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The API Methodology for risk-biased inspection (RBI) analysis for the petroleum and petrochemical industry.

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SUMMARY

Twenty-one petroleum and petrochemical companies are currently sponsoring a project to develop risk-based inspection (RBI) methodology for application in the refining and petrochemical industry. This paper describes that particular RBI methodology and provides a summary of the three levels of RBI analysis developed by the project. Also included is a review of the first pilor project to validate the methodology by applying RBI to several existing refining unites.

The failure of pressure equipment in a process unit from corrosion or deterioration can have several undesirable effects. For the purpose of RBI analysis, the API RBI program categorizes these effects into four basic risk outcomes: flammable events, toxic releases, major environmental damage., and business interruption losses. API RBI is a strategic process, both qualitative an quantitative for understanding and reducing these risks associated with operating pressure equipment in corrosive services. This paper will show how API RBI assesses the potential consequences of a failure of the pressure boundary, as well as assessing the likelihood of failure. Risk-based inspection also prioritizes risk levels in a systematic manner so that the owner-user can then plan an inspection program that focuses more resources on the higher risk equipment; while possibly saving inspection resources that are not doing an effective job of reducing risk. At the same time, if consequence of failure is significant driving force for high risk equipment items, plant management also has the option of applying consequence mitigation steps to minimize the impact of a hazardous release, should on occur.

The target audience for this paper is engineers, inspectors, and managers who want ot understand what API Risk-Based Inspection is all about, what are the benefits and limitations of RBI and how inspection practices can be changed to reduce risks and/or save costs without impacting safety risk.

INSTRODUCTION

The concepts of risk analysis have been around for a long time. What is new and encouraging, is that the media and the public are beginning to understand and appreciate that governmental entities do not have the resources to eliminate every minute risk of every undesirable event known to man, and that prioritizing our concerns with a systematic process that exposed "real risk" makes sense.

RBI adapts risk analysis to the process of inspecting for corrosion damage in pressurized equipment. We know that there are two extremes of inspection, both undesirable. One extreme is very little inspection replacing pressure equipment and piping when it leaks or fail. The reason why this extreme is unacceptable is obvious. On the other extreme is inspection of all pressure equipment so often and so thoroughly that it becomes uneconomic to compete in the marketplace. So enter RBI to help us decide what, when, and how to inspect pressure equipment to manage and/or optimize our risk reduction program.

On the other hand RBI is a bit of a misnomer. It is really RBM, Risk-Based Management, since the risk assessment process utilized in RBI also may expose opportunities for management decision making to reduce risks through consequence mitigation.

So where do we start? How can we cost-effectively reduce the risk of a catastrophic event associated with the failure of our pressurized equipment from various forms of corrosion or other metallurgical deterioration? What is our highest risk equipment? How do we design a cost-effective inspection program that doesn’t just find corrosion but actually reduces the risk of failure?

Engineers know that all equipment contains flaws, in a pragmatic sense, there is no perfect fabricated equipment. Fortunately, most flaws are innocuous, or what I refer to as a "fortuitous collection" of flaws. Like the last airplane on which you flew, which also contained many flaws, though none of them critical, the industry pressure equipment contains many flaws. A few might lead to leaks, and extremely few might lead to catastrophic failure. The challenge for us is to be able to cost-effectively find those few critical flaws that could lead to nasty events. Risk-based inspection technology can point us in the right direction.

API RBI covers only the breach of pressure containing members, i.e. vessels, columns, exchangers, piping, furnace tubes, tanks, etc. It does not cover the functional failure of non-pressurized equipment, e. g. instruments, electrical gear. Control systems, etc.

THE OBJECTIVE OF RISK-BASED INSPECTION

Risk-based Inspection (RBI) is an integrated methodology that factors RISK into inspection and maintenance decision making. RBI is both a qualitative and quantitative process for systematically combining both the likelihood of failure and the consequence of failure to establish a prioritized list of pressure equipment basis total risk. Form tat list, the RBI user has the opportunity to design an inspection program that manages (reduces or maintains) the risk of equipment failures.

