatment*

Environmental Severity	*Susceptibility to SSC as a Function of Heat Treatment*					
	As-Welded Max Brinnell			*PWHT Max Brinnell Hardness*		
	< 200	200-237	> 237	< 200	200-237	> 237
High	*Low*	*Medium*	*High*	*Not*	*Low*	*Medium*
Moderate	*Low*	*Medium*	*High*	*Not*	*Not*	*Low*
Low	*Low*	*Low*	*Medium*	*Not*	*Not*	*Not*

Sumber: API 581, 2016

3. Berdasarkan kerawanannya, menentukan index keparahan (*severity index*), S_{rt}, dengan menggunakan Tabel 3.9.

   Tabel 3.9 *Severity Index Sulfide Stress Corrosion Cracking*

Susceptibility	*Severity Index* - S_{rt}
Tinggi	100
Sedang	10
Rendah	1
Tidak ada	0

   Sumber: API 581, 2016

4. Menentukan umur operasi sejak tingkat inspeksi A, B, C terakhir kali dilakukan tanpa adanya retakan yang teridentifikasi atau retakan yang telah diperbaiki.
5. Penentuan jumlah inspeksi dan kategori *inspection effectiveness* yang sesuai untuk inspeksi yang telah dilakukan selama umur operasi.
6. Menentukan *base Damage Factor* untuk *sulfide stress cracking*, DF_{fB}^{SSC}, menggunakan Tabel 3.10 Berdasarkan jumlah dan efektivitas inspeksi tertinggi begitu juga dengan *severity index*.

   Tabel 3.10 *Base Damage factor*

S_{vt}	*Inspection Effectiveness*												
	E	1 *inspection*				2 *inspection*				3 *inspection*			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10
S_{vt}	*Inspection Effectiveness*												
	E	4 *inspection*				5 *inspection*				6 *inspection*			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	20	2	1

Sumber: API 581, 2016

7. Menghitung *damage factor* berdasarkan umur operasi dengan persamaan :

$$D_f^{SSC} = D_{fB}^{SSC}.(Max[age, 1.0])^{1.1} \quad (3.22)$$

c) Menentukan mekanisme faktor kerusakan HIC/ SOHIC-H_2S

Perhitungan faktor kerusakan akibat HIC/ SOHIC-H_2S dapat dilakukan sebagai berikut:

1. Menentukan kondisi keparahan lingkungan (tingkat potensi dari hydrogen *flux*) untuk dasar keretakan untuk kandungan H_2S pada air dan pH dengan menggunakan Tabel 3.11 sebagai berikut.

Tabel 3.11 *Environmental Severity as Function of H_2S Content of Water*

pH of Water	Environmental Severity as Function of H_2S content of water			
	< 50 ppm	50 to 1.000 ppm	1000 to 10.000 ppm	> 10.000 ppm
< 5,5	Low	Moderate	High	High
5,5 to 7,5	Low	Low	Low	Moderate
7,6 to 8,3	Low	Moderate	Moderate	Moderate
8,4 to 8,9	Low	Moderate	Moderate*	High*
> 9,0	Low	Moderate	High*	High*

Sumber: API 581, 2016

2. Menentukan kerawanan dari keretakan menggunakan Tabel 3.12 Berdasarkan kondisi keparahan lingkungan, kandungan sulfur dan *carbon steel* dan penggunaan PWHT.

Tabel 3.12 *Susceptibility SSC*

Enviromental severity	*Susceptibility to SSC as function of heat treatment*					
	High sulfur steel > 0,01% S		*Low sulfur steel ≤ 0,01%*		*Seamless/ extrude pipe*	
	As-welded	PWHT	*As-welded*	PWHT	*As-welded*	PWHT
Tinggi	Tinggi	Tinggi	Tinggi	Sedang	Sedang	Rendah
Sedang	Tinggi	Sedang	Sedang	Rendah	Rendah	Rendah
Rendah	Sedang	Rendah	Rendah	Rendah	Rendah	Rendah

Sumber: API 581, 2016

3. Berdasarkan kerawanannya, menentukan index keparahan (*severity index*), S_{rt}, dengan menggunakan Tabel 3.9.

4. Menentukan umur operasi sejak tingkat inspeksi A, B, C terakhir kali dilakukan tanpa adanya retakan yang teridentifikasi atau retakan yang telah diperbaiki.
5. Penentuan jumlah inspeksi dan kategori *inspection effectiveness* yang sesuai untuk inspeksi yang telah dilakukan selama umur operasi.
6. Menentukan *base Damage Factor* untuk Hic/ Sohic-H_2S *cracking*, $DF_{fB}^{\mathrm{HIC/SOHIC-H2S}}$, menggunakan Tabel 3.10 berdasarkan jumlah dan efektivitas inspeksi tertinggi begitu juga dengan *severity index*.
7. Menentukan faktor *on-line adjustment*, F_{OM}, menggunakan Tabel 3.13

Tabel 3.13 *On-line Adjustment*

On-Line monitoring method	Adjusment Factors as a function of On-line monitoring- Fom
Key process variables	2
Hydrogen probes	2
Key process variables & hydrogen probes	4

Sumber: API 581, 2016

8. Menghitung *final damage factor* dengan persamaan:

$$D_f^{SSC} = D_{fB}^{SSC}.(Max[age, 1.0])^{1.1} \quad (3.23)$$

d) Menentukan mekanisme faktor kerusakan *alkaline carbonate stress corrosion cracking*

Dalam API RP 581, ACSCC dapat terjadi pada komponen dengan material karbon atau *alloy* dan terdapat *alkaline water* dengan pH > 7,5. Perhitungan faktor kerusakan akibat ACSCC dapat dilakukan sebagai berikut:

1. Menentukan *susceptibility* adanya keretakan berdasarkan pH air, konsentrasi CO_3 dan perlakuan PWHT pada *pressure vessel* yang dianalisis. *Susceptibility* ACSCC dapat ditentukan dengan menggunakan Tabel 3.14

Tabel 3.14 *Susceptibility to cracking ACSCC*

pH of water	*Susceptibility to cracking as a function of CO_3*		
	PWHT, possible cold working	*No PWHT, possible cold working*	
	CO_3 all concentration	*CO_3 < 100 ppm*	*CO_3 ≥ 100 ppm*
< 7,5	*None*	*None*	*None*
≥ 7,5 to 8,0	*None*	*Low*	*Medium*
≥ 8,0 to 9,0	*None*	*Low*	*High*
≥ 9,0	*None*	*High*	*High*

Sumber: API 581, 2016

2. Menentukan *severity index* dengan menggunakan Tabel 3.15.

Tabel 3.15 *Severity Index Alkaline Carbonate Stress Corrosion Cracking*

Susceptibility	*Severity Index - S_{rt}*
Tinggi	1000
Sedang	100
Rendah	10
Tidak ada	0

Sumber: API 581, 2016

3. Menentukan umur operasi sejak tingkat inspeksi A, B, C terakhir kali dilakukan tanpa adanya retakan yang teridentifikasi atau retakan yang telah diperbaiki.
4. Menentukan jumlah inspeksi dan kategori *inspection effectiveness* yang sesuai untuk inspeksi yang telah dilakukan selama umur operasi.
5. Menentukan *base Damage Factor* untuk ACSCC, DF_{fB}^{ACSCC}, menggunakan Tabel 3.10 berdasarkan jumlah dan efektivitas inspeksi tertinggi begitu juga dengan *severity index*.
6. Menghitung *damage factor* berdasarkan umur operasi dengan persamaan :

$$D_f^{ACSSC} = D_{fB}^{ACSSC}.(Max[age, 1.0])^{1.1} \quad (3.24)$$

e) Menentukan mekanisme faktor kerusakan *external corrosion*

Dalam API RP 581, *external corrosion* ditentukan oleh area dimana *plant* berada. Perhitungan faktor kerusakan akibat *external corrosion* dapat dilakukan sebagai berikut:

1. Menentukan *furnished thickness* dan *umur* komponen dari waktu instalasi
2. Menentukan laju korosi, $C_{r,B}$, berdasarkan pada *driver* dan temperatur operasi menggunakan Tabel 3.16.

Tabel 3.16 *Corrosion Rate for Calculation of the Damage Factor – External Corrosion*

Operating temperature (°C)	*Corrosion Rate as a Function of Driver* (mm/y)			
	Marine/ cooling tower drift area	*Temperate*	*Arid/ dry*	*Severe*
-12	0	0	0	0
-8	0.025	0	0	0
6	0.127	0.076	0.025	0.0254
32	0.127	0.076	0.025	0.0254
71	0.127	0.051	0.025	0.0254
107	0.025	0	0	0.051
121	0	0	0	0

Sumber: API 581, 2016

3. Menentukan *corrosion rate* akhir, C_r.

$$C_r = C_{rB}.max[F_{EQ}, F_{IF}] \quad (3.25)$$

4. Menentukan waktu *beroperasi*, age_{tk}, begitu juga *thickness equipment* berdasarkan inspeksi terakhir yang dilakukan, t_{rde}. Jika tidak ada pengukuran ketebalan t_{rde} = t dan age_{tk} = age. t_{rde} merupakan ketebalan yang akan terkena efek dari korosi eksternal.
5. Menentukan waktu *in-service*, age_{coat}, semenjak *coating* pertamakali terpasang dapat menggunakan persamaan:

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date \quad (3.26)$$

6. Menentukan pengaturan *coating*, $coat_{adj}$, sebagai berikut:

Jika $age_{tk} \geq age_{coat}$ maka,

Tanpa *Coating* atau kualitas *coating* buruk:

$$coat_{adj} = 0 \quad (3.27)$$

Kualitas *coating* medium:

$$coat_{adj} = min[5, age_{coat}] \quad (3.28)$$

Kualitas *coating* baik:

$$coat_{adj} = min[15, age_{coat}] \quad (3.29)$$

Jika $age_{tk} < age_{coat}$ maka,

$$coat_{adj} = 0 \quad (3.30)$$

Kualitas *coating* medium:

$$coat_{adj} = min[5, age_{coat}] - min[5, age_{coat} - age_{tk}] \quad (3.31)$$

Kualitas *coating* baik:

$$coat_{adj} = min[15, age_{coat}] - min[15, age_{coat} - age_{tk}] \quad (3.32)$$

7. Menentukan waktu umur operasi, Ketika *external corrosion* mulai terjadi dapat menggunakan persamaan berikut:

$$age = age_{tk} - Coat_{adj} \quad (3.33)$$

8. Menghitung A_{rt} berdasarkan age dan t_{rde} dapat menggunakan persamaan berikut:

$$A_{rt} = \frac{C_{r.bm} . age_{tk}}{t_{rde}} \quad (3.34)$$

9. Menghitung *flow stress*, FS^{thin}, dengan persamaan:

$$FS^{Thin} = \frac{(YS + TS)}{2} . E . 1{,}1 \quad (3.35)$$

10. Menghitung SR_P^{Thin} , menggunakan persamaan:

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max(t_{min} , t_c)}{t_{rdi}} \quad (3.36)$$

11. Menentukan jumlah inspeksi untuk setiap efektivitas inspeksi, N_A^{Thin} , N_B^{Thin}, N_C^{Thin}, N_D^{Thin}
12. Menentukan faktor efektivitas inspeksi, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}, menggunakan persamaan sebagai berikut, *prior probabilities* Pr_{p1}^{Thin} , Pr_{p2}^{Thin} , Pr_{p3}^{Thin} ,

dengan Tabel 3.5 kemudian Co_{p1}^{Thin}, Co_{p2}^{Thin}, Co_{p3}^{Thin}, dengan Tabel 3.6 dan jumlah inspeksi N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}

$$I_1^{extcr} = Pr_{p1}^{extcr}\left(Co_{p1}^{extcrA}\right)^{N_A^{extcr}} Pr_{p1}^{extcr}\left(Co_{p1}^{extcrB}\right)^{N_B^{extcr}} Pr_{p1}^{extcr}\left(Co_{p1}^{extcrC}\right)^{N_C^{extcr}} Pr_{p1}^{extcr}\left(Co_{p1}^{extcrD}\right)^{N_D^{extcr}} \quad (3.37)$$

$$I_2^{extcr} = Pr_{p2}^{extcr}\left(Co_{p2}^{extcrA}\right)^{N_A^{extcr}} Pr_{p2}^{extcr}\left(Co_{p2}^{extcrB}\right)^{N_B^{extcr}} Pr_{p2}^{extcr}\left(Co_{p2}^{extcrC}\right)^{N_C^{extcr}} Pr_{p2}^{extcr}\left(Co_{p2}^{extcrD}\right)^{N_D^{extcr}} \quad (3.38)$$

$$I_3^{extcr} = Pr_{p3}^{extcr}\left(Co_{p3}^{extcrA}\right)^{N_A^{extcr}} Pr_{p3}^{extcr}\left(Co_{p3}^{extcrB}\right)^{N_B^{extcr}} Pr_{p3}^{extcr}\left(Co_{p3}^{extcrC}\right)^{N_C^{extcr}} Pr_{p3}^{extcr}\left(Co_{p3}^{extcrD}\right)^{N_D^{extcr}} \quad (3.39)$$

13. Menghitung *posterior probabilities* $Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}$ menggunakan persamaan:

$$Po_{p1}^{extcr} = \frac{I_1^{extcr}}{I_1^{extcr} + I_2^{extcr} + I_3^{extcr}} \quad (3.40)$$

$$Po_{p2}^{extcr} = \frac{I_1^{extcr}}{I_1^{extcr} + I_2^{extcr} + I_3^{extcr}} \quad (3.41)$$

$$Po_{p3}^{extcr} = \frac{I_1^{extcr}}{I_1^{extcr} + I_2^{extcr} + I_3^{extcr}} \quad (3.42)$$

14. Menghitung parameter, β_1^{Thin}, β_2^{Thin}, β_3^{Thin} menggunakan persamaan di bawah dengan beberapa parameter pendukung $COV_{\Delta t} = 0.20$, $COV_{S_f} = 0.20$, $COV_P = 0.05$ dan D_{S_1} = 1, D_{S_2} = 2, D_{S_3} = 4

$$\beta_1^{extcr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcr}}{\sqrt{{D_{S_1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{extcr}\right)^2.{COV_P}^2}} \quad (3.43)$$

$$\beta_2^{extcr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcr}}{\sqrt{{D_{S_2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{extcr}\right)^2.{COV_P}^2}} \quad (3.44)$$

$$\beta_3^{extcr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcr}}{\sqrt{{D_{S_3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{extcr}\right)^2.{COV_P}^2}} \quad (3.45)$$

15. Melakukan perhitungan *base damage factor*, D_{fB}^{Thin} , menggunakan persamaan:

$$D_{fB}^{extcr} = \left[\frac{\left(Po_{p1}^{extcr}\Phi\left(-\beta_1^{extcr}\right)\right) + \left(Po_{p2}^{extcr}\Phi\left(-\beta_2^{extcr}\right)\right) + \left(Po_{p3}^{extcr}\Phi\left(-\beta_3^{extcr}\right)\right)}{1.56E-04}\right] \quad (3.46)$$

3.4.2 Analisis *consequence of failure* API 581

Perhitungan *consequnce of failure* (COF) memiliki langkah-langkah yang sama dengan melalui prosedur sebagai berikut :

1. Fluida representatif

Untuk menentukan fluida representative beserta sifatnya yang akan digunakan dalam penentuan analisis konsekuensi, terdapat prosedur perhitungan sebagai berikut :

1.1 Menentukan fluida representative

1.2 Menentuka fasa fluida yang tersimpan

1.3 Menentukan sifat fluida yang tersimpan

1.4 Menentukan fasa stabil fluida ketika terlepas ke atmosfer

2. Ukuran lubang pelepasan

Terdapat tahapan perhitungan pemilihan ukuran lubang kebocoran yang dapat dilakukan sebagai berikut :

2.1 Memilih diameter lubang pelepasan , d_n, berdasarkan tipe *equipment*, dapat dilihat pada Tabel 3.17.

Tabel 3.17 Jenis Ukuran Lubang

Release Hole Number	*Release Hole Size*	*Range of Hole Diameters (inch)*	*Release Hole Diameter, d_n (inch)*
1	*Small*	0 - ¼	d_1 = 0.25
2	*Medium*	> ¼ - 2	d_1 = 1
3	*Large*	> 2 – 6	d_1 = 4
4	*Rupture*	> 6	d_1 = min [D, 16]

Sumber: API 581, 2016

2.2 Menentukan gff_n dan gff_{total}

3. Laju pelepasan

Menghitung laju pelepasan terdapat langkah-langkah sebagai berikut :

3.1 Menentukan persamaan laju pelepasan berdasarkan fasa fluida tersimpanya

3.2 Menghitung area A_n pada setiap ukuran lubang pelepasan:

$$A_n = \frac{\pi \; x \; d_n^2}{4} \qquad (3.47)$$

3.3 Setiap lubang pelepasan perlu adanya perhitungan laju pelepasan, W_n , untuk setiap area pelepasan, A_n , dengan menggunakan persamaan :

Jika fase cair,

$$W_n = C_d \; x \; K_{v,n} \; x \; \rho_l x \; \frac{A_n}{Cl} \sqrt{\frac{2 \; x \; g_c x \; (P_s - P_{atm})}{\rho_l}} \tag{3.48}$$

Jika fase uap,

$$W_n = \frac{C_d}{C_2} \; x \; A_n \; x \; P_s \sqrt{\frac{k \; x \; MW \; x \; g_c}{R \; x \; T_s} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{3.49}$$

$$W_n = \frac{C_d}{C_2} \; x \; A_n \; x \; P_s \sqrt{\frac{MW \; x \; g_c}{R \; x \; T_s} \left(\frac{2 \; x \; k}{k-1}\right) \left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}} \left(1 - \left(\frac{P_{atm}}{P_s}\right)\right)^{\frac{k-1}{k}}} \tag{3.50}$$

4. Persediaan fluida tersedia yang terlepas
   4.1 Menentukan kelompok komponen dan *equipment* kedalam grup *inventory*
   4.2 Menentukan massa fluida, $mass_{comp}$, dari komponen yang dianalisis
   4.3 Menghitung massa fluida setiap komponen dalam grup inventori, $mass_{comp,i}$
   4.4 Menghitung massa fluida dalam grup inventori, $mass_{inv}$, menggunakan persamaan :

$$mass_n = \sum_{i=1}^{N} mass_{comp,i} \tag{3.51}$$

   4.5 Menghitung laju aliran dari lubang dengan diameter 8 inch, W_{max8}, menggunakan persamaan laju pelepasan 3.46 atau 3.47 dan 3.48. Ini merupakan laju aliran maksimum yang dapat masuk ke dalam *equipment* dari *equipment* di sekitarnya dalam grup inventori
   4.6 Menghitung massa fluida yang ditambahkan, $mass_{add,n}$, untuk setiap ukuran lubang kebocoran hasil dari aliran selama 3 menit dari grup inventori menggunakan persamaan sebagai berikut :

$$mass_{add,n} = 180. \min[W_n, W_{max8}] \tag{3.52}$$

   4.7 Menghitung massa yang tersedia pada kebocoran untuk setiap ukuran lubang pelepasan menggunakan persamaan sebagai berikut :

$$mass_{avail} = min\left[\{mass_{comp} + mass_{avail,n}\}, mass_{inv}\right] \tag{3.53}$$

5. Tipe pelepasan

API RBI memberikan 2 metode tipe kebocoran, yaitu *instantaneous* dan *continuous*. Tipe *instantaneous* tipe pelepasan yang berlangsung sangat cepat sedang *continuous* merupakan tipe pelepasan yang berlangsung dalam waktu cukup lama. Untuk menentukan tipe pelepasan dapat dilakukan sebagai berikut :

5.1 Menghitung waktu yang dibutuhkan tiap lubang pelepasan untuk mengeluarkan fluida sebesar 10000 lbs dengan persamaan sebagai berikut :

$$t_n = \frac{C_3}{W_n} \quad (3.54)$$

5.2 Untuk setiap lubang pelepasan, perlu ditentukan tipe pelepasan *instantaneous* atau *continous* pada setiap ukuran lubang dengan kriteria sebagai berikut :

a) Jika ukuran lubang pelepasan adalah 0,25 inch atau lebih kecil maka tipe pelepasan adalah *continuous*.

b) Jika $t_n \leq 180$ detik atau massa yang terlepas lebih dari 10000 lbs maka tipe pelepasan adalah *instantaneous*, bila belum tidak mencapai kriteria ini maka termasuk dalam *continuous*.

6. Mengestimasi dampak dari sistem deteksi dan isolasi pada besarnya pelepasan

Plant maupun perusahaan yang bergerak di bidang petrokimia, *oil* & *gas* maupun lainnya memiliki beragam sistem deteksi, isolasi dan mitigasi yang sudah didesain untuk mnegurangi efek dari pelepasan atau kebocoran dari fluida berbahaya. Adapun langkah-langkah untuk menentukan dampak dari sistem deteksi dan isolasi dari *equipment* :

6.1 Menentukan sistem deteksi dan isolasi yang terdapat pada *equipment*

6.2 Memilik klasifikasi yang sesuai untuk sistem deteksi

6.3 Memilik klasifikasi yang sesuai untuk sistem isolasi

6.4 Menentukan faktor reduksi pelepasan, $fact_{di}$,

6.5 Menentukan total durasi kebocoran untuk setiap ukuran lubang, $id_{max,n}$,

7. Laju massa kebocoran untuk analisis konsekuensi

Langkah dalam menghitung laju dan massa pelepasan adalah sebagai berikut :

7.1 Menghitung laju pelepasan untuk setiap lubang pelepasan, W_n dan $fact_{di}$. Hitung laju pelepasan yang telah disesuaikan, $rate_n$, dengan menggunakan persamaan sebagai berikut :

$$rate_n = W_n(1 - fact_{dl}) \quad (3.55)$$

7.2 Menghitung durasi kebocoran, ld_n, pada setap lubang kebocoran berdasarkan parameter massa yang tersedia, $mass_{avail,n}$, dari langkah ke

4 dan laju pelepasan diatur, $rate_n$ pada langkah 7. Perhitungan dapat menggunakan persamaan :

$$ld_n = min\ \left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}\left\{60.\, ld_{max,n}\right\}\right] \quad (3.56)$$

7.3 Menghitung massa kebocoran, $mass_n$, pada setiap ukuran lubang pelepasan dengan berdasarkan laju pelepasan, $rate_n$, durasi maksimum, $ld_{max,n}$, dan massa tersedia, $mass_{avail,n}$, menggunakan persamaan :

$$mass_n = min\left[\{rate_n\ x\ ld_n\}, mass_{avail,n}\right] \quad (3.57)$$

8 Konsekuensi flammable dan explosion

8.1 Memilih faktor reduksi area mitigasi, $fact_{mit}$, dengan menggunakan

8.2 Menghitung faktor koreksi efisiensi energi,$eneff_n$, menggunakan persamaan :

$$eneff_n = 4. log_{10}\ [C_{4A}. mass_n] - 15 \quad (3.58)$$

8.3 Menentukan tipe fluida, TYPE 0 atau TYPE 1 dengan menggunakan

8.4 Menghitung *component damage consequences area* untuk *auto-ignition not likely, continuous release* (AINL-CONT), $CA_{cmd,n}^{AINL-CONT}$, pada setiap ukuran lubang pelepasan menggunakan persamaan:

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b\, .\, (1 - fact_{mit}) \quad (3.59)$$

8.5 Menghitung *component damage consequences area* untuk *auto-ignition likely, continuous release* (AIL-CONT), $CA_{cmd,n}^{AIL-CONT}$, pada setiap ukuran lubang pelepasan menggunakan persamaan:

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b\, .\, (1 - fact_{mit}) \quad (3.60)$$

8.6 Menghitung *component damage consequences area* untuk *auto-ignition not likely, intantaneous release* (AINL-INST), $CA_{cmd,n}^{AINL-INST}$, pada setiap ukuran lubang pelepasan menggunakan persamaan :

$$CA_{cmd,n}^{AINL-INST} = a(mass_n)^b\, .\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (3.61)$$

8.7 Menghitung *component damage consequences area* untuk *auto-ignition not likely, intantaneous release* (AIL-INST), $CA_{cmd,n}^{AIL-INST}$, pada setiap ukuran lubang pelepasan menggunakan persamaan :

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b\, .\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (3.62)$$

8.8 Menghitung *personnel injury consequence areas* untuk *auto-ignition not likely, continuous release* (AINL-CONT), $CA_{inj,n}^{AINL-CONT}$, pada setiap lubang pelepasan menggunakan persamaan :

$$CA_{inj,n}^{AINL-CONT} = [a.(rate_n^{AINL-CONT})^b].(1 - fact_{mit}) \quad (3.63)$$

8.9 Menghitung *personnel injury consequence areas* untuk *auto-ignition likely, continuous release* (AIL-CONT), $CA_{inj,n}^{AINL-CONT}$, pada setiap lubang pelepasan menggunakan persamaan :

$$CA_{inj,n}^{AIL-CONT} = [a.(rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (3.64)$$

8.10 Menghitung *personnel injury consequence areas* untuk *auto-ignition not likely, instantaneous release* (AINL-INST), $CA_{inj,n}^{AINL-INST}$, pada setiap lubang pelepasan menggunakan persamaan :

$$CA_{inj,n}^{AINL-INST} = [a.(mass_n^{AINL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (3.65)$$

8.11 Menghitung *personnel injury consequence areas* untuk *auto-ignition likely, instantaneous release* (AIL-INST), $CA_{inj,n}^{AIL-INST}$, pada setiap lubang pelepasan menggunakan persamaan :

$$CA_{inj,n}^{AIL-INST} = [a.(mass_n^{AIL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (3.66)$$

8.12 Menghitung *instantaneous*/ *continuous blending factor*, $fact_n^{IC}$, pada setiap ukuran lubang pelepasan menggunakan persmaan :

a) Pelepasan *continuous*- untuk pelepasan *continuous* yang mendekati transisi titik *instantaneous* (2,536 kgs (10,000 lbs) dalam 3 menit, atau laju pelepasan 25.2 kg/s (55.6 lb/s)) dapat menggunakan persamaan *blending factor* sebagai berikut :

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_s}\right\}\right], 1.0 \quad (3.67)$$

b) Pelepasan *instantaneous*- untuk pelepasan ini *blending* tidak dibutuhkan dan dapat menggunakan persamaan sebagai berikut :

$$fact_n^{IC} = 1.0 \quad (3.68)$$

8.13 Menghitung AIT *blending factor* , $fact^{AIT}$ dengan menggunakan persamaan

$$fact^{AIT} = 0 \qquad \text{jika } T_s + C_6 \leq AIT \qquad (3.69)$$

$$fact^{AIT} = \frac{T_s - AIT + C_6}{2.C_6} \qquad \text{jika } T_s + C_6 > T_s > T_s - C_6 \qquad (3.70)$$

$$fact^{AIT} = 1 \qquad \text{jika } T_s - C_6 \geq AIT \qquad (3.71)$$

8.14 Menghitung *continuous/ instantaneous blended qonsequence areas* untuk komponen dengan menggunakan persamaan :

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}.(1 - fact_n^{IC}) \qquad (3.72)$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}.fact_n^{IC} + CA_{inj,n}^{AIL-CONT}.(1 - fact_n^{IC}) \qquad (3.73)$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{ANIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}.(1 - fact_n^{IC}) \qquad (3.74)$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST}.fact_n^{IC} + CA_{inj,n}^{AINL-CONT}.(1 - fact_n^{IC}) \qquad (3.75)$$

8.15 Menghitung AIT *blended consequence area* untuk setiap ukuran lubang pelepasan dapat menggunakan persamaan sebagai berikut. Berdasarkan hasil konsekuensi area *component damage* dan *personnel injury* yang sudah ditentukan :

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL}.fact^{AIT} + CA_{cmd,n}^{AIL}.(1 - fact_n^{IC}) \qquad (3.76)$$

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}.fact^{AIT} + CA_{inj,n}^{AIL}.(1 - fact_n^{IC}) \qquad (3.77)$$

8.16 Menentukan area konsekuensi akhir untuk kerusakan komponen dan cedera pada personil dengan menggunakan persamaan

$$CA_{cmd,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n.CA_{cmd,n}^{flam}}{gff_{total}}\right) \qquad (3.78)$$

$$CA_{inj,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n.CA_{inj,n}^{flam}}{gff_{total}}\right) \qquad (3.79)$$

9. Menentukan konsekuensi *toxic*

Prosedur dalam menentukan koensekuensi *toxic* adalah sebagai berikut :

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n.CA_{inj,n}^{tox}}{gff_{total}}\right) \qquad (3.80)$$

10. Menentukan non-flammable non-toxic consequences

$$CA_{cmd,n}^{leak} = 0.0 \qquad (3.81)$$

$$CA_{inj}^{inft} = \left(\frac{\sum_{n=1}^{4} gff_n.CA_{inj,n}^{leak}}{gff_{total}}\right) \qquad (3.82)$$

11. Menentukan component damage dan personnel injury consequences areas

11.1 Menghitung *final component damage consequences area*, CA_{cmd} , dengan persamaan :

$$CA_{cmd} = CA_{cmd}^{flam} \quad (3.83)$$

11.2 Menghitung *final personnel injury consequences area*, CA_{inj} , dengan persamaan :

$$CA_{cmd} = max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right] \quad (3.84)$$

11.3 Menghitung *final consequences area*, CA_{cmd} , dengan persamaan :

$$CA = max\left[CA_{cmd}, CA_{inj}\right] \quad (3.85)$$

3.5 Penentuan Level Risiko

Setelah didapatkan *probability of failure* dan *consequence of failure* maka akan ditentukan level risikonya dengan menggunakan matrix risiko dengan 4 jenis kategori risko yaitu :

- *Low risk*
- *Medium risk*
- *Medium high risk*
- *High risk*

Level risiko berdasarkan API 581 ditentukan dengan menggunakan perhitungan manual sesuai dengan standard API 581. Dengan menggunakan Persamaan 2.3 dimana risiko sama dengan probabilitas dikalikan dengan konsekuensi kegagalan. Klasifikasi probabilitas kegagalan dan konsekuensi kegagalan dapat dilihat pada Tabel 2.13 yang kemudian dapat disesuaikan dengan menggunakan matriks risiko seperti pada Gambar 3.2.

3.6 Perencanaan Inspeksi

Setelah didapatkan level risiko dari *equipment* maka dapat direncanakan jenis dan penjadwalan inspeksinya dengan mengacu pada API RP 581. Setiap level risiko yang ada memiliki interval waktu inspeksinya dan jenis inspeksinya juga ditentukan oleh jenis *equipment* yang sedang dilakukan analisis.

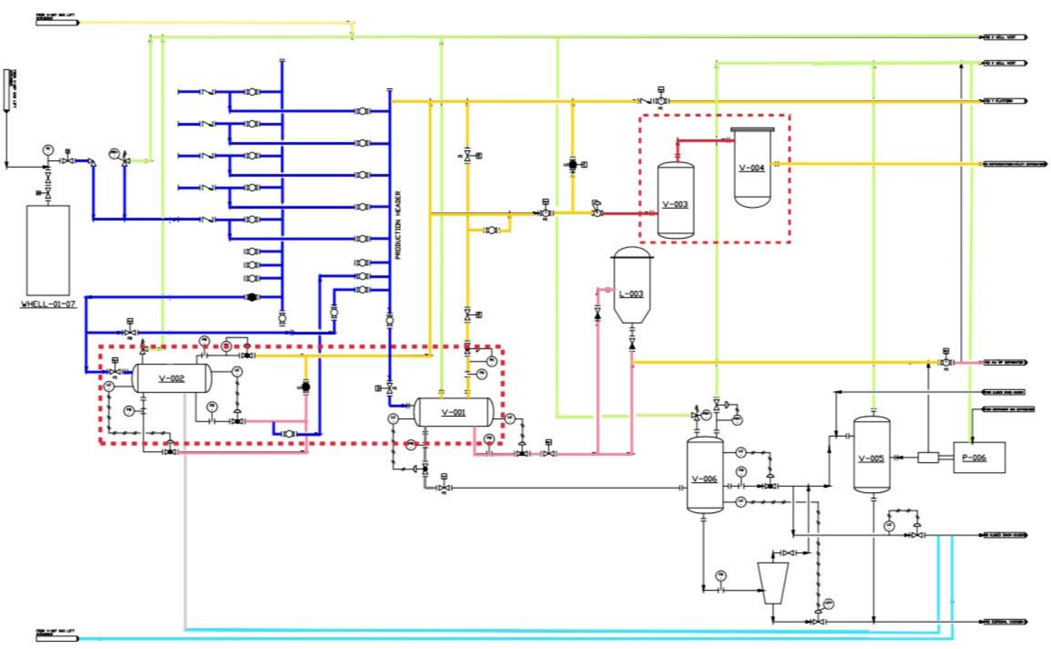
BAB 4
HASIL DAN PEMBAHASAN

4.1 Deskripsi Proses

Penelitian ini menganalisis *pressure vessel* dengan kode V-001, V-002, V-003 dan V-004. *General data pressure vessel* dan *corrosion loop* yang dianalisa adalah sebagai berikut :

Tabel 4.1 *General data pressure vessel*

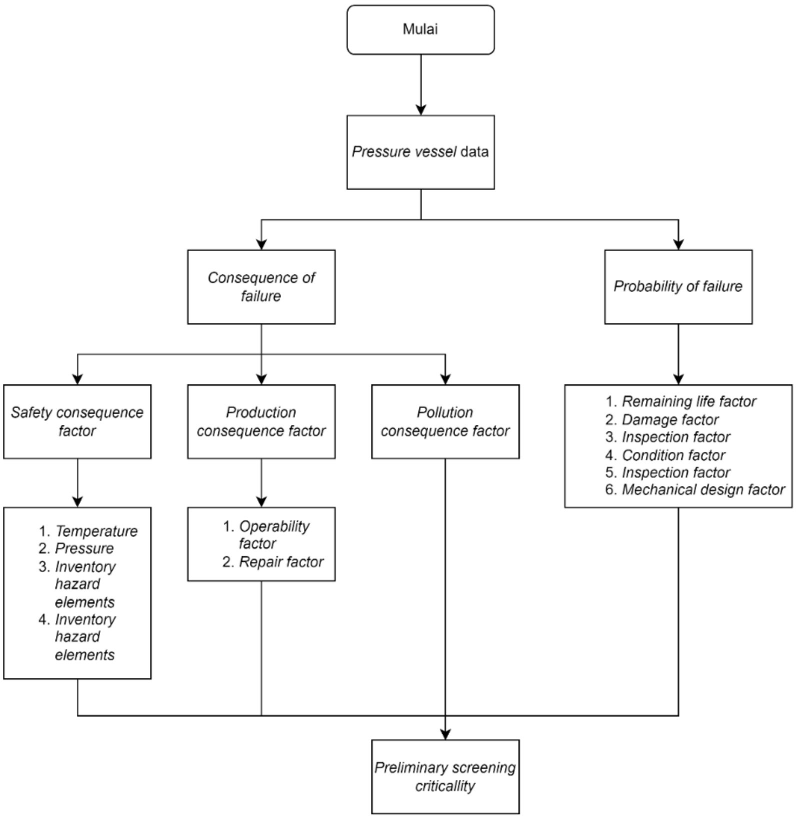
No.	*Pressure vessel*	*Year built*	*Operate. Pressure*	*Operate. Temperature*	*Material*	*Year prev. insp.*	*Joint eff.*
1.	V-001	2001	1340 psi	100 °C	A 516 Gr. 70	2019	1
2.	V-002	1996	710 psi	200 °C	A 516 Gr. 70	2019	1
3.	V-003	1998	260 psi	150 °C	A 106 Gr. B	2019	1
4.	V-004	1998	260 psi	200 °C	A 106 Gr. B	2019	1



Gambar 4.1 *Corrosion Loop* pada *Process Flow Diagram Pressure Vessel* yang Dianalisa

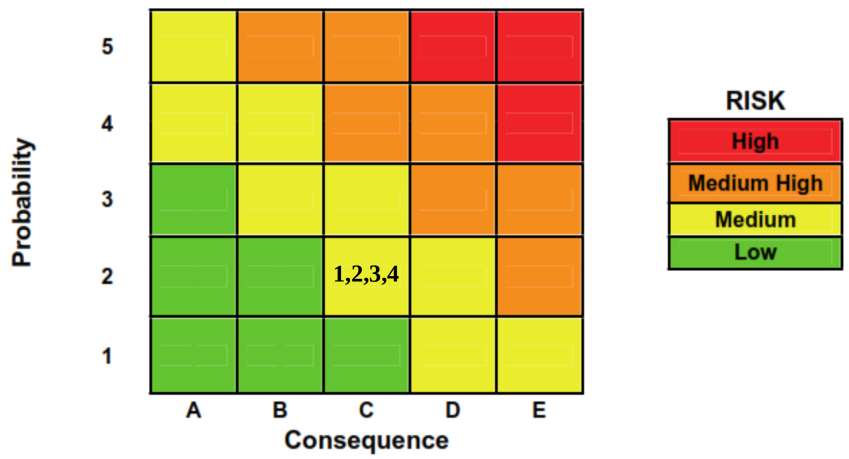
4.2 *Preliminary Screening Criticality*

Preliminary screening criticality dilakukan untuk menentukan prioritas inspeksi pada *equipment* dengan mempertimbangkan PoF dan CoF. *Preliminary screening criticality* merupakan acuan awal dalam penentuan risiko sebuah objek yang dianalisis untuk mengetahui apakah analisis lebih lanjut diperlukan. Alur pengerjaan *preliminary screening criticality* dapat dilihat pada Gambar 4.2. Mengumpulkan data-data *pressure vessel* yang dibutuhkan kemudian menentukan PoF dan CoF dari *pressure vessel* dengan menentukan parameter-parameter yang ada. CoF memiliki beberapa factor yang diperlukan antara lain *safety consequence factor*, *production consequence factor* dan *pollution consequence factor* yang pada setiap faktor memiliki parameter masing-masing yang dapat ditentukan dengan mengikuti langkah-langkah yang ada pada sub Bab 3.3. PoF memiliki faktor-faktor seperti tertera pada Gambar di bawah dengan setiap faktornya memiliki nilai masing-masing yang dapat dihitung dan ditentukan dengan menggunakan tabel pada sub Bab 3.3 beserta dengan Langkah-langkahnya.



Gambar 4.2 Diagram Alir Pengerjaan *Preliminary Screening Criticallity*

Didapatkan hasil bahwa *equipment* yang telah dilakukan *preliminary screening criticality* yakni V-001, V-002, V-003 dan V-004 memiliki risiko *medium risk*. Hasil tersebut perlu dilakukan analisis lanjutan dengan menggunakan metode RBI untuk mengetahui lebih lanjut mengenai mekanisme kerusakan yang terjadi dan untuk menentukan jadwal inspeksi juga rekomendasi inspeksi yang akan dilakukan. Hasil *preliminary screening criticality* bukan merupakan acuan akhir yang menentukan level risiko dari setiap *pressure vessel* yang dianalisis.



Gambar 4.3 Kategori Risiko Berdasarkan *Preliminary Screening Criticallity*

4.3 Analisis Level Risiko Peralatan *Pressure Vessel*

Pada analisis level risiko peralatan *pressure vessel* terdapat beberapa hal yang perlu diperhatikan seperti *damage factor*, *probability of failure* dan *consequence of failure* seperti pada perhitungan berikut ini.

4.3.1 *Damage Mechanism*

Screening damage mechanism yang digunakan dapat dilihat pada lampiran. *Damage factor* yang dapat terjadi antara lain :

1. *Thinning Damage Factor*
2. SCC *Damage Factor – Sulfide Stress Cracking*
3. SCC *Damage Factor* – HIC/SOHIC – H_2S
4. SCC *Damage Factor – Alkaline Carbonate Stress Corrosion Cracking*
5. *External Corrosion Damage Factor*

4.3.2 Perhitungan *Probability of Failure* API 581

Perhitungan yang dapat dilakukan dapat menggunakan langkah-langkah sebagai berikut:

4.3.2.1 *Thinning damage factor*

Thinning merupakan pengurangan ketebalan pada sebuah material yang disebabkan oleh korosi ataupun jenis degradasi lainnya. Parameter-parameter yang dapat mempengaruhi antara lain spesifikasi material, jenis fluida, tekanan dan temperatur operasi. Hasil perhitungan *thinning* pada V-001 sampai dengan V-004 menghasilkan *damage factor* seperti dapat dilihat pada Tabel 4.2. Berdasarkan Persamaan 3.21 hasil perhitungan *thinning base damage factor* dengan *adjustment factor* untuk seluruh *pressure vessel* memiliki nilai lebih kecil dari 0,1. Maka digunakan nilai 0,1 sebagai *thinning damage factor* untuk *presseure vessel* V-001 sampai dengan V-004. Detail perhitungan *thinning damage factor* dapat dilihat pada lampiran.

Tabel 4.2 *Thinning Damage Factor*

Vessel V-001		
Thinning Damage Factor	RBI date	Plan date
Left head	0,1	0,1
Shell	0,1	0,1
Righ head	0,1	0,1
Vessel V-002		
Thinning Damage Factor	RBI date	Plan date
Left head	0,1	0,1
Shell	0,1	0,1
Righ head	0,1	0,1
Vessel V-003		
Thinning Damage Factor	RBI date	Plan date
Upper head	0,1	0,1

Shell	0,1	0,1
Bottom head	0,1	0,1
Vessel V-004		
Thinning Damage Factor	RBI date	Plan date
Upper head	0,1	0,1
Shell	0,1	0,1
Bottom head	0,1	0,1

4.3.2.2 SCC *damage factor – sulfide stress cracking*

SCC merupakan korosi yang dapat terjadi akibat adanya kombinasi antara *tensile strength* dan kondisi lingkungan yang korosif, hal tersebut dapat menyebabkan dua jenis keretakan yaitu retak antar butir *(Intergranular)* dan retak di dalam butir (*Transgranular*). Kerentanan material terhadap *sulfide stress cracking* dapat diturunkan dengan perlakuan PWHT (*post weld heat treatment*) pada komponen sehingga PWHT dapat menghindarkan komponen dari *Sulfide stress cracking*. SCC lebih mudah terjadi pada material dengan Tingkat kekerasa yang tinggi (*hardness*) . Pada *pressure vessel* ini terdapat perlakuan PWHT pada V-001 saja sehingga didapatkan hasil 0 dan didapatkan hasil pada *pressure vessel* V-002 sampai dengan V-004 sebesar 5,873095 pada RBI *date* dan 12,58925 pada *plant date* seperti pada Tabel 4.3.

Tabel 4.3 SCC- *Sulfide Stress Cracking Damage factor*

Vessel V-001		
SSC	RBI date	Plan date
Left head	0	0
Shell	0	0
Righ head	0	0
Vessel V-002		
SSC	RBI date	Plan date
Left head	5,873095	12,58925
Shell	5,873095	12,58925
Righ head	5,873095	12,58925

Vessel V-003		
SSC	RBI date	Plan date
Upper head	5,873095	12,58925
Shell	5,873095	12,58925
Bottom head	5,873095	12,58925
Vessel V-004		
SSC	RBI date	Plan date
Upper head	5,873095	12,58925
Shell	5,873095	12,58925
Bottom head	5,873095	12,58925

4.3.2.3 SCC *damage factor* – HIC/ SOHIC – H_2S

HIC/SOHIC-H_2S merupakan *hydrogen induced cracking* dan *stress oriented hydrogen induced cracking* yang dipengaruhi oleh H_2S. HIC merupakan retakan internal bertahap yang menghubungakan hydrogen blister yang berdekatan pada bidang yang berbeda dalam logam atau ke permukaan logam sedangkan SOHIC merupakan susunan blister yang tergabung karena *hydrogen induced cracking* yang sejajar dengan arah ketebalan logam sebagai hasil dari tegangan Tarik yang terjadi secara local dan menghasilkan *damage factor* seperti tertera pada Tabel 4.4.

