

Risk-Based Decisions

Important decisions in life and business are:

Know when to **accept** the risk.

Know when to **reject** the risk.

The math for risk is easy to express: $\$Risk = (\text{probability of failure}) * (\$Consequence)$.

The hard part of risk is:

1. Understanding how much risk (\$Risk) you can tolerate.
2. Deciding the probability of failure.
3. Evaluating the \$Consequence.

These same elements are included in risk-based inspection (RBI) decisions described by publications from both [API](#) and [ASME](#).

A Simple Insurance Issue To Illustrate Some Ideas:

In our private lives, we set the limit on how much risk (\$Risk) we can tolerate. You do this when selecting the deductible limits on automobile insurance. For some people the amount we have to pay out of our pocket for an accident is US\$100, while others with more financial ability may accept US\$5000 as the limit for the little example in Table 1.

The financial consequence for automobile insurance is determined by the calamity of an accident. If the consequences involve the loss of human life the price, in the litigious USA, may vary from US\$5,000,000 (for the loss of a single life) to US\$30,000,000 (for the permanent disablement of a human). Five hundred years ago Niccolo Machiavelli, in his book [The Prince](#), warned of the high cost for wounding an individual versus the costs for a fatality! The cost consequence for loss of a human life has a different value in various parts of the world.

Cost for the loss of multiple lives accelerates at a rapid rate which in turn infers the allowed probability for loss of multiple lives must be substantially less to control the \$Risk and society sets limits for some probability of failure. Societal risks are explained in tables/figures in Dr. Ernest J. Henley's book, [Probabilistic Risk Assessment and Management for Engineers and Scientists](#), 2nd edition along with guidance in Henley's book for legal and regulatory risks.

Automobile Insurance Risk Issues		
Low \$Risk	\$	100
High \$Risk		\$ 5,000
Low \$Consequence	\$ 5,000,000	\$ 5,000,000
High \$Consequence	\$ 30,000,000	\$ 30,000,000
Low Probability Of Failure	0.000020	0.001000
High Probability Of Failure	0.000003	0.000167
Societal Limits On POF For Human Life	0.0001	0.0001
Insurance Premium Payment	High	Low

The automobile insurance example says we can only tolerate the probability of failure in the range of 0.000003 to 0.001 as shown in the table below. However, don't be enamored with the math. Common sense must prevail because society sets limits

on what is an acceptable probability of failure where human life is involved (i.e., the probability of failure cannot exceed 0.0001). Furthermore practical abilities set the limit on the experience of a large number of drives for the accident rates stored in history files of insurance companies.

From this little example, you can see some people/businesses will be risk adverse or risk accepting. Also each person/business will have different values for the probability of failure. Furthermore society demands a cap on the probability of failure for some events thus the math model must be used with good judgment.

Watch out for the lure of making risk-based decisions a mathematics problem. ***Start with and use common sense.*** Begin with a qualitative approach. A top-down fault tree mentality can speed your analysis. You'll be amazed at what you can learn and how effective simplicity can be in resolving issues. In the second pass, grow the issues to a semi-qualitative analysis. Finally, (if required) perform a quantitative analysis.

Risk-Based ASME International resources:

A good first book for risk-based methodology is available from the [ASME Bookstore](#) with the title [Risk-Based Methods For Equipment Life Management: An Application Handbook](#). (2003) (price US\$175) This book is from the Center for Research and Technology Development, Research Committee on Risk Technology, CRTD-Vol. 41 which includes a CD with spreadsheet templates for risk analysis, fault trees, etc. The Handbook supplements:

[1991 Risk-Based Inspection-Development Of Guidelines: General Document: Volume 1](#) (1991) (price US\$100) which "...describes and recommends appropriate processes and methods using risk-based information to establish inspection guidelines for facilities or structural systems." **A**

[Risk-Based Inspection-Dev Gdlns-Light Water Reactor Nuclear Power Plant Components: Volume 2 Pt 1](#) (1992) (price US\$100) "Includes relationship to general risk-based inspection methodology, overall process for risk based inspection, overview of the methodology, status and plans for further development, text references, figures, and tables." **B**

[Risk-Based Inservice Testing dev of Gdlns Light Water Reator Nuclear Pwr Plnt Comp: Volume 2 Pt 2](#) (1996) (price US\$100) "...is the *second* in a series...which describes a general risk-based process..."

