CHAPTER 1
INTRODUCTION OF PROJECT

1.1 Background of Study

Recently the Oil & Gas and petrochemical sector have faces tougher safety ,environmental and mechanical integrity regulation as well as challenges associated with the need for both cost and leak reduction to improve competitiveness. Under these circumstances it has become crucial to manage operational risk through the use of effective technology and best practices for inspection and maintenance planning [2].

Risk based Inspection is a risk-based approach to inspection in the Oil and Gas industries. It is implementing to prioritize inspection, usually by the means of non-destructive evaluations, requirements for major oil refineries and chemical installations around the world [4]. Risk-Based Inspection is a series of process that identifies, assesses and maps industrial risks (due to corrosion and stress cracking), which can compromise equipment integrity in both pressurized equipment and structural elements. Risk-Based Inspection addresses risks that can be controlled through proper inspections and analysis. During the Risk-Based Inspection process, the personnel involve such as; engineers would design inspection strategies (based on what, when and how to inspect) that most efficiently match forecasted or observed degradation mechanisms [8].

Risk Based Inspection is the one of the latest model for effective maintenance and inspection. Risk Based Inspection is increasingly being used in the petrochemical process and petroleum upstream and downstream industries. Risk Based Inspection prioritizes inspection and associated maintenance activities on the basis of actual condition or risk. [2]

1.2 Problem Statement

Conventional inspection methods were inefficient and as the result could gave significant effect on cost operation a more efficient method that can eliminate the unnecessary inspection and focus just only to the high level risk item equipment [2].

There is a need to develop the maintenance and proposed strategy for inspection program in the future. The problem is related to how the inspection is done on the platform or plant whereby conventional inspections are costly and inefficient to reduce risk because it relay on time based inspection governed by minimum compliance with rules, regulation and standards for inspection [3].

1.3 Objective of project

The objectives of the Final Year Project entitled Risk Based Inspection study on relief valves at the offshore and onshore plant listed as follow:

- To generate the criticality ranking or risk ranking, for the operating relief valves at offshore and onshore plant
- To identify the differences in risk ranking and develop the inspection planning strategy.

1.4 Significance of Study

The significance of the study was to trace down the risk and to minimize the cost of inspection and maintenances by using a more comprehensive inspection under the guideline of risk based inspection. By focusing the inspection on to the high level risk items could equipment eliminate the unnecessary inspections. The result is a safer work environment and fatality accidents can be put out of sight.

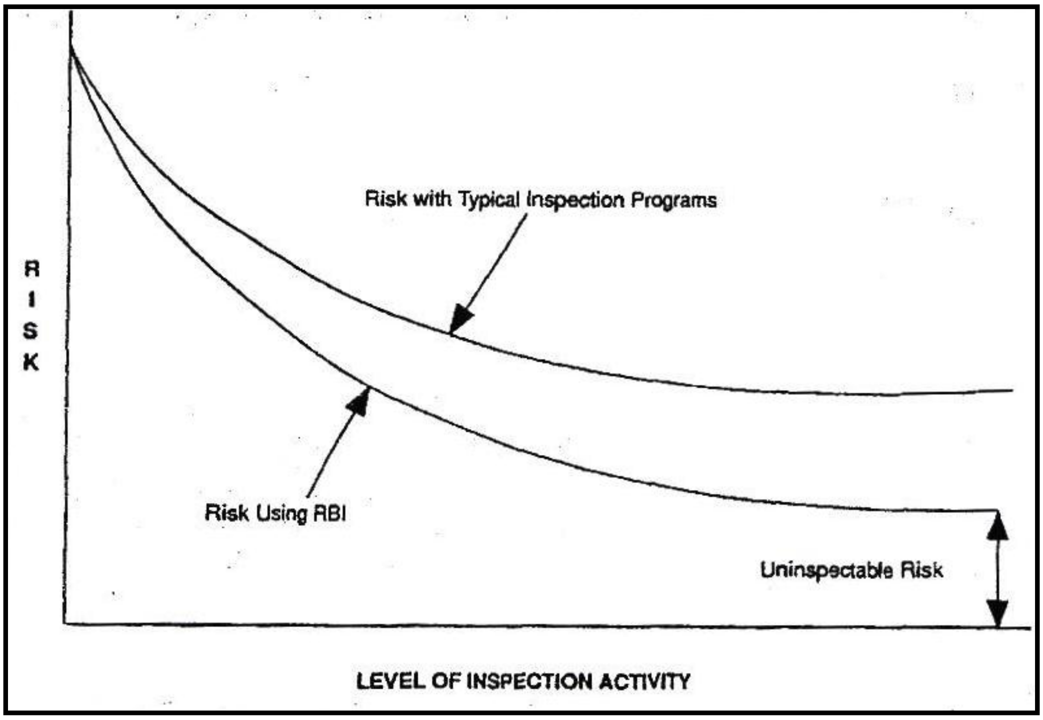

Figure 1.1 : Comparison between Typical inspection and Risk Based inspection method in reducing of risk [1]

As shown in the Figure 1.1 the risk cannot be reduced to zero solely by the inspection effort. Increase in inspection may reduce the risk through a reduction in future failure frequencies by corrective and preventive measures taken after the inspection has identified problem areas

Typical inspection did not altered the consequences of failure factor which the another component of risk. Consequences of failure would changed through design change or other corrective action applied. For Risk Based Inspection methodology it could identified areas where consequences of possible failure event can be reduced.

1.5 Scope of study

Basically, during undertaken industrial internship with company *Oil and Gas Management (M) Sdn Bhd (OGM)* author has been involved in several Risk Based Inspection study project with different numbers of company's client. So this is on-going research base project study that author completed for Final Year Project. For this time the project has been scheduled at one of the Petrochemicals Plant in Johor.

The project scope of work has covered all the relief valves within plants namely as Plant-1 and Plant-2 which consist 350 number of relief valves. This project that has been started on early September 2008 completed on early of April 2009.The scope of study includes developing Criticality Rankings and inspection plans for each relief valves based on the for Risk Based Inspection methodology. This effort would optimize the existing inspection and maintenance program and minimizes unnecessary inspection and maintenance activities.

Apart from the above, the following also tasks would be carried out:

- Collected all the required data for the criticality analysis for all relief valves.
- Reviewed the process data for the various facilities. Establish representative fluids, operating condition and fluid phases for protected equipment.
- Reviewed and summarized the inspection and maintenance history for each relief valve to determine their respective quantity and confidence of maintenance activity.
- Performed corrosion and fouling study for the facilities by evaluating process condition, prior failure or maintenance results of the relief valves.
- Developed the Inspection Work Plan summary for each relief valve. The plans was include applicable inspection and maintenance activities for each damage mechanism, inspection intervals and inspection due dates.

CHAPTER 2:
LITERATURE REVIEW OF PROJECT

2.1 Overview

Risk Based Inspection is a methodology which prioritized inspection activities on the basis of risk. In this approach, the general risk analysis principles was applied in order to prioritized and managed the inspection program for plant equipment. More and more industries have been implemented to reduce inspection costs through optimized frequency while maintaining and improving mechanical integrity and reliability. Risk Based Inspection designed to meet the requirements of API 581 is a systematic process for evaluating risk and factoring it into decisions concerning how, where, and when to inspect.[1]

The purpose of Risk Based Inspection analysis is to focus inspection activities on those pieces of equipment where failure risks associated with an active damage mechanism would be highest. The term risk defined as the product of two separates term the Likelihood or probability of Failure and the Consequence of the failure

2.1.1 Consequence of Failure

Consequence of failure is the outcome of a failure event and usually contributed by the loss of containment. It was the outcome of a failure mode and can be expressed in terms of safety personnel, economic loss or damage to the environment. As example consequences failure is injury to a person, damage to equipment, loss of money.