Tabel 4.4 SCC- HIC/ SOHIC-H_2S *Damage factor*

Vessel V-001		
SSC	RBI date	Plan date
Left head	2,93655	6,29463
Shell	2,93655	6,29463
Righ head	2,93655	6,29463
Vessel V-002		
SSC	RBI date	Plan date
Left head	2,93655	6,29463
Shell	2,93655	6,29463
Righ head	2,93655	6,29463

Vessel V-003		
SSC	RBI date	Plan date
Upper head	2,93655	6,29463
Shell	2,93655	6,29463
Bottom head	2,93655	6,29463
Vessel V-004		
SSC	RBI date	Plan date
Upper head	2,93655	6,29463
Shell	2,93655	6,29463
Bottom head	2,93655	6,29463

4.3.2.4 SCC *damage factor – Alkaline Carbonate Stress Corrosion Cracking*

Alkaline carbonate stress corrosion cracking atau ACSCC merupakan istilah yang biasa digunakan untuk permukaan yang rusak akibat keretakan yang terjadi pada las *carbon* atau *low alloy steel* dengan kombinasi tegangan tarik dan adanya kandungan CO_3 pada air dengan tingkat konsentrasi sedang maupun tinggi. PWHT dapat dilakukan sebagai perlakuan panas untuk mengurangi *residual stress* yang ada pada material. Pada *pressure vessel* V-001 dilakukan PWHT dan V-002 tidak. Sehingga didapatkan nilai *damage factor* sebagai berikut.

Tabel 4.5 SCC – *Alkaline Carbonate Stress Corrosion Cracking*

Vessel V-001		
ACSCC	*RBI date*	*Plan date*
Left head	0	0
Shell	0	0
Righ head	0	0
Vessel V-002		
ACSCC	*RBI date*	*Plan date*
Left head	58,73095	125,89254
Shell	58,73095	125,89254
Righ head	58,73095	125,89254

Perhitungan SSC maksimal dari *pressure vessel* merupakan nilai paling tinggi pada seluruh perhitungan *damage factor* yang memiliki indikasi terjadinya SCC. Dari seluruh *pressure vessel* yang telah dianalisis didapatkan hasil sebagai berikut pada Tabel 4.6.

Tabel 4.6 Maksimum SCC *Damage Factor*

Vessel V-001		
Maks. SSC *damage factor*	RBI date	Plan date
Left head	2,93655	6,29463
Shell	2,93655	6,29463
Righ head	2,93655	6,29463
Vessel V-002		
Maks. SSC *damage factor*	RBI date	Plan date
Left head	58,73095	125,89254
Shell	58,73095	125,89254
Righ head	58,73095	125,89254
Vessel V-003		
Maks. SSC *damage factor*	RBI date	Plan date
Upper head	5,873095	12,58925
Shell	5,873095	12,58925
Bottom head	5,873095	12,58925
Vessel V-004		
Maks. SSC *damage factor*	RBI date	Plan date
Upper head	5,873095	12,58925
Shell	5,873095	12,58925
Bottom head	5,873095	12,58925

4.3.2.5 *External corrosion damage factor*

Plant dengan kondisi lingkungan yang lembab rentan terhadap korosi eksternal. Selain perngaruh dari lingkungan sekitar, juga dapat dipengaruhi oleh jarak antara *unit* dengan *cooling tower* dan *steam vent,* dan *unit* dengan siklus suhu operasi yang melalui titik embun (*dew point*) secara teratur. Hal ini mengakibatkan *unit* rentan terhadap korosi eksternal. Diasumsikan tidak dilakukan inpeksi apapun untuk *external corrosion* selama *pressure vessel* beroperasi sehingga didapatkan hasil sebagai berikut.

Tabel 4.7 External *Corrosion Damage Factor*

Vessel V-001		
External Corrosion Damage Factor	RBI date	Plan date
Left head	1,82569	1,85869
Shell	1,71822	1,78456
Righ head	1,95268	1,98865
Vessel V-002		
External Corrosion Damage Factor	RBI date	Plan date
Left head	0.62057	0.63979
Shell	0.70919	0.73215
Righ head	0.615201	0.63420
Vessel V-003		
External Corrosion Damage Factor	RBI date	Plan date
Upper head	0,005615	0,005766
Shell	0,007139	0,007421
Bottom head	0,005595	0,005744
Vessel V-004		
External Corrosion Damage Factor	RBI date	Plan date
Upper head	0,005242	0,005561
Shell	0,007552	0,007875
Bottom head	0,006855	0,00711

Dalam menentukan nilai POF dibutuhkan tiga nilai yaitu, *damage factor*, *generic failure frequency* dan *factor management system*. Semua *pressure vessel* pada penelitian ini memiliki *factor management system* senilai 1. Adapun dapat menggunakan Persamaan 2.2 untuk menentukan nilai *probability of failure*. Perhitungan *Probability of* failure dapat dilihat pada Tabel 4.8.

Tabel 4.8 *Probability of Failure Pressure Vessel*

Vessel V-001								
Component	gff	F_{MS}	RBI date			Plan date		
			Df^{Total}	PoF	Cat.	Df^{Total}	PoF	Cat.
Left head	3,06 x 10^{-5}	1	4,76224	0,0001457	2	8,15332	0,0002495	2
Shell	3,06 x 10^{-5}	1	4,56476	0,0001424	2	8,04438	0,0002461	2
Righ head	3,06 x 10^{-5}	1	4,88923	0,0001496	2	8,28328	0,0002535	2
Vessel V-002								
Left head	3,06 x 10^{-5}	1	59,3515	0,0018162	3	126,532	0,0038719	4
Shell	3,06 x 10^{-5}	1	59,4401	0,0018189	3	126,625	0,0038747	4
Righ head	3,06 x 10^{-5}	1	59,3461	0,0018160	3	126,527	0,0038717	4
Vessel V-003								
Upper head	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3
Shell	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3
Bottom head	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3
Vessel V-004								
Upper head	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3
Shell	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3
Bottom head	3,06 x 10^{-5}	1	5,97309	0,0001828	2	12,6893	0,0003883	3

4.3.3 Perhitungan *Consequence of Failure* API 581

Terdapat beberapa data dan faktor yang diperlukan juga 11 langkah yang dapat digunakan dalam menghitung *consequence of failure*:

4.3.3.1 Menentukan fluida representatif beserta karakteristiknya

Fluida representatif yang dianalisis merupakan fluida C1-C2. Fluida C1-C2 termasuk dalam tabel data yang telah disediakan API 581 sehingga fluida tersebut dapat dianalisis menggunakan *consequence analysis* level 1.

4.3.3.2 Memilih ukuran lubang pelepasan (*release hole size*)

Terdapat 4 ukuran lubang pelepasan sesuai dengan API 581 yakni, *small, medium, large, rupture*. Adapun untuk setiap ukuran lubang yang ada sebesar 0,25 inch, 1 inch, 4 inch dan max [D,16] inch yang mana pada ukuran lubang terakhir menyesuaikan dengan diameter pada *pressure vessel*. Analisan konsekuensi dihitung untuk setiap ukuran lubang dan membatasi ukuran lubang pelepasan dapat membantu dalam analisis.

4.3.3.3 Menghitung *release rate* (W_n)

Perhitungan ini dibagi menjadi dua perhitungan antara pelepasan berupa cair ataupun pelepasan berupa gas. Pada penelitian ini pelepasan yang terjadi berupa gas dan terdapat data yang dibutuhkan salah satunya luas ukuran setiap lubang pelepasan (A_n). Hasil W_n yang diapat dari setiap *pressure vessel* dapat dilihat pada Tabel 4.9. Hasil yang didapatkan W_n terbesar pada V-001 dengan $W_{rupture}$ sebesar 66,33579 kg/s.

Tabel 4.9 *Release rate Vessel*

Vessel V-001	
W_{small}	0,01648 kg/s
W_{medium}	0,25152 kg/s
W_{large}	4,18693 kg/s
$W_{rupture}$	66,33579kg/s
Vessel V-002	
W_{small}	0,00858 kg/s
W_{medium}	0,13095 kg/s
W_{large}	2,17895 kg/s
$W_{rupture}$	34,53646 kg/s

Vessel V-003	
W_{small}	0,00121 kg/s
W_{medium}	0,01844 kg/s
W_{large}	0,30702 kg/s
$W_{rupture}$	0,93289 kg/s
Vessel V-004	
W_{small}	0,00123 kg/s
W_{medium}	0,01874 kg/s
W_{large}	0,3119 kg/s
$W_{rupture}$	0,94772 kg/s

4.3.3.4 Estimasi jumlah fluida yang dilepaskan

Hasil perhitungan massa komponen, massa *inventory* dan massa tambahan digunakan untuk menentukan massa fluida yang dapat dilepaskan. Massa fluida yang dilepaskan pada setiap *pressure vessel* merupakan massa minimal dari massa komponen dan massa tambahan, atau massa *inventory* adalah sebagai berikut:

Tabel 4.10 Estimasi Jumlah Fluida yang Dilepaskan

Vessel V-001	
$Mass_{avail.small}$	744,27403 kgs
$Mass_{avail.medium}$	785,39301 kgs
$Mass_{avail.large}$	1473,87751 kgs
$Mass_{avail.rupture}$	2712,91943 kgs
Vessel V-002	
$Mass_{avail.small}$	308,17144 kgs
$Mass_{avail.medium}$	330,19771 kgs
$Mass_{avail.large}$	698,99928 kgs
$Mass_{avail.rupture}$	999,65469 kgs
Vessel V-003	
$Mass_{avail.small}$	2,15616 kgs
$Mass_{avail.medium}$	5,25845 kgs
$Mass_{avail.large}$	57,20223 kgs
$Mass_{avail.rupture}$	169,859 kgs

Vessel V-004	
$Mass_{avail.small}$	9,119 kgs
$Mass_{avail.medium}$	12,271 kgs
$Mass_{avail.large}$	65,040 kgs
$Mass_{avail.rupture}$	179,488 kgs

4.3.3.5 Menentukan tipe pelepasan

Terdapat dua jenis tipe pelepasan yang ada yaitu, *continuous* dan *intaneous*. Untuk menentukan jenis keluaran yang sesuai, berapa banyak waktu yang dibutuhkan untuk melepaskan 4.536 kg (10.000 lbs) fluida melalui setiap lubang pelepasan. Pelepasan *continuous* cenderung terjadi dalam waktu yang cukup lama sedangkan pelepasan *instaneous* terjadi sangat cepat dan dalam waktu di bawah 180 detik. Pada V-001 dan V-002 terdapat setidaknya satu pelepasan *nstantaneous* dengan waktu pelepasan pada V-001 $t_{rupture}$ 70 detik dan V-002 $t_{rupture}$ 138 detik. Pada V-003 juga V-004 hanya memiliki tipe pelepasan *continuous* seluruhnya.

Tabel 4.11 Tipe Pelepasan

Vessel V-001	
t_{small}	283129,995 s (*continuous*)
t_{medium}	18555,207 s (*continuous*)
t_{large}	1114,668 s (*continuous*)
$t_{rupture}$	70,355 s (*instantaneous*)
Vessel V-002	
t_{small}	528551,472 s (*continous*)
t_{medium}	34639,149 s (*continuous*)
t_{large}	2080,879 s (*continuous*)
$t_{rupture}$	131,339 s (*instantaneous*)
Vessel V-003	
t_{small}	375271,453 s (*continuous*)
t_{medium}	245937,96 s (*continuous*)
t_{large}	14774,243 s (*continuous*)
$t_{rupture}$	4862,304 s (*continuous*)

Vessel V-004	
t_{small}	3693991,24 s (*continuous*)
t_{medium}	242089,41 s (*continuous*)
t_{large}	14543,049 s (*continuous*)
$t_{rupture}$	4786,216 s (*continuous*)

4.3.3.6 Mengestimasi dampak dari sistem deteksi dan isolasi

Terdapat banyak jenis sistem deteksi, isolasi dan mitigasi yang didesain untuk mengurangi efek dari pelepasan sebuah material yang berbahaya pada setiap *plant* yang ada. Pada seluruh objek yang dianalisis pada *plant* ini dididapatkan bahwa sistem deteksi bernilai A dan isolasi bernilai C yang dapat ditentukan dengan menggunakan Tabel 3.23. Maka waktu maksimum setiap *pressure vessel* untuk setiap lubang kebocoran yakni :

$id_{max.1}$ = 40 minutes

$id_{max.2}$ = 30 minutes

$id_{max.3}$ = 20 minutes

$id_{max.4}$ = 20 minutes

4.3.3.7 Menentukan *adjusted release rate* dan *mass for consequence of failure*

Terdapat dua jenis pelepasan pada *pressure vessel* yang dianalisis yaitu tipe pelepasan *continuous* dan tipe pelepasan *instantaneous*. Berikut merupakan hasil perhitungan *adjusted release rate* dan release *mass* untuk setiap lubang pelepasan:

Tabel 4.12 *Release Rate* dan *Mass for Consequence of Failure*

Vessel V-001		
Hole Size	*Release Rate* ($rate_n$) kg/s	*Release Mass* ($Mass_n$) kg
Small	0,01442 kg/s	34,60156 kg
Medium	0,22001 kg/s	396,02468 kg
Large	3,66244 kg/s	1473,87751 kg
Rupture	58,02589 kg/s	2712,91493 kg

Vessel V-002		
Hole Size	*Release Rate* ($rate_n$) kg/s	*Mass* ($Mass_n$) kg
Small	0,00772 kg/s	18,537 kg
Medium	0,11786 kg/s	212,13196 kg
Large	1,96186 kg/s	698,99928 kg
Rupture	31,08282 kg/s	999,65469 kg
Vessel V-003		
Hole Size	*Release Rate* ($rate_n$) kg/s	*Mass* ($Mass_n$) kg
Small	0,00109 kg/s	2,15616 kg
Medium	0,01660 kg/s	5,25845 kg
Large	0,27632 kg/s	57,20233 kg
Rupture	0,83960 kg/s	169,859 kg
Vessel V-004		
Hole Size	*Release Rate* ($rate_n$) kg/s	*Mass* ($Mass_n$) kg
Small	0,00111 kg/s	2,65235 kg
Medium	0,01686 kg/s	12,27082 kg
Large	0,28071 kg/s	65,04047 kg
Rupture	0,85295 kg/s	179,48806 kg

4.3.3.8 Menentukan *flammable/ explosive consequence*

Hasil yang didapatkan dalam perhitungan *flammable consequence* pada *pressure vessel* didapatkan V-001 memiliki konsekuensi paling besar dengan nilai 265,39308 m^2 dan dengan konsekuensi paling kecil pada V-004 sebesar 0,78506 m^2 seperti pada tabel berikut:

Tabel 4.13 *Flammable Consequence* pada Komponen

Pressure Vessel	CA_{cmd}^{flam} (m^2)
V-001	265,39308 m^2
V-002	10,33788 m^2
V-003	0,38206 m^2
V-004	0,38791 m^2

Sedangkan untuk perhitungan *flammable consequence* pada personel didapatkan konsekuensi pada V-001 sebesar 438,9355 m^2, V-001 sebesar 18,57332 m^2, V-003 sebesar 2,12151 m^2 dan V-004 sebesar 2,01479 m^2. Berikut adalah hasil perhitungan *personnel flammability consequences*:

Tabel 4.14 *Flammable Consequence* pada Personel

Pressure Vessel	CA_{inj}^{flam} (m^2)
V-001	438,93355 m^2
V-002	18,76443 m^2
V-003	0,99499 m^2
V-004	1,00992 m^2

4.3.3.9 Menentukan *toxic consequence*

Berdasarkan komposisi kimia didapatkan kandungan H_2S sebesar 0,01% dan Cl sebesar 0,0017. Untuk melakukan perhitungan *toxic consequences* dibutuhkan nilai *release duration* dan *release rate*. Hasil perhitungan *toxic consequences* didapatkan sebagai berikut:

Tabel 4.15 *Toxic Consequence*

Pressure Vessel	CA_{inj}^{tox} (m^2)
V-001	2,56714 m^2
V-002	0,84536 m^2
V-003	0.00144 m^2
V-004	0.00147 m^2

4.3.3.10 Menentukan *non-flammable* dan *non-toxic consequence*

Pada langkah ini konsekuensi dihitung untuk kebocoran uap. Kebocoran *acid/caustic* tidak menyebabkan konsekuensi pada komponen tetapi konsekuensi area *semi-circular* dengan bentuk fluida cair yang menyebar atau berbentuk *raiout*. Diasumsikan *rainout* hanya terjadi pada pelepasan *continuous* sehingga pada pelepasan *instantaneous* memiliki nilai konsekuensi 0. Sehingga perhitungan akibat kebocoran *acid/caustic* yang didapatkan pada *final non-flammable, non-toxic consequence area* adalah sebagai berikut:

Tabel 4.16 *Non-flammable* dan *Non-toxic Consequence*

Pressure Vessel	CA_{inj}^{nfnt} (m^2)
V-001	43,38431 m^2
V-002	51,01491 m^2
V-003	0.10867 m^2
V-004	0.11008 m^2

4.3.3.11 Menentuka final consequence area

Nilai *final consequence area* merupakan nilai maksimum dari konsekuensi kerusakan komponen dan konsekuensi dampak pada personal yang telah dihitung:

Tabel 4.17 *Final Consequence Area*

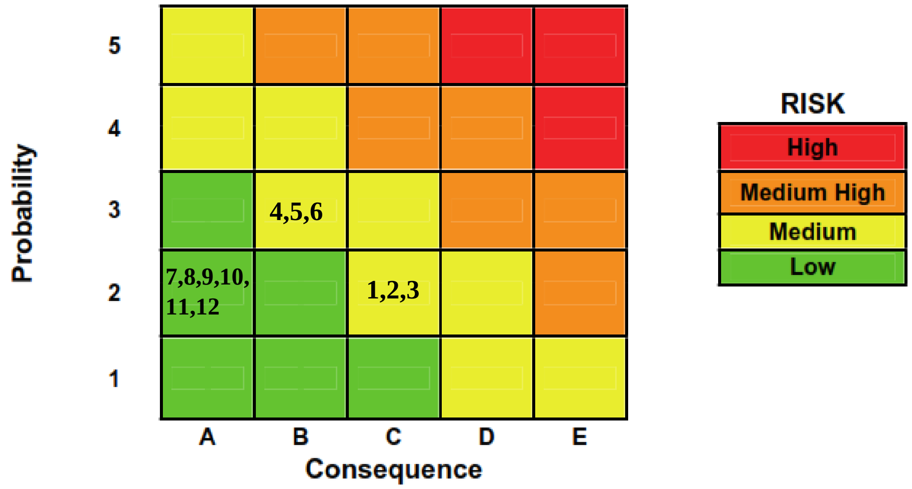
Pressure Vessel	Final Consequence Area (m^2)	Kategori *consequence of failure*
V-001	439.11366 m^2	C
V-002	51,01491 m^2	B
V-003	0,99499 m^2	A
V-004	1,00992 m^2	A

Hasil perhitungan risiko *pressure vessel* pada saat RBI *date* dan *Plan date* beserta kategori risiko masing-masing *pressure vessel* dapat dilihat pada Tabel 4.18.

Tabel 4.18 Level Risiko pada *Pressure Vessel*

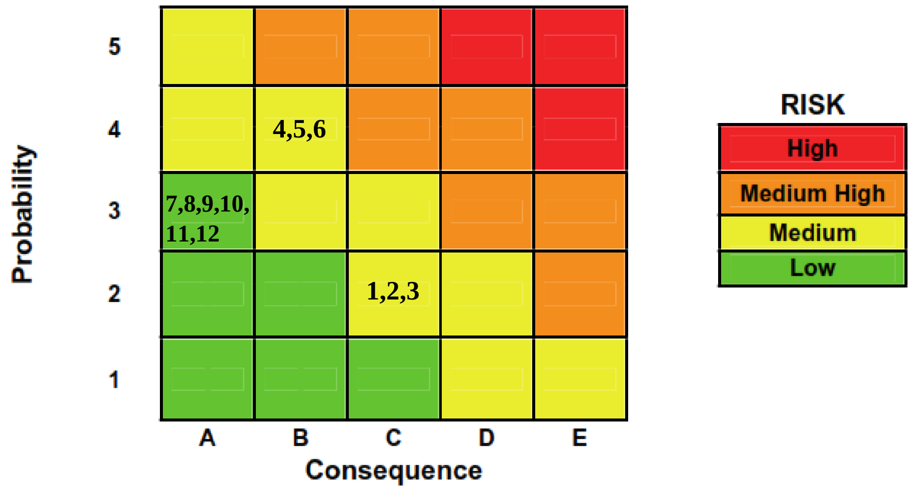
No.	*Pressure Vessel*	Risiko		
		RBI date (m^2/yr)	Plan date (m^2/yr)	Kategori risiko
1.	V-001 (*left head*)	0,063990	0,109555	*Medium risk*
2.	V-001 (*shell*)	0,062545	0,108078	*Medium risk*
3.	V-001 (*right head*)	0,065696	0,111303	*Medium risk*
4.	V-002 (*left head*)	0,09265	0,19752	*Medium risk*
5.	V-002 (*shell*)	0,09279	0,19767	*Medium risk*
6.	V-002 (*right head*)	0,09264	0,19752	*Medium risk*
7.	V-003 (u*pper head*)	0,0001828	0,0003883	*Low risk*
8.	V-003 (*shell*)	0,0001828	0,0003883	*Low risk*
9.	V-003 (*bottom head*)	0,0001828	0,0003883	*Low risk*
10.	V-004 (u*pper head*)	0,000185	0,000392	*Low risk*
11.	V-004 (*shell*)	0,000185	0,000392	*Low risk*
12.	V-004 (*bottom head*)	0,000185	0,000392	*Low risk*

Didapatkan kategori risiko dari hasil analisis risiko pada *pressure vessel* menggunakan metode *risk based inspection*, *pressure vessel* V-001 dan V-002 memiliki kategori risiko *medium* risk dan *pressure vessel* V-003 dan V-004 memiliki kategori risiko *low risk* pada RBI *date*.



Gambar 4.4 *Risk Level RBI Date*

Didapatkan kategori risiko dari hasil analisis risiko pada *pressure vessel* menggunakan metode *risk based inspection*, *pressure vessel* V-001 dan V-002 memiliki kategori risiko *medium* risk dan *pressure vessel* V-003 dan V-004 memiliki kategori risiko *low risk* pada *Plan date*.

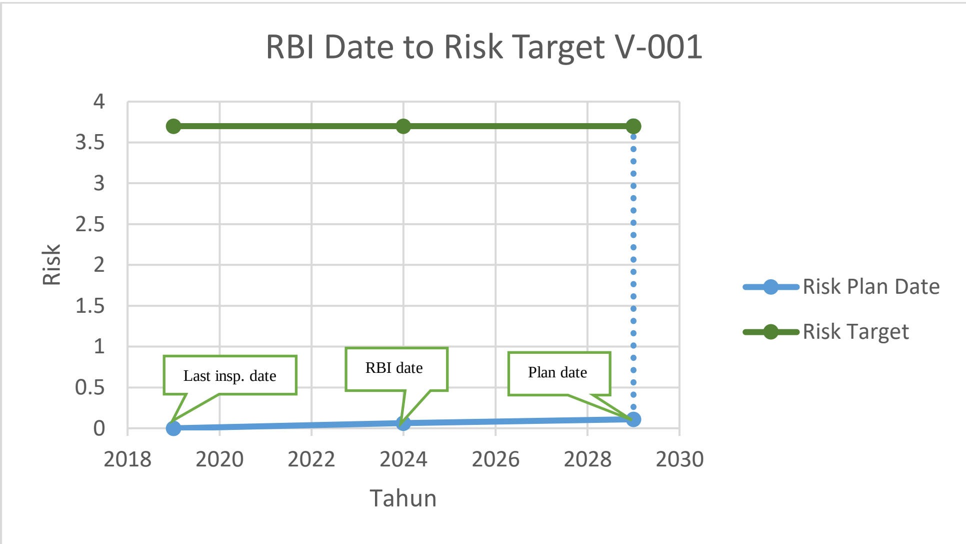


Gambar 4.5 *Risk Level Plan Date*

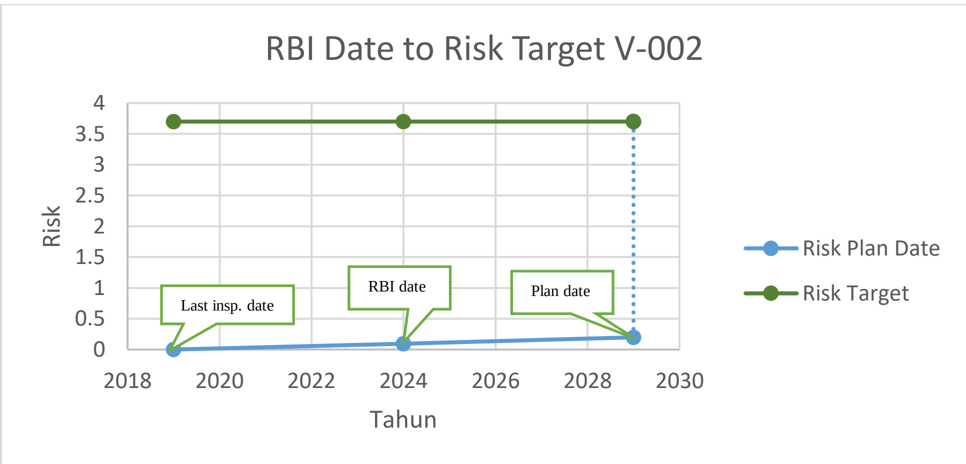
Didapatkan hasil yang berbeda dari *preliminary screening criticality* dengan *Risk Based Inspection* pada *pressure vessel* V-003 dan V-004 untuk hasil Tingkat risiko yang ada. *Preliminary screening criticality* memberikan hasil *medium risk* pada kedua *vessel* tersebut sedangkan pada metode RBI memberikan hasil bahwa kedua *vessel* tersebut memiliki kategori risiko *low risk*. Hal ini dikarenakan pada proses skrining terdapat beberapa parameter yang berpengaruh pada penentuan risikonya. Seperti jenis-jenis *damage factor* yang terjadi dan memiliki potensi terjadi merupakan salah satu parameter penentu dalam proses skrining. *Real life factor*, *condition factor*, *inspection factor* dan *mechanical design* juga merupakan beberapa parameter yang berpengaruh dalam penentuan risiko yang ada dalam metode *preliminary screening criticality*. Terdapat beberapa faktor lain yaitu *safety factor, pollution factor* dan *production factor* yang juga berpengaruh dalam penentuan kategori risiko pada metode ini

4.4 Strategi Inspeksi

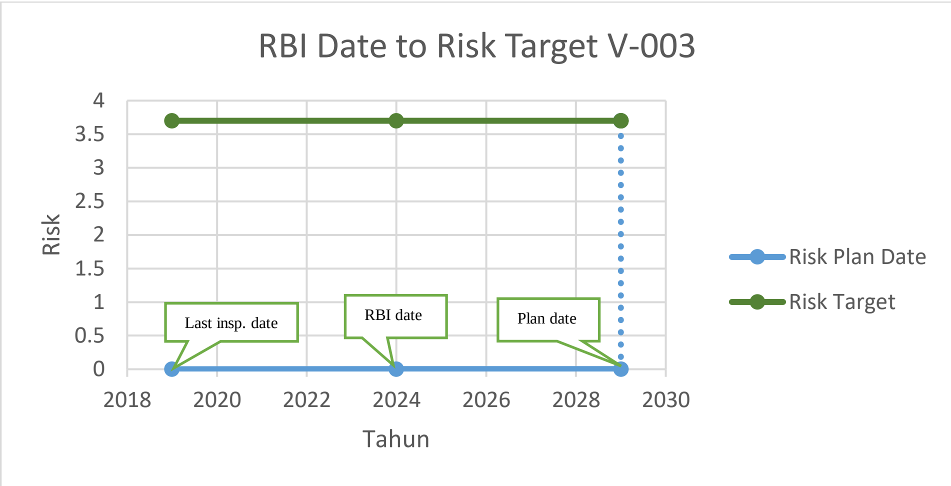
Strategi inspeksi merupakan sebuah perencanaan dari serangkaian rencana terukur untuk menentukan interval inspeksi pada peralatan. Berdasarkan API 510 periode inspeksi *pressure vessel* untuk *internal* atau *on-stream* maksimal setiap 10 tahun atau saat usia *pressure vessel* setengah dari *remaining life*. Dari hasil yang didapat bahwa *pressure vessel* V-001 hingga V-004 memiliki risiko yang secara siginifikan meningkat dari tahun terakhir dilakukan inspeksi hingga tahun *plan date* yang telah ditentukan. Hasil risiko yang didapat tidak melebihi target risiko yang sudah ditentukan yaitu sebesar 3,7. Maka direkomendasikan tanggal inspeksi untuk penjadwalan inspeksi pada periode *plan date* yang jatuh pada tahun 2029. Gambar 4.6 hingga Gambar 4.9 merupakan grafik risiko yang terjadi pada masing-masing *pressure vessel*. *Pressure vessel* dengan Tingkat risiko paling tinggi di antara keempat *vessel* tersebut merupakan V-002 memiliki jenis *damage factor* yang sama dengan V-001 tetapi memiliki Tingkat risiko yang berbeda. V-003 dan V-004 memiliki jenis *damage factor* yang sama dan memiliki tingkat risiko paling rendah dibandingkan dengan keempat *pressure vessel* tersebut hal tersebut juga dipengaruhi oleh banyaknya volume yang dapat ditampung V-003 dan V-004 tergolong paling kecil. Pada *pressure vessel* V-001 meskipum memiliki jenis *damage factor* yang sama tetapi memiliki tingkat risiko yang cenderung lebih rendah dari V-002, hal tersebut dikarenakan pada V-001 dilakukan adanya PWHT (*Post weld heat treatment*) yang merupakan perlakuan panas yang dilakukan setelah kegiatas pengelasan dilakukan. Fungsi dari dilakukannya PWHT salah satunya untuk mengurangi tegangan sisa (*Resdiual stress*) yang ada pasca dilakukan pengelasan.



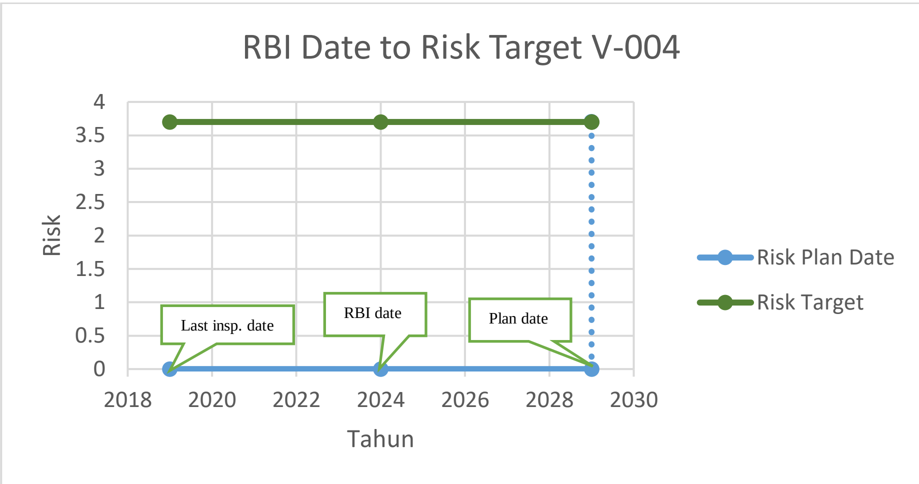
Gambar 4.6 Grafik RBI *Date to Risk Target* V-001



Gambar 4.7 Grafik RBI *Date to Risk Target* V-002



Gambar 4.8 Grafik RBI *Date to Risk Target* V-003



Gambar 4.9 Grafik RBI *Date to Risk Target* V-004

Strategi inspeksi diterapkan untuk mendapatkan data maupun informasi yang lebih akurat terkait kerusakan yang terjadi, kondisi aktual pada objek. Seperti perkiraan tingkat kerusakan dan evaluasi. Strategi inspeksi yang dirancang dan dilakukan berdasarkan pada jenis *damage factor* yang terjadi maupun potensial pada *pressure vessel*. Berikut ini merupakan rekomendasi inspeksi untuk setiap jenis kerusakan berdasarkan API 571, ASME PCC-3, ASME sec. V:

4.4.1 Faktor kerusakan *thinning*

Kategori inspeksi pada setiap *pressure vessel* yang terjadi faktor kerusakan *thinning* termasuk dalam kategori inspeksi dan dapat menggunakan strategi inspeksi seperti berikut:

1. Kategori inspeksi

Tabel 4.19 Kategori Inspeksi *Thinning Damage Factor*

Damage factor	*Inspection effectiveness*	*Description*	*Pressure Vessel*
Thinning damage factor	C	*For the total suspect area: >50% coverage of the CML'S using ultrasonic scanning or profile radiography*	• V-001 • V-002 • V-003 • V-004

2. Strategi inspeksi

- *Visual testing/ visual examination*
- *Radiography test (RT)*
- *Ultrasonic test:*
  - *Ultrasonic for thickness (UT)*
  - *Ultrasonic straight beam (UTS)*
  - *Ultrasonic shear wave (UTSW)*
  - *Ultrasonic shear wave adv. techniques (UTSWA)*

4.4.2 Faktor kerusakan *sulfide stress cracking*

Kategori inspeksi pada setiap *pressure vessel* yang terjadi faktor kerusakan *sulfide stress cracking* termasuk dalam kategori inspeksi dan dapat menggunakan strategi inspeksi seperti berikut:

1. Kategori inspeksi

Tabel 4.20 Kategori Inspeksi *Sulfide Stress Corrosion Cracking*

Damage factor	*Inspection effectiveness*	*Description*	*Pressure Vessel*
Sulfide Stress Corrosion Cracking	C	*For selected welds/ weld area: >35% automated or manual ultrasonic scanning*	• V-001 • V-002 • V-003 • V-004
		OR	
		>35% radiographic testing	

2. Strategi inspeksi

Surface:

- *Visual testing/ visual examination*
- *Liquid penetrant test (PT)*
- *Wet fluorescent magnetic particle test (WFMT)*

Subsurface:

- *Ultrasonic for thickness (UT)*
- *Radiography test (RT)*

Metode lainnya :

- *Dimensional measurement*
- *Hardness test*

4.4.3 Faktor kerusakan HIC/SOHIC-H_2S

Kategori inspeksi pada setiap *pressure vessel* yang terjadi faktor kerusakan HIC/SOHIC-H_2S termasuk dalam kategori inspeksi dan dapat menggunakan strategi inspeksi seperti berikut:

1. Kategori inspeksi

Tabel 4.21 Kategori Inspeksi *HIC/SOHIC-H_2S Cracking*

Damage factor	*Inspection effectiveness*	*Description*	*Pressure Vessel*
HIC/SOHIC-H_2S Cracking	C	*For the total surface area:* *>35% C scan of the base metal using advanced UT*	• V-001 • V-002 • V-003 • V-004
		AND	
		***HIC:** one 1-ft^2area, C scan of the base metal using advanced UT on each plate on the heads*	

2. Strategi inspeksi

Surface:

- *Visual testing/ visual examination*
- *Liquid penetrant test (PT)*
- *Wet fluorescent magnetic particle test (WFMT)*

Subsurface:

- *Ultrasonic for thickness (UT)*
- *Radiography test (RT)*

Metode lainnya:

- *Dimensional measurement*
- *Hardness test*

4.4.4 Faktor kerusakan alkaline carbonate stress corrosion cracking

Kategori inspeksi pada setiap *pressure vessel* yang terjadi faktor kerusakan *alkaline carbone stress corrosion cracking* termasuk dalam kategori inspeksi dan dapat menggunakan strategi inspeksi seperti berikut:

1. Kategori inspeksi

Tabel 4.22 Kategori Inspeksi *Alkaline Carbone Stress Corrosion Cracking*

Damage factor	*Inspection effectiveness*	*Description*	*Pressure vessel*
Alkaline Carbone Stress Corrosion Cracking	B	*For selected welds/ weld area: >75% automated or manual ultrasonic scanning*	• V-002
		OR	
		AE testing with 100% follow-up of relevant indication	

2. Strategi inspeksi

Surface:

- *Liquid penetrant test (PT)*
- *Fluorescent liquid penetrant test (FPT)*
- *Magnetic particle test (MT)*

Subsurface:

- *Ultrasonic for thickness (UT)*
- *Ultrasonic straight beam (UTS)*
- *Radiography test (RT)*

Metode lainnya:

- *Eddy current test (ET)*
- *Acoustic emission test (AET)*
- *Dimensional measurement*
- *Hardness test*
- *In-place metallography (replication)*
- *Boat/ plug sample*

4.4.5 Faktor kerusakan *external corrosion*

Kategori inspeksi pada setiap *pressure vessel* yang terjadi faktor kerusakan *external corrosion* termasuk dalam kategori inspeksi dan dapat menggunakan strategi inspeksi seperti berikut:

1. Kategori inspeksi

Tabel 4.23 Kategori Inspeksi *External Corrosion*

Damage factor	*Inspection effectiveness*	*Description*	*Pressure Vessel*
External corrosion damage factor	C	*Visual inspection of >30% of the exposed surface area with follow-up by UT, RT or pit gauge as required*	• V-001 • V-002 • V-003 • V-004

2. Strategi inspeksi

- *Visual testing/ visual examination*
- *Radiography test (RT)*
- *Ultrasonic test:*
  - *Ultrasonic for thickness (UT)*
  - *Ultrasonic straight beam (UTS)*
  - *Ultrasonic shear wave (UTSW)*
  - *Ultrasonic shear wave adv. techniques (UTSWA)*

Pada setiap jenis kerusakan yang ada, terdapat beberapa metode yang selalu direkomendasikan antara lain *visual inspection*, *ultrasonic test* dan *radiographic test* karena merupakan metode inspeksi yang sering kali digunakan dan umum digunakan pada jenis-jenis damage factor tersebut. *Visual inspection* merupakan metode yang dilakukan untuk melakukan inspeksi pada *pressure vessel* secara kasat mata apabila terdapat perubahan atau kejanggalan yang terjadi. *Ultrasonic test* dan *radiographic test* merupakan metode inspeksi yang digunakan untuk mengetahui bagian *surface* ataupun *sub surface* dari *pressure vessel* apakah atau keretakan atau jenis cacat lainnya, selain itu digunakan untuk mengetahui ketebalan dari *pressure vessel*. *Radiographic test* memiliki fungsi lain yang digunakan untuk melakukan kontrol kualitas apabila terjadi adanya cacat pada las *pressure vessel*.

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BAB 5
KESIMPULAN

5.1 Kesimpulan

Dari hasil penelitian ini dapat disimpulkan sebagai berikut :

1. Hasil analisis *probability* dan *consequence* dari *pressure vessel* menggunakan *preliminary screening criticality* didapatkan *pressure vessel* V-001, V-002, V-003 dan V-004 termasuk dalam kategori *medium risk* sedangkan dengan menggunakan metode selanjutnya yaitu RBI V-001 dan V-002 termasuk dalam kategori *medium risk,*V-003 dan V-004 memiliki kategori risiko *low risk* dengan semua *pressure vessel* tidak melebihi *risk acceptance* yang ada. Perbedaan antara hasil antara *preliminary screening criticality* dan *risk based inspection* dikarenakan pada proses skrining terdapat beberapa parameter yang berpengaruh pada penentuan risikonya. Seperti jenis-jenis *damage factor* yang terjadi dan memiliki potensi terjadi merupakan salah satu parameter penentu dalam proses skrining.
2. Strategi inspeksi yang digunakan pada kasus penelitian ini terbagi menjadi 3 bagian yaitu *surface, subsurface* dan metode lainnya yang dapat digunakan antara lain: *Visual testing/ visual examination, liquid penetrant test (PT), fluorescent liquid penetrant test (FPT), magnetic particle test (MT), wet fluorescent magnetic particle test (WFMT), ultrasonic for thickness (UT), ultrasonic straight beam (UTS), ultrasonic shear wave (UTSW), Ultrasonic shear wave adv. techniques (UTSWA), radiography test (RT), eddy current test (ET), acoustic emission test (AET), dimensional measurement, hardness test, in-place metallography (replication), boat/ plug sample*

5.2 Saran

Metode skrining merupakan salah satu metode yang dapat digunakan dalam tahap awal untuk melakukan analisis risiko. Metode ini tidak bisa digunakan sebagai acuan dalam penentuan risiko akhir suatu objek yang dianalisis tetapi digunakan sebagai langkah awal dalam menentukan dan memilah *equipment* maupun sistem perpipaan mana saja yang perlu dilakukan analisis risiko lebih lanjut. Terdapat jenis-jenis metode skrining lainnya yang dapat digunakan sebagai metode awal dalam penentuan objek yang perlu dilakukan analisis lebih lanjut.

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BIODATA PENULIS

Penulis yang memiliki nama lengkap Muhammad Ali Reza lahir di Surabaya, Maret 1998 merupakan putra kedua dari tiga bersaudara. Sampai saat ini penulis telah menempuh Pendidikan formal di SDN Kertajaya, SMPN 19 Surabaya, SMAN 6 Surabaya, D-IV Teknik Perpipaan Politeknik Perkapalan Negeri Surabaya (PPNS) (2016 – 2020) kemudian melanjutkan Pendidikan Magister di Departemen Teknik Sistem Perkapalan ITS skema Reguler (2021 – 2024), Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember (ITS) Surabaya. Semoga thesis ini mampu memberikan kontribusi positif bagi berbagai pihak.

