HAZOP Risk Assessment via the RRR Matrix

The GATE Approach to Risk Ranking

The GATE approach to risk ranking makes risk assessment easier, more accurate and more repeatable by incorporating LOPA insights into the risk matrix approach.

Required Risk Reduction (RRR) Matrix

Figure 1 is an example of a required risk reduction (RRR) matrix.

The important features of this matrix are:

1. The frequency axis is in years/event units following a logarithmic scale, with an order of magnitude change from one column to the next.
2. The consequence axis is also a logarithmic scale with roughly order of magnitude differences between rows.
3. The numeric cell entries represent the required risk reductions (in orders of magnitude) required to reach a 'target' or 'maximum acceptable' risk level.

Generating the Matrix: Identifying the Anchor 0

Note the large bold "0" in cell A4. This is the anchor point. The selection of cell A4 as the anchor point of this matrix was determined as follows:

1. First, we define a "Major" event as one likely to cause a single fatality.
2. The average healthy 30-year-old person has about a 1/1,000 (10-3) annual probability of dying from all causes (e.g., injury, illness, etc.).
3. We want the workplace to be safer than the world at large, in this case 1 order of magnitude safer; hence cell A4 has a '0'.

This selected anchor point is for illustration only. Another point may be selected to reflect the risk tolerance of the operating company.

Severity		Safety	Environmental (BBLs Dead Oil)	Cost
Catastrophic	5	Multiple Fatalities	50,0000	100 Million $US
Major	4	Single Fatality	5,000	10 Million $US
Severe	3	Serious Injury	500	1 Million $US
Minor	2	Minor Injury	50	100 Thousand $US
Slight	1	First Aid	5	10 Thousand $US

Table 1: Consequence Definitions

Once this point is selected all the others are easily populated by adding 1 when moving one cell to the right (scenario is one order of magnitude more likely) or moving one cell up (scenario is one order of magnitude more serious).

Consequence	Catastrophic	5	1	2	3	4	5	6
	Major	4	**0**	1	2	3	4	5
	Severe	3	-1	0	1	2	3	4
	Minor	2	-2	-1	0	1	2	3
	Slight	1	-3	-2	-1	0	1	2
			A	B	C	D	E	F
			1/10,000 Years	1/1,000 Years	1/100 Years	1/10 Years	1/1 Years	10/1 Years
								Frequency

Figure 1: Example Required Risk Reduction (RRR) Matrix

Making the Consequence Judgment

We can define the consequence categories to achieve or approximate order of magnitude steps between rows as shown in Table 1.

Consequence of Vessel Overpressure

Whereas Table 1 provides good guidance for typical scenarios, an easier approach is suggested when the scenario under consideration is overpressure.

The ASME pressure vessel code provides for a design safety factor of about 3.5 for Div 1 vessels (most vessels are designed per Div 1). Topsides piping designed to B31.3 has a similar safety factor.

While exceeding the design pressure is a notable event, we should not expect catastrophic vessel failure at pressures less than 3 times the MAWP, assuming little corrosion and no extreme temperature.

For a major process vessel, we can estimate consequences severity as a simple function of overpressure as shown in Table 2.

Pressure	Consequence	Severity	
3 x MAWP	Vessel Failure	Catastrophic	5
2 x MAWP	Vessel Damage, Major Gasket Leaks	Major	4
1.5 x MAWP	Potential Gasket Leaks	Severe	3
1.2 x MAWP	Process Shutdown, Gas Flaring	Minor	2
0.9 x MAWP	Process Shutdown	Slight	1

Table 2: Severity Rating vs. Overpressure – ASME Section 8 Div 1 Vessel, B31.3 Piping

Making the Frequency Judgment

Frequency of occurrence judgements are based on LOPA data as shown in Tables 3 and 4.

The Value of Safeguards

Following LOPA guidelines, only Independent Protection Layers (IPLs) are counted for assessing the mitigated risk. These have associated characteristic probabilities of failure on demand (PFD) as you can see in Table 5.

IPLs vs. Safeguards

HAZOPs identify multiple safeguards. These will not all count as IPLs under LOPA rules. In order to be considered an IPL, a protective function must be:

1. Effective in preventing the consequence when it functions as designed.
    - Can the IPL detect the condition that requires it to act?
    - Can it respond in time?
    - Does it have adequate capacity?
2. Independent of the initiating event.
3. Independent of any other IPL for which credit has already been taken.
4. Auditable and testable.