One of the significant benefits of RBI is that it is a very helpful tool for integrating engineering knowledge of corrosion mechanisms with the inspection discipline. Corrosion engineers know why corrosion occurs, what form of corrosive attack is likely to occur (e.g. general thinning. Localized corrosion, potting, stress corrosion cracking, etc.) and they also know where to look for the anticipated degradation. The API RBI process effectively integrates this knowledge base into inspection practices in order to reduce risk of failure. In his regard one of the real benefits of the API RBI methodology is that the user has distinct choices with regard to utilizing corrosion data and/or information:

1. Entering corrosion rates from measured thickness data.
2. Entering estimated corrosion rates from literature, laboratory data, or expert opinion of knowledgeable resources, or
3. Having the RBI corrosion models calculate a rate for the user.

Utilizing more than one of these options allows the user to achieve a rank of corrosion rates, which when used like a "what if" analysis leads to a rank of calculated risk.

AN EXAMPLE OF RBI IN ACTION

Imagine, if you will, that you have completed an RBI analysis on your gas fractionation plant. You now have a prioritized list of all 600 pieces of pressure equipment (including all piping circuits). This list clearly indicates that 80% of your risk of failure is associated with only 20%. Figure 1 shows a typical risk plot for our hypothetical case. It may not always happen that way but it is not unusual. For instance, you now know where to focus your inspection and testing resources to avoid high risk failures. For example, you now know that the 12 inch diameter line on the overhead of your depropanizer ranks number 18 on your prioritized risk list of 600 items, and that if it should happen to fall that 25,000 square feet of your plant might be at risk of destruction, from a possible vapor cloud explosion.

Table 1 shows an example of 8 pieces of equipment selected from a list of 60 equipment items prioritized in the gas treater section of our hypothetical case. From this list, one can see how total risk in a process unit can vary by 4 orders of magnitude, and how risk for some items is driven by likelihood of failure (LOF) and others are driven by consequence of failure (COF). Note specifically that the highest risk piece of equipment is driven by high LOF and high COF. However, the fourth highest risk piece of equipment has a "relatively" low COF, but is the highest LOF piece of equipment. And vice versa, the ninth highest risk piece of equipment is "relatively" low on the LOF scale, but number one in the COF list. This sort of information about what drives total risk is vitally important to the eventual decision making on how to reduce risk.

With this information you could concentrate more of your resources on preventing failure of those relatively few high risk pieces of equipment that are driven by potentially high consequence events or high likelihood of failure. As you look back on your current inspection program, as good as you might think it is, you might discover that you have been focusing mostly on equipment with higher likelihood of a leak, and not so much on equipment with a high combined total risk, driven also by higher consequence potential.

INDUSTRY LOSSES

According to one report of the 170 major losses in our industry during the last 30 years, upwards to half of those losses are caused by mechanical failure of equipment (Figure 2). Over 80% of the equipment failure category are caused by the failure of pressurized equipment, e.g. piping, vessels, columns, reactors, tanks, pumps and exchangers (Figure 3). Risk-based inspection methodology is focused on that pressure envelope, including the potential for pump seal failure. The frequency and cost of those 170 largest losses has increased significantly over the last 30 years (Figure 4). Application of RBI should be able to reduce those losses attributed to mechanical failure.

LEVELS OF RBI

Three levels of risk based inspection have been developed by the API sponsor group for prioritizing risk levels associated with individual pieces of pressure equipment.

Level I Qualitative RBI which utilizes a simple, single-screen format to risk rank process equipment into a 5 X 5 risk matrix (Figure 5). Because of its simplicity, Level I is quick and easy, but results in fairly conservative risk rankings. Level I analysis is meant for initial pre-screening of risk, and is a good tool for demonstrating API RBI methodology.

Level II Semi-quantitative RBI, which is an intermediate method of quantitative RBI (Level III), for risk ranking individual pieces of equipment in a process unit. Level II also uses a 5 X 5 risk matrix for displaying risk analysis results (Figure 5). Level II RBI analysis asks more questions, and therefore takes more time to accomplish, but results in more accuracy and avoids overly conservative risk ranking that may result from simpler methods.

Level III Quantitative RBI which is more detailed (and more accurate) method of risk ranking individual pieces of equipment in a process unit. Level III calculates a specific consequence score, a specific likelihood of failure score and a specific risk score for each piece of equipment in a process unit. Typically, the user is expected to utilize Level III analysis for equipment that ranked up into the higher risk categories when prioritized by Level II analysis.

Each of these three types of RBI are explained more fully in the following sections. A software package is being developed for all three levels of RBI analysis. Level I and II RBI software has now been issued for use by sponsor group companies. Level III software should be available by 3Q/1998, in a totally integrated software package containing all three levels of API RBI.