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LAMPIRAN A

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Tabel A 1 *Real Life Factor*

RL	RLF
RL < 5	15
5 ≤ RL < 10	10
10 ≤ RL < 20	5
20 ≤ RL	0

Tabel A 2 *Damage factor*

DF	*Definition*	*Value*
DF 1	*If the are known active damage mechanism that can cause corrosion cracking in carbon or alloy steel*	5
DF 2	*If there is a potential for catastrophic brittle fracture*	4
DF 3	*If there are placed in the unit where mechanically thermally-induces fatigue failure has occurred*	4
DF 4	*If there is known high-temperature hydrogen attack occurring*	3
DF 5	*If there is known corrosion cracking of austenitic stainless steel occurring as a result of process*	3
DF 6	*If localized corrosion is occurring*	3
DF 7	*If general corrosion is occurring*	2
DF 8	*If creep damage is known to be occurring in high-temperature process, including furnaces and heaters*	1
DF 9	*If material degradation is known to be occurring, with such mechanism as sigma phase formation, carburization, spheroidization*	1
DF 10	*If other active damage mechanism have been identified*	1
DF 11	*If potential damage mechanism in the operating unit has not been evaluated and is not being periodically reviewed by a qualified material engineer*	10

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Tabel A 3 *Inspection Factor*

Inspection	*Definition*	*Value*
Vessel Inspection	*The inspection program is extensive (use of a variety of inspection methods)*	-5
	If there is a formal inspection program in place (visual and UT thickness reading)	-2
	If there is no formal inspection program in place	0
Piping Inspection	*The inspection program is extensive (use of a variety of inspection methods)*	-5
	If there is a formal inspection program in place (visual and UT thickness reading)	-2
	If there is no formal inspection program in place	0
Overall Inspection Program	*If the inspection program is carried out based on an evaluation of the Damage Mechanism that occurs on each equipment; Inspection is carried out by a competent inspector or material engineer.*	-5
	If the inspection program is carried out without paying attention to the Damage Mechanism evaluation that occurs on each equipment, or does not include a critical review of the inspection results.	-2
	If Inspection program meets neither of the criteria of the previous paragraph	0

Tabel A 4 *Condition Factor*

Condition factor	*Value*
Parameter Condition - 1 (Housekeeping and Maintenance)	
Significantly better than industry standards	0
Almost close industry standards	2
Significantly below the industry standards	5
Parameter Condition - 2 (The quality of plant design and construction)	
Significantly better than industry standards	0
Almost close industry standards	2
Significantly below the industry standards	5

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Condition factor	*Value*
Parameter Condition - 3 (The effectiveness plant maintenance program)	
Highly Effective *- All maintenance program officially documented and up to date, formal schedule for routine maintenance based on operating history, government regulations, and accepted industry practices*	0
Usually Effective - Almost of maintenance program officially documented and up to date, formal schedule for routine maintenance based on government regulations practices	1
Fairly Effective - Only critical maintenance program were officially documented, formal schedule for routine maintenance	2
Poorly Effective - Maintenance program are not officially documented, maintenance is scheduled informally	3
Ineffective - Breakdown maintenance, fire fighting, no stated goals	4
Highly Ineffective - No Evidence	5

Tabel A 5 *Process Factor*

Process factor	*Value*
Parameter 1- The number of planned or unplanned process interruptions in an average year	
0–1 interruption	0
2–4 interruptions	1
5–8 interruptions	3
9–12 interruptions	4
More than 12 interruptions	5
Parameter 2- Assess the potential for exceeding key process variables in operation being evaluated	
If process is extremely stable, and no combination of the upset condition is known	0
If only very unusual circumstances could cause upset conditions to escalate into an unsafe situation	1
If upset conditions are known to exist that can result in accelerated equipment damage or other unsafe conditions	3
If possibility of loss of control is inherent in the process	5
Parameter 3- Assess the potential for protection devices, such as relief devices and critical sensing elements	
Clean service, no plugging potential	0
Slight; fouling or plugging potential	1
Significant fouling or plugging potential	3
Protective devices have been found impaired in service	5

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Tabel A 6 Sitem Deteksi dan Sistem Isolasi

Tipe Sistem Deteksi	Klasifikasi Deteksi
Instrumentation designed spesifically to detect material losses by changes in operating conditions in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Tipe Sistem Isolasi	Klasifikasi Isolasi
Isolation or shutdown systems activated directly from process instrumentation or detector, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually operated valves	C

Tabel A 7 Klasifikasi Sistem Deteksi dan Isolasi

Klasifikasi Sistem		Pengaturan besar pelepasan	Faktor Reduksi, $fact_{dl}$
Deteksi	Isolasi		
A	A	Mereduksi pelepasan atau massa sebesar 25%	0.25
A	B	Mereduksi pelepasan atau massa sebesar 20%	0.20
A atau B	C	Mereduksi pelepasan atau massa sebesar 10%	0.10
B	B	Mereduksi pelepasan atau massa sebesar 15%	0.15
C	C	Tidak ada pengaturan pada pelepasan atau massa	0.00

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Tabel A 8 Durasi Maksimum Kebocoran

Kategori Sistem Deteksi	Kategori Sistem Isolasi	Durasi Maksimum kebocoran, id_{max}
A	A	20 menit untuk kebocoran ¼ inch 10 menit untuk kebocoran 1 inch 5 menit untuk kebocoran 4 inch
A	B	30 menit untuk kebocoran ¼ inch 20 menit untuk kebocoran 1 inch 10 menit untuk kebocoran 4 inch
A	C	40 menit untuk kebocoran ¼ inch 30 menit untuk kebocoran 1 inch 20 menit untuk kebocoran 4 inch
B	A atau B	40 menit untuk kebocoran ¼ inch 30 menit untuk kebocoran 1 inch 20 menit untuk kebocoran 4 inch
B	C	1 jam untuk kebocoran ¼ inch 30 menit untuk kebocoran 1 inch 20 menit untuk kebocoran 4 inch
C	A, B, atau C	1 jam untuk kebocoran ¼ inch 40 menit untuk kebocoran 1 inch 20 menit untuk kebocoran 4 inch

Tabel A 9 *Consequence Area Reduction Factor*

Mitigation System	*Consequence Area Adjustment*	*Consequence Area Reduction Factor,* $fact_{mit}$
Inventory blowdown, coupled with isolation system classification B or hingher	*Reduce consequence area by 25%*	0.25
Fire water system and monitors	*Reduce consequence area by 20%*	0.20

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Mitigation System	*Consequence Area Adjustment*	*Consequence Area Reduction Factor, $fact_{mit}$*
Fire water monitors only	*Reduce consequence area by 5%*	0.05
Foam spray system	*Reduce consequence area by 15%*	0.15

Tabel A 10 Fluida Representatif

Fluida Representatif	Tipe Fluida	Contoh Material
C_1-C_2	TYPE 0	*Methane, ethane, Ethylene, LNG, Fuel gas*
C_3-C_4	TYPE 0	*Propane, Butane, Isobutane, LPG*
C_5	TYPE 0	*Pentane*
C_6-C_8	TYPE 0	*Gasoline, Naphtha, Light Straight Run, Heptane*
C_9-C_{12}	TYPE 0	*Diesel, Kerosene*
C_{13}-C_{16}	TYPE 0	*Jet Fuel, Kerosene, Atmospheric Gas Oil*
C_{17}-C_{25}	TYPE 0	*Gas Oil, Typical Crude*
C_{25+}	TYPE 0	*Residuum, Heavy Crude, Lube Oil, Seal Oil*
H_2	TYPE 0	*Hydrogen*
H_2S	TYPE 0	*Hydrogen Sulfiide*
HF	TYPE 0	*Hydrogen Fluoide*
Water	TYPE 0	*Water*
Steam	TYPE 0	*Steam*
Acid	TYPE 0	*Acid, Caustic*
Aromatics	TYPE 0	*Benzene, Toluene, Xylene, Cumene*
AICI3	TYPE 0	*Aluminum Chloride*
Pyrophoric	TYPE 0	*Pyrophoric Materials*
Ammonia	TYPE 0	*Ammonia*
Chlorine	TYPE 0	*Chlorine*

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Fluida Representatif	Tipe Fluida	Contoh Material
CO	TYPE 1	*Carbon Monoxide*
DEE	TYPE 1	*Diethyl Ether*
HCL	TYPE 0	*Hydrogen Chloride*
Nitric Acid	TYPE 0	*Nitric Acid*
NO_2	TYPE 0	*Nitrogen Dioxide*
Phosgene	TYPE 0	*Phosgene*
TDI	TYPE 0	*Toluene Diisocyanate*
Methanol	TYPE 1	*Methanol*
PO	TYPE 1	*Propylene Oxide*
Styrene	TYPE 1	*Styrene*
EEA	TYPE 1	*Ethylene Glyclo Monoethyl Ether Acetale*
EE	TYPE 1	*Ethylene Glyclo Monoethyl Ether*
EG	TYPE 1	*Ethylene Glyclol*
EO	TYPE 1	*Ethylene Oxide*

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Tabel A 11 GFF *equipment*

Equipmt type	Comp. type	Gff as a function of hole size (failures/yr)				Gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	0.000008	0.00002	0.000002	0	0.00003
Compressor	COMPR	0.000008	0.00002	0.000002	0.0000006	0.0000306
Heat Exchanger	HEXSS	0.000008	0.00002	0.000002	0.0000006	0.0000306
Heat Exchanger	HEXTS	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pipe	PIPE-1	0.000028	0	0	0.0000026	0.0000306
Pipe	PIPE-2	0.000028	0	0	0.0000026	0.0000306
Pipe	PIPE-4	0.000008	0.00002	0	0.0000026	0.0000306
Pipe	PIPE-6	0.000008	0.00002	0	0.0000026	0.0000306
Pipe	PIPE-8	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pipe	PIPE-10	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pipe	PIPE-12	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pipe	PIPE-16	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pipe	PIPEGT16	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pump	PUMP2S	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pump	PUMPR	0.000008	0.00002	0.000002	0.0000006	0.0000306
Pump	PUMP1S	0.000008	0.00002	0.000002	0.0000006	0.0000306
Tank650	TANKBOTTOM	0.00072	0	0	0.000002	0.00072
Tank650	COURSE1-10	0.00007	0.000025	0.000005	0.0000001	0.0001
Vessel/FinFan	KODRUM	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	COLBTM	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	FINFAN	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	FILTER	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	DRUM	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	REACTOR	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	COLTOP	0.000008	0.00002	0.000002	0.0000006	0.0000306
Vessel/FinFan	COLMID	0.000008	0.00002	0.000002	0.0000006	0.0000306

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LAMPIRAN B

Equipment Criticality Analysis

Code. PV : V-001

Step 1: General Data

Equipment Data

· Type Vessel	:	Horizontal Pressure Vessel			
· Code	:	V-001			
· Year built	:	2001			
· Design pressure	:	1440.0	**psi**	99.285	**bar**
· Design temperature	:	100	**F**	37.78	**C**
· Operating pressure	:	1340.0	**psi**	92.390	**bar**
· Operating temperature	:	100	**F**	37.78	**C**
· Service Fluid	:	2 Phase (Gas, Oil)			

HEAD (LEFT)

Type of head	=	Elipsoidal	
Head material	=	SA-516- GR 70	
Outside diameter	=	45.50	inch
Inside diameter	=	42.00	inch
Nominal thickness	=	1.75	inch
Thickness last inspection	=	1.694	inch
Required Thickness	=	1.530	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

HEAD (RIGHT)

Type of head	=	Ellipsoidal	
Head material	=	SA-516- GR 70	
Outside diameter	=	45.44	inch
Inside diameter	=	42.00	inch
Nominal thickness	=	1.72	inch
Thickness last inspection	=	1.675	inch
Required Thickness	=	1.530	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

SHELL 1

Type of shell	=	Cylindrical	
Shell material	=	SA-516- GR 70	
Outside diameter	=	45.50	inch
Inside diameter	=	42.00	inch
Nominal thickness	=	1.75	inch
Thickness last inspection	=	1.68	inch
Required Thickness	=	1.08	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

Step 2: Probability of Failure (PoF)

A. Remaining Life Factor (RLF)

The RLF is an estimated measure of the risk associated with a useful life of equipment's taking into account wall thickness reduction which can cause to an end for that item.

$$Corrosion\ Rate\ (CR) = \frac{(t_{initial} - t_{actual})}{time\ between\ t_{initial}\ and\ t_{actual}}$$

$$Remaining\ Life\ (RL) = \frac{(t_{actual} - t_{required})}{Corrosion\ Rate}$$

Remaining Life = **52.71** years, then RL > 20

Value = **0**

B. Damage Factor (DF)

The Damage Factor is a measure of the risk associated with common damage mechanisms that are either active or potentially active in operation

Damage Group	Type of DF	Description	Value
Thinning	DF7	If general corrosion is occurring	2
Stress Corrosion Cracking	DF1	If there are known, active damage mechanisms that can cause corrosion cracking in carbon or alloy steels	5
Brittle	N/A	Not Applicable	-
Fatigue Failure	N/A	Not Applicable	-
HTHA	N/A	Not Applicable	-
Creep Damage	N/A	Not Applicable	-
Material Degradation	N/A	Not Applicable	-
Other Damage	N/A	Not Applicable	-
DM has not been evaluated	DF11	If potential damage mechanism in the operating unit has not been evaluated and is not being periodically reviewed by a qualified material engineer	10
		Total Value	10

Total Max. Score = 10

C. Inspection Factor (IF)

The Inspection Factor aims to measure the effectiveness of the inspection program to identify the active or anticipated damage mechanisms in the unit.

Unit Inspection	Description of Inspection	Value
Vessel Inspection	If there is a formal inspection program in place (visual and UT thickness reading)	-2
Line Inspection	If there is no formal inspection program in place	0
Overall Inspection Program	If the inspection program is carried out without paying attention to the Damage Mechanism evaluation that occurs on each equipment, or does not include a critical review of the inspection results.	-2
	Total Value	-4

D. *Condition Factor (CF)*

The Condition Factor is intended to measure the effectiveness of plant maintenance and housekeeping efforts.

Paramater Condition - 1 (CF1) *In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?*	
Almost close industry standards	***2***

Paramater Condition - 2 (CF2) *The quality of plant design and construction is*	
Almost close industry standards	***2***

Paramater Condition - 3 (CF3) *The effectiveness of the plant maintenance program, including fabrication, PM programs, and QA/QC is*	
Usually Effective - Almost of maintenance program officially documented and up to date, formal schedule for routine maintenance based on government regulations	***1***

Total Value **5**

E. *Process Factor (PF)*

Process Factor is a measure to indicate the abnormal operations or upset conditions which are prone to loss of containment events.

Process Factor - 1 (PF1) *The number of planned or unplanned process interruptions in an average year*	
0–1 interruption	***0***

Process Factor - 2 (PF2) *Assess the potential for exceeding key process variables in operation being evaluated*	
If only very unusual circumstances could cause upset conditions to escalate into an unsafe situation	***1***

Process Factor - 3 (PF3) *Assess the potential for protection devices, such as relief devices and critical sensing elements*	
Slight; fouling or plugging potential	***1***

Total Value **2**

F. Mechanical Design Factor (MDF)

Mechanical Design Factor refers to certain aspects of the design of operating equipment.

Mechanical Design Factor - 1 (MDF1) *Does Operating Pressure (OP) over Maximum Allowable Working Pressure*	
Operating Pressure (OP) < Max. Allowable Working Pressure (MAWP)	***0***

Mechanical Design Factor - 2 (MDF2) *Assess the potential for exceeding key process variables in operation being*	
Impossible - The pressure source cannot, under any conceivable chain of events, overpressure the equipment.	***1***

Total Value = ***1***

Probability of Failure (PoF) = $RLF + DF + IF + CF + PF + MDF$ = ***14***

= ***2***

So, the probability of failure is catogorized as ***Unlikely***

Step 3: Consequence of Failure (CoF)

A. Safety Consequence Factor (C_{saf})

Safety Consequence Factor (Csaf) consists of four parameters, including temperature (Ft), pressure (Fp), inventory hazard element (Fi), and inventory size (Fis).

1. *Temperature (Ft)*
   Operating Temp. (^{0}C) = *37.78*, *then* $-10 \leq T \leq 70$
   Value = ***1***

2. *Pressure (Fp)*
   Operating Pressure (barg) = *92.39*, *then* $P \geq 30$
   Value = ***5***

3. *Inventory Haz. Element (Fi)* = *2 Phase*, *then* *Process Gas; HC Liquid*
   Score = ***5***

4. *Inventory Size Element (Fis)* = *5919*, *then* $V \geq 5000$
   (in Liter)
   Value = ***2***

$$C_{saf} = \frac{F_t \times F_p \times F_i \times F_{is}}{25} = 2$$

B. Environment Consequence Factor (Cenv)

The consequences associated with pollution refers to the time after the loss of containment occurs and the pollution inventory is released to the environment.

1. *Pollution inventory* = *2 Phase*, *then* *Process Gas*
   Value = ***1***

C_{env} = ***1***

C. Production Consequence Factor (C_{prod})

The production consequence risk ranking (Cprod) refers to the effect of the failure of a particular item on production. It consists two parameters, including repair factor (F_{rep}) and operability factor (F_{op})

1. *Repair Factor (Frep)*
   Repair factor depends on the complexity of repairing an item that has failed due to corrosion.

PWHT		
Value	=	**2**

2. *Operability Factor (Fop)*
   Operability factor refers to the period of time that takes to the failed item to remain in shut down status until it has repaired and/or replaced.

Loss in production (partial or system shutdown involving some deferment)

Value = **2** **pts**

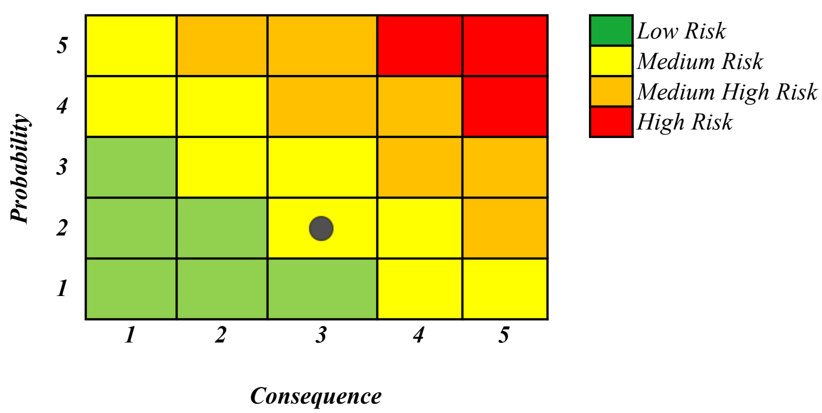
Final C_{prod} = **4**

Final Consequence of Failure (CoF) $= \frac{C_{saf} + C_{env} + C_{prod}}{12} =$ **0.5833** = **3**

So, the consequence of failure is catogorized as **Moderate**

Step 4: Risk Ranking

Consequence of Failure	**Moderate**	**3**	**Risk**	**Medium Risk**
Probability of Failure	**Unlikely**	**2**		



	Equipment Criticality Analysis	**Code. PV** : V-002

Step 1: General Data

Equipment Data

· Type Vessel	:	Horizontal Pressure Vessel			
· Code	:	V-002			
· Year built	:	1996			
· Design pressure	:	825.0	**psi**	56.88	**bar**
· Design temperature	:	200	**F**	93.33	**C**
· Operating pressure	:	710.0	**psi**	48.950	**bar**
· Operating temperature	:	120	**F**	48,89	**C**
· Service Fluid	:	2 Phase (Gas, Oil)			

HEAD (LEFT)

Type of head	=	Elipsoidal	
Head material	=	SA-516- GR 70	
Outside diameter	=	34.99	inch
Inside diameter	=	33.00	inch
Nominal thickness	=	1.00	inch
Thickness last inspection	=	0.946	inch
Required Thickness	=	0.689	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

HEAD (RIGHT)

Type of head	=	Ellipsoidal	
Head material	=	SA-516- GR 70	
Outside diameter	=	34.99	inch
Inside diameter	=	33.00	inch
Nominal thickness	=	1.00	inch
Thickness last inspection	=	0.947	inch
Required Thickness	=	0.689	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

SHELL 1

Type of shell	=	Cylindrical	
Shell material	=	SA-516- GR 70	
Outside diameter	=	35.00	inch
Inside diameter	=	33.00	inch
Nominal thickness	=	1.00	inch
Thickness last inspection	=	0.92	inch
Required Thickness	=	0.70	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	20000.00	psi
Joint efficiency	=	1	

Step 2: Probability of Failure (PoF)

A. Remaining Life Factor (RLF)

The RLF is an estimated measure of the risk associated with a useful life of equipment's taking into account wall thickness reduction which can cause to an end for that item.

$$Corrosion\ Rate\ (CR) = \frac{(t_{initial} - t_{actual})}{time\ between\ t_{initial}\ and\ t_{actual}}$$

$$Remaining\ Life\ (RL) = \frac{(t_{actual} - t_{required})}{Corrosion\ Rate}$$

Remaining Life = **118.22** *years, then* RL > 20

Value = **0**

B. Damage Factor (DF)

The Damage Factor is a measure of the risk associated with common damage mechanisms that are either active or potentially active in operation

Damage Group	Type of DF	Description	Value
Thinning	DF7	If general corrosion is occurring	2
Stress Corrosion Cracking	DF1	If there are known, active damage mechanisms that can cause corrosion cracking in carbon or alloy steels	5
Brittle	N/A	Not Applicable	-
Fatigue Failure	N/A	Not Applicable	-
HTHA	N/A	Not Applicable	-
Creep Damage	N/A	Not Applicable	-
Material Degradation	N/A	Not Applicable	-
Other Damage	N/A	Not Applicable	-
DM has not been evaluated	DF11	If potential damage mechanism in the operating unit has not been evaluated and is not being periodically reviewed by a qualified material engineer	10
		Total Value	10

Total Max. Score = 10

C. Inspection Factor (IF)

The Inspection Factor aims to measure the effectiveness of the inspection program to identify the active or anticipated damage mechanisms in the unit.

Unit Inspection	Description of Inspection	Value
Vessel Inspection	If there is a formal inspection program in place (visual and UT thickness reading)	-2
Line Inspection	If there is no formal inspection program in place	0
Overall Inspection Program	If the inspection program is carried out without paying attention to the Damage Mechanism evaluation that occurs on each equipment, or does not include a critical review of the inspection results.	-2
	Total Value	-4

D. Condition Factor (CF)

The Condition Factor is intended to measure the effectiveness of plant maintenance and housekeeping efforts.

Paramater Condition - 1 (CF1) *In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?*	
Almost close industry standards	***2***

Paramater Condition - 2 (CF2) *The quality of plant design and construction is*	
Almost close industry standards	***2***

Paramater Condition - 3 (CF3) *The effectiveness of the plant maintenance program, including fabrication, PM programs, and QA/QC is*	
Usually Effective - Almost of maintenance program officially documented and up to date, formal schedule for routine maintenance based on government regulations	***1***

Total Value ***5***

E. Process Factor (PF)

Process Factor is a measure to indicate the abnormal operations or upset conditions which are prone to loss of containment events.

Process Factor - 1 (PF1) *The number of planned or unplanned process interruptions in an average year*	
0–1 interruption	***0***

Process Factor - 2 (PF2) *Assess the potential for exceeding key process variables in operation being evaluated*	
If only very unusual circumstances could cause upset conditions to escalate into an unsafe situation	***1***

Process Factor - 3 (PF3) *Assess the potential for protection devices, such as relief devices and critical sensing elements*	
Slight; fouling or plugging potential	***1***

Total Value ***2***

F. Mechanical Design Factor (MDF)

Mechanical Design Factor refers to certain aspects of the design of operating equipment.

Mechanical Design Factor - 1 (MDF1) *Does Operating Pressure (OP) over Maximum Allowable Working Pressure*	
Operating Pressure (OP) < Max. Allowable Working Pressure (MAWP)	***0***

Mechanical Design Factor - 2 (MDF2) *Assess the potential for exceeding key process variables in operation being*	
Impossible - The pressure source cannot, under any conceivable chain of events, overpressure the equipment.	***1***

Total Value ***1***

Final Probability of Failure (PoF) = $RLF + DF + IF + CF + PF + MDF$ = ***14***

= ***2***

So, the probability of failure is catogorized as ***Unlikely***

Step 3: Consequence of Failure (CoF)

A. Safety Consequence Factor (C_{saf})

Safety Consequence Factor (Csaf) consists of four parameters, including temperature (Ft), pressure (Fp), inventory hazard element (Fi), and inventory size (Fis).

1. *Temperature (Ft)*
   Operating Temp. (^{0} C) = *48,89* , *then* *-10 ≤ T ≤ 70*
   Value = ***1***

2. *Pressure (Fp)*
   Operating Pressure (barg) = *48.95* , *then* *P ≥ 30*
   Value = ***5***

3. *Inventory Haz. Element (Fi)* = *2 Phase* , *then* *Process Gas; HC Liquid*
   Score = ***5***

4. *Inventory Size Element (Fis)* = *2448* , *then* *500 ≤ V < 5000*
   (in Liter)
   Value = ***1.9***

$$\textbf{Final } C_{saf} = \frac{F_t \; x \; F_p \; x \; F_i \; x \; F_{is}}{25} = 2$$

B. Environment Consequence Factor (Cenv)

The consequences associated with pollution refers to the time after the loss of containment occurs and the pollution inventory is released to the environment.

1. *Pollution inventory* = *2 Phase* , *then* *Process Gas*
   Value = ***1***

$$\textbf{Final } C_{env} = 1$$

C. *Production Consequence Factor (C_{prod})*

The production consequence risk ranking (Cprod) refers to the effect of the failure of a particular item on production. It consists two parameters, including repair factor (F_{rep}) and operability factor (F_{op})

1. *Repair Factor (Frep)*
   Repair factor depends on the complexity of repairing an item that has failed due to corrosion.

Not PWHT		
Value	=	***1.8***

2. *Operability Factor (Fop)*
   Operability factor refers to the period of time that takes to the failed item to remain in shut down status until it has repaired and/or replaced.

Loss in production (partial or system shutdown involving some deferment)

Value = ***2*** ***pts***

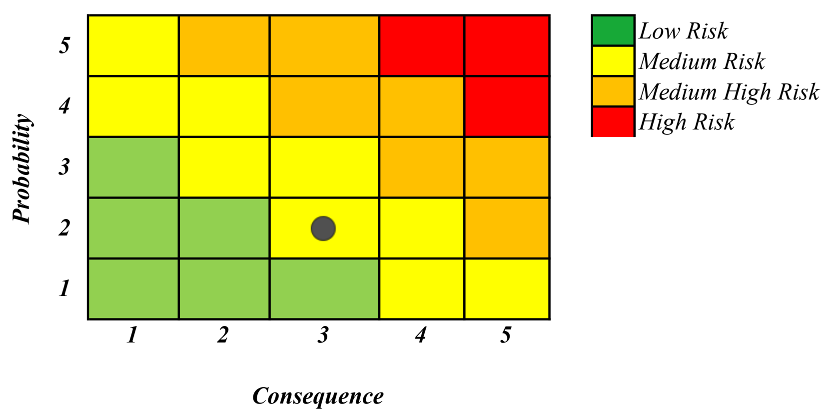
Final C_{prod} = ***3.6***

Final Consequence of Failure (CoF) $= \frac{C_{saf} + C_{env} + C_{prod}}{12}$ = ***0.5417*** = ***3***

So, the consequence of failure is catogorized as ***Moderate***

Step 4: Risk Ranking

Consequence of Failure	***Moderate***	***3***	***Risk***	***Medium Risk***
Probability of Failure	***Unlikely***	***2***		



	Equipment Criticality Analysis	Code. PV : V-003

Step 1: General Data

Equipment Data

· Type Vessel	:	Vertical Pressure Vessel			
· Code	:	V-003			
· Year built	:	1998			
· Design pressure	:	260.0	**psi**	17.93	**bar**
· Design temperature	:	150	**F**	65.56	**C**
· Operating pressure	:	100.0	**psi**	6.890	**bar**
· Operating temperature	:	120	**F**	48.89	**C**
· Service Fluid	:	2 Phase (Gas, Oil)			

HEAD (TOP)

Type of head	=	Elipsoidal	
Head material	=	SA-106 GR B	
Outside diameter	=	6.825	inch
Inside diameter	=	5.79	inch
Nominal thickness	=	0.52	inch
Thickness last inspection	=	0.511	inch
Required Thickness	=	0.063	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	17100.00	psi
Joint efficiency	=	1	

HEAD (BOTTOM)

Type of head	=	Ellipsoidal	
Head material	=	SA-106 GR B	
Outside diameter	=	6.825	inch
Inside diameter	=	5.78	inch
Nominal thickness	=	0.52	inch
Thickness last inspection	=	0.513	inch
Required Thickness	=	0.063	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	17100.00	psi
Joint efficiency	=	1	

SHELL 1

Type of shell	=	Cylindrical	
Shell material	=	SA-106 GR B	
Outside diameter	=	6.825	inch
Inside diameter	=	5.96	inch
Nominal thickness	=	0.432	inch
Thickness last inspection	=	0.426	inch
Required Thickness	=	0.04	inch
Year Last Inspection	=	2019	
Corrosion allowance	=	0.125	inch
Max allowable stress	=	17100.00	psi
Joint efficiency	=	1	

Step 2: Probability of Failure (PoF)

A. Remaining Life Factor (RLF)

The RLF is an estimated measure of the risk associated with a useful life of equipment's taking into account wall thickness reduction which can cause to an end for that item.

$$Corrosion\ Rate\ (CR) = \frac{(t_{initial} - t_{actual})}{time\ between\ t_{initial}\ and\ t_{actual}}$$

$$Remaining\ Life\ (RL) = \frac{(t_{actual} - t_{required})}{Corrosion\ Rate}$$

Remaining Life = **1176.00** *years, then* RL > 20

Value = **0**

B. Damage Factor (DF)

The Damage Factor is a measure of the risk associated with common damage mechanisms that are either active or potentially active in operation

Damage Group	Type of DF	Description	Value
Thinning	DF7	If general corrosion is occurring	2
Stress Corrosion Cracking	DF1	If there are known, active damage mechanisms that can cause corrosion cracking in carbon or alloy steels	5
Brittle	N/A	Not Applicable	-
Fatigue Failure	N/A	Not Applicable	-
HTHA	N/A	Not Applicable	-
Creep Damage	N/A	Not Applicable	-
Material Degradation	N/A	Not Applicable	-
Other Damage	N/A	Not Applicable	-
DM has not been evaluated	DF11	If potential damage mechanism in the operating unit has not been evaluated and is not being periodically reviewed by a qualified material engineer	10
		Total Value	10

Total Max. Score = 10

C. Inspection Factor (IF)

The Inspection Factor aims to measure the effectiveness of the inspection program to identify the active or anticipated damage mechanisms in the unit.

Unit Inspection	Description of Inspection	Value
Vessel Inspection	If there is a formal inspection program in place (visual and UT thickness reading)	-2
Line Inspection	If there is no formal inspection program in place	0
Overall Inspection Program	If the inspection program is carried out without paying attention to the Damage Mechanism evaluation that occurs on each equipment, or does not include a critical review of the inspection results.	-2
	Total Value	-4

D. Condition Factor (CF)

The Condition Factor is intended to measure the effectiveness of plant maintenance and housekeeping efforts.

Paramater Condition - 1 (CF1) *In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?*	
Almost close industry standards	***2***

Paramater Condition - 2 (CF2) *The quality of plant design and construction is*	
Almost close industry standards	***2***

Paramater Condition - 3 (CF3) *The effectiveness of the plant maintenance program, including fabrication, PM programs, and QA/QC is*	
Usually Effective - Almost of maintenance program officially documented and up to date, formal schedule for routine maintenance based on government regulations	***1***

Total Value ***5***

E. Process Factor (PF)

Process Factor is a measure to indicate the abnormal operations or upset conditions which are prone to loss of containment events.

Process Factor - 1 (PF1) *The number of planned or unplanned process interruptions in an average year*	
2–4 interruptions	***1***

Process Factor - 2 (PF2) *Assess the potential for exceeding key process variables in operation being evaluated*	
If only very unusual circumstances could cause upset conditions to escalate into an unsafe situation	***1***

Process Factor - 3 (PF3) *Assess the potential for protection devices, such as relief devices and critical sensing elements*	
Slight; fouling or plugging potential	***1***

Total Value ***3***

F. Mechanical Design Factor (MDF)

Mechanical Design Factor refers to certain aspects of the design of operating equipment.

Mechanical Design Factor - 1 (MDF1) *Does Operating Pressure (OP) over Maximum Allowable Working Pressure*	
Operating Pressure (OP) < Max. Allowable Working Pressure (MAWP)	***0***

Mechanical Design Factor - 2 (MDF2) *Assess the potential for exceeding key process variables in operation being*	
Impossible - The pressure source cannot, under any conceivable chain of events, overpressure the equipment.	***1***

Total Value ***1***

Final Probability of Failure (PoF) = $RLF + DF + IF + CF + PF + MDF$ = ***15***

= ***2***

So, the probability of failure is catogorized as ***Unlikely***

Step 3: Consequence of Failure (CoF)

A. Safety Consequence Factor (C_{saf})

Safety Consequence Factor (Csaf) consists of four parameters, including temperature (Ft), pressure (Fp), inventory hazard element (Fi), and inventory size (Fis).

1. *Temperature (Ft)*
   Operating Temp. (^{0}C) = *48.89*, then $-10 \leq T \leq 70$; **Value** = ***1***

2. *Pressure (Fp)*
   Operating Pressure (barg) = *6.89*, then $5 \leq P < 10$; **Value** = ***3***

3. *Inventory Haz. Element (Fi)* = *2 Phase*, then *Process Gas; HC Liquid*; **Score** = ***5***

4. *Inventory Size Element (Fis)* = *20.9*, then $20 \leq V < 50$; **Value** = ***1.6***
   (in Liter)

$$\text{Final } C_{saf} = \frac{F_t \ x \ F_p \ x \ F_i \ x \ F_{is}}{25} = 1$$

B. Environment Consequence Factor (Cenv)

The consequences associated with pollution refers to the time after the loss of containment occurs and the pollution inventory is released to the environment.

1. *Pollution inventory* = *2 Phase*, then *Process Gas*; **Value** = ***1***

Final C_{env} = ***1***

C. *Production Consequence Factor (C_{prod})*

The production consequence risk ranking (Cprod) refers to the effect of the failure of a particular item on production. It consists two parameters, including repair factor (F_{rep}) and operability factor (F_{op})

1. *Repair Factor (Frep)*
   Repair factor depends on the complexity of repairing an item that has failed due to corrosion.

Not PWHT		
Value	=	***1.8***

2. *Operability Factor (Fop)*
   Operability factor refers to the period of time that takes to the failed item to remain in shut down status until it has repaired and/or replaced.

Loss in production (partial or system shutdown involving some deferment)

Value = ***2*** ***pts***

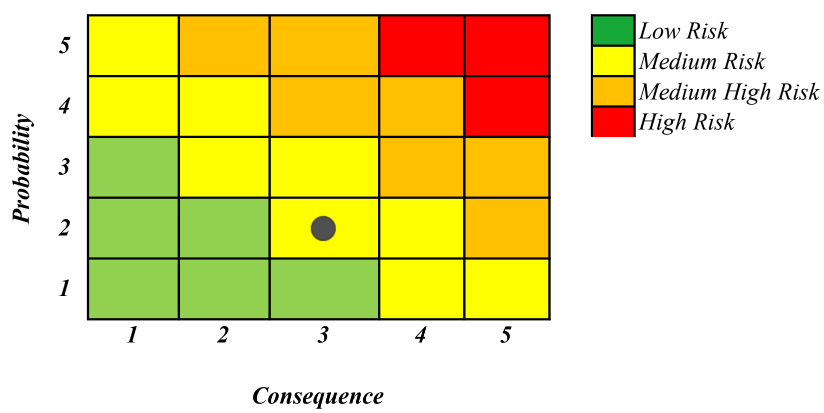
Final C_{prod} = ***3.6***

Final Consequence of Failure (CoF) $= \frac{C_{saf} + C_{env} + C_{prod}}{12}$ = ***0.4633*** = ***3***

So, the consequence of failure is catogorized as ***Moderate***

Step 4: Risk Ranking

Consequence of Failure	***Moderate***	***3***	***Risk***	***Medium Risk***
Probability of Failure	***Unlikely***	***2***		



	Equipment Criticality Analysis	***Code. PV*** :	*V-004*

Step 1: General Data

Equipment Data

· *Type Vessel*	:	*Vertical Pressure Vessel*			
· *Code*	:	*V-004*			
· *Year built*	:	*2001*			
· *Design pressure*	:	*260.0*	***psi***	*17.93*	***bar***
· *Design temperature*	:	*200*	***F***	*93.33*	***C***
· *Operating pressure*	:	*100.0*	***psi***	*6.895*	***bar***
· *Operating temperature*	:	*120*	***F***	*48.89*	***C***
· *Service Fluid*	:	*2 Phase (Gas, Oil)*			

HEAD (TOP)

Type of head	=	*Elipsoidal*	
Head material	=	*SA-516- GR 70*	
Outside diameter	=	*6.63*	*inch*
Inside diameter	=	*5.54*	*inch*
Nominal thickness	=	*0.55*	*inch*
Thickness last inspection	=	*0.526*	*inch*
Required Thickness	=	*0.063*	*inch*
Year Last Inspection	=	*2019*	
Corrosion allowance	=	*0.125*	*inch*
Max allowable stress	=	*17100.00*	*psi*
Joint efficiency	=	*1*	

HEAD (BOTTOM)

Type of head	=	*Ellipsoidal*	
Head material	=	*SA-516- GR 70*	
Outside diameter	=	*6.63*	*inch*
Inside diameter	=	*5.71*	*inch*
Nominal thickness	=	*0.46*	*inch*
Thickness last inspection	=	*0.438*	*inch*
Required Thickness	=	*0.037*	*inch*
Year Last Inspection	=	*2019*	
Corrosion allowance	=	*0.125*	*inch*
Max allowable stress	=	*17100.00*	*psi*
Joint efficiency	=	*1*	

SHELL 1

Type of shell	=	*Cylindrical*	
Shell material	=	*SA-516- GR 70*	
Outside diameter	=	*6.63*	*inch*
Inside diameter	=	*5.76*	*inch*
Nominal thickness	=	*0.43*	*inch*
Thickness last inspection	=	*0.41*	*inch*
Required Thickness	=	*0.04*	*inch*
Year Last Inspection	=	*2019*	
Corrosion allowance	=	*0.125*	*inch*
Max allowable stress	=	*17100.00*	*psi*
Joint efficiency	=	*1*	

Step 2: Probability of Failure (PoF)

A. *Remaining Life Factor (RLF)*

The RLF is an estimated measure of the risk associated with a useful life of equipment's taking into account wall thickness reduction which can cause to an end for that item.

$$Corrosion\ Rate\ (CR) = \frac{(t_{initial} - t_{actual})}{time\ between\ t_{initial}\ and\ t_{actual}}$$

$$Remaining\ Life\ (RL) = \frac{(t_{actual} - t_{required})}{Corrosion\ Rate}$$

Remaining Life = ***438.63*** *years, then* *RL > 20*

Value = ***0***

B. ***Damage Factor (DF)***

The Damage Factor is a measure of the risk associated with common damage mechanisms that are either active or potentially active in operation

Damage Group	Type of DF	Description	Value
Thinning	DF7	If general corrosion is occurring	2
Stress Corrosion Cracking	DF1	If there are known, active damage mechanisms that can cause corrosion cracking in carbon or alloy steels	5
Brittle	N/A	Not Applicable	-
Fatigue Failure	N/A	Not Applicable	-
HTHA	N/A	Not Applicable	-
Creep Damage	N/A	Not Applicable	-
Material Degradation	N/A	Not Applicable	-
Other Damage	N/A	Not Applicable	-
DM has not been evaluated	DF11	If potential damage mechanism in the operating unit has not been evaluated and is not being periodically reviewed by a qualified material engineer	10
		Total Value	10

Total Max. Score = 10

C. ***Inspection Factor (IF)***

The Inspection Factor aims to measure the effectiveness of the inspection program to identify the active or anticipated damage mechanisms in the unit.

Unit Inspection	Description of Inspection	Value
Vessel Inspection	If there is a formal inspection program in place (visual and UT thickness reading)	-2
Line Inspection	If there is no formal inspection program in place	0
Overall Inspection Program	If the inspection program is carried out without paying attention to the Damage Mechanism evaluation that occurs on each equipment, or does not include a critical review of the inspection results.	-2
	Total Value	-4

D. Condition Factor (CF)

The Condition Factor is intended to measure the effectiveness of plant maintenance and housekeeping efforts.

Paramater Condition - 1 (CF1) *In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?In a plant walkthrough, how would the plant housekeeping is judged (including painting and insulation maintenance program)?*	
Almost close industry standards	***2***

Paramater Condition - 2 (CF2) *The quality of plant design and construction is*	
Almost close industry standards	***2***

Paramater Condition - 3 (CF3) *The effectiveness of the plant maintenance program, including fabrication, PM programs, and QA/QC is*	
Usually Effective - Almost of maintenance program officially documented and up to date, formal schedule for routine maintenance based on government regulations	***1***

Total Value ***5***

E. Process Factor (PF)

Process Factor is a measure to indicate the abnormal operations or upset conditions which are prone to loss of containment events.

Process Factor - 1 (PF1) *The number of planned or unplanned process interruptions in an average year*	
2–4 interruptions	***1***

Process Factor - 2 (PF2) *Assess the potential for exceeding key process variables in operation being evaluated*	
If only very unusual circumstances could cause upset conditions to escalate into an unsafe situation	***1***

Process Factor - 3 (PF3) *Assess the potential for protection devices, such as relief devices and critical sensing elements*	
Slight; fouling or plugging potential	***1***

Total Value ***3***

F. Mechanical Design Factor (MDF)

Mechanical Design Factor refers to certain aspects of the design of operating equipment.

Mechanical Design Factor - 1 (MDF1) *Does Operating Pressure (OP) over Maximum Allowable Working Pressure*	
Operating Pressure (OP) < Max. Allowable Working Pressure (MAWP)	***0***

Mechanical Design Factor - 2 (MDF2) *Assess the potential for exceeding key process variables in operation being*	
Impossible - The pressure source cannot, under any conceivable chain of events, overpressure the equipment.	***1***

Total Value **1**

Final Probability of Failure (PoF) = $RLF + DF + IF + CF + PF + MDF$ = ***15***

= ***2***

So, the probability of failure is catogorized as ***Unlikely***

Step 3: Consequence of Failure (CoF)

A. Safety Consequence Factor (C_{saf})

Safety Consequence Factor (Csaf) consists of four parameters, including temperature (Ft), pressure (Fp), inventory hazard element (Fi), and inventory size (Fis).

1. *Temperature (Ft)*
   Operating Temp. ($^0 C$) = *48.89* , *then* $-10 \leq T \leq 70$ — **Value** = ***1***

2. *Pressure (Fp)*
   Operating Pressure (barg) = *6.90* , *then* $5 \leq P < 10$ — **Value** = ***3***

3. *Inventory Haz. Element (Fi)* = *2 Phase* , *then* *Process Gas; HC Liquid* — **Score** = ***5***

4. *Inventory Size Element (Fis)* = *35.52* , *then* $50 \leq V < 500$ — **Value** = ***1.8***
   (in Liter)

$$C_{saf} = \frac{F_t \; x \; F_p \; x \; F_i \; x \; F_{is}}{25} = 1$$

B. Environment Consequence Factor (Cenv)

The consequences associated with pollution refers to the time after the loss of containment occurs and the pollution inventory is released to the environment.

1. *Pollution inventory* = *2 Phase* , *then* *Process Gas* — **Value** = ***1***

$$C_{env} = 1$$

C. *Production Consequence Factor (C_{prod})*

The production consequence risk ranking (Cprod) refers to the effect of the failure of a particular item on production. It consists two parameters, including repair factor (F_{rep}) and operability factor (F_{op})

1. *Repair Factor (Frep)*
   Repair factor depends on the complexity of repairing an item that has failed due to corrosion.

Not PWHT		
Value	=	***1.8***

2. *Operability Factor (Fop)*
   Operability factor refers to the period of time that takes to the failed item to remain in shut down status until it has repaired and/or replaced.

