BACHELOR THESIS – ME 141502

Risk Based Inspection (RBI) Of Gas-Cooling Heat Exchanger

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DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember
Surabaya
2017

SKRIPSI – ME 141502

Analisa Penjadwalan Inspeksi pada *Heat Exchanger* Pendingin Gas dengan Menggunakan Metode Inspeksi Bedasarkan Analisa Risiko

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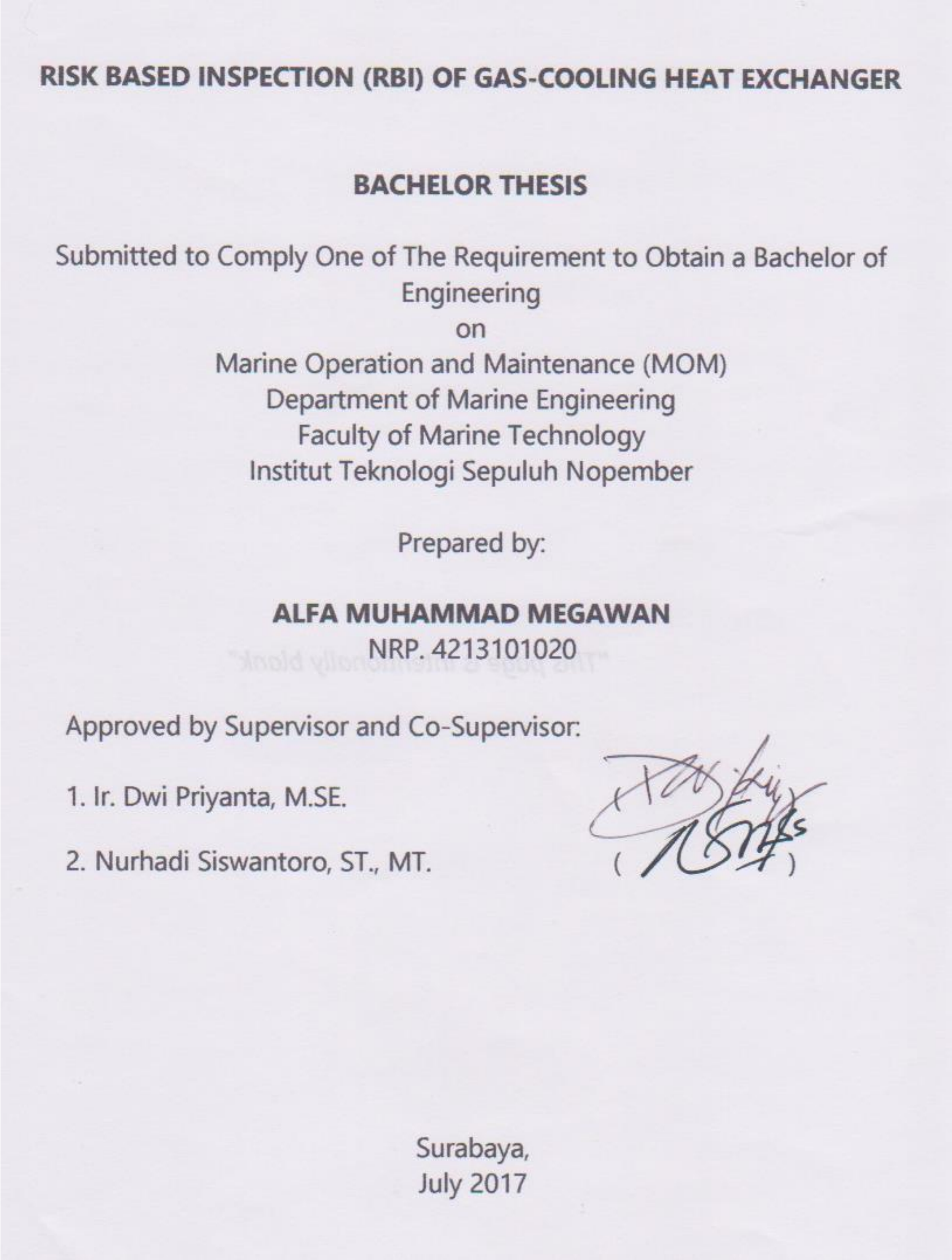
Surabaya
2017

APPROVAL FORM



RISK BASED INSPECTION (RBI) OF GAS-COOLING HEAT EXCHANGER

BACHELOR THESIS

Submitted to Comply One of The Requirement to Obtain a Bachelor of Engineering
on
Marine Operation and Maintenance (MOM)
Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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Surabaya,
July 2017

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Risk Based Inspection (RBI) of Gas-Cooling Heat Exchanger

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ABSTRACT

On October 2013, Pertamina Hulu Energi Offshore North West Java (PHE – ONWJ) platform personnel found 93 leaking tubes locations in the finfan coolers/ gas-cooling heat exchanger. After analysis had been performed, the crack in the tube strongly indicate that stress corrosion cracking was occurred by chloride. Chloride stress corrosion cracking (CLSCC) is the cracking occurred by the combined influence of tensile stress and a corrosive environment. CLSCC is the one of the most common reasons why austenitic stainless steel pipework or tube and vessels deteriorate in the chemical processing, petrochemical industries and maritime industries. In this thesis purpose to determine the appropriate inspection planning for two main items (tubes and header box) in the gas-cooling heat exchanger using risk based inspection (RBI) method. The result, inspection of the tubes must be performed on July 6, 2024 and for the header box inspection must be performed on July 6, 2025. In the end, RBI method can be applicated to gas-cooling heat exchanger. Because, risk on the tubes can be reduced from 4.537 m^2/year to 0.453 m^2/year. And inspection planning for header box can be reduced from 4.528 m^2/year to 0.563 m^2/year.

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Analisa Penjadwalan Inspeksi pada *Heat Exchanger* Pendingin Gas dengan Menggunakan Metode Inspeksi Bedasarkan Analisa Risiko

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ABSTRAK

Pada bulan Oktober 2013, personel anjungan lepas pantai dari Pertamina Hulu Energi Offshore North West Java (PHE-ONWJ) menemukan 93 pipa yang terindikasi terdapat kebocoran yang terdapat pada *finfan cooler/ gas cooler heat exchanger* nya. seteah analisa mendalam dilakukan keretakan pada pipa tersebut dapat disimpulkan tejadi *Chloride Stress Corrosion Cracking (CLSCC).* CLSCC adalah satu dari banyak sebab mengapa pipa *austenitic stainless steel* dan *pressure vessel* menjadi turun kualitasnya, khususnya industry yang berfokus pada proses kimia, industry perminyakan dan industri maritim. Tugas akhir ini bertujuan untuk menentukan perencanaan inspeksi terbaik pada dua bagian utama pada *gas cooling heat exchanger* (*Header box* dan *tube)* menggunakan metode *risk based inspection* (RBI). Hasilnya adalah, inspeksi pada *tube* atau pipa dapat dilakukan pada 6 Juli 2024 dan pada *header box* inspeksi dapat dilakukan pada 6 Juli 2025. Sebagai penutup, RBI dapat di lakukan pada *gas cooling heat exchanger* dikarenakan risiko pada tube/ pipa dapat diturunkan dari 4.537 m^2/tahun menjadi 0.453 m^2/tahun. Dan untuk risiko pada header box dapat diturunkan dari 4.528 m^2/tahun menjadi 0.563 m^2/tahun.

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PREFACE

Alhamdulillahirobbil 'alamin. Praise is merely to the Almighty Allah SWT for the gracious mercy and tremendous blessing which enables the author to accomplish this bachelor thesis.

This thesis report entitled: "Risk Based Inspection (RBI) of Gas-Cooling Heat Exchanger" is submitted to fulfill one of the requirements in accomplishing the bachelor degree program at Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember Surabaya. Conducting this research study is not possible without all helps and supports from various parties. Therefore, the author would like to thank to all people who has support the author for accomplishing this bachelor thesis, among others:

1. Mr. Dr. Eng. Muhammad Badrus Zaman, ST., MT. as the Head of Marine Engineering Department.
2. Mr. Prof. Semin, ST., MT., Ph.D as the Secretary of Marine Engineering Department.
3. Mr. Dr. I Made Ariana, ST., MT. as Author's Lecturer Advisor since first semester until eighth semester.
4. Mr. Ir. Dwi Priyanta, M.SE. as Author's Thesis Supervisor and Secretary of Double Degree Program in Marine Engineering Department who has giving the ideas, correction, and guidance during the thesis is conducted.
5. Mr. Nurhadi Siswantoro, ST., MT. as Author's Thesis Co-Supervisor who has giving the motivation and every necessary information to help finish the bachelor thesis.
6. Irfan Syarif Arief, ST., MT. as the head of MMD Laboratory who has giving permission to do any activities inside the lab and provides place during the working of bachelor thesis.
7. To my parents, Mr Firmansyah, Mrs. Yuyun Suniarti and also my lovely brother who always give their loves, prayers, supports, and encouragements for every single path the author chooses.
8. Muthya Shinta Devi, S.Ked who always be author's loyal supporter in every conditions.
9. Eqi Ramadhan, Datya A. Fiantara, Adi Osis Nugroho, Dante Taufiq Akbar, Danuja Wijayanto and Angya Prambiksono as the thesis team.

10. Mr Apri Densi and Mr Indarta Muhammad and All of PHE ONWJ Mechanical and Piping Team for giving any data required for this thesis.
11. BARAKUDA ’13 and Marine Double Degree ’13 for the assistance and support.
12. Great amounts of friends that can’t be mentioned, for their support, help and ideas for this thesis.

The author realizes that this thesis remains far away from perfect. Therefore, every constructive suggestion and idea from all parties is highly expected by author for this bachelor thesis correction and improvement in the future.

Finally, may Allah SWT bestow His grace, contentment and blessings to all of us. Hopefully, this bachelor thesis can be advantageous for all of us particularly for the readers.

Surabaya, July 2017

Author

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CHAPTER 1
INTRODUCTION

1.1. Overview

On October, 2013, Pertamina Hulu Energi Offshore North West Java (PHE – ONWJ) platform personnel found 93 leaking tubes reported in gas cooling heat exchanger (figure 1.1) on the one of Pertamina platform. This situation made the gas cooling heat exchanger not in a good performance. For the forward PHE-ONWJ need effective maintenance strategy for oil and gas platform equipment especially for gas cooling heat exchanger.

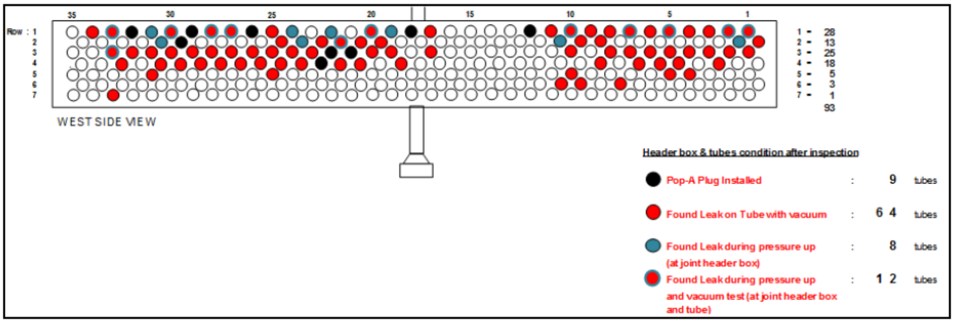

Figure 1.1 Gas-cooling heat exchanger leakage report (Company report, 2013)[1]

According to the function of heat exchangers, there are view types of heat exchangers used in oil and gas facility, they are; shell and tube, double pipe, plate and frame, aerial cooler, bath type, forced air, and direct fired. (Arnold & Stewart, 1989)

Based on the explanation above, Pertamina PHE-ONWJ gas cooling heat exchanger classified as areal cooler heat exchanger because its function is cooling the gas with a fan in to near ambient temperature.

Heat exchanger is the one of crucial equipment in the processing facility especially in the oil and gas industry sector. Heat exchanger is used to transfer heat between one and more fluids. Ones of heat exchanger application is for cooling the gas before injected to the oil reservoir. Gas injection is the method to increase oil production by boosting depleted pressure in the reservoir (figure 1.2). Another function of gas cooling heat

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[1] Pertamina PHE-ONWJ inspection report, 2013

exchanger is for cooling the gas before supply the gas turbine to generated electric power on the platform.

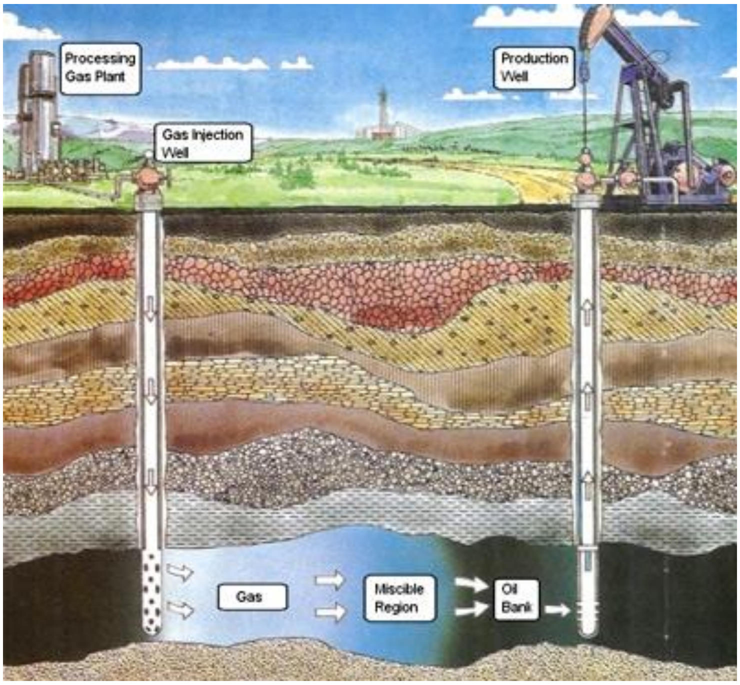

Figure 1.2 optimization oil production by gas injection method [2]

American Petroleum Institute (API) is the one of the most widely used standard guideline in oil and gas company around the world besides DNV-GL. PHE-ONWJ as an Indonesian national oil and gas company install API standard for their company equipment. For the example PHE-ONWJ platform adopt guidelines from API 660 and API 661 for gas cooling heat exchanger fabrication and installation.

One of maintenance strategies for gas cooling heat exchanger can be developed by using Risk Based Inspection (RBI). by using RBI company will get information using risk analysis to develop an effective inspection plan. Identification of company equipment is the beginning of the systematic process in the inspection planning. Probability of failure and consequence of failure are the basic formula to calculate the RBI and must be evaluated by considering all damage mechanism directly effect to the equipment or

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[2] http://www.rigzone.com/training/insight.asp?insight_id=345, visited on march 2017

the system. However, failure scenarios according to the actual damage mechanism should be develop and considered.

RBI methodology produces optimal inspection planning for the asset and make the priority from the lower risk to the higher risk. In other word inspection planning in RBI focused to identification what to inspect, how to inspect, where to inspect and how often to inspect. Inspection planning used to control degradation of the asset and the company will get considerable impact in the system operation and the appropriate economic consequences. (Faber, 2001)

1.2. Problems

According to the overview above the main problems of thesis are:

1. How to determine damage factor for the gas cooling heat exchanger based on RBI method?
2. How to determine the risk level for the gas cooling heat exchanger based on RBI method?
3. How to determine appropriate inspection planning with the gas cooling heat exchanger condition?
4. How to determine the remaining useful life according to the risk level of the gas cooling heat exchanger?

1.3. Limitations

The limitations of the thesis are:

1. Gas cooling heat exchanger which is the object of study belong to PHE-ONWJ.
2. All of the study and calculation based on API 581.
3. Natural disasters are not taken into consideration.

1.4. Objectives

The objectives of this thesis are:

1. Determine damage factor of gas cooled heat exchanger according to RBI method.
2. Determine risk level of gas cooling heat exchanger.
3. Determine remaining life according to the gas cooling heat exchanger risk level.
4. Determining inspection plan for the Gas cooled heat exchanger.

1.5. Benefits

The benefits of the thesis are:

1. This thesis can be company consideration materials to determine priority of the maintenance and inspection strategy as a preventive effort to minimalized the failure.
2. Introduce RBI as a maintenance and inspection strategy based on risk analyze of the pressure vessel.
3. Improve the level of safety on the oil and gas platform.

CHAPTER 2
LITERATURE STUDY

2.1. Asset Overview

2.1.1. Gas Cooling Heat Exchanger

2.1.1.1. Operating Principal

As shown in figure (2.1), Gas cooling heat exchangers or aerial coolers are often used to cooling a hot fluid to near ambient temperature. They are mechanically simple and flexible. They eliminate the nuisance and cost of a cold source. In warm climates, aerial coolers may not be capable of providing as low a temperature as shell-and-tube heat exchangers, which use a cool medium. In aerial coolers, the tube bundle is on the discharge or suction side of a fan, depending on whether the fan is blowing air across the tubes or sucking air through them. This type of exchanger can be used to cool a hot fluid to something near ambient temperature as in a compressor inter stage cooler, or it can be used to heat the air as in a space heater.

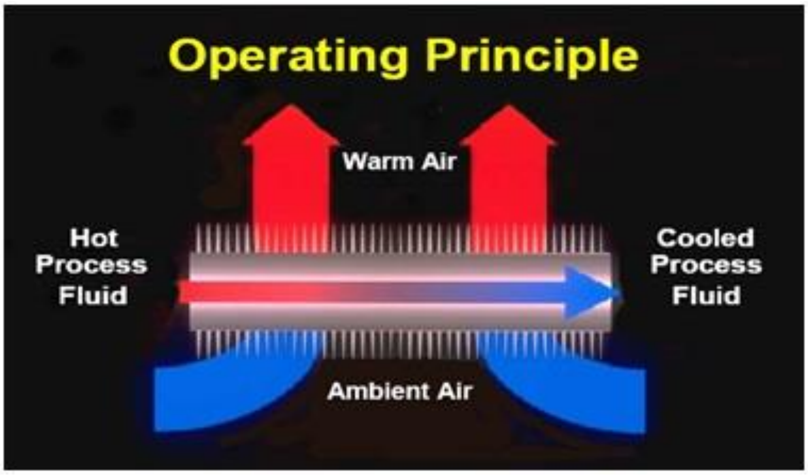

Figure 2.1 gas cooling heat exchanger operation principle[3]

2.1.1.2. Type of Gas-Cooling Heat Exchanger

When the tube bundle is on the discharge of the fan, the exchanger is referred to as "forced draft" (Figure 2.2). When the tube bundle is on the suction of the fan it is referred to as an "induced draft" exchanger (Figure 2.2). In figure 2.2 the process fluid enters one of the nozzles on

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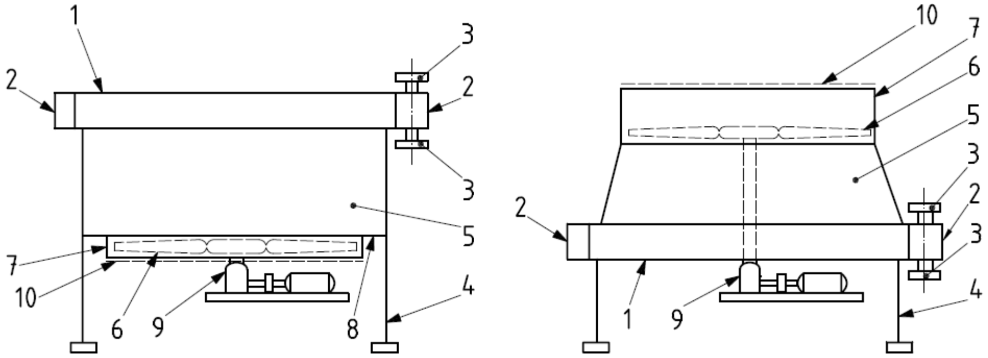
[3] http://www.whatispiping.com//air-cooled-heat-exchanger, visited on August 2016

the fixed end and the pass partition plate forces it to flow through the tubes to the floating end (tie plate). Here it crosses over to the remainder of the tubes and flows back to the fixed end and out the other nozzle. Air is blown vertically across the finned section to cool the process fluid. Plugs are provided opposite each tube on both ends so that the tubes can be cleaned or individually plugged if they develop leaks, tube bundle could also be mounted in a vertical plane, in which case air would be blown horizontally through the cooler.



a) Forced draught **b) Induced draught**

Key

1	tube bundle
2	header
3	nozzle
4	supporting column
5	plenum
6	fan
7	fan ring
8	fan deck
9	drive assembly
10	fan guard

Figure 2.2 Structure of gas cooling heat exchanger (API 661, 2006)

2.1.1.3. Structure of Gas Cooling Heat Exchanger

Typically fin fan cooled exchanger consist of a finned tube bundle with rectangular box Headers on both end of the tubes. Cooling air is provided by one or more fans. Usually air blows upwards through a horizontal tube bundle. The fans can be either forced or induced draft depending on whether the air is pushed or pulled through the tube bundle. The space between the fans and the tube bundle is enclosed by a plenum chamber which directs the air. The whole assembly is usually mounted on legs or a pipe rack.