[Fossil Fuel-Fired Electric Power Generating Station Appl Risk-Based Inspection Dev: Volume 3](#) (1994) (price US\$100) "the *third* in a series ...on risk-based inspection guidelines [which] describes a general risk-based process that can be used to develop inspection guidelines that address structural integrity concerns..." **C**

[Risk-Based Inspection-Development of Guidelines: Light Water Reactor Nuc Pwr Plant Component Vol 2 Pt 2](#) (1997) (price US\$100) "This volume, *fourth* in the series...describes and recommends a risk-based selection process for application to piping..." **D**

[Risk Based Inspection-Development of Guidelines Series: 4 Volumes \(CRTD201-204\)](#) which contains **A, B, C** and **D** (price US\$275)

[Risk Based Inspection Dev Gdlns-Light Water Reactor Nuclear Power Plant](#)

[Components: 2 Volumes \(CRTD202/204\)](#) which contains **B** and **D** (price US\$165)
[1995 Risk and Safety Assessment: Where Is the Balance?](#) (1995) (price US\$150)

“...the 54 papers in this volume discuss the following topics: Risk-Based Decision Making; Risk Assessment Methods and Approaches; Applications of Risk-Based Methods; Risk Reduction Strategies...”

[Risk-Based Inservice Testing—Development of Guidelines Volume 1—General Document](#) (2000) (price US\$60) which introduces risk-based processes centered on three major areas:

1. “The identification of high-risk and low-risk impact operating equipment using risk-ranking techniques that take into account system functions, component performance and equipment service conditions.”

2. “The identification of equipment or component-specific failure-cause processes, to develop highly effective test strategies, in terms of both safety and economics, for determining precursors to failure that are applicable to the high-risk impact components.”

3. “The identification of test strategies that adequately assess the performance of low-risk impact equipment”

[ASME Standard PCC-3-2007: Inspection Planning Using Risk-Based Methods](#) was developed specifically for planning and executing risk-based inspection of fixed pressure-containing equipment and components. Equipment covered includes piping, boilers, pumps, compressors, heat exchangers, furnaces, storage tanks, and valves. The planning takes the concepts of RBI and applies them to issues such as frequency of inspection. The standard is largely based on concepts started in API’s RP-580 on Risk-Based Inspection and RP-581 on Risk-Based Inspection Technology.

It is API’s intention to migrate the recommended practice (RP-580) to PCC-3 over a several year time frame.

In PCC-3 risk is defined as the possibility of suffering a harmful event which is defined as Risk = (probability of an event)*(consequence if the event happens). The probability of failure is based on identifying both active and plausible damage mechanisms along with established rates of damage and the effectiveness of inspection programs for the damage mechanisms [If you believe 100% inspection is absolute identical to finding all defects, take the [Inspection Test](#) to see how effective you are in either numbers or words as listed in the downloadable [Monte Carlo models](#)—be sure to rigorously perform your inspections in the allotted 5 minute test period].

PCC-3 allows both qualitative RBI (the analysis is dependent upon using descriptive information based on engineering judgment and experience to determine a probability and consequence of failure) and quantitative RBI (the analysis is based on numerical measure for the change of failure and it varies from 0 which says it will never happen to 1 which says it will always happen) and the standard does not consider qualitative vs quantitative to be better as most RBI programs are mixtures of each method.

PCC-3 is not intended to be used for nuclear power plant components: see ASME BPV, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.

An easy to read article on PCC-3 was published in ASME’s magazine *Mechanical Engineering*, March 2009, pages 38-41.

Price for the print book is US\$65 (ASME order number A16807) and for a digital

PDF is US\$65 (ASME order number A1680Q).

[ASME Risk-Based Methods for Equipment Life Management: An Application Handbook, A Step-by-Step Instruction Manual With Sample Applications](#) is a supporting document from the Center for Research and Technology Development, Volume 41 (CRTD-41) for ASME Standard PCC-3-2007. Price is US\$175 or US\$140 for members for the 300 page book (ASME order number I00474).