Loss in production (partial or system shutdown involving some deferment)

Value = ***2*** ***pts***

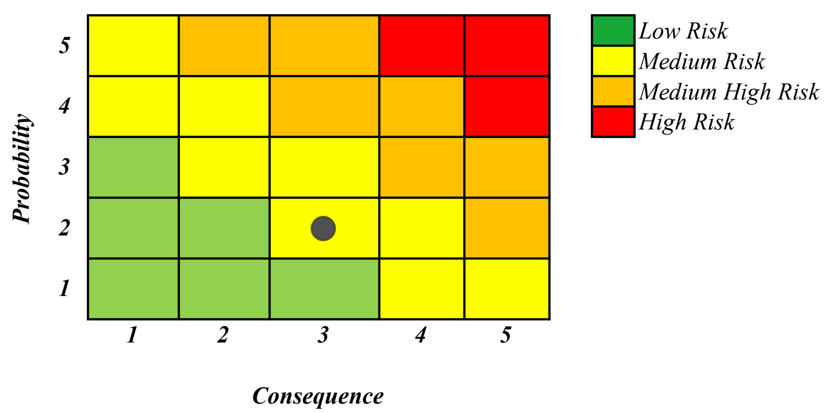
C_{prod} = ***3.6***

Consequence of Failure (CoF) $= \frac{C_{saf} + C_{env} + C_{prod}}{12} =$ ***0.4733*** = ***3***

So, the consequence of failure is catogorized as ***Moderate***

Step 4: Risk Ranking

Consequence of Failure	***Moderate***	***3***	***Risk***	***Medium Risk***
Probability of Failure	***Unlikely***	***2***		



LAMPIRAN C

V-001

No.	Damage Factor	Screening Criteria		
1.	Thinning	All component should be checked fot thinning	Y	Y
2.	Component Lining	If the component has an inorganic lining, then the component should be evaluated for lining damage.	N	N
3.	SCC - Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	N	N
4.	SCC - Amine Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	N	N
5.	SCC - Sulfide Stress Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to sulfide stress cracking.	Y	Y
6.	SCC - HIC/SOHIC-H_2S Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-H_2S cracking	Y	Y
7.	SCC - Alkaline Carbonate Stress Corrosion Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains alkaline water at pH > 7.5 in any concentration, then the component should be considered for evaluation for susceptibility to ACSCC. Another trigger would be changes in FCCU feed sulfur and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.	Y	Y
8.	SCC - Polythionic Acid Stress Corrosion Cracking	If the component's material of construction is austenitic stainless steel or nickel based alloys and the component is exposed to sulfur bearing compounds, then the component should be evaluated for susceptibility to PASCC cracking	N	N
9.	SCC - Chloride Stress Corrosion Cracking	If all of the following are true, then the component should be evaluated for susceptibilty to CLSCC cracking. a. The componen's material of construction is an austenitic stainless steel	N	N
		b. The componen is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and process conditions)	N	
		c. The operating temperature is above 38°C (100°F)	N	
10.	SCC - Hydrogen Stress Corrosion Cracking/ HF	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.	N	N
11.	SCC - HIC/SOHIC-HF Cracking	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.	N	N

12.	External Corrosion - Ferritic Component		If the component is uninsulated and subject to any of the following, then the component should be evaluated for external damage from corrosion	N	Y
		a.	Areas exposed to mist overspray from cooling towers		
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge systems	N	
		d.	Area subject to process spills, ingress of moisture, or acid vapors	N	
		e.	Carbon steel systems, operating between -12°C and 177°C (10°F and 350°F). External corrosion is particularly aggressive where operating temperatures cause frequent or continous condensation and reevaporation of atmospheric moisture.	Y	
		f.	Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittenly or are subjected to frequent outages.	N	
		g.	Systems with deteriorated coating and/ or wrappings	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point	N	
		i.	Un-insulated nozzles or other protrusions components of insulated quipment in cold service conditions.	N	
13.	CUI - Ferritic Component		Spesific locations and/ or systems, such as penetrations and visually damaged insulation areas, are highly suspect and should be considered during inspection program development. Examples of highly suspect areas iclude, but are not limited to the following :	N	N
			a. Penetrations		
		1.	All penetrations or breaches in te insulation jacketing systems, such as dead leg (vents, drains, and other similar item), hangers and other supports, valves, and fittings, bolted on pipe shoesm ladder and platforms.		
		2.	Steam tracer tubing penetrations	N	
		3.	Termination of insulation at flanges and other components.	N	
		4.	Poorly designed insulation support rings.	N	
		5.	Stiffener rings.	N	
			b. Damaged Insulation Areas	N	
		1.	Damaged or missing insulation jacketing		
		2.	Termination of insulation in vertical pipe or piece of equipment	N	
		3.	Caulking that has hardened, has separated, or is missing	N	
		4.	Bulges, staining of the jacketing system or issing bands (bulges may indicates corrosion produt build up)	N	
		5.	Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.	N	
		6.	Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking - Austenic Component		If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.	N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		c.	The operating temperature is between 50°C and 150°C (120°F and 300°F)or the system heat or cools into this range intermittently		

15.	External Chloride Stress Corrosion Cracking Under Insulation (CUI) - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component is insulated		
		c.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		d.	The operating temperature is between 50°C and 150°C (120°F and 300°F) or the system heat or cools into this range intermittently		
16.	HTHA	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The material is carbon steel, C-$^1/_2$ Mo, or a CR-Mo low alloy steel (such as $^1/_2$ Cr-$^1/_2$ Mo, 1 Cr-$^1/_2$ Mo, $^1/_4$ Cr-$^1/_2$ Mo, 2 $^1/_4$ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-$^1/_2$ Mo, 7 Cr-1 Mo and 9 Cr-1 Mo,)		
		b.	The operating temperature is greater than 177°C (350°F)	N	
		c.	The operating hydrogen partial pressure is greater than 0.345 Mpa (50 psia)	N	
17.	Brittle fracture	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is carbon seel or a low alloy steel		
		b.	The Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Temperature (MAT), T_{MAT} is unknown, or the MDMT is known but the component may operate at below	N	
18.	Low Alloy Steel Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is 1.25 Cr-0.5 Mo, 2.25 CR-0.5 Mo or3 Cr-1 Mo low alloy steel		
		b.	The operating temperature is between 343°C and 577°C (650°F and 1070°F)	N	
19.	885°F Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	chromium (>12% Cr) ferritic steel		
		b.	The operating temperature is between 371°C and 566°C (700°F and 1050°F)	N	
20.	Sigma Phase Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material an austenitic stainless steel		
		b.	The operating temperature is between 593°C and 927°C (1100°F and 1700°F)	N	
21.	Piping Mechanical Fatigue	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The component is pipe		
		b.	There have been past fatigue failures in this piping system or there is visible/ audible shaking in this piping system or there is a source of cyclic shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters [50 feet] and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continous or intermittent. Transient conditions often cause intermittent vibration.	N	

V-002

No.	Damage Factor	Screening Criteria		
1.	Thinning	All component should be checked fot thinning	Y	Y
2.	Component Lining	If the component has an inorganic lining, then the component should be evaluated for lining damage.	N	N
3.	SCC - Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	N	N
4.	SCC - Amine Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	N	N
5.	SCC - Sulfide Stress Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to sulfide stress cracking.	Y	Y
6.	SCC - HIC/SOHIC-H_2S Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-H_2S cracking	Y	Y
7.	SCC - Alkaline Carbonate Stress Corrosion Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains alkaline water at pH > 7.5 in any concentration, then the component should be considered for evaluation for susceptibility to ACSCC. Another trigger would be changes in FCCU feed sulfur and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.	Y	Y
8.	SCC - Polythionic Acid Stress Corrosion Cracking	If the component's material of construction is austenitic stainless steel or nickel based alloys and the component is exposed to sulfur bearing compounds, then the component should be evaluated for susceptibility to PASCC cracking	N	N
9.	SCC - Chloride Stress Corrosion Cracking	If all of the following are true, then the component should be evaluated for susceptibilty to CLSCC cracking.	N	N
		a. The componen's material of construction is an austenitic stainless steel		
		b. The componen is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and process conditions)	N	
		c. The operating temperature is above 38°C (100°F)	N	
10.	SCC - Hydrogen Stress Corrosion Cracking/ HF	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.	N	N
11.	SCC - HIC/SOHIC-HF Cracking	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.	N	N

12.	External Corrosion - Ferritic Component		If the component is uninsulated and subject to any of the following, then the component should be evaluated for external damage from corrosion	N	Y
		a.	Areas exposed to mist overspray from cooling towers		
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge systems	N	
		d.	Area subject to process spills, ingress of moisture, or acid vapors	N	
		e.	Carbon steel systems, operating between -12°C and 177°C (10°F and 350°F). External corrosion is particularly aggressive where operating temperatures cause frequent or continous condensation and reevaporation of atmospheric moisture.	Y	
		f.	Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittently or are subjected to frequent outages.	N	
		g.	Systems with deteriorated coating and/ or wrappings	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point	N	
		i.	Un-insulated nozzles or other protrusions components of insulated quipment in cold service conditions.	N	
13.	CUI - Ferritic Component		Spesific locations and/ or systems, such as penetrations and visually damaged insulation areas, are highly suspect and should be considered during inspection program development. Examples of highly suspect areas iclude, but are not limited to the following :	N	N
			a. Penetrations		
		1.	All penetrations or breaches in te insulation jacketing systems, such as dead leg (vents, drains, and other similar item), hangers and other supports, valves, and fittings, bolted on pipe shoesm ladder and platforms.		
		2.	Steam tracer tubing penetrations	N	
		3.	Termination of insulation at flanges and other components.	N	
		4.	Poorly designed insulation support rings.	N	
		5.	Stiffener rings.	N	
			b. Damaged Insulation Areas	N	
		1.	Damaged or missing insulation jacketing		
		2.	Termination of insulation in vertical pipe or piece of equipment	N	
		3.	Caulking that has hardened, has separated, or is missing	N	
		4.	Bulges, staining of the jacketing system or issing bands (bulges may indicates corrosion produt build up)	N	
		5.	Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.	N	
		6.	Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking - Austenic Component		If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.	N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		c.	The operating temperature is between 50°C and 150°C (120°F and 300°F)or the system heat or cools into this range intermittently		

15.	External Chloride Stress Corrosion Cracking Under Insulation (CUI) - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component is insulated		
		c.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		d.	The operating temperature is between 50°C and 150°C (120°F and 300°F) or the system heat or cools into this range intermittently		
16.	HTHA	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The material is carbon steel, C-$^{1}/_{2}$ Mo, or a CR-Mo low alloy steel (such as $^{1}/_{2}$ Cr-$^{1}/_{2}$ Mo, 1 Cr-$^{1}/_{2}$ Mo, $^{1}/_{4}$ Cr-$^{1}/_{2}$ Mo, 2 $^{1}/_{4}$ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-$^{1}/_{2}$ Mo, 7 Cr-1 Mo and 9 Cr-1 Mo,)		
		b.	The operating temperature is greater than 177°C (350°F)	N	
		c.	The operating hydrogen partial pressure is greater than 0.345 Mpa (50 psia)	N	
17.	Brittle fracture	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is carbon seel or a low alloy steel		
		b.	The Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Temperature (MAT), T_{MAT} is unknown, or the MDMT is known but the component may operate at below	N	
18.	Low Alloy Steel Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is 1.25 Cr-0.5 Mo, 2.25 CR-0.5 Mo or3 Cr-1 Mo low alloy steel		
		b.	The operating temperature is between 343°C and 577°C (650°F and 1070°F)	N	
19.	885°F Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	chromium (>12% Cr) ferritic steel		
		b.	The operating temperature is between 371°C and 566°C (700°F and 1050°F)	N	
20.	Sigma Phase Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material an austenitic stainless steel		
		b.	The operating temperature is between 593°C and 927°C (1100°F and 1700°F)	N	
21.	Piping Mechanical Fatigue	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The component is pipe		
		b.	There have been past fatigue failures in this piping system or there is visible/ audible shaking in this piping system or there is a source of cyclic shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters [50 feet] and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continous or intermittent. Transient conditions often cause intermittent vibration.	N	

V-003

No.	Damage Factor	Screening Criteria		
1.	Thinning	All component should be checked fot thinning	Y	Y
2.	Component Lining	If the component has an inorganic lining, then the component should be evaluated for lining damage.	N	N
3.	SCC - Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	N	N
4.	SCC - Amine Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	N	N
5.	SCC - Sulfide Stress Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to sulfide stress cracking.	Y	Y
6.	SCC - HIC/SOHIC-H_2S Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-H_2S cracking	Y	Y
7.	SCC - Alkaline Carbonate Stress Corrosion Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains alkaline water at pH > 7.5 in any concentration, then the component should be considered for evaluation for susceptibility to ACSCC. Another trigger would be changes in FCCU feed sulfur and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.	N	N
8.	SCC - Polythionic Acid Stress Corrosion Cracking	If the component's material of construction is austenitic stainless steel or nickel based alloys and the component is exposed to sulfur bearing compounds, then the component should be evaluated for susceptibility to PASCC cracking	N	N
9.	SCC - Chloride Stress Corrosion Cracking	If all of the following are true, then the component should be evaluated for susceptibilty to CLSCC cracking. a. The componen's material of construction is an austenitic stainless steel	N	N
		b. The componen is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and process conditions)	N	
		c. The operating temperature is above 38°C (100°F)	N	
10.	SCC - Hydrogen Stress Corrosion Cracking/ HF	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.	N	N
11.	SCC - HIC/SOHIC-HF Cracking	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.	N	N

12.	External Corrosion - Ferritic Component	If the component is uninsulated and subject to any of the following, then the component should be evaluated for external damage from corrosion		N	Y
		a.	Areas exposed to mist overspray from cooling towers		
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge systems	N	
		d.	Area subject to process spills, ingress of moisture, or acid vapors	N	
		e.	Carbon steel systems, operating between -12°C and 177°C (10°F and 350°F). External corrosion is particularly aggressive where operating temperatures cause frequent or continous condensation and reevaporation of atmospheric moisture.	Y	
		f.	Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittenly or are subjected to frequent outages.	N	
		g.	Systems with deteriorated coating and/ or wrappings	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point	N	
		i.	Un-insulated nozzles or other protrusions components of insulated quipment in cold service conditions.	N	
13.	CUI - Ferritic Component	Spesific locations and/ or systems, such as penetrations and visually damaged insulation areas, are highly suspect and should be considered during inspection program development. Examples of highly suspect areas iclude, but are not limited to the following :		N	N
		a. Penetrations			
		1.	All penetrations or breaches in te insulation jacketing systems, such as dead leg (vents, drains, and other similar item), hangers and other supports, valves, and fittings, bolted on pipe shoesm ladder and platforms.		
		2.	Steam tracer tubing penetrations	N	
		3.	Termination of insulation at flanges and other components.	N	
		4.	Poorly designed insulation support rings.	N	
		5.	Stiffener rings.	N	
		b. Damaged Insulation Areas		N	
		1.	Damaged or missing insulation jacketing		
		2.	Termination of insulation in vertical pipe or piece of equipment	N	
		3.	Caulking that has hardened, has separated, or is missing	N	
		4.	Bulges, staining of the jacketing system or issing bands (bulges may indicates corrosion produt build up)	N	
		5.	Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.	N	
		6.	Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		c.	The operating temperature is between 50°C and 150°C (120°F and 300°F)or the system heat or cools into this range intermittently		

15.	External Chloride Stress Corrosion Cracking Under Insulation (CUI) - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component is insulated		
		c.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		d.	The operating temperature is between 50°C and 150°C (120°F and 300°F) or the system heat or cools into this range intermittently		
16.	HTHA	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The material is carbon steel, C-$^{1}/_{2}$ Mo, or a CR-Mo low alloy steel (such as $^{1}/_{2}$ Cr-$^{1}/_{2}$ Mo, 1 Cr-$^{1}/_{2}$ Mo, $^{1}/_{4}$ Cr-$^{1}/_{2}$ Mo, 2 $^{1}/_{4}$ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-$^{1}/_{2}$ Mo, 7 Cr-1 Mo and 9 Cr-1 Mo,)		
		b.	The operating temperature is greater than 177°C (350°F)	N	
		c.	The operating hydrogen partial pressure is greater than 0.345 Mpa (50 psia)	N	
17.	Brittle fracture	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is carbon seel or a low alloy steel		
		b.	The Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Temperature (MAT), T_{MAT} is unknown, or the MDMT is known but the component may operate at below	N	
18.	Low Alloy Steel Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is 1.25 Cr-0.5 Mo, 2.25 CR-0.5 Mo or3 Cr-1 Mo low alloy steel		
		b.	The operating temperature is between 343°C and 577°C (650°F and 1070°F)	N	
19.	885°F Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	chromium (>12% Cr) ferritic steel		
		b.	The operating temperature is between 371°C and 566°C (700°F and 1050°F)	N	
20.	Sigma Phase Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material an austenitic stainless steel		
		b.	The operating temperature is between 593°C and 927°C (1100°F and 1700°F)	N	
21.	Piping Mechanical Fatigue	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The component is pipe		
		b.	There have been past fatigue failures in this piping system or there is visible/ audible shaking in this piping system or there is a source of cyclic shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters [50 feet] and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continous or intermittent. Transient conditions often cause intermittent vibration.	N	

V-004

No.	Damage Factor	Screening Criteria		
1.	Thinning	All component should be checked fot thinning	Y	Y
2.	Component Lining	If the component has an inorganic lining, then the component should be evaluated for lining damage.	N	N
3.	SCC - Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	N	N
4.	SCC - Amine Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	N	N
5.	SCC - Sulfide Stress Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to sulfide stress cracking.	Y	Y
6.	SCC - HIC/SOHIC-H_2S Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains water and H_2S in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-H_2S cracking	Y	Y
7.	SCC - Alkaline Carbonate Stress Corrosion Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains alkaline water at pH > 7.5 in any concentration, then the component should be considered for evaluation for susceptibility to ACSCC. Another trigger would be changes in FCCU feed sulfur and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.	N	N
8.	SCC - Polythionic Acid Stress Corrosion Cracking	If the component's material of construction is austenitic stainless steel or nickel based alloys and the component is exposed to sulfur bearing compounds, then the component should be evaluated for susceptibility to PASCC cracking	N	N
9.	SCC - Chloride Stress Corrosion Cracking	If all of the following are true, then the component should be evaluated for susceptibilty to CLSCC cracking.	N	N
		a. The componen's material of construction is an austenitic stainless steel		
		b. The componen is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and process conditions)	N	
		c. The operating temperature is above 38°C (100°F)	N	
10.	SCC - Hydrogen Stress Corrosion Cracking/ HF	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.	N	N
11.	SCC - HIC/SOHIC-HF Cracking	If the component's material of construction is carbon or low alloy steel and the component is exposed to hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.	N	N

12.	External Corrosion - Ferritic Component	If the component is uninsulated and subject to any of the following, then the component should be evaluated for external damage from corrosion		N	Y
		a.	Areas exposed to mist overspray from cooling towers		
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge systems	N	
		d.	Area subject to process spills, ingress of moisture, or acid vapors	N	
		e.	Carbon steel systems, operating between -12°C and 177°C (10°F and 350°F). External corrosion is particularly aggressive where operating temperatures cause frequent or continous condensation and reevaporation of atmospheric moisture.	Y	
		f.	Systems that do not normally operate between -12°C and 177°C (10°F and 350°F) but cool or heat into this range intermittently or are subjected to frequent outages.	N	
		g.	Systems with deteriorated coating and/ or wrappings	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point	N	
		i.	Un-insulated nozzles or other protrusions components of insulated quipment in cold service conditions.	N	
13.	CUI - Ferritic Component	Spesific locations and/ or systems, such as penetrations and visually damaged insulation areas, are highly suspect and should be considered during inspection program development. Examples of highly suspect areas iclude, but are not limited to the following :		N	N
		a. Penetrations			
		1.	All penetrations or breaches in te insulation jacketing systems, such as dead leg (vents, drains, and other similar item), hangers and other supports, valves, and fittings, bolted on pipe shoesm ladder and platforms.		
		2.	Steam tracer tubing penetrations	N	
		3.	Termination of insulation at flanges and other components.	N	
		4.	Poorly designed insulation support rings.	N	
		5.	Stiffener rings.	N	
		b. Damaged Insulation Areas		N	
		1.	Damaged or missing insulation jacketing		
		2.	Termination of insulation in vertical pipe or piece of equipment	N	
		3.	Caulking that has hardened, has separated, or is missing	N	
		4.	Bulges, staining of the jacketing system or issing bands (bulges may indicates corrosion produt build up)	N	
		5.	Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.	N	
		6.	Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		c.	The operating temperature is between 50°C and 150°C (120°F and 300°F)or the system heat or cools into this range intermittently		

15.	External Chloride Stress Corrosion Cracking Under Insulation (CUI) - Austenic Component	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The component's material of construction is an austenitic stainles steel		
		b.	The component is insulated		
		c.	The component's external surface is exposed to chloride containing fluid, mists or solids.		
		d.	The operating temperature is between 50°C and 150°C (120°F and 300°F) or the system heat or cools into this range intermittently		
16.	HTHA	If all of the following are true, then the component should be evaluated for susceptibilty to external CLSCC.		N	N
		a.	The material is carbon steel, C-$^{1}/_{2}$ Mo, or a CR-Mo low alloy steel (such as $^{1}/_{2}$ Cr-$^{1}/_{2}$ Mo, 1 Cr-$^{1}/_{2}$ Mo, $^{1}/_{4}$ Cr-$^{1}/_{2}$ Mo, 2 $^{1}/_{4}$ Cr-1 Mo, 3 Cr-1 Mo, 5 Cr-$^{1}/_{2}$ Mo, 7 Cr-1 Mo and 9 Cr-1 Mo,)		
		b.	The operating temperature is greater than 177°C (350°F)	N	
		c.	The operating hydrogen partial pressure is greater than 0.345 Mpa (50 psia)	N	
17.	Brittle fracture	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is carbon seel or a low alloy steel		
		b.	The Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Temperature (MAT), T_{MAT} is unknown, or the MDMT is known but the component may operate at below	N	
18.	Low Alloy Steel Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material is 1.25 Cr-0.5 Mo, 2.25 CR-0.5 Mo or3 Cr-1 Mo low alloy steel		
		b.	The operating temperature is between 343°C and 577°C (650°F and 1070°F)	N	
19.	885°F Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	chromium (>12% Cr) ferritic steel		
		b.	The operating temperature is between 371°C and 566°C (700°F and 1050°F)	N	
20.	Sigma Phase Embrittlement	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The material an austenitic stainless steel		
		b.	The operating temperature is between 593°C and 927°C (1100°F and 1700°F)	N	
21.	Piping Mechanical Fatigue	If all of the following are true, then the component should be evaluated for susceptibilty to brittle fracture.		N	N
		a.	The component is pipe		
		b.	There have been past fatigue failures in this piping system or there is visible/ audible shaking in this piping system or there is a source of cyclic shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters [50 feet] and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continous or intermittent. Transient conditions often cause intermittent vibration.	N	

LAMPIRAN D

GENERAL DATA

Doc. PV : V-001

Design code :	ASME Sec. VIII	Date RBI assessment :	2024
Equipment Name :	V-001	Date last inspection :	2019
Vessel type :	Horizontal Vessel	Plan date :	2029

Size :		
Diameter :	1104.9	mm
Volume total :	5.919	m^3
Year built :	2001	
Fluid category :	C1- C2	
Fluid phase :	Gas	
Cladding :	No	
Coating :	High	
Design pressure :	100	bar
	1440	psi
Design temperature :	100	℃
	37.38	℉
Operating pressure :	92.39	bar
	1340	psi
	9239.3	kPa
Operating temperature :	37.78	℃
	100	℉
	310.93	K
Atmospheric pressure :	101.28755	kPa

Head data 1 :

Type :	2:1 Ellipsoidal	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	44.52	mm
	1.753	inch
Minimum wall thickness :	38.92	mm
	1.532	inch
Corrosion allowance:	3.2	mm
	0	inch
Last inspection thickness :	43.04	mm
	1.694	inch

Head data 2 :

Type :	2:1 Ellipsoidal	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	43.59	mm
	1.716	inch
Minimum wall thickness :	38.92	mm
	1.532	inch
Corrosion allowance:	3.2	mm
	0	inch
Last inspection thickness :	42.55	mm
	1.675	inch

Shell data :

Type :	Cylindrical shell	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	44.45	mm
	1.75	inch
Minimum wall thickness :	27.49	mm
	1.082	inch
Corrosion allowance:	3.2	mm
	0	inch
Last inspection thickness :	43.49	mm
	1.712	inch

Material data :

Allowable stress :	138000	kPa
Tensile strength :	485000	kPa
Yield strength :	260000	kPa
Mass density (ρ_m) :	250.512	kg/m^3

	PROBABILITY OF FAILURE Thinning	Doc. PV : V-001

1.-Furnished thickness & Age

(left head)			(shell)			(right head)		
head t =	44.52	mm	shell t =	44.45	mm	head t =	43.59	mm
	1.753	inch		1.75	inch		1.716	inch

age = 23 year

2.-Corrosion rate for base metal ($C_{r,bm}$)

Based on API 510

$$LTCR = \frac{t_{initial} - t_{actual}}{years\ between}$$

left head $C_{r,bm}$ =	0.082222222	mm/year
shell $C_{r,bm}$ =	0.053333333	mm/year
right head $C_{r,bm}$ =	0.057777778	mm/year

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Last inspection date :	2019	
RBI date :	2024	
Plan date :	2029	

(left head)		
t_{rdi} =	43.04	mm
	1.694	inch
(shell)		
t_{rdi} =	43.49	mm
	1.712	inch
(right head)		
t_{rdi} =	42.55	mm
	1.675	inch
age_{tk} =	5	year
age_{pd} =	10	year

4.- For cladding/ weld overlay pressure vessel components, calculate the age from the date of the starting thickness from STEP 3 required to corrode away the cladding/ weld overlay material (age_{rc})

$$age_{rc} = \left[\left(\frac{t_{rdi} - t_{bm}}{C_{r,cm}}\right)\right], 0.0$$

age_{rc} = 0

$C_{r,cm}$ =	0	mm/year
	0	

5.- Determine t_{min}

According to Data or ASME Sec. VIII

(left head)			(shell)			(right head)		
t_{min} =	38.92	mm	t_{min} =	27.49	mm	t_{min} =	38.92	mm
	1.532	inch		1.082	inch		1.532	inch

6.- Determine A_{rt}

$$A_{rt} = \frac{Cr_{b.m}.age_{tk}}{t_{rdi}}$$

RBI date :		Plan date :	
(left head)		(left head)	
A_{rt} =	0.009551838	A_{rt} =	0.019103676
(shell)		(shell)	
A_{rt} =	0.006131678	A_{rt} =	0.012263356
(right head)		(right head)	
A_{rt} =	0.006789398	A_{rt} =	0.013578796

$C_{r,bm}$ =	0.082222222	mm/year
$C_{r,bm}$ =	0.053333333	mm/year
$C_{r,bm}$ =	0.057777778	mm/year
age_{tk} =	5	year
age_{pd} =	10	year

7.- Calculate the flow stress FS^{thin}

$FS^{thin} = \frac{(YS+TS)}{2}.E.1,1$

FS^{thin} =	409750		Yield strength =	260000	kPa
			Tensile strength =	485000	kPa
			Joint efficiency =	1	

8.- Calculate strength ratio parameter (SR_p^{thin})

$SR_P^{thin} = \frac{S.E}{FS^{thin}}.\frac{Max\,(t_{min},\ t_c)}{t_{rdi}}.$

Allowable stress =	138000
Joint efficiency =	1

	(left head)		(shell)		(right head)
Sr_p^{thin} =	0.304551465	Sr_p^{thin} =	0.212885193	Sr_p^{thin} =	0.308058638

9.- Determine the number of inspections for each of the corresponding inspection effectiveness

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	2
N_D^{Thin} =	0

10. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinD}\right)^{N}$$

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

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

I_1^{Thin} =	0.1024	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	4.55625E-05	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000025	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

11. - Calculate the posterior probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Po_{p1}^{Thin} =	0.999552812
Po_{p2}^{Thin} =	0.000444747
Po_{p3}^{Thin} =	2.44031E-06

12.- Calculate the parameters

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$$\beta_2^{Thin} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$$\beta_3^{Thin} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$COV_{\Delta t}$ = coefficient of variances for thickness, 0.1≤ COV ≤0.2: 0.2

COV_{S_f} = flow stress coefficient of variance: 0.2

COV_P = pressure coefficient of variance: 0.05

D_{S_1} = damage step 1: 1

D_{S_2} = damage step 2: 2

D_{S_3} = damage step 3: 4

RBI date :

(left head)	
β_1^{Thin}	3.452212111
β_2^{Thin}	3.436598952
β_3^{Thin}	3.403427426

(shell)	
β_1^{Thin}	3.923311343
β_2^{Thin}	3.916376088
β_3^{Thin}	3.901776481

(right head)	
β_1^{Thin}	3.438775017
β_2^{Thin}	3.427748444
β_3^{Thin}	3.404734059

Plan date :

	(left head)
β_1^{Thin}	3.436598952
β_2^{Thin}	3.403427426
β_3^{Thin}	3.328627716

	(shell)
β_1^{Thin}	3.916376088
β_2^{Thin}	3.901776481
β_3^{Thin}	3.86947487

	(right head)
β_1^{Thin}	3.427748444
β_2^{Thin}	3.404734059
β_3^{Thin}	3.354624369

13.- For all component (excluding tank bottoms) calculate base damage factor

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(left head)
$D_{fB}^{Thin} =$ 1.78213277

(shell)
$D_{fB}^{Thin} =$ 0.279940118

(right head)
$D_{fB}^{Thin} =$ 1.872960361

Plan date :

(left head)
$D_{fB}^{Thin} =$ 1.888146799

(shell)
$D_{fB}^{Thin} =$ 0.288117055

(right head)
$D_{fB}^{Thin} =$ 1.950747219

14.- Determine the DF for thinning (D_f^{Thin})

$$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin}.F_{IP}.F_{DL}F_{WD}F_{AM}F_{SM}}{F_{OM}}\right), \quad 0.1\right]$$

$F_{IP} =$ DF ofr injection/ mix point (for piping circuit)
0

$F_{DL} =$ DF for dead legs (for piping only used to intermittent service)
0

$F_{WD} =$ DF for welded construction (for AST bottom only)
0

$F_{AM} =$ DF for AST maintenance in accordance (for AST bottom only)
0

$F_{SM} =$ DF for settlement (for AST bottom only)
0

$F_{OM} =$ DF for on-line monitoring
1

RBI date :

(left head)
$D_f^{Thin} =$ 0.1

(shell)
$D_f^{Thin} =$ 0.1

(right head)
$D_f^{Thin} =$ 0.1

Plan date :

(left head)
$D_f^{Thin} =$ 0.1

(shell)
$D_f^{Thin} =$ 0.1

(right head)
$D_f^{Thin} =$ 0.1

	PROBABILITY OF FAILURE SCC-SULFIDE STRESS CRACKING	Doc. PV : V-001

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity	Low	pH :	5.5 - 7.5
		H2S concentration	< 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	As-Welded Max Brinnel Hardness			PWHT Max Brinnel Hardness		
	< 200	200 - 237	> 237	< 200	200 - 237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderates	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

			(left head)
PWHT :	yes	Max brinnel hardness :	< 200
			(shell)
PWHT :	yes	Max brinnel hardness :	< 200
			(right head)
PWHT :	yes	Max brinnel hardness :	< 200

	(left head)
Enviromental severity :	Not
	(shell)
Enviromental severity :	Not
	(right head)
Enviromental severity :	Not

3.- Determine the severity index S_{v1}

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

	(left head)
Sv1 :	0
	(shell)
Sv1 :	0
	(right head)
Sv1 :	0

4.- Determine the time in-service, age

Age_{tk} =	5	Last Inspection	2019
Age_{PD} =	10	RBI date	2024
		Panned date	2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection :	1
Inspection effectiveness :	B

6.- Determine the base DF for sulfide stress cracking

S_{v1}	E	Inspection Effectiveness											
		1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{v1}	E	Inspection Effectiveness											
		4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

$D_{fB}^{SCC} =$	0		Number of inspection :	1
	0		Inspection effectiveness :	B
	0			

7. - Calculate the escalation in the DF based on the time service sing the last inspection

$$D_f^{SCC} = D_f^{SCC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$$

RBI Date :		**Plan Date :**	
(left head)		(left head)	
$D_f^{SCC} =$	0	$D_f^{SCC} =$	0
(shell)		(shell)	
$D_f^{SCC} =$	0	$D_f^{SCC} =$	0
(right head)		(right head)	
$D_f^{SCC} =$	0	$D_f^{SCC} =$	0

	PROBABILITY OF FAILURE SCC-HIC/SOHIC-H2S	Doc. PV : V-001

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low
pH : 5.5 - 7.5
H2S concentration: < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	High Sulfur Steel > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Seamless/ Extruded pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderates	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

	susceptibility :	sulfur content :	PWHT :
(left head)	low	≤ 0.01%	yes
(shell)	low	≤ 0.01%	yes
(right head)	low	≤ 0.01%	yes

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

(left head) Sv1 = 1
(shell) Sv1 = 1
(right head) Sv1 = 1

4.- Determine the time in-service, age

Age_{tk} = 5
Age_{PD} = 10

Last Inspection: 2019
RBI date: 2024
Panned date: 2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1
Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{vl}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10
S_{vl}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

(left head)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(shell)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(right head)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

Number of inspection : 1

Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

On-Line monitoring method	Adjusment Factors as a function of On-line monitoring- Fom
Key process variables	2
Hydrogen probes	2
Key process variables & hydrogen pr	4

On-Line monitoring method

F_{om} 2

8. - Calculate the final DF accounting based on time in-service since the last inespection

$$D_f^{HIC/SOHIC-H2S} = \frac{D_{fB}^{HIC/SOHIC-a2S} . (Max[age, 1.0])^{1.1}}{F_{OM}}$$

RBI Date :

(left head)

$D_f^{SC} =$ 2.936547358

(shell)

$D_f^{SC} =$ 2.936547358

(right head)

$D_f^{SC} =$ 2.936547358

Plan Date :

(left head)

$D_f^{SCC} =$ 6.294627059

(shell)

$D_f^{SCC} =$ 6.294627059

(right head)

$D_f^{SCC} =$ 6.294627059

Damage factor for stress corrosion cracking

$$D_{f-gov}^{SCC} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{HIC/SOHIC-H2S}, D_f^{ACSCC} \\ , D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC-H}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

RBI Date :

$D_{f-gov}^{SCC} =$ 2.936547358 (left head)

$D_{f-gov}^{SCC} =$ 2.936547358 (shell)

$D_{f-gov}^{SCC} =$ 2.936547358 (right head)

Plan Date :

$D_{f-gov}^{SCC} =$ 6.294627059 (left head)

$D_{f-gov}^{SCC} =$ 6.294627059 (shell)

$D_{f-gov}^{SCC} =$ 6.294627059 (right head)

PROBABILITY OF FAILURE
EXTERNAL CORROSION FACTOR

Doc. PV : V-001

1.- Determine furnished thickness,t and age

	(left head)			(shell)			(right head)	
t =	44.52	mm	t =	44.45	mm	t =	43.59	mm
	1.753	inch		1.75	inch		1.716	inch

age = 23 year

2.- Corrosion rate ($C_{r,bm}$) based on the driver and operating temperature

Operating tempertaure (°C)	Corrosion rate as a function of driver (mm/y)			
	Marine/ cooling tower drift area	Temperate	Acid/ dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.0127	0.076	0.025	0.254
32	0.0127	0.076	0.025	0.254
71	0.0127	0.051	0.025	0.254
107	0.025	0	0	0
121	0	0	0	0

$C_{r,bm}$ = 0.0127 mm/y

Opr. Temperature = 37.78 °C
100 °F

3. - Calculate the final corrosion rate, C_r

$$C_r = CR_B.max[F_{EQ}.F_{IF}]$$

$C_r =$ 0.0254

F_{EQ} = adjusment for equipment design or fabrication
2

F_{IF} = adjusment for interface
1

4. - Determine time in service, age_{tk}, since the last known inspection, t_{rde}

(left head)
head t_{rdi} = 43.04 mm
1.694 inch

(shell)
shell t_{rdi} = 43.49 mm
1.712 inch

(right head)
head t_{rdi} = 42.55 mm
1.675 inch

age_{tk} = 23 year
age_{pd} = 28 year

Last inspection date : 2001
RBI date : 2024
Plan date : 2029

5. - Determine time in-service, age_{coat}

$$age_{coat} = calculation\ date - coating\ installation\ date$$

RBI Calc. date : 2019
Coat. inst date : 2001
Plan Calc. date : 2029

RBI date :

$age_{coat} = calc.date - C.I\ date$

$age_{coat} =$ 18

Plan date :

$age_{coat} = planned\ date - C.I\ date$

$age_{coat} =$ 28

6. - Determine coating adjustment, $Coat_{adj}$

$if\ Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}]$	if high coating quality

$if\ Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}] - \min[5, Age_{coat} - Age_{tk}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}] - \min[15, Age_{coat} - Age_{tk}]$	if high coating quality

RBI date :

$Coat_{adj} =$ 15

Plan date :

$Coat_{adj} =$ 15

7. - Determine the in-service time, age, over which external corrosion may have occurred

$age = age_{tk} - coat_{adj}$

RBI date :			Plan date :		
age =	8	year	age =	13	year

8. - Determine allowable stress, S , weld joint eff., E, thick min., t_{min}

	(left head)			(shell)			(right head)	
t_{min} =	38.92	mm	t_{min} =	27.49	mm	t_{min} =	38.92	mm
	1.532	inch		1.082	inch		1.532	inch

S =		psi
	138000	kPa
E =	1	

9. - Determine A_{rt} parameter

$$A_{rt} = \frac{C_r . age}{t_{rde}}$$

RBI date :		**Plan date :**	
	(left head)		(left head)
head A_{rt} =	0.01357342	head A_{rt} =	0.016524164
	(shell)		(shell)
shell A_{rt} =	0.013432973	shell A_{rt} =	0.016353185
	(right head)		(right head)
head A_{rt} =	0.01372973	head A_{rt} =	0.016714454

10 . - Calculate Flow Stress ($FS^{extcorr}$)

$$FS^{extcorr} = \frac{(YS+TS)}{2}. E. 1,1$$

$FS^{extcorr} =$ 409750

YS =	260000	kPa
TS =	485000	kPa
E =	1	

11. - Calculate strength ratio parameter, $SR_P^{extcorr}$

$$SR_P^{extcorr} = \frac{S.E}{FS^{extcorr}} . \frac{Max\ (t_{min},\ t_c)}{t_{rde}} .$$

	(left head)		(shell)		(right head)
$SR_P^{extcorr} =$	0.304551465	$SR_P^{extcorr} =$	0.301400208	$SR_P^{extcorr} =$	0.308058638

12. - Determine the number of inspections

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	0
N_D^{Thin} =	0

13. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{extcorr} = Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrD}\right)^{i}$$

$$I_2^{extcorr} = Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrD}\right)^{i}$$

$$I_3^{extcorr} = Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrD}\right)^{i}$$

I_1^{Thin} =	0.4096	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	0.00050625	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000625	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

14. - Calculate posterior probabilities

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$Po_{p1}^{extcorr}$ =	0.998750343
$Po_{p2}^{extcorr}$ =	0.001234417
$Po_{p3}^{extcorr}$ =	1.52397E-05

15. - Calculate parameters, $\beta n^{extcorr}$

$$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$COV_{\Delta t}$ =	coefficient of variances for thickness, 0.1≤ COV ≤0.2	0.2
COV_{S_f} =	flow stress coefficient of variance	0.2
COV_P =	pressure coefficient of variance	0.05
D_{S_1} =	damage step 1	1
D_{S_2} =	damage step 2	2
D_{S_3} =	damage step 3	4

RBI date :		**Plan date :**	
	(left head)		(left head)
β_1^{Thin}	3.445715145	β_1^{Thin}	3.440877522
β_2^{Thin}	3.422955968	β_2^{Thin}	3.412648764
β_3^{Thin}	3.373368325	β_3^{Thin}	3.350003486
	(shell)		(shell)
β_1^{Thin}	3.462076873	β_1^{Thin}	3.457339652
β_2^{Thin}	3.439791345	β_2^{Thin}	3.429699726
β_3^{Thin}	3.391246915	β_3^{Thin}	3.36837878
	(right head)		(right head)
β_1^{Thin}	3.427499736	β_1^{Thin}	3.422549125
β_2^{Thin}	3.404207487	β_2^{Thin}	3.393657614
β_3^{Thin}	3.353445364	β_3^{Thin}	3.329521155

16.- Calculate DF for thinning (D_f^{extcor})

$$D_f^{extcor} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(Left head)
$D_f^{extcor} =$ 1.825687853

(Shell)
$D_f^{extcor} =$ 1.718216085

(Right head)
$D_f^{extcor} =$ 1.952682448

Plan date :

(Left head)
$D_f^{extcor} =$ 1.858694926

(Shell)
$D_f^{extcor} =$ 1.748757936

(Right head)
$D_f^{extcor} =$ 1.988648089

	PROBABILITY OF FAILURE	Doc. PV : V-001

PROBABILITY OF FAILURE

$P_f(t) = gff_{total}.D_f(t).F_{MS}$

$P_f(t)$ = Probability of Failure as a function of time
gff_{total} = Generic failure frequency
$D_f(t)$ = Total damage factor
F_{MS} = Management system factor

DETERMINING DAMAGE FACTOR

$D_f = max[D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ local thinning

$D_f = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ general thinning

RBI date :

(left head)
D_{f-to} = 4.76224

(shell)
$D_{f-total}$ = 4.65476

(right head)
D_{f-tota} = 4.88923

Plan date :

(left head)
$D_{f-total}$ = 8.15332

(shell)
$D_{f-total}$ = 8.04338

(right head)
D_{f-tot} = 8.28328

GENERIC FAILURE FREQUENCY

Equipment type	Component type	gff as a Function of hole size (failures/yr)				gfftotal (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	DRUM	0.000008	0.00002	0.000002	0.0000006	0.0000306

MANAGEMENT SYSTEM FACTOR

(Left head) Category
PoF = 0.0001457 2

(Shell)
PoF = 0.0001424 2

(Right Head)
PoF = 0.0001496 2

(Left head)
0.0002495 2

(Shell)
0.0002461 2

(Right Head)
0.0002535 2

	# CONSEQUENCE OF FAILURE	Doc. PV : V-001

1.- Release phase

1.1 - Representative fluids

C1 - C2

1.2 - Determine the store liquid phase

fluid phase = Gas

1.3 -

Store liquid		Store vapor or gas	
NBP =	-	NBP =	-125
Density =	-	MW =	23
AIT =	-	k =	1.22466
		Cp =	45.321385
		AIT =	558

1.4 - Determine the steady state phase of the fluid release

steady state phase = Gas

2.- Release hole size

2.1 - Determine release hole size diameter (dn)

Release hole number	Release hole size	Range of hole diameter	Release hole diameter, dn (mm)
1	Small	0 - 6.4	d_1 = 6.4
2	Medium	> 6.4 - 51	d_2 = 25
3	Large	> 51 - 152	d_3 = 102
4	Rupture	> 152	d_4 = 406

2.2 - Determine the generic failure frequency gffn

Component type =	DRUM	
gff small =	0.000008	failure/ year
gff medium =	0.00002	failure/ year
gff large =	0.000002	failure/ year
gff rupture =	0.0000006	failure/ year
gff_{total} =	0.0000306	failure/ year

3. - Release rate

3.1 - Select appropiate release rate equation according to stored fluid phase

Stored fluid phase =

3.2 - Calculate each release hole size area

$$A_n = \frac{\pi . d_n^2}{4}$$

A_{small} =	3.21699E-05	m^2
	0.049087385	$inch^2$
A_{medium} =	0.000490874	m^2
	0.785398163	$inch^2$
A_{large} =	0.008171282	m^2
	12.56637061	$inch^2$
$A_{rupture}$ =	0.129461892	m^2
	201.0619298	$inch^2$

3.3 - Calculate release rate (W_n) for each hole size

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

Ptrans = 180.9602839 kPa

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\, x\, A_n\, x\, P_s \sqrt{\frac{k\, x\, MW\, x\, g_c}{R\, x\, T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{small} =	0.01648	kg/s	Cd =	0.9	satuan
W_{medium} =	0.25152	kg/s	C2 =	1	mm^2/m^2
W_{large} =	4.18693	kg/s	Ps =	9239.3	kPa
$W_{rupture}$ =	66.33579	kg/s	k =	1.2246579	
			MW =	23	
			gc =	1	kg-m/N-s^2
			R =	8.314	J/kg-mol-K
			Ts =	310.93	K

For now choose between which value is exposed

W_{small} =	0.016484	kg/s
W_{medium} =	0.251522	kg/s
W_{large} =	4.186935	kg/s
$W_{rupture}$ =	66.335793	kg/s

4.- Calculation of inventory mass

4.1 - Determine the group components and equipment items into inventory groups

DRUM

4.2 - Calculate fluid mass ($mass_{comp}$) in the component

$mass_{component}$ = 741.390264 kg

4.3 - Calculate fluid mass in each of other component that are included in inventory group ($mass_{comp.i}$)

$mass_{comp,i}$= 1971.524669 kg

4.4 - Calculate the fluid mass in the inventory group ($mass_{inv}$)

$$mass_n = \sum_{i=1}^{N} mass_{comp,i}$$

$mass_{inv}$= 2712.914933 kg

4.5 - Calculate the flow rate 8 inch diameter hole (W_{max8})

Vapor phase

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\, x\, A_n\, x\, P_s \sqrt{\frac{k\, x\, MW\, x\, g_c}{R\, x\, T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{max8} =	16.58394818	kg/s	Cd =	0.9	satuan
			C2 =	1	mm^2/m^2
			Ps =	9239.3	kPa
			k =	1.2246579	
			MW =	23	
			gc =	1	kg-m/N-s^2
			R =	8.314	J/kg-mol-K
			Ts =	310.93	K