INITIAL SCREENING OF PROCESS UNITS

The first step in the application of RBI is the qualitative risk-ranking of entire process units (or segments thereof) utilizing a risk-matrix like that shown in Figure 5. A 17-page workbook has been developed to rank the risks associated with each process units, based upon the consequence of an event as well as the likelihood of an event. Fifty different aspects of health, safety, and mechanical integrity of process units are covered in the workbook, and it only takes 2-4 hours to complete the workbook for each process unit, depending upon the availability of data and information. In the analysis, each process unit is given a potential likelihood ranking (1-5) and a potential consequence ranking (A-E), which then places the unit in one of the 25 segments of the risk matrix shown in Figure 5.

After screening all of the process units or portions of units at a given manufacturing site, the user gains appreciable insight as to where to begin conducting RBI analysis utilizing Level I,II, or III for equipment items.

Interestingly, when the RBI development sponsor group each conducted qualitative ranking on two selected refining units from their own sites, the group was surprised to see how similar process units ranked so differently on the matrix. For example, similar catalytic cracking units could rank quite differently from each other based on issues like proximity to community, record of unscheduled shut-downs, the presence of safety systems and management systems to improve safety, total inventory of flammable or toxic hydrocarbons, existence of isolation valves, proximity to other high value capital assets, as well as the mechanical integrity record of the units. All these issues, and several more, can have a significant effect on the total risk associated with each process unit.

Having qualitatively risk-ranked all process units in a plant, the user is then ready to select a higher risk process unit for a qualitative, semi-qualitative, or quantitative risk-based inspection analysis on each piece of pressure equipment in the selected process unit. The quantitative RBI analysis (Level III) will be described next, because semi-quantitative (Level II) RBI analysis will then be easier to explain, since it is just a simplified version of Level III. Likewise, Level I RBI analysis is the quickest, easiest risk ranking method. It is a simple qualitative method that the user can apply to each piece of equipment and have results in a matter of minutes.

QUANTITATIVE RISK RANKING

A simplified block diagram of the quantitative (Level III) RBI methodology is shown in Figure 6. A glance at the diagram reveals why we refer to RBI as an integrated methodology. The analysis looks not only at the inspection records and equipment design and maintenance records, but also at numerous process safety management issues and all other significant issues that can affect the overall mechanical integrity and safety of a process unit. RBI analysis does not look solely at hardware programs to establish risk.

The likelihood of failure is calculated for each piece of pressure equipment in the process unit. Starting with generic failure frequencies gleaned from several sources of available data, an adjusted failure frequency(AFF) is calculated by modifying the generic failure frequency (GFF) to arrive at a failure frequency that is specific to each piece of your equipment. The calculation is represented by the following formulas and is shown schematically in Figure 7.

$$AFF = GFF * F_E * F_M$$

The generic failure frequency (GFF) is modified by a factor (hardware factor F_E), that is specific to the mechanical integrity of the specific piece of pressure equipment being evaluated, and also by a factor (management factor F_M), that is specific to the quality of your management of safety systems that affect mechanical integrity. The latter is obtained by the use of a workbook that evaluates the effectiveness of your safety management program.

The adjusted frequency of failure (AFF) is then combined with the consequence analysis in a model that produces the risk ranking of all pieces of pressure equipment. Some of the issues that are assessed (quantitatively) to calculate the specific equipment modification factors (F_E) include:

- Type and rate of damage expected (e.g. corrosion, cracking, property degradation)
- Quality and scope of inspection program (e.g. frequency, methods, tools)
- Maintenance and repair quality control program (e.g. control of workmanship)
- Design and construction standards utilized (e.g. active code, API codes)
- Equipment and process histories (e.g. quality of inspection records)
- Preventive maintenance programs (e.g. PSV servicing, insulation maintenance)

Most of the issues that are assessed to calculate the specific management factor(F_M) come directly from API-RP 750, Management of Process Hazards. This evaluation is also facilitated by the use of a 19 page workbook that assesses the potential impact on mechanical integrity of various management system factors like:

- Maintenance procedures and training
- Process safety information
- Management of change procedures and practices
- Operating procedures
- Process hazards analysis

ASSESSMENT OF EQUIPMENT DETERIORATION

The heart of the equipment modification factor (F_E) is the assessment of potential damage mechanisms (e.g. localized corrosion or wet H_2S cracking) and damage rates (e.g. corrosion rates or cracking rates). This assessment is embodied in the technical modules which are used to calculate the equipment modification factor.