2.1.2 Probability of Failure

Probability of failure is the chances of failure to occur. The probability of failure assessment was conducted to estimate the probability of occurrence base on scenarios identified in the previous phase of the risk analysis. Failure is the loss of ability to perform the design function. The event is driven by material damage mechanisms, their rate of progression, and the tolerance of the equipment to damage, amount and type of inspection activities that have been performed in the past. As example of failures were internal corrosion, external corrosion and cracking.

2.2 Risk Ranking

The Risk ranking estimates the probability of failure (*PoF*) along with the failure consequence (*CoF*). The Risk ranking analysis is a dynamic calculation with ability to take into account changes in the process or results from an inspection. It allows optimum inspection types and intervals to be selected, based on deterioration rates of the identified failure mechanisms for each equipment item.[1]

Risk = Probability of Failure (PoF) X Consequence of Failure (CoF)

The risk rating analysis was focus inspection on the highest risk equipment items and also recognizes all of the damage mechanisms that are identified in the corrosion study. For static equipment and piping systems including relief valves system, the primary failure mode was contribute by loss of containment, which was the basis for this study. Both the consequence and probability rankings are calibrated in order of magnitude steps. [1]

Refer to Figure 2.1, the criticality rating matrix consist of the range of Consequence Ranking is from “A” (catastrophic) to “E” (minor). The consequence results were primarily based on the combination of production loss, flammability of the hydrocarbon streams as well as the toxic streams present in the plant.

Since the failure of a relief valves to perform its function may cause failure to the protected equipment (such as pressure vessel), the Consequence of Failure for the relief valves is based on the consequence of that protected equipment .Each relief valves was also rated for its Probability of Failure. The Probability of Failure ratings range from 1 (Very High) to 5 (Very Low).The Probability of failure is determined from fouling and corrosion study, date since last inspection and adjusted for redundancy, challenge rate and materials of construction.

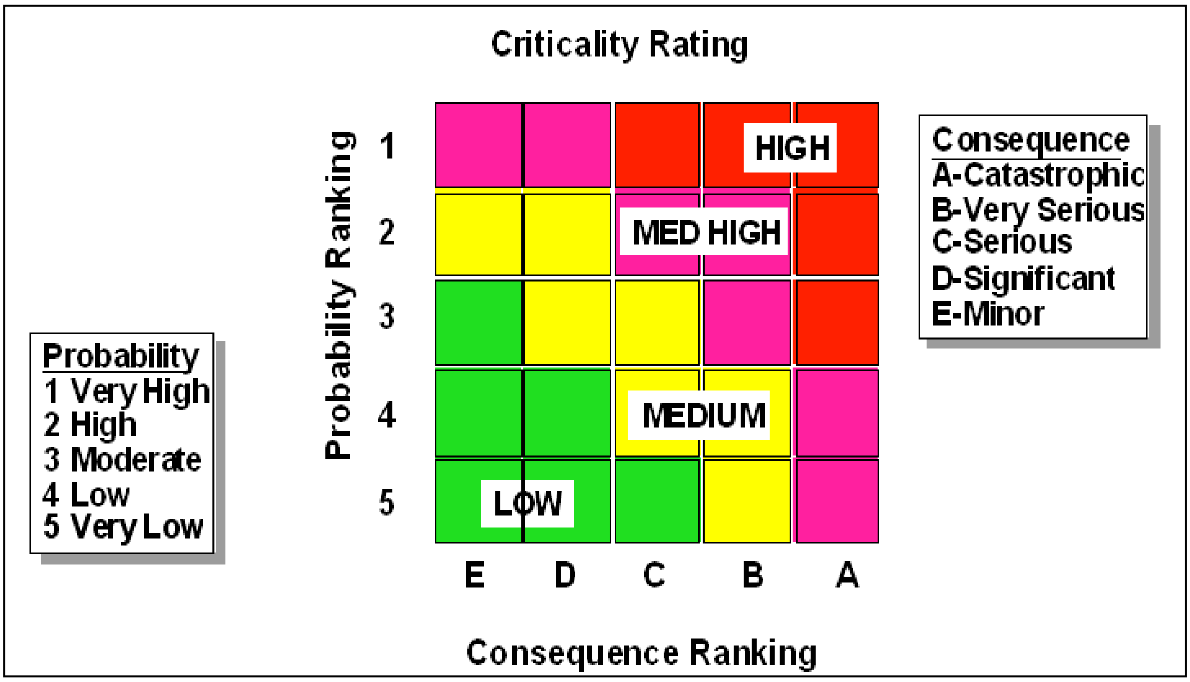

Figure 2.1: Risk Ranking Matrix [1].

2.3 Relief Valve Overview

As one type of the relief devices, relief valve application was to control the pressure in a system of its protected equipment which can build up by a process trouble, instrument or equipment failure. The relief valve is set to open at a predetermined pressure as a shield in order to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. The relief valve is function to relieve the pressure by allowing the pressurised fluid from its protected equipment to flow from an auxiliary passage out of the system.

The main component of a relief valve unit consists of body, bonnet, disc, disc holder, stem, spring and gasket. When the pressure setting is exceeded, the relief valve becomes the path of least resistance as the valve is forced open and a portion of the fluid is diverted through the auxiliary route. The diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a flare header or relief header to a central, elevated gas flare where it is usually burned and the resulting combustion gases was released to the atmosphere [3].

As the fluid is diverted, the pressure inside the vessel would drop. Once it reaches the valve's re-seating pressure, the valve would re-close. This pressure, also called blow down, is usually within several percent of the set-pressure. The pressure relief system may be considered in three separate parts which were the pressure relief valves, connection to the equipment which it protects, and the disposal arrangement downstream of the relief valves.

The most common used relief valve are safety valves and bursting discs, its types either singly or in combination, although there are other relief valves s that can be used in special circumstances. Each of the relief valves s has its own advantages and disadvantages in term of maintenance, durability and safety. It is worth remembering that not all tanks and vessels require a dedicated pressure relief valves such as tank operating at atmospheric pressure and vented to atmosphere.

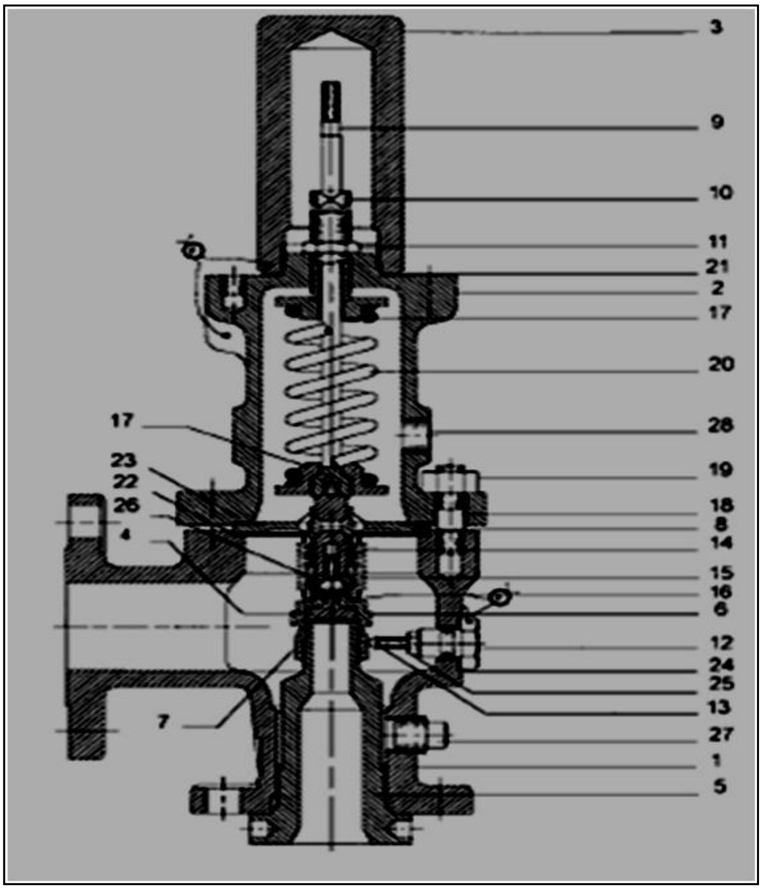

Figure 2.2: Relief Valve component [4].