W_{max8} = 16.58394818 kg/s

4.6 - Calculate added fluid mass ($mass_{add,n}$) for each release hole size resulting from three minutes of flow from inventory group

$$mass_{add,n} = 180.\min[W_n, W_{max8}]$$

$mass_{add,1}$ =	2.96707	kgs
$mass_{add,2}$ =	45.27395	kgs
$mass_{add,3}$ =	753.64827	kgs
$mass_{add,4}$ =	2985.11067	kgs

4.7 - Calculate the available mass for release of each hole size ($mass_{avail,n}$)

$$mass_{avail} = min\left[\{mass_{comp} + mass_{add,n}\}, mass_{inv}\right]$$

$mass_{avail\ 1}$ =	744.35734	kgs
$mass_{avail\ 2}$ =	786.66421	kgs
$mass_{avail\ 3}$ =	1495.03853	kgs
$mass_{avail\ 4}$ =	2712.91493	kgs

5. - Release type

5.1 - Calculate time required to release 4,536 kgs of fluid for each hole size

$$t_n = \frac{C_3}{W_n}$$

C3 = 4536 kg

t_{small} =	275180.238	sec
t_{medium} =	18034.212	sec
t_{large} =	1083.370	sec
$t_{rupture}$ =	68.379	sec

5.2 - Determine the release type instaneous or continous

1.) if the release hole size is 6.35 mm(0.25 inch) = Continous

2.) if tn ≤ 180 sec and the release mass is greater than 4.536 kgs (10,000 lbs) = Instantaneous

t_{small} =	CONTINOUS
t_{medium} =	CONTINOUS
t_{large} =	CONTINOUS
$t_{rupture}$ =	INSTANTANEOUS

6. - Detection and isolation

6.1 - determine the dectection and isolation system

Type of detection system	Detection classification
Instrumentation designed spesifically to detect material losses by changes in operating conditions in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of isolation system	**Detection classification**
Isolation or shutdown systems activated directly from process instrumentation or detector, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually operated valves	C

6.2 - select appropiate classification for detection system

A

6.3 - select appropiate classification for isolation system

C

6.4 - determine the release reduction factor ($fact_{di}$)

System classification		Release magnitude adjusment	Reductioin factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A	C	Reduce release rate or mass by 10%	0.10
B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjusment to release rate or mass	0

release reduction factor = 0.1

6.5 - determine the total leak durations for each of the hole size ($ld_{dimax,n}$)

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 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
C	A, B or C	1 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks

$Id_{max,1}$ = 40 minutes
$Id_{max,2}$ = 30 minutes
$Id_{max,3}$ = 20 minutes
$Id_{max,4}$ = 20 minutes

7. - Release rate and mass

7.1 - calculate the adjusted release rate ($rate_n$) for each hole size

$$rate_n = W_n(1 - fact_{dl})$$

W_1 = 0.016483742 kg/s
W_2 = 0.25152194 kg/s
W_3 = 4.186934818 kg/s
W_4 = 66.33579273 kg/s

$rate_{small}$ = 0.01484 kg/s
$rate_{medium}$ = 0.22637 kg/s
$rate_{large}$ = 3.76824 kg/s
$rate_{rupture}$ = 59.70221 kg/s

7.2 - calculate the leak duration (ld_n) for each hole size

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}\{60.ld_{max,n}\}\right]$$

ld_{small} =	2400	s	$Id_{max,1}$ =	40	minutes
ld_{medium} =	1800	s	$Id_{max,2}$ =	30	minutes
ld_{large} =	396.7470228	s	$Id_{max,3}$ =	20	minutes
$ld_{rupture}$ =	45.44077641	s	$Id_{max,4}$ =	20	minutes

7.3 - calculate the release mass ($mass_n$) for each hole size

$$mass_n = min[\{rate_n \; x \; ld_n\}, mass_{avail,n}]$$

$mass_{small}$ =	35.60488	kg
$mass_{medium}$ =	407.46554	kg
$mass_{large}$ =	1495.03853	kg
$mass_{rupture}$ =	2712.91493	kg

8. - Determine flammable and explosive consequence

8.1 - Select the consequence area mitigatian reduction factor ($fact_{mit}$)

$fact_{mit}$ = 0.05

8.2 - Calculate the energy efficiency correction factor ($eneff_n$) for each release hole size

$$eneff_n = 4.log_{10}[C_{4A}.mass_n] - 15$$

C4A = 2.205 1/kg

$eneff_1$ =	0
$eneff_2$ =	0
$eneff_3$ =	0
$eneff_4$ =	0.10737908

8.3 - Determine the fluid type

fluid type = C1 - C2

8.4 - calculate component damage consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{cmd,n}^{AINL-CONT}$)

8.4.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AINL-CONT}$

a = 8.669

b = $b_{cmd}^{AINL-CON}$

b = 0.98

8.4.2 - calculate consequence area

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b . (1 - fact_{mit})$$

$fact_{mit}$ = 0.05

$Ca_{cmd.small}^{AINL-CONT}$ =	0.132912233	m^2
$Ca_{cmd.medium}^{AINL-CONT}$ =	1.92050138	m^2
$Ca_{cmd.large}^{AINL-CONT}$ =	30.22097999	m^2
$Ca_{cmd.rupture}^{AINL-CONT}$ =	0	m^2

8.5 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{cmd,n}^{AIL-CONT}$)

8.5.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AIL-CONT}$

a = 55.13

b = $b_{cmd}^{AIL-CONT}$

b = 0.95

8.5.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b . (1 - fact_{mit})$$

$fact_{mit}$ = 0.05

$Ca_{cmd.small}^{AIL-CONT}$ =	0.959058273	m^2
$Ca_{cmd.medium}^{AIL-CONT}$ =	12.76994603	m^2
$Ca_{cmd.large}^{AIL-CONT}$ =	184.6899959	m^2
$Ca_{cmd.rupture}^{AIL-CONT}$ =	0	m^2

8.6 - calculate component damage consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{cmd,n}^{AINL-INST}$)

8.6.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AINL-INS}$

a = 6.469

$b = b_{cmd}^{AINL-INST}$

b = 0.69

8.6.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b . \left(\frac{1 - fact_{mit}}{eneff_n}\right)$$

$Ca_{cmd1}^{AINL-INST}$ =	0	m^2	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AINL-INST}$ =	0	m^2		
$Ca_{cmd3}^{AINL-INST}$ =	0	m^2		
$Ca_{cmd4}^{AINL-INST}$ =	13387.88708	m^2		

8.7 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-INST ($Ca_{cmd,n}^{AIL-INST}$)

8.7.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 163.7

$b = b_{cmd}^{AIL-INST}$

b = 0.62

8.7.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b . \left(\frac{1 - fact_{mit}}{eneff_n}\right)$$

$Ca_{cmd1}^{AIL-INST}$ =	0	m^2	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AIL-INST}$ =	0	m^2		
$Ca_{cmd3}^{AIL-INST}$ =	0	m^2		
$Ca_{cmd4}^{AIL-INST}$ =	194797.3465	m^2		

8.8 - calculate personnel injury consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{inj,n}^{AINL-CONT}$)

8.8.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-CONT}$

a = 21.83

$b = b_{inj}^{AINL-CONT}$

b = 0.96

8.8.2 - calculate consequence area

$$CA_{inj,n}^{AINL-CONT} = [a.(rate_n^{AINL-CONT})\ ].(1 - fact_{mit})$$

$Ca_{inj1}^{AINL-CONT}$ =	0.364102551	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-CONT}$ =	4.981991575		
$Ca_{inj3}^{AINL-CONT}$ =	74.108923		
$Ca_{inj4}^{AINL-CONT}$ =	0		

8.9 - calculate personnel injury consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{inj,n}^{AIL-CONT}$)

8.9.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AIL-CONT}$

a = 143.2

$b = b_{inj}^{AIL-CONT}$

b = 0.92

8.9.2 - calculate consequence area

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

$Ca_{inj1}^{AIL-CONT}$ =	2.826578634	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AIL-CONT}$ =	34.6816328		
$Ca_{inj3}^{AIL-CONT}$ =	461.0141291		
$Ca_{inj4}^{AIL-CONT}$ =	0		

8.10 - calculate personnel injury consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{inj,n}^{AINL-INST}$)

8.10.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-INST}$

a = 12.46

$b = b_{inj}^{AINL-INS}$

b = 0.67

8.10.2 - calculate consequence area

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

$Ca_{inj1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-INST}$ =	0		
$Ca_{inj3}^{AINL-INST}$ =	0		
$Ca_{inj4}^{AINL-INST}$ =	22015.27975		

8.11 - calculate personnel injury consequence areas for auto-ignition likely, instantaneous release, AIL-INST ($Ca_{inj,n}^{AIL-INST}$)

8.11.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 473.9

$b = b_{cmd}^{AIL-INST}$

b = 0.63

8.11.2 - calculate consequence area

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

$CA_{inj1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$CA_{inj2}^{AIL-INST}$ =	0		
$CA_{inj3}^{AIL-INST}$ =	0		
$CA_{inj4}^{AIL-INST}$ =	610316.9446		

8.12 - calculate the instantaneous/ continous blending factor ($fact_n^{IC}$)

Continous

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$$

C5 = 25.2 kg/s

Instantaneous

$$fact_n^{IC} = 1.0$$

$fact_1^{IC}$ =	0.000588705
$fact_2^{IC}$ =	0.008982926
$fact_3^{IC}$ =	0.149533386
$fact_4^{IC}$ =	1

8.13 - calculate AIT (auto ignition temperature) blending factor ($fact^{AIT}$)

$T_s + C_6 \leq AIT$	$fact^{AIT} = 0$	C6 =	55.6 K
$T_s + C_6 > AIT > T_s - C_6$	$fact^{AIT} = \frac{T_s - AIT + C_6}{2.C_6}$	Ts =	37.78 C
			100 F
$T_s - C_6 \geq AIT$	$fact^{AIT} = 1$		310.93 K
$fact^{AIT}$ = 0		AIT =	558 K

8.14 - calculate the continous/ instantaneous blended consequnces areas for the component and the continous/ instantaneous blending factor ($fact_n^{IC}$)

8.14.1 - calculate continous/ instantaneous blended consequence area for auto ignition likely for component damage

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AIL}$ =	0.95849367 m^2	$CA_{cmd1}^{AIL-INST}$ =	0
		$fact_1^{IC}$ =	0.000588705
		$CA_{cmd1}^{AIL-CONT}$ =	0.959058273
$CA_{cmd,2}^{AIL}$ =	12.65523454 m^2	$CA_{cmd2}^{AIL-INST}$ =	0
		$fact_2^{IC}$ =	0.008982926
		$CA_{cmd2}^{AIL-CONT}$ =	12.76994603
$CA_{cmd,3}^{AIL}$ =	157.0726754 m^2	$CA_{cmd3}^{AIL-INST}$ =	0
		$fact_3^{IC}$ =	0.149533386
		$CA_{cmd3}^{AIL-CONT}$ =	184.6899959
$CA_{cmd,4}^{AIL}$ =	194797.3465 m^2	$CA_{cmd4}^{AIL-INST}$ =	194797.3465
		$fact_4^{IC}$ =	1
		$CA_{cmd4}^{AIL-CONT}$ =	0

8.14.2 - calculate continous/ instantaneous blended consequence area for auto ignition likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INS} .fact_n^{IC} + CA_{inj,n}^{AIL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AIL} =$	2.824914613 m^2	$CA_{inj1}^{AIL-INST} =$	0
		$fact_1^{IC} =$	0.000588705
		$CA_{inj1}^{AIL-CONT} =$	2.826578634
$CA_{inj,2}^{AIL} =$	34.37009024 m^2	$CA_{inj2}^{AIL-INST} =$	0
		$fact_2^{IC} =$	0.008982926
		$CA_{inj2}^{AIL-CONT} =$	34.6816328
$CA_{inj,3}^{AIL} =$	392.0771252 m^2	$CA_{inj3}^{AIL-INST} =$	0
		$fact_3^{IC} =$	0.149533386
		$CA_{inj3}^{AIL-CONT} =$	461.0141291
$CA_{inj,4}^{AIL} =$	610316.9446 m^2	$CA_{inj4}^{AIL-INST} =$	610316.9446
		$fact_4^{IC} =$	1
		$CA_{inj4}^{AIL-CONT} =$	0

8.14.3 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for component damage

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INS} .fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AINL} =$	0.132833987	$CA_{cmd1}^{AINL-INST} =$	0
		$fact_1^{IC} =$	0.000588705
		$CA_{cmd1}^{AINL-CONT} =$	0.132912233
$CA_{cmd,2}^{AINL} =$	1.903249658	$CA_{cmd2}^{AINL-INST} =$	0
		$fact_2^{IC} =$	0.008982926
		$CA_{cmd2}^{AINL-CONT} =$	1.92050138
$CA_{cmd,3}^{AINL} =$	25.70193451	$CA_{cmd3}^{AINL-INST} =$	0
		$fact_3^{IC} =$	0.149533386
		$CA_{cmd3}^{AINL-CONT} =$	30.22097999
$CA_{cmd,4}^{AINL} =$	13387.88708	$CA_{cmd4}^{AINL-INST} =$	13387.88708
		$fact_4^{IC} =$	1
		$CA_{cmd4}^{AINL-CONT} =$	0

8.14.4 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AINL-INST}.fact_n^{IC} + CA_{inj,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AINL} =$	0.363888202	$CA_{inj1}^{AINL-INST} =$	0
		$fact_1^{IC} =$	0.000588705
		$CA_{inj1}^{AINL-CONT} =$	0.364102551
$CA_{inj,2}^{AINL} =$	4.937238711	$CA_{inj2}^{AINL-INST} =$	0
		$fact_2^{IC} =$	0.008982926
		$CA_{inj2}^{AINL-CONT} =$	4.981991575
$CA_{inj,3}^{AINL} =$	63.02716479	$CA_{inj3}^{AINL-INST} =$	0
		$fact_3^{IC} =$	0.149533386
		$CA_{inj3}^{AINL-CONT} =$	74.108923
$CA_{inj,4}^{AINL} =$	22015.27975	$CA_{inj4}^{AINL-INST} =$	22015.27975
		$fact_4^{IC} =$	1
		$CA_{inj4}^{AINL-CONT} =$	0

8.15 - calculate AIT blended consequence areas for the component damage and personnel injury flammable consequence area

8.15.1 - calculate AIT blended consequence areas for daage component

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL}.fact^{AIT} + CA_{cmd,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{cmd1}^{flam} =$	0.132833987	$CA_{cmd1}^{AIL} =$	0.95849367
		$fact^{AIT} =$	0
		$CA_{cmd1}^{AINL} =$	0.132833987
$CA_{cmd2}^{flam} =$	1.903249658	$CA_{cmd2}^{AIL} =$	12.65523454
		$fact^{AIT} =$	0
		$CA_{cmd2}^{AINL} =$	1.903249658
$CA_{cmd3}^{flam} =$	25.70193451	$CA_{cmd3}^{AIL} =$	157.0726754
		$fact^{AIT} =$	0
		$CA_{cmd3}^{AINL} =$	25.70193451
$CA_{cmd4}^{flam} =$	13387.88708	$CA_{cmd4}^{AIL} =$	194797.3465
		$fact^{AIT} =$	0
		$CA_{cmd4}^{AINL} =$	13387.88708

8.15.2 - calculate AIT blended consequence areas for personnel injury

$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}.fact^{AIT} + CA_{inj,n}^{AINL}.(1 - fact^{AIT})$

$CA_{inj,1}^{AINL}$ =	0.363888202
$CA_{inj,2}^{AINL}$ =	4.937238711
$CA_{inj,3}^{AINL}$ =	63.02716479
$CA_{inj,4}^{AINL}$ =	22015.27975

CA_{inj1}^{AIL} =	2.824914613
$fact^{AIT}$ =	0
CA_{inj1}^{AINL} =	0.363888202
CA_{inj2}^{AIL} =	34.37009024
$fact^{AIT}$ =	0
CA_{inj2}^{AINL} =	4.937238711
CA_{inj3}^{AIL} =	392.0771252
$fact^{AIT}$ =	0
CA_{inj3}^{AINL} =	63.02716479
CA_{inj4}^{AIL} =	610316.9446
$fact^{AIT}$ =	0
CA_{inj4}^{AINL} =	22015.27975

8.16 - determine the final consequence areas for component damage and personnel injury

$$CA_{cmd,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1.CA_{cmd,1}^{flam}\right) + \left(gff_2.CA_{cmd,2}^{flam}\right) + \left(gff_3.CA_{cmd,3}^{flam}\right) + \left(gff_4.CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{cmd,n}^{flam}$ = 265.46614 m^2

$$CA_{inj,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj,n}^{flam} = \left(\frac{\left(gff_1.CA_{inj,1}^{flam}\right) + \left(gff_2.CA_{inj,2}^{flam}\right) + \left(gff_3.CA_{inj,3}^{flam}\right) + \left(gff_4.CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{inj,n}^{flam}$ = 439.11366 m^2

9.- Calculation of toxic consequences areas

9.1 - calculate the effective duration of toxic release

$$Id_n^{tox} = min\left(3600, \left\{\frac{mass_n}{W_n}\right\}, \{60.Id_{max.n}\}\right)$$

$CA_{inj,1}^{CONT}$ =	2160 s	$mass_1$ =	35.60488238	W_1 =	0.016484	$Id_{max.1}$ =	40
$CA_{inj,2}^{CONT}$ =	1620 s	$mass_2$ =	407.4655424	W_2 =	0.251522	$Id_{max.2}$ =	30
$CA_{inj,3}^{CONT}$ =	357.0723205 s	$mass_3$ =	1495.038531	W_3 =	4.186935	$Id_{max.3}$ =	20
$CA_{inj,4}^{CONT}$ =	40.89669877 s	$mass_4$ =	2712.914933	W_4 =	66.335793	$Id_{max.4}$ =	20

9.2 - determine the toxic percentage of the toxic component ($mfrac^{tox}$)

$mfrac^{tox}$ =	0.0001	H_2S =	0.01%
$mfrac^{tox}$ =	0.000017	Cl =	0.0017%

9.3 - calculate the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$

For H_2S

$rate_n^{tox} = mfrac^{tox}.W_n$

$rate_1^{tox}$ =	1.64837E-06 kg/s	W_1 =	0.016484 kg/s
$rate_2^{tox}$ =	2.51522E-05 kg/s	W_2 =	0.251522 kg/s
$rate_3^{tox}$ =	0.000418693 kg/s	W_3 =	4.186935 kg/s
$rate_4^{tox}$ =	0.006633579 kg/s	W_4 =	66.335793 kg/s

$mass_n^{tox} = mfrac^{tox}.mass_n$

$mass_1^{tox}$ =	0.003560488 kgs	$mass_1$ =	35.60488 kgs
$mass_2^{tox}$ =	0.040746554 kgs	$mass_2$ =	407.46554 kgs
$mass_3^{tox}$ =	0.149503853 kgs	$mass_3$ =	1495.03853 kgs
$mass_4^{tox}$ =	0.271291493 kgs	$mass_4$ =	2712.91493 kgs

For Cl

$rate_n^{tox} = mfrac^{tox}.W_n$

$rate_1^{tox}$ =	2.80224E-07 kg/s
$rate_2^{tox}$ =	4.27587E-06 kg/s
$rate_3^{tox}$ =	7.11779E-05 kg/s
$rate_4^{tox}$ =	0.001127708 kg/s

$mass_n^{tox} = mfrac^{tox}.mass_n$

$mass_1^{tox}$ =	0.000605283 kgs
$mass_2^{tox}$ =	0.006926914 kgs
$mass_3^{tox}$ =	0.025415655 kgs
$mass_4^{tox}$ =	0.046119554 kgs

9.4 - calculate the toxic consequence area

$$CA_{inj,n}^{tox-CON} = C_8 . 10^{\left(c.log_{10}\left[C_{4B}.rate_n^{tox}\right]+d\right)}$$

$$CA_{inj,n}^{tox-INST} = C_8 . 10^{\left(c.log_{10}\left[C_{4B}.mass_n^{tox}\right]+d\right)}$$

$CA_{inj,small}^{tox-CON} =$	0.000539985	m^2
$CA_{inj,medium}^{tox-CON} =$	0.015278723	m^2
$CA_{inj,large}^{tox-CON} =$	0.283202931	m^2
$CA_{inj.rupture}^{ox-IN} =$	34.36650317	m^2

$C_8 =$	0.0929	m^2. sec
c1 =	1.2266	
c2 =	1.2266	
c3 =	1.237	
c4 =	0.9674	
d1 =	4.4365	
d2 =	4.4365	
d3 =	4.238	
d4 =	2.784	
$C_{4B} =$	2.205	sec/kg

$$CA_{inj,n}^{tox-CONT} = e\left(rate_n^{tox}\right)^f$$

$$CA_{inj,n}^{tox-INST} = e\left(mass_n^{tox}\right)^f$$

$CA_{inj,small}^{tox-CONT} =$	0.0006487	m^2
$CA_{inj,medium}^{tox-CONT} =$	0.0082419	m^2
$CA_{inj,large}^{tox-CONT} =$	0.1275033	m^2
$CA_{inj.rupture}^{ox-INST} =$	94.3889894	m^2

e1 =	6860
e2 =	5312
e3 =	4191
e4 =	3528
f1 =	1.072
f2 =	1.082
f3 =	1.089
f4 =	1.177

9.5 - if there is additional toxic component step 9.2 through 9.4 should be repeated

9.6 - determine the final toxic consequnces areas for personnel injury

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n . CA_{inj.n}^{tox}}{gff_{total}}\right)$$

$$CA_{inj,n}^{tox} = \left(\frac{\left(gff_1 . CA_{inj,1}^{tox}\right) + \left(gff_2 . CA_{cinj2}^{tox}\right) + \left(gff_3 . CA_{inj,3}^{tox}\right) + \left(gff_4 . CA_{inj,4}^{tox}\right)}{gff_{total}}\right)$$

$CA_{inj}^{tox} =$ 2.56714 m^2

10. - calculation of non-flammable, Non-toxic consequences area

10.1 - calculate CA $_{inj.n}^{CONT}$ and CA $_{inj.n}^{INST}$

for acid caustic

$$CA_{inj,n}^{CONT} = 0.2 . C_8 . g \left(C_4 . rate_n\right)^h$$

$$CA_{inj,n}^{INST} = 0$$

$$g = 2696 - 21.9 . C_{11}(P_s - P_{atm}) + 1.474\left[C_{11}(P_s - P_{atm})\right]^2$$

g = 2664.605841

$$h = 0.31 - 0.00032\left[C_{11}(P_s - P_{atm}) - 40\right]^2$$

h = 0.081021712

$CA_{inj,n}^{CONT} =$	37.52646849
$CA_{inj,n}^{CONT} =$	46.79813202
$CA_{inj,n}^{CONT} =$	58.77355792
$CA_{inj,n}^{INST} =$	0

$rate_{small} =$	0.014835	kg/s
$rate_{med} =$	0.226370	kg/s
$rate_{large} =$	3.768241	kg/s
$rate_{ruptr} =$	59.702213	kg/s
$C_8 =$	0.0929	m^2. sec
$C_4 =$	2.205	sec/kg
$C_{11} =$	0.145	1/kPa
$P_s =$	9239.3	kPa
$P_{atm} =$	101.28755	kPa

10.2 - calculate the instantaneous/continous blending factor $fact_n^{IC}$

$$fact_{in}^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1\right],$$

$fact_{small}^{IC} =$	0.000588705	$C_5 =$	25.2	kg/sec
$fact_{medium}^{IC} =$	0.008982926	$P_s =$	9239.3	kPa
$fact_{large}^{IC} =$	0.149533386	$P_{atm} =$	101.28755	kPa
$fact_{rupture}^{IC} =$	1			

10.3 - calculate the blended non-flammable, non-toxic personnel injury consequence area for steam acid leaks $CA_{inj.n}^{leak}$

$CA_{cmd.n}^{leak} =$ 0

$$CA_{lak.n}^{leak} = CA_{inj.n}^{INST}.fact_n^{IC} + CA_{inj.n}^{CONT}.(1 - fact_n^{IC})$$

$fact_n^{IC} =$	0.0005887
$fact_n^{IC} =$	0.0089829
$fact_n^{IC} =$	0.1495334
$fact_n^{IC} =$	1

$CA_{lak.n}^{leak} =$	37.50437646	m^2
$CA_{lak.n}^{leak} =$	46.37774785	m^2
$CA_{lak.n}^{leak} =$	49.98494878	m^2
$CA_{lak.n}^{leak} =$	0	m^2

10.4 - determine the final non-flammable, non-toxic personnel injury CA_{inj}^{nfnt}

$CA_{cmd.n}^{nfnt} =$ 0

$$CA_{inj}^{nfnt} = \left(\frac{(gff_1.CA_{cmd,1}^{leak}) + (gff_2.CA_{cmd,2}^{leak}) + (gff_3.CA_{cmd,3}^{leak}) + (gff_4.CA_{cmd,4}^{leak})}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 43.38431 m^2

11. - Calculation of final consequence area

11.1 - calculate the final component damage consequence area, CA_{cmd}

$$CA_{cmd} = CA_{cmd}^{flam}$$

$CA_{cmd} =$ 265.46614 m^2

11.2 - calculate the final personnel injury consequence area, CA_{inj}

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$$

$CA_{inj} =$ 439.11366 m^2

11.3 - calculate the final consequence area, CA

$$CA = \max[CA_{cmd}, CA_{inj}]$$

CA = 439.11366 m^2 Category C

GENERAL DATA

Doc. PV : V-002

General Data :

Design code :			Date RBI assessment :	2024
Equipment Name :	V-002		Date last inspection :	2019
Vessel type :	Horizontal Vessel		Plan date :	2029
Size :				
Diameter :	863.6	mm		
Volume total :	2.448	m^3		
Year built :	1996			
Fluid category :	C1- C2			
Fluid phase :	Liquid			
Cladding :	No			
Coating :	High			
Design pressure :	56.88	bar		
	825	psi		
Design temperature :	93.33	°C		
	200	°F		
Operating pressure :	48.95	bar		
	710	psi		
	4895.45	kPa		
Operating temperature :	48.89	°C		
	120	°F		
	322.04	°K		
Atmospheric pressure :	101.28755	kPa		

Head data 1 :

Type :	2:1 Ellipsoidal	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	25.31	mm
	0.996	inch
Minimum wall thickness :	17.490	mm
	0.689	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	24.020	mm
	0.946	inch

Head data 2 :

Type :	2:1 Ellipsoidal	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	25.28	mm
	0.995	inch
Minimum wall thickness :	17.490	mm
	0.689	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	24.060	mm
	0.947	inch

Shell data :

Type :	Cylindrical shell	
Material :	SA 516 Gr.70	
Joint efficiency :	1	
Thickness :	25.4	mm
	1	inch
Minimum wall thickness :	17.73	mm
	0.698	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	23.420	mm
	0.922	inch

Material data :

Allowable stress :	138000	kPa
Tensile strength :	485000	kPa
Yield strength :	260000	kPa
Mass density (ρ_m) :	250.512	kg/m^3

1.-Furnished thickness & Age

(left head)			(shell)			(right head)		
head t =	25.31	mm	shell t =	25.4	mm	head t =	25.28	mm
	0.996456693	inch		1	inch		0.995275591	inch

age = 28 year

2.-Corrosion rate for base metal ($C_{r,bm}$)

Based on API 510

$$LTCR = \frac{t_{initial} - t_{actual}}{years\ between}$$

left head $C_{r,bm}$ =	0.056086957	mm/year
shell $C_{r,bm}$ =	0.086086957	mm/year
right head $C_{r,bm}$ =	0.053043478	mm/year

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

(left head)		
t_{rdi} =	24.02	mm
	0.945669291	inch
(shell)		
t_{rdi} =	23.42	mm
	0.922047244	inch
(right head)		
t_{rdi} =	24.06	mm
	0.947244094	inch
age_{tk} =	5	year
age_{pd} =	10	year

Last inspection date :	2019
RBI date :	2024
Plan date :	2029

4.- For cladding/ weld overlay pressure vessel components, calculate the age from the date of the starting thickness from STEP 3 required to corrode away the cladding/ weld overlay material (age_{rc})

$$age_{rc} = \left[\left(\frac{t_{rdi} - t_{bm}}{C_{r,cm}}\right)\right], 0.0$$

age_{rc} = 0

$C_{r,cm}$ = 0 mm/year

0

5.- Determine t_{min}

According to Data or ASME Sec. VIII

	(left head)			(shell)			(right head)	
t_{min} =	17.49	mm	t_{min} =	17.73	mm	t_{min} =	17.49	mm
	0.688582677	inch		0.698031496	inch		0.688582677	inch

6.- Determine A_{rt}

$$A_{rt} = \frac{Cr_{b.m}.age_{tk}}{t_{rdi}}$$

RBI date :		Plan date :	
(left head)		(left head)	
A_{rt} =	0.011675053	A_{rt} =	0.023350107
(shell)		(shell)	
A_{rt} =	0.01837894	A_{rt} =	0.036757881
(right head)		(right head)	
A_{rt} =	0.011023167	A_{rt} =	0.022046333

$C_{r,bm}$ =	0.056086957	mm/year
$C_{r,bm}$ =	0.086086957	mm/year
$C_{r,bm}$ =	0.053043478	mm/year
age_{tk} =	5	year
age_{pd} =	10	year

7.- Calculate the flow stress FS^{thin}

$$FS^{thin} = \frac{(YS+TS)}{2} . E . 1,1$$

FS^{thin} =	409750		Yield strength =	260000 kPa
			Tensile strength =	485000 kPa
			Joint efficiency =	1

8.- Calculate strength ratio parameter (SR_p^{thin})

$$SR_P^{thin} = \frac{S.E}{FS^{thin}} . \frac{Max\,(t_{min},\ t_c)}{t_{rdi}} .$$

Allowable stress =	138000
Joint efficiency =	1

(left head)		(shell)		(right head)	
Sr_p^{thin} =	0.245231882	Sr_p^{thin} =	0.254965823	Sr_p^{thin} =	0.244824181

9.- Determine the number of inspections for each of the corresponding inspection effectiveness

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	2
N_D^{Thin} =	0

10. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinD}\right)^{N}$$

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

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

I_1^{Thin}=	0.1024	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin}=	4.55625E-05	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin}=	0.00000025	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

11. - Calculate the posterior probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Po_{p1}^{Thin}=	0.999552812
Po_{p2}^{Thin}=	0.000444747
Po_{p3}^{Thin}=	2.44031E-06

12.- Calculate the parameters

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$$\beta_2^{Thin} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$$\beta_3^{Thin} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{Thin}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + \left(SR_P^{Thin}\right)^2.COV_P{}^2}}$$

$COV_{\Delta t}$ = coefficient of variances for thickness, 0.1≤ COV ≤0.2
0.2

COV_{S_f} = flow stress coefficient of variance
0.2

COV_P = pressure coefficient of variance
0.05

D_{S_1} = damage step 1
1

D_{S_2} = damage step 2
2

D_{S_3} = damage step 3
4

RBI date :		**Plan date :**	
(left head)		(left head)	
β_1^{Thin}	3.751883057	β_1^{Thin}	3.736105665
β_2^{Thin}	3.736105665	β_2^{Thin}	3.70169653
β_3^{Thin}	3.70169653	β_3^{Thin}	3.620132834
(shell)		(shell)	
β_1^{Thin}	3.692878942	β_1^{Thin}	3.665842738
β_2^{Thin}	3.665842738	β_2^{Thin}	3.604192292
β_3^{Thin}	3.604192292	β_3^{Thin}	3.445144544
(right head)		(right head)	
β_1^{Thin}	3.754818322	β_1^{Thin}	3.740017325
β_2^{Thin}	3.740017325	β_2^{Thin}	3.707887339
β_3^{Thin}	3.707887339	β_3^{Thin}	3.63240439

13.- For all component (excluding tank bottoms) calculate base damage factor

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(left head)
$D_{fB}^{Thin} =$ 0.56255285

(shell)
$D_{fB}^{Thin} =$ 0.710707818

(right head)
$D_{fB}^{Thin} =$ 0.556000102

Plan date :

(left head)
$D_{fB}^{Thin} =$ 0.599053047

(shell)
$D_{fB}^{Thin} =$ 0.790242965

(right head)
$D_{fB}^{Thin} =$ 0.589803673

14.- Determine the DF for thinning (D_f^{Thin})

$$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin}.F_{IP}.F_{DL}F_{WD}F_{AM}F_{SM}}{F_{OM}}\right), \quad 0.1\right]$$

$F_{IP} =$ DF ofr injection/ mix point (for piping circuit)
0

$F_{DL} =$ DF for dead legs (for piping only used to intermittent service)
0

$F_{WD} =$ DF for welded construction (for AST bottom only)
0

$F_{AM} =$ DF for AST maintenance in accordance (for AST bottom only)
0

$F_{SM} =$ DF for settlement (for AST bottom only)
0

$F_{OM} =$ DF for on-line monitoring
1

RBI date :

(left head)
$D_f^{Thin} =$ 0.1

(shell)
$D_f^{Thin} =$ 0.1

(right head)
$D_f^{Thin} =$ 0.1

Plan date :

(left head)
$D_f^{Thin} =$ 0.1

(shell)
$D_f^{Thin} =$ 0.1

(right head)
$D_f^{Thin} =$ 0.1

PROBABILITY OF FAILURE

SCC-SULFIDE STRESS CRACKING

Doc. PV : V-002

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low

pH : 5.5 - 7.5

H2S concentration : < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	As-Welded Max Brinnel Hardness			PWHT Max Brinnel Hardness		
	< 200	200 - 237	> 237	< 200	200 - 237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderates	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

			(left head)
PWHT :	no	Max brinnel hardness :	< 200
			(shell)
PWHT :	no	Max brinnel hardness :	< 200
			(right head)
PWHT :	no	Max brinnel hardness :	< 200

	(left head)
Enviromental severity :	Low
	(shell)
Enviromental severity :	Low
	(right head)
Enviromental severity :	Low

3.- Determine the severity index S_{v1}

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

	(left head)
Sv1 :	1
	(shell)
Sv1 :	1
	(right head)
Sv1 :	1

4.- Determine the time in-service, age

Age_{tk} = 5

Age_{PD} = 10

Last Inspection 2019

RBI date 2024

Panned date 2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1

Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{v1}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{v1}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

$D_{fB}^{SCC} =$ 1, 1, 1

Number of inspection : 1

Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

$$D_f^{SCC} = D_f^{SCC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$$

RBI Date :		Plan Date :	
(left head)		(left head)	
$D_f^{SCC} =$	5.873094715	$D_f^{SCC} =$	5.873094715
(shell)		(shell)	
$D_f^{SCC} =$	5.873094715	$D_f^{SCC} =$	5.873094715
(right head)		(right head)	
$D_f^{SCC} =$	5.873094715	$D_f^{SCC} =$	5.873094715

	PROBABILITY OF FAILURE SCC-HIC/SOHIC-H2S	Doc. PV : V-002

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low — pH : 5.5 - 7.5
H2S concentration : < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	High Sulfur Steel > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Seamless/ Extruded pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderates	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

susceptibility :	(left head) low	sulfur content :	(left head) ≤ 0.01%	PWHT :	(left head) no
	(shell) low	sulfur content :	(shell) ≤ 0.01%	PWHT :	(shell) no
	(right head) low	sulfur content :	(right head) ≤ 0.01%	PWHT :	(right head) no

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

(left head) Sv1 = 1
(shell) Sv1 = 1
(right head) Sv1 = 1

4.- Determine the time in-service, age

Age_{tk} =	5	Last Inspection	2019
Age_{PD} =	10	RBI date	2024
		Panned date	2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1
Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{vl}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{vl}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

(left head)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(shell)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(right head)

$D_{fB}^{HIC/SOHIC-H2} =$ 1

Number of inspection : 1

Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

On-Line monitoring method	Adjusment Factors as a function of On-line monitoring- Fom
Key process variables	2
Hydrogen probes	2
Key process variables & hydrogen p	4

On-Line monitoring method

F_{om} 2

8. - Calculate the final DF accounting based on time in-service since the last inespection

$$D_f^{HIC/SOHIC-H2} = \frac{D_{fB}^{HIC/SOHIC-a2S} \cdot (Max[age,1.0])^{1.1}}{F_{OM}}$$

RBI Date :

(left head)

$D_f^{SC} =$ 2.936547358

(shell)

$D_f^{SC} =$ 2.936547358

(right head)

$D_f^{SC} =$ 2.936547358

Plan Date :

(left head)

$D_f^{SCC} =$ 6.294627059

(shell)

$D_f^{SCC} =$ 6.294627059

(right head)

$D_f^{SCC} =$ 6.294627059

PROBABILITY OF FAILURE

SCC-ACSCC

Doc. PV : V-002

1.-Determine susceptibility for cracking based on PH water and CO3 concentration

pH of water	Susceptibility to cracking as co3 concentration in water		
	PWHT, possible cold working	No PWHT, possible cold working	
	CO_3 all concentration	CO_3 < 100 ppm	CO_3 ≥ 100 ppm
< 7.5	None	None	None
≥ 7.5 - 8.0	None	Low	Medium
≥ 8.0 - 9.0	None	Low	High
≥ 9.0	None	High	High

Env. Severity: Medium

pH : ≥ 7.5 - 8.0

CO_3 concentration : No PWHT, possible cold working

2.-Determine the severity index, S_{vt}

Susceptibility	Severity Index-Sv1
High	1000
Medium	100
Low	10
None	0

(left head) Sv1 = 100

(shell) Sv1 = 100

(right head) Sv1 = 100

3.-Time in service (age_{tk}), since the last inspection

Age_{tk} = 5

Age_{PD} = 10

Last Inspection 2019

RBI date 2024

Panned date 2029

4.- Determine the number of inspection and the corresponding inspection effectiveness category

S_{vl}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{vl}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

Number of inspection : 1

Inspection effectiveness : B

5.- Determine the base DF for alkaline carbonate stress corrosion cracking

	(left head)	Number of inspection :	1
$D_{fB}^{ACSCC} =$	10	Inspection effectiveness :	B
	(shell)		
$D_{fB}^{ACSCC} =$	10		
	(right head)		
$D_{fB}^{ACSCC} =$	10		

6. - Calculate the final DF accounting based on time in-service since the last inespection

$$D_f^{SCC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$$

RBI Date :		**Plan Date :**	
	(left head)		(left head)
$D_f^{SC} =$	58.73094715	$D_f^{SCC} =$	125.8925412
	(shell)		(shell)
$D_f^{SC} =$	58.73094715	$D_f^{SCC} =$	125.8925412
	(right head)		(right head)
$D_f^{SC} =$	58.73094715	$D_f^{SCC} =$	125.8925412

Damage factor for stress corrosion cracking

$$D_{f-go}^{SCC} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{HIC/SOHIC-H2}, D_f^{ACSCC} \\ , D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC-HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

RBI Date :			Plan Date :		
$D_{f-gov}^{SCC} =$	58.73094715	(left head)	$D_{f-gov}^{SCC} =$	125.8925412	(left head)
$D_{f-gov}^{SCC} =$	58.73094715	(shell)	$D_{f-gov}^{SCC} =$	125.8925412	(shell)
$D_{f-gov}^{SCC} =$	58.73094715	(right head)	$D_{f-gov}^{SCC} =$	125.8925412	(right head)

PROBABILITY OF FAILURE
EXTERNAL CORROSION

Doc. PV : V-002

1.- Determine furnished thickness,t and age

	(left head)			(shell)			(right head)	
t =	25.31	mm	t =	25.4	mm	t =	25.28	mm
	0.996456693	inch		1	inch		0.995275591	inch

age = 28 year

2.- Corrosion rate ($C_{r,bm}$) based on the driver and operating temperature

Operating tempertaure (°C)	Corrosion rate as a function of driver (mm/y)			
	Marine/ cooling tower drift area	Temperate	Acid/ dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.0127	0.076	0.025	0.254
32	0.0127	0.076	0.025	0.254
71	0.0127	0.051	0.025	0.254
107	0.025	0	0	0
121	0	0	0	0

$C_{r,bm}$ = 0.0127 mm/y

Opr. Temperature = 48.89 °C
120 °F

3. - Calculate the final corrosion rate, C_r

$C_r = CR_B.max[F_{EQ}.F_{IF}]$

$C_r =$ 0.0254

F_{EQ} = adjusment for equipment design or fabrication
2

F_{IF} = adjusment for interface
1

4. - Determine time in service, age_{tk}, since the last known inspection, t_{rde}

(left head)
head t_{rdi} = 24.02 mm
0.945669291 inch

(shell)
shell t_{rdi} = 23.42 mm
0.922047244 inch

(right head)
head t_{rdi} = 24.06 mm
0.947244094 inch

age_{tk} = 28 year
age_{pd} = 33 year

Last inspection date : 1996
RBI date : 2024
Plan date : 2029

5. - Determine time in-service, age_{coat}

$age_{coat} = calculation\ date - coating\ installation\ date$

RBI Calc. date : 2024
Coat. inst date : 1996
Plan Calc. date : 2029

RBI date :

$age_{coat} = calc.date - C.I\ date$

$age_{coat} =$ 28

Plan date :

$age_{coat} = planned\ date - C.I\ date$

$age_{coat} =$ 33

6. - Determine coating adjustment, $Coat_{adj}$

$if\ Age_{tk} \geq Age_{coat}$	
$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}]$	if high coating quality

$if\ Age_{tk} < Age_{coat}$	
$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}] - \min[5, Age_{coat} - Age_{tk}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}] - \min[15, Age_{coat} - Age_{tk}]$	if high coating quality

RBI date :

$Coat_{adj} =$ 15

Plan date :

$Coat_{adj} =$ 15

7. - Determine the in-service time, age, over which external corrosion may have occurred

$$age = age_{tk} - coat_{adj}$$

RBI date :			Plan date :		
age =	13	year	age =	18	year

8. - Determine allowable stress, S , weld joint eff., E, thick min., t_{min}

	(left head)			(shell)			(right head)	
t_{min} =	17.49	mm	t_{min} =	17.73	mm	t_{min} =	17.49	mm
	0.688582677	inch		0.698031496	inch		0.688582677	inch

S =	20000	psi
	138000	kPa
E =	1	

9. - Determine A_{rt} parameter

$$A_{rt} = \frac{C_r.\,age}{t_{rde}}$$

RBI date :		**Plan date :**	
	(left head)		(left head)
head A_{rt} =	0.029608659	head A_{rt} =	0.03489592
	(shell)		(shell)
shell A_{rt} =	0.030367208	shell A_{rt} =	0.035789923
	(right head)		(right head)
head A_{rt} =	0.029559435	head A_{rt} =	0.034837905

10 . - Calculate Flow Stress ($FS^{extcorr}$)

$$FS^{extcorr} = \frac{(YS+T\ )}{2}.\,E.\,1{,}1$$

		YS =	260000	kPa
		TS =	485000	kPa
$FS^{extcorr}$ =	409750	E =	1	

11. - Calculate strength ratio parameter, $SR_P^{extcorr}$

$$SR_P^{extcorr} = \frac{S.E}{FS^{extcorr}} \cdot \frac{Max\ (t_{min},\ t_c)}{t_{rde}}.$$

	(left head)		(shell)		(right head)
$SR_P^{extcorr}$ =	0.245231882	$SR_P^{extcorr}$ =	0.251514509	$SR_P^{extcorr}$ =	0.244824181

12. - Determine the number of inspections

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	0
N_D^{Thin} =	0

13. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{extcorr} = Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrD}\right)^{i}$$

$$I_2^{extcorr} = Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrD}\right)^{i}$$

$$I_3^{extcorr} = Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrD}\right)^{i}$$

I_1^{Thin} =	0.4096	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	0.00050625	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000625	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

