Key Performance Indicators (KPI) for installed SIS

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Abstract

The intent of this presentation is to :

- Introduce API RP 754
- Briefly walk though the concepts of KPIs, define and explain Leading and Lagging indicators,
- Application of these KPIs to Safety Instrumented Systems (SIS) designed and implemented using ISA 84.00.01.

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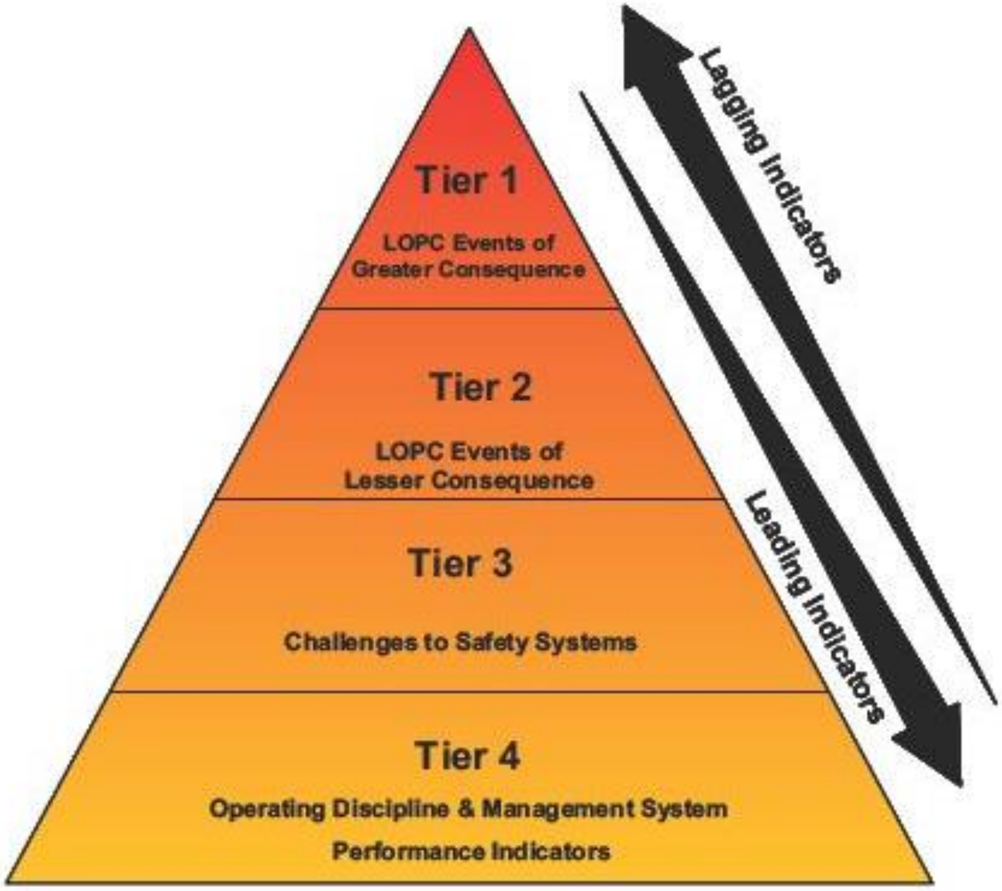