2.2. Method Overview

2.2.1. Risk Based Inspection (RBI)

Inspection can be interpreted as planning, implementation and evaluation of examinations to determine physical and metallurgical condition of equipment during the performance of good service. Examination methods including visual surveys and nondestructive test techniques, such as ultrasonic inspection magnetic particle inspection, radiographic inspection and so on, design to detect and calculate wall thinning and defects.

The information of inspection planning in risk based inspection based on the risk analysis of the equipment. The purpose of the risk analysis is to identify the potential degradation mechanisms and threats to the integrity of the equipment and to assess the consequences and risk of failure. (J B Wintle & G J Amphlett, 2001)

2.2.1.1. Risk

Risk is defined as the combination probability of asset failure and consequence if the failure happened. Risk can be expressed numerically with formula (2.1) as shown below.

$$Risk = Probability \times Consequence \tag{2.1}$$

2.2.1.2. Probability of Failure

The probability of failure may be determined based on one, or a combination of the following methods:

a) Structural reliability models – In this method, a limit state is defined based on a structural model that includes all relevant damage mechanisms, and uncertainties in the independent variables of this models are defined in terms of statistical distributions. The resulting model is solved directly for the probability of failure.
b) Statistical models based on generic data – In this method, generic data is obtained for the component and damage mechanism under evaluation and a statistical model is used to evaluate the probability of failure.
c) Expert judgment – In this method, expert solicitation is used to evaluate the component and damage mechanism, a probability of failure can typically only be assigned on a relative basis using this method.

In API RBI, a combination of the above is used to evaluate the probability of failure in terms of a generic failure frequency and damage factor. The probability of failure calculation is obtained from the equation (2.2).

$$Pof\ (t) = gff \times Df\ (t) \times FMS \tag{2.2}$$

Where:
gff = *generic failure frequency*
Df (t) = *damage factor*
FMS = *management system factor*

2.2.1.2.1. Generic Failure Frequency (*gff*)

The generic failure frequency can be determined by industry average of asset failure. The generic failure frequency is expected to the previous failure frequency to any specific damage happening from exposure to the operating environment. There are four different damage hole sizes model the release scenarios covering a full range of events they are small, medium, large, and rupture.

If the data of the asset is complete, actual probabilities of the failure could be calculated with actual observed failures. Even if a failure has not occurred in a component, the true probability of failure is likely to be greater than zero because the component may not have operated long enough to experience a failure. As a first step in estimating this non-zero probability, it is necessary to examine a larger set of data of similar components to find enough failures such that a reasonable estimate of a true probability of failure can be made.

This generic component set of data is used to produce a generic failure frequency for the component. The generic failure frequency of a component type is estimated using records from all plants within a company or from various plants within an industry, from literature sources, and commercial reliability data bases. Therefore, these generic values typically represent an industry in general and do not reflect the true failure frequencies for a specific component subject to a specific damage mechanism.

The generic failure frequency is intended to be the failure frequency representative of failures due to degradation from relatively benign service prior to accounting for any specific operating environment, and are provided for several discrete hole sizes for various types of processing equipment (i.e. process vessels, drums, towers, piping systems, tankage, etc.).

A recommended list of generic failure frequencies is provided in table (2.1) The generic failure frequencies are assumed to follow a log-normal distribution, with error rates ranging from 3% to 10%. Median values are given in table (2.1) The data presented in the table (2.1) is based on the best available sources and the experience of the API RBI Sponsor Group.

The overall generic failure frequency for each component type was divided across the relevant hole sizes, i.e. the sum of the generic failure frequency for each hole size is equal to the total generic failure frequency for the component.

Table 2.1 Suggested Component Generic Failure Frequencies (gff*)*

Equipment type	**Component type**	***gff* as a Function of Hole Size (failures/yr)**				***gff(total)***
		Small	**Medium**	**Large**	**Rupture**	**(failures/yr)**
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXTS	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXTUBE	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-10	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-12	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

*Table 2.1 Suggested Component Generic Failure Frequencies (*gff*) (Continue)*

Equipment type	Component type	***gff* as a Function of Hole Size (failures/yr)**				***gff(total)***
		Small	**Medium**	**Large**	**Rupture**	**(failures/yr)**
Pump	PUMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank650	TANKBOT	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-2	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-3	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-4	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-5	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-6	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-7	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-8	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-9	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	COURSE-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Vessel/ FinFan	KODRUM	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	COLBTM	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	FINFAN	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	FILTER	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	DRUM	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	REACTOR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	COLTOP	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Vessel/ FinFan	COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

2.2.1.2.2. Damage Mechanism or Damage Factor

The damage factor is determined based on the applicable damage mechanisms (local and general corrosion, cracking, creep, etc.) relevant to the materials of construction and the process service, the physical condition of the component, and the inspection techniques used to quantify damage. The damage factor modifies the industry generic failure frequency and makes it specific to the component under evaluation.

The basic function of the damage factor is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity to quantify that damage.

Damage factor estimates are currently provided for the following damage mechanisms:

a) Thinning (general and local) - d_f^{thin}.
b) Component Linings - d_f^{elin}.
c) External Damage (corrosion and stress corrosion cracking) - d_f^{extd}.
d) Stress Corrosion Cracking (internal based on process fluid, operating conditions and materials of construction) - d_f^{SCC}.
e) High Temperature Hydrogen Attack - d_f^{htha}.
f) Mechanical Fatigue (Piping Only) - d_f^{mfat}.
g) Brittle Fracture (including low-temperature brittle fracture, temper embrittlement, 885 embrittlement, and sigma phase embrittlement.) - d_f^{brit}.

Damage factors are calculated based on the techniques described in probability of failure calculation method paragraph, but are not intended to reflect the actual probability of failure for the purposes of reliability analysis. Damage factors reflect a relative level of concern about the component based on the stated assumptions in each of the applicable paragraphs of the document.

If the damage factor has combination or multiple damage mechanism then the rules and the formulas are as follows:

a) Total damage factor, $D_{f\text{-total}}$ – If more than one damage mechanism is present, the following rules are used to combine the damage factors. The total damage factor is given by equation (2.3) when the thinning is local:

$$D_{f\text{-total}} = \max[d_{f-gov}^{thin}, d_{f-gov}^{extd}] + d_{f-gov}^{SCC} + d_{f-gov}^{htha} + d_{f-gov}^{brit} + d_{f-gov}^{mfat} \quad (2.3)$$

If the thinning damage is general, then the total damage factor is given by equation (2.4):

$$D_{f\text{-total}} = d_f^{thin} + d_f^{extd} + d_{f-gov}^{SCC} + d_{f-gov}^{htha} + d_{f-gov}^{brit} + d_{f-gov}^{mfat} \quad (2.4)$$

*if a damage factor is less than or equal to one, then this damage factor shall be set to zero in the summation.
*if $D_{f\text{-total}}$ is computed as less than or equal to one, then $D_{f\text{-total}}$ shall be set equal to one.

b) Governing Thinning Damage Factor, $\mathrm{D}_{\mathrm{f-gov}}^{\mathrm{thin}}$ – governing thinning damage factor is determined based on the presence of an internal liner using equations (2.5) and (2.6).

$$d_{f-gov}^{thin} = \min\,[d_f^{thin}, d_f^{elin}] \textit{ when an internal liner is present} \quad (2.5)$$

$$d_{f-gov}^{thin} = d_f^{thin} \textit{ when an internal liner is not present} \quad (2.6)$$

c) Governing Stress Corrosion Cracking Damage Factor, d_{f-gov}^{SCC} – The governing stress corrosion cracking damage factor is determined from equation (2.7).

$$d_{f-gov}^{SCC} = \max\,[d_f^{caustic}, d_f^{amine}, d_f^{SCC}, d_f^{\frac{HIC}{SOHIC}-H2S}, d_f^{carbonate}, d_f^{PTHA}, d_f^{CLSCC}, d_f^{HSC-HF}, d_f^{\frac{HIC}{SOHIC}-HF}] \quad (2.7)$$

d) Governing External Damage Factor, $\mathrm{d}_{\mathrm{f-gov}}^{\mathrm{extd}}$, governing external damage factor is determined from equation (2.8).

$$d_{f-gov}^{\mathrm{extd}} = \max\,[\, d_f^{extd}, d_f^{CUIF}, d_f^{extd-CLSCC}, d_f^{CUI-CLSCC}] \quad (2.8)$$

e) Governing Brittle Fracture Damage Factor, d_{f-gv}^{brit} The governing brittle fracture damage factor is determined from equation (2.9).

$$d_{f-gov}^{brit} = \max\,[(d_f^{britfract} + d_f^{\mathrm{tempe}}), d_f^{885}, d_f^{sigma}) \quad (2.9)$$

*if a damage factor is less than or equal to one (i.e. the damage is inactive), then this damage factor shall be set to zero in the summation.

Table 2.2 damage factor defined

Damage Factor Variable	Damage Factor Description
d_f^{thin}	Damage factor for general and localized thinning
D_f^{liner}	Damage factor of inorganic and organis linings for all component types
$D_f^{caustic}$	Damage factor for caustic cracking
D_f^{amine}	Damage factor for amine cracking
D_f^{ssc}	Damage factor for sulfide stress corrosion cracking
$D_f^{HIC-SOHIC-H2S}$	Damage factor for HIC/SOHIC cracking in H_2S environments
$D_f^{carbonate}$	Damage factor for carbonate cracking
D_f^{PTA}	Damage factor for polythionic acid cracking in austenitic stainless steel and nonferrous alloy components
D_f^{CLSCC}	Damage factor for chloride stress corrosion cracking
D_f^{HSC-HF}	Damage factor for hydrogen stress cracking in HF environment
$D_f^{\mathrm{HIC/SOHIC-HF}}$	Damage factor for HIC/SOHIC cracking in HF environments
D_f^{extor}	Damage factor for external corrosion on ferritic components
D_f^{CUIF}	Damage factor for CUI on insulted ferritic components
$D_f^{ext-CLSCC}$	Damage factor for external chloride stress corrosion cracking on austenitic stainless steel components
$D_f^{CUI-CLSCC}$	Damage factor for external chloride stress corrosion cracking on austenitic stainless steel insulated components
D_f^{htha}	Damage factor for high temperature hydrogen attack
$D_f^{britfract}$	Damage factor for brittle fracture of carbon steel and low alloy components
D_f^{tempe}	Damage factor for temper embrittlement of Cr-Mo low alloy components
D_f^{885}	Damage factor for 885 embrittlement
D_f^{sigma}	Damage factor for sigma phase embrittlement
D_f^{mfat}	Damage factor for mechanical fatigue

2.2.1.2.3. Inspection Effectiveness Category

Damage factors are determined as a function of inspection effectiveness. There are five categories of inspection effectiveness, which is shown in table (2.3) The inspection effectiveness categories presented are meant to be examples and provide a guideline for assigning actual inspection effectiveness.

Inspections are ranked according to their expected effectiveness at detecting damage and correctly predicting the rate of damage. The actual effectiveness of a given inspection technique depends on the characteristics of the damage mechanism.

The effectiveness of each inspection performed within the designated time period is characterized for each damage mechanism. The number of highest effectiveness inspections will be used to determine the damage factor. If multiple inspections of a lower effectiveness have been conducted during the designated time period, they can be approximated to an equivalent higher effectiveness inspection in accordance with the following relationships:

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A
b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) Inspection, or 2C = 1B
c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) Inspection, or 2D = 1C

*Note that these equivalent higher inspection rules shall not be applied to No Inspections (E).

Table 2.3 Inspection Effectiveness Categories

Quantitative Inspection Effectiveness Category	**Description**
Highly Effective	The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence).
Usually Effective	The inspection methods will correctly identify the true damage state most of time (or 60-80% confidence).
Fairly Effective	The inspection methods will correctly identify the true damage state about half of time (or 40-60% confidence).
Poorly Effective	The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence).

Table 2.3 Inspection Effectiveness Categories (continue)

Quantitative Inspection Effectiveness Category	Description
Ineffective	The inspection methods will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the spesific damage mechanism (less than 20% confidence).

2.2.1.2.4. Management System Factor (fms)

Management system factor used to measure how good the facility management system that may arise due to an accident and labor force of the plant is trained to handle the asset. This evaluation consists of a series of interviews with plant management, operations, inspection, maintenance, engineering, training, and safety personnel.

The management systems evaluation procedure developed for API RBI covers all areas of a plant's PSM system that impact directly or indirectly on the mechanical integrity of process equipment. The management systems evaluation is based in large part on the requirements contained in API Recommended Practices and Inspection Codes. It also includes other proven techniques in effective safety management. A listing of the subjects covered in the management systems evaluation and the weight given to each subject is presented in table (2.4).

Table 2.4 Management Systems Evaluation

Table	Title	Questions	Points
2.A.1	Leadership and Administration	6	70
2.A.2	Process Safety Information	10	80
2.A.3	Process Hazard Analysis	9	100
2.A.4	Management of Change	6	80
2.A.5	Operating Procedures	7	80
2.A.6	Safe Work Practices	7	85
2.A.7	Training	8	100
2.A.8	Mechanical Integrity	20	120
2.A.9	Pre-Startup Safety Review	5	60
2.A.10	Emergency Response	6	65
2.A.11	Incident Investigation	9	75
2.A.12	Contractors	5	45
2.A.13	Audits	4	40
Total		**102**	**1000**
Note: Tabels 2.A.1 through 2.A.13 are located in Annex 2.A.			

The management systems evaluation covers a wide range of topics and, as a result, requires input from several different disciplines within the facility to answer all questions. Ideally, representatives from the following plant functions should be interviewed:

a) Plant Management
b) Operations
c) Maintenance
d) Safety
e) Inspection
f) Training
g) Engineering

The scale recommended for converting a management systems evaluation score to a management systems factor is based on the assumption that the "average" plant would score 50% (500 out of a possible score of 1000) on the management systems evaluation, and that a 100% score would equate to a one order-of magnitude reduction in total unit risk. Based on this ranking, Equation (2.10) may be used to compute a management systems factor, F_{MS}, for any management systems evaluation score.

*Note that the management score must first be converted to a percentage (between 0 and 100) as follows:

$$pscore = \frac{Score}{1000}\ x\ 100\ [unit\ is\ \%]$$

$$F_{MS} = 10^{(-0.02pscore+1)} \tag{2.10}$$

The approximate formula above can be modified and improved over time as more data become available on management systems evaluation results. It should be remembered that the management systems factor applies equally to all components and, therefore, does not change the risk ranking of components for inspection prioritization.

2.2.1.2.5. Thinning

Thinning damage factor calculation estimates the percentage of asset wall loss. A statistical distribution is applied to a thinning corrosion rate over time, accounting for the variability of the actual thinning corrosion rate which can be greater than the rate assigned. The amount of uncertainty in the corrosion rate is determined by the number and effectiveness of inspections and the on-line monitoring that has been performed. Confidence that the assigned corrosion rate is the rate that is experienced in-service increases with more thorough inspection, a greater number of inspections, and/or more relevant information gathered through the on-line monitoring. The DF is updated based on increased confidence in the measured corrosion rate provided by using Bayes Theorem and the improved knowledge of the component condition. (L.C. Kaley, 2014)

The calculation procedures of thinning damage factor are:

a) Determine the number of inspections, and the corresponding inspection effectiveness category for all past inspections. Combine the inspections to the highest effectiveness performed.

b) Determine the time in-service (*age)* since the last inspection thickness reading (t_{rd}).

c) Determine the corrosion rate for the base metal ($C_{r,bm}$) based on the material of construction and process environment, where the component has cladding, a corrosion rate ($C_{r,cm}$) must also be obtained for the cladding.

d) Determine the minimum required wall thickness (t_{min}) per the original construction code or using API 579. If the component is a tank bottom, then in accordance with API 653 (t_{min} = 0.1 in) if the tank does not have a release prevention barrier and (t_{min} = 0.05 in) if the tank has a release prevention barrier.

e) For clad components, calculate the time or age from the last inspection required to corrode away the clad material, age_{rc} , using equation (2.11).

$$age_{rc} = \max\left[\left(\frac{t_{rd}-t}{C_{r,cm}}\right), 0.0\right] = \text{N/A} \qquad 2.11$$

f) Determine the A_{rt} parameter using Equation (2.12) or (2.13), based on the age and from step 2.2.1.2.5.b, from step 2.2.1.2.5.c, from step 2.2.1.2.5.d and the age required to corrode away the cladding, age_{rc}, if applicable from step 2.2.1.2.5.e. For components without cladding, and for components where the cladding is corroded away at the time of the last inspection (i.e. age_{rc} = 0.0), use Equation (2.12).

$$A_{rt} = \max[1 - \frac{t_{rd} - C_{r,cm} \cdot age}{t_{min} + CA}, 0.0] \qquad 2.12$$

g) Determine the damage factor for thinning, D_f^{thin}, using Equation (2.13).

$$D_f^{thin} = \frac{D_{fb}^{thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \qquad 2.13$$

2.2.1.2.6. Stress Corrosion Cracking (CL-SCC)

Chloride stress corrosion cracking (CLSCC) is one of the most common reasons why austenitic stainless steel pipework and vessels deteriorate in the chemical processing and petrochemical industries. SCC is an insidious form of corrosion; it produces a marked loss of mechanical strength with little metal loss; the damage is not obvious to casual inspection and the stress corrosion cracks can trigger mechanical fast fracture and catastrophic failure of components and structures. Several major disasters have involved stress corrosion cracking, including the rupture of high-pressure gas transmission pipes, the explosion of boilers, and the destruction of power stations and oil refineries. (National Physical Laboratory, 2000)

The calculation procedures of chloride stress corrosion cracking (CL-SCC) damage factor are:

a) Determine the number of inspections, and the corresponding inspection effectiveness category for all past inspections. Combine the inspections to the highest effectiveness performed.
b) Determine the time in-service (*age)* since the last *Level A*, *B*, *C* or *D* inspection was performed.
c) Determine the susceptibility for cracking using table 2.5 based on the operating temperature and concentration of the chloride ions. Note that a HIGH susceptibility should be used if cracking is known to be present.

Table 2.5 Susceptibility to Cracking – CLSCC

pH ≤ 10				
Temperature (°C)	**Susceptibility to Cracking as a Function of Chloride ion (ppm)**			
	1-10	**11-100**	**101-1000**	**>1000**
38 – 66	Low	Medium	Medium	High
>66 – 93	Medium	Medium	High	High
>93 – 149	Medium	High	High	High
pH > 10				
Temperature (°C)	**Susceptibility to Cracking as a Function of Chloride ion (ppm)**			
	1-10	**11-100**	**101-1000**	**>1000**
< 93	Low	Low	Low	Low
93 -149	Low	Low	Low	Medium

d) Based on the susceptibility in step 2.2.1.2.6.c, and determine the severity index, S_{VI} from table 2.6.

Table 2.6 Determination of Severity Index – CLSCC

Susceptibility	**Severity Index – S_{VI}**
High	5000
Medium	500
Low	50
None	1

e) Determine the base damage factor for CLSCC, D_{fb}^{CLSCC} using table 2.7 based on the number of, and the highest inspection effectiveness determined in step 2.2.1.2.6.a, and the severity index, S_{VI}, from step 2.2.1.2.6.d.