The other primary issues assessed by the technical modules are the effectiveness of the current inspection program in finding and monitoring the identified damage mechanisms. Inspection effectiveness for each damage mechanism is rated as:

- Highly Effective – finds the damage nearly always
- Usually Effective – finds the damage most of the time
- Fairly Effective – finds the damage about half of the time
- Poorly Effective – usually does not find the damage
- Ineffective – does not find the damage

Separate technical modules are being developed for each of the different types of damage mechanism operative in petrochemical process equipment, as for example:

- General or localized corrosion mechanisms
- Stress corrosion cracking mechanisms
- Hydrogen assisted cracking problems
- High temperature hydrogen damage
- Brittle fracture, and other mechanical/thermal effects

To date, technical modules for the following specific damage types are complete; Metal thinning due to corrosion:

- HF Acid
- H_2SO_4
- HCL
- Napthenic Acid
- Sour Water
- Oxidation
- Corrosion under Insulation
- High Temperature Sulfide
- Amines

Environmental cracking damage mechanisms:

- Caustic
- Amines
- HIC/SOHIC
- Carbonates
- Sulfides
- Hydrogen (HF Systems)
- Polyphonic Acid
- Chlorides
- Hot Hydrogen

In the near future, technical modules for the following mechanical/metallurgical damage mechanisms are expected to be completed:

- Temper embrittlement
- 885 F embrittlement
- Sigma phase embrittlement
- Graphitization
- Erosion
- Brittle fracture
- Fatigue
- Creep/creep cracking

CONSEQUENCE ASSESSMENT

A simplified block diagram of how failure consequences are assessed is shown in Figure 9. Equipment size and installed isolation devices play a big part in the calculation of available inventory for potential events. The size of the leak or rupture and the likelihood of a release being instantaneous or continuous for a period of time will have much to do with the size and type of potential event. Hole size calculations for four events are calculated and summed, ranging from ¼" leak up to full rupture. For flammable events, calculations are made to determine if the event is likely to be a vapor cloud explosion, a flash fire, a jet fire, a liquid pool fire, or safe dispersion (no ignition).

The effect (dollar loss) of business interruption is included when a quantity of capital assets might be lost or shut-down for a period of time after an event. The cost of catastrophic environmental effects can be included, especially in the event a potential liquid release might flow off-site, as for instance into a water resource. Potential human toxic outcomes are also assessed, where a toxic gas might be released.

The final report on each RBI contains, not only the prioritized risk ranking (combined likelihood and consequence of failure), but also contains a prioritized list of equipment by both likelihood of failure only and consequence of failure only. This allows the user to focus on the specific issues that drive up total risk, and to understand whether total risk is driven primarily by likelihood of failure or primarily by consequence of failure. That understanding is vital to user decision making about how to reduce risk levels associated with each piece of equipment.

RISK ANALYSIS

Since risk is the product of both likelihood of a failure and the consequence of a failure, the mathematical expression for risk is:

$$RISK_S = C_S \text{ X } Fs$$

Where,

S = Failure Scenario Anticipated (Hole Size)

C_S = Consequence for Each Failure Scenario

F_S = Frequency Anticipated for Each Scenario

The frequency anticipated for each scenario (F_S) is calculated using the Adjusted Failure Frequency (AFF).

Then the risk for each piece of equipment (press vessel, pipe circuit, etc.) is the summation of all the risk calculations for each of four hole sizes:

$$RISK_{EQUIP} = \Sigma_s RISK_s$$

Where,

$RISK_s$ = Risk for Each Scenario (1/4", 1", 4", and rupture cases)

$RISK_{EQUIP}$ = Total Risk for Each Piece of Equipment

The units of risk are expressed in terms of potential damaged area/year for flammable and toxic events, or potential dollars lost/year for business interruption or major environmental damage.

SEMI-QUANTITATIVE RBI

A semi-quantitative version of risk-based inspection has also been developed. This shortened process (Level II) is an 80/20 version of that described previously, and is expected to produce 80% of the results with 20% of the effort. The API sponsor group foresees Level II RBI analysis being more widely accepted for a broader range of RBI analysis, while the accuracy and depth of Level III RBI analysis is expected to be more oriented toward the higher risk process equipment identified in Level II RBI analysis.