Risk-Based API resources:

Another reference that will tell you voluminous details about risk-based inspection methodology is **API Publ 581 Base Resource Document—Risk-Based Inspection**. To find the abstract, go to

http://www.api.org/Publications/upload/2009_Catalog_Web_MarchUpdate.pdf and search for **Publ 581** (price US\$644 for hardcopy or PDF). The API abstract for Publ 581 sets three major goals for the RBI program:

1. “Provide the capability to define and quantify the risk of process equipment failure, creating an effective tool for managing many of the important elements of a process plant.”
2. “Allow management to review safety, environmental, and business-interruption risks in an integrated, cost-effective manner.”
3. “Systematically reduce the likelihood and consequence of failure by allocating inspection resources to high risk equipment.”

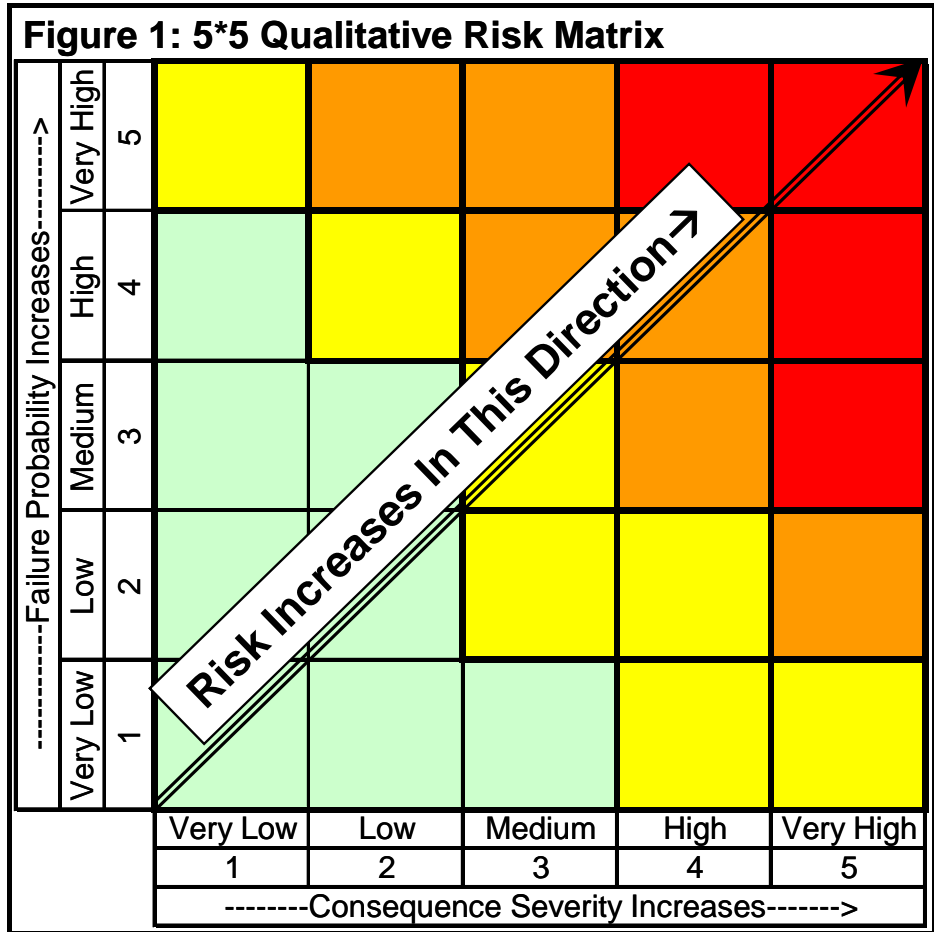
API’s RBI also owner/users to establish inspection plans as an alternative to the traditional:

API 510 Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration, 8th edition (price US\$107 for hardcopy or PDF) of the 33 page document, or

API 570 Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems, 2nd edition (price US\$93 for hardcopy or PDF) of the 38 page document.

You can order these API documents from [Global Engineering Documents](http://www.globalengineeringdocuments.com) website.

The Risk Matrix:



Both ASME and API risk-based techniques generally use a 5*5 risk matrix as shown in Figure 1.

Why only 5 zones of consequence and only 5 zones of failure probability? Experience has shown this is a practical range for many issues. More zones and you spend much time splitting hairs. Fewer zones and you

have many arguments over the appropriate categories. Be pragmatic about the number of zones required as no perfect answer exists.

If qualitative numbers are used in Figure 1 they represent the likelihood of occurrences. The maximum score of 25 is obtained by multiplying the score of probability times the severity; and the least score is 1. The verbal descriptions and the numeric descriptions respond to end users who either think by the numbers or think by the simple language describing the events. The scoring systems are not unlike failure mode and effects analysis (FMEA) rating systems.

Risk increases along the diagonal from the lower left hand corner to the upper right hand corner. Each color generally represents zones of roughly equal amounts of \$Risk. Again, use judgment in setting the color bands to conform to your special situations. The colors and hence the \$Risks are not always fixed.

The upper right hand corner red zone demands special consideration and special attention. Expect this zone to represent 10% to 20% of the issues with 60% to 80% of the

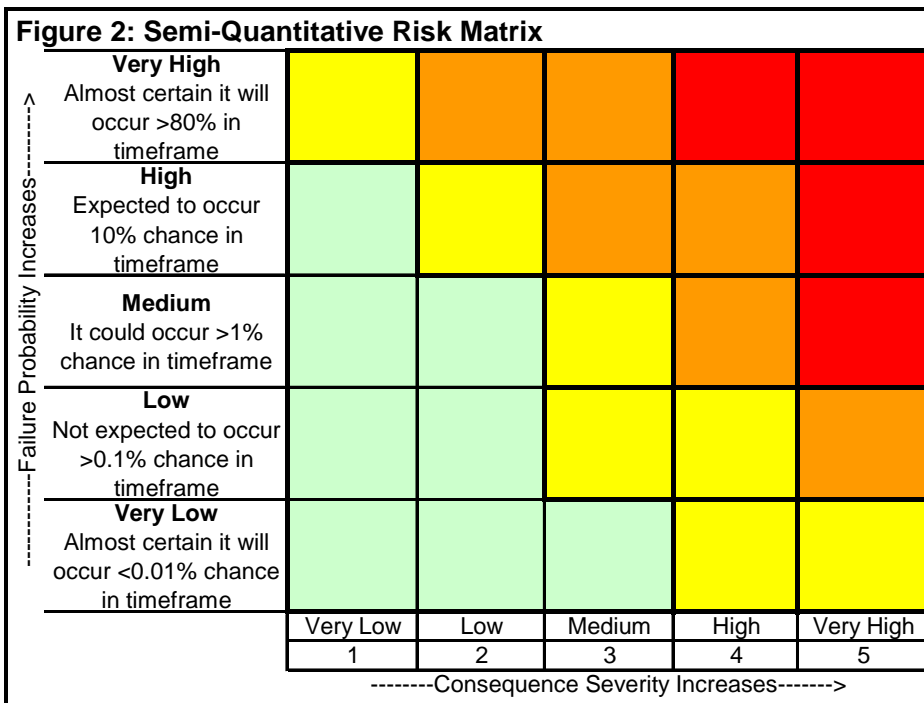
money. Tend to this hot zone very carefully! Address these issues with the Pareto principle: Separate the vital few problems from the trivial many problems.

The very high ratings can also represent severe safety issues, severe environmental issues, and/or major political issues.

The lower left hand corner contains the most issues, by nose count, but little money exposure. Work on these low level issues in the white zone only when time permits.

The orange zone gets second level attention, followed by the yellow zone.

The matrix starts out with a simple **qualitative risk matrix** in Figure 1 as the beginning level—this illustrates the concept and is very useful for the initial pre-screening of risk. The qualitative matrix is useful for screening purposes using words most people understand when common sense is applied by knowledgeable individuals.



Moving up the food chain one notch uses a more complicated **semi-quantitative risk matrix** in Figure 2 as the intermediate level. This level requires more questions and more analysis to avoid overly conservative risk ranking which may occur with the

qualitative risk matrix of Figure 1. Of course this takes more time and consumes more costs for the semi-quantitative risk matrix analysis.

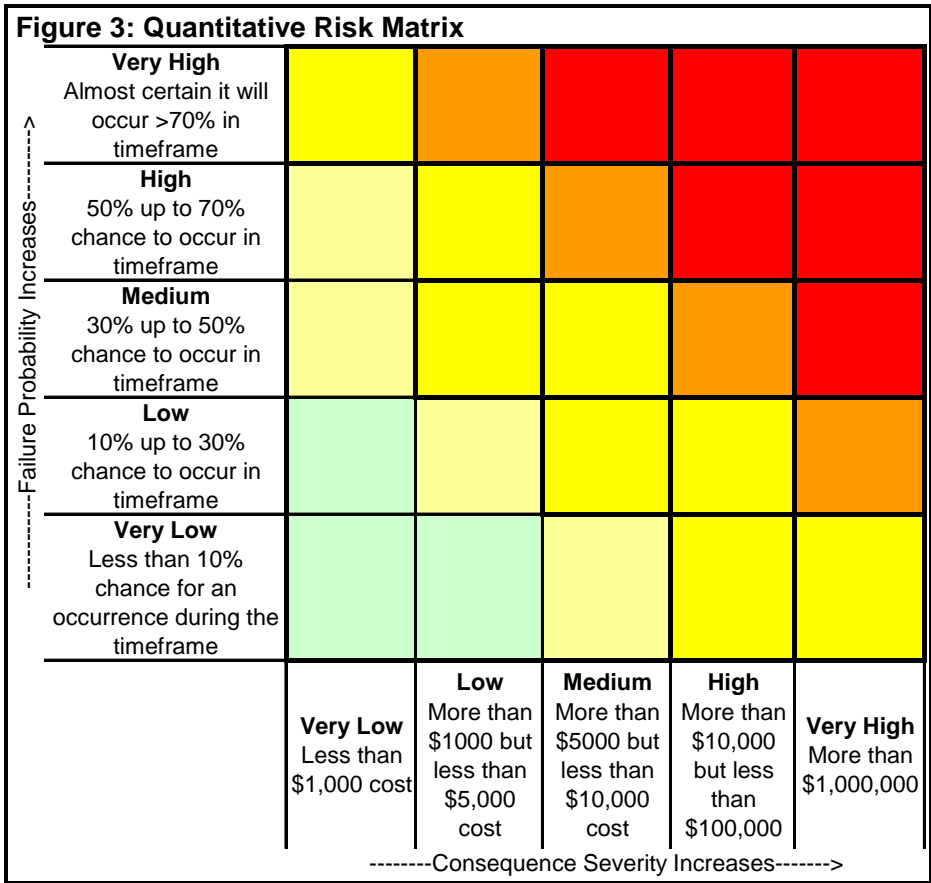
What's the advantage of the semi-quantitative risk matrix? You start to make your numbers speak with an understandable voice. The numbers provide greater depth of understanding. You can apply the semi-quantitative values to either the probability of failure or to the consequence of the failures—it doesn't matter which you do first.

Are the numbers always the same from one company to another and from one business to another business? Usually they are not the same. Each location has different goals,

different performance standards, and different money restrictions which cause the numbers to be different.

Figure 2 helps prioritize effort and provides guidelines for taking action as well as not taking action on some problems. The wide applicability of the risk matrix has been successful in design, maintenance, and operational decisions.

Too often problems are described in “near hysterical terms” of the major calamity that could or might occur. The calamity is described without out regard to the probability of the occurrence. When the two terms (probability and consequence) are brought together, the facts often reduce the hysteria to a more moderate perspective. The mergers of semi-quantitative information is an important considerations particularly for potential “[whistle-blowers](#)” to make sure the suspected situation is worthy of the clamor to be generated when the facts are presented.



Finally the matrix grows to the third level for a **quantitative risk matrix** with specific failure probability scales for the vital few items that are worthy of the increased attention and costs. This requires establishing criteria for probability of failure and the cost consequences for the matrix

and for the cost consequences as shown in Figure 3.

Remember the scales can be changed to fit the risk environment. For example, a risk accepting organization may have large failure probabilities whereas a risk adverse organization may not allow high probabilities of failures. Each organization must select the risk they can tolerate and use that as a guide.

Each organization must know the \$Risk level that can be tolerated for each organization level. The \$Risk must be spelled out in monetary terms so engineers and managers can work to the numbers rather than over/under reacting as they try to guess what will be tolerated. This issue is addressed in the technical paper presented to the API Pipeline Conference: [Reliability Issues From A Management Perspective](#).

Working through the logic of a quantitative risk matrix requires teamwork to assess situations and to use the wisdom of knowledgeable people working for the common good of the organization. The teamwork effort avoids the extremes of too pessimistic or too optimistic views typically expressed by individuals but the team effort seems to knock off the sharp corners as issues are debated and logic prevails over emotion.

Most problems are not appropriate for the quantitative risk matrix! This approach is for the vital few issues and this is driven by the cost to perform the analysis and the time consumed in the effort.

Another example of a risk matrix is described in Figure 4 based on details from [MIL-STD-882 Rev D](#).

Figure 4: Risk Adverse Matrix Derived From MIL-STD-882 Rev D.

Likelihood Of Occurrence		Failure Probability Increases →	Consequence Severity Increases →				
A	Frequent		High Risk	High Risk	Very High Risk	Very High Risk	Very High Risk
B	Probable		Medium Risk	High Risk	High Risk	Very High Risk	Very High Risk
C	Occasional		Low Risk	Medium Risk	High Risk	Very High Risk	Very High Risk
D	Remote		Low Risk	Low Risk	Medium Risk	High Risk	Very High Risk
E	Improbable		Low Risk	Low Risk	Medium Risk	High Risk	High Risk
		1	2	3	4	5	
		Negligible	Marginal	Important	Critical	Catastrophic	

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Consequence Descriptions

Catastrophic	5	Could result in death, permanent total disability, loss exceeding \$1,000,000, or irreversible severe environmental damage that violates laws or regulation.
Critical	4	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding \$200,000 but less than \$1,000,000, or reversible environmental damage causing a violation of law or regulation.
Important	3	Could result in injury, pollution/spills, visible/invisible evidence which would result in news headlines in the local newspaper or local TV coverage causing an undesirable political event to occur to the disadvantage of the facility and loss of public trust in performance of the facility as a desirable employer and workplace. Losses may range from \$5,000 up to \$500,000.
Marginal	2	Could result in injury or occupational illness resulting in one or more lost work days, loss exceeding \$10,000 but less than \$200,000, or mitigatable environmental damage without violation of laws or regulation where restoration activities can be accomplished.
Negligible	1	Could result in injury or illness not resulting in a lost work day, loss exceeding \$2,000 but less than \$10,000 or minimal environmental damage not violating law or regulation.

Likelihood Range Descriptions

Frequent	A	Likely to occur often in the life of an item, with a probability of occurrence greater than 10^{-1} in that life. Continuously experienced.
Probable	B	Will occur several times in the life of an item, with a probability of occurrence less than 10^{-1} but greater than 10^{-3} in the life. Will occur frequently.
Occasional	C	Likely to occur some time in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in that life, Will occur several times
Remote	D	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10^{-3} but greater than 10^{-6} in that life. Unlikely but can reasonable be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in that life. Unlikely to occur, but possible.

Finally, keep in mind the need to communicate clearly to the workforce the desirable actions required to prevent failure.

Figure 5: Broad Use Of The Matrix--Memory Joggers

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		Ways to express the probability								
Failure Probability Increases ^	1.0 to 0.1	Once/yr to Once/10yr	Occurs several times/yr	It will happen!	Mitigate	Fix Now!	Avoid!	Avoid!	Avoid!	
	0.1 to 0.01	Once/10yr to Once/100yr	Occurs in 10 to 100 years	It may happen	Lower Priority	Mitigate	Fix Now!	Avoid!	Avoid!	
	0.01 to 0.001	Once/100yr to Once/1,000yr	May occur within company	Would be unusual if it occurred	Lowest Priority	Lower Priority	Mitigate	Fix Now!	Avoid!	
	0.001 to 0.0001	Once/1,000yr to Once/10,000yr	Occurs within our industry	We can conceive it occurring	Lowest Priority	Lowest Priority	Mitigate	Mitigate	Fix Now!	
	Less than 0.0001	Less Than Once/10,000yr	Never heard of occurring	We can't conceive it occurring	Lowest Priority	Lowest Priority	Lowest Priority	Mitigate	Mitigate	
						-----Consequence Severity Increases----->				
Consequences In Various Régimes	People/Health Issues-->				No health/injury risks	First aid case or slight health problem	Lost time injury or potential health problem	Partial disability or major health problem	Total disability/fatality(s) severe health problem	
	Environmental-->				Negligible effect confined to inplant grounds/environment	Minor effect neighbors adjacent to plant complain	Localized release makes local TV coverage/newspapers	Major release makes national TV coverage/newspapers	Massive damage makes international TV coverage/newspapers	
	Product or Service Quality-->				Some product or service fails to meet standards	Several customers complain verbally	Several customers complain in writing	Important/major customers cancel orders	Loss of substantial market share for problem(s)	
	Assest Or Financial Loss-->				Slight damage is less than \$10,000	Noticable damage exceeds \$10,000	Large damage exceeds \$0.1 million	Major damage exceeds \$1 million	Severe damage exceeds \$10 million	
	Local, National, or International Reputation-->				Slight to moderate impact	Loss of community reputation	Loss of state reputation	Loss of national reputation	Loss of international reputation	

Many different examples of a risk matrix have been presented. Some simple, some complex, some risk accepting, and some risk adverse. No one version fits all cases. Be

flexible and keep in mind you must sell the program to not be too risk adverse and not to be too risk accepting. You must fit the pattern to the specific case.

ASME Innovative Technologies Institute ([ASME-ITI](#)) has contracted with the US Government Department of Homeland Security (DHS) to develop risk guidelines to protect critical USA infrastructure. The risk methodology is known as Risk Analysis and Management for Critical Asset Protection ([RAMCAP](#)). The purpose of RAMCAP is to provide essential information about consequences and vulnerabilities in the private sector which owns 85% of the nation's critical infrastructure.

RAMCAP's risk consequence formula is $\text{Risk\$} = F * V * \C

where

F is the frequency/likelihood of a threat (how attractive is the target, how easy to attack, and how much damage an attack could do),

V is the vulnerability of the target (openness to different types of attacks and likelihood an attack would succeed), and

\$C is the cost of the consequences (sum of lives lost, damage incurred, business interruption cost, harmful substances released on future lives loses, damage to public moral, etc.).

RAMCAP is a seven step process for asset analysis and is being developed as an American National Standard. You can purchase a printed book or obtain a PDF digital file from [ASME's Product Catalog](#) with details concerning:

1. Asset characterization,
2. Threat characterization,
3. Consequence analysis,
4. Vulnerability analysis,
5. Threat assessment,
6. Risk assessment, and
7. Risk management.

RAMCAP has completed risk analysis in the following sector-specific areas:

1. Commercial Nuclear Power Plants
2. Nuclear Spent Fuel Storage and Transportation
3. Chemical Manufacturing
4. Petroleum Refining
5. Liquefied Natural Gas Facilities
6. Dams, Locks, and Levees
7. Water and Water Treatment

Return to the list of problems by [clicking here](#).

Refer to the caveats on the [Problem Of The Month Page](#) about the limitations of the solution above. Maybe you have a better idea on how to solve the problem. Maybe you find where I've screwed-up the solution and you can point out my errors as you check my calculations. E-mail your comments, criticism, and corrections to: Paul Barringer by



[clicking here](#). [Return to the top of this problem](#).

You can download a PDF copy of this Problem Of The Month by clicking [here](#).

You can also [download](#) a Risk Matrix slide presentation made to the [Houston Business Roundtable](#) on January 11, 2006 which includes other matrix details and examples.

Simple Tools



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