Table 2.7 SCC Damage Factors – All SCC Mechanisms

S_{VI}	**Inspection Effectiveness**												
	E	**1 Inspection**				**2 Inspections**				**3 Inspections**			
		D	**C**	**B**	**A**	**D**	**C**	**B**	**A**	**D**	**C**	**B**	**A**
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	2000	500	80	10

f) Calculate the escalation in the damage factor based on the time in-service since the last inspection using the *age* from STEP 2 and equation (2.14). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

$$D_f^{CLSCC} = D_{fB}^{CLSCC} \text{ (age)}^{1.1} \qquad 2.14$$

2.2.1.3. Consequences of Failure

The consequences of failure are the result if the asset getting failure. According to API RBI, consequences of failure assessment is performed to determining a ranking of equipment items on the basis of risk. There are four consequence categories such as; flammable, toxic consequences, non-flammable and non-toxic release and financial consequence. API RBI also provide two level consequences of failure methodology.

2.2.1.3.1. Consequence Categories

The major consequence categories are analyzed using different technique.

a) Flammable and explosive consequences are calculated using event trees to determine the probabilities of various outcomes (e.g., pool fires, flash fires, vapor cloud explosions), combined with computer modeling to determine the magnitude of the consequence. Consequence areas can be determined based on serious personnel injuries and component damage from thermal radiation and explosions. Financial losses are also determined based on the area affected by the release.

b) Toxic consequences are calculated using computer modeling to determine the magnitude of the consequence area as a result of overexposure of personnel to toxic concentrations within a vapor cloud. Where fluids are flammable and toxic, the toxic event probability assumes that if the release is ignited, the toxic consequence is negligible (i.e. toxics are consumed in the fire). Financial losses are also determined based on the area affected by the release.

c) Non-flammable, non-toxic releases are also considered since they can still result in serious consequences. Consequences from chemical splashes and high temperature steam burns are determined based on serious injuries to personnel. Physical explosions and BLEVEs can also cause serious personnel injuries and component damage.

d) Financial Consequences includes losses due to business interruption and costs associated with environmental releases. Business interruption consequences are estimated as a function of the flammable and non-flammable consequence area results. Environmental consequences are determined directly from the mass available for release or from the release rate.

2.2.1.3.2. Methodology of Consequence Analysis

2.2.1.3.2.1. Level 1 Consequence Analysis

The Level 1 consequence analysis can be used for a limited number of representative fluids. This simplified method contains table lookups and graphs that can readily be used to calculate the consequence of releases without the need of specialized consequence modeling software or techniques.

The following simplifying assumptions are made in the Level 1 consequence analysis:

a) The fluid phase upon release can only be either a liquid or a gas, depending on the storage phase and the phase expected to occur upon release to the atmosphere, in general, no consideration is given to the cooling effects of flashing liquid, rainout, jet liquid entrainment or two-phase.
b) Fluid properties for representative fluids containing mixtures are based on average values (e.g. MW, NBP, density, specific heats, AIT)
c) Probabilities of ignition, as well as the probabilities of other release events (VCE, pool fire, jet fire, etc.) have been pre-determined for each of the representative fluids as a function of temperature, fluid AIT and release type. These probabilities are constants, totally independent of the release rate.

Consequence calculation procedures for level 1 consequence analysis are; determine the representative fluid and associated properties, determine release hole size selection, determine release rate calculation, estimate the fluid inventory available for release, determine the release type (continuous or instantaneous), estimate the impact of detection and isolation systems on release magnitude, determine the release rate and mass for consequence analysis, determine flammable and explosive consequences.

2.2.1.3.2.1.1. Calculation Procedures of Determining the Representative Fluid and Associated Properties

The calculation procedures are:

a) Select a representative fluid group from table (2.8).

Table 2.8 List of Representative Fluids Available for Level 1 Analysis

Representative Fluid	**Fluid TYPE**	**Examples of Applicable Materials**
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, naptha, light stright 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 only
H_2S	TYPE 0	hydrogen sulfide only
HF	TYPE 0	hydrogen fluoride
Water	TYPE 0	Water
Steam	TYPE 0	Steam
acid (low)	TYPE 0	acid, caustic
Aromatics	TYPE 1	benzene, toluene, xylene, cumene
AlCl3	TYPE 0	aluminum chloride
Pyrophoric	TYPE 0	pyrophoric materials
Ammonia	TYPE 0	Ammonia
Chlorine	TYPE 0	Chlorine
CO	TYPE 1	carbon monoxide
DEE	TYPE 1 (see note 2)	diethyl ether
HCL	TYPE 0 (see note 1)	hydrogen chloride
nitric acid	TYPE 0 (see note 1)	nitric acid
NO_2	TYPE 0 (see note 1)	nitrogen dioxide
Phosgene	TYPE 0	Phosgene
TDI	TYPE 0 (see note 1)	toluene diisocyanate
Methanol	TYPE 1	Methanol

Table 2.8 List of Representative Fluids Available for Level 1 Analysis (Continue)

PO	TYPE 1	propylene oxide
Styrene	TYPE 1	Styrene
EEA	TYPE 1	ethylene glycol monoethyl ether acetate
EE	TYPE 1	ethylene glycol monoethyl ether
EG	TYPE 1	ethylene glycol
EO	TYPE 1	ethylene oxide
Notes: 1. HCL, Nitric Acid, NO_2, and TDI are TYPE 1 toxic fluids 2. DEE is a TYPE 0 toxic fluid		

b) Determine the stored fluid phase; Liquid or Vapor.

c) Determine the stored fluid properties.

- MW – Molecular weight, kg/kg-mol [lb/lb-mol], can be estimated from table (2.9).
- k – Ideal gas specific heat ratio, can be estimated using equation (2.15) and the P C values as determined using table (2.9).

$$k = \frac{C_p}{C_p - R} \tag{2.15}$$

- AIT – Auto-ignition temperature, K [°R], can be estimated from table (2.9).

Table 2.9 Properties of the Representative Fluids Used in Level 1 Analysis

Fluid	**MW**	**Liquid Density (kg/m³)**	**NBP (°C)**	**Ambient State**	**Ideal Gas Specific Heat Eq.**	**Cp**					**Auto-Ignition Temp. (°C)**
						Ideal Gas Constant *A*	**Ideal Gas Constant *B***	**Ideal Gas Constant *C***	**Ideal Gas Constant *D***	**Ideal Gas Constant *E***	
C_1-C_2	23	250.512	-125	Gas	Note 1	12.3	1.15E-01	-2.87E-05	-1.30E-09	N/A	558
C_3-C_4	51	538.379	-21	Gas	Note 1	2.632	0.3188	-1.35E+04	1.47E-08	N/A	369
C_5	72	625.199	36	Liquid	Note 1	-3.626	0.4873	-2.60E-04	5.30E-08	N/A	284
C_6-C_8	100	684.018	99	Liquid	Note 1	-5.146	6.76E-01	-3.65E-04	7.66E-08	N/A	223
C_9-C_{12}	149	734.012	184	Liquid	Note 1	-8.5	1.01E+00	-5.56E-04	1.18E-07	N/A	208
C_{13}-C_{16}	205	764.527	261	Liquid	Note 1	-11.7	1.39E+00	-7.72E-04	1.67E-07	N/A	202
C_{17}-C_{25}	280	775.019	344	Liquid	Note 1	-22.4	1.94E+00	-1.12E-03	-2.53E-07	N/A	202
C_{25+}	422	900.026	527	Liquid	Note 1	-22.4	1.94E+00	-1.12E-03	-2.53E-07	N/A	202

d) Determine the steady state phase of the fluid after release to the atmosphere, using table (2.10) and the phase of the fluid stored in the equipment as determined in step 2.2.1.3.2.1.1.b.

Table 2.10 Consequence Analysis Guidelines for Determining the Phase of a Fluid

Phase of Fluid at Normal Operating (Storage) Conditions	**Phase of Fluid at Ambient (after release) Conditions**	**API RBI Determination of Final Phase for Consequence Calculation**
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

2.2.1.3.2.1.2. Calculation Procedure of Release Hole Size Selection

The calculation procedures are:

a) Based on the component type and table (2.11), determine the release hole size diameters (d_n).

b) Determine the generic failure frequency (gff_n), and the total generic failure frequency from this table or from equation (2.16).

$$gff_{total} = \sum_{n-1}^{4} gff_n \qquad 2.16$$

Table 2.11 Release Hole Sizes and Area used

Release Hole Number	Release Hole Size	Range of Hole Diameters (mm)	Release Hole Diameter, d_n (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	$D_4 = \min[D, 406]$

2.2.1.3.2.1.3. Calculation Procedure of Release Rate Calculation

The calculation procedures are:

a) Select the appropriate release rate equation as described above using the stored fluid phase

b) For each release hole size, compute the release hole size area (A_n) using Equation (2.17) based on d_n.

$$A_n = \frac{\pi\, {d_n}^2}{4} \qquad 2.17$$

c) For each release hole size, calculate the release rate (W_n) with equation 2.18 for each release area (A_n)

$$W_n = \frac{C_d}{C_2} \text{ x } A_n \text{ x } P_s \text{ x } \sqrt{\left(\frac{k \, x \, MW \, x \, g_c}{R \, x \, T_s}\right) x \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}} \quad 2.18$$

2.2.1.3.2.1.4. Calculation Procedure of Estimate the Fluid Inventory Available for Release (Available Mass)

The Calculation procedures are:

a) Group components and equipment items into inventory groups (table 2.12)

b) Calculate the fluid mass ($mass_{comp}$) in the component being evaluated.

c) Calculate the fluid mass in each of the other components that are included in the inventory group ($mass_{comp,i}$).

d) Calculate the fluid mass in the inventory group ($mass_{inv}$) using Equation (2.19)

$$mass_{inv} = \sum_{i=1}^{N} mass_{comp,i} \quad 2.19$$

Table 2.12 Assumption When Calculating Liquid Inventories Within Equipment

Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns two or three items) - top half - middle section - bottom half	COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns Liquid/Liquid Columns	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums	50% liquid Typically, 2-phase drums are liquid level controlled at 50%

Table 2.12 Assumption When Calculating Liquid Inventories Within Equipment (Continue)

Equipment Description	**Component Type**	**Examples**	**Default Liquid Volume Percent**
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums, Flare Drums, Air Dryers.	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Heat Exchangers	HEXSS HEXTS	Shell and Tube Heat Exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 Analysis

e) Calculate the flow rate from a 203 mm [8 in] diameter hole (W_{max8}) using equations (2.18), as applicable, with 8 32,450 *n A* = *A* = mm2 [50.3 in2]. This is the maximum flow rate that can be added to the equipment fluid mass from the surrounding equipment in the inventory group.

f) For each release hole size, calculate the added fluid mass ($mass_{add,n}$) resulting from three minutes of flow from the inventory group using equation (2.20) where W_n is the leakage rate for the release hole size being evaluated and W_{max8} is from last step.

$$mass_{add,n} = 180 \, . \, \min \, [W_n \, , \, W_{max8}] \qquad 2.20$$

g) For each release hole size, calculate the available mass for release using Equation (2.21)

$$Mass_{avail,n} = \min[\{mass_{comp} + mass_{add,n}\}, mass_{inv}] \qquad 2.21$$

2.2.1.3.2.1.5. Calculation Procedure of Determining the Release Type (Continuous or Instantaneous)

The Calculation procedures are:

a) For each release hole size, calculate the time required to release 4,536 kgs [10,000 lbs] of fluid.

$$t_n = \frac{C_3}{W_n} \qquad 2.22$$

b) For each release hole size, determine if the release type is instantaneous or continuous using the following criteria.
   - If the release hole size is 6.35 mm [0.25 inches] or less, then the release type is continuous.
   - If 180 $t_n \leq sec$ or the release mass is greater than 4,536 kgs [10,000 lbs], then the release is instantaneous; otherwise, the release is continuous.

2.2.1.3.2.1.6. Estimate the Impact of Detection and Isolation Systems on Release Magnitude

The Calculation procedures are:

a) Determine the detection and isolation systems present in the unit.

b) Using table (2.13), select the appropriate classification (A, B, C) for the detection system.

Table 2.13 Detection and Isolation System Rating Guide

Type of Detection System	**Detection Classification**
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system	A
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	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually-operated valves	C

c) Using table (2.13), select the appropriate classification (A, B, C) for the isolation system.

d) Using (2.14) and the classifications determined in step 2.2.1.3.2.1.6.b & 2.2.1.3.2.1.6.c, determine the release reduction factor, $fact_{di}$.

Table 2.14 Adjustments to Release Based on Detection and Isolation Systems

System Classifications		**Release Magnitude Adjustment**	**Reduction 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 or 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 adjustment to release rate to mass	0.00

e) Using table (2.15) and the classifications determined in step 2.2.1.3.2.1.6.b & 2.2.1.3.2.1.6.c, determine the total leak durations for each of the selected release hole sizes, $ld_{max,n}$.

Table 2.15 Leak Durations Based on Detection and Isolation Systems

Detecting System Rating	**Isolation System Rating**	**Maximum Leak Duration, ld_{max}**
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

2.2.1.3.2.1.7. Determining the Release Rate and Mass for Consequence Analysis

The Calculation Procedure are:

a) For each release hole size, calculate the adjusted release rate (*$rate_n$*) using Equation 4.12 where the theoretical release rate (*W_n*) is from step 4.4.3.b. Note that the release reduction factor (*$fact_{di}$*) determined in step 4.4.6.d accounts for any detection and isolation systems that are present.

$$rate_n = W_n(1\text{-}fact_{di}) \qquad 2.23$$

b) For each release hole size, calculate the leak duration *(ld_n)* of the release using Equation 4.13, based on the available *mass* ($mass_{avail,n}$), and the adjusted release rate (*$rate_n$*) Note that the leak duration cannot exceed the maximum duration ($Id_{max,n}$) determined in step 2.2.1.3.2.1.6.e.

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\}, \left\{60xId_{max,n}\right\}\right] \qquad 2.24$$

c) For each release hole size, calculate the release mass (*$mass_n$*) , using equation (4.14) based on the release rate (*$rate_n$*) from step 2.2.1.3.2.1.3.b, the leak duration (*ld_n*) , from step 2.2.1.3.2.1.7.b, and the available mass (*$mass_{avail,n}$*) from step 2.2.1.3.2.1.4.f.

$$mass_n = min\ [\{rate_n\ .\ ld_n\}\ ,\ mass_{avail,n}] \qquad 2.25$$

2.2.1.3.2.1.8. Flammable and Explosive Consequence

The Calculation Procedure are:

a) Select the consequence area mitigation reduction factor (*$fact_{mit}$*) from table (2.16).

Table 2.16 Adjustments to Flammable Consequences for Mitigation Systems

Mitigation System	**Consequence Area Adjustment**	**Consequensce Area Reduction Factor, *factmit***
Inventory blowdown, coupled with isolation system classification B or higher	Reduce consequence area by 25%	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.20
Fire water monitors only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

b) For each release hole size, calculate the energy efficiency correction factor, $eneff_n$, using equation (2.26).

$$eneff_n = 4\ x\ log_{10}[C_4\ x\ mass_n] - 15 \qquad 2.26$$

c) Determine the fluid type, either TYPE 0 or TYPE 1 from table (2.8).

d) For each release hole size, compute the component damage consequence areas for Autoignition Not Likely, Continuous Release (AINL-CONT) $\left(CA_{cmd,n}^{AINL-CONT}\right)$.

1) Determine the appropriate constants a $(a_{cmd}^{AIL-CONT})$ and b $(b_{cmd}^{AIL-CONT})$ from the table (2.17) The release phase as determined in step 2.2.1.3.2.1.1.d. will be needed to assure selection of the correct constants.

2) If the release is a gas or vapor and the fluid type is TYPE 0, then use Equation (2.27) for the consequence area and Equation (2.28) for the release rate.

$$CA_{cmd,n}^{AINL-CONT} = a(rate_n)^b \text{ x } (1 - fact_{mit}) \qquad 2.27$$

$$effrate_n^{AINL-CONT} = rate_n \qquad 2.28$$

Table 2.17 Component Damage Flammable Consequence Equation Constants

Fluid	**Continuous Releases Constants**							
	Auto-Ignition Not Likely (CAINL)				**Auto-Ignition Likely (CAIL)**			
	Gas		Liquid		Gas		Liquid	
	a	*b*	*a*	*B*	*A*	*b*	*a*	*B*
C_1-C_2	8.669	0.98			55.13	0.95		
C_3-C_4	10.13	1.00			64.23	1.00		
C_5	5.115	0.99	100.6	0.89	62.41	1.00		
C_6-C_8	5.846	0.98	34.17	0.89	63.98	1.00	103.4	0.95
C_9-C_{12}	2.419	0.98	24.6	0.90	76.98	0.95	110.3	0.95
C_{13}-C_{16}			12.11	0.90			196.7	0.92
C_{17}-C_{25}			3.785	0.90			165.5	0.92
C_{25+}			2.098	0.91			103.0	0.90
H_2	13.13	0.992			86.02	1.00		
H_2S	6.554	1.00			38.11	0.89		
Fluid	**Instantaneous Releases Constants**							
	Auto-Ignition Not Likely (IAINL)				**Auto-Ignition Likely (IAIL)**			
	Gas		Liquid		Gas		Liquid	
	a	*b*	*a*	*B*	*A*	*b*	*a*	*B*
C_1-C_2	6.469	0.67			163.7	0.62		
C_3-C_4	4.590	0.72			79.94	0.63		
C_5	2.214	0.72	0.271	0.85	41.38	0.61		
C_6-C_8	2.188	0.66	0.749	0.78	41.49	0.61	8.180	0.55
C_9-C_{12}	1.111	0.66	0.559	0.76	42.28	0.61	0.848	0.53
C_{13}-C_{16}			0.086	0.88			1.714	0.88
C_{17}-C_{25}			0.021	0.91			1.068	0.91
C_{25+}			0.006	0.99			0.284	0.99
H_2	9.605	0.657			216.5	0.618		
H_2S	22.63	0.63			53.72	0.61		

e) For each release hole size, compute the component damage consequence areas for Autoignition Likely, Continuous Release (AIL-CONT), ($CA_{cmd,n}^{AIL-CONT}$)

1) Determine the appropriate constants, *a* ($a_{cmd}^{AIL-CONT}$) and *b* ($b_{cmd}^{AIL-CONT}$) The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
2) If the release type is gas or vapor, Type 0 or Type 1, then use Equation (2.29) to compute the consequence area and Equation (2.30) to compute the effective release rate.

$$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b \text{ x } (1 - fact_{mit}) \qquad 2.29$$

$$effrate_n^{AIL-CONT} = rate_n \qquad 2.30$$

f) For each release hole size, compute the component damage consequence areas for Autoignition Not Likely, Instantaneous Release (AINL-INST)

1) Determine the appropriate constants *a* ($a_{cmd}^{AINL-INST}$) and *b* ($b_{cmd}^{AINL-INST}$). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
2) If the release is a gas or vapor and the fluid type is TYPE 0, or the fluid type is TYPE 1, then use equation (2.31) for the consequence area and equation (2.32) for the effective release rate.

$$CA_{cmd,n}^{AINL-INST} = a(mass_n)^b \text{ x } \left(\frac{1 - fact_{mit}}{eneff_n}\right) \qquad 2.31$$

$$effrate_n^{AINL-INST} = mass_n \qquad 2.32$$

g) For each release hole size, compute the component damage consequence areas for Autoignition Likely, Instantaneous Release (AIL-INST) ($CA_{cmd,n}^{AIL-INST}$)

1) Determine the appropriate constants *a* ($a_{cmd}^{AIL-INST}$) and *b* ($b_{cmd}^{AIL-INST}$). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
2) If the release type is gas or vapor, Type 0 or Type 1, then use Equation (2.31) to compute the consequence area and Equation (2.32) to compute the effective release rate.

$$CA_{cmd,n}^{AIL-INST} = a(mass_n)^b \text{ x } \left(\frac{1 - fact_{mit}}{eneff_n}\right) \qquad 2.33$$

$$effrate_n^{AIL-INST} = mass_n \qquad 2.34$$

h) For each release hole size, compute the personnel injury consequence areas for Auto-ignition Not Likely, Continuous Release (AINL-CONT) ($CA_{inj,n}^{AINL-CONT}$)
   1) Determine the appropriate constants *a* ($a_{inj}^{AINL-CONT}$) and *b* ($b_{inj}^{AINL-CONT}$). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
   2) Compute the consequence area using Equation (2.35) where $effrate_n^{AINL-CONT}$ is from step 2.2.1.3.2.1.8.d.

$$CA_{inj,n}^{AINL-CONT} = a(effrate_n^{AINL-CONT})^b \text{ x } (1 - fact_{mit}) \qquad 2.35$$

i) For each release hole size, compute the personnel injury consequence areas for Auto-ignition Likely, Continuous Release (AIL-CONT) ($CA_{inj,n}^{AIL-CONT}$)
   1) Determine the appropriate constants *a* ($a_{inj}^{AIL-CONT}$) and *b* ($b_{inj}^{AIL-CONT}$). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
   2) Compute the consequence area using Equation (2.36) where $effrate_n^{AIL-CONT}$ is from step 2.2.1.3.2.1.8.e.

$$CA_{inj,n}^{AIL-CONT} = a(effrate_n^{AIL-CONT})^b \text{ x } (1 - fact_{mit}) \qquad 2.36$$

j) For each release hole size, compute the personnel injury consequence areas for Auto-ignition Not Likely, Instantaneous Release (AINL-INST) ($CA_{inj,n}^{AINL-INST}$)
   1) Determine the appropriate constants *a* ($a_{inj}^{AINL-INST}$) and *b* ($b_{inj}^{AINL-INST}$). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.
   2) Compute the consequence area using equation (2.36) where $effrate_n^{AINL-INST}$ is from step 2.2.1.3.2.1.1.f.

$$CA_{inj,n}^{AINL-INST} = a(effrate_n^{AINL-CONT})^b \text{ x } \left(\frac{1 - fact_{mit}}{eneff_n}\right) \qquad 2.36$$

k) For each release hole size, compute the personnel injury consequence areas for Auto-ignition Likely, Instantaneous Release (AIL-INST) ($CA_{inj,n}^{AIL-INST}$)

1) Determine the appropriate constants *a* (*$a_{inj}^{AIL-INST}$*) and *b* (*$b_{inj}^{AIL-INST}$*). The release phase as determined in step 2.2.1.3.2.1.1.d will be needed to assure selection of the correct constants.