The semi-quantitative RBI analysis (Level II) retains all of the vital aspects of risk analysis utilized in Level III analysis, but makes numerous simplifying assumptions, thus significantly reducing the time and effort to collect data and to conduct an RBI analysis.

Likelihood of failure is based solely upon the assessment of potential damage mechanisms and the effectiveness of the inspection program for finding those identified damage mechanisms. All other aspects of process safety management and mechanical integrity programs included in Level III analysis are deleted for the simplified Level II analysis.

The consequence analysis is largely the same as it is in quantitative RBI analysis. However, the data collection and calculation of consequences are significantly simplified by classification of equipment into size categories rather than detailed calculation of equipment and piping size and inventory.

The results of Level II analysis are plotted on the dame risk matrix utilized for Level I analysis (Figure 5).

RISK REDUCTION THROUGH INSPECTION

The final report for Level III RBI on a particular process unit will contain a prioritization ranking of each piece of equipment for three different levels of inspection activity:

1. a minimal inspection plan
2. the current actual level of inspection, and
3. an optimized level of inspection

These print-outs yield an understanding to the user of how different inspection programs with different levels of inspection activity affect total risk levels by changing the likelihood of failure.

Having calculated a total risk for each piece of equipment, the next step is to decide what to do with the risk-prioritized list of equipment. There are a lot of opportunities for risk reduction in our business, and clearly refines and petrochemical companies are spending millions of dollars toward that end, one of those potential risk reduction efforts is our inspection and testing (I&T) program. Once we know what our highest priority pressure equipment, we will be able to determine very specifically where our IT efforts should be focused to reduce total risk.

First, and most obviously, the frequency of inspection can be adjusted. But also, the methods and tools for I&T can be changed. The scope, quality, and extent of the inspection and data taking can be adjusted. More global I&T techniques (like AE and thermography) can be applied, when appropriate. More on-stream inspections can be utilized to assess damage occurring while in-service. Inspections can be more focused at areas of expected damage. Where appropriate, more sophisticated tools and techniques can be used to find and characterize localized damage and cracking (like automated ultrasonic backscatter or tomoscanning).

These changes in inspection activity are tan planned into upcoming scheduled inspection, e.g. turnaround planning, as shown in Figure 10. Once the inspections are conducted, results analyzed, equipment assessed for continued fitness for service, recommended repairs conducted, then the user is ready to feed the information back into the RBI model to determine how total risk for each piece of equipment was affected by the changes in inspection activity. After "a few turns of the crank". Out pops another reprioritizes list of equipment, and the user gains an appreciation, quantitatively, for how the risk of a nasty event in the process unit has been changed.

Lower risk equipment might have received less inspection resources and activity, while not appreciably affecting its risk of failure. Higher risk equipment on the list might have dropped in risk ranking appreciably, as a result of having received more inspection and maintenance attention during turnaround. Overall, you may reduce not only the potential for injury, capital asset loss, and production losses, but you may be able to accomplish that with fewer inspection resources.

Inspection program optimization

One possible outcome of RBI analysis could be an effort to optimize your inspection program, by obtaining the lowest reasonable risk at the lowest cost. To accomplish this, a company may find that it can shift its limited inspection resources away from low risk equipment (which may be over-inspected) toward the higher risk equipment (that may be under-inspected). Figure 11 shows a log-log risk plot for a hypothetical process unit. The iso-risk lines (lines of constant risk) help to clearly differentiate higher risk equipment from lower risk equipment.

From these kinds of log-log plots, management will eventually have the opportunity to focus inspection and/or mitigation resources on equipment items that fail above a maximum acceptable risk level in such a manner tah total rsik is minimized. The changes in risk brought about changes in planned inspection activity can then be assessed with RBI analysis, and compared to changes in inspection resources utilized, to determine if risk optimization is being approached, i.e. that total risk is decreasing and inspection costs are decreasing.

INITIAL RBI PILOT PROJECT

As part of API sponsored project for RBI methodology development, a pilot project was carried out at one of the sponsor company operating sites. Two complete and two partial process units (including 500+ pieces of equipment) were selected for RBI analysis utilizing the methodology developed for this project. The results validated that the RBI methodology does what it was designed to do. In each case the highest risk equipment was clearly identified and the driving force behind the higher risk pieces of equipment was indicated. Print ours were delivered that indicated whether higher risk items were driven by higher likelihood of failure, higher consequences of failure or both.

