Second Annual Symposium, Mary Kay O'Connor Process Safety Center
"Beyond Regulatory Compliance: Making Safety Second Nature"
Reed Arena, Texas A&M University, College Station, Texas
October 30-31, 2001

# Risk Based Inspection Case Studies: Does RBI improve plant safety?

**Stephen Anderson**
APTECH Engineering
12012 Wickchester, Suite 120
Houston TX 77079

Phone: (281) 558 3200
Email: steve_ander@hotmail.com

## ABSTRACT

In order for a facility to extend the operating lifetime of pressure vessels and piping, safely and cost effectively, it is necessary to implement the latest inspection and maintenance strategies. Risk Based Inspection (RBI) has its roots in Process Safety Management and Mechanical Integrity programs and is gradually becoming accepted as good engineering practice for the implementation of inspection and maintenance programs. This paper describes the methodology, analysis and results of Risk Based Inspection studies conducted on several refineries and petrochemical facilities. These studies have resulted in numerous benefits for the plants, which include safety and compliance issues, cost savings, focussed inspection plans and assisting management in making informed, defensible operational decisions.

An important aspect of any RBI program is the practical application of the methodology in a facility. Inspection departments want to know how and when to inspect specific pieces of equipment and how to track inspections over a relatively long period of time. Typically 5,10 and 15 year plans are useful for a facility when planning scheduled maintenance and turnaround activities. It is therefore important that once equipment items have been risk ranked and prioritized, a comprehensive inspection program is developed. The frequency and scope of inspections as well as appropriate NDE techniques need to be described in comprehensive inspection plans for each equipment item. By conducting the correct inspections, using the correct inspection techniques, and carefully documenting the inspection findings, facilities can reduce the overall risk associated with equipment items and improve plant reliability.

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## Abstract

In order for a facility to extend the operating lifetime of pressure vessels and piping, safely and cost effectively, it is necessary to implement the latest inspection and maintenance strategies. Risk Based Inspection (RBI) has its roots in Process Safety Management and Mechanical Integrity programs and is gradually becoming accepted as good engineering practice for the implementation of inspection and maintenance programs. This paper describes the methodology, analysis and results of Risk Based Inspection studies conducted on several refineries and petrochemical facilities. These studies have resulted in numerous benefits for the plants, which include safety and compliance issues, cost savings, focussed inspection plans and assisting management in making informed, defensible operational decisions.

## INTRODUCTION

Risk Based Inspection (RBI) is rooted in the power industry, and in particular, the nuclear industry where probabilistic risk analysis (PRA), that was initially required by regulation, is now being used routinely for maintenance prioritization and risk informed decision making. These programs were designed to deal with what were called "Extreme Events" which were the low likelihood, high consequence scenarios. In the chemical industries, OSHA 1910. 119 and the Mechanical Integrity requirements were similarly developed to deal with the avoidance of high consequence or catastrophic failure events. Since fully quantitative risk assessments are expensive and time consuming to implement, organizations such as American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME) have begun to develop focused, practical programs specifically for the oil, gas, petrochemical and chemical industries[1].

Traditional inspection methods have involved inspecting equipment when the need or opportunity arose. These inspections were usually time based and were often unfocussed and indiscriminate, resulting in large amounts of irrelevant or meaningless data that contributed little to the risk management of equipment. RBI breaks from traditional programs in that it uses risk as a basis for prioritizing and managing the efforts of an inspection program. Since a relatively large percentage of the risk is associated with a small percentage of the equipment items, RBI permits the shift of inspection and maintenance resources to provide a higher level of coverage on the high-risk items and an appropriate effort on lower risk equipment. A potential benefit of a RBI program is to focus inspection resources on particular deterioration mechanisms and increase operating times and run lengths of process facilities while improving, or at least maintaining, the same level of risk. RBI represents the next generation of inspection approaches and interval setting, recognizing that the ultimate goal of inspection is the safety and reliability of operating facilities[2].

Risk based inspection focuses on mechanical integrity issues for the avoidance of catastrophic failure of plant equipment. It does not incorporate factors such as human, design and outside influences. As shown in figure 1, mechanical factors are the cause of approximately half the known catastrophic failures on facilities. The other half are caused by other influences not impacted on by mechanical integrity. These other factors should all be included in a comprehensive Process Safety Management (PSM) program.

## CONDUCTING A RISK ASSESSMENT

A risk assessment can be defined as the process of gathering data and analyzing information in order to develop an understanding of the risk of a particular process.