2) Compute the consequence area using equation (2.37) where $effrate_n^{AIL-INST}$ is from step 2.2.1.3.2.1.1.g.

$$CA_{inj,n}^{AIL-INST} = a(effrate_n^{AIL-CONT})^b \text{ x } \left(\frac{1-fact_{mit}}{eneff_n}\right) \qquad 2.37$$

l) For each release hole size, calculate the instantaneous/continuous blending factor ($fact_n^{IC}$).

1) For Continuous Releases – To smooth out the results for releases that are near the continuous to instantaneous transition point (4,536 kgs [10,000 lbs] in 3 minutes, or a release rate of 25.2 kg/s [55.6 lb/s]), then the blending factor use equation (2.38).

$$fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\},\ 1.0\right] \qquad 2.38$$

2) For Instantaneous Releases – Blending is not required. Since the definition of an instantaneous release is one with a adjusted release rate ($rate_n$) greater than 25.2 kg/s [55.6 lb/s] (4536 kg [10,000 lbs] in 3 minutes), then the blending factor use equation (2.39).

$$fact_n^{IC} = 1.0 \qquad 2.39$$

m) Calculate the AIT blending factor ($fact^{AIT}$), using some equations, as applicable. Since Ts (450.15 kelvin) + C_6 (56) < AIT (831.150) then the equation:

$$fact^{AIT} = 0 \qquad 2.40$$

n) Compute the continuous/instantaneous blended consequence areas for the component using equations (2.41) through (2.48).

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-CONT} \; x \, fact_n^{IC} + \; CA_{cmd,n}^{AIL-INST} \; x \, (1 - fact_n^{IC} \,) \qquad 2.41$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-CONT} \; x \, fact_n^{IC} + \; CA_{cmd,n}^{AIL-INST} \; x \, (1 - fact_n^{IC} \,) \qquad 2.42$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-CONT} \; x \, fact_n^{IC} + \; CA_{cmd,n}^{AINL-INST} \; x \, (1 - fact_n^{IC}) \qquad 2.43$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-CONT} \; x \, fact_n^{IC} + \; CA_{cmd,n}^{AINL-INST} \; x \, (1 - fact_n^{IC}) \qquad 2.44$$

o) Compute the AIT blended consequence areas for the component using equations (2.45) and (2.46). The resulting consequence areas are the component damage and personnel injury flammable consequence areas.

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \, x \, fact^{AIT} + \; CA_{cmd,n}^{AINL} \, x \, (1 - fact^{AIT} \,) \qquad 2.45$$

$$CA_{inj,n}^{flam} = CA_{inj,n}^{AIL} \, x \, fact^{AIT} + \; CA_{inj,n}^{AINL} \, x \, (1 - fact^{AIT} \,) \qquad 2.46$$

p) STEP 8.16 – Determine the final consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (2.47) and (2.48).

$$CA_{cmd}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \; x \; CA_{cmd,n}^{flam}}{gff_{total}} \right) \qquad 2.47$$

$$CA_{inj}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n \; x \; CA_{inj,n}^{flam}}{gff_{total}} \right) \qquad 2.48$$

2.2.1.3.2.2. Level 2 Consequence Analysis

The Level 2 consequence analysis may be used in cases where the assumptions of the Level 1 consequence analysis are not valid.

Examples of where the more rigorous calculations may be necessary are cited below.

a) The specific fluid is not represented adequately within the list of reference fluid groups provided in the Level 1 analysis, including cases where the fluid is a wide-range boiling mixture or where the fluids toxic consequences are not represented adequately by any of the reference fluid groups.
b) The stored fluid is close to its critical point, in which case, the ideal gas assumptions for the vapor release equations are invalid.
c) The effects of two-phase releases, including liquid jet entrainment as well as rainout need to be included in the assessment.
d) The effects of BLEVES are to be included in the assessment (not included in the Level 1 analysis).
e) The effects of pressurized non-flammable explosions, such as possible when non-flammable pressurized gases (e.g. air or nitrogen) are released during a vessel rupture are to be included in the assessment (not included in the Level 1 analysis).
f) The meteorological assumptions used in the dispersion calculations that form the basis for the Level 1 consequence analysis table lookups do not represent the site data.

2.2.1.4. Remaining Lifetime Analysis

The remaining lifetime of the equipment is the time for which the existing equipment can continue to operate before it has to be replaced/discarded for technical reasons, such as the age of the equipment, safety reasons, or deteriorated performance. The remaining lifetime is expressed in years or hours of operation. The calculation to analyze can be generate by equation (2.49).

$$Remaining\ life = \frac{t_{act} - t_{rd}}{CR} \qquad 2.49$$

Where:
T_{act} = wall thickness when inspection
t_{rd} = design wall thickness
CR = Corrosion rate

CHAPTER 3
METHODOLOGY

The following methodology flowchart shows the process diagram of bachelor thesis.

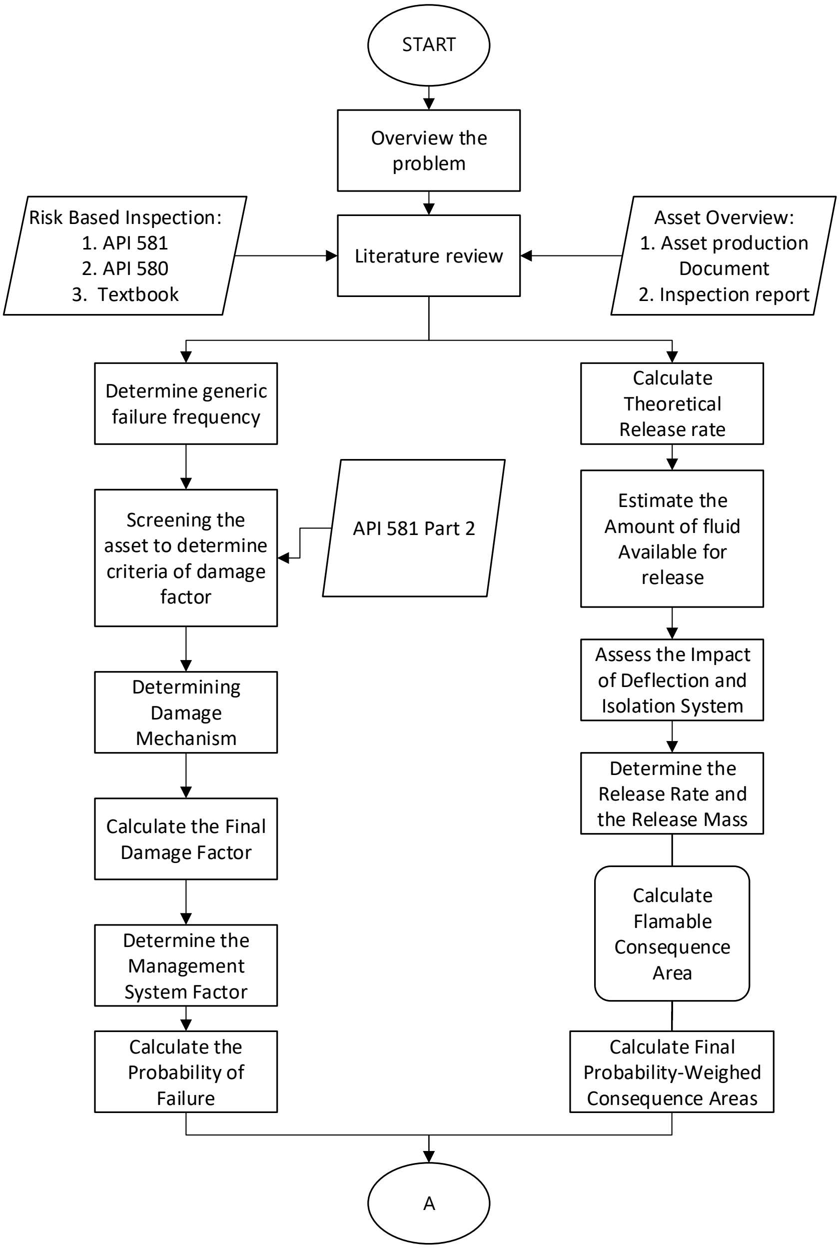


Figure 3.1 Bachelor thesis methodology

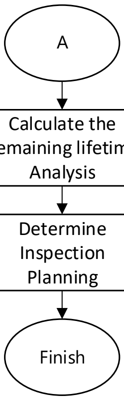


Figure 3.1 Bachelor thesis methodology (Continue)

3.1. Literatures Study

Literatures of bachelor thesis study is started with reading and analyze the rules in this case is American Petroleum Institute (API), the bachelor thesis uses API 580 for risk based inspection, API 581 for risk based inspection technology and API 579 to determine fitness for service of the asset.

Besides API, author also uses textbook and journal to analyze RBI. The textbooks are around offshore oil and gas platform and maritime sector. Then, author also needs journal to determine the procedure of RBI according to the previous occurrence.

3.2. Determine Generic Failure Frequency

Generic failure frequency is starting from determining what type of asset we have. Then starting to determine the generic failure frequency from the table.

3.3. Determining Damage Mechanism

The first step to identify damage mechanism is prepare for the data. Then, according to the data the kind of damage mechanism can be identified and for the step and the calculation can be obtained in the RBI 581.

3.4. Final Damage Factor Calculation

Final damage factor calculation can be calculated if the damage mechanism has already determined. Then calculate the final damage factor using RBI 58. After that, the result is ready to use for calculating probability of failure.

CHAPTER 4
DATA ANALYSIS

4.1. Collecting Asset Data

The first step is learning about the asset working process in figure (4.1). The asset (Gas-cooling heat exchanger) is incorporated with offshore used to gas lift to lift crude oil. The flow station compression system at flow station is completed with two stage compressor, scrubber and coolers. Combined gas from gas wells supply to 1st Stage Suction Scrubber and then compressed by 1st Stage Compressor. Increasing gas pressure will increase gas temperature. Therefore, the gas should be cooling down by cooler before feed into 2nd Stage Compression system. In the 2nd Stage Compression System, gas will be compressed with the same process described above. The final compressed gas then mainly used as gas lift to lift crude oil. The specific location of the asset (Gas-cooling heat exchanger) is in the 2nd stage compression system.

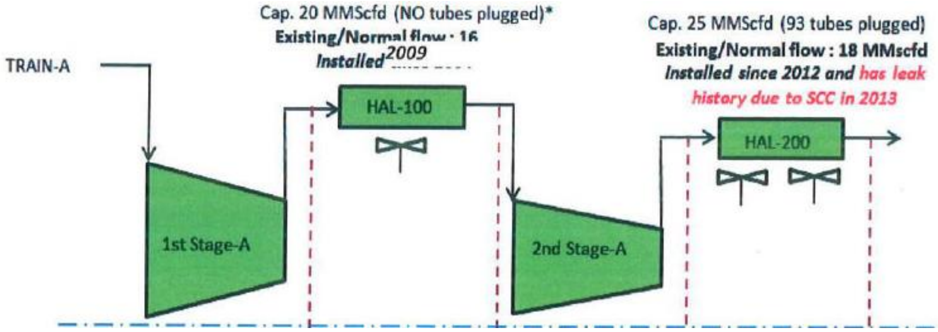


Figure 4.1 Simplified compression diagram

Then, next step is collecting asset data. There are 2 kinds of data are needed in the RBI. The first is asset specification data (table 4.1) and previous inspection report. The specification data (table 4.1) must be qualified because RBI needs the actual and comprehensive data to obtain the perfect goal. And don't forget to notice the accident of the asset for the example the asset has a history of down by chloride stress corrosion cracking (cl-scc) so cl-scc must be input to the damage factor.

Table 4.1 Asset specification data

Year Installed	2012
Last inspection	2013
Design pressure	6205.28 kPa

Table 4.1 Asset specification data (Continue)

Tube material	Seamless SS A 316L
Header box material	SS SA 240 TP 316L
Corrosion allowance (tubes) (mm)	1.99
Corrosion allowance (header box) (mm)	1.27
Corrosion rate (mm/year)	0.023
Tube diameter (inch)	1
Inlet pressure (psig)	710
Inlet temperature (ºF)	238
Outlet pressure (psig)	690
Outlet temperature (ºF)	107
Design capacity (MMScfd)	25
Current flow rate (MMScfd)	18
Inlet pressure (psig)	710
Inlet temperature (ºF)	238
Outlet pressure (psig)	690
Outlet temperature (ºF)	107
Molecular weight (J/kmol.K)	25
Universal gas constant (J/(kg.mol)K	8.314
Auto ignition temperature (°C)	558
Steady state phase	Gas
Phase of the fluid stored in equipment	Gas

4.2. Generic Failure Frequency (*gff)*

Determine generic failure frequency is the first part to calculate probability of failure Generic failure frequency table is provided in table 2.1. The result of generic failure frequency in for the tube and for the header box is 3.06 x 10^{-5} and the answer is shown by the table 4.2.

Table 4.2 Determine the generic failure frequency from table.

Equipment type	Component type	***gff* as a Function of Hole Size (failures/yr)**				***gff(total)* (failures/yr)**
		Small	**Medium**	**Small**	**Medium**	
Pipe	PIPE-1	2.80E-05	0	0	2.60E-06	3.06E-05
Vessel/ FinFan	FINFAN	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

4.3. Damage Mechanism Identification

Generating damage mechanism identification started from screening few criteria of damage mechanism; the first one is material composition of the asset, fluid data in the asset, environment around the asset, and other factors which is related to the damage mechanism. According to the asset data and identify damage mechanism with table (4.3) there are two type of damage factor chosen. The first is thinning damage factor and the second is CL-SCC damage factor.

Table 4.3 damage mechanism identification

No.	***Type Damage Mechanism***	***Criteria based on API 581***	**Yes/No**	**Result**
1	*Thinning Damage factor*	In an API RBI assessment, all components should be checked for thinning.	Yes	Yes
2	*Component Lining Damage Factor*	The component has an inorganic or organic lining, then the component should be evaluated for lining damage.	No	No
3	*SCC Damage Factor - Caustic Cracking*	The component's material of construction is carbon or low alloy steel	Yes	No
		The process environment contains caustic in any concentration	No	
4	*SCC Damage Factor - Amine Cracking*	The component's material of construction is carbon or low alloy steel	Yes	No
		The process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration.	No	
5	*SCC Damag Factor - Sulfide Stress Cracking*	The component's material of construction is carbon or low alloy steel	Yes	No
		The process environment contains water and H2S in any concentration	No	
6	*SCC Damage Factor - HIC/SOHIC-H2S*	If the component's material of construction is carbon or low alloy steel	Yes	No
		the process environment contains water and H2S in any concentration	No	
7	*SCC Damage Factor - Carbonate Cracking*	If the component's material of construction is carbon or low alloy steel	Yes	No
		the process environment contains sour water at pH > 7.5 in any concentration	No	

Table 4.3 damage mechanism identification (Continue)

No.	*Type Damage Mechanism*	*Criteria based on API 581*	Yes/No	Result
8	*SCC Damage Factor - PTA Cracking*	If the component's material of construction is an austenitic stainless steel or nickel based alloys	No	No
		The component is exposed to sulfur bearing compounds	No	
9	*SCC Damage Factor - CLSCC*	The component's material of construction is an austenitic stainless steel	Yes	Yes
		The component 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)	Yes	
		The operating temperature is above 38°C [100°F]	Yes	
10	*SCC Damage Factor - HSC-HF*	If the component's material of construction is carbon or low alloy steel	Yes	No
		the component is exposed to hydrofluoric acid in any concentration	No	
11	*SCC Damage Factor - HIC/SOHIC-HF*	If the component's material of construction is carbon or low alloy steel	Yes	No
		the component is exposed to hydrofluoric acid in any concentration	No	

4.3.1. Calculation of Thinning Damage Factor

Determining the number of inspections is the first step to calculate the thinning damage factor, and the corresponding inspection effectiveness category using table (4.4) and table (4.5) for general thinning and local thinning. Combine the inspections to the highest effectiveness performed using paragraph 2.2.1.2.2. Then, obtained three answers; number of inspection = 1 (on October 2013); Inspection category = A (highly effectiveness) for the tube and C (fairly effectiveness) for the header box.

Table 4.4 Guidelines for Assigning Inspection Effectiveness – General Thinning

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example	Non-intrusive Inspection Example
A	Highly Effective	50 to 100% examination of the surface (partial internals removed), and accompanied by thickness measurements	50 to 100% ultrasonic scanning coverage (automated or manual) or profile radiography
B	Usually Effective	Nominally 20% examination (no internals removed), and spot external ultrasonic thickness measurements	Nominally 20% ultrasonic scanning coverage (automated or manual), or profile radiography, or external spot thickness (statistically validated)
C	Fairly Effective	Visual examination with thickness measurements	2 to 3% examination, spot external ultrasonic thickness measurements, and little or no internal visual examination
D	Poorly Effective	Visual examination	Several thickness measurements, and a documented inspection planning system
E	Ineffective	No Inspection	Several thickness measurements taken only externally, and a poorly documented inspection planning system

Table 4.5 Guidelines for Assigning Inspection Effectiveness – Local Thinning

Inspection Category	Inspection Effectiveness Category	Intusive Inspection Example	Non-intrusive Inspection Example
A	Highly Effective	100% visual examination (with removal of internal packing, trays, etc.) and thickness measurements	50 to 100% coverage using automated ultrasonic scanning, or profile radiography in areas specified by a corrosion engineer or other knowledgeable specialist.

Table 4.5 Guidelines for Assigning Inspection Effectiveness – Local Thinning (Continue)

B	Usually Effective	100% visual examination (with partial removal of the internals) including manways, nozzles, etc. and thickness measurements.	20% coverage using automated ultrasonic scanning, or 50% manual ultrasonic scanning, or 50% profile radiography in areas specified by a corrosion engineer or other knowledgeable specialist.
C	Fairly Effective	Nominally 50% visual examination and spot ultrasonic thickness measurements	Nominally 20% coverage using automated or manual ultrasonic scanning, or profile radiography, and spot thickness measurements at areas specified by a corrosion engineer or other knowledgeable specialist.
D	Poorly Effective	Nominally 20% visual examination and spot ultrasonic thickness measurements	Spot ultrasonic thickness measurements or profile radiography without areas being specified by a corrosion engineer or other knowledgeable specialist.
E	Ineffective	No Inspection	Spot ultrasonic thickness measurements without areas being specified by a corrosion engineer or other knowledgeable specialist.