1. Body
2. Bonnet
3. Cap
4. Disc
5. Disc Holder
6. Guide
7. Stem
8. Spring Adjusting Screw
9. Jam Nut
10. Blow Down Ring
11. Lock Screw
12. Spring
13. Spring Button
14. Stem Shoulder
15. Grooved Pin
16. Lift Stop Ring
17. Retaining Ring/ Stem Shoulder
18. Cap Gasket
19. Body Gasket
20. Guide Gasket

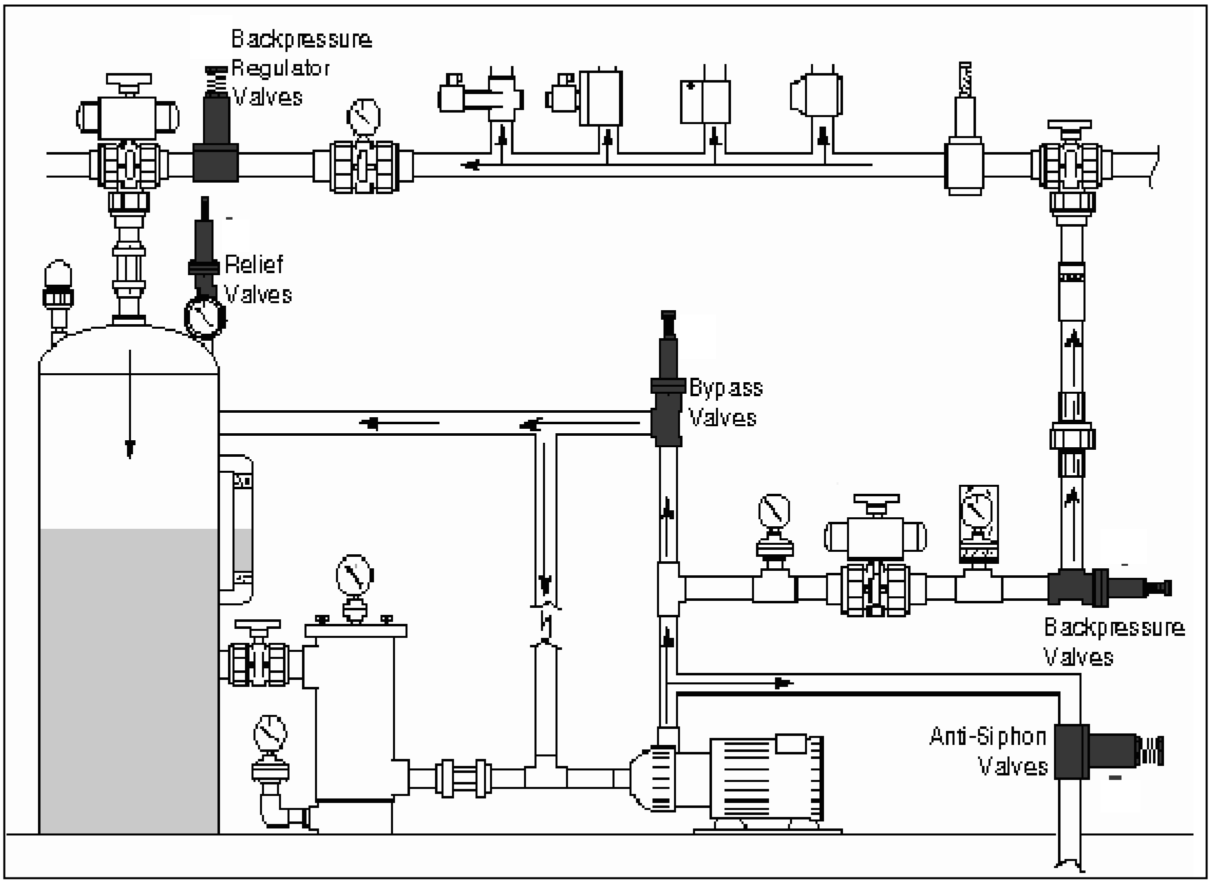

Figure 2.3: Relief Valve orientation with its protected equipment

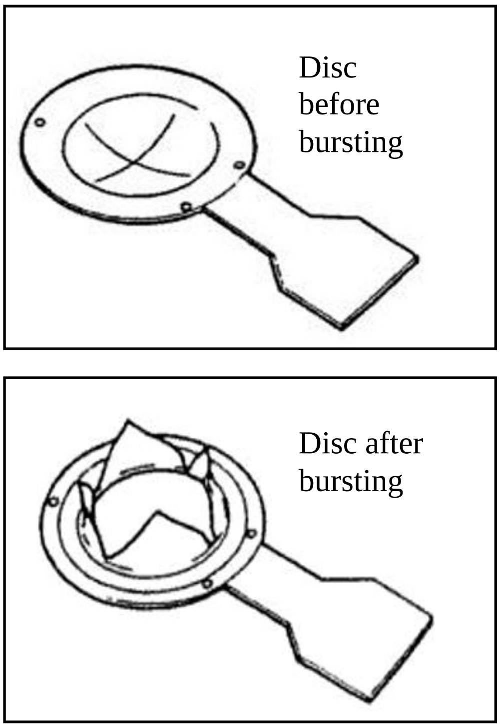

Figure 2.4: Bursting disc mechanism before and after [3]

2.4 Risk Based Inspection related software

Reliability Based Mechanical Integrity (RBMI) software is a well defined software for managing inspection program of Risk Based inspection methodology. It was developed to meet the requirements of API recommended practice 580 it manage data by prioritize the equipment data to be collected and maintained, collect less inspection data but good interpretation data, evaluate the equipment condition and make appropriate data available with queries. From this study has evaluated the risks for the associated with possible failure of the pressure relieve valves that may result in failure to operate and hence cause safety and financial consequence [2].

The Risk Based Inspection related software capable to recognizes how equipment was fail by identified likelihood failure mechanism, determine the appropriate inspection methods, confirming prediction with measurements and uses business rules to create a dynamic inspection plans. The software philosophy is firstly to incorporate business rules into inspection and maintenance planning strategies by provide consistency in improving maintenance plans to optimum and let the software make recommendations.

The approach of software uses best available failure data and modifies it specifically for design, operation, and deterioration in the process. Risk based inspection continually compares condition monitoring results with predictions of deterioration and were reassess the prediction if result monitoring does not agree with the prediction.

2.5 Assessing Risk of Relief Valve

During functioned to protect its protected equipment relief valves was exposed to various factors of failure either internal or external .Most of the common failure scenarios of relief valve during it operates involves:

- Pressure boundary loss of containment.
- Valve leak-through relief valve body.
- Relief Valve Failure to relieve at set pressure.

The most critical failure scenario of relief valve is failure to relieve at design pressure caused by the potential for internal corrosion, fouling and plugging as relief valve function as a layer of protection to prevent over-pressurization of the system and potential failure of the equipment protected. Thus it would affect the risk raking integrity of the relief valves items under risk based inspection study analysis.