14. - Calculate posterior probabilities

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$Po_{p1}^{extcorr}$ =	0.998750343
$Po_{p2}^{extcorr}$ =	0.001234417
$Po_{p3}^{extcorr}$ =	1.52397E-05

15. - Calculate parameters, $\beta n^{extcorr}$

$$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$COV_{\Delta t}$ = coefficient of variances for thickness, 0.1≤ COV ≤0.2: 0.2

COV_{S_f} = flow stress coefficient of variance: 0.2

COV_P = pressure coefficient of variance: 0.05

D_{S_1} = damage step 1: 1

D_{S_2} = damage step 2: 2

D_{S_3} = damage step 3: 4

RBI date :

	(left head)
β_1^{Thin}	3.727265403
β_2^{Thin}	3.681580558
β_3^{Thin}	3.568509079

	(shell)
β_1^{Thin}	3.693477527
β_2^{Thin}	3.64535557
β_3^{Thin}	3.526071926

	(right head)
β_1^{Thin}	3.729456053
β_2^{Thin}	3.683927081
β_3^{Thin}	3.571252523

Plan date :

	(left head)
β_1^{Thin}	3.719582321
β_2^{Thin}	3.663620618
β_3^{Thin}	3.520093368

	(shell)
β_1^{Thin}	3.685387748
β_2^{Thin}	3.626425392
β_3^{Thin}	3.474929322

	(right head)
β_1^{Thin}	3.72179899
β_2^{Thin}	3.666029167
β_3^{Thin}	3.52301092

16.- Calculate DF for thinning (D_f^{extcor})

$$D_f^{extcor} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(Left head)
$D_f^{extcor} =$ 0.620571

(Shell)
$D_f^{extcor} =$ 0.709191

(Right head)
$D_f^{extcor} =$ 0.615201

Plan date :

(Left head)
$D_f^{extcor} =$ 0.639797025

(Shell)
$D_f^{extcor} =$ 0.732153436

(Right head)
$D_f^{extcor} =$ 0.634204702

PROBABILITY OF FAILURE

PROBABILITY OF FAILURE

$P_f(t) = gff_{total} . D_f(t) . F_{MS}$

$P_f(t)$ =	Probability of Failure as a function of time
gff_{total} =	Generic failure frequency
$D_f(t)$ =	Total damage factor
F_{MS} =	Management system factor

DETERMINING DAMAGE FACTOR

$D_f^{extcor} = max[D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ local thinning

$D_f^{extcor} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ general thinning

RBI date :

(left head)
$D_{f-total}$ = 59.3515

(shell)
D_{f-tota} = 59.4401

(right head)
D_{f-tota} = 59.3461

Plan date :

(left head)
D_{f-tot} = 126.5323

(shell)
$D_{f-total}$ = 126.6247

(right head)
D_{f-tot} = 126.5267

GENERIC FAILURE FREQUENCY

Equipment type	Component type	gff as a Function of hole size (failures/yr)				gfftotal (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	DRUM	0.000008	0.00002	0.000002	0.0000006	3.06E-05

MANAGEMENT SYSTEM FACTOR

	(Left head)	Category	(Left head)	Category
PoF =	0.0018162	3	0.0038719	4
	(Shell)		(Shell)	
PoF =	0.0018189	3	0.0038747	4
	(Right Head)		(Right Head)	
PoF =	0.0018160	3	0.0038717	4

	# CONSEQUENCE OF FAILURE	Doc. PV : V-002

1.- Release phase

1.1 - Representative fluids

C1 - C2

1.2 - Determine the store liquid phase

fluid phase = Gas

1.3 -

Store liquid		Store vapor or gas	
NBP =	-	NBP =	-125
Density =	-	MW =	23
AIT =	-	k =	1.22466
		Cp =	45.321385
		AIT =	558

1.4 - Determine the steady state phase of the fluid release

steady state phase = Gas

2.- Release hole size

2.1 - Determine release hole size diameter (dn)

Release hole number	Release hole size	Range of hole diameter	Release hole diameter, dn (mm)
1	Small	0 - 6.4	d_1 = 6.4
2	Medium	> 6.4 - 51	d_2 = 25
3	Large	> 51 - 152	d_3 = 102
4	Rupture	> 152	d_4 = 406

2.2 - Determine the generic failure frequency gffn

Component type =	DRUM	
gff small =	0.000008	failure/ year
gff medium =	0.00002	failure/ year
gff large =	0.000002	failure/ year
gff rupture =	0.0000006	failure/ year
gff_{total} =	0.0000306	failure/ year

3. - Release rate

3.1 - Select appropiate release rate equation according to stored fluid phase

Stored fluid phase =

3.2 - Calculate each release hole size area

$$A_n = \frac{\pi . d_n^2}{4}$$

A_{small} =	3.21699E-05	m^2
	0.049087385	$inch^2$
A_{medium} =	0.000490874	m^2
	0.785398163	$inch^2$
A_{large} =	0.008171282	m^2
	12.56637061	$inch^2$
$A_{rupture}$ =	0.129461892	m^2
	201.0619298	$inch^2$

3.3 - Calculate release rate (W_n) for each hole size

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

Ptrans = 180.9602839 kPa

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s\sqrt{\frac{k\ x\ MW\ x\ g_c}{R\ x\ T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{small} =	0.00858	kg/s	Cd =	0.9	satuan
W_{medium} =	0.13095	kg/s	C2 =	1	mm^2/m^2
W_{large} =	2.17985	kg/s	Ps =	4895.45	kPa
$W_{rupture}$ =	34.53646	kg/s	k =	1.2246579	
			MW =	23	
			gc =	1	kg-m/N-s^2
			R =	8.314	J/kg-mol-K
			Ts =	322.04	K

For now choose between which value is exposed

W_{small} =	0.00858	kg/s
W_{medium} =	0.13095	kg/s
W_{large} =	2.17985	kg/s
$W_{rupture}$ =	34.53646	kg/s

4.- Calculation of inventory mass

4.1 - Determine the group components and equipment items into inventory groups

DRUM

4.2 - Calculate fluid mass ($mass_{comp}$) in the component

$mass_{component}$ = 306.626688 kg

4.3 - Calculate fluid mass in each of other component that are included in inventory group ($mass_{comp.i}$)

$mass_{comp,i}$= 693.028

4.4 - Calculate the fluid mass in the inventory group ($mass_{inv}$)

$$mass_n = \sum_{i=1}^{N} mass_{comp,i}$$

$mass_{inv}$= 999.654688

4.5 - Calculate the flow rate 8 inch diameter hole (W_{max8})

Vapor phase

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s\sqrt{\frac{k\ x\ MW\ x\ g_c}{R\ x\ T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{max8} =	8.634116155	kg/s	Cd =	0.9	satuan
			C2 =	1	mm^2/m^2
			Ps =	4895.45	kPa
			k =	1.2246579	
			MW =	23	
			gc =	1	kg-m/N-s^2
			R =	8.314	J/kg-mol-K
			Ts =	322.04	K

W_{max8} = 8.634116155 kg/s

4.6 - Calculate added fluid mass ($mass_{add,n}$) for each release hole size resulting from three minutes of flow from inventory group

$$mass_{add,n} = 180.\min[W_n, W_{max8}]$$

$mass_{add,1}$ =	1.54475	kgs
$mass_{add,2}$ =	23.57102	kgs
$mass_{add,3}$ =	392.37259	kgs
$mass_{add,4}$ =	1554.14091	kgs

4.7 - Calculate the available mass for release of each hole size ($mass_{avail,n}$)

$$mass_{avail} = min\left[\{mass_{comp} + mass_{add,n}\}, mass_{inv}\right]$$

$mass_{avail\ 1}$ =	308.17144	kgs
$mass_{avail\ 2}$ =	330.19771	kgs
$mass_{avail\ 3}$ =	698.99928	kgs
$mass_{avail\ 4}$ =	999.65469	kgs

5. - Release type

5.1 - Calculate time required to release 4,536 kgs of fluid for each hole size

$$t_n = \frac{C_3}{W_n}$$

C3 = 4536 kg

t_{small} =	528551.472	sec
t_{medium} =	34639.149	sec
t_{large} =	2080.879	sec
$t_{rupture}$ =	131.339	sec

5.2 - Determine the release type instaneous or continous

1.) if the release hole size is 6.35 mm(0.25 inch) = Continous

2.) if tn ≤ 180 sec and the release mass is greater than 4.536 kgs (10,000 lbs) = Instantaneous

t_{small} =	CONTINOUS
t_{medium} =	CONTINOUS
t_{large} =	CONTINOUS
$t_{rupture}$ =	INSTANTANEOUS

6. - Detection and isolation

6.1 - determine the dectection and isolation system

Type of detection system	Detection classification
Instrumentation designed spesifically to detect material losses by changes in operating conditions in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of isolation system	**Detection classification**
Isolation or shutdown systems activated directly from process instrumentation or detector, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually operated valves	C

6.2 - select appropiate classification for detection system

A

6.3 - select appropiate classification for isolation system

C

6.4 - determine the release reduction factor ($fact_{di}$)

System classification		Release magnitude adjusment	Reductioin factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A	C	Reduce release rate or mass by 10%	0.10
B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjusment to release rate or mass	0

release reduction factor = 0.1

6.5 - determine the total leak durations for each of the hole size ($ld_{dimax,n}$)

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 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
C	A, B or C	1 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks

$Id_{max,1}$ = 40 minutes
$Id_{max,2}$ = 30 minutes
$Id_{max,3}$ = 20 minutes
$Id_{max,4}$ = 20 minutes

7. - Release rate and mass

7.1 - calculate the adjusted release rate ($rate_n$) for each hole size

$$rate_n = W_n(1 - fact_{dl})$$

W_1 = 0.008581946 kg/s
W_2 = 0.130950098 kg/s
W_3 = 2.179847715 kg/s
W_4 = 34.53646462 kg/s

$rate_{small}$ = 0.00772 kg/s
$rate_{medium}$ = 0.11786 kg/s
$rate_{large}$ = 1.96186 kg/s
$rate_{rupture}$ = 31.08282 kg/s

7.2 - calculate the leak duration (ld_n) for each hole size

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}\{60.ld_{max,n}\}\right]$$

ld_{small} =	2400 s		$Id_{max,1}$ =	40	minutes
ld_{medium} =	1800 s		$Id_{max,2}$ =	30	minutes
ld_{large} =	356.2936336 s		$Id_{max,3}$ =	20	minutes
$ld_{rupture}$ =	32.16100557 s		$Id_{max,4}$ =	20	minutes

7.3 - calculate the release mass ($mass_n$) for each hole size

$$mass_n = min[\{rate_n \ x \ ld_n\}, mass_{avail,n}]$$

$mass_{small}$ =	18.53700 kg
$mass_{medium}$ =	212.13916 kg
$mass_{large}$ =	698.99928 kg
$mass_{rupture}$ =	999.65469 kg

8. - Determine flammable and explosive consequence

8.1 - Select the consequence area mitigatian reduction factor ($fact_{mit}$)

$fact_{mit}$ = 0.05

8.2 - Calculate the energy efficiency correction factor ($eneff_n$) for each release hole size

$$eneff_n = 4.log_{10}[C_{4A}.mass_n] - 15$$

C4A = 2.205 1/kg

$eneff_1$ =	0
$eneff_2$ =	0
$eneff_3$ =	0
$eneff_4$ =	1.626965597

8.3 - Determine the fluid type

fluid type = C1 - C2

8.4 - calculate component damage consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{cmd,n}^{AINL-CONT}$)

8.4.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AINL-CONT}$

a = 8.669

b = $b_{cmd}^{AINL-CONT}$

b = 0.98

8.4.2 - calculate consequence area

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b.(1 - fact_{mit})$$

$fact_{mit}$ = 0.05

$Ca_{cmd.small}^{AINL-CONT}$ =	0.070107473 m^2
$Ca_{cmd.medium}^{AINL-CONT}$ =	1.013010576 m^2
$Ca_{cmd.large}^{AINL-CONT}$ =	15.94071874 m^2
$Ca_{cmd.rupture}^{AINL-CONT}$ =	0 m^2

8.5 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{cmd,n}^{AIL-CONT}$)

8.5.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AIL-CONT}$

a = 55.13

b = $b_{cmd}^{AIL-CONT}$

b = 0.95

8.5.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-CON} = a(rate_n)^b.(1 - fact_{mit})$$

$fact_{mit}$ = 0.05

$Ca_{cmd.small}^{AIL-CONT}$ =	0.515879717
$Ca_{cmd.medium}^{AIL-CONT}$ =	6.868984221
$Ca_{cmd.large}^{AIL-CONT}$ =	99.34518632
$Ca_{cmd.rupture}^{AIL-CONT}$ =	0

8.6 - calculate component damage consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{cmd,n}^{AINL-INST}$)

8.6.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AINL-INST}$

a = 6.469

$b = b_{cmd}^{AINL-INST}$

b = 0.69

8.6.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b . \left(\frac{1 - fact_{mit}}{eneff_n}\right)$$

$Ca_{cmd1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AINL-INST}$ =	0		
$Ca_{cmd3}^{AINL-INST}$ =	0		
$Ca_{cmd4}^{AINL-INST}$ =	443.6892349		

8.7 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-INST ($Ca_{cmd,n}^{AIL-INST}$)

8.7.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 163.7

$b = b_{cmd}^{AIL-INST}$

b = 0.62

8.7.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b . \left(\frac{1 - fact_{mit}}{eneff_n}\right)$$

$Ca_{cmd1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AIL-INST}$ =	0		
$Ca_{cmd3}^{AIL-INST}$ =	0		
$Ca_{cmd4}^{AIL-INST}$ =	6923.105016		

8.8 - calculate personnel injury consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{inj,n}^{AINL-CONT}$)

8.8.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-CON}$

a = 21.83

$b = b_{inj}^{AINL-CON}$

b = 0.96

8.8.2 - calculate consequence area

$$CA_{inj,n}^{AINL-CONT} = [a.(rate_n^{AINL-CONT})^b].(1 - fact_{mit})$$

$Ca_{inj1}^{AINL-CONT}$ =	0.194577437	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-CONT}$ =	2.662390441		
$Ca_{inj3}^{AINL-CONT}$ =	39.60401884		
$Ca_{inj4}^{AINL-CONT}$ =	0		

8.9 - calculate personnel injury consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{inj,n}^{AIL-CONT}$)

8.9.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AIL-CON}$

a = 143.2

$b = b_{inj}^{AIL-CONT}$

b = 0.92

8.9.2 - calculate consequence area

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

$Ca_{inj1}^{AIL-CONT}$ =	1.550488789	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AIL-CONT}$ =	19.02423027		
$Ca_{inj3}^{AIL-CONT}$ =	252.8842573		
$Ca_{inj4}^{AIL-CONT}$ =	0		

8.10 - calculate personnel injury consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{inj,n}^{AINL-INST}$)

8.10.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-INS}$

a = 12.46

$b = b_{inj}^{AINL-INST}$

b = 0.67

8.10.2 - calculate consequence area

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

$Ca_{inj1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-INST}$ =	0		
$Ca_{inj3}^{AINL-INST}$ =	0		
$Ca_{inj4}^{AINL-INST}$ =	744.3253027		

8.11 - calculate personnel injury consequence areas for auto-ignition likely, instantaneous release, AIL-INST ($Ca_{inj,n}^{AIL-INST}$)

8.11.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 473.9

$b = b_{cmd}^{AIL-INST}$

b = 0.63

8.11.2 - calculate consequence area

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

$CA_{inj1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$CA_{inj2}^{AIL-INST}$ =	0		
$CA_{inj3}^{AIL-INST}$ =	0		
$CA_{inj4}^{AIL-INST}$ =	21475.21146		

8.12 - calculate the instantaneous/ continous blending factor ($fact_n^{IC}$)

Continous

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$$

C5 = 25.2 kg/s

Instantaneous

$$fact_n^{IC} = 1.0$$

$fact_1^{IC}$ =	0.000306498
$fact_2^{IC}$ =	0.004676789
$fact_3^{IC}$ =	0.077851704
$fact_4^{IC}$ =	1

8.13 - calculate AIT (auto ignition temperature) blending factor ($fact^{AIT}$)

$T_s + C_6 \leq AIT$ $fact^{AIT} = 0$

$T_s + C_6 > AIT > T_s - C_6$ $fact^{AIT} = \frac{T_s - AIT + C_6}{2.C_6}$

$T_s - C_6 \geq AIT$ $fact^{AIT} = 1$

$fact^{AIT}$ = 0

C6 =	55.6	K
Ts =	48.89	C
	120	F
	322.04	K
AIT =	558	K

8.14 - calculate the continous/ instantaneous blended consequnces areas for the component and the continous/ instantaneous blending factor ($fact_n^{IC}$)

8.14.1 - calculate continous/ instantaneous blended consequence area for auto ignition likely for component damage

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CON}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AIL}$ =	0.515721601	m^2
$CA_{cmd,2}^{AIL}$ =	6.83685943	m^2
$CA_{cmd,3}^{AIL}$ =	91.61099427	m^2

$CA_{cmd1}^{AIL-INST}$ =	0
$fact_1^{IC}$ =	0.000306498
$CA_{cmd1}^{AIL-CONT}$ =	0.515879717
$CA_{cmd2}^{AIL-INST}$ =	0
$fact_2^{IC}$ =	0.004676789
$CA_{cmd2}^{AIL-CONT}$ =	6.868984221
$CA_{cmd3}^{AIL-INST}$ =	0
$fact_3^{IC}$ =	0.077851704
$CA_{cmd3}^{AIL-CONT}$ =	99.34518632

$CA_{cmd,4}^{AIL} =$	6923.105016	m^2	$CA_{cmd4}^{AIL\text{-}INST} =$	6923.105016
			$fact_4^{IC} =$	1
			$CA_{cmd4}^{AIL\text{-}CONT} =$	0

8.14.2 - calculate continous/ instantaneous blended consequence area for auto ignition likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}.fact_n^{IC} + CA_{inj,n}^{AIL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AIL} =$	1.550013567	m^2	$CA_{inj1}^{AIL\text{-}INST} =$	0
			$fact_1^{IC} =$	0.000306498
			$CA_{inj1}^{AIL\text{-}CONT} =$	1.550488789
$CA_{inj,2}^{AIL} =$	18.93525796	m^2	$CA_{inj2}^{AIL\text{-}INST} =$	0
			$fact_2^{IC} =$	0.004676789
			$CA_{inj2}^{AIL\text{-}CONT} =$	19.02423027
$CA_{inj,3}^{AIL} =$	233.1967869	m^2	$CA_{inj3}^{AIL\text{-}INST} =$	0
			$fact_3^{IC} =$	0.077851704
			$CA_{inj3}^{AIL\text{-}CONT} =$	252.8842573
$CA_{inj,4}^{AIL} =$	21475.21146	m^2	$CA_{inj4}^{AIL\text{-}INST} =$	21475.21146
			$fact_4^{IC} =$	1
			$CA_{inj4}^{AIL\text{-}CONT} =$	0

8.14.3 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for component damage

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST}.fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AINL} =$	0.070085985	$CA_{cmd1}^{AINL\text{-}INST} =$	0
		$fact_1^{IC} =$	0.000306498
		$CA_{cmd1}^{AINL\text{-}CONT} =$	0.070107473
$CA_{cmd,2}^{AINL} =$	1.008272939	$CA_{cmd2}^{AINL\text{-}INST} =$	0
		$fact_2^{IC} =$	0.004676789
		$CA_{cmd2}^{AINL\text{-}CONT} =$	1.013010576
$CA_{cmd,3}^{AINL} =$	14.69970662	$CA_{cmd3}^{AINL\text{-}INST} =$	0
		$fact_3^{IC} =$	0.077851704
		$CA_{cmd3}^{AINL\text{-}CONT} =$	15.94071874
$CA_{cmd,4}^{AINL} =$	443.6892349	$CA_{cmd4}^{AINL\text{-}INST} =$	443.6892349
		$fact_4^{IC} =$	1
		$CA_{cmd4}^{AINL\text{-}CONT} =$	0

8.14.4 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AINL-INST}.fact_n^{IC} + CA_{inj,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AINL} =$	0.1945178	$CA_{inj1}^{AINL\text{-}INST} =$	0
		$fact_1^{IC} =$	0.000306498
		$CA_{inj1}^{AINL\text{-}CONT} =$	0.194577437
$CA_{inj,2}^{AINL} =$	2.649939002	$CA_{inj2}^{AINL\text{-}INST} =$	0
		$fact_2^{IC} =$	0.004676789
		$CA_{inj2}^{AINL\text{-}CONT} =$	2.662390441
$CA_{inj,3}^{AINL} =$	36.52077849	$CA_{inj3}^{AINL\text{-}INST} =$	0
		$fact_3^{IC} =$	0.077851704
		$CA_{inj3}^{AINL\text{-}CONT} =$	39.60401884
$CA_{inj,4}^{AINL} =$	744.3253027	$CA_{inj4}^{AINL\text{-}INST} =$	744.3253027
		$fact_4^{IC} =$	1
		$CA_{inj4}^{AINL\text{-}CONT} =$	0

8.15 - calculate AIT blended consequence areas for the component damage and personnel injury flammable consequence area

8.15.1 - calculate AIT blended consequence areas for daage component

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL}.fact^{AIT} + CA_{cmd,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{cmd1}^{flam} =$	0.070085985	$CA_{cmd1}^{AIL} =$	0.515721601
		$fact^{AIT} =$	0
		$CA_{cmd1}^{AINL} =$	0.070085985
$CA_{cmd2}^{flam} =$	1.008272939	$CA_{cmd2}^{AIL} =$	6.83685943
		$fact^{AIT} =$	0
		$CA_{cmd2}^{AINL} =$	1.008272939
$CA_{cmd3}^{flam} =$	14.69970662	$CA_{cmd3}^{AIL} =$	91.61099427
		$fact^{AIT} =$	0
		$CA_{cmd3}^{AINL} =$	14.69970662
$CA_{cmd4}^{flam} =$	443.6892349	$CA_{cmd4}^{AIL} =$	6923.105016
		$fact^{AIT} =$	0
		$CA_{cmd4}^{AINL} =$	443.6892349

8.15.2 - calculate AIT blended consequence areas for personnel injury

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}.fact^{AIT} + CA_{inj,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{inj,1}^{AINL} =$	0.1945178	$CA_{inj1}^{AIL} =$	1.550013567
		$fact^{AIT} =$	0
		$CA_{inj1}^{AINL} =$	0.1945178

$CA_{inj,2}^{AINL}$ =	2.649939002	CA_{inj2}^{AIL} =	18.93525796
		$fact^{AIT}$ =	0
		CA_{inj2}^{AINL} =	2.649939002
$CA_{inj,3}^{AINL}$ =	36.52077849	CA_{inj3}^{AIL} =	233.1967869
		$fact^{AIT}$ =	0
		CA_{inj3}^{AINL} =	36.52077849
$CA_{inj,4}^{AINL}$ =	744.3253027	CA_{inj4}^{AIL} =	21475.21146
		$fact^{AIT}$ =	0
		CA_{inj4}^{AINL} =	744.3253027

8.16 - determine the final consequence areas for component damage and personnel injury

$$CA_{cmd,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1 . CA_{cmd,1}^{flam}\right) + \left(gff_2 . CA_{cmd,2}^{flam}\right) + \left(gff_3 . CA_{cmd,3}^{flam}\right) + \left(gff_4 . CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{cmd,n}^{flam}$ = 10.33788 m^2

$$CA_{inj,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj,n}^{flam} = \left(\frac{\left(gff_1 . CA_{inj,1}^{flam}\right) + \left(gff_2 . CA_{inj,2}^{flam}\right) + \left(gff_3 . CA_{inj,3}^{flam}\right) + \left(gff_4 . CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{inj,n}^{flam}$ = 18.76443 m^2

9.- Calculation of toxic consequences areas

9.1 - calculate the effective duration of toxic release

$$Id_n^{tox} = min\left(3600, \left\{\frac{mass_n}{W_n}\right\}, \{60 . Id_{max.n}\}\right)$$

Id_{small}^{tox} =	2160 s	$mass_1$ =	18.53700257	W_1 =	0.008582	$Id_{max.1}$ =	40
Id_{medium}^{tox} =	1620 s	$mass_2$ =	212.1391591	W_2 =	0.130950	$Id_{max.2}$ =	30
Id_{large}^{tox} =	320.6642702 s	$mass_3$ =	698.9992766	W_3 =	2.179848	$Id_{max.3}$ =	20
$Id_{rupture}^{tox}$ =	28.94490502 s	$mass_4$ =	999.654688	W_4 =	34.536465	$Id_{max.4}$ =	20

9.2 - determine the toxic percentage of the toxic component ($mfrac^{tox}$)

$mfrac^{tox}$ =	0.0001	H_2S =	0.01%
$mfrac^{tox}$ =	0.000017	H_2S =	0.0017%

9.3 - calculate the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$

For H_2S

$rate_n^{tox} = mfrac^{tox} . W_n$

$rate_1^{tox}$ =	0.000001 kg/s	W_1 =	0.007724 kg/s
$rate_2^{tox}$ =	0.000012 kg/s	W_2 =	0.117855 kg/s
$rate_3^{tox}$ =	0.000196 kg/s	W_3 =	1.961863 kg/s
$rate_4^{tox}$ =	0.003108 kg/s	W_4 =	31.082818 kg/s

$mass_n^{tox} = mfrac^{tox} . mass_n$

$mass_1^{tox}$ =	0.0018537 kgs	$mass_1$ =	18.53700 kgs
$mass_2^{tox}$ =	0.021213916 kgs	$mass_2$ =	212.13916 kgs
$mass_3^{tox}$ =	0.069899928 kgs	$mass_3$ =	698.99928 kgs
$mass_4^{tox}$ =	0.099965469 kgs	$mass_4$ =	999.65469 kgs

For Cl

$rate_n^{tox} = mfrac^{tox} . W_n$

$rate_1^{tox}$ =	1.31304E-07 kg/s
$rate_2^{tox}$ =	2.00354E-06 kg/s
$rate_3^{tox}$ =	3.33517E-05 kg/s
$rate_4^{tox}$ =	0.000528408 kg/s

$mass_n^{tox} = mfrac^{tox} . mass_n$

$mass_1^{tox}$ =	0.000315129 kgs
$mass_2^{tox}$ =	0.003606366 kgs
$mass_3^{tox}$ =	0.011882988 kgs
$mass_4^{tox}$ =	0.01699413 kgs

9.4 - calculate the toxic consequence area for H2S,

$$CA_{inj,n}^{tox-CON} = C_8 . 10^{\left(c . log_{10}\left[C_{4B} . rate_n^{tox}\right] + d\right)}$$

$$CA_{inj,n}^{tox-INST} = C_8 . 10^{\left(c . log_{10}\left[C_{4B} . mass_n^{tox}\right] + d\right)}$$

C_8 =	0.0929 m^2. sec
c1 =	1.2266
c2 =	1.2266
c3 =	1.237
c4 =	0.9674

$CA_{inj,small}^{tox-CONT}$ = 0.000213084 m^2

tox CONT

$CA^{tox-CONT}_{inj,medium}$ =	0.006029157	m^2	d1 =	4.4365	
$CA^{tox-CONT}_{inj,large}$ =	0.110877463	m^2	d2 =	4.4365	
$CA^{ox-INST}_{inj.rupture}$ =	13.08229941	m^2	d3 =	4.238	
			d4 =	2.784	
			C_{4B} =	2.205	sec/kg

$CA^{tox-CONT}_{inj,n} = e(rate^{tox}_n)^f$

$CA^{tox-INST}_{inj,n} = e(mass^{tox}_n)^f$

			e1 =	6860	
			e2 =	5312	
			e3 =	4191	
$CA^{tox-CONT}_{inj,small}$ =	0.0002878	m^2	e4 =	3528	
$CA^{tox-CONT}_{inj,medium}$ =	0.0036291	m^2	f1 =	1.072	
$CA^{tox-CONT}_{inj,large}$ =	0.0558461	m^2	f2 =	1.082	
$CA^{ox-INST}_{inj.rupture}$ =	29.1467687	m^2	f3 =	1.089	
			f4 =	1.177	

9.5 - if there is additional toxic component step 9.2 through 9.4 should be repeated

9.6 - determine the final toxic consequnces areas for personnel injury

$$CA^{tox}_{inj} = \left(\frac{\sum gff_n . CA^{tox}_{inj.n}}{gff_{total}}\right)$$

$$CA^{tox}_{inj,n} = \left(\frac{(gff_1 . CA^{tox}_{inj,1}) + (gff_2 . CA^{tox}_{cinj}\ ) + (gff_3 . CA^{tox}_{inj,3}) + (gff_4 . CA^{tox}_{inj,4})}{gff_{total}}\right)$$

CA^{tox}_{inj} = 0.84536 m^2

10. - calculation of non-flammable, Non-toxic consequences area

10.1 - calculate CA $_{inj.n}^{CONT}$ and CA $_{inj.n}^{INST}$

for acid caustic

$CA^{CONT}_{inj,n} = 0.2 . C_8 . g\ (C_4 . rate_n\ )^h$

$CA^{INST}_{inj,n} = 0$

$g = 2696\ - 21.9 . C_{11}(P_s - P_{atm}) + 1.474[C_{11}(P_s - P_{atm})]^2$

g = 2614.991053

$h = 0.31\ - 0.00032[C_{11}(P_s - P_{atm}) - 40]^2$

h = -0.039509303

$rate_{small}$ =	0.007724	kg/s
$rate_{med}$ =	0.117855	kg/s
$rate_{large}$ =	1.961863	kg/s
$rate_{ruptr}$ =	31.082818	kg/s
C_8 =	0.0929	m^2. sec
C_4 =	2.205	sec/kg
C_{11} =	0.145	1/kPa
P_s =	4895.45	kPa
P_{atm} =	101.28755	kPa

$CA^{CONT}_{inj,n}$ =	57.06877042
$CA^{CONT}_{inj,n}$ =	51.24346196
$CA^{CONT}_{inj,n}$ =	45.85481523
$CA^{INST}_{inj,n}$ =	0

10.2 - calculate the instantaneous/continous blending factor $fact_n^{IC}$

$$fact^{IC}_{in} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1\right],$$

$fact^{IC}_{small}$ =	0.000306498		C_5 =	25.2	kg/sec
$fact^{IC}_{medium}$ =	0.004676789		P_s =	0	kPa
$fact^{IC}_{large}$ =	0.077851704		P_{atm} =	0	kPa
$fact^{IC}_{rupture}$ =	1				

10.3 - calculate the blended non-flammable, non-toxic personnel injury consequence area for steam acid leaks CA $_{inj.n}^{leak}$

$CA^{leak}_{cmd.n}$ = 0

$CA^{leak}_{lak.n} = CA^{INST}_{inj.n} . fact^{IC}_n + CA^{CONT}_{inj.n} . (1 - fact^{IC}_n)$

$fact^{IC}_n$ =	0.0003065
$fact^{IC}_n$ =	0.0046768
$fact^{IC}_n$ =	0.0778517
$fact^{IC}_n$ =	1

$CA^{leak}_{lak.n}$ =	57.05127896	m^2
$CA^{leak}_{lak.n}$ =	51.00380709	m^2
$CA^{leak}_{lak.n}$ =	42.28493972	m^2
$CA^{leak}_{lak.n}$ =	0	m^2

10.4 - determine the final non-flammable, non-toxic personnel injury CA $_{inj}^{nfnt}$

$CA^{nfnt}_{cmd.n}$ = 0

$$CA^{nfnt}_{inj} = \left(\frac{(gff_1 . CA^{leak}_{cmd,1}) + (gff_2 . CA^{leak}_{cmd,2}) + (gff_3 . CA^{leak}_{cmd,3}) + (gff_4 . CA^{leak}_{cmd,4})}{gff_{total}}\right)$$

CA^{nfnt}_{inj} = 51.01491 m^2

11. - Calculation of final consequence area

11.1 - calculate the final component damage consequence area, CA_{cmd}

$CA_{cmd} = CA^{flam}_{cmd}$

$CA_{cmd} =$ 10.33788 m^2

11.2 - calculate the final personnel injury consequence area, CA_{inj}

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$$

$CA_{inj} =$ 51.01491 m^2

11.3 - calculate the final consequence area, CA

$$CA = \max\left[CA_{cmd}, CA_{inj}\right]$$

CA = 51.01491 m^2 Category B

	# GENERAL DATA	Doc. PV : V-003

General Data :

Design code :			Date RBI assessment :	2024
Equipment Name :	V-003		Date last inspection :	2019
Vessel type :	Vertical Vessel		Plan date :	2029
Size :				
Diameter :	177.8	mm		
Volume total :	0.020914875	m^3		
Year built :	1998			
Fluid category :	C1- C2			
Fluid phase :	Gas			
Cladding :	No			
Coating :	High			
Design pressure :	17.93	bar		
	260	psi		
Design temperature :	65.56	°C		
	150	°F		
Operating pressure :	6.89	bar		
	100	psi		
	689.5	kPa		
Operating temperature :	48.89	°C		
	120	°F		
	322.039	°K		
Atmospheric pressure :	101.28755	kPa		

Head data 1 :

Type :	2:1 Ellipsoidal	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	13.18	mm
	0.519	inch
Minimum wall thickness :	1.6000	mm
	0.0630	inch
Corrosion allowance:	3.2000	mm
	0.1260	inch
Last inspection thickness :	12.9800	mm
	0.5110	inch

Head data 2 :

Type :	2:1 Ellipsoidal	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	13.31	mm
	0.5240	inch
Minimum wall thickness :	1.6000	mm
	0.0630	inch
Corrosion allowance:	3.2000	mm
	0.1260	inch
Last inspection thickness :	13.0200	mm
	0.5126	inch

Shell data :

Type :	Cylindrical shell	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	10.9728	mm
	0.432	inch
Minimum wall thickness :	1.1	mm
	0.0433	inch
Corrosion allowance:	3.2000	mm
	0.1260	inch
Last inspection thickness :	10.8200	mm
	0.4260	inch

Material data :

Allowable stress :	118000	kPa
Tensile strength :	415000	kPa
Yield strength :	240000	kPa
Mass density (ρ_m) :	250.512	kg/m^3

PROBABILITY OF FAILURE
Thinning

Doc. PV : V-003

1.-Furnished thickness & Age

(top head)			(shell)			(bottom head)		
head t =	13.18	mm	shell t =	10.9728	mm	head t =	13.31	mm
	0.518897638	inch		0.432	inch		0.524015748	inch

age = 26 year

2.-Corrosion rate for base metal ($C_{r,bm}$)

Based on API 510

$$LTCR = \frac{t_{initial} - t_{actual}}{years\ between}$$

left head $C_{r,bm}$ =	0.00952381	mm/year
shell $C_{r,bm}$ =	0.00727619	mm/year
right head $C_{r,bm}$ =	0.013809524	mm/year

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

(top head)		
t_{rdi} =	12.98	mm
	0.511023622	inch
(shell)		
t_{rdi} =	10.82	mm
	0.425984252	inch
(bottom head)		
t_{rdi} =	13.02	mm
	0.512598425	inch
age_{tk} =	5	year
age_{pd} =	10	year

Last inspection date :	2019
RBI date :	2024
Plan date :	2029

4.- For cladding/ weld overlay pressure vessel components, calculate the age from the date of the starting thickness from STEP 3 required to corrode away the cladding/ weld overlay material (age_{rc})

$$age_{rc} = \left[\left(\frac{t_{rdi} - t_{bm}}{C_{r,cm}}\right)\right], 0.0$$

age_{rc} = 0

$C_{r,cm}$ = 0 mm/year
0

5.- Determine t_{min}

According to Data or ASME Sec. VIII

	(top head)			(shell)			(bottom head)	
t_{min} =	1.6	mm	t_{min} =	1.1	mm	t_{min} =	1.6	mm
	0.062992126	inch		0.043307087	inch		0.062992126	inch

6.- Determine A_{rt}

$$A_{rt} = \frac{Cr_{b.m} \cdot age_{tk}}{t_{rdi}}$$

RBI date :		Plan date :	
(top head)		(top head)	
A_{rt} =	0.003668648	A_{rt} =	0.007337295
(shell)		(shell)	
A_{rt} =	0.00336238	A_{rt} =	0.00672476
(bottom head)		(bottom head)	
A_{rt} =	0.005303197	A_{rt} =	0.010606393

$C_{r,bm}$ =	0.00952381	mm/year
$C_{r,bm}$ =	0.00727619	mm/year
$C_{r,bm}$ =	0.013809524	mm/year
age_{tk} =	5	year
age_{pd} =	10	year

7.- Calculate the flow stress FS^{thin}

$$FS^{thin} = \frac{(YS+TS)}{2}.E.1,1$$

FS^{thin} = 360250

Yield strength =	240000	kPa
Tensile strength =	415000	kPa
Joint efficiency =	1	

8.- Calculate strength ratio parameter (SR_p^{thin})

$$SR_P^{thin} = \frac{S.E}{FS^{thin}}.\frac{Max\,(t_{min},\ t_c)}{t_{rdi}}.$$

Allowable stress =	118000
Joint efficiency =	1

(top head)		(shell)		(bottom head)	
Sr_p^{thin} =	0.040376002	Sr_p^{thin} =	0.033299939	Sr_p^{thin} =	0.040251958

9.- Determine the number of inspections for each of the corresponding inspection effectiveness

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	2
N_D^{Thin} =	0

10. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinD}\right)^{N}$$

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

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

I_1^{Thin} =	0.1024	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	4.55625E-05	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000025	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

11. - Calculate the posterior probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Po_{p1}^{Thin} =	0.999552812
Po_{p2}^{Thin} =	0.000444747
Po_{p3}^{Thin} =	2.44031E-06

12.- Calculate the parameters

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$$\beta_2^{Thin} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$$\beta_3^{Thin} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$COV_{\Delta t}$ = coefficient of variances for thickness, 0.1≤ COV ≤0.2: 0.2

COV_{S_f} = flow stress coefficient of variance: 0.2

COV_P = pressure coefficient of variance: 0.05

D_{S_1} = damage step 1: 1

D_{S_2} = damage step 2: 2

D_{S_3} = damage step 3: 4

RBI date :

	(top head)		(shell)		(bottom head)
β_1^{Thin}	4.797097938	β_1^{Thin}	4.832742481	β_1^{Thin}	4.79735353
β_2^{Thin}	4.796248817	β_2^{Thin}	4.832092597	β_2^{Thin}	4.796059062
β_3^{Thin}	4.79433015	β_3^{Thin}	4.830609588	β_3^{Thin}	4.792999656

Plan date :

	(top head)		(shell)		(bottom head)
β_1^{Thin}	4.796248817	β_1^{Thin}	4.832092597	β_1^{Thin}	4.796059062
β_2^{Thin}	4.79433015	β_2^{Thin}	4.830609588	β_2^{Thin}	4.792999656
β_3^{Thin}	4.789568036	β_3^{Thin}	4.826877462	β_3^{Thin}	4.784865464

13.- For all component (excluding tank bottoms) calculate base damage factor

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi(-\beta_1^{Thin})\right) + \left(Po_{p2}^{Thin}\Phi(-\beta_2^{Thin})\right) + \left(Po_{p3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-04} \right]$$

RBI date :		**Plan date :**	
(top head) $D_{fB}^{Thin} =$	0.005159654	(top head) $D_{fB}^{Thin} =$	0.005181576
(shell) $D_{fB}^{Thin} =$	0.00431619	(shell) $D_{fB}^{Thin} =$	0.004330316
(bottom head) $D_{fB}^{Thin} =$	0.005153082	(bottom head) $D_{fB}^{Thin} =$	0.005186497

14.- Determine the DF for thinning (D_f^{Thin})

$$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin}.F_{IP}.F_{DL}F_{WD}F_{AM}F_{SM}}{F_{OM}}\right), \quad 0.1\right]$$

$F_{IP} =$	DF ofr injection/ mix point (for piping circuit)	0
$F_{DL} =$	DF for dead legs (for piping only used to intermittent service)	0
$F_{WD} =$	DF for welded construction (for AST bottom only)	0
$F_{AM} =$	DF for AST maintenance in accordance (for AST bottom only)	0
$F_{SM} =$	DF for settlement (for AST bottom only)	0
$F_{OM} =$	DF for on-line monitoring	1

RBI date :		**Plan date :**	
(top head) $D_f^{Thin} =$	0.1	(top head) $D_f^{Thin} =$	0.1
(shell) $D_f^{Thin} =$	0.1	(shell) $D_f^{Thin} =$	0.1
(bottom head) $D_f^{Thin} =$	0.1	(bottom head) $D_f^{Thin} =$	0.1

PROBABILITY OF FAILURE

SCC-SULFIDE STRESS CRACKING

Doc. PV : V-003

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low

pH : 5.5 - 7.5

H2S concentration: < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	As-Welded Max Brinnel Hardness			PWHT Max Brinnel Hardness		
	< 200	200 - 237	> 237	< 200	200 - 237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderates	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

	(top head)		(top head)
PWHT :	No.	Max brinnel hardness :	< 200
	(shell)		(shell)
PWHT :	No.	Max brinnel hardness :	< 200
	(bottom head)		(bottom head)
PWHT :	No.	Max brinnel hardness :	< 200

	(top head)
Enviromental severity :	Low
	(shell)
Enviromental severity :	Low
	(bottom head)
Enviromental severity :	Low

3.- Determine the severity index S_{v1}

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

	(top head)
Sv1 :	1
	(shell)
Sv1 :	1
	(bottom head)
Sv1 :	1

4.- Determine the time in-service, age

Age_{tk} = 5

Age_{PD} = 10

Last Inspection: 2019

RBI date: 2024

Panned date: 2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1

Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{vI}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{vI}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

$D_{fB}^{SCC} =$ 1
1
1

Number of inspection : 1
Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

$$D_f^{SCC} = D_f^{SCC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$$

RBI Date :

(top head)
$D_f^{SCC} =$ 5.873094715
(shell)
$D_f^{SCC} =$ 5.873094715
(bottom head)
$D_f^{SCC} =$ 5.873094715

Plan Date :

(top head)
$D_f^{SCC} =$ 12.58925412
(shell)
$D_f^{SCC} =$ 12.58925412
(bottom head)
$D_f^{SCC} =$ 12.58925412

	# PROBABILITY OF FAILURE	Doc. PV : V-003
	SCC-HIC/SOHIC-H2S	

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low

pH : 5.5 - 7.5

H2S concentration: < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	High Sulfur Steel > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Seamless/ Extruded pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderates	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

	susceptibility :	sulfur content :	PWHT :
(top head)	low	≤ 0.01%	No.
(shell)	low	≤ 0.01%	No.
(bottom head)	low	≤ 0.01%	No.