Step two is to determine the time in-service (age), since the last inspection thickness reading, (t_{rd}). And the answer is one year. Then step three is to determine the corrosion rate for the base metal, ($C_{r,bm}$), based on the material of construction and process environment, Where the component has cladding, a corrosion rate, ($C_{r,bm}$), must also be obtained for the cladding. But this asset has no cladding and the Corrosion rate is 0.023 mm/yr.

Step 4 is to determine the minimum required wall thickness (t_{min}) per the original construction code or using API 579 for the tube then applicable minimum required wall thickness for the tube is 1.13 mm. And the the header box has no release prevention barrier then the t_{min} is 0.1 in or 2.54 mm. And the last step, determine the A_{rt} parameter using Equation (4.1) based on the age and from STEP 2, from STEP 3, from STEP 4 and the age required to corrode away the cladding.

$$A_{rt} = max[1 - \frac{t_{rd} - C_{r,cm} \cdot age}{t_{min} + CA},\ 0.0] \tag{4.1}$$

Where:
t_{rd} = 1.65 mm, C_r = 0.023 mm/yr, Age = 1 yr, t_{min} = 1.13 mm (for tube), 2.54 mm (for header box) & CA = 1.27 mm (for tube), 1.59 mm (for header box)[4]

Then, from the equation (2.12) the A_{rt} for tube is known: 0.348 in RBI date and 0.444 in plan date, and 0 in RBI date and 0 in plan date. Then use table (2.13) and table 2.7 to determine basic damage factor. Table (4.4) shown the way to determine basic damage factor from A_{rt} value. For the example A_{rt} of tube in RBI date is 0.348 then according to the table, 0.348 is between 0.3 and 0.35 then use interpolation formula to determine basic damage factor then, the basic damage factor value for the tube in RBI date is 544.124. For the tube, basic damage factor in plan date is 831.799. And for the Header box basic damage factor is 1 in RBI date and plan date.

Table 4.6 basic damage factor determining for tube in RBI date

A_{rt}	**Inspection Effectiveness**												
	E	**1 Inspection**				**2 Inspections**				**3 Inspections**			
		D	**C**	**B**	**A**	**D**	**C**	**B**	**A**	**D**	**C**	**B**	**A**
0.02	1	1	1	1	1	1	1	1	1	1	1	1	1
0.04	1	1	1	1	1	1	1	1	1	1	1	1	1
0.06	1	1	1	1	1	1	1	1	1	1	1	1	1
0.08	1	1	1	1	1	1	1	1	1	1	1	1	1
0.10	2	2	1	1	1	1	1	1	1	1	1	1	1
0.12	6	5	3	2	1	4	2	1	1	3	1	1	1
0.14	20	17	10	6	1	13	6	1	1	10	3	1	1
0.16	90	70	50	20	3	50	20	4	1	40	10	1	1
0.18	250	200	130	70	7	170	70	10	1	130	35	3	1
0.20	400	300	210	110	15	290	120	20	1	260	60	5	1
0.25	520	450	290	150	20	350	170	30	2	240	80	6	1
0.30	650	550	400	200	30	400	200	40	4	320	110	9	2
0.35	750	650	550	300	80	600	300	80	10	540	150	20	5

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[4] Corrosion allowance based on ASME B31.3.

4.6 basic damage factor determining for tube in RBI date

0.40	900	800	700	400	130	700	400	120	30	600	200	50	10
0.45	1050	900	810	500	200	800	500	160	40	700	270	60	20
0.50	1200	1100	970	600	270	1000	600	200	60	900	360	80	40
0.55	1350	1200	1130	700	350	1100	750	300	100	1000	500	130	90
0.60	1500	1400	1250	850	500	1300	900	400	230	1200	620	250	210

4.3.2. Calculation of CL-SCC Damage Factor

First step is to determine the number of inspections, and the corresponding inspection effectiveness category using chapter 2.2.1.2.6. For all past inspections. Combine the inspections to the highest effectiveness, obtained number of past inspection = 1; inspection category = C (for header box), A (for tube); Inspection effectiveness category = Fairly effectiveness (for header box), Highly effectives (for tube). Second step is to determine the time in-service, *age*, since the last *Level A*, *B*, *C* or *D* inspection was performed. Then the age obtained 3.75 year (RBI date), 14 years (plan date). Next step is to determine the susceptibility for cracking using table 4.7, based on the operating temperature and concentration of the chloride ions. Since the cracking is known present in the asset then the susceptibility must be high. According to the inspection report and the asset specification data obtained the temperature is 41,67°C – 114,44°C; the chloride content is 16000 ppm; and this asset is reported has already cracked on the October 2013. Then the susceptibility to cracking of the asset is high for tube and header box in RBI date and plan date.

Table 4.7 Susceptibility to Cracking – CLSCC

pH ≤ 10				
Temperature (°C)	**Susceptibility to Cracking as a Function of Chloride ion (ppm)**			
	1-10	**11-100**	**101-1000**	**>1000**
38 - 66	Low	Medium	Medium	High
>66 - 93	Medium	Medium	High	High
>93 - 149	Medium	High	High	High

Step four is to determine the severity index based on the susceptibility, S_{VI} from Table 4.8 then obtained; S_{VI} = 5000 for tube and header box in RBI date and plan date.

Table 4.8 Determination of Severity Index – CLSCC

Susceptibility	**Severity Index – S_{VI}**
High	5000

Step five is to determine the base damage factor for CLSCC, D_{fb}^{CLSCC} using Table 4.9, and the highest inspection effectiveness determined in step 1, and the severity index, S_{VI}, from step 4. D_{fB}^{CLSCC} = 250 (for tube), 1670 (for header box).

Table 4.9 Based SCC Damage Factors (red square is for the header box and blue square is for the tube)

S_{VI}	**Inspection Effectiveness**												
	E	**1 Inspection**				**2 Inspections**				**3 Inspections**			
		D	**C**	**B**	**A**	**D**	**C**	**B**	**A**	**D**	**C**	**B**	**A**
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	2000	500	80	10

And the last step is to calculate the escalation in the damage factor based on the period in-service since the last inspection using the *age* from step 2 and Equation (4.2). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

$$D_f^{CLSCC} = D_{fB}^{CLSCC}\ (\text{age})^{1.1} \tag{4.2}$$

$= 250 \times 3.75^{1.1} = 1070$ (RBI date for tube)
$= 250 \times 14^{1.1} = 4557$ (RBI plan date for tube)
$= 1670 \times 3.75^{1.1} = 7147.45$ (RBI date for header box)
$= 1670 \times 14^{1.1} = 30440.9$ (RBI plan date for header box)

4.3.3. Total Damage Factor

Total damage factor is the final damage factor calculation. In this calculation combine all damage factors which are obtained.

$$\mathrm{D}_{\mathrm{f-total}} = D_f^{thin} + D_f^{CLSCC} \tag{4.3}$$

$= 2720.62 + 1070 = 3790.6$ (RBI date)
$= 4158.99 + 4557 = 8716.01$ (RBI plan date)
$= 7.5 + 7147.45 = 7154.95$ (RBI date)
$= 7.5 + 30440.9 = 30448.4$ (RBI plan date)

4.4. Calculation of Consequence

The consequence analysis in an RBI program is performed to provide discrimination between equipment items on the basis of the significance of a potential failure. The consequence analysis should be a repeatable, simplified, credible estimate of what might be expected to happen if a failure were to occur in the equipment item being assessed. The COF analysis should be performed to estimate the consequences that occur due to a failure mode typically resulting from an identified damage mechanism.

In general, an RBI program will be managed by plant inspectors or inspection engineers, who will normally manage risk by managing the POF with inspection and maintenance planning. They will not normally have much ability to modify the COF. On the other hand, management and process safety personnel may desire to manage the consequence side of the risk equation. For all of these users, the consequence analysis is an aid in establishing a relative risk ranking of equipment items. The consequence analysis should address all credible failure modes to which the equipment item is susceptible. There are two kinds of consequences used in the thesis, they are consequences for the tube and consequences for the header box.

4.4.1. Determining the Representative Fluid and Associated Properties

In the Level 1 Consequence Analysis, a representative fluid that most closely matches the fluid contained in the pressurized system being evaluated is selected from the representative fluids shown in table 2.8 Because very few refinery and chemical plant streams are pure materials, the selection of a representative fluid almost always involves making some assumptions.

According to the chapter 2.2.1.3.2.1.1. the first step is selecting a representative fluid group from table 2.8. according to the company data the fluid is known as C_1 then the fluid type is "TYPE 0". Then the phase of fluid known as vapor and not change into liquid. After that, from the table 2.9, the molecular weight is 23 kg/kg-mol. Then using the equation (2.15) the ideal gas specific ratio is 1.167 and the auto ignition temperature is 558 ^{o}C. And for the steady phase of fluid is gas and the fluid in the storage is also gas.

4.4.2. Release Hole Size Selection

A discrete set of release events or release hole sizes are used in the Level 1 (and Level 2) consequence analysis. It would be impractical to perform the consequence calculations for a continuous spectrum of release hole sizes. Limiting the number of release hole sizes allows for an analysis that is manageable yet still reflects the range of possible outcomes.

There are two kinds of determining release hole size diameter. For the tube, using small (6.4 mm) and rupture (155 mm) because in the table of generic failure frequency (gff)(table 2.1) frequency the tube is same as one inch pipe. For the header box, using small (6.4 mm), medium (25 mm), large (102 mm) and rupture (155 mm).

4.4.3. Release Rate Calculation

Release rates depend upon the physical properties of the material, the initial phase, the process operating conditions, and the assigned release hole sizes. The correct release rate equation must be chosen, based on the phase of the material when it is inside the equipment item, and its discharge regime (sonic or subsonic), as the material is released.

The release hole size area for tube and for header box of heat exchanger are shown in the table (4.10).

Table 4.10 Summary of release hole size area

Header box		Tube	
A_1	32.18285714 mm^2	A_1	32.18285714 mm^2
A_2	491.0714286 mm^2	A_4	18876.78571 mm^2
A_3	8174.571429 mm^2		
A_4	18876.8 mm^2		

The summaries of calculation of release rate shown in the table (4.11).

Table 4.11 Summary of release hole size area

Header box		Tube	
W_1	9.535346584 kg/s	W_1	9.535346584 kg/s
W_2	145.4978422 kg/s	W_2	5592.937052kg/s
W_3	2422.01528 kg/s		
W_4	5592.937052 kg/s		

4.4.4. Estimate the Fluid Inventory Available for Release (Available Mass)

The consequence calculation requires an upper-limit for the amount of fluid, or fluid inventory that is available for release from an equipment item. In theory, the total amount of fluid that can be released is the amount that is held within pressure containing equipment between isolation valves that can be quickly closed. In reality, emergency operations can be performed over time to close manual valves, de-inventory sections, or otherwise stop a leak. In addition, piping restrictions and differences in elevation can serve to effectively slow or stop a leak. The inventory calculation as presented here is used as an upper limit and does not indicate that this amount of fluid would be released in all leak scenarios.

First step to calculate available mass is group component items into inventory groups using table 2.12 then the inventory group is Finfan cooler & finfan then for header box and pipe-1 for the tube, the $mass_{comp}$ is 0.009112178 kgs for the header box and 0.054284 kgs for the tube then because the header box only two so the mass inventory is 6.24266 kgs and 4472.582 for the tube because the tube is 115 items. Then calculate flow rate from 203 mm diameter hole (W_{max8}) and get 9614.49741 kgs for the tube and header box. Next step, calculate the Added fluid mass ($mass_{add,n}$) and the summaries of fluid mass calculation for header box and for tube shown in the table 4.12

Table 4.12 Summary of fluid mass calculation ($mass_{add,n}$)

Header box		Tube	
$mass_{add,1}$	1716.362385 kgs	$mass_{add,1}$	1716.362385 kgs
$mass_{add,2}$	26189.61159 kgs	$mass_{add,4}$	1006728.669 kgs
$mass_{add,3}$	435962.7503 kgs		
$mass_{add,4}$	1006728.669 kgs		

Then for the available mass for release ($mass_{avail,n}$)

Table 4.13 Summary of available mass for release ($mass_{avail,n}$)

Header box		Tube	
$mass_{avail,1}$	0.018224357 kgs	$mass_{avail,1}$	6.24266 kgs
$mass_{avail,2}$	0.018224357 kgs	$mass_{avail,4}$	6.24266 kgs
$mass_{avail,3}$	0.018224357 kgs		
$mass_{avail,4}$	0.018224357 kgs		

4.4.5. Determining the Release Type (Continuous or Instantaneous)

Different analytical models and methods are used to estimate the effects of an instantaneous versus a continuous type of release. The calculated consequences can differ greatly, depending on the type of analytical model chosen to represent the release. Therefore, it is very important that a release is properly categorized into one of the two release types.

As an example of the importance of proper model selection is the case for vapor cloud explosions, VCEs. A review of historical data on fires and explosions shows that *unconfined* vapor cloud explosions are more likely to occur for instantaneous vapor releases than they are for continuous releases. For API RBI a threshold for the instantaneous release model is if more than 4,536 kilograms [10,000 pounds] of fluid are released in a short period of time. Using this threshold to define continuous releases reflects the tendency for amounts released in a short period of time, less than 4,536 kilograms [10,000 pounds], to result in a flash fire rather than a VCE.

The summaries of time required to release and release type shown in table (4.14) for header box and table (4.15) for tube.

Table 4.14 time required to release and release type (Header Box)

d_1 =	6.4 mm	$mass_{avail,1}$ =	0.018224 mm	t_1 =	475.7037 second	Continuous
d_2 =	25 mm	$mass_{avail,2}$ =	0.018224 mm	t_2 =	31.1757 second	Instantaneous
d_3 =	102 mm	$mass_{avail,3}$ =	0.018224 mm	t_3 =	1.8728 second	Instantaneous
d_4 =	155 mm	$mass_{avail,4}$ =	0.018224 mm	t_4 =	0.8110 second	Instantaneous

Table 4.15 time required to release and release type (Tube)

d_1 =	6.4 mm	$mass_{avail,1}$ =	6.243 mm	t_1 =	475.7037 second	Continuous
d_4 =	155 mm	$mass_{avail,4}$ =	6.243 mm	t_4 =	0.8110 second	Instantaneous

4.4.6. Estimate the Impact of Detection and Isolation Systems on Release Magnitude

Petrochemical processing plants typically have a variety of detection, isolation and mitigation systems that are designed to reduce the effects of a release of hazardous materials. A simplified methodology for assessing the effectiveness of various types of detection, isolation and mitigation systems is included in API RBI. These systems affect a release in different ways. Some systems reduce magnitude and duration of the release by detecting and isolating the leak. Other systems reduce the consequence area by minimizing the chances for ignition or limiting the spread of material.

To generated impact of detection and isolation system on release magnitude, use table (2.13) to classify detection and isolation and the result of detection system is A and isolation system is B for header box and tube. Then use table (2.14) to determine reduction factor ($fact_{di}$) and the reduction factor is 0,2 for header box and tube. Then for the total leak duration for each of the release hole sizes selection shown in table (4.16).

Table 4.16 total leak duration for each of the release hole sizes selection

Header box		Tube	
$Id_{max,1}$	30 minutes for 6.4 mm leaks	$Id_{max,1}$	30 minutes for 6.4 mm leaks
$Id_{max,2}$	20 minutes for 25 mm leaks	$Id_{max,4}$	0.0167 minutes for 155 mm leaks
$Id_{max,3}$	10 minutes for 102 mm leaks		
$Id_{max,4}$	0.0167 minutes for 155 mm leaks		

4.4.7. Determine the Release Rate and Mass for Consequence Analysis

For continuous releases, the release is modeled as a steady state plume; therefore, the release rate (kg/s) is used as the input to the consequence analysis. For transient instantaneous puff releases, the release mass is required to perform the analysis.

According to the chapter 2.2.1.3.2.1.7. the result of the release rate and mass for consequences analysis shown in table (4.17) for header box and table (4.18) for tube.

Table 4.17 release rate and mass for consequences analysis results

$rate_1$ =	7.628277267 kg/s	Id_1 =	0.002389053 s	$mass_1$ =	0.01822 kgs
$rate_2$ =	116.3982737 kg/s	$Id_{,2}$ =	0.000156569 s	$mass_2$ =	0.01822 kgs
$rate_3$ =	1937.612224 kg/s	Id_3 =	9.40557E-06 s	$mass_3$ =	0.01822 kgs
$rate_4$ =	4474.349642 kg/s	Id_4 =	4.07307E-06 s	$mass_4$ =	0.01822 kgs

Table 4.18 release rate and mass for consequences analysis results

$rate_1$ =	7.628277267 kg/s	Id_1 =	0.818357774 s	$mass_1$ =	6.24266 kgs
$rate_4$ =	4474.349642 kg/s	Id_4 =	0.001395211 s	$mass_4$ =	6.24266 kgs

4.4.8. Determine Flammable and Explosive Consequence

Determining flammable and explosive consequence is the last calculation for consequences and first step is determining reduction factor ($fact_{mit}$)

and according to table (2.16) the result for header box and tube is 0.2. Then the second step is calculating energy efficiency correction factor (*$eneff_n$*) for instantaneous release (determining continuous and instantaneous release generated in chapter 4.4.5) and the result shown in table 4.19 for header box and 4.20 for tube.

Table 4.19 energy efficiency correction factor (Header box)

t_1 =	475.7037 second	Continuous	eneff,$_1$	N/A
t_2 =	31.1757 second	Continuous	eneff,$_2$	-20.5838
t_3 =	1.8728 second	Instantaneous	eneff,$_3$	-20.5838
t_4 =	0.8110 second	Instantaneous	eneff,$_4$	-20.5838

Table 4.20 energy efficiency correction factor (Header box)

t_1 =	475.7037 second	Continuous	eneff,$_1$	N/A
t_4 =	0.8110 second	Instantaneous	eneff,$_4$	-10.445

Then the before we got flammable and explosive consequences we must calculate the component damage consequence areas for autoignition not likely, continuous release (AINL-CONT) ($CA_{cmd,n}^{AINL-CONT}$), component damage consequence areas for autoignition likely, continuous release (AIL-CONT) ($CA_{cmd,n}^{AIL-CONT}$), component damage consequence areas for autoignition not likely, instantaneous release (AINL-INST) ($CA_{cmd,n}^{AINL-INST}$), component damage consequence areas for autoignition likely, instantaneous release (AIL-INST) ($CA_{cmd,n}^{AIL-INST}$), personnel injury consequence areas for autoignition not likely, continuous release (AINL-CONT) ($CA_{inj,n}^{AINL-CONT}$), personnel injury consequence areas for autoignition likely, continuous release (AIL-CONT) ($CA_{inj,n}^{AIL-CONT}$), personnel injury consequence areas for autoignition not likely, instantaneous release (AINL-INST) ($CA_{inj,n}^{AINL-INST}$), personnel injury consequence areas for autoignition likely, instantaneous release (AIL-INST) ($CA_{inj,n}^{AIL-INST}$). Then the summaries of those results shown in table 4.21 (for header box and tube).