Additionally, log-log plots like that shown in Figure 11 were supplied on each process unit, which graphically reinforce the risk prioritization lists.

Inspection optimization print-outs were also supplied that indicated how to reduce the risks associated with higher risk equipment by increasing either the effectiveness of the inspection technique or the frequency of inspection. On the other hand, it was aslo obvious from the RBI analysis that some equipment may be receiving more inspection attention than is necessary or appropriate for lower risk equipment. As such, the user has the option of shifting some resource away from lower risk equipment, and applying them to lower the risk of the few pieces of higher risk equipment. In one process unit, the results showed that implementation of an optimized inspection plan could lower total existing risk for the unit by a factor of four.

RSIK BASED MANAGEMENT

RBI is really RBM (Risk-Based Management); though RBI is focused on risk mitigation through inspection activities, its application is much broader. Since RBI is a fully integrated methodology, the user also has the opportunity to reduce risk by means other than changing the inspection program. There may be a number of opportunities to strengthen process safety management systems and procedures. The user can also lower risk by installing safety systems, leak detection systems, isolation valves, and anything else that might mitigate consequences, once a release has occurred. So RBI is a management tool for risk reduction that goes beyond inspection activities.

RELATIONSHIP OF RBI TO MECHANICAL INTERGRITY STANDARDS AND REGULATIONS

Risk-based inspection integrates well with current editions of industry inspection codes/standards like: API-510, the Pressure Vessel Inspection Code, API-570, the Process Piping Inspection Code, and API-653, the Storage Tank Inspection Standard. In fact, just recently the API CRE (Committee on Refinery Equipment) balloted and accepted recognition of RBI in both API-510 and API-570. The new paragraphs will be published in the 1998 addenda to codes. API-653 is now in the process of balloting RBI recognition for storage tanks. Though each of these standards sets forth minimum practices for inspection frequencies and many recommended practices for inspection activities associated with pressure equipment, each now allows inspection plans and strategies (including frequency) to be established by following the principles of a quality RBI program. Just as is the case with the mechanical integrity aspects of process safety management regulations (OSHA 29 CFR1910.119), these codes now offer the user much flexibility and many options relative to the frequency, scope and extent of inspection options to optimize the inspection program for the purpose of reducing risk.

THE FUTURE OF RBI

RBI software is being created and improved to minimize the resources necessary to conduct an RBI analysis for Level I, II, and III. Additionally there is a need to closely align, and perhaps integrate, this methodology with Reliability Centered Maintenance (RCM). RCM focused on the functionality of equipment to determine what preventive maintenance may be needed to improve the reliability (availability) of process equipment. Clearly, the failure of the pressure boundary of equipment is the ultimate reliability impact, and can have a large, long term impact on process unit reliability. Utilizing RBI to assess the potential for loss of containment integrates very well with RCM, by yielding a more complete analysis of total reliability.

Additionally, RBI integrates very well with PHA (Process Hazards Analysis). PHA’s focus primarily on process hazards and not as well on mechanical integrity hazards (which are what RBI focuses on). So integrating the results of RBI with PHA’s can significantly increase the quality of your PHA risk assessments. After all, over 40% of the largest catastrophic losses in our industry are caused by mechanical integrity problems (Figure 2).

We also are building an industry failure data base for pressure equipment. An industry specific and equipment specific failure data base will increase the accuracy of our failure frequency calculations, as well as efficiency of the RBI analysis. This effect is now underway with the creation of the CCPS and Solomon On-Stream failure databases that will collect failure data in the petroleum and petrochemical industry for both RBI and RCM analysis.

Eventually the future of RBI is envisioned to be full acceptance by refining and petrochemical operators, and acceptance by jurisdictions and insurers as a sound basis for lowering facility risk levels by applying the appropriate inspection and maintenance activities to each item, depending upon risk level.

As of this writing, the concepts and application of RBI in the petroleum and petrochemical industry are still on a steep learning and application curve. It is my hope and expectation that the application of RBI within the industry will be starting to mature by the turn of the century. Figure 12 shows what I forecast to be the stage of RBI technology development and field application in our industry by the year 2000, as well as depicting where I believe the technology and application stand today.

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