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

(left head) Sv1 = 1

(shell) Sv1 = 1

(right head) Sv1 = 1

4.- Determine the time in-service, age

Age_{tk} = 5

Age_{PD} = 10

Last Inspection 2019

RBI date 2024

Panned date 2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1

Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{vl}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{vl}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

(top head)
$D_{fB}^{HIC/SOHIC-H2} =$ 1

(shell)
$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(bottom head)
$D_{fB}^{HIC/SOHIC-H2S} =$ 1

Number of inspection : 1
Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

On-Line monitoring method	Adjusment Factors as a function of On-line monitoring- Fom
Key process variables	2
Hydrogen probes	2
Key process variables & hydrogen p	4

On-Line monitoring method
F_{om} 2

8. - Calculate the final DF accounting based on time in-service since the last inespection

$$D_f^{HIC/SOHIC-H2S} = \frac{D_{fB}^{HIC/SOHIC-a2S} . (Max[age, 1.0])^{1.1}}{F_{OM}}$$

RBI Date :

(top head)
$D_f^{SC} =$ 2.936547358

(shell)
$D_f^{SC} =$ 2.936547358

(bottom head)
$D_f^{SC} =$ 2.936547358

Plan Date :

(top head)
$D_f^{SCC} =$ 6.294627059

(shell)
$D_f^{SCC} =$ 6.294627059

(bottom head)
$D_f^{SCC} =$ 6.294627059

Damage factor for stress corrosion cracking

$$D_{f-gov}^{SCC} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{HIC/SOHIC-H2S}, D_f^{ACSCC} \\ , D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC} \quad , D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

RBI Date :

$D_{f-gov}^{SCC} =$ 5.873094715 (top head)
$D_{f-gov}^{SCC} =$ 5.873094715 (shell)
$D_{f-gov}^{SCC} =$ 5.873094715 (bottom head)

Plan Date :

$D_{f-go}^{SCC} =$ 12.58925412 (top head)
$D_{f-gov}^{SCC} =$ 12.58925412 (shell)
$D_{f-gov}^{SCC} =$ 12.58925412 (bottom head)

PROBABILITY OF FAILURE

EXTERNAL CORROSION

Doc. PV : V-003

1.- Determine furnished thickness,t and age

	(top head)			(shell)			(bottom head)	
t =	13.18	mm	t =	10.9728	mm	t =	13.31	mm
	0.518897638	inch		0.432	inch		0.524015748	inch

age = 26 year

2.- Corrosion rate ($C_{r,bm}$) based on the driver and operating temperature

Operating tempertaure (°C)	Corrosion rate as a function of driver (mm/y)			
	Marine/ cooling tower drift area	Temperate	Acid/ dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.0127	0.076	0.025	0.254
32	0.0127	0.076	0.025	0.254
71	0.0127	0.051	0.025	0.254
107	0.025	0	0	0
121	0	0	0	0

$C_{r,bm}$ = 0.0127 mm/y

Opr. Temperature = 48.89 °C
120 °F

3. - Calculate the final corrosion rate, C_r

$C_r = CR_B . max[F_{EQ} . F_{IF}]$

$C_r =$ 0.0254

F_{EQ} = adjusment for equipment design or fabrication
2

F_{IF} = adjusment for interface
1

4. - Determine time in service, age_{tk}, since the last known inspection, t_{rde}

(top head)
head t_{rdi} = 12.98 mm
0.511023622 inch

(shell)
shell t_{rdi} = 10.82 mm
0.425984252 inch

(bottom head)
head t_{rdi} = 13.02 mm
0.512598425 inch

age_{tk} = 26 year
age_{pd} = 31 year

Last inspection date : 1998
RBI date : 2024
Plan date : 2029

5. - Determine time in-service, age_{coat}

$age_{coat} = calculation\ date - coating\ installation\ date$

RBI Calc. date : 2024
Coat. inst date : 2001
Plan Calc. date : 2029

RBI date :

$age_{coat} = calc. date - C.I\ date$

$age_{coat} =$ 23

Plan date :

$age_{coat} = planned\ date - C.I\ date$

$age_{coat} =$ 28

6. - Determine coating adjustment, $Coat_{adj}$

$if\ Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}]$	if high coating quality

$if\ Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}] - \min[5, Age_{coat} - Age_{tk}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}] - \min[15, Age_{coat} - Age_{tk}]$	if high coating quality

RBI date :

$Coat_{adj} =$ 15

Plan date :

$Coat_{adj} =$ 15

7. - Determine the in-service time, age, over which external corrosion may have occurred

$age = age_{tk} - coat_{adj}$

RBI date :			Plan date :		
age =	11	year	age =	16	year

8. - Determine allowable stress, S , weld joint eff., E, thick min., t_{min}

	(top head)			(shell)			(bottom head)	
t_{min} =	1.6	mm	t_{min} =	1.1	mm	t_{min} =	1.6	mm
	0.062992126	inch		0.043307087	inch		0.062992126	inch

S =		psi
	118000	kPa
E =	1	

9. - Determine A_{rt} parameter

$$A_{rt} = \frac{C_r.\,age}{t_{rde}}$$

RBI date :		**Plan date :**	
	(top head)		(top head)
head A_{rt} =	0.050878274	head A_{rt} =	0.060662558
	(shell)		(shell)
shell A_{rt} =	0.06103512	shell A_{rt} =	0.072772643
	(bottom head)		(bottom head)
head A_{rt} =	0.050721966	head A_{rt} =	0.06047619

10 . - Calculate Flow Stress ($FS^{extcorr}$)

$$FS^{extcorr} = \frac{(YS+TS)}{2}.\,E.\,1,1$$

$FS^{extcorr} =$ 360250

YS =	240000	kPa
TS =	415000	kPa
E =	1	

11. - Calculate strength ratio parameter, $SR_P^{extcorr}$

$$SR_P^{extcorr} = \frac{S.E}{FS^{extcorr}}.\frac{Max\,(t_{min},\ t_c)}{t_{rde}}.$$

	(top head)		(shell)		(bottom head)
$SR_P^{extcorr} =$	0.040376002	$SR_P^{extcorr} =$	0.048436275	$SR_P^{extcorr} =$	0.040251958

12. - Determine the number of inspections

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	0
N_D^{Thin} =	0

13. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{extcorr} = Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrD}\right)^{l}$$

$$I_2^{extcorr} = Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrD}\right)^{l}$$

$$I_3^{extcorr} = Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrD}\right)^{l}$$

I_1^{Thin} =	0.4096	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	0.00050625	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000625	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

14. - Calculate posterior probabilities

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$Po_{p1}^{extcorr}$=	0.998750343
$Po_{p2}^{extcorr}$=	0.001234417
$Po_{p3}^{extcorr}$=	1.52397E-05

15. - Calculate parameters, $\beta n^{extcorr}$

$$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$COV_{\Delta t}$ =	coefficient of variances for thickness, 0.1≤ COV ≤0.2	0.2
COV_{S_f} =	flow stress coefficient of variance	0.2
COV_P =	pressure coefficient of variance	0.05
D_{S_1} =	damage step 1	1
D_{S_2} =	damage step 2	2
D_{S_3} =	damage step 3	4

RBI date :

	(top head)
β_1^{Thin}	4.780165022
β_2^{Thin}	4.744605271
β_3^{Thin}	4.598442846

	(shell)
β_1^{Thin}	4.731697629
β_2^{Thin}	4.678693977
β_3^{Thin}	4.452551023

	(right head)
β_1^{Thin}	4.780898374
β_2^{Thin}	4.745575999
β_3^{Thin}	4.600476451

Plan date :

	(top head)
β_1^{Thin}	4.774860797
β_2^{Thin}	4.725105836
β_3^{Thin}	4.507362756

	(shell)
β_1^{Thin}	4.723882993
β_2^{Thin}	4.649141482
β_3^{Thin}	4.308697745

	(bottom head)
β_1^{Thin}	4.775628603
β_2^{Thin}	4.726211802
β_3^{Thin}	4.510092477

16.- Calculate DF for thinning (D_f^{extcor})

$$D_f^{extcor} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(top head)
$D_f^{extcor} =$ 0.005615

(Shell)
$D_f^{extcor} =$ 0.007139

(bottom head)
$D_f^{extcor} =$ 0.005595

Plan date :

(top head)
$D_f^{extcor} =$ 0.005766051

(Shell)
$D_f^{extcor} =$ 0.007420862

(bottom head)
$D_f^{extcor} =$ 0.005744075

PROBABILITY OF FAILURE

PROBABILITY OF FAILURE

$P_f(t) = gff_{total}.D_f(t).F_{MS}$

$P_f(t)$ = Probability of Failure as a function of time

gff_{total} = Generic failure frequency

$D_f(t)$ = Total damage factor

F_{MS} = Management system factor

DETERMINING DAMAGE FACTOR

$D_f^{extcor} = max[D_{f-gov}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ local thinning

$D_f^{extcor} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ general thinning

RBI date :

(top head)
$D_{f-total}$ = 5.97309

(shell)
$D_{f-total}$ = 5.97309

(bottom head)
$D_{f-total}$ = 5.97309

Plan date :

(top head)
$D_{f-total}$ = 12.68925

(shell)
D_{f-tota} = 12.68925

(bottom head)
D_{f-tota} = 12.68925

GENERIC FAILURE FREQUENCY

Equipment type	Component type	gff as a Function of hole size (failures/yr)				gfftotal (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	DRUM	0.000008	0.00002	0.000002	0.0000006	0.0000306

MANAGEMENT SYSTEM FACTOR

	(top head)	Category	(top head)	Category
PoF =	0.0001828	2	0.0003883	3
	(Shell)		(Shell)	
PoF =	0.0001828	2	0.0003883	3
	(bottom head)		(bottom head)	
PoF =	0.0001828	2	0.0003883	3

	CONSEQUENCE OF FAILURE	Doc. PV : V-003

1.- Release phase

1.1 - Representative fluids

C1 - C2

1.2 - Determine the store liquid phase

fluid phase = Gas

1.3 -

Store liquid		Store vapor or gas	
NBP =	-	NBP =	-125
Density =	-	MW =	23
AIT =	-	k =	1.22466
		Cp =	45.321385
		AIT =	558

1.4 - Determine the steady state phase of the fluid release

steady state phase = Gas

2.- Release hole size

2.1 - Determine release hole size diameter (dn)

Release hole number	Release hole size	Range of hole diameter	Release hole diameter, dn (mm)
1	Small	0 - 6.4	d_1 = 6.4
2	Medium	> 6.4 - 51	d_2 = 25
3	Large	> 51 - 152	d_3 = 102
4	Rupture	> 152	d_4 = 406

2.2 - Determine the generic failure frequency gffn

Component type =	COLBTM	
gff small =	0.000008	failure/ year
gff medium =	0.00002	failure/ year
gff large =	0.000002	failure/ year
gff rupture =	0.0000006	failure/ year
gff_{total} =	0.0000306	failure/ year

3. - Release rate

3.1 - Select appropiate release rate equation according to stored fluid phase

Stored fluid phase =

3.2 - Calculate each release hole size area

$$A_n = \frac{\pi . d_n^2}{4}$$

A_{small} =	3.21699E-05	m^2
	0.049087385	$inch^2$
A_{medium} =	0.000490874	m^2
	0.785398163	$inch^2$
A_{large} =	0.008171282	m^2
	12.56637061	$inch^2$
$A_{rupture}$ =	0.024828666	m^2
	38.48451001	$inch^2$

3.3 - Calculate release rate (W_n) for each hole size

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

Ptrans = 180.9602839 kPa

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\, x\, A_n\, x\, P_s\sqrt{\frac{k\, x\, MW\, x\, g_c}{R\, x\, T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{small} =	0.00121	kg/s
W_{medium} =	0.01844	kg/s
W_{large} =	0.30702	kg/s
$W_{rupture}$ =	0.93289	kg/s

Cd =	0.9	satuan
C2 =	1	mm^2/m^2
Ps =	689.5	kPa
k =	1.2246579	
MW =	23	
gc =	1	kg-m/N-s^2
R =	8.314	J/kg-mol-K
Ts =	322.04	K

For now choose between which value is exposed

W_{small} =	0.00121	kg/s
W_{medium} =	0.01844	kg/s
W_{large} =	0.30702	kg/s
$W_{rupture}$ =	0.93289	kg/s

4.- Calculation of inventory mass

4.1 - Determine the group components and equipment items into inventory groups

COLBTM

4.2 - Calculate fluid mass ($mass_{comp}$) in the component

$mass_{component}$ = 1.938588051 kg

4.3 - Calculate fluid mass in each of other component that are included in inventory group ($mass_{comp.i}$)

$mass_{comp,i}$= 1728.1144

4.4 - Calculate the fluid mass in the inventory group ($mass_{inv}$)

$$mass_n = \sum_{i=1}^{N} mass_{comp,i}$$

$mass_{inv}$= 1730.052988

4.5 - Calculate the flow rate 8 inch diameter hole (W_{max8})

Vapor phase

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\, x\, A_n\, x\, P_s\sqrt{\frac{k\, x\, MW\, x\, g_c}{R\, x\, T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{max8} = 1.216072698 kg/s

Cd =	0.9	satuan
C2 =	1	mm^2/m^2
Ps =	689.5	kPa
k =	1.2246579	
MW =	23	
gc =	1	kg-m/N-s^2
R =	8.314	J/kg-mol-K
Ts =	322.04	K

W_{max8} = 1.216072698 kg/s

4.6 - Calculate added fluid mass ($mass_{add,n}$) for each release hole size resulting from three minutes of flow from inventory group

$$mass_{add,n} = 180.\min[W_n, W_{max8}]$$

$mass_{add,1}$ =	0.217570453	kgs
$mass_{add,2}$ =	3.319861644	kgs
$mass_{add,3}$ =	55.26374488	kgs
$mass_{add,4}$ =	167.920408	kgs

4.7 - Calculate the available mass for release of each hole size ($mass_{avail,n}$)

$$mass_{avail} = min\left[\{mass_{comp} + mass_{add,n}\}, mass_{inv}\right]$$

$mass_{avail\ 1}$ =	2.15616	kgs
$mass_{avail\ 2}$ =	5.25845	kgs
$mass_{avail\ 3}$ =	57.20233	kgs
$mass_{avail\ 4}$ =	169.85900	kgs

5. - Release type

5.1 - Calculate time required to release 4,536 kgs of fluid for each hole size

$$t_n = \frac{C_3}{W_n}$$

C3 = 4536 kg

t_{small} =	3752715.453	sec
t_{medium} =	245937.960	sec
t_{large} =	14774.243	sec
$t_{rupture}$ =	4862.304	sec

5.2 - Determine the release type instaneous or continous

1.) if the release hole size is 6.35 mm(0.25 inch) = Continous

2.) if tn ≤ 180 sec and the release mass is greater than 4.536 kgs (10,000 lbs) = Instantaneous

t_{small} =	CONTINOUS
t_{medium} =	CONTINOUS
t_{large} =	CONTINOUS
$t_{rupture}$ =	CONTINOUS

6. - Detection and isolation

6.1 - determine the dectection and isolation system

Type of detection system	Detection classification
Instrumentation designed spesifically to detect material losses by changes in operating conditions in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of isolation system	**Detection classification**
Isolation or shutdown systems activated directly from process instrumentation or detector, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually operated valves	C

6.2 - select appropiate classification for detection system

A

6.3 - select appropiate classification for isolation system

C

6.4 - determine the release reduction factor ($fact_{di}$)

System classification		Release magnitude adjusment	Reductioin factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A	C	Reduce release rate or mass by 10%	0.10
B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjusment to release rate or mass	0

release reduction factor = 0.1

6.5 - determine the total leak durations for each of the hole size ($ld_{dimax,n}$)

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 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
C	A, B or C	1 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks

$Id_{max,1}$ = 40 minutes
$Id_{max,2}$ = 30 minutes
$Id_{max,3}$ = 20 minutes
$Id_{max,4}$ = 20 minutes

7. - Release rate and mass

7.1 - calculate the adjusted release rate ($rate_n$) for each hole size

$$rate_n = W_n(1 - fact_{dl})$$

W_1 = 0.001208725 kg/s
W_2 = 0.018443676 kg/s
W_3 = 0.307020805 kg/s
W_4 = 0.932891155 kg/s

$rate_{small}$ = 0.00109 kg/s
$rate_{medium}$ = 0.01660 kg/s
$rate_{large}$ = 0.27632 kg/s
$rate_{rupture}$ = 0.83960 kg/s

7.2 - calculate the leak duration (ld_n) for each hole size

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}\{60.ld_{max,n}\}\right]$$

ld_{small} =	1982.03247	s	$Id_{max,1}$ =	40	minutes
ld_{medium} =	316.78728	s	$Id_{max,2}$ =	30	minutes
ld_{large} =	207.01577	s	$Id_{max,3}$ =	20	minutes
$ld_{rupture}$ =	202.30894	s	$Id_{max,4}$ =	20	minutes

7.3 - calculate the release mass ($mass_n$) for each hole size

$$ld_n = min[\{rate_n \ x \ ld_n\}, mass_{avail,n}]$$

$mass_{small}$ =	2.15616	kg
$mass_{medium}$ =	5.25845	kg
$mass_{large}$ =	57.20233	kg
$mass_{rupture}$ =	169.85900	kg

8. - Determine flammable and explosive consequence

8.1 - Select the consequence area mitigatian reduction factor ($fact_{mit}$)

$fact_{mit}$ = 0.05

8.2 - Calculate the energy efficiency correction factor ($eneff_n$) for each release hole size

$$eneff_n = 4.log_{10}[C_{4A}.mass_n] - 15$$

C4A = 2.205 1/kg

$eneff_1$ =	0
$eneff_2$ =	0
$eneff_3$ =	0
$eneff_4$ =	0

8.3 - Determine the fluid type

fluid type = C1 - C2

8.4 - calculate component damage consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{cmd,n}^{AINL\text{-}CONT}$)

8.4.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AINL-CONT}$

a = 8.669

b = $b_{cmd}^{AINL-CONT}$

b = 0.98

8.4.2 - calculate consequence area

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b.(1 - fact_{mit})$$

$Ca_{cmd.small}^{AINL\text{-}CONT}$ =	0.01026907	m^2
$Ca_{cmd.medium}^{AINL\text{-}CONT}$ =	0.148381856	m^2
$Ca_{cmd.large}^{AINL\text{-}CONT}$ =	2.334934581	m^2
$Ca_{cmd.rupture}^{AINL\text{-}CONT}$ =	6.938804055	m^2

$fact_{mit}$ = 0.05

8.5 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{cmd,n}^{AIL\text{-}CONT}$)

8.5.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AIL-CONT}$

a = 55.13

b = $b_{cmd}^{AIL-CONT}$

b = 0.95

8.5.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b.(1 - fact_{mit})$$

$Ca_{cmd.small}^{AIL\text{-}CONT}$ =	0.08014068
$Ca_{cmd.medium}^{AIL\text{-}CONT}$ =	1.067080264
$Ca_{cmd.large}^{AIL\text{-}CONT}$ =	15.433037
$Ca_{cmd.rupture}^{AIL\text{-}CONT}$ =	44.35896542

$fact_{mit}$ = 0.05

8.6 - calculate component damage consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{cmd,n}^{AINL-INST}$)

8.6.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AINL-INS}$

a =	6.469

$b = b_{cmd}^{AINL-INST}$

b =	0.69

8.6.2 - calculate consequence area

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

$Ca_{cmd1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AINL-INST}$ =	0		
$Ca_{cmd3}^{AINL-INST}$ =	0		
$Ca_{cmd4}^{AINL-INST}$ =	0		

8.7 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-INST ($Ca_{cmd,n}^{AIL-INST}$)

8.7.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a =	163.7

$b = b_{cmd}^{AIL-INST}$

b =	0.62

8.7.2 - calculate consequence area

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

$Ca_{cmd1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AIL-INST}$ =	0		
$Ca_{cmd3}^{AIL-INST}$ =	0		
$Ca_{cmd4}^{AIL-INST}$ =	0		

8.8 - calculate personnel injury consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{inj,n}^{AINL-CONT}$)

8.8.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-CONT}$

a =	21.83

$b = b_{inj}^{AINL-CONT}$

b =	0.96

8.8.2 - calculate consequence area

$$CA_{inj,n}^{AINL-CONT} = [a.(rate_n^{AINL-CONT})\ ].(1 - fact_{mit})$$

$Ca_{inj1}^{AINL-CONT}$ =	0.029640428	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-CONT}$ =	0.405568046		
$Ca_{inj3}^{AINL-CONT}$ =	6.032971084		
$Ca_{inj4}^{AINL-CONT}$ =	17.53427795		

8.9 - calculate personnel injury consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{inj,n}^{AIL-CONT}$)

8.9.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AIL-CONT}$

a =	143.2

$b = b_{inj}^{AIL-CONT}$

b =	0.92

8.9.2 - calculate consequence area

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

$Ca_{inj1}^{AIL-CONT}$ =	0.255452966	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AIL-CONT}$ =	3.134363875		
$Ca_{inj3}^{AIL-CONT}$ =	41.66430227		
$Ca_{inj4}^{AIL-CONT}$ =	115.8281792		

8.10 - calculate personnel injury consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{inj,n}^{AINL-INST}$)

8.10.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-INS}$

a =	12.46

$b = b_{inj}^{AINL-INST}$

b =	0.67

8.10.2 - calculate consequence area

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

$Ca_{inj1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-INST}$ =	0		
$Ca_{inj3}^{AINL-INST}$ =	0		
$Ca_{inj4}^{AINL-INST}$ =	0		

8.11 - calculate personnel injury consequence areas for auto-ignition likely, instantaneous release, AIL-INST ($Ca_{inj,n}^{AIL-INST}$)

8.11.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a =	473.9

$b = b_{cmd}^{AIL-INST}$

b =	0.63

8.11.2 - calculate consequence area

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

$CA_{inj1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$CA_{inj2}^{AIL-INST}$ =	0		
$CA_{inj3}^{AIL-INST}$ =	0		
$CA_{inj4}^{AIL-INST}$ =	0		

8.12 - calculate the instantaneous/ continous blending factor ($fact_n^{IC}$)

Continous

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$$

C5 = 25.2 kg/s

Instantaneous

$$fact_n^{IC} = 1.0$$

$fact_1^{IC}$ =	4.31687E-05
$fact_2^{IC}$ =	0.000658703
$fact_3^{IC}$ =	0.010965029
$fact_4^{IC}$ =	0.033317541

8.13 - calculate AIT (auto ignition temperature) blending factor ($fact^{AIT}$)

$T_s + C_6 \le AIT$	$fact^{AIT} = 0$	C6 =	55.6	K
$T_s + C_6 > AIT > T_s - C_6$	$fact^{AIT} = \frac{T_s - AIT + C_6}{2.C_6}$	Ts =	48.89	C
			120	F
$T_s - C_6 \ge AIT$	$fact^{AIT} = 1$		322.039	K
$fact^{AIT}$ = 0		AIT =	558	K

8.14 - calculate the continous/ instantaneous blended consequnces areas for the component and the continous/ instantaneous blending factor ($fact_n^{IC}$)

8.14.1 - calculate continous/ instantaneous blended consequence area for auto ignition likely for component damage

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CON}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AIL}$ =	0.08013722 m^2	$CA_{cmd1}^{AIL-INST}$ =	0
		$fact_1^{IC}$ =	4.31687E-05
		$CA_{cmd1}^{AIL-CONT}$ =	0.08014068
$CA_{cmd,2}^{AIL}$ =	1.066377375 m^2	$CA_{cmd2}^{AIL-INST}$ =	0
		$fact_2^{IC}$ =	0.000658703
		$CA_{cmd2}^{AIL-CONT}$ =	1.067080264
$CA_{cmd,3}^{AIL}$ =	15.2638133 m^2	$CA_{cmd3}^{AIL-INST}$ =	0
		$fact_3^{IC}$ =	0.010965029
		$CA_{cmd3}^{AIL-CONT}$ =	15.433037
$CA_{cmd,4}^{AIL}$ =	42.88103376 m^2	$CA_{cmd4}^{AIL-INST}$ =	0
		$fact_4^{IC}$ =	0.033317541
		$CA_{cmd4}^{AIL-CONT}$ =	44.35896542

8.14.2 - calculate continous/ instantaneous blended consequence area for auto ignition likely for personnel injury

$$CA^{AIL}_{inj,n} = CA^{AIL-INST}_{inj,n}.fact^{IC}_{n} + CA^{AIL-CONT}_{inj,n}.(1 - fact^{IC}_{n})$$

$CA_{inj,1}^{AIL}$ =	0.255441938 m^2	$CA_{inj1}^{AIL-INST}$ =	0
		$fact_1^{IC}$ =	4.31687E-05
		$CA_{inj1}^{AIL-CONT}$ =	0.255452966
$CA_{inj,2}^{AIL}$ =	3.132299261 m^2	$CA_{inj2}^{AIL-INST}$ =	0
		$fact_2^{IC}$ =	0.000658703
		$CA_{inj2}^{AIL-CONT}$ =	3.134363875
$CA_{inj,3}^{AIL}$ =	41.207452 m^2	$CA_{inj3}^{AIL-INST}$ =	0
		$fact_3^{IC}$ =	0.010965029
		$CA_{inj3}^{AIL-CONT}$ =	41.66430227
$CA_{inj,4}^{AIL}$ =	111.9690691 m^2	$CA_{inj4}^{AIL-INST}$ =	0
		$fact_4^{IC}$ =	0.033317541
		$CA_{inj4}^{AIL-CONT}$ =	115.8281792

8.14.3 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for component damage

$$CA^{AINL}_{cmd,n} = CA^{ANIL-INST}_{cmd,n}.fact^{IC}_{n} + CA^{AINL-CONT}_{cmd,n}.(1 - fact^{IC}_{n})$$

$CA_{cmd,1}^{AINL}$ =	0.010268627	$CA_{cmd1}^{AINL-INST}$ =	0
		$fact_1^{IC}$ =	4.31687E-05
		$CA_{cmd1}^{AINL-CONT}$ =	0.01026907
$CA_{cmd,2}^{AINL}$ =	0.148284116	$CA_{cmd2}^{AINL-INST}$ =	0
		$fact_2^{IC}$ =	0.000658703
		$CA_{cmd2}^{AINL-CONT}$ =	0.148381856
$CA_{cmd,3}^{AINL}$ =	2.309331956	$CA_{cmd3}^{AINL-INST}$ =	0
		$fact_3^{IC}$ =	0.010965029
		$CA_{cmd3}^{AINL-CONT}$ =	2.334934581
$CA_{cmd,4}^{AINL}$ =	6.707620165	$CA_{cmd4}^{AINL-INST}$ =	0
		$fact_4^{IC}$ =	0.033317541
		$CA_{cmd4}^{AINL-CONT}$ =	6.938804055

8.14.4 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for personnel injury

$$CA^{AIL}_{inj,n} = CA^{AINL-INST}_{inj,n}.fact^{IC}_{n} + CA^{AINL-CONT}_{inj,n}.(1 - fact^{IC}_{n})$$

$CA_{inj,1}^{AINL}$ =	0.029639148	$CA_{inj1}^{AINL-INST}$ =	0
		$fact_1^{IC}$ =	4.31687E-05
		$CA_{inj1}^{AINL-CONT}$ =	0.029640428
$CA_{inj,2}^{AINL}$ =	0.405300897	$CA_{inj2}^{AINL-INST}$ =	0
		$fact_2^{IC}$ =	0.000658703
		$CA_{inj2}^{AINL-CONT}$ =	0.405568046
$CA_{inj,3}^{AINL}$ =	5.966819382	$CA_{inj3}^{AINL-INST}$ =	0
		$fact_3^{IC}$ =	0.010965029
		$CA_{inj3}^{AINL-CONT}$ =	6.032971084
$CA_{inj,4}^{AINL}$ =	16.95007892	$CA_{inj4}^{AINL-INST}$ =	0
		$fact_4^{IC}$ =	0.033317541
		$CA_{inj4}^{AINL-CONT}$ =	17.53427795

8.15 - calculate AIT blended consequence areas for the component damage and personnel injury flammable consequence area

8.15.1 - calculate AIT blended consequence areas for daage component

$$CA^{flam}_{cmd,n} = CA^{AIL}_{cmd,n}.fact^{AIT} + CA^{AINL}_{cmd,n}.(1 - fact^{AIT})$$

CA_{cmd1}^{flam} =	0.010268627	CA_{cmd1}^{AIL} =	0.08013722
		$fact^{AIT}$ =	0
		CA_{cmd1}^{AINL} =	0.010268627
CA_{cmd2}^{flam} =	0.148284116	CA_{cmd2}^{AIL} =	1.066377375
		$fact^{AIT}$ =	0
		CA_{cmd2}^{AINL} =	0.148284116
CA_{cmd3}^{flam} =	2.309331956	CA_{cmd3}^{AIL} =	15.2638133
		$fact^{AIT}$ =	0
		CA_{cmd3}^{AINL} =	2.309331956
CA_{cmd4}^{flam} =	6.707620165	CA_{cmd4}^{AIL} =	42.88103376
		$fact^{AIT}$ =	0
		CA_{cmd4}^{AINL} =	6.707620165

8.15.2 - calculate AIT blended consequence areas for personnel injury

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}.fact^{AIT} + CA_{inj,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{inj,1}^{AINL}$ =	0.029639148	CA_{inj1}^{AIL} =	0.255441938
		$fact^{AIT}$ =	0
		CA_{inj1}^{AINL} =	0.029639148
$CA_{inj,2}^{AINL}$ =	0.405300897	CA_{inj2}^{AIL} =	3.132299261
		$fact^{AIT}$ =	0
		CA_{inj2}^{AINL} =	0.405300897
$CA_{inj,3}^{AINL}$ =	5.966819382	CA_{inj3}^{AIL} =	41.207452
		$fact^{AIT}$ =	0
		CA_{inj3}^{AINL} =	5.966819382
$CA_{inj,4}^{AINL}$ =	16.95007892	CA_{inj4}^{AIL} =	111.9690691
		$fact^{AIT}$ =	0
		CA_{inj4}^{AINL} =	16.95007892

8.16 - determine the final consequence areas for component damage and personnel injury

$$CA_{cmd,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1.CA_{cmd,1}^{flam}\right) + \left(gff_2.CA_{cmd,2}^{flam}\right) + \left(gff_3.CA_{cmd,3}^{flam}\right) + \left(gff_4.CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{cmd,n}^{flam}$ = 0.38206 m^2

$$CA_{inj,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj,n}^{flam} = \left(\frac{\left(gff_1.CA_{inj,1}^{flam}\right) + \left(gff_2.CA_{inj,2}^{flam}\right) + \left(gff_3.CA_{inj,3}^{flam}\right) + \left(gff_4.CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{inj,n}^{flam}$ = 0.99499 m^2

9.- Calculation of toxic consequences areas

9.1 - calculate the effective duration of toxic release

$$Id_n^{tox} = min\left(3600, \left\{\frac{mass_n}{W_n}\right\}, \{60.Id_{max.n}\}\right)$$

$CA_{inj,1}^{CONT}$ =	1783.829219	s	$mass_1$ =	2.156158504	W_1 =	0.001209	$Id_{max.1}$ =	40
$CA_{inj,2}^{CONT}$ =	285.1085517	s	$mass_2$ =	5.258449696	W_2 =	0.018444	$Id_{max.2}$ =	30
$CA_{inj,3}^{CONT}$ =	186.3141912	s	$mass_3$ =	57.20233293	W_3 =	0.307021	$Id_{max.3}$ =	20
$CA_{inj,4}^{CONT}$ =	182.0780431	s	$mass_4$ =	169.858996	W_4 =	0.932891	$Id_{max.4}$ =	20

9.2 - determine the toxic percentage of the toxic component ($mfrac^{tox}$)

$mfrac^{tox}$ = 0.0001 H_2S = 0.01%

9.3 - calculate the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$

$$rate_n^{tox} = mfrac^{tox}.W_n$$

			W_1 =	0.001209	kg/s
$rate_1^{tox}$ =	1.20872E-07	kg/s	W_2 =	0.018444	kg/s
$rate_2^{tox}$ =	1.84437E-06	kg/s	W_3 =	0.307021	kg/s
$rate_3^{tox}$ =	3.07021E-05	kg/s	W_4 =	0.932891	kg/s
$rate_4^{tox}$ =	9.32891E-05	kg/s			

$$mass_n^{tox} = mfrac^{tox}.mass_n$$

			$mass_1$ =	2.156158504	kgs
$mass_1^{tox}$ =	0.000215616	kgs	$mass_2$ =	5.258449696	kgs
$mass_2^{tox}$ =	0.000525845	kgs	$mass_3$ =	57.20233293	kgs
$mass_3^{tox}$ =	0.005720233	kgs	$mass_4$ =	169.858996	kgs
$mass_4^{tox}$ =	0.0169859	kgs			

9.4 - calculate the toxic consequence area for H2S,

$$CA_{inj,n}^{tox-CONT} = C_8 . 10^{\left(c.log_{10}\left[C_{4B}.rate_n^{tox}\right]+d\right)}$$

$$CA_{inj,n}^{tox-INST} = C_8 . 10^{\left(c.log_{10}\left[C_{4B}.mass_n^{tox}\right]+d\right)}$$

2.1904E-05	m^2
0.000619768	m^2
0.011179921	m^2
0.015326524	m^2

C_8 =	0.0929	m^2. sec
c1 =	1.2266	
c2 =	1.2266	
c3 =	1.237	
c4 =	0.9674	
d1 =	4.4365	
d2 =	4.4365	
d3 =	4.238	
d4 =	2.784	
C_{4B} =	2.205	sec/kg

9.5 - if there is additional toxic component step 9.2 through 9.4 should be repeated

9.6 - determine the final toxic consequnces areas for personnel injury

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n . CA_{inj.n}^{tox}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1 . CA_{cmd,1}^{flam}\right) + \left(gff_2 . CA_{cmd,2}^{flam}\right) + \left(gff_3 . CA_{cmd,3}^{flam}\right) + \left(gff_4 . CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

CA_{inj}^{tox} = 0.00144 m^2

10. - calculation of non-flammable, Non-toxic consequences area

10.1 - calculate CA $_{inj.n}^{CONT}$ and CA $_{inj.n}^{INST}$

for acid caustic

$$CA_{inj,n}^{CONT} = 0.2 . C_8 . g \left(C_4 . rate_n\right)^h$$

$$CA_{inj,n}^{INST} = 0$$

$$g = 2696 - 21.9 . C_{11}(P_s - P_{atm}) + 1.474[C_{11}(P_s - P_{atm})]^2$$

g = 2678.385496

$$h = 0.31 - 0.00032[C_{11}(P_s - P_{atm}) - 40]^2$$

h = -0.180387892

$CA_{inj,n}^{CONT}$ =	147.754
$CA_{inj,n}^{CONT}$ =	90.375
$CA_{inj,n}^{CONT}$ =	54.417
$CA_{inj,n}^{INST}$ =	44.532

$rate_{small}$ =	0.001088	kg/s
$rate_{med}$ =	0.016599	kg/s
$rate_{large}$ =	0.276319	kg/s
$rate_{ruptr}$ =	0.839602	kg/s
C_8 =	0.0929	m^2. sec
C_4 =	2.205	sec/kg
C_{11} =	0.145	1/kPa
P_s =	689.5	kPa
P_{atm} =	101.28755	kPa

$inj,..$

10.2 - calculate the instantaneous/continous blending factor $fact_n^{IC}$

$$fact_{in}^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1\right],$$

$fact_{small}^{IC} =$	4.31687E-05	$C_5 =$	25.2	kg/sec
$fact_{medium}^{IC} =$	0.000658703	$P_s =$	689.5	kPa
$fact_{large}^{IC} =$	0.010965029	$P_{atm} =$	101.28755	kPa
$fact_{rupture}^{IC} =$	0.033317541			

10.3 - calculate the blended non-flammable, non-toxic personnel injury consequence area for steam acid leaks $CA_{inj.n}^{leak}$

$CA_{cmd.n}^{leak} =$ 0

$$CA_{lak.n}^{leak} = CA_{inj.n}^{INST}.fact_n^{IC} + CA_{inj.n}^{CONT}.(1 - fact_n^{IC})$$

$fact_n^{IC} =$	4.317E-05
$fact_n^{IC} =$	0.0006587
$fact_n^{IC} =$	0.010965
$fact_n^{IC} =$	0.0333175

$CA_{lak.n}^{leak} =$	0.00637835	m^2
$CA_{lak.n}^{leak} =$	0.059529976	m^2
$CA_{lak.n}^{leak} =$	0.596684329	m^2
$CA_{lak.n}^{leak} =$	1.483683305	m^2

10.4 - determine the final non-flammable, non-toxic personnel injury CA_{inj}^{nfnt}

$CA_{cmd.n}^{nfnt} =$ 0

$$CA_{inj}^{nfnt} = \left(\frac{(gff_1.CA_{cmd,1}^{leak}) + (gff_2.CA_{cmd,2}^{leak}) + (gff_3.CA_{cmd,3}^{leak}) + (gff_4.CA_{cmd,4}^{leak})}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 0.10867 m^2

11. - Calculation of final consequence area

11.1 - calculate the final component damage consequence area, CA_{cmd}

$$CA_{cmd} = CA_{cmd}^{flam}$$

$CA_{cmd} =$ 0.38206 m^2

11.2 - calculate the final personnel injury consequence area, CA_{inj}

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$$

$CA_{inj} =$ 0.99499 m^2

11.3 - calculate the final consequence area, CA

$$CA = \max[CA_{cmd}, CA_{inj}]$$

CA = 0.99499 m^2 Category A

GENERAL DATA

Doc. PV : V-004

General Data :

Design code :			Date RBI assessment :	2024
Equipment Name :	V-004		Date last inspection :	2019
Vessel type :	Vertical Vessel		Plan date :	2029
Size :				
Diameter :	177.8	mm		
Volume total :	0.03552	m^3		
Year built :	1998			
Fluid category :	C1- C2			
Fluid phase :	Gas			
Cladding :	No			
Coating :	High			
Design pressure :	18	bar		
	260	psig		
Design temperature :	93.33	°C		
	200	°F		
Operating pressure :	6.895	bar		
	100	psig		
	689.5	kPa		
Operating temperature :	38.89	°C		
	120	°F		
	322.039	°K		
Atmospheric pressure :	101.28755	kPa		

Head data 1 :

Type :	2:1 Ellipsoidal	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	13.85	mm
	0.545	inch
Minimum wall thickness :	1.600	mm
	0.063	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	13.370	mm
	0.526	inch

Shell data 2 :

Type :	Cylindrical shell	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	11.66	mm
	0.459	inch
Minimum wall thickness :	0.950	mm
	0.037	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	11.130	mm
	0.438	inch

Shell data :

Type :	Cylindrical shell	
Material :	SA 106 Gr.B	
Joint efficiency :	1	
Thickness :	10.973	mm
	0.432	inch
Minimum wall thickness :	0.950	mm
	0.037	inch
Corrosion allowance:	3.200	mm
	0.126	inch
Last inspection thickness :	10.420	mm
	0.410	inch

Material data :

Allowable stress :	118000	kPa
Tensile strength :	415000	kPa
Yield strength :	240000	kPa
Mass density (ρ_m) :	250.512	kg/m^3

PROBABILITY OF FAILURE

Thinning

Doc. PV : V-004

1.-Furnished thickness & Age

(bottom head)			(shell)			(shell)		
head t =	13.85	mm	shell t =	10.9728	mm	head t =	11.66	mm
	0.545275591	inch		0.432	inch		0.459055118	inch

age = 26 year

2.-Corrosion rate for base metal ($C_{r,bm}$)

Based on API 510

$$LTCR = \frac{t_{initial} - t_{actual}}{years\ between}$$

left head $C_{r,bm}$ =	0.022857143	mm/year
shell $C_{r,bm}$ =	0.02632381	mm/year
right head $C_{r,bm}$ =	0.025238095	mm/year

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Last inspection date :	2019
RBI date :	2024
Plan date :	2029

(bottom head)

t_{rdi} =	13.37	mm
	0.526	inch

(shell)

t_{rdi} =	10.420	mm
	0.410	inch

(shell)

t_{rdi} =	11.130	mm
	0.438	inch

age_{tk} =	5	year
age_{pd} =	10	year

4.- For cladding/ weld overlay pressure vessel components, calculate the age from the date of the starting thickness from STEP 3 required to corrode away the cladding/ weld overlay material (age_{rc})

$$age_{rc} = \left[\left(\frac{t_{rdi} - t_{bm}}{C_{r,cm}}\right)\right], 0.0$$

age_{rc} = 0

$C_{r,cm}$ =	0	mm/year
	0	

5.- Determine t_{min}

According to Data or ASME Sec. VIII

	(bottom head)			(shell)			(shell)	
t_{min} =	1.6	mm	t_{min} =	0.95	mm	t_{min} =	0.95	mm
	0.0630	inch		0.0374	inch		0.0374	inch

6.- Determine A_{rt}

$$A_{rt} = \frac{Cr_{b.m}.age_{tk}}{t_{rdi}}$$

RBI date :		Plan date :	
(bottom head)		(bottom head)	
A_{rt} =	0.008547922	A_{rt} =	0.017095844
(shell)		(shell)	
A_{rt} =	0.012631387	A_{rt} =	0.025262773
(shell)		(shell)	
A_{rt} =	0.011337868	A_{rt} =	0.022675737

$C_{r,bm}$ =	0.022857143	mm/year
$C_{r,bm}$ =	0.02632381	mm/year
$C_{r,bm}$ =	0.025238095	mm/year
age_{tk} =	5	year
age_{pd} =	10	year
t_{rdi} =		mm
	0.526377953	inch

7.- Calculate the flow stress FS^{thin}

$$FS^{thin} = \frac{(YS+TS)}{2}.E.1,1$$

FS^{thin} = 360250

Yield strength =	240000	kPa
Tensile strength =	415000	kPa
Joint efficiency =	1	

8.- Calculate strength ratio parameter (SR_p^{thin})

$$SR_P^{thin} = \frac{S.E}{FS^{thin}}.\frac{Max\ (t_{min},\ t_c)}{t_{rdi}}.$$

Allowable stress =	118000
Joint efficiency =	1

(bottom head)		(shell)		(shell)	
Sr_p^{thin} =	0.039198242	Sr_p^{thin} =	0.029863032	Sr_p^{thin} =	0.027958023

9.- Determine the number of inspections for each of the corresponding inspection effectiveness

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	2

N_D^{Thin} =	0

10. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}} Pr_{p1}^{Thin}\left(Co_{p1}^{ThinD}\right)^{N}$$

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

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

I_1^{Thin} =	0.1024	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	4.55625E-05	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000025	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

11. - Calculate the posterior probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Po_{p1}^{Thin} =	0.999552812
Po_{p2}^{Thin} =	0.000444747
Po_{p3}^{Thin} =	2.44031E-06

12.- Calculate the parameters

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$$\beta_2^{Thin} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$$\beta_3^{Thin} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{Thin}}{\sqrt{{D_{S_3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.{COV_{S_f}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2}}$$

$COV_{\Delta t}$ =	coefficient of variances for thickness, 0.1≤ COV ≤0.2	0.2
COV_{S_f} =	flow stress coefficient of variance	0.2
COV_P =	pressure coefficient of variance	0.05
D_{S_1} =	damage step 1	1
D_{S_2} =	damage step 2	2
D_{S_3} =	damage step 3	4

RBI date :

(bottom head)

β_1^{Thin}	4.801906017
β_2^{Thin}	4.799635427
β_3^{Thin}	4.793820539

(shell)

β_1^{Thin}	4.848239356
β_2^{Thin}	4.845045915
β_3^{Thin}	4.835747888

(shell)

β_1^{Thin}	4.858165946
β_2^{Thin}	4.855535603
β_3^{Thin}	4.847971832

Plan date :

(bottom head)

β_1^{Thin}	4.799635427
β_2^{Thin}	4.793820539
β_3^{Thin}	4.776508329

(shell)

β_1^{Thin}	4.845045915
β_2^{Thin}	4.835747888
β_3^{Thin}	4.803482367

(shell)

β_1^{Thin}	4.855535603
β_2^{Thin}	4.847971832
β_3^{Thin}	4.822192503

13.- For all component (excluding tank bottoms) calculate base damage factor

$$D_{fB}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right.$$

RBI date :		Plan date :	
(bottom head) $D_{fB}^{Thin} =$	0.005037284	(bottom head) $D_{fB}^{Thin} =$	0.005094771
(shell) $D_{fB}^{Thin} =$	0.003992403	(shell) $D_{fB}^{Thin} =$	0.004057217
(shell) $D_{fB}^{Thin} =$	0.003797398	(shell) $D_{fB}^{Thin} =$	0.003848201

14.- Determine the DF for thinning (D_f^{Thin})

$$D_f^{Thin} = max\left[\left(\frac{D_{fB}^{Thin}.F_{IP}.F_{DL}F_{WD}F_{AM}F_{SM}}{F_{OM}}\right), \quad 0.1\right]$$

$F_{IP} =$ DF ofr injection/ mix point (for piping circuit)
0

$F_{DL} =$ DF for dead legs (for piping only used to intermittent service)
0

$F_{WD} =$ DF for welded construction (for AST bottom only)
0

$F_{AM} =$ DF for AST maintenance in accordance (for AST bottom only)
0

$F_{SM} =$ DF for settlement (for AST bottom only)
0

$F_{OM} =$ DF for on-line monitoring
1

RBI date :		Plan date :	
(bottom head) $D_f^{Thin} =$	0.1	(bottom head) $D_f^{Thin} =$	0.1
(shell) $D_f^{Thin} =$	0.1	(shell) $D_f^{Thin} =$	0.1
(shell) $D_f^{Thin} =$	0.1	(shell) $D_f^{Thin} =$	0.1

PROBABILITY OF FAILURE

SCC-SULFIDE STRESS CRACKING

Doc. PV : V-004

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity: Low

pH : 5.5 - 7.5

H2S concentration: < 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	As-Welded Max Brinnel Hardness			PWHT Max Brinnel Hardness		
	< 200	200 - 237	> 237	< 200	200 - 237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderates	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

PWHT : No. — Max brinnel hardness : (left head) < 200

PWHT : No. — Max brinnel hardness : (shell) < 200

PWHT : No. — Max brinnel hardness : (right head) < 200

Enviromental severity : (left head) Low

Enviromental severity : (shell) Low

Enviromental severity : (right head) Low

3.- Determine the severity index S_{v1}

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

Sv1 : (bottom head) 1

Sv1 : (shell) 1

Sv1 : (shell) 1

4.- Determine the time in-service, age

Age_{tk} = 5

Age_{PD} = 10

Last Inspection 2019

RBI date 2024

Panned date 2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection : 1

Inspection effectiveness : B

6.- Determine the base DF for sulfide stress cracking

S_{v1}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{v1}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

$D_{fB}^{SCC} =$ 1
1
1

Number of inspection : 1
Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

$$D_f^{SCC} = D_f^{SCC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$$

RBI Date :

(bottom head)
$D_f^{SCC} =$ 5.873094715

(shell)
$D_f^{SCC} =$ 5.873094715

(shell)
$D_f^{SCC} =$ 5.873094715

Plan Date :

(bottom head)
$D_f^{SCC} =$ 12.58925412

(shell)
$D_f^{SCC} =$ 12.58925412

(shell)
$D_f^{SCC} =$ 12.58925412

1.-Determine the enviromental severity for cracking based on the H2S content of the water and its PH

pH of water	Environmental Severity as a Function of H2S content of water			
	< 50 ppm	50 - 1,000 ppm	50 - 1,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 - 7.5	Low	Low	Low	Moderate
7.6 - 8.3	Low	Moderate	Moderate	Moderate
8.4 - 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Env. Severity	Low	pH :	5.5 - 7.5
		H2S concentration	< 50 ppm

2.-Determine the susceptibility for cracking

Enviromental severity	Susceptibility to SSC as function of Heat Treatment					
	High Sulfur Steel > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Seamless/ Extruded pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderates	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

	(bottom head)		(bottom head)		(bottom head)
susceptibility :	low	sulfur content :	≤ 0.01%	PWHT :	No.
	(shell)		(shell)		(shell)
	low	sulfur content :	≤ 0.01%	PWHT :	No.
	(shell)		(shell)		(shell)
	low	sulfur content :	≤ 0.01%	PWHT :	No.