Table 4.21 Summaries of calculation consequence results (1)

	Header Box		**Tube**	
$\boldsymbol{CA_{cmd,n}^{AINL-CONT}}$	$CA_{cmd,1}^{AINL-CONT}$ =	50.7969 m^2	$CA_{cmd,1}^{AINL-CONT}$ =	50.7969 m^2
$\boldsymbol{CA_{cmd,n}^{AIL-CONT}}$	$CA_{cmd,1}^{AIL-CONT}$ =	303.937 m^2	$CA_{cmd,1}^{AIL-CONT}$ =	303.937 m^2
$\boldsymbol{CA_{cmd,n}^{AINL-INST}}$	$CA_{cmd,2}^{AINL-INST}$ =	-0.01718 m^2	$CA_{cmd,4}^{AINL-INST}$ =	-1.69013 m^2
	$CA_{cmd,3}^{AINL-INST}$ =	-0.01718 m^2		

Table 4.21 Summaries of calculation results (1) (continue)

	Header Box		Tube	
	$CA_{cmd,4}^{AINL-INST}=$	-0.01718 m^2		
$\boldsymbol{CA_{cmd,n}^{AIL-INST}}$	$CA_{cmd,2}^{AIL-INST}=$	-0.53115 m^2	$CA_{cmd,4}^{AIL-INST}=$	-39.0269 m^2
	$CA_{cmd,3}^{AIL-INST}=$	-0.53115 m^2		
	$CA_{cmd,4}^{AIL-INST}=$	-0.53115 m^2		
$\boldsymbol{CA_{inj,n}^{AINL-CONT}}$	$CA_{inj,1}^{AINL-CONT}=$	122.821 m^2	$CA_{inj,1}^{AINL-CONT}=$	122.821 m^2
$\boldsymbol{CA_{inj,n}^{AIL-CONT}}$	$CA_{inj,1}^{AIL-CONT}=$	742.789 m^2	$CA_{inj,1}^{AIL-CONT}=$	742.788 m^2
$\boldsymbol{CA_{inj,n}^{AINL-INST}}$	$CA_{cmd,2}^{AINL-INST}$	-0.03309 m^2	$CA_{cmd,4}^{AINL-INST}=$	-3.25538 m^2
	$CA_{cmd,3}^{AINL-INST}$	-0.03309 m^2		
	$CA_{cmd,4}^{AINL-INST}$	-0.03309 m^2		
$\boldsymbol{CA_{inj,n}^{AIL-INST}}$	$CA_{inj,2}^{AIL-INST}=$	-1.47728 m^2	$CA_{inj,4}^{AIL-INST}=$	-115.068 m^2
	$CA_{inj,3}^{AIL-INST}=$	-1.47728 m^2		
	$CA_{inj,4}^{AIL-INST}=$	-1.47728 m^2		

Then calculate the instantaneous/continuous AIT Blending Factor ($fact_n^{IC}$) and AIT blending factor ($fact^{AIT}$). After that, calculate continuous/ instantaneous blended consequence areas and calculate AIT blended consequence areas. The summaries of the result of these equations shown in table 4.22.

Table 4.22 Summaries of calculation consequence results (2)

	Header Box		Tube	
$\boldsymbol{fact_n^{IC}}$	$fact_1^{IC}=$	0.302709415	$fact_1^{IC}=$	0.302709415
	$fact_2^{IC}=$	1	$fact_4^{IC}=$	1
	$fact_3^{IC}=$	1		
	$fact_4^{IC}=$	1		
$\boldsymbol{fact^{AIT}}$	$fact^{AIT}=$	0	$fact^{AIT}$	0
$\boldsymbol{CA_{cmd,n}^{AIL}}$	$CA_{cmd,1}^{AIL}=$	92.0045 m^2	$CA_{cmd,1}^{AIL}=$	92.0045 m^2
	$CA_{cmd,2}^{AIL}=$	0 m^2	$CA_{cmd,4}^{AIL}=$	0 m^2
	$CA_{cmd,3}^{AIL}=$	0 m^2		
	$CA_{cmd,4}^{AIL}=$	0 m^2		
$\boldsymbol{CA_{inj,n}^{AIL}}$	$CA_{inj,1}^{AIL}=$	224.8492 m^2	$CA_{inj,1}^{AIL}=$	224.849 m^2
	$CA_{inj,2}^{AIL}=$	0 m^2	$CA_{inj,4}^{AIL}=$	-15.0683 m^2
	$CA_{inj,3}^{AIL}=$	0 m^2		
	$CA_{inj,4}^{AIL}=$	0 m^2		
$\boldsymbol{CA_{cmd,n}^{AINL}}$	$CA_{cmd,1}^{AINL}=$	15.3767 m^2	$CA_{cmd,1}^{AINL}=$	15.3767 m^2
	$CA_{cmd,2}^{AINL}=$	0 m^2	$CA_{cmd,4}^{AINL}=$	0 m^2
	$CA_{cmd,3}^{AINL}=$	0 m^2		
	$CA_{cmd,4}^{AINL}=$	0 m^2		
$\boldsymbol{CA_{inj,n}^{AINL}}$	$CA_{inj,1}^{AINL}=$	37.1791 m^2	$CA_{inj,1}^{AINL}=$	37.1791 m^2
	$CA_{inj,2}^{AINL}=$	0 m^2	$CA_{inj,4}^{AINL}=$	0 m^2
	$CA_{inj,3}^{AINL}=$	0 m^2		
	$CA_{inj,4}^{AINL}=$	0 m^2		

Table 4.22 Summaries of calculation consequence results (2)

	Header Box		Tube	
$\boldsymbol{CA^{flam}_{cmd,n}}$	$CA^{flam}_{cmd,1}$ =	15.3767 m^2	$CA^{flam}_{cmd,1}$ =	15.3767 m^2
	$CA^{flam}_{cmd,2}$ =	0 m^2	$CA^{flam}_{cmd,4}$ =	0 m^2
	$CA^{flam}_{cmd,3}$ =	0 m^2		
	$CA^{flam}_{cmd,4}$ =	0 m^2		
$\boldsymbol{CA^{flam}_{inj,n}}$	$CA^{flam}_{inj,1}$ =	37.2 m^2	$CA^{AINL}_{inj,1}$ =	37.1791 m^2
	$CA^{flam}_{inj,2}$ =	0 m^2	$CA^{AINL}_{inj,4}$ =	0 m^2
	$CA^{flam}_{inj,3}$ =	0 m^2		
	$CA^{flam}_{inj,4}$ =	0 m^2		

For the calculation of final consequence areas for component damage and personal injury as shown in the equation (2.47) and (2.48) then the result is 4 m^2 for component damage and 9.7 m^2 for personnel injury for the header box and 14.1 m^2 for component damage and 34.0 m^2 for personnel injury for the tube.

4.5. Risk determining

According to the equation 2.1 the results of the risk calculation for the header box is 1.064 m^2/year for the RBI date and 4.528 m^2/year for the plan date. For the tube is 1.973 m^2/year for the RBI date and 4.537 m^2/year for the plan date.

4.6. Inspection Planning

For the first step to determine the inspection planning is calculate the target inspection date based on table 4.23 and diagram in the figure 4.2 for the tube. And table 4.24 and diagram in figure 4.3 for the header box.

Table 4.23 determining target inspection date table (tube)

	Date	Age	Risk
RBI Date	07/17/2017	3.75	1.973035017
Risk Target	12/20/2019	10.71903108	3.71612
Plan Date	07/17/2027	14	4.536751674

Table 4.24 determining target inspection date table (Header box)

	Date	Age	Risk
RBI Date	07/17/2017	3.75	1.064058236
Risk Target	07/06/2025	11.59720107	3.71612
Plan Date	07/17/2027	14	4.528176567

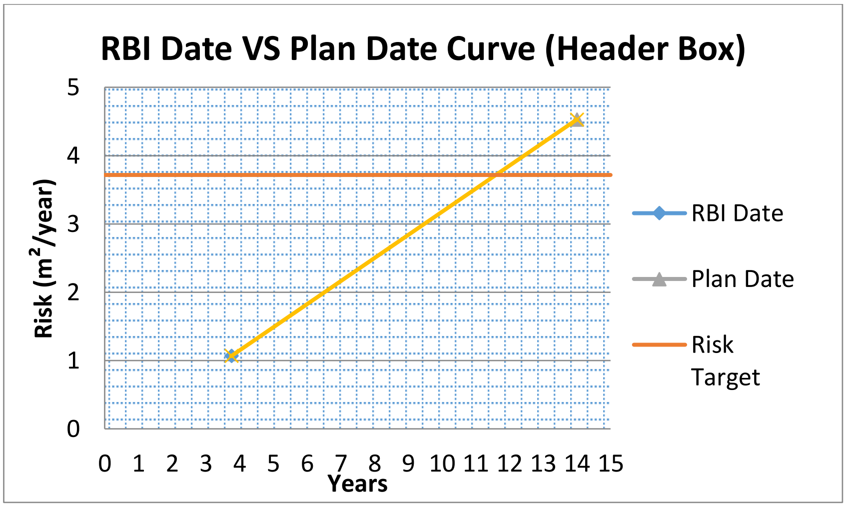

Figure 4.2 Target inspection date diagram (Header Box)

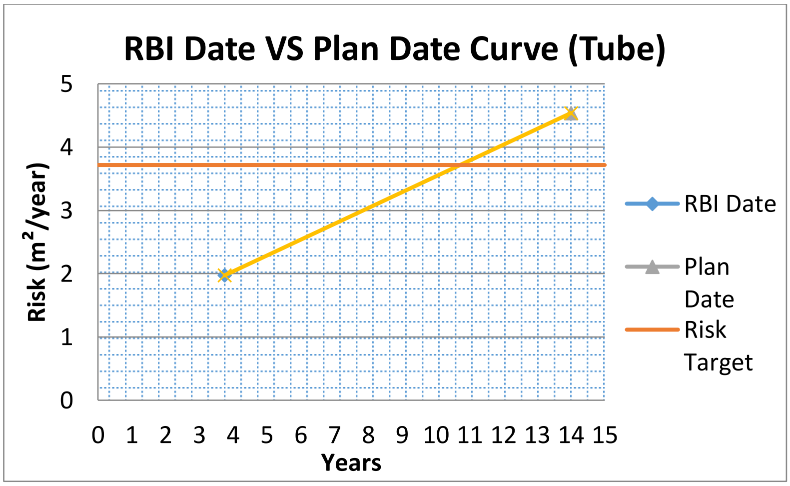

Figure 4.3 Target inspection date diagram (tube)

4.7. Determine New Thinning and CL-SCC New Damage Factor

Before determine the new damage factor the first step is proposed inspection into the better inspection effectiveness. Then for the tube, new inspection effectiveness is 3A for the thinning inspection and 2A for the CL-SCC inspection. Then the new damage factor obtained 191.5 for the thinning and 370.4 for the CL-SCC for the tube. And the total damage factor for the tube is 561.906.

Then for the header box, new inspection effectiveness is 1.25A for the thinning inspection and 1A for the CL-SCC inspection. Then the new damage factor obtained 76.9665 for the thinning and 3705 for the CL-

SCC for the header box. And the total damage factor for the header box is 3782.44.

4.8. Determine the risk at plan date with inspection

The result of the new risk at plan date for the tube is shown at summaries below.

- Fms = 50%
- Gff Total = 0.000036
- POF with inspection = 0.0086 Failure/year
- COF with inspection = 34.02 m^2
- Risk area with inspection = 0.29248 m^2/year

The result of the new risk at plan date for the header box is shown at summaries below.

- Fms = 50%
- Gff Total = 0.000036
- POF with inspection = 0.05787 Failure/year
- COF with inspection = 9.72 m^2
- Risk area with inspection = 0.56251 m^2/year

4.9. Remaining Lifetime Analysis

Using the equation (2.49) then, the result of remaining lifetime analysis is:
$Remaining\ life = \frac{1.85 - 1.65}{0.023}$ = 8. 696 years

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CHAPTER 5
CONCLUSION

5.1. Conclusion

According to the analysis of the research study, then some conclusion could be taken as explain below:

1. There are two damage factors obtained for the tube and header box. They are; thinning damage factor and CL-SCC damage factor and the result of the damage factor for the header box is 7154.95 at RBI date and 30448.4 at plan date. For the tube, the damage factor is 2720.62 at RBI date and 4158.99 at the plan date.
2. The risk area value for the tubes in the new inspection plan is 0.29248 m^2/year and for the header box the new inspection plan is 0.56251 m^2/year.
3. The inspection planning for the tubes could be generated on July 6, 2024 and inspection planning for the header box could be generated on July 6, 2025.
4. Remaining life for the asset is 8.696 years.

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ATTACHMENT 1: DAMAGE FACTOR CALCULATION SUMMARIES (HEADER BOX)

1) Determine the number of inspections, and the corresponding inspection effectiveness category. Combine the inspections to the highest effectiveness.
   - Number past inspection performed: 1
   - Inspection category: C
   - Inspection effectiveness category: Highly Effectives
2) Determine the time in-service (age), since the last inspection thickness reading, (trd).
   = Age: 4 Year (RBI Date)
   = Age: 14 Year (RBI Plan Date)
   = Trd: 26 mm
3) Determine the corrosion rate for the base metal (Crbm) based on the material of construction and process environment, see Annex 2.B. Where the component has cladding, a corrosion rate (Crbm) must also be obtained for the cladding.
   = $C_{r,bm}$ = 0.023 mm/year
4) Determine the minimum required wall thickness (tmin) per the original construction code. If the component is a tank bottom, then tmin = 0.1 in if the tank does not have a release prevention barrier and tmin = 0.05 in if the tank has a release prevention barrier.
   = t_{min} = 0.1 inch = 2.54 mm
5) For clad components, calculate the time or age from the last inspection required to corrode away the clad material (agerc).
   = age_{rc} = max $[(\frac{t_{rd} - t}{C_{r,cm}}), 0.0]$ = N/A
6) Determine the Art parameter, based on the age and from STEP 2, from STEP 3, from STEP 4 and the age required to corrode away the cladding (agerc) if applicable from STEP 5.
   - For components without cladding, and for components where the cladding is corroded away at the time of the last inspection (i.e. agerc= 0.0), use Equation (2.12).

$$A_{rt} = \max[1 - \frac{t_{rd} - C_{r,cm} \cdot age}{t_{min} + CA}, 0.0]$$

CA: 0.06 inch = 1.59 mm

   = 0 (RBI Date)
   = 0 (Plan Date)
7) Determine the damage factor for thinning (Dfthin) using Equation (2.13).

$$D_f^{thin} = \frac{D_{fb}^{thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}$$

	RBI Date	Plan Date
D_{fb}^{thin}	1	1
FIP	1	1
FDL	1	1
FWD	1	1
FAM	5	5
FSM	1.50	1.50
FOM	1	1

D_{fb}^{thin} = 7.5 (RBI Date)
= 7.5 (Plan Date)

8) Determine the number of inspections, and the corresponding inspection effectiveness category. Combine the inspections to the highest effectiveness performed.
   - Number past inspection performed: 1
   - Inspection category: C
   - Inspection effectiveness category: Highly Effectives

9) Determine the time in-service (age), since the last inspection thickness reading, (trd).
   = Age: 3.75 Year (RBI Date)
   = Age: 14 Year (Plan Date)
   = Trd: 26 mm

10) Determine the susceptibility for cracking based on the operating temperature and concentration of the chloride ions. Note that a HIGH susceptibility should be used if cracking is
   = High

11) Based on the susceptibility in STEP 3, determine the severity index (SVI).
   = S_{VI} = 5000

12) Determine the base damage factor for CLSCC, and the highest inspection effectiveness determined in STEP 1, and the severity index (SVI) from STEP 4.
   = D_{fB}^{CLSCC} = 1670

13) Calculate the escalation in the damage factor based on the time in-service since the last inspection. In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other
   - $D_{f}^{CLSCC} = D_{fB}^{CLSCC}\,(\mathrm{age})1.1$
   = 7147.45 (RBI Date)
   = 30440.9 (Plan Date)

14) Total Damage Factor:
   - $\mathrm{D}_{\mathrm{f-total}} = D_{f}^{thin} + D_{f}^{CLSCC}$
   = 7154.95 (RBI Date)
   = 30448.4 (Plan Date)

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ATTACHMENT 2: CONSEQUENCE CALCULATION SUMMARIES (HEADER BOX)

1.1) Representative fluids
= C1 - C2

1.2) Stored Fluid Phase
= Vapor

1.3) Fluid Properties
- MW : molecular weigh
  = 23 kgb/kg.mol
- Cp : constant pressure specific heat
  = 58.1 J/kmol.K
- R : universal gas constant
  = 8.31 J/(kg.mol)K
- k : ideal gas specific heat capacity ratio

$$k = \frac{C_p}{C_p - R}$$

  = 1.167
- Auto-Ignition Temperature, AIT
  = 558 °C

1.4) - Steady State Phase
  = Gas
- Phase of the fluid stored in equipment
  = Gas

2.1) Release Hole Size Diameters, dn
- Small : 0 - 6.4 mm, (d_1)
  = 6.4 mm
- Medium : > 6.4 - 51 mm (d_2)
  = 25 mm
- large : > 51 - 152 mm (d_3)
  = 102 mm
- Rupture : > 152 mm (d_4)
  = Min [D, 406] mm 155 mm

2.2) Determine The Generic Failure Frequency, gffn
- Small (gff_1)
  = 8.00E-06 failures/yr
- Medium (gff_2)
  = 2.00E-05 failures/yr
- Large (gff_3)
  = 2.00E-06 failures/yr
- Rupture (gff_4)
  = 6.00E-07 failures/yr

= gff tot = 3.06E-05 failures/yr

3.1) Select The Appropiate Release Rate Equation as Described Above Using The Stored Fluid Phase
= Vapor

3.2) Compute The Release Hole Size Area (An)
π : 3.14286

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

= A_1 = 32.1829 mm^2

= A_2 = 491.071 mm^2

= A_3 = 8174.57 mm^2

= A_4 = 18876.8 mm^2

3.3) Calculate The Viscosity Correction Factor, Kv,n (Not Available)

3.4) Calculate The Release Rate, Wn

- Ptrans : transition back pressure (kPa)

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

Patm : athmospheric pressure 101.325 kPa)

Ps : storage or normal operating pressure 6205.28 kPa)

= 177.453 kPa

- Ps > Ptrans, then Wn formula is:

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

Wn : heoritical release rate associated with the nth release hole size (kg/s)

Cd : release hole coefficient of discharge (1)

C2 : customary conversion factors (1000)

gc : gravitational constant (0.9 kg.mol/N.s^2)

Ts : storage/ normal operating temperatur 450.150 kelvin)

= W_1 = 9.53534658 kg/s

= W_2 = 145.497842 kg/s

= W_3 = 2422.01528 kg/s

= W_4 = 5592.93705 kg/s

4.1) Group Components and Equipment Items Into Inventory Groups:

= Fin fan cooler & Fin fan

4.2) Calculate The Fluid Mass, masscomp

masscomp = ρ x 25% x V

V = 0.05556 m^3

ρ = 7E-01 kg/m^3

= 0.00911218 kgs

4.3) Calculate The Fluid Mass in Each of The Other Components That Are Included in The Inventory Group (masscomp,i)

= The other tube of fin fan cooler is identic so the masscomp,i is same with masscomp

4.4) Calculate The Fluid Mass in The Inventory Group (massinv)

- total header box = 2

$$mass_{inv} = \sum_{i=1}^{N} mass_{comp,i}$$

= 0.01822436 kgs

4.5) Calculate The Flow Rate from a 203 mm diameter hole (Wmax8)

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

- with An = A8 = 32450 mm^2

= 9614.49741 kgs

4.6) Calculate The Added Fluid Mass, massadd,n

$$mass_{add,n} = 180 \text{ x min } [W_n, W_{max}]$$

- $massadd_1$= 180 x min(9.54 9614.50)

= 1716.36239 kgs

- $massadd_2$=181 x min(145.50 9614.50)

= 26189.6116 kgs

- $massadd_3$=182 x min(2422.02 9614.50)

= 435962.75 kgs

- $massadd_4$= 183 x min(5592.94 9614.50)

= 1006728.67 kgs

4.7) Calculate The Available Mass For Release

$$mass_{avail,n} = \text{min } \left[\left(mass_{comp} + mass_{add,n}\right), mass_{inv}\right]$$

- $massavail,_1$ = min[(1716.3715), 0.01822]

= 0.01822436 kgs

- $massavail,_2$= min[(26189.6116), 0.01822]

= 0.01822436 kgs

- $massavail,_3$= min[(435962.75), 0.01822]

= 0.01822436 kgs

- $massavail,_4$= min[(1006728.67), 0.01822]

= 0.01822436 kgs

5.1) Calculate The Time Required to Release 4,356 kgs (10,000 lbs) of Fluid

$$t_n = \frac{C_3}{W_n}$$

- C_3 : customary conversion factors = 4536

= t_1 = 475.703737 second

= t_2 = 31.1757201 second

= t_3 = 1.87282055 second

= t_4 = 0.8110229 second

5.2) For Each Release Hole Size, Determine if The Release Type is Instantaneous or Continous Using The Following Criteria