Three basic questions are considered to establish the basis for defining risk as follows:

- What could go wrong (scenario or event)?
- How often might it happen (likelihood)?
- What are the effects (consequences)?

Risk, may in its most simple form, be characterized as the product of probability of a given failure event, the Likelihood of Failure (LOF) and the consequences of that event, the Consequence of Failure (COF).

Risk assessments can be qualitative in nature through to quantitative. All assessments between these extremes are denoted as semi-quantitative. Qualitative answers are often sufficient to make robust decisions but as more detail is required, more quantitative methods are necessary in order to make difficult risk decisions. Calculating absolute risk can be very time and cost consuming and often, due to many uncertainties, is impossible. In the RBI methodologies, it is recognized that there are many variables in calculating the risks of loss of containment in petroleum and petrochemical facilities and the determination of absolute risk numbers is often not cost effective. RBI is focused more on a systematic determination of relative risks[2]. The key to conducting a successful risk analysis is choosing the correct method for the particular problem at hand, or choosing the appropriate techniques necessary to achieve corporate goals.

There are two impediments with implementing risk based inspection programs on facilities. The first is the need for the overall group to accept the notion of risk. The second is the acquisition of data. Plant personnel often feel that they have insufficient failure data in order to determine the frequency of failure.

If you can remove the misconceptions that

1) Risk is a theoretical tool without practical application and
2) Meaningful risk calculations cannot be performed in situations with sparse data,

the hardest part of the project is over[3].

### Process

In order to conduct a risk assessment in a systematic and methodical manner, a particular stepwise process is followed. Basic steps would include:

1) Hazard Identification
2) Likelihood Assessment
3) Consequence Assessment
4) Risk Evaluation and Reporting
5)

1) *Hazard Identification* - Hazard identification can help focus a risk analysis on key hazards and create discussion on what hazardous scenarios may occur. Hazard identification can be an implicit step that is not systematically performed (ie, a refinery contains large volumes of toxic, flammable

materials) or it can be explicitly performed using structured techniques. A HAZOP study identifies hazards and hazardous scenarios and their consequence but does not look at the frequency or probability of these scenarios.

2) *Likelihood Assessment* - Estimating the frequency of hazardous events can be conducted using several approaches. These include investigating historical data (inspection data or frequency of failure data), expert assessment of a system, conducting an event tree or fault tree analysis or using a cause analysis. The approach taken will depend on the goals of the program, the data available and the required sensitivity of the study.

3) *Consequence Assessment* - The modeling of consequences can involve the use of analytical models to predict the effects of certain scenarios. Many models exist for consequence modeling and these include dispersion models, source term models, environmental effects modeling, blast and thermal modeling as well as the effects of mitigation devices. Many databases exist that contain data on the toxic effects of materials on humans and the fire and blast effects on buildings and structures. Assessments can focus on business, safety, and environmental consequences.

4) *Risk Evaluation and Reporting* - The simplest form of reporting relative risk is by prioritization using numbers, or simply high, medium or low. Another approach is to use a risk matrix to assign risk. This is the preferred approach in RBI studies. An example of a risk matrix and its definitions is shown in figure 2. Each equipment item will fall within a cell in the matrix, corresponding to the likelihood and consequence of failure. One of the goals of a RBI program will be to define appropriate risk categories and what the response will be to each category. When conducting a fully quantitative risk assessment it is useful to demonstrate the sensitivity of the risk results in order to demonstrate the degree of uncertainty in the analysis.

## RISK MANAGEMENT

Based on the ranking of items and the risk threshold, the risk management process begins. For risks that are judged acceptable, no mitigation is required and no further action is necessary. For risks considered unacceptable, and, therefore, requiring risk treatment, there are various mitigation categories that should be evaluated.

It may appear that risk management and risk reduction are synonymous. However, risk reduction is only part of risk management. Risk management is a process to assess risks, to determine if risk reduction is required, and to develop a plan to maintain risks at an acceptable level. By using risk management, some risks may be identified as acceptable so that no risk reduction is required[2]. Figure 3 provides and overview of the risk management process. Risk reduction is the act of mitigating a known risk to a lower level of risk.

### Risk Reduction

The risk on a facility can be reduced by lowering the COF or LOF of equipment items, or both.
If the consequence of failure is deemed unacceptable, it may be reduced or mitigated by taking certain steps. These steps may include, emergency isolation, emergency depressurizing or de-inventory, modifying the process, reducing inventory or installing water spray, isolation valves, deluge systems etc.