CHAPTER 3
METHODOLOGY OF PROJECT

3.1 Project Steps

There are some procedures to be followed in order to carry out and implement the project. This is to ensure that the project can be accomplished within the given timeframe. The methodology of Risk Based Inspection is a life cycle inspection database. The methodology to conduct Risk Based Inspection study for relief valves can be divided into procedures listed below:

1. Defining Project Scope
2. Data Gathering and Collection.
3. Process study
4. Field Verification.
5. Data uploading.
6. Risk Assessment
7. Risk Assessment Review
8. Development of Inspection Work Plans strategy.

- **Defined Project Scope**

There were some kick-off meeting held in order to define the scope of project. There were 2 main plants involved in this project study namely as Plant-1 and Plant-2.For plant-1 which consist of 269 relief valves and for plant-2 consist of 81 unit relief valves installed on their protected equipments .The total of relief valve involved for this study from both plants were 350 units of relief valves.

- **Data Gathering and Collection**

The data collection process was conducted with the assistance of client's team members. Documents such as piping and instrumentation diagram (P&ID), process flow diagram (PFD), relief valves datasheet, relief valve inspection and service report, relief valve manufacturer catalogue and others related sources that were very crucial in maintaining the integrity of the data based on the equipment history, corrosion study or screening inspection process study. The gathered data then was entered in a spreadsheet of Microsoft excel.

- **Process study**

For this project some operational data related to plant operation such as fluid flow, operating pressure and operating temperature were taken from the data or given by the operation personnel so that the data reflects the actual condition of the protected equipment which the relief valve is protecting that need to be analysed in this study.

- **Field verification**

In order to get the correct and reliable data upon completion of the data collection stage, the data collection need to be verified by doing some visit on the plants involved. Before entered the plant for relief valves study, it was required to attended the safety course conducted by government authority body in order all the regulation obey by each of the personnel during working in the hazardous plant.

- **Uploading Data**

After the data collecting and gathering completed as well as the field verification, the data was uploading into risk based inspection RBMI software at client database. All these data uploaded would be used in the next stages of the project including the criticality analysis and development of inspection strategies.

- **Risk Assessment**

A quantitative Risk assessment for all relief valves was performed using risk based inspection RBMI software. The risk results were presented in the form of a 5 x 5 matrix as shown above. In addition, a summary of risk report for both plant-1 and plant-2 that contains of material specification and grade, risk rating, fouling, corrosion rates and others was also presented.

- **Risk Assessment Review**

The risk resulted above has been reviewed for the purpose of reviewing the risk result and develop Inspection Work Plans. During the reviewing assessment progress, there some new information from inspection, maintenance or process personnel was input in to the system for a better analysis and result.

- **Development of Inspection Work Plans**

With a built-in inspection planning, risk based inspection RBMI software was developed Inspection work plans for relief valves based on the outcome of the risk analysis. The plans define the following key parameters

  - *Where to inspect* : which relief valves to inspect.
  - *How to inspect* : defining the inspection effectiveness of the method to be applied.
  - *When to inspect* : defining the period in time which inspection to be performed.
  - *How Frequency* of Relief Valve inspection.

The inspection plans had identified the inspection activities strategies suggested in order to maintain the integrity of the relief valves, described the extent of each inspection, and define the inspection activity intervals. Using a combination of risk and grouping of equipment in the same service, the inspection plans were able to reduce the number of relief valves s that needs to be service.

3.2 Project Flow and Gantt chart

The summary steps processes of the Risk based Inspection study for relief valve shown in Figure 3.1:

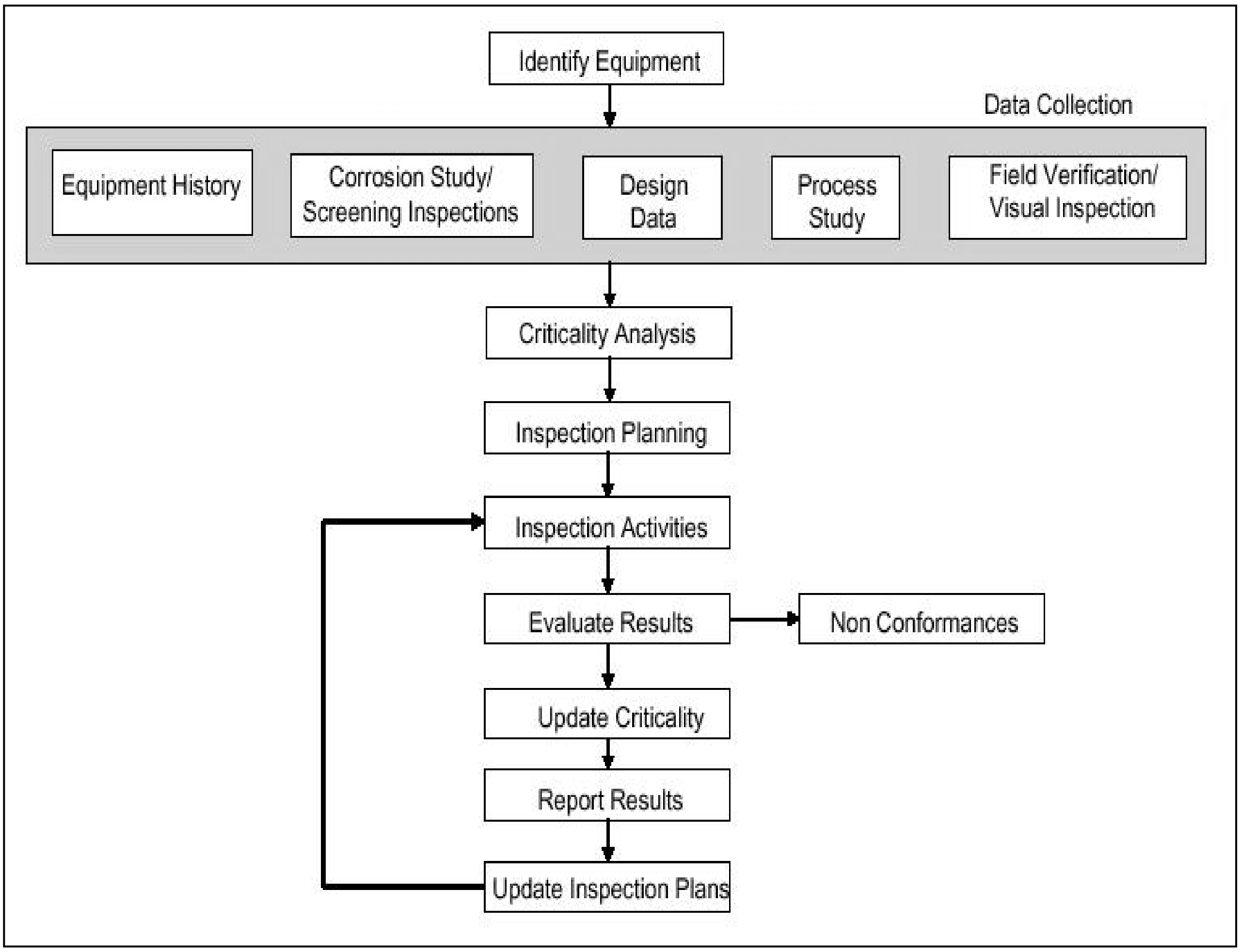

Figure 3.1: Risk based Inspection relief valve Project work flow diagram [1]

Table 3.1: Gantt chart progress of Final Year Project -I

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Final Year project topic.	■	■												
2	Preliminary of Risk Based inspection research project progress		■	■	■										
3	Submission of Preliminary report				■										
4	Seminar 1					■									
5	Data of relief valves collection from all the relevant sources.					■	■	■	■	■	■				
6	Submission of Progress report									■					
7	Seminar 2									■					
8	Data gathering and uploading into database and plant process study.									■	■	■	■	■	
9	Submission of final draft of interim report													■	
10	FYP-I Oral Presentation.														■ ●

■	*Suggested Progress*
●	*Suggested milestone*

Table 3.2: Gantt chart progress of Final Year Project -II

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue ▪ Practical /evaluation work progress														
2	Submission of Progress Report 1														
3	Project Work / evaluation work progress														
4	Submission of Progress Report 2														
5	Project work / evaluation Work progress														
6	Poster Submission														
7	Submission of Softbound Dissertation														
8	Oral Final Presentation														
9	Submission of FYP Hardbound														●

	Suggested Progress
●	*Suggested milestone*

CHAPTER 4
DISCUSSION AND RESULT

4.1 Overview of the Plants.

In this particular chapter, the project progress would be brief the progress involved throughout activity that have been done throughout the final year project period, which were started with defined the project scope, data collected and gathered stages and field verification until the end of the part of project completed.