- If The Release Hole size is 6.35 mm (0.25 inches) or less, then the release type is Continuous
- If tn <= 180 sec or the release mass is greater than 4,536 kgs (10,000 lbs), then the release is instantaneous; otherwise, the release is continuous

d_1 =	6.4	mm	massavail, 1 =	0.01822436	kgs	t_1 =	475.703737	second	Continuous
d_2 =	25	mm	massavail, 2 =	0.01822436	kgs	t_2 =	31.1757201	second	Instantaneou
d_3 =	102	mm	massavail, 3 =	0.01822436	kgs	t_3 =	1.87282055	second	Instantaneou
d_4 =	155	mm	massavail, 4 =	0.01822436	kgs	t_4 =	0.8110229	second	Instantaneou

6.1) Determine The Detection and Isolartion Systems Present in The Unit

- Detection and isolation system can be detect and control the pressure and the gas flow automatically by the operator

6.2) Select The Appropiate Classification For The Detection System

= A

6.3) Select The Appropiate Classification For The Isolation System

= B

6.4) Determine The Release Reduction Factor, factdi

= 0.2

6.5) Determine The Total Leak Duration For Each of The Selected Release Hole Sizes, ldmax,n

= ldmax,$_1$ = 30 minutes for 6.4 mm leaks
= ldmax,$_2$ = 20 minutes for 25 mm leaks
= ldmax,$_3$ = 10 minutes for 102 mm leaks
= ldmax,$_4$ = 0.01667 miinutes for 155mm leaks

7.1) Calculate The Adjusted Release Rate, raten

- rate,n = $W_n(1 - fact_{di})$

= rate,$_1$ = 7.62827727 kg/s
= rate,$_2$ = 116.398274 kg/s
= rate,$_3$ = 1937.61222 kg/s
= rate,$_4$ = 4474.34964 kg/s

7.2) Calculate The Leak Duration, ldn

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\},\{60xId_{max,n}\}\right]$$

= min [{ 0.00239 },{ 1800 }] = 0.00239 seconds
= min [{ 0.00016 },{ 1200 }] = 0.00016 seconds
= min [{ 9.4E-06 },{ 600 }] = 9.4E-06 seconds
= min [{ 4.1E-06 },{ 1 }] = 4.1E-06 seconds

7.3) Calculate The Release Mass, massn

$$mass_n = \text{min}\ [\{rate_n\ x\ Id_n\}\ , mass_{avail,n}]$$

= min [{ 0.01822 },{ 0.01822 }] = 0.01822 kgs
= min [{ 0.01822 },{ 0.01822 }] = 0.01822 kgs
= min [{ 0.01822 },{ 0.01822 }] = 0.01822 kgs
= min [{ 0.01822 },{ 0.01822 }] = 0.01822 kgs

8.1) Select The Consequence Area Mitigation Reduction Factor, factmit

= 0.2

8.2) Calculate The Energy Efficiency Correction Factor, eneff,n (not applied to continous release)

$$eneff_n = 4\ x\ log_{10}[C_4\ x\ mass_n] - 15$$

= eneff,$_1$ = N/A
= eneff,$_2$ = -20.5838
= eneff,$_3$ = -20.5838
= eneff,$_4$ = -20.5838

8.3) Determine The Fluid Type

= Type 0

8.4) Compute The Component Damage Consequence Areas For Autoignition Not Likely, Continuous Release (AINL-CONT)

- Determine The Appropiate Constants a and b
  - = $a_{cmd}^{AINL-CONT}$ = 8.67
  - = $b_{cmd}^{AINL-CONT}$ = 0.98
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,1}^{AINL-CONT}$ = 50.7969 m²

$effrate_n^{AINL-CONT} = rate_n$

= $effrate_1^{AINL-CONT}$ = 7.62828 kg/s

8.5) Compute The Component Damage Consequence Areas For Autoignition Likely, Continuous Release (AIL-CONT)

- Determine The Appropiate Constants a and b
  - = $a_{cmd}^{AIL-CONT}$ = 55.1
  - = $b_{cmd}^{AIL-CONT}$ = 0.95
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,1}^{AIL-CONT}$ = 303.937 m²

$effrate_n^{AIL-CONT} = rate_n$

= $effrate_1^{AIL-CONT}$ = 7.62828 kg/s

8.6) Compute The Component Damage Consequence Areas For Autoignition Not Likely, Instantaneous Release (AINL-INST)

- Determine The Appropiate Constants a and b
  - = $a_{cmd}^{AINL-INST}$ = 6.47
  - = $b_{cmd}^{AINL-INST}$ = 0.67
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,2}^{AINL-INST}$ = -0.01718 m²

= $CA_{cmd,3}^{AINL-INST}$ = -0.01718 m²

= $CA_{cmd,4}^{AINL-INST}$ = -0.01718 m²

$effrate_n^{AINL-INST} = mass_n$

= $effrate_2^{AINL-INST}$ = 0.01822 kg/s

= $effrate_3^{AINL-INST}$ = 0.01822 kg/s

= $effrate_4^{AINL-INST}$ = 0.01822 kg/s

8.7) Compute The Component Damage Consequence Areas For Autoignition Likely, Instantaneou Release (AIL-INST)

- Determine The Appropiate Constants a and b
  - = $a_{cmd}^{AIL-INST}$ = 164
  - = $b_{cmd}^{AIL-INST}$ = 0.62
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd.2}^{AIL-INST}$ = -0.53115 m²

= $CA_{cmd,3}^{AIL-INST}$= -0.53115 m^2

= $CA_{cmd,4}^{AIL-INST}$= -0.53115 m^2

$effrate_{n}^{AIL-INST}$= $mass_n$

= $effrate_{3}^{AIL-INST}$= 0.01822 kg/s

= $effrate_{3}^{AIL-INST}$= 0.01822 kg/s

= $effrate_{4}^{AIL-INST}$= 0.01822 kg/s

8.8) Compute The Personnel Injury Consequence Areas For Autoignition Not Likely, Continuous Release (AINL-CONT)

- Determine The Appropiate Constants a and b

  = $a_{inj}^{AINL-CONT}$ = 21.8

  = $b_{inj}^{AINL-CONT}$ = 0.96

- Then the Consequence area:

  $CA_{inj,n}^{AINL-CONT}$= $a(effrate_{n}^{AINL-CONT})^{b}$ x $(1 - fact_{mit})$

  = $CA_{inj,1}^{AINL-CONT}$= 122.821 m^2

8.9) Compute The Personnel Injury Consequence Areas For Autoignition Likely, Continuous Release (AIL-CONT)

- Determine The Appropiate Constants a and b

  = $a_{inj}^{AIL-CONT}$ = 143

  = $b_{inj}^{AIL-CONT}$ = 0.92

- Then the Consequence area:

  $CA_{inj,n}^{AIL-CONT}$= $a(effrate_{n}^{AIL-CONT})^{b}$ x $(1 - fact_{mit})$

  = $CA_{inj,1}^{AIL-CONT}$= 742.789 m^2

8.10) Compute The Personnel Injury Consequence Areas For Autoignition Not Likely, Instantaneous Release (AINL-INST)

- Determine The Appropiate Constants a and b

  = $a_{inj}^{AINL-INST}$ = 12.5

  = $b_{inj}^{AINL-INST}$ = 0.67

- Then the Consequence area:

  $CA_{inj,n}^{AINL-INST}$= $a(effrate_{n}^{AINL-CONT})^{b}$ x $\left(\frac{1-fact_{mit}}{eneff_n}\right)$

  = $CA_{cmd,3}^{AINL-INST}$= -0.03309 m^2

  = $CA_{cmd,3}^{AINL-INST}$= -0.03309 m^2

  = $CA_{cmd,4}^{AINL-INST}$= -0.03309 m^2

8.11) Compute The Personnel Injury Consequence Areas For Autoignition Likely, Instantaneous Release (AIL-INST)

- Determine The Appropiate Constants a and b

  = $a_{inj}^{AIL-INST}$ = 474

  = $b_{inj}^{AIL-INST}$ = 0.63

- Then the Consequence area:

  $CA_{inj,n}^{AIL-INST}$= $a(effrate_{n}^{AIL-CONT})^{b}$ x $\left(\frac{1-fact_{mit}}{eneff_n}\right)$

  = $CA_{inj,3}^{AIL-INST}$=-1.47728 m^2

  = $CA_{inj,3}^{AIL-INST}$= -1.47728 m^2

  = $CA_{inj,4}^{AIL-INST}$= -1.47728 m^2

8.12) Calculate The Instantaneous/Continuous Blending Factor, factICn

- For Continuous Releases – To smooth out the results for releases that are near the continuous to instantaneous transition point (4,536 kgs [10,000 lbs] in 3 minutes, or a release rate of 25.2 kg/s [55.6 lb/s]), then the blending factor:

  $fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$ C_5 = 25.2

  = factIC$_1$ = 0.3

  = factIC$_2$ = 1
- For Instantaneous Releases – Blending is not required. Since the definition of an instantaneous release is one with a adjusted release rate, n rate , greater than 25.2 kg/s [55.6 lb/s] (4536 kg [10,000 lbs] in 3 minutes), then the blending factor:

  $fact_n^{IC} = 1.0$

  = factIC$_3$ = 1

  = factIC$_4$ = 1

8.13) Calculate The AIT Blending Factor, factAIT

- Ts : 450.150 kelvin
- C_6 : 56
- AIT: 831.150 kelvin
- Because Ts + C_6 < AIT then the equation:

  = $fact^{AIT} = 0$

8.14) Compute The Continuous/Instantaneous Blended Consequence Areas For The Component

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

  =$CA_{cmd,1}^{AIL} =$ 92.0045 m^2

  =$CA_{cmd,2}^{AIL} =$ 0 m^2

  =$CA_{cmd,3}^{AIL} =$ 0 m^2

  =$CA_{cmd,4}^{AIL} =$ 0 m^2
- $CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-CONT}\ x\ fact_n^{IC} + CA_{cmd,n}^{AIL-INST}\ x\ (1 - fact_n^{IC})$

  = $CA_{inj,1}^{AIL} =$ 224.849 m^2

  = $CA_{inj,2}^{AIL} =$ 0 m^2

  = $CA_{inj,3}^{AIL} =$ 0 m^2

  = $CA_{inj,4}^{AIL} =$ 0 m^2
- $CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-CONT}\ x\ fact_n^{IC} + CA_{cmd,n}^{AINL-INST}\ x\ (1 - fact_n^{IC})$

  = $CA_{cmd,1}^{AINL} =$ 15.3767 m^2

  = $CA_{cmd,2}^{AINL} =$ 0 m^2

  = $CA_{cmd,3}^{AINL} =$ 0 m^2

  = $CA_{cmd,4}^{AINL} =$ 0 m^2
- $CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-CONT}\ x\ fact_n^{IC} + CA_{cmd,n}^{AINL-INST}\ x\ (1 - fact_n^{IC})$

  = $CA_{inj,1}^{AINL} =$ 37.1791 m^2

  = $CA_{inj,2}^{AINL} =$ 0 m^2

  = $CA_{inj,3}^{AINL} =$ 0 m^2

  = $CA_{inj,4}^{AINL} =$ 0 m^2

8.15) Compute The AIT Blended Consequence Areas For The Component

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

= $CA_{cmd,1}^{flam} =$ 15.3767 m²

= $CA_{cmd,2}^{flam} =$ 0 m²

= $CA_{cmd,3}^{flam} =$ 0 m²

= $CA_{cmd,4}^{flam} =$ 0 m²

- $CA_{inj,n}^{flam} = CA_{inj,n}^{AIL}\ x\ fact^{AIT} + CA_{inj,n}^{AINL}\ x\ (1 - fact^{AIT})$

= $CA_{inj,1}^{flam} =$ 37.2 m²

= $CA_{inj,2}^{flam} =$ 0 m²

= $CA_{inj,3}^{flam} =$ 0 m²

= $CA_{inj,4}^{flam} =$ 0 m²

8.16) Determine The Final Consequence Areas For Component Damage and Personnel Injury

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

= CA_{cmd}^{flam} = 4.0 m²

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

= CA_{inj}^{flam} = 9.7 m²

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ATTACHMENT 3: FINAL RISK ANALYSIS CALCULATION SUMMARIES (HEADER BOX)

1) Damage factor total at RBI date

= D_f = 7154.94572

2) Damage factor total at plan date

= D_f = 30448.3875

3) Total generic failure frequency for finfan cooler

= g_{ff} = 0.0000306

4) Total Factor Management System

= F_{MS} = 50%

5) Probability of Failure at RBI date

= PoF = 0.109471

6) Probability of Failure at plan date

= PoF = 0.465860

7) Total consequence area for equipment damage

= CA_{cmd} = 4.02004968

8) Total consequence area for personel injury

= Cainj = 9.72003041

9) Final consequence area

= CA = 9.72003041

10) Risk at RBI date

= Risk = 1.06405824

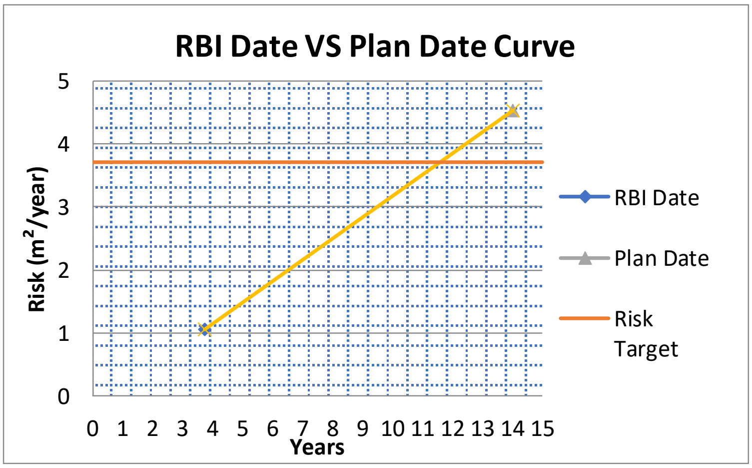
11) Risk at Plan date

= Risk = 4.52817657

12) Risk Target

= Risk = 3.71612

	Date	Age	Risk
RBI Date	07/17/2017	3.75	1.06406
Risk Target	07/06/2025	11.6	3.71612
Plan Date	07/17/2027	14	4.52818



13) Determine damage factor at risk target

	Age	Risk	DF
RBI Date	3.75	1.06406	7154.95
Risk Target	11.5972	3.71612	24988
Plan Date	14	4.52818	30448.4

14) Determine new damage factor

	RBI date	Target date	Plan Date
Df thin	2720.62	?	4158.99
Df cl-scc	1069.98	?	4557.02
Df total	3790.6	24988 /lower	8716.01

- Proposed Inspection:
  > Thinning Inspection (It should be 2A thinning inspection since we need to lower DF as many as possible)
  > CLSCC Inspection (It should be 2A thinning inspection since we need to lower DF as many as possible)

15) Calculate *new thinning damage factor:*

- Previous thinning inspection at:
  = 10/17/2013 = 1C
- Propose thinning inspection at target date
  = 07/06/2025 = 1A
- Thinning inspection effectiveness after proposed thinning inspection executed at plan date:
  = 1C + 1A = 1.25A
- Art value at plan date:
  = 0.44393
- Then new thinning damage factor:

Art	1A	1.25A	2A
0.4	130	55	30
0.44393	191.506	76.9665	38.7866
0.45	200	80	40

= D_f^{thin} = 76.9665

16) Calculate *new CL-SCC damage factor* :

- Proposed CLSCC inspection at target date
  = 07/06/2025 = 1A
- Age at the plan end date:
  = Age plan = Plan date - Last inspection date
  = 07/06/2025 - 10/17/2013
  = 11.6 years

17) Determine the severity index (SVI).

= S_{VI} = 5000

18) Determine the base damage factor for CLSCC based on the new inspection effectiveness and the severity index (SVI) from the last step.

= D_{fB}^{CLSCC} = 250

19) Calculate the escalation in the damage factor based on the time in-service since the last inspection. In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

- $D_f^{CLSCC} = D_{fB}^{CLSCC}$ (age)1.1
  = 3705

Total Damage Factor:

- $\mathrm{D}_{\mathrm{f-total}} = D_f^{thin} + D_f^{CLSCC}$
  = 3782.44

20) Calculate risk at plan date with inspection

- Fms = 50%
- gff total = 0.0000306
- POF with Inspection = 0.05787 Failure/year
- COF with inspection = 9.72 m^2
- Risk area with inspection = 0.56251 m^2/year

ATTACHMENT 4: DAMAGE FACTOR CALCULATION SUMMARIES (TUBE)

1) Determine the number of inspections, and the corresponding inspection effectiveness category. Combine the inspections to the highest effectiveness.
 - Number past inspection performed: 1
 - Inspection category: A
 - Inspection effectiveness category: Highly Effectives

2) Determine the time in-service (age), since the last inspection thickness reading, (trd).
 = Age: 3.75 Year (RBI Date)
 = Age: 13.75 Year (Plan Date)
 = Trd: 1.65 mm

3) Determine the corrosion rate for the base metal (Crbm) based on the material of construction and process environment. Where the component has cladding, a corrosion rate (Crbm) must also be obtained for the cladding.
 = $C_{r,bm}$ = 0.023 mm/year

4) Determine the minimum required wall thickness (tmin) per the original construction code or using API 579 with the following formula. If the component is a tank bottom, tmin = 0.1 in if the tank does not have a release prevention barrier and tmin = 0.05 in if the tank has a release
 = t_{min}^{C} = 1.13 mm

$$t_{min}^{C} = \frac{P\ x\ R_c}{S\ x\ E\ - 0.6P}$$

 = P = Design Pressure = 6502.28 kPa
 = Rc = inside Radius in corroded conditi = 14 mm
 = S = Allowable design stress = 99284.5 kPa
 = E = Weld point efficienc = 0.85

$$R_c = \frac{D + 2\ x\ CA}{2}$$

 = D = Tube diameter = 1 in = 25.4 mm
 = CA = Corrosion Allowance = 1.27 mm
 = Rc = inside Radius in corroded conditi = 14 mm

5) For clad components, calculate the time or age from the last inspection required to corrode away the clad material (agerc).
 = age_{rc} = max $[(\frac{t_{rd} - t}{C_{r,cm}}), 0.0]$ = N/A

6) Determine the Art parameter, based on the age and from STEP 2, from STEP 3, from STEP 4 and the age required to corrode away the cladding (agerc) if applicable from STEP 5.
 - For components without cladding, and for components where the cladding is corroded away at the time of the last inspection (i.e. agerc= 0.0), use Equation (2.13).

$$A_{rt} = \max[1 - \frac{t_{rd} - C_{r,cm} \cdot age}{t_{min} + CA}, 0.0]$$

CA: 1.27 mm

 = 0.34804 (RBI Date)
 = 0.44393 (Plan Date)

7) Determine the damage factor for thinning, Dfthin, using Equation (2.15).

$$D_{f}^{thin} = \frac{D_{fb}^{thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}$$

	RBI Date	Plan Date
D_{fb}^{thin}	544.124	831.799
FIP	1	1
FDL	1	1
FWD	1	1
FAM	5	5
FSM	1	1
FOM	1	1

D_{f}^{thin} = 2720.62 (RBI Date)
= 4158.99 (Plan Date)

8) Determine the number of inspections, and the corresponding inspection effectiveness category. Combine the inspections to the highest effectiveness performed.
   - Number past inspection performed: 1
   - Inspection category: A
   - Inspection effectiveness category: Highly Effectives
9) Determine the time in-service (age), since the last inspection thickness reading, (trd).
   = Age: 3.75 Year (RBI Date)
   = Age: 14 Year (Plan Date)
   = Trd: 1.65 mm
10) Determine the susceptibility for cracking based on the operating temperature and concentration of the chloride ions. Note that a HIGH susceptibility should be used if cracking is
   = High
11) Based on the susceptibility in STEP 3, determine the severity index (SVI).
   = S_{VI} = 5000
12) Determine the base damage factor for CLSCC, and the highest inspection effectiveness determined in STEP 1, and the severity index (SVI) from STEP 4.
   = D_{fB}^{CLSCC} = 250
13) Calculate the escalation in the damage factor based on the time in-service since the last inspection. In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other
   - $D_{f}^{CLSCC} = D_{fB}^{CLSCC}\,(\mathrm{age})1.1$
   = 1070 (RBI Date)
   = 4557 (Plan Date)
14) Total Damage Factor:
   - $\mathrm{D}_{\mathrm{f-total}} = D_{f}^{thin} + D_{f}^{CLSCC}$
   = 3790.6 (RBI Date)
   = 8716.01 (Plan Date)