If the likelihood of failure is deemed unacceptable it may be reduced or mitigated by equipment replacement or repair, evaluating flaws for fitness for service, equipment modification, redesign and re-rating, etc.

Obviously, inspection does not arrest or mitigate deterioration mechanisms. Inspection serves to discover, monitor, and measure the deterioration mechanism(s). Also, it is invaluable input in the prediction of when the deterioration rate will reach a critical point. Correct application of inspections will improve the user's ability to predict the deterioration mechanisms and rates of deterioration. The better the predictability, the less uncertainty there will be as to when a failure will occur. Mitigation (repair, replacement etc.) can then be planned and undertaken prior to the predicted failure date. The reduction in uncertainty and increase in predictability through inspection translate directly into a reduction in the probability of a failure and therefore a reduction in the risk. Inspection influences the risk associated with pressure equipment primarily by improving the predictability of the probability of failure[2].

## CASE STUDIES

**Example 1.** Occidental Permian owns several gas plants located in west Texas. Some of these facilities are approaching the end of their design life, resulting in increased failures and longer more costly turnarounds. In addition to this, the design of these plants does not lend itself to the partial shutdown and inspection of much of the equipment while the plant remains on-line. This has necessitated that management explore and implement the latest maintenance and inspection programs. Occidental (then Altura Energy) requested that Aptech Engineering Services, Inc. (APTECH) provide a RBI study at their plants, utilizing the API RBI methodology and software. The objective of the program was to create a safer workplace at the facilities by increasing confidence in the mechanical integrity of the equipment and decreasing or eliminating the cost associated with lost production incurred during extended shutdowns.

Results from this study indicate that the majority of risk carried by the Slaughter facility is contained in about 30% of the vessels and piping circuits. This number is higher than the industry average because of the age and condition of the plant. These results are shown in Figure 4. Many of the high risk items are driven by high consequence rather than by high likelihood. Since it is the objective of the inspection program to impact on the LOF of equipment items, a critical equipment list was developed for the facility. This list was based on all high risk items that contained a high LOF. It was recommended that these vessels receive priority and are inspected at first opportunity so as to reduce their risk and improve overall plant safety[4].

A week after the RBI study was completed, a caustic heat exchanger failed due to caustic cracking. This vessel had been identified as a critical vessel in the study because of its operating conditions and the fact that it had not been post weld heat treated (PWHT). NACE corrosion curves recommended that such a vessel undergo PWHT so as to avoid caustic cracking and this had been highlighted during the RBI study.

**Example 2.** On another facility, a Selexol regenerator was identified as a critical vessel due to its susceptibility to chloride stress corrosion cracking (SCC). Associated equipment in the re-boiler loop had failed previously due to SCC but the regenerator had not been considered susceptible. Subsequent internal inspections, recommended by the RBI study, found extensive chloride cracking. After a fitness for service study the vessel was recommended for replacement. The RBI study had recommended timely and pertinent inspections, resulting in the detection of damage that may have gone undetected and may have resulted in serious failure.

**Example 3.** Eastman Chemical Company owns and operates chemical, plastics, and fibers manufacturing plants through out the world. In late 1996, Eastman decided to pilot an RBI program for managing vessel inspections on it's largest manufacturing site in Kingsport, Tennessee. There are over 12,000 vessels at the Kingsport site, 5,000 of which are deemed critical and are included in the RBI program. These include a group of 200 vessels in one of Eastman's cellulose acetate production units, which had its biannual shutdown during July 2001.

In the past, a majority of these 200 vessels where opened for internal inspection every 2 years. Based on the results of the RBI study, it was found that only 12 vessels were critical and had to be opened during the July shutdown. The scope of inspection for these 12 critical vessels was increased significantly from previous inspections. This focused inspection plan resulted in successfully predicting and repairing three columns prior to pending failures. In all three vessels, severe crevice corrosion resulting from chlorides, in an acidic process stream, was predicted during the RBI study and then subsequently found on the gasket surfaces of manways and nozzles during the shutdown. This predicted discovery aided turnaround time. As a corrective course of action, the damaged 904L stainless steel gasket surfaces were weld overlayed with the more resistant alloy C-276 and re-machined to a flat sealing surface. This repair has mitigated the risk in these three critical process vessels by reducing the likelihood of a future failure.