3.-Time in service (age_{tk}), since the last inspection known thickness (t_{rdi})

Susceptibility	Severity Index-Sv1
High	100
Medium	10
Low	1
None	0

	(bottom head)
Sv1 =	1
	(shell)
Sv1 =	1
	(shell)
Sv1 =	1

4.- Determine the time in-service, age

Age_{tk} =	5	Last Inspection	2019
Age_{PD} =	10	RBI date	2024
		Panned date	2029

5.- Determine the number of inspection and the corresponding inspection effectiveness category

Number of inspection :	1
Inspection effectiveness :	B

6.- Determine the base DF for sulfide stress cracking

S_{vI}	Inspection Effectiveness												
	E	1 inspection				2 inspection				3 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2500	500	80	10

S_{vI}	Inspection Effectiveness												
	E	4 inspection				5 inspection				6 inspection			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	5	1	1	1	1	1	1	1	1
100	100	20	5	1	10	2	1	1	1	5	1	1	1
500	500	100	25	1	50	10	1	1	5	25	5	1	1
1000	1000	200	50	1	100	25	2	1	10	50	10	1	1
5000	5000	1000	250	2	500	125	5	1	50	250	50	2	1

(bottom head)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(shell)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

(shell)

$D_{fB}^{HIC/SOHIC-H2S} =$ 1

Number of inspection : 1

Inspection effectiveness : B

7. - Calculate the escalation in the DF based on the time service sing the last inspection

On-Line monitoring method	Adjusment Factors as a function of On-line monitoring- Fom
Key process variables	2
Hydrogen probes	2
Key process variables & hydrogen p	4

On-Line monitoring method

F_{om} 2

8. - Calculate the final DF accounting based on time in-service since the last inespection

$$D_f^{HIC/SOHIC-H2} = \frac{D_{fB}^{HIC/SOHIC-a2S} .(Max[age,1.0])^{1.1}}{F_{OM}}$$

RBI Date :

(bottom head)

$D_f^{SC} =$ 2.936547358

(shell)

$D_f^{SC} =$ 2.936547358

(shell)

$D_f^{SC} =$ 2.936547358

Plan Date :

(bottom head)

$D_f^{SCC} =$ 6.294627059

(shell)

$D_f^{SCC} =$ 6.294627059

(shell)

$D_f^{SCC} =$ 6.294627059

Damage factor for stress corrosion cracking

$$D_{f-gov}^{SCC} = max \begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{HIC/SOHIC-H2}, D_f^{ACSCC} \\ , D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC-HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

RBI Date :

$D_{f-gov}^{SCC} =$ 5.873094715 (bottom head)

$D_{f-gov}^{SCC} =$ 5.873094715 (shell)

$D_{f-gov}^{SCC} =$ 5.873094715 (shell)

Plan Date :

$D_{f-gov}^{SCC} =$ 12.58925412 (bottom head)

$D_{f-gov}^{SCC} =$ 12.58925412 (shell)

$D_{f-gov}^{SCC} =$ 12.58925412 (shell)

PROBABILITY OF FAILURE

EXTERNAL CORROSION FACTOR

1.- Determine furnished thickness,t and age

	(left head)			(shell)			(right head)	
t =	13.85	mm	t =	10.9728	mm	t =	11.66	mm
	0.545275591	inch		0.432	inch		0.459055118	inch

age = 26 year

2.- Corrosion rate ($C_{r,bm}$) based on the driver and operating temperature

Operating tempertaure (°C)	Corrosion rate as a function of driver (mm/y)			
	Marine/ cooling tower drift area	Temperate	Acid/ dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0
6	0.0127	0.076	0.025	0.254
32	0.0127	0.076	0.025	0.254
71	0.0127	0.051	0.025	0.254
107	0.025	0	0	0
121	0	0	0	0

$C_{r,bm}$ = 0.0127 mm/y

Opr. Temperature = 38.89 °C
120 °F

3. - Calculate the final corrosion rate, C_r

$C_r = CR_B.max[F_{EQ}.F_{IF}]$

$C_r =$ 0.0254

F_{EQ} = adjusment for equipment design or fabrication
2

F_{IF} = adjusment for interface
1

4. - Determine time in service, age_{tk}, since the last known inspection, t_{rde}

	(left head)	
head t_{rdi} =	13.37	mm
	0.526377953	inch
	(shell)	
shell t_{rdi} =	10.42	mm
	0.41023622	inch
	(right head)	
head t_{rdi} =	11.13	mm
	0.438188976	inch
age_{tk} =	26	year
age_{pd} =	31	year

Last inspection date : 1998
RBI date : 2024
Plan date : 2029

5. - Determine time in-service, age_{coat}

$age_{coat} = calculation\ date - coating\ installation\ date$

RBI Calc. date : 2024
Coat. inst date : 1998
Plan Calc. date : 2029

RBI date :

$age_{coat} = calc. date - C.I\ date$

$age_{coat} =$ 26

Plan date :

$age_{coat} = planned\ date - C.I\ date$

$age_{coat} =$ 31

6. - Determine coating adjustment, $Coat_{adj}$

$if\ Age_{tk} \geq Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}]$	if high coating quality

$if\ Age_{tk} < Age_{coat}$

$Coat_{adj} = 0$	if no or poor coating quality
$Coat_{adj} = \min[5, Age_{coat}] - \min[5, Age_{coat} - Age_{tk}]$	if medium coating quality
$Coat_{adj} = \min[15, Age_{coat}] - \min[15, Age_{coat} - Age_{tk}]$	if high coating quality

RBI date :

$Coat_{adj} =$ 15

Plan date :

$Coat_{adj} =$ 15

7. - Determine the in-service time, age, over which external corrosion may have occurred

$age = age_{tk} - coat_{adj}$

RBI date :		Plan date :	
age =	11 year	age =	16 year

8. - Determine allowable stress, S , weld joint eff., E, thick min., t_{min}

	(left head)			(shell)			(right head)	
t_{min} =	1.6	mm	t_{min} =	0.95	mm	t_{min} =	1.6	mm
	0.062992126	inch		0.037401575	inch		0.062992126	inch

S =		psi
	118000	kPa
E =	1	

9. - Determine A_{rt} parameter

$$A_{rt} = \frac{C_r.\,age}{t_{rde}}$$

RBI date :		**Plan date :**	
	(left head)		(left head)
head A_{rt} =	0.049394166	head A_{rt} =	0.058893044
	(shell)		(shell)
shell A_{rt} =	0.063378119	shell A_{rt} =	0.075566219
	(right head)		(right head)
head A_{rt} =	0.05933513	head A_{rt} =	0.070745732

10 . - Calculate Flow Stress ($FS^{extcorr}$)

$FS^{extcorr} = \frac{(YS+TS)}{2}.\,E.\,1{,}1$

$FS^{extcorr} =$ 360250

YS =	240000	kPa
TS =	415000	kPa
E =	1	

11. - Calculate strength ratio parameter, $SR_P^{extcorr}$

$$SR_P^{extcorr} = \frac{S.E}{FS^{extcorr}}.\frac{Max\,(t_{min},\ t_c)}{t_{rde}}.$$

	(left head)		(shell)		(right head)
$SR_P^{extcorr}$ =	0.039198242	$SR_P^{extcorr}$ =	0.050295633	$SR_P^{extcorr}$ =	0.047087197

12. - Determine the number of inspections

N_A^{Thin} =	0
N_B^{Thin} =	0
N_C^{Thin} =	0
N_D^{Thin} =	0

13. - Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, I_3^{Thin}

$$I_1^{extcorr} = Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrD}\right)^{i}$$

$$I_2^{extcorr} = Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrD}\right)^{i}$$

$$I_3^{extcorr} = Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrA}\right)^{N_A^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrB}\right)^{N_B^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrC}\right)^{N_C^{extcorr}} Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrD}\right)^{i}$$

I_1^{Thin} =	0.4096	Pr_{p1}^{thin} =	0.8	Co_{p1}^{thin} =	0.5
I_2^{Thin} =	0.00050625	Pr_{p2}^{thin} =	0.15	Co_{p2}^{thin} =	0.3
I_3^{Thin} =	0.00000625	Pr_{p3}^{thin} =	0.05	Co_{p3}^{thin} =	0.2

14. - Calculate posterior probabilities

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$Po_{p1}^{extcorr}$ =	0.998750343
$Po_{p2}^{extcorr}$ =	0.001234417
$Po_{p3}^{extcorr}$ =	1.52397E-05

15. - Calculate parameters, $\beta n^{extcorr}$

$$\beta_1^{extcorr} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_1}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_2^{extcorr} = \frac{1 - D_{S_2}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_2}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$$\beta_3^{extcorr} = \frac{1 - D_{S_3}.A_{rt} - SR_P^{extcorr}}{\sqrt{D_{S_3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2 + \left(1 - D_{S_3}.A_{rt}\right)^2.COV_{S_f}{}^2 + (SR_P^{extcorr})^2.COV_P{}^2}}$$

$COV_{\Delta t}$ = coefficient of variances for thickness, 0.1≤ COV ≤0.2
0.2

COV_{S_f} = flow stress coefficient of variance
0.2

COV_P = pressure coefficient of variance
0.05

D_{S_1} = damage step 1
1

D_{S_2} = damage step 2
2

D_{S_3} = damage step 3
4

RBI date :

	(left head)
β_1^{Thin}	4.787112882
β_2^{Thin}	4.753770194
β_3^{Thin}	4.61750396

	(shell)
β_1^{Thin}	4.720286527
β_2^{Thin}	4.662674464
β_3^{Thin}	4.414880004

	(right head)
β_1^{Thin}	4.739922531
β_2^{Thin}	4.690122291
β_3^{Thin}	4.478914988

Plan date :

	(left head)
β_1^{Thin}	4.782130793
β_2^{Thin}	4.735532016
β_3^{Thin}	4.532896733

	(shell)
β_1^{Thin}	4.711814934
β_2^{Thin}	4.630432737
β_3^{Thin}	4.256683836

	(right head)
β_1^{Thin}	4.732565987
β_2^{Thin}	4.662431559
β_3^{Thin}	4.344952306

16.- Calculate DF for thinning (D_f^{extcor})

$$D_f^{extcor} = \left[\frac{\left(Po_{p1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E-04}\right]$$

RBI date :

(Left head)

$D_f^{extcor} =$ 0.005424

(Shell)

$D_f^{extcor} =$ 0.007552

(Right head)

$D_f^{extcor} =$ 0.006855

Plan date :

(Left head)

$D_f^{extcor} =$ 0.005561172

(Shell)

$D_f^{extcor} =$ 0.007874857

(Right head)

$D_f^{extcor} =$ 0.007109908

PROBABILITY OF FAILURE

PROBABILITY OF FAILURE

$P_f(t) = gff_{total}.D_f(t).F_{MS}$

$P_f(t)$ = Probability of Failure as a function of time

gff_{total} = Generic failure frequency

$D_f(t)$ = Total damage factor

F_{MS} = Management system factor

DETERMINING DAMAGE FACTOR

$D_f^{extcor} = max[D_{f-go}^{thin}, D_{f-gov}^{extd}] + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ local thinning

$D_f^{extcor} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{SCC} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$ general thinning

RBI date :

(left head)
D_{f-tota} = 5.97309

(shell)
D_{f-tot} = 5.97309

(right head)
D_{f-tot} = 5.97309

Plan date :

(left head)
D_{f-tot} = 12.68925

(shell)
D_{f-tot} = 12.68925

(right head)
$D_{f-total}$ = 12.68925

GENERIC FAILURE FREQUENCY

Equipment type	Component type	gff as a Function of hole size (failures/yr)				gfftotal (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	DRUM	0.000008	0.00002	0.000002	0.0000006	0.0000306

MANAGEMENT SYSTEM FACTOR

	RBI date	Category	Plan date	Category
PoF =	(Left head) 0.0001828	2	(Left head) 0.0003883	3
PoF =	(Shell) 0.0001828	2	(Shell) 0.0003883	3
PoF =	(Right Head) 0.0001828	2	(Right Head) 0.0003883	3

	CONSEQUENCE OF FAILURE	Doc. PV : V-004

1.- Release phase

1.1 - Representative fluids
C1 - C2

1.2 - Determine the store liquid phase
fluid phase = Gas

1.3 -

Store liquid		Store vapor or gas	
NBP =	-	NBP =	-125
Density =	-	MW =	23
AIT =	-	k =	1.22466
		Cp =	45.321385
		AIT =	558

1.4 - Determine the steady state phase of the fluid release
steady state phase = Gas

2.- Release hole size

2.1 - Determine release hole size diameter (dn)

Release hole number	Release hole size	Range of hole diameter	Release hole diameter, dn (mm)
1	Small	0 - 6.4	d_1 = 6.4
2	Medium	> 6.4 - 51	d_2 = 25
3	Large	> 51 - 152	d_3 = 102
4	Rupture	> 152	d_4 = 406

2.2 - Determine the generic failure frequency gffn

Component type =	FILTER	
gff small =	0.000008	failure/ year
gff medium =	0.00002	failure/ year
gff large =	0.000002	failure/ year
gff rupture =	0.0000006	failure/ year
gff_{total} =	0.0000306	failure/ year

3. - Release rate

3.1 - Select appropiate release rate equation according to stored fluid phase
Stored fluid phase =

3.2 - Calculate each release hole size area

$$A_n = \frac{\pi . d_n^2}{4}$$

A_{small} =	3.21699E-05	m^2
	0.049087385	$inch^2$
A_{medium} =	0.000490874	m^2
	0.785398163	$inch^2$
A_{large} =	0.008171282	m^2
	12.56637061	$inch^2$
$A_{rupture}$ =	0.024828666	m^2
	38.48451001	$inch^2$

3.3 - Calculate release rate (W_n) for each hole size

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

Ptrans = 180.9602839 kPa

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s\sqrt{\frac{k\ x\ MW\ x\ g_c}{R\ x\ T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{small} =	0.001228	kg/s	Cd =	0.9	satuan		1.122580
W_{medium} =	0.018737	kg/s	C2 =	1	mm^2/m^2		
W_{large} =	0.311902	kg/s	Ps =	689.5	kPa		
$W_{rupture}$ =	0.947722	kg/s	k =	1.2246579			
			MW =	23			
			gc =	1	kg-m/N-s^2		
			R =	8.314	J/kg-mol-K		
			Ts =	312.04	K		

For now choose between which value is exposed

W_{small} =	0.00123	kg/s
W_{medium} =	0.01874	kg/s
W_{large} =	0.31190	kg/s
$W_{rupture}$ =	0.94772	kg/s

4.- Calculation of inventory mass

4.1 - Determine the group components and equipment items into inventory groups

FILTER

4.2 - Calculate fluid mass ($mass_{comp}$) in the component

$mass_{component}$ = 8.89818624 kg

4.3 - Calculate fluid mass in each of other component that are included in inventory group ($mass_{comp.i}$)

$mass_{comp,i}$= 1721.155

4.4 - Calculate the fluid mass in the inventory group ($mass_{inv}$)

$$mass_n = \sum_{i=1}^{N} mass_{comp,i}$$

$mass_{inv}$= 1730.053186

4.5 - Calculate the flow rate 8 inch diameter hole (W_{max8})

Vapor phase

$$P_{trans} = P_{atm}\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

If storage pressure (Ps) > transition pressure (Ptrans)

$$W_n = \frac{C_d}{C_2}\ x\ A_n\ x\ P_s\sqrt{\frac{k\ x\ MW\ x\ g_c}{R\ x\ T_s}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

W_{max8} =	1.23540488	kg/s	Cd =	0.9	satuan
			C2 =	1	mm^2/m^2
			Ps =	689.5	kPa
			k =	1.2246579	
			MW =	23	
			gc =	1	kg-m/N-s^2
			R =	8.314	J/kg-mol-K
			Ts =	312.04	K

W_{max8} = 1.23540488 kg/s

4.6 - Calculate added fluid mass ($mass_{add,n}$) for each release hole size resulting from three minutes of flow from inventory group

$$mass_{add,n} = 180.\min[W_n, W_{max8}]$$

$mass_{add,1}$ =	0.221	kgs
$mass_{add,2}$ =	3.373	kgs
$mass_{add,3}$ =	56.142	kgs
$mass_{add,4}$ =	170.590	kgs

4.7 - Calculate the available mass for release of each hole size ($mass_{avail,n}$)

$$mass_{avail} = min\left[\{mass_{comp} + mass_{add,n}\}, mass_{inv}\right]$$

$mass_{avail\ 1}$ =	9.119	kgs
$mass_{avail\ 2}$ =	12.271	kgs
$mass_{avail\ 3}$ =	65.040	kgs
$mass_{avail\ 4}$ =	179.488	kgs

5. - Release type

5.1 - Calculate time required to release 4,536 kgs of fluid for each hole size

$$t_n = \frac{C_3}{W_n}$$

C3 = 4536 kg

t_{small} =	3693991.240	sec
t_{medium} =	242089.410	sec
t_{large} =	14543.049	sec
$t_{rupture}$ =	4786.216	sec

5.2 - Determine the release type instaneous or continous

1.) if the release hole size is 6.35 mm(0.25 inch) = Continous

2.) if tn ≤ 180 sec and the release mass is greater than 4.536 kgs (10,000 lbs) = Instantaneous

t_{small} =	CONTINOUS
t_{medium} =	CONTINOUS
t_{large} =	CONTINOUS
$t_{rupture}$ =	CONTINOUS

6. - Detection and isolation

6.1 - determine the dectection and isolation system

Type of detection system	Detection classification
Instrumentation designed spesifically to detect material losses by changes in operating conditions in the system	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope	B
Visual detection, cameras, or detectors with marginal coverage	C
Type of isolation system	**Detection classification**
Isolation or shutdown systems activated directly from process instrumentation or detector, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually operated valves	C

6.2 - select appropiate classification for detection system

A

6.3 - select appropiate classification for isolation system

C

6.4 - determine the release reduction factor ($fact_{di}$)

System classification		Release magnitude adjusment	Reductioin factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A	C	Reduce release rate or mass by 10%	0.10
B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjusment to release rate or mass	0

release reduction factor = 0.1

6.5 - determine the total leak durations for each of the hole size ($ld_{dimax,n}$)

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 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
C	A, B or C	1 hours for 1/4 inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks

$Id_{max,1}$ = 40 minutes
$Id_{max,2}$ = 30 minutes
$Id_{max,3}$ = 20 minutes
$Id_{max,4}$ = 20 minutes

7. - Release rate and mass

7.1 - calculate the adjusted release rate ($rate_n$) for each hole size

$$rate_n = W_n(1 - fact_{dl})$$

W_1 = 0.00122794 kg/s
W_2 = 0.018736879 kg/s
W_3 = 0.311901584 kg/s
W_4 = 0.947721537 kg/s

$rate_{small}$ = 0.00111 kg/s
$rate_{medium}$ = 0.01686 kg/s
$rate_{large}$ = 0.28071 kg/s
$rate_{rupture}$ = 0.85295 kg/s

7.2 - calculate the leak duration (ld_n) for each hole size

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}\{60.ld_{max,n}\}\right]$$

ld_{small} =	2400.00000 s		$Id_{max,1}$ =	40	minutes
ld_{medium} =	727.66918 s		$Id_{max,2}$ =	30	minutes
ld_{large} =	231.69870 s		$Id_{max,3}$ =	20	minutes
$ld_{rupture}$ =	210.43226 s		$Id_{max,4}$ =	20	minutes

7.3 - calculate the release mass ($mass_n$) for each hole size

$$ld_n = min[\{rate_n\ x\ ld_n\}, mass_{avail,n}]$$

$mass_{small}$ =	2.65235	kg
$mass_{medium}$ =	12.27082	kg
$mass_{large}$ =	65.04047	kg
$mass_{rupture}$ =	179.48806	kg

8. - Determine flammable and explosive consequence

8.1 - Select the consequence area mitigatian reduction factor ($fact_{mit}$)

$fact_{mit}$ = 0.05

8.2 - Calculate the energy efficiency correction factor ($eneff_n$) for each release hole size

$$eneff_n = 4.log_{10}[C_{4A}.mass_n] - 15$$

C4A = 2.205 1/kg

$eneff_1$ =	0
$eneff_2$ =	0
$eneff_3$ =	0
$eneff_4$ =	0

8.3 - Determine the fluid type

fluid type = C1 - C2

8.4 - calculate component damage consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{cmd,n}^{AINL-CONT}$)

8.4.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AINL-CON}$

a = 8.669

b = $b_{cmd}^{AINL-CONT}$

b = 0.98

8.4.2 - calculate consequence area

$$CA_{cmd,n}^{AINL-CON} = a(rate_n)^b.(1 - fact_{mit})$$

$Ca_{cmd.small}^{AINL-CONT}$ =	0.01042903	m^2	$fact_{mit}$ =	0.05
$Ca_{cmd.medium}^{AINL-CONT}$ =	0.150693173	m^2		
$Ca_{cmd.large}^{AINL-CONT}$ =	2.371305432	m^2		
$Ca_{cmd.rupture}^{AINL-CONT}$ =	7.046888542	m^2		

8.5 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{cmd,n}^{AIL-CONT}$)

8.5.1 -determine appropiate constant a and b to ssure selection of the correct constant

a = $a_{cmd}^{AIL-CON}$

a = 55.13

b = $b_{cmd}^{AIL-CONT}$

b = 0.95

8.5.2 - calculate consequence area

$$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b.(1 - fact_{mit})$$

$Ca_{cmd.small}^{AIL-CONT}$ =	0.081350515	$fact_{mit}$ =	0.05
$Ca_{cmd.medium}^{AIL-CONT}$ =	1.083189329		
$Ca_{cmd.large}^{AIL-CONT}$ =	15.66602023		
$Ca_{cmd.rupture}^{AIL-CONT}$ =	45.02862591		

8.6 - calculate component damage consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{cmd,n}^{AINL-INST}$)

8.6.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AINL-INST}$

a = 6.469

$b = b_{cmd}^{AINL-INS}$

b = 0.69

8.6.2 - calculate consequence area

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

$Ca_{cmd1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AINL-INST}$ =	0		
$Ca_{cmd3}^{AINL-INST}$ =	0		
$Ca_{cmd4}^{AINL-INST}$ =	0		

8.7 - calculate component damage consequence areas for auto-ignition likely, continous release, AIL-INST ($Ca_{cmd,n}^{AIL-INST}$)

8.7.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 163.7

$b = b_{cmd}^{AIL-INST}$

b = 0.62

8.7.2 - calculate consequence area

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

$Ca_{cmd1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{cmd2}^{AIL-INST}$ =	0		
$Ca_{cmd3}^{AIL-INST}$ =	0		
$Ca_{cmd4}^{AIL-INST}$ =	0		

8.8 - calculate personnel injury consequence areas for auto-ignition not likely, continous release, AINL-CONT ($Ca_{inj,n}^{AINL-CONT}$)

8.8.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-CON}$

a = 21.83

$b = b_{inj}^{AINL-CONT}$

b = 0.96

8.8.2 - calculate consequence area

$$CA_{inj,n}^{AINL-CONT} = [a.(rate_n^{AINL-CONT})^b].(1 - fact_{mit})$$

$Ca_{inj1}^{AINL-CONT}$ =	0.030092637	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-CONT}$ =	0.4117556		
$Ca_{inj3}^{AINL-CONT}$ =	6.125013174		
$Ca_{inj4}^{AINL-CONT}$ =	17.80178986		

8.9 - calculate personnel injury consequence areas for auto-ignition likely, continous release, AIL-CONT ($Ca_{inj,n}^{AIL-CONT}$)

8.9.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AIL-CONT}$

a = 143.2

$b = b_{inj}^{AIL-CONT}$

b = 0.92

8.9.2 - calculate consequence area

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

$Ca_{inj1}^{AIL-CONT}$ =	0.259186718	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AIL-CONT}$ =	3.180176366		
$Ca_{inj3}^{AIL-CONT}$ =	42.27327607		
$Ca_{inj4}^{AIL-CONT}$ =	117.5211471		

8.10 - calculate personnel injury consequence areas for auto-ignition not likely, instantaneous release, AINL-INST ($Ca_{inj,n}^{AINL-INST}$)

8.10.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{inj}^{AINL-INST}$

a = 12.46

$b = b_{inj}^{AINL-INST}$

b = 0.67

8.10.2 - calculate consequence area

$$CA_{inj,n}^{AINL-INS} = [a.(mass_n^{AINL-INST})].\left(\frac{1 - fact_{mit}}{eneff_n}\right)$$

$Ca_{inj1}^{AINL-INST}$ =	0	$fact_{mit}$ =	0.05
$Ca_{inj2}^{AINL-INST}$ =	0		
$Ca_{inj3}^{AINL-INST}$ =	0		
$Ca_{inj4}^{AINL-INST}$ =	0		

8.11 - calculate personnel injury consequence areas for auto-ignition likely, instantaneous release, AIL-INST ($Ca_{inj,n}^{AIL-INST}$)

8.11.1 -determine appropiate constant a and b to ssure selection of the correct constant

$a = a_{cmd}^{AIL-INST}$

a = 473.9

$b = b_{cmd}^{AIL-INST}$

b = 0.63

8.11.2 - calculate consequence area

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

$CA_{inj1}^{AIL-INST}$ =	0	$fact_{mit}$ =	0.05
$CA_{inj2}^{AIL-INST}$ =	0		
$CA_{inj3}^{AIL-INST}$ =	0		
$CA_{inj4}^{AIL-INST}$ =	0		

8.12 - calculate the instantaneous/ continous blending factor ($fact_n^{IC}$)

Continous

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$$

C5 = 25.2 kg/s

Instantaneous

$$fact_n^{IC} = 1.0$$

$fact_1^{IC}$ =	4.3855E-05
$fact_2^{IC}$ =	0.000669174
$fact_3^{IC}$ =	0.011139342
$fact_4^{IC}$ =	0.033847198

8.13 - calculate AIT (auto ignition temperature) blending factor ($fact^{AIT}$)

$T_s + C_6 \leq AIT$ $\quad fact^{AIT} = 0$

$T_s + C_6 > AIT > T_s - C_6$ $\quad fact^{AIT} = \frac{T_s - AIT + C_6}{2.C_6}$

$T_s - C_6 \geq AIT$ $\quad fact^{AIT} = 1$

$fact^{AIT}$ = 0

C6 =	55.6	K
Ts =	38.89	C
	120	F
	322.039	K
AIT =	558	K

8.14 - calculate the continous/ instantaneous blended consequnces areas for the component and the continous/ instantaneous blending factor ($fact_n^{IC}$)

8.14.1 - calculate continous/ instantaneous blended consequence area for auto ignition likely for component damage

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}.fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AIL}$ =	0.081346947 m^2
$CA_{cmd,2}^{AIL}$ =	1.082464487 m^2
$CA_{cmd,3}^{AIL}$ =	15.49151107 m^2

$CA_{cmd1}^{AIL-INST}$ =	0
$fact_1^{IC}$ =	4.3855E-05
$CA_{cmd1}^{AIL-CONT}$ =	0.081350515
$CA_{cmd2}^{AIL-INST}$ =	0
$fact_2^{IC}$ =	0.000669174
$CA_{cmd2}^{AIL-CONT}$ =	1.083189329
$CA_{cmd3}^{AIL-INST}$ =	0
$fact_3^{IC}$ =	0.011139342
$CA_{cmd3}^{AIL-CONT}$ =	15.66602023

$CA_{cmd,4}^{AIL} =$ 43.5045331 m^2

$CA_{cmd4}^{AIL-INST} =$ 0
$fact_4^{IC} =$ 0.033847198
$CA_{cmd4}^{AIL-CONT} =$ 45.02862591

8.14.2 - calculate continous/ instantaneous blended consequence area for auto ignition likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}.fact_n^{IC} + CA_{inj,n}^{AIL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AIL} =$	0.259175351 m^2	$CA_{inj1}^{AIL-INST} =$	0
		$fact_1^{IC} =$	4.3855E-05
		$CA_{inj1}^{AIL-CONT} =$	0.259186718
$CA_{inj,2}^{AIL} =$	3.178048274 m^2	$CA_{inj2}^{AIL-INST} =$	0
		$fact_2^{IC} =$	0.000669174
		$CA_{inj2}^{AIL-CONT} =$	3.180176366
$CA_{inj,3}^{AIL} =$	41.80237957 m^2	$CA_{inj3}^{AIL-INST} =$	0
		$fact_3^{IC} =$	0.011139342
		$CA_{inj3}^{AIL-CONT} =$	42.27327607
$CA_{inj,4}^{AIL} =$	113.5433856 m^2	$CA_{inj4}^{AIL-INST} =$	0
		$fact_4^{IC} =$	0.033847198
		$CA_{inj4}^{AIL-CONT} =$	117.5211471

8.14.3 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for component damage

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INS}\ .fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{cmd,1}^{AINL} =$	0.010428572	$CA_{cmd1}^{AINL-INST} =$	0
		$fact_1^{IC} =$	4.3855E-05
		$CA_{cmd1}^{AINL-CONT} =$	0.01042903
$CA_{cmd,2}^{AINL} =$	0.150592333	$CA_{cmd2}^{AINL-INST} =$	0
		$fact_2^{IC} =$	0.000669174
		$CA_{cmd2}^{AINL-CONT} =$	0.150693173
$CA_{cmd,3}^{AINL} =$	2.344890649	$CA_{cmd3}^{AINL-INST} =$	0
		$fact_3^{IC} =$	0.011139342
		$CA_{cmd3}^{AINL-CONT} =$	2.371305432
$CA_{cmd,4}^{AINL} =$	6.808371112	$CA_{cmd4}^{AINL-INST} =$	0
		$fact_4^{IC} =$	0.033847198
		$CA_{cmd4}^{AINL-CONT} =$	7.046888542

8.14.4 - calculate continous/ instantaneous blended consequence area for auto ignition not likely for personnel injury

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AINL-INST}.fact_n^{IC} + CA_{inj,n}^{AINL-CONT}.(1 - fact_n^{IC})$$

$CA_{inj,1}^{AINL} =$	0.030091317	$CA_{inj1}^{AINL-INST} =$	0
		$fact_1^{IC} =$	4.3855E-05
		$CA_{inj1}^{AINL-CONT} =$	0.030092637
$CA_{inj,2}^{AINL} =$	0.411480063	$CA_{inj2}^{AINL-INST} =$	0
		$fact_2^{IC} =$	0.000669174
		$CA_{inj2}^{AINL-CONT} =$	0.4117556
$CA_{inj,3}^{AINL} =$	6.056784555	$CA_{inj3}^{AINL-INST} =$	0
		$fact_3^{IC} =$	0.011139342
		$CA_{inj3}^{AINL-CONT} =$	6.125013174
$CA_{inj,4}^{AINL} =$	17.19924916	$CA_{inj4}^{AINL-INST} =$	0
		$fact_4^{IC} =$	0.033847198
		$CA_{inj4}^{AINL-CONT} =$	17.80178986

8.15 - calculate AIT blended consequence areas for the component damage and personnel injury flammable consequence area

8.15.1 - calculate AIT blended consequence areas for daage component

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL}.fact^{AIT} + CA_{cmd,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{cmd1}^{flam} =$	0.010428572	$CA_{cmd1}^{AIL} =$	0.081346947
		$fact^{AIT} =$	0
		$CA_{cmd1}^{AINL} =$	0.010428572
$CA_{cmd2}^{flam} =$	0.150592333	$CA_{cmd2}^{AIL} =$	1.082464487
		$fact^{AIT} =$	0
		$CA_{cmd2}^{AINL} =$	0.150592333
$CA_{cmd3}^{flam} =$	2.344890649	$CA_{cmd3}^{AIL} =$	15.49151107
		$fact^{AIT} =$	0
		$CA_{cmd3}^{AINL} =$	2.344890649
$CA_{cmd4}^{flam} =$	6.808371112	$CA_{cmd4}^{AIL} =$	43.5045331
		$fact^{AIT} =$	0
		$CA_{cmd4}^{AINL} =$	6.808371112

8.15.2 - calculate AIT blended consequence areas for personnel injury

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}.fact^{AIT} + CA_{inj,n}^{AINL}.(1 - fact^{AIT})$$

$CA_{inj,1}^{AINL} =$	0.030091317	$CA_{inj1}^{AIL} =$	0.259175351
		$fact^{AIT} =$	0
		$CA_{inj1}^{AINL} =$	0.030091317

$CA_{inj,2}^{AINL}$ =	0.411480063
$CA_{inj,3}^{AINL}$ =	6.056784555
$CA_{inj,4}^{AINL}$ =	17.19924916

CA_{inj2}^{AIL} =	3.178048274
$fact^{AIT}$ =	0
CA_{inj2}^{AINL} =	0.411480063
CA_{inj3}^{AIL} =	41.80237957
$fact^{AIT}$ =	0
CA_{inj3}^{AINL} =	6.056784555
CA_{inj4}^{AIL} =	113.5433856
$fact^{AIT}$ =	0
CA_{inj4}^{AINL} =	17.19924916

8.16 - determine the final consequence areas for component damage and personnel injury

$$CA_{cmd,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1 . CA_{cmd,1}^{flam}\right) + \left(gff_2 . CA_{cmd,2}^{flam}\right) + \left(gff_3 . CA_{cmd,3}^{flam}\right) + \left(gff_4 . CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{cmd,n}^{flam}$ = 0.38791 m^2

$$CA_{inj,n}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}}\right)$$

$$CA_{inj,n}^{flam} = \left(\frac{\left(gff_1 . CA_{inj,1}^{flam}\right) + \left(gff_2 . CA_{inj,2}^{flam}\right) + \left(gff_3 . CA_{inj,3}^{flam}\right) + \left(gff_4 . CA_{inj,4}^{flam}\right)}{gff_{total}}\right)$$

$CA_{inj,n}^{flam}$ = 1.00992 m^2

9.- Calculation of toxic consequences areas

9.1 - calculate the effective duration of toxic release

$$Id_n^{tox} = min\left(3600, \left\{\frac{mass_n}{W_n}\right\}, \{60 . Id_{max.n}\}\right)$$

$CA_{inj,1}^{CONT}$ =	2160 s	$mass_1$ =	2.652350632	W_1 =	0.001228	$Id_{max.1}$ =	40
$CA_{inj,2}^{CONT}$ =	654.902261 s	$mass_2$ =	12.27082447	W_2 =	0.018737	$Id_{max.2}$ =	30
$CA_{inj,3}^{CONT}$ =	208.5288267 s	$mass_3$ =	65.04047135	W_3 =	0.311902	$Id_{max.3}$ =	20
$CA_{inj,4}^{CONT}$ =	189.3890303 s	$mass_4$ =	179.4880629	W_4 =	0.947722	$Id_{max.4}$ =	20

9.2 - determine the toxic percentage of the toxic component ($mfrac^{tox}$)

$mfrac^{tox}$ = 0.0001 H_2S = 0.01%

9.3 - calculate the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$

$$rate_n^{tox} = mfrac^{tox} . W_n$$

$rate_1^{tox}$ =	1.22794E-07 kg/s	W_1 =	0.001228 kg/s
$rate_2^{tox}$ =	1.87369E-06 kg/s	W_2 =	0.018737 kg/s
$rate_3^{tox}$ =	3.11902E-05 kg/s	W_3 =	0.311902 kg/s
$rate_4^{tox}$ =	9.47722E-05 kg/s	W_4 =	0.947722 kg/s

$$mass_n^{tox} = mfrac^{tox} . mass_n$$

$mass_1^{tox}$ =	0.000265235 kgs	$mass_1$ =	2.652350632 kgs
$mass_2^{tox}$ =	0.001227082 kgs	$mass_2$ =	12.27082447 kgs
$mass_3^{tox}$ =	0.006504047 kgs	$mass_3$ =	65.04047135 kgs
$mass_4^{tox}$ =	0.017948806 kgs	$mass_4$ =	179.4880629 kgs

9.4 - calculate the toxic consequence area for H2S,

$$CA_{inj,n}^{tox-CONT} = C_8 . 10^{\left(c . log_{10}\left[C_{4B} . rate_n^{tox}\right] + d\right)}$$

$$CA_{inj,n}^{tox-INST} = C_8 . 10^{\left(c . log_{10}\left[C_{4B} . mass_n^{tox}\right] + d\right)}$$

		C_8 =	0.0929 m^2. sec
		c1 =	1.2266
		c2 =	1.2266
		c3 =	1.237
2.23319E-05 m^2		c4 =	0.9674
0.000631875 m^2		d1 =	4.4365
0.011400185 m^2		d2 =	4.4365
0.01556217 m^2		d3 =	4.238
		d4 =	2.784
		C_{4B} =	2.205 sec/kg

9.5 - if there is additional toxic component step 9.2 through 9.4 should be repeated

9.6 - determine the final toxic consequnces areas for personnel injury

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n . CA_{inj.n}^{tox}}{gff_{total}}\right)$$

$$CA_{cmd,n}^{flam} = \left(\frac{\left(gff_1 . CA_{cmd,1}^{flam}\right) + \left(gff_2 . CA_{cmd,2}^{flam}\right) + \left(gff_3 . CA_{cmd,3}^{flam}\right) + \left(gff_4 . CA_{cmd,4}^{flam}\right)}{gff_{total}}\right)$$

tox

$CA_{inj}^{tox} =$ 0.00147 m^2

10. - calculation of non-flammable, Non-toxic consequences area

10.1 - calculate CA $_{inj.n}^{CONT}$ and CA $_{inj.n}^{INST}$

for acid caustic

$$CA_{inj,n}^{CONT} = 0.2 \cdot C_8 \cdot g \, (C_4 \cdot rate_n)^h$$

$$CA_{inj,n}^{INST} = 0$$

$$g = 2696 - 21.9 \cdot C_{11}(P_s - P_{atm}) + 1.474[C_{11}(P_s - P_{atm})]^2$$

g = 2678.385496

$$h = 0.31 - 0.00032[C_{11}(P_s - P_{atm}) - 40]^2$$

h = -0.180387892

$rate_{small}$ =	0.001105	kg/s
$rate_{med}$ =	0.016863	kg/s
$rate_{large}$ =	0.280711	kg/s
$rate_{ruptr}$ =	0.852949	kg/s
C_8 =	0.0929	m^2. sec
C_4 =	2.205	sec/kg
C_{11} =	0.145	1/kPa
P_s =	689.5	kPa
P_{atm} =	101.28755	kPa

$CA_{inj,n}^{CONT} =$ 147.334

$CA_{inj,n}^{CONT} =$ 90.118

$CA_{inj,n}^{CONT} =$ 54.262

$CA_{inj,n}^{INST} =$ 44.405

10.2 - calculate the instantaneous/continous blending factor $fact_n^{IC}$

$$fact_{in}^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1\right],$$

$fact_{small}^{IC} =$ 4.3855E-05

$fact_{medium}^{IC} =$ 0.000669174

$fact_{large}^{IC} =$ 0.011139342

$fact_{rupture}^{IC} =$ 0.033847198

C_5 =	25.2	kg/sec
P_s =	689.5	kPa
P_{atm} =	101.28755	kPa

10.3 - calculate the blended non-flammable, non-toxic personnel injury consequence area for steam acid leaks CA $_{inj.n}^{leak}$

$CA_{cmd.n}^{leak} =$ 0

$$CA_{lak.n}^{leak} = CA_{inj.n}^{INST} \cdot fact_n^{IC} + CA_{inj.n}^{CONT} \cdot (1 - fact_n^{IC})$$

$fact_n^{IC} =$	4.386E-05
$fact_n^{IC} =$	0.0006692
$fact_n^{IC} =$	0.0111393
$fact_n^{IC} =$	0.0338472

$CA_{lak.n}^{leak} =$ 0.006461338 m^2

$CA_{lak.n}^{leak} =$ 0.06030452 m^2

$CA_{lak.n}^{leak} =$ 0.604447785 m^2

$CA_{lak.n}^{leak} =$ 1.502987498 m^2

10.4 - determine the final non-flammable, non-toxic personnel injury CA $_{inj}^{nfnt}$

$CA_{cmd.n}^{nfnt} =$ 0

$$CA_{inj}^{nfnt} = \left(\frac{(gff_1 \cdot CA_{cmd,1}^{leak}) + (gff_2 \cdot CA_{cmd,2}^{leak}) + (gff_3 \cdot CA_{cmd,3}^{leak}) + (gff_4 \cdot CA_{cmd,4}^{leak})}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 0.11008 m^2

11. - Calculation of final consequence area

11.1 - calculate the final component damage consequence area, CA_{cmd}

$$CA_{cmd} = CA_{cmd}^{flam}$$

$CA_{cmd} =$ 0.38791 m^2

11.2 - calculate the final personnel injury consequence area, CA_{inj}

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$$

$CA_{inj} =$ 1.00992 m^2

11.3 - calculate the final consequence area, CA

$$CA = \max[CA_{cmd}, CA_{inj}]$$

CA = 1.00992 m^2 Category A