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ATTACHMENT 5: CONSEQUENCE CALCULATION SUMMARIES (TUBE)

1.1) Representative fluids

= C1 - C2

1.2) Stored Fluid Phase

= Vapor

1.3) Fluid Properties

- MW : molecular weigh

  = 23 kgb/kg.mol

- Cp : constant pressure specific heat

  = 58.1 J/kmol.K

- R : universal gas constant

  = 8.31 J/(kg.mol)K

- k : ideal gas specific heat capacity ratio

$$k = \frac{C_p}{C_p - R}$$

  = 1.167

- Auto-Ignition Temperature, AIT

  = 558 °C

1.4) - Steady State Phase

  = Gas

- Phase of the fluid stored in equipment

  = Gas

2.1) Release Hole Size Diameters, dn

- Small : 0 - 6.4 mm, (d_1)

  = 6.4 mm

- Rupture : > 152 mm (d_4)

  = Min [D, 406] mm 155 mm

2.2) Determine The Generic Failure Frequency, gffn

- Small (gff_1)

  = 2.80E-05 failures/yr

- Rupture (gff_4)

  = 2.60E-06 failures/yr

= gff tot = 3.06E-05 failures/yr

3.1) Select The Appropiate Release Rate Equation as Described Above Using The Stored Fluid Phase

= Vapor

3.2) Compute The Release Hole Size Area (An)

π : 3.14286

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

= A_1 = 32.1829 mm^2

= A_4 = 18876.8 mm^2

3.3) Calculate The Viscosity Correction Factor, Kv,n (Not Available)

3.4) Calculate The Release Rate, Wn

- Ptrans : transition back pressure (kPa)

  Patm : athmospheric pressure 101.325 kPa)

Ps : storage or normal operating pressure 6205.28 kPa)

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

= 177.453 kPa

- Ps > Ptrans, then Wn formula is:

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

Wn : heoritical release rate associated with the nth release hole size (kg/s)

Cd : release hole coefficient of discharge (1)

C2 : customary conversion factors (1000)

gc : gravitational constant (0.9 kg.mol/N.s^2)

Ts : storage/ normal operating temperatur 450.150 kelvin)

= W_1 = 9.53534658 kg/s

= W_4 = 5592.93705 kg/s

4.1) Group Components and Equipment Items Into Inventory Groups:

= Fin fan cooler & Fin fan

4.2) Calculate The Fluid Mass, masscomp

masscomp = ρ x 25% x V

V = 0.331 m^3

ρ = 7E-01 kg/m^3

= 0.054284 kgs

4.3) Calculate The Fluid Mass in Each of The Other Components That Are Included in The Inventory Group (masscomp,i)

= The other tube of fin fan cooler is identic so the masscomp,i is same with masscomp

4.4) Calculate The Fluid Mass in The Inventory Group (massinv)

- total tubes = 115

$$mass_{inv} = \sum_{i=1}^{N} mass_{comp,i}$$

= 6.24266 kgs

4.5) Calculate The Flow Rate from a 203 mm diameter hole (Wmax8)

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

- with An = A8 = 32450 mm^2

= 9614.49741 kgs

4.6) Calculate The Added Fluid Mass, massadd,n

$$mass_{add,n} = 180 \text{ x } \min\left[W_n, W_{max}\right]$$

- massadd$_1$= 180 x min(9.5353 9614.50)

= 1716.36239 kgs

- massadd$_4$= 183 x min(5592.94 9614.50)

= 1006728.67 kgs

4.7) Calculate The Available Mass For Release

$$mass_{avail,n} = \min\left[\left(mass_{comp} + mass_{add,n}\right), mass_{inv}\right]$$

- massavail$_{,1}$ = min[(1716.41667), 6.24266]
  = 6.24266 kgs
- massavail$_{,4}$= min[(1006728.67), 6.24266]
  = 6.24266 kgs

5.1) Calculate The Time Required to Release 4,356 kgs (10,000 lbs) of Fluid

$$t_n = \frac{C_3}{W_n}$$

- C_3 : customary conversion factors = 4536
  = t_1 = 475.703737 second
  = t_4 = 0.8110229 second

5.2) For Each Release Hole Size, Determine if The Release Type is Instantaneous or Continous Using The Following Criteria

- If The Release Hole size is 6.35 mm (0.25 inches) or less, then the release type is Continuous
- If tn <= 180 sec or the release mass is greater than 4,536 kgs (10,000 lbs), then the release is instantaneous; otherwise, the release is continuous

d_1 =	6.4 mm	massavail, 1 =	6.24266 kgs	t_1 =	475.703737 second	Continuous
d_4 =	155 mm	massavail, 4 =	6.24266 kgs	t_4 =	0.8110229 second	Instantaneous

6.1) Determine The Detection and Isolartion Systems Present in The Unit

- Detection and isolation system can be detect and control the pressure and the gas flow automatically by the operator

6.2) Select The Appropiate Classification For The Detection System
= A

6.3) Select The Appropiate Classification For The Isolation System
= B

6.4) Determine The Release Reduction Factor, factdi
= 0.2

6.5) Determine The Total Leak Duration For Each of The Selected Release Hole Sizes, ldmax,n
= ldmax$_{,1}$ = 30 minutes for 6.4 mm leaks
= ldmax$_{,2}$ = 20 minutes for 25 mm leaks
= ldmax$_{,3}$ = 10 minutes for 102 mm leaks
= ldmax$_{,4}$ = 0.01667 miinutes for 155mm leaks

7.1) Calculate The Adjusted Release Rate, raten

- rate,n =$W_n(1 - fact_{di})$
  = rate$_{,1}$ = 7.62827727 kg/s
  = rate$_{,4}$ = 4474.34964 kg/s

7.2) Calculate The Leak Duration, ldn

$$ld_n = min\left[\left\{\frac{mass_{avail,n}}{rate_n}\right\},\{60xId_{max,n}\}\right]$$

= min [{ 0.81836 },{ 1800 }] = 0.81836 seconds
= min [{ 0.0014 },{ 1 }] = 0.0014 seconds

7.3) Calculate The Release Mass, massn

$mass_n = \min\left[\{rate_n\ x\ Id_n\}\ , mass_{avail,n}\right]$

= min [{ 6.24266 },{ 6.24266 }] = 6.24266 kgs

= min [{ 6.24266 },{ 6.24266 }] = 6.24266 kgs

8.1) Select The Consequence Area Mitigation Reduction Factor, factmit

= 0.2

8.2) Calculate The Energy Efficiency Correction Factor, eneff,n (not applied to continous release)

$eneff_n = 4\ x\ log_{10}[C_4\ x\ mass_n]$ - 15

= eneff,$_4$ = -10.4449

8.3) Determine The Fluid Type

= Type 0

8.4) Compute The Component Damage Consequence Areas For Autoignition Not Likely, Continuous Release (AINL-CONT)

- Determine The Appropiate Constants a and b
  = $a_{cmd}^{AINL-CONT}$ = 8.67
  = $b_{cmd}^{AINL-CONT}$ = 0.98
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,1}^{AINL-CONT}$ = 50.7969 m^2

$effrate_n^{AINL-CONT} = rate_n$

= $effrate_1^{AINL-CONT}$ = 7.62828 kg/s

8.5) Compute The Component Damage Consequence Areas For Autoignition Likely, Continuous Release (AIL-CONT)

- Determine The Appropiate Constants a and b
  = $a_{cmd}^{AIL-CONT}$ = 55.1
  = $b_{cmd}^{AIL-CONT}$ = 0.95
- Because the release is a gas or vapor then use equation:

$CA_{cmd,n}^{AIL-CONT} = a(rate_n)^b$ x $(1 - fact_{mit})$

= $CA_{cmd,1}^{AIL-CONT}$ = 303.937 m^2

$effrate_n^{AIL-CONT} = rate_n$

= $effrate_1^{AIL-CONT}$ = 7.62828 kg/s

8.6) Compute The Component Damage Consequence Areas For Autoignition Not Likely, Instantaneous Release (AINL-INST)

- Determine The Appropiate Constants a and b
  = $a_{cmd}^{AINL-INST}$ = 6.47
  = $b_{cmd}^{AINL-INST}$ = 0.67
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,4}^{AINL-INST}$ = -1.69013 m^2

$effrate_n^{AINL-INST} = mass_n$

= $effrate_4^{AINL-INST}$ = 6.24266 kg/s

8.7) Compute The Component Damage Consequence Areas For Autoignition Likely, Instantaneous Release (AIL-INST)

- Determine The Appropiate Constants a and b
  - = $a_{cmd}^{AIL-INST}$ = 164
  - = $b_{cmd}^{AIL-INST}$ = 0.62
- Because the release is a gas or vapor then use equation:

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

= $CA_{cmd,4}^{AIL-INST}$= -39.0269 m²

$effrate_n^{AIL-INST}$= $mass_n$

= $effrate_4^{AIL-INST}$= 6.24266 kg/s

8.8) Compute The Personnel Injury Consequence Areas For Autoignition Not Likely, Continuous Release (AINL-CONT)

- Determine The Appropiate Constants a and b
  - = $a_{inj}^{AINL-CONT}$ = 21.8
  - = $b_{inj}^{AINL-CONT}$ = 0.96
- Then the Consequence area:

$CA_{inj,n}^{AINL-CONT}$= $a(effrate_n^{AINL-CONT})^b$ x $(1 - fact_{mit})$

= $CA_{inj,1}^{AINL-CONT}$= 122.821 m²

8.9) Compute The Personnel Injury Consequence Areas For Autoignition Likely, Continuous Release (AIL-CONT)

- Determine The Appropiate Constants a and b
  - = $a_{inj}^{AIL-CONT}$ = 143
  - = $b_{inj}^{AIL-CONT}$ = 0.92
- Then the Consequence area:

$CA_{inj,n}^{AIL-CONT}$= $a(effrate_n^{AIL-CONT})^b$ x $(1 - fact_{mit})$

= $CA_{inj,1}^{AIL-CONT}$= 742.789 m²

8.10) Compute The Personnel Injury Consequence Areas For Autoignition Not Likely, Instantaneous Release (AINL-INST)

- Determine The Appropiate Constants a and b
  - = $a_{inj}^{AINL-INST}$ = 12.5
  - = $b_{inj}^{AINL-INST}$ = 0.67
- Then the Consequence area:

$CA_{inj,n}^{AINL-INST}$= $a(effrate_n^{AINL-CONT})^b$ x $\left(\frac{1-fact_{mit}}{eneff_n}\right)$

= $CA_{cmd,4}^{AINL-INST}$= -3.25538 m²

8.11) Compute The Personnel Injury Consequence Areas For Autoignition Likely, Instantaneous Release (AIL-INST)

- Determine The Appropiate Constants a and b
  - = $a_{inj}^{AIL-INST}$ = 474
  - = $b_{inj}^{AIL-INST}$ = 0.63
- Then the Consequence area:

$CA_{inj,n}^{AIL-INST}$= $a(effrate_n^{AIL-CONT})^b$ x $\left(\frac{1-fact_{mit}}{eneff_n}\right)$

= $CA^{AIL-INST}_{inj,4}$= -115.068 m^2

8.12) Calculate The Instantaneous/Continuous Blending Factor, factICn

- For Continuous Releases – To smooth out the results for releases that are near the continuous to instantaneous transition point (4,536 kgs [10,000 lbs] in 3 minutes, or a release rate of 25.2 kg/s [55.6 lb/s]), then the blending factor:

  $fact^{IC}_n$= min$\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$ C_5 = 25.2 = factIC$_1$ = 0.3

- For Instantaneous Releases – Blending is not required. Since the definition of an instantaneous release is one with a adjusted release rate, n rate , greater than 25.2 kg/s [55.6 lb/s] (4536 kg [10,000 lbs] in 3 minutes), then the blending factor:

  $fact^{IC}_n$= 1.0 = factIC$_4$ = 1

8.13) Calculate The AIT Blending Factor, factAIT

- Ts : 450.150 kelvin
- C_6 : 56
- AIT: 558.000 kelvin
- Because Ts + C_6 < AIT then the equation:

  = $fact^{AIT} = 0$

8.14) Compute The Continuous/Instantaneous Blended Consequence Areas For The Component

- $CA^{AIL}_{cmd,n} = CA^{AIL-CONT}_{cmd,n}\ x\ fact^{IC}_n +\ CA^{AIL-INST}_{cmd,n}\ x\ (1 - fact^{IC}_n\ )$

  =$CA^{AIL}_{cmd,1}$ = 92.0045 m^2

  =$CA^{AIL}_{cmd,4}$ = 0 m^2

- $CA^{AIL}_{inj,n} = CA^{AIL-CONT}_{inj,n}\ x\ fact^{IC}_n +\ CA^{AIL-INST}_{cmd,n}\ x\ (1 - fact^{IC}_n\ )$

  = $CA^{AIL}_{inj,1}$ = 224.849 m^2

  = $CA^{AIL}_{inj,4}$ = -115.068 m^2

- $CA^{AINL}_{cmd,n} = CA^{AINL-CONT}_{cmd,n}\ x\ fact^{IC}_n +\ CA^{AINL-INST}_{cmd,n}\ x\ (1 - fact^{IC}_n\ )$

  = $CA^{AINL}_{cmd,1}$ = 15.3767 m^2

  = $CA^{AINL}_{cmd,4}$ = 0 m^2

- $CA^{AINL}_{inj,n} = CA^{AINL-CONT}_{inj,n}\ x\ fact^{IC}_n +\ CA^{AINL-INST}_{cmd,n}\ x\ (1 - fact^{IC}_n\ )$

  = $CA^{AINL}_{inj,1}$ = 37.1791 m^2

  = $CA^{AINL}_{inj,4}$ = 0 m^2

8.15) Compute The AIT Blended Consequence Areas For The Component

- $CA^{flam}_{cmd,n} = CA^{AIL}_{cmd,n}\ x\ fact^{AIT} +\ CA^{AINL}_{cmd,n}\ x\ (1 - fact^{AIT}\ )$

  = $CA^{flam}_{cmd,1}$ = 15.3767 m^2

  = $CA^{flam}_{cmd,4}$ = 0 m^2

- $CA^{flam}_{inj,n} = CA^{AIL}_{inj,n}\ x\ fact^{AIT} +\ CA^{AINL}_{inj,n}\ x\ (1 - fact^{AIT}\ )$

  = $CA^{flam}_{inj,1}$ = 37.1791 m^2

  = $CA^{flam}_{inj,4}$ = 0 m^2

8.16) Determine The Final Consequence Areas For Component Damage and Personnel Injury

$$CA^{flam}_{cmd} = \left(\frac{\sum_{n=1}^{4} gff_n\ x\ CA^{flam}_{cmd,n}}{gff_{total}}\right)$$ CA^{flam}_{cmd} = 14.1 m^2

$$CA^{flam}_{inj} = \left(\frac{\sum_{n=1}^{4} gff_n\ x\ CA^{flam}_{inj,n}}{gff_{total}}\right)$$ CA^{flam}_{inj} = 34.0 m^2

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ATTACHMENT 6: FINAL RISK ANALYSIS CALCULATION SUMMARIES (TUBE)

1) Damage factor total at RBI date

   = D_f = 3790.59769

2) Damage factor total at plan date

   = D_f = 8716.0138

3) Total generic failure frequency for finfan cooler

   = g_{ff} = 0.0000306

4) Total Factor Management System

   = F_{MS} = 50%

5) Probability of Failure at RBI date

   = PoF = 0.057996

6) Probability of Failure at plan date

   = PoF = 0.133355

7) Total consequence area for equipment damage

   = CA_{cmd} = 14.0701739

8) Total consequence area for personel injury

   = Cainj = 34.0201064

9) Final consequence area

   = CA = 34.0201064

10) Risk at RBI date

   = Risk = 1.97303502

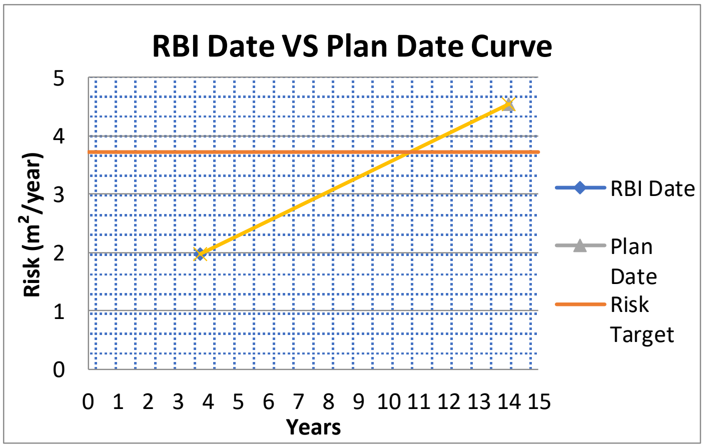
11) Risk at Plan date

   = Risk = 4.53675167

12) Risk Target

   = Risk = 3.71612

	Date	Age	Risk
RBI Date	07/17/2017	3.75	1.97304
Risk Target	07/06/2024	10.7	3.71612
RBI Plan Date	07/17/2027	14	4.53675



13) Determine damage factor at risk target

	Age	Risk	DF
RBI Date	3.75	1.97304	3790.6
Risk Target	10.719	3.71612	7139.42
Plan Date	14	4.53675	8716.01

14) Determine new damage factor

	RBI date	Target date	Plan Date
Df thin	2720.62	?	4158.99
Df cl-scc	1069.98	?	4557.02
Df total	3790.6	7139.42 /lower	8716.01

- Proposed Inspection:
  - > Thinning Inspection (It should be 2A thinning inspection since we need to lower DF as many as possible)
  - > CLSCC Inspection (It should be 2A thinning inspection since we need to lower DF as many as possible)

15) Calculate *new thinning damage factor:*

- Previous thinning inspection at:

= 10/17/2013 = 1A

- Propose thinning inspection at target date

= 07/06/2024 = 2A

- Thinning inspection effectiveness after proposed thinning inspection executed at plan date:

= 1A + 2A = 3A

- Art value at plan date:

= 0.44393

- Then new thinning damage factor:

= D_f^{thin} = 191.506

16) Calculate *new CL-SCC damage factor* :

- Proposed CLSCC inspection at target date

= 07/06/2024 = 2A

- Age at the plan end date:

= Age plan = Plan date - Last inspection date
= 07/06/2024 - 10/17/2013
= 10.7 years

17) Determine the severity index (SVI).

= S_{VI} = 5000

18) Determine the base damage factor for CLSCC based on the new inspection effectiveness and the severity index (SVI) from the last step.

= D_{fB}^{CLSCC} = 50

19) Calculate the escalation in the damage factor based on the time in-service since the last inspection. In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

- $D_f^{CLSCC} = D_{fB}^{CLSCC}$ (age)1.1

= 679

Total Damage Factor:

- $\mathrm{D_{f-total}} = D_f^{thin} + D_f^{CLSCC}$

  = 870.93

20) Calculate risk at plan date with inspection

- Fms	=	50%	
- gff total	=	0.0000306	
- POF with Inspection	=	0.01333	Failure/year
- COF with inspection	=	34	m^2
- Risk area with inspection	=	0.45333	m^2/year

AUTHOR BIOGRAPHY

The Author was born in Jakarta, December 14, 1994 as the oldest child from two siblings. He started his formal education in Bani Saleh 6 elementary school, Al-Azhar 9 Islamic junior high school, and AL-Azhar 4 Islamic senior high school. In 2013, author proceed to pursue bachelor degree at Department of Marine Engineering (Double Degree Program with Hochschule Wismar), Faculty of Marine Engineering, Institut Teknologi Sepuluh Nopember Surabaya specializes in marine operation and maintenance field. During the study period, Author did many activities in campus organizations such as: treasurer in Shorinji Kempo ITS (2014-2016) and Student coordinator of Marine Manufacture Laboratory (2016-2017). The Autor also joined in several event organizers such as seminar, Music event and in 2015 author was trusted to lead the committee in Shorinji Kempo National Championship – Surabaya Mayor Cup.

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