## CONCLUSIONS

A significant economic advantage can be obtained by applying risk-based prioritization strategies to establish the most effective methods for scheduling and performing maintenance and inspection activities. A risk-assessment program can be developed to assist plant management in meeting corporate objectives of high reliability and low-cost operations. In this age of increasing global competition among producers, programs aimed at lowering production costs without adverse environmental, safety, and health impacts are critical. A risk assessment program will help plant management in meeting these objectives[1].

Pilot studies and full plant implementation have highlighted the benefits that can be obtained from such programs. These studies show the importance of the practical application of this technology in identifying potential damage mechanisms, and the timely prevention of possible failures. Finally, the broader application of these methods will be driven by the need to do more maintenance as equipment ages, with less resources, and, in particular, less manpower. This will establish the need for smart systems that ultimately integrate information from many different sources in order to enable maintenance and inspection decisions to be made effectively and safely.

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## Authors Details:

Stephen Anderson
Technology Manager
APTECH Engineering
12012 Wickchester, Suite 120
Houston, Texas
77079

(281) – 5583200 (phone)
(281) – 5583761 (fax)

sanderson@aptecheng.com

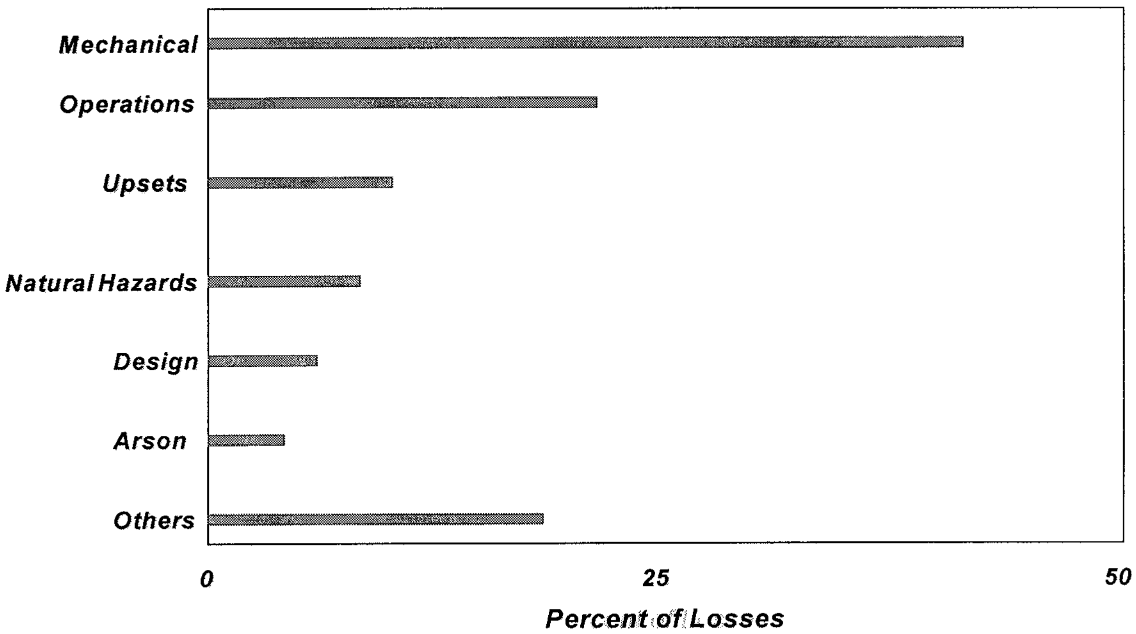


Figure 1 – Causes of Large Property Losses

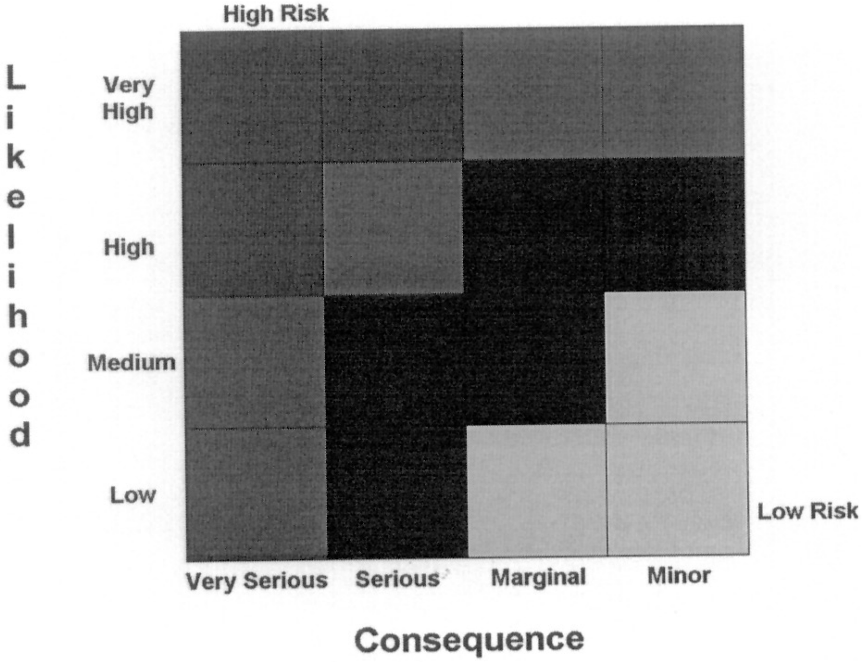


Figure 2 – RBI Risk Matrix

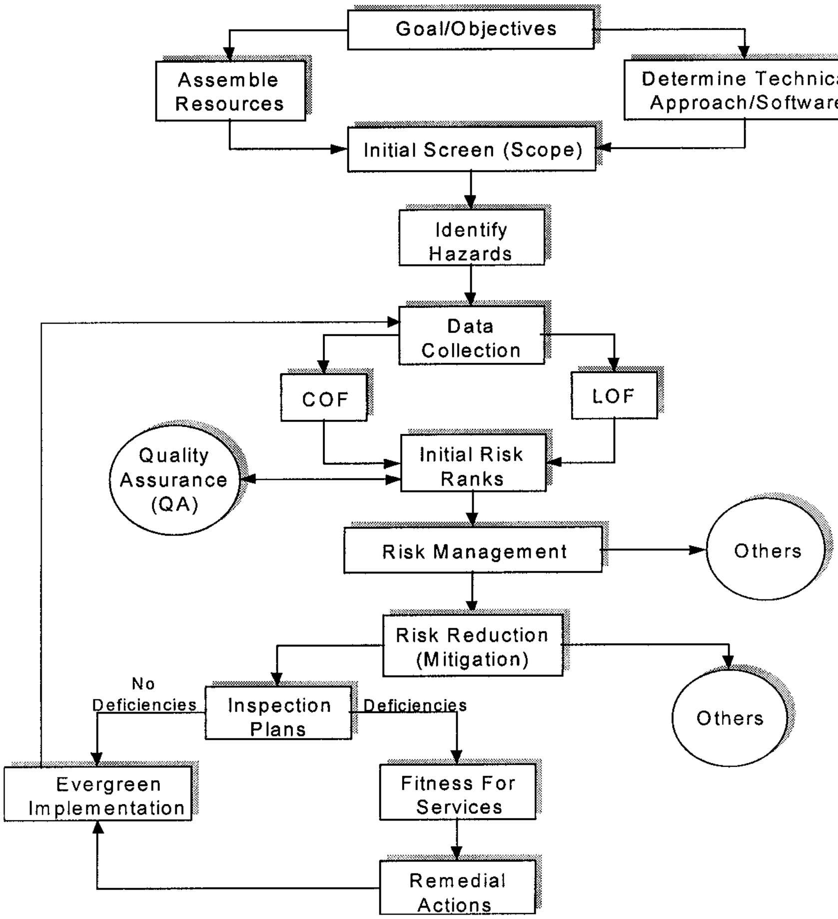
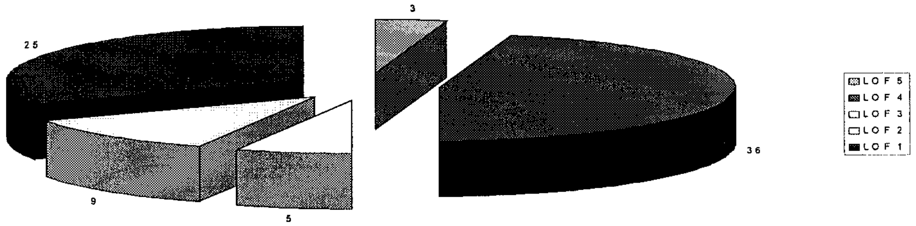


**Figure 3 – Risk Management Process**



**80 High Risk Vessels**
**39 High LOF Vessels**
**– Critical Equipment List**

**Figure 4 – Risk Based Inspection Results**