As for this project for FYP, there were numbers of 350 units of relief valve involved in this project study which divided into two different plant namely as plant-1 consist of 269 items of relief valves and at Plant-2 consist another 81 unit of relief valves .Based on the plant operator previous record, the type of relief valve used range from the spring loaded valve type which could be group into conventional design type and bellows type design.

The project was conducted on a chemical polymer processing plants to produce plastics polymer raw material product for customer. Most of the substance used in the processing utilizes the hydrocarbon material including C1 until C8 hydrocarbon group substances and other hazardous fluid related. The attached document in the appendix shown as generally the properties of the fluid involved.

In addition, for this project, there restriction of company's confidential policy on some types of data provided could not be reveal such data were the details on specific fluid used, the related plant design data, the design of plant and etc .The type of data that presented in this particular report was already with permission of the company's personnel for the FYP project purposes.

4.2 Data Collection and Gathering

The data received and gathered is for used of the project in order in order to performing vital analysis in the next steps of the project including to analysis the criticality of the relief valve based on the given two major Probability of failure and consequence of failure.

The data collected and gathered systematically in the Microsoft excel spreadsheets for the verification and risk analysis purposes. The Risk based Inspection related data for each of the relief valves involve that was listed in Table 4.1:

Table 4.1 : The type of data for criticality analysis.

▪ Location ID.	▪ Existence of rupture disk (Y/N).
▪ Relief valves ID.	▪ Rupture disk ID.
▪ Protected equipment of RV.	▪ Existence of redundant relief valves .
▪ Component type.	▪ P&ID number
▪ Type of material	▪ Representative Fluids
▪ Operating condition.	▪ Design type.
▪ Design pressure	▪ Initial state /phase
▪ Set pressure	▪ Inlet/Outlet diameter size of RV.
▪ Operating Temperature	▪ Last inspection date.
▪ Back pressure	▪ Visual inspection data.
▪ Leakage test pressure	▪ Current condition of RV

A part of data gathered was shown in the Table 4.2. For the field verification project stage, it was the requirement of the plant operator to provide the safety training to their contractor in order all the regulation especially regarded to safety obey by all the personnel or contractor working in the petrochemicals hazardous plant. The safety training was conducted by N.I.O.S.H (National Institute of Safety and Health, Malaysia) which later would issued with the plant safety passport as the permission to enter the plant. Author himself had attending the course and holder of the passport.

Basically entered the plant is necessary in this project for field verification in order to verify the condition of the relief valve and verified the data required.

During the data collection and gathering, there were some missed or disappeared data especially on the previous inspection data of the relief valve. So that it required getting the information from the plant operator personnel assistance as well as the visited plant for field verification in order to completed the data gathering process in the excel spreadsheets.

Table 4.2: A part of the excel spreadsheets data collection and gathering of relief valves

Plant	RV I.D	Protected equipment	Representative fluid	Rupture Disk (Y/N)	Design pressure (kPa)	Operating Pressure (kPa)	Operating temp. (°C)	Initial State	Diameter (mm)	Material	Last Inspection Date
Plant-1	PSV-0123	C-409	H2O	N	2100.0	981.0	82.0	Liquid	700.0	CS	16/03/2006
Plant-1	PSV-0189	Z-068	H2O	N	2100.0	981.0	82.0	Liquid	700.0	CS	29/07/1997
Plant-1	PSV-3929	PK-210	Lube Oil	N	686.0	613.0	45.0	Liquid	610.0	SS	08/03/2006
Plant-1	PSV-4101	C-300	Lube oil	N	686.0	613.0	10.5	Liquid	457.2	SS	08/03/2006
Plant-1	PSV-6714	C-200	HCL	N	490.0	294.0	35.0	Liquid	610.0	CS	29/07/1997
Plant-1	PSV-6720	C-320	HCL	N	490.0	294.0	35.0	Liquid	914.0	CS	04/07/1997
Plant-1	PSV-8281	C-650	Steam	N	68.65	13.34	51.6	Liquid	457.2	CS	06/03/2006
Plant-1	PSV-8296	PK-3204	Steam	N	68.65	13.34	51.6	Liquid	457.2	CS	07/05/2004
Plant-1	PSV-9162	PK-3100	NaOH	N	490.0	294.0	35.0	Liquid	498.0	CS	12/03/2003
Plant-1	PSV-9540	PK-3200	NaOH	N	490.0	294.0	35.0	Liquid	498.0	CS	08/03/2006

4.3 Criticality ranking evaluation.

The criticality ranking calculation and dynamic evaluation flow for relief valve involved both qualitative and quantitative methods of analysis. It was then to evaluate and to quantify the risk ranking of associates on relief valves of the protected equipment.

As mention previously criticality ranking or the risk ranking of the particular relief valve component determine or evaluating was based on probability category evaluation and also consequence category evaluation of the relief valve component and its protected equipment.

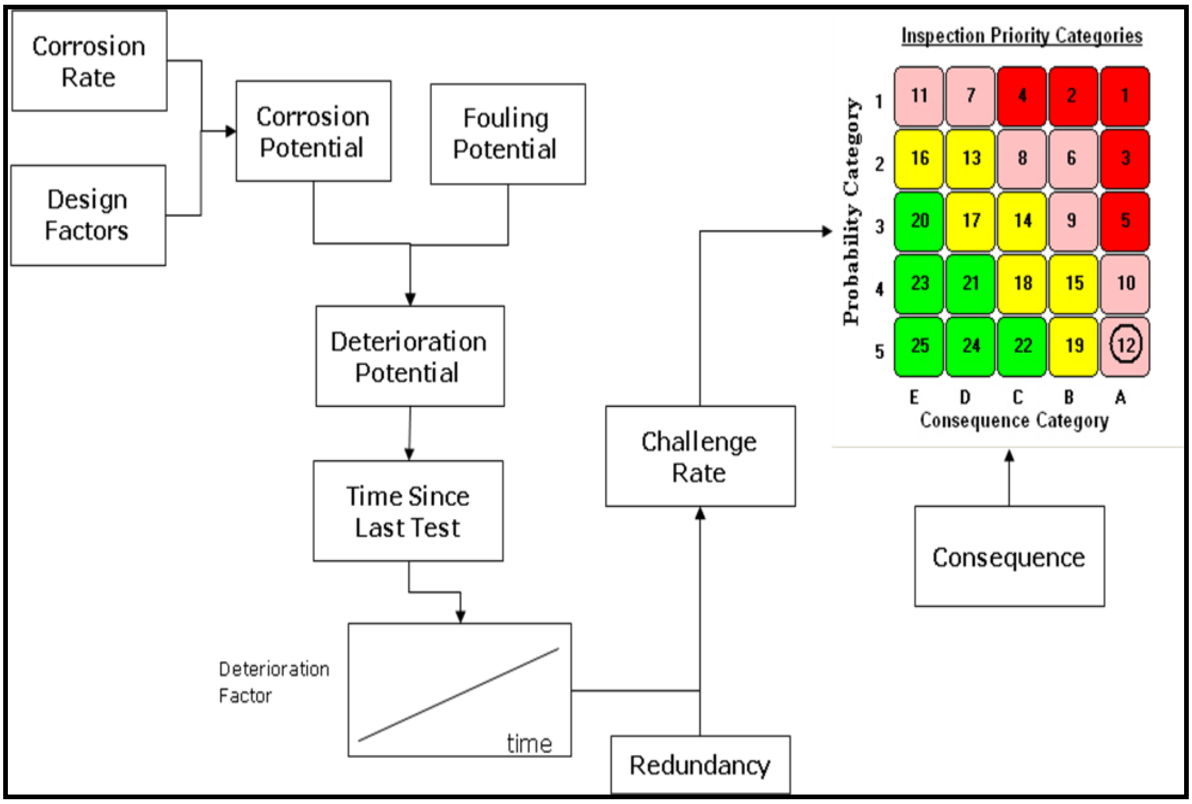

Figure 4.1: Criticality calculation flow [2].

Refer on the Figure 4.1 above, for probability category analysis, the first step of flow is the corrosion potential determined by corrosion rate and the design factor of material of the particular relief valve component. As for the corrosion rate, the expected corrosion rate assigned to the equipment item that the relief valves is protecting. Such case for material of carbon steel its corrosion rate is 0.05 mm/year.

While if the relief valve was made of higher alloy metals, bellows design or rupture disk protected the corrosion potential was decrease in value. The corrosion potential is given by the corrosion experts based on the upper point. The corrosion potential would increase if the relief valves relieve to atmosphere because moisture can enter the valve and accelerate the corrosion on valves internal.

Fouling refers to the accumulation of unwanted material on solid surfaces. The occurrence of this phenomenon may cause relief valve fail to function properly [1]. Then for the fouling potential evaluation flow, they were two methods to quantify both quantitative and qualitative. As for the Qualitative evaluation they are consist of four degree of fouling which are based on level of severity. For fouling to point of degraded capacity in less than a year is indicated that as very high level of severity. For fouling to point of degraded capacity within 1 to 2 years is indicate as high level of severity while fouling seen in 2 to 3 years of service is indicate medium level of severity and for fouling almost never occurs is indicate low severity.

For the quantitative evaluation of fouling potential is done by measuring the internal diameter of the orifice of Relief valve after the relief valves has been in service for one year. From the measurement done if the result shown that there is no reduction in the diameter due to fouling or 0% reduction in internal diameter, it is classified by a low potential of fouling.

If there 0.1% to 5.0% of reduction in the diameter due to fouling, it is given a medium potential for fouling. If there is 5.1% to 10.0% reduction in diameter due to fouling, it is given a medium-high potential for fouling. Lastly if there were more than 10% reduction in diameter it is given a high potential for fouling.

For the *deterioration potential* flow is where the corrosion potential and fouling potential were being evaluated together to result the level severity of deterioration potential [1]. Whereby the higher potential stage is being uses for representing the condition of the relief valves. Let say if the particular relief valve has High level of severity and for the fouling potential has medium level of severity, the high level would be taken as the level of severity for deterioration potential. In the other hand if the two were having the same stage of potential and is not in low potential stage. The deterioration potential is raise to the next level of severity.

Years since last inspection value is the recorded time of the previous inspection to the current inspection based on the inspection history of the relief valves [2]. This was needed to calculate the distribution of deterioration factor value. Based on the deterioration potential value the deterioration factor can be determined. The graph is show in Figure 4.2.

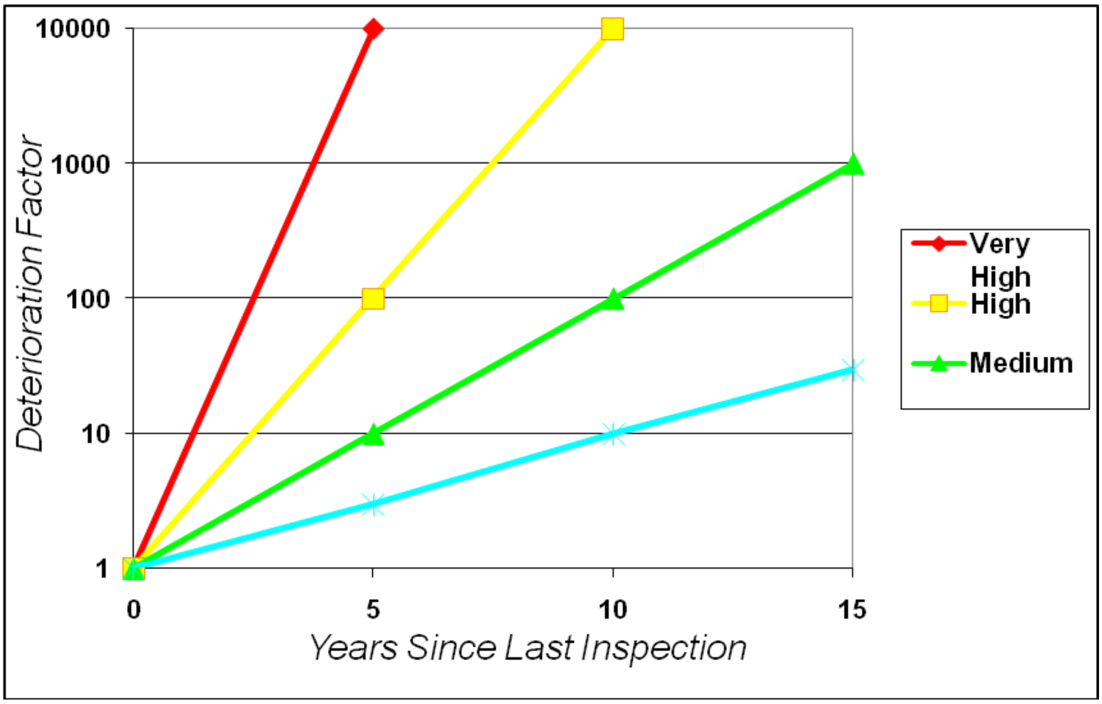

Figure 4.2: Deterioration factor *vs* years since last inspection of relief valve. [1]

Deterioration factor is then revaluating again by checking if the relief valves have a redundancy valve in the equipment it protected. This means one protected equipment such as pressure vessel has been installed by more than one relief valve at the same time of operation. If there is a redundancy valve on the equipment, the deterioration factor is divided by ten. This was because the existed of redundancy valves help to elongated the time of the relive valves study.

This would continued by challenge rate stage where it accounts the probability of demand on the relief valves to determine the challenge factor. The value is then multiplied with the deterioration factor to get the adjustable deterioration factor.

There were two methods to assess and evaluate the challenge factor value. It could be done by calculating the ratio of operating pressure, OP (*in psi unit*) to the design pressure, DP (*in psi unit*) the challenge factor result as shown in Table 4.4. Another method is by evaluation estimation from the experienced process or operation engineer in charge at the particular plant of relief valves installed at the protected equipment. The guideline table for process engineer estimating the rate is given by Table 4.3.

Table 4.3 : Usage of relief valve interest [1].

Frequency of Challenge	Challenge Factor
Once within < 6 months	3
Once within 6 months to 2 years	1
Once within 2 to 5 years	0.7
Once within 5 to 10 years	0.5
Once for every > 10 years	0.3

Table 4.4: Ratio of pressure. [1]

Ratio of Operating pressure (OP) to Design Pressures (DP)	**Challenge Factor**
Greater than 0.90	3
0.75 to 0.89	1
0.50 to 0.74	0.7
Less than 0.50	0.3

Whereby after verify the challenge factor it is then multiplied with the deterioration factor to determine the finalize value of the deterioration factor. The value is the used to determine the probability category of the relief valves.

Table 4.5 shows the finalize deterioration factor determines the probability category of the relief valves.

Table 4.5: Probability Category based on the adjusted deterioration Factor. [1]

Adjusted Deterioration Factor	**Probability Category**
1-9	4
10-99	3
100-999	2
1000+	1

For the Criticality ranking analysis of consequence category analysis, the risk assessment is based on the defining a failure scenario. The scenario should describe the causes and consequences of each identified failure. Typically, defining the Consequence of the Failure involves using an event tree that could lead to different end events. Each end event has a certain probability of occurring. It is important to develop credible failure scenarios for each identified failure mechanism.

Since Consequence Analysis constitutes half of the risk equation, it is reasonable to expect that an effort similar to that used to define Probability of Failure should be applied to determining Consequence of Failure. Flammable event, toxic releases, environmental risk, business interruption and asset repair and maintenance costs ,such example for Consequence of Failure. For the Consequence of Failure, “A” is categorized as a Catastrophic and “E” as Minor

4.4 Result and Discussion

Each of the relief valve items would be result of their risk ranking based on their real risk associates in particular relief valve. The risk ranking summary shows the distribution according to risk ranking category which were *High, Medium High, Medium and Low.*

Based on distribution Table 4.6, there were 5 of relief valves was in "*High*" criticality category. The number of relief valves in "*Medium High*" category was 59 relief valves which 38 of them was from plant-1 and 21 of relief valves were from plant-2. Another 193 items of relief valves in total was within category of *"Medium"* and 93 falls within "*Low"* category.

Table 4.6 : Distribution of Risk Ratings

Plant	Items Unit	High	Medium High	Medium	Low
1	269	4	38	152	75
2	81	1	21	41	18
Total	350	5	59	193	93

The criticality rankings were calculated in order to provide required information for the baseline inspection planning. They were derived from the results of the process/ corrosion information, previous plant inspection history and basic data gathering. Based on the results of this study, inspection work plans have been developed for the unit to provide guidance to inspection and maintenance to ensure the current criticality ratings was maintained or lowered.

Without further inspection and maintenance, the equipment criticality ratings could be expected to increase, assuming process conditions remain constant. Through the implementation of the RBMI software, the criticality rating of each relief valves in the study can be kept within the acceptable limit. Figures 4.3 and Figure 4.4 shows the Criticality Distribution of the risk matrix for all of the relief valves in the study. The criticality rating considers both the probability and consequence of failure categories both plants.

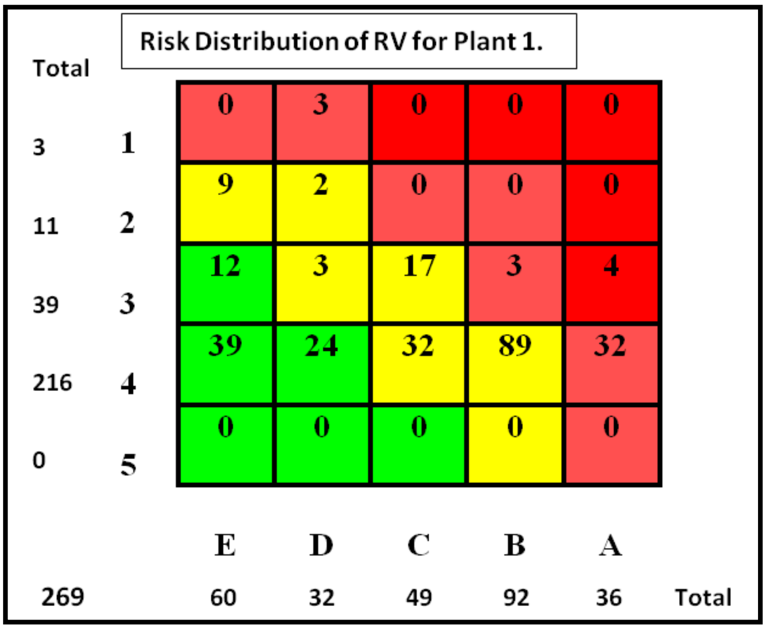

Figure 4.3: Criticality Distribution for all of the relief valves for plant-1.

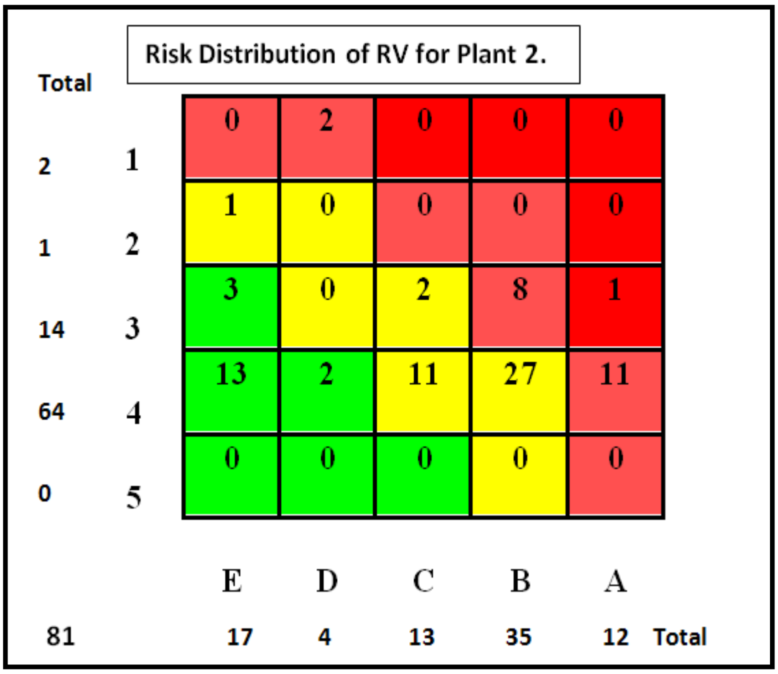

Figure 4.4: Criticality Distribution for all of the relief valves for plant-2.

4.4.1 Consequence of Failure result

Risk assessment is based on the defining a failure scenario. The scenario should describe the causes and consequences of each identified failure of relief valves. Typically, defining the Consequence of the Failure involves using an event tree that could lead to different end events. Each end event has a certain probability of occurring. It was important to develop credible failure scenarios for each identified failure mechanism.

Since Consequence Analysis constitutes half of the risk equation, it is reasonable to expect that an effort similar to that used to define Probability of Failure should be applied to determining Consequence of Failure. Flammable event, toxic releases, environmental risk, business interruption and asset repair and maintenance costs such example for Consequence of Failure. For the Consequence of Failure, “A” was categorized as a Catastrophic and “E” as Minor.

The Consequence of Failure Distribution for plant-1 and plant-2 relief valves was shown in Figure 4.5 and Figure 4.6.

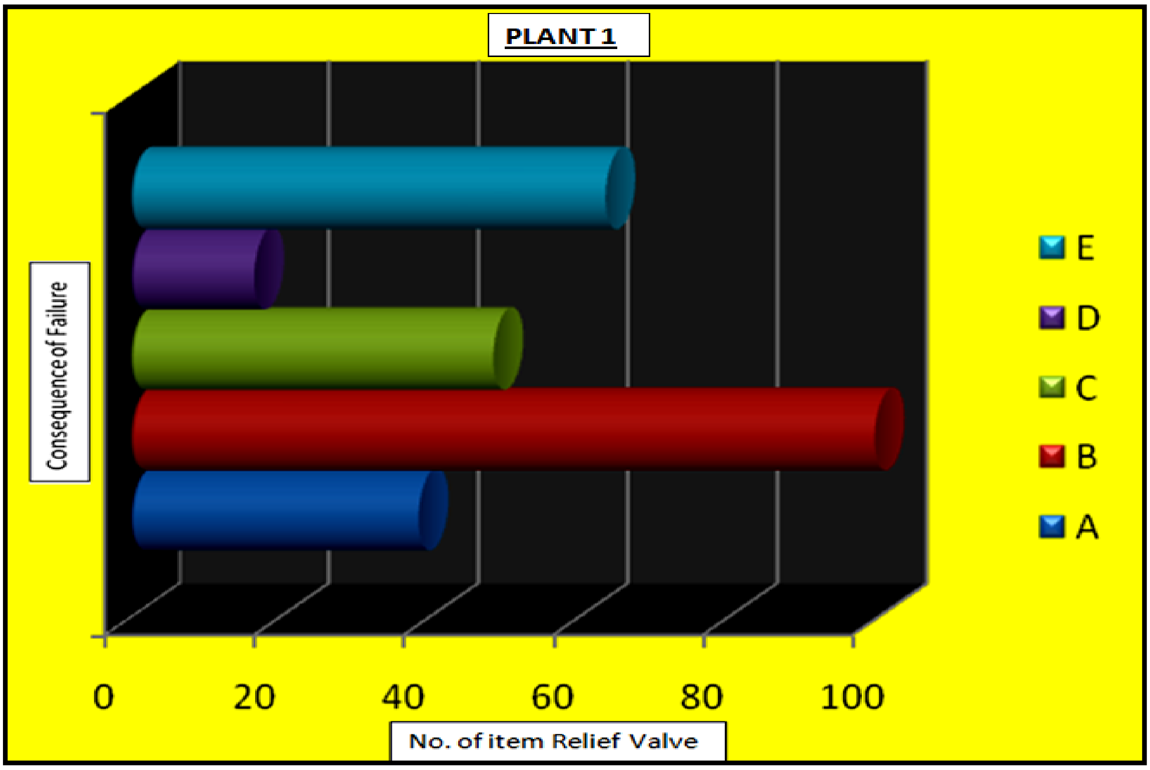

Figure 4.5: Consequence of Failure Distribution for plant-1.

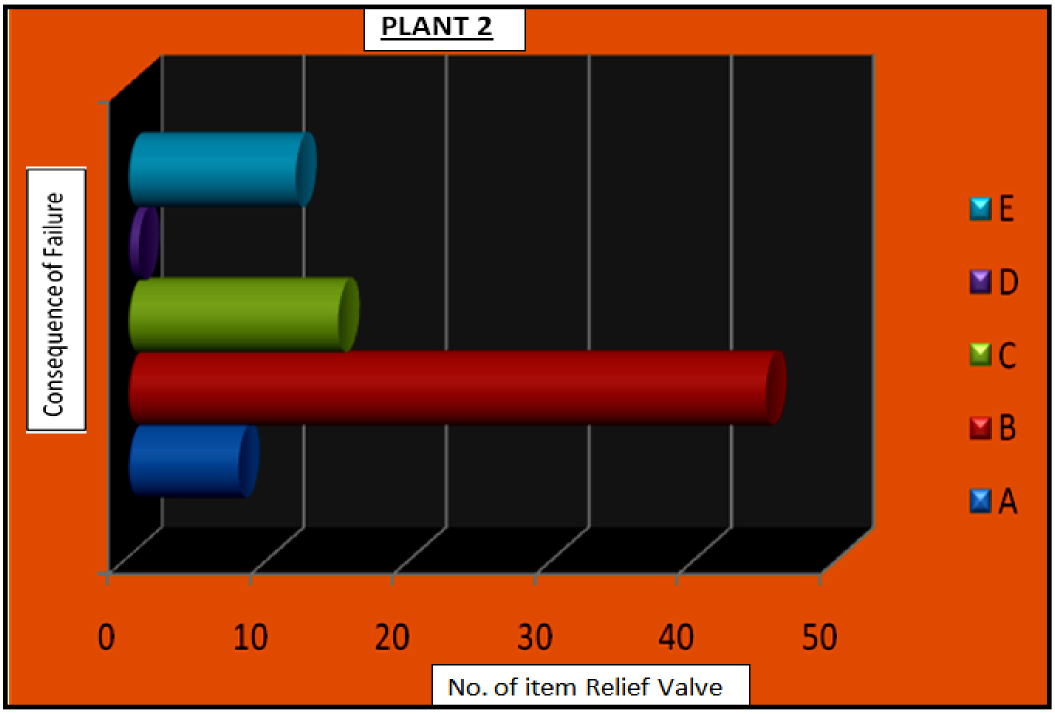

Figure 4.6: Consequence of Failure Distribution for plant-2

4.5 Risk distribution Summary

In the appendices part shown the Probability of Failure category, Consequence of Failure Category and Inspection Priority for all the relief valves included in the scope of work for relief valves at plant-1 and plant-2. (*refer to appendix 1 and appendix 2*)

4.6 Inspection Work Plan Summary and Planning Strategies

Inspection plans were generated for all relief valves in the study and was based on the LR Capstone inspection planning rules. Each plan includes the relief valves Inspection Priority Ranking, the extent or inspection coverage and the inspection frequency. The Inspection Priority Matrix in Figure 4.7 defines where each Inspection Priority Ranking falls within the matrix. The Inspection Priority Ranking is a combination of the consequence of failure and probability of failure.

	E	D	C	B	A
1	11	7	4	2	1
2	16	13	8	6	3
3	20	17	14	9	5
4	23	21	18	15	10
5	25	24	22	19	12

Figure 4.7: Inspection Priority Matrix.

The Inspection Planning Strategies describe how to manage the risk based inspection program by equipment type, identified failure mechanism and inspection method. This project utilised Inspection Planning Strategies that were developed by Risk Based Inspection to optimise a risk based inspection program. With a built in inspection planning, RBMI software has developed Inspection Work Plans for relief valves based on the outcome of the risk analysis. The plans define the following key parameters:

- Where to inspect - which equipment to inspect.
- How to inspect - defining the inspection method to be applied.
- When to inspect - defining the period in time which inspection to be performed.
- Frequency of inspection duration.

Inspection plans were generated for each Relief valves of the study in most cases, based on the *Capstone* inspection planning rules. As for relief valves at plant-1 and plant-2 of the corrosion study generally provided estimates of corrosion rates based on current inspection results.[2]

Potential inspection locations for the equipment were not quantified for the purpose of this study, as they typically were derived from the visual inspection results. For this study, the inspection plans was recommended a percentage of potential internal and external inspection locations for each applicable equipment item. The Inspection Work Plans is based on the *Capstone Engineering* inspection planning rules with either 1,5, 10 or 15 year interval depending on the criticality rating and the inspection priority[2].

After reviewed the inspection plan we could identified the equipment items which require internal inspections that can be completed outside of the shutdown. When the internal work does not require a shutdown, the "*availability*" field in the inspection plan can be changed to "*off line*" to differentiate from "*shutdown*."

Table 4.7: Relief valve test inspection planning strategies.

Criticality Rating	Conditions	Test Interval
High	All Cases	1 Year
Medium-high	In-place Testing Or High Fouling Service	3 Years
	Shop Tested	5 Years
Medium	In-place Testing Or High Fouling Service	5 Years
	Shop Tested	10 Years
Low	In-place Testing	5 Years
	Shop Tested	10 Years

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion and Recommendation

The purpose of using Risk Based Inspection methodology to relief valve in this study is to manage the probability of failure associated with the components while establishing an optimum inspection program. As more data is gathered from upcoming inspections and damage mechanism continues to be defined, the result of risk ranking should be updated to provide guidance for further inspections.

The plan of the inspection work based on the inspection planning suggested by the software and conditional monitoring of the relief valve directly and equipment and piping indirectly. By managing the inspection work, it would improve the equipment condition confidence and consequently, the risk associated with the equipment and piping can be managed to an acceptable level with the lowest inspection plan cost.

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