Safeguards Not Usually Considered IPLs

1. Check valves (though 2 dissimilar valves in series may be counted)
2. Procedures, Certification, Training
3. Testing, Inspection, Maintenance
4. Communication Systems, Signs
5. Active Fire Fighting Systems

Initiating Course	Likelihood (Events/Yr)	Likelihood (10^{-x})
Control Loop Failure	1/10	10^{-1}
Rotating Equip Trip	1/1	10^{0}
Loss of Power	1/10	10^{-1}
Utility Failure	1/10	10^{-1}

Table 3: Initiating Event Frequencies

Situation	Error
Well Trained Operator with Stress	1 per 10 Opportunities
Well Trained Operator, No Stress	1 per 100 Opportunities
Well Trained Operator, No Stress, Independent Verification	1 per 1,000 Opportunities

Table 4: Human Error Frequencies

IPL	PFD	Risk Reduction
PSV, Rupture Disk	1/100	2
Independent Control Loop	1/10	1

Table 5: Some Typical IPL PFDs

SIL	SIF PFD
1	**1/10** - 1/100
2	**1/100** - 1/1,000
3	**1/1,000** - 1/10,000
4	**1/10,000** - 1/1,000,000

Table 6: SIL Definitions

Determining PFDs of SIFs

Safety Integrity Level (SIL)

The accepted reliability standard for a Safety Instrumented Function (SIF) is the Safety Integrity level (SIL) rating. This is a measure of the SIF's PFD. Table 6 defines SIL levels and associated PFD ranges.

For example, if we require that a SIF work effectively at least 99 times out of 100 tries, then we need a SIL 2 rated SIF.

In order to establish the SIL rating of a SIF, the failure probabilities of the SIF's individual components must be statistically combined and a testing frequency established. The testing frequency is an important consideration. Since these systems are used very infrequently, latent (unrevealed) failure is a concern. Even the best engineered SIF cannot be expected to work forever without maintenance, and its reliability cannot be proved without testing.

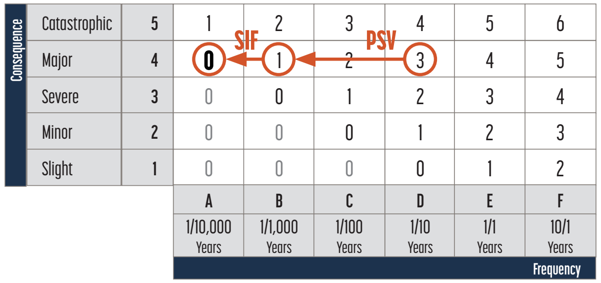
The discussion below provides general guidance on what is practically achievable in SIFs.

- **Achieving SIL 1:** A single safety switch actuating a single SDV can generally achieve SIL 1.
- **Achieving SIL 2:** Achieving SIL 2 may require multiple sensing devices in a voting arrangement actuating two SDVs in series, in conjunction with more onerous testing requirements. Expert guidance is required.
- SIL 3 and SIL 4 systems are not commonly applied. Expert guidance is required.

Example of Applying the RRR Matrix

Hazard scenario: A blocked outlet of a relatively small vessel could yield overpressure high enough to rupture the vessel. A PSV is installed, but no other safeguarding is provided.

1. First, determine the unmitigated risk:
    - The HAZOP team identifies potential for a fatality (Row 4, Major).
    - The initiating event is pressure control loop failure. Per Table 3, control loop failure occurs 1/10 years (Column D).
    - Enter the matrix at 4D. The required risk reduction (RRR) target is 3.
2. The only safeguard provided is the vessel PSV which provides a 2 order of magnitude improvement (see Table 5).
3. That leaves a 1 order of magnitude risk reduction requirement. That requirement could be provided by a safety instrumented function (SIF) or other valid independent protection layer (IPL) with a SIL rating of 1.



Consequence								
	Catastrophic	5	1	2	3	4	5	6
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								Frequency

Figure 5: Example Use of the Required Risk Reduction Matrix

Some Advantages of this Approach

1. The first estimate made in the example (RRR = 3) reflects the inherent, unmitigated process risk, without safeguards. This allows judgment of inherent risk that is not usually apparent in a HAZOP. A process with a very high unmitigated RRR should be considered unacceptable and require redesign rather than mitigation.
2. The final risk assessment reflects the mitigated risk with existing safeguards. This makes it very clear to all participants whether the risk judgment being made is the mitigated or unmitigated risk and provides clear guidance on whether the mitigated risk is acceptable.
3. If a recommendation needs to be made it can be much more precisely articulated. In this case, the recommendation would be to reduce risk by at least one order of magnitude.

We are on a mission to improve the way industry does process hazard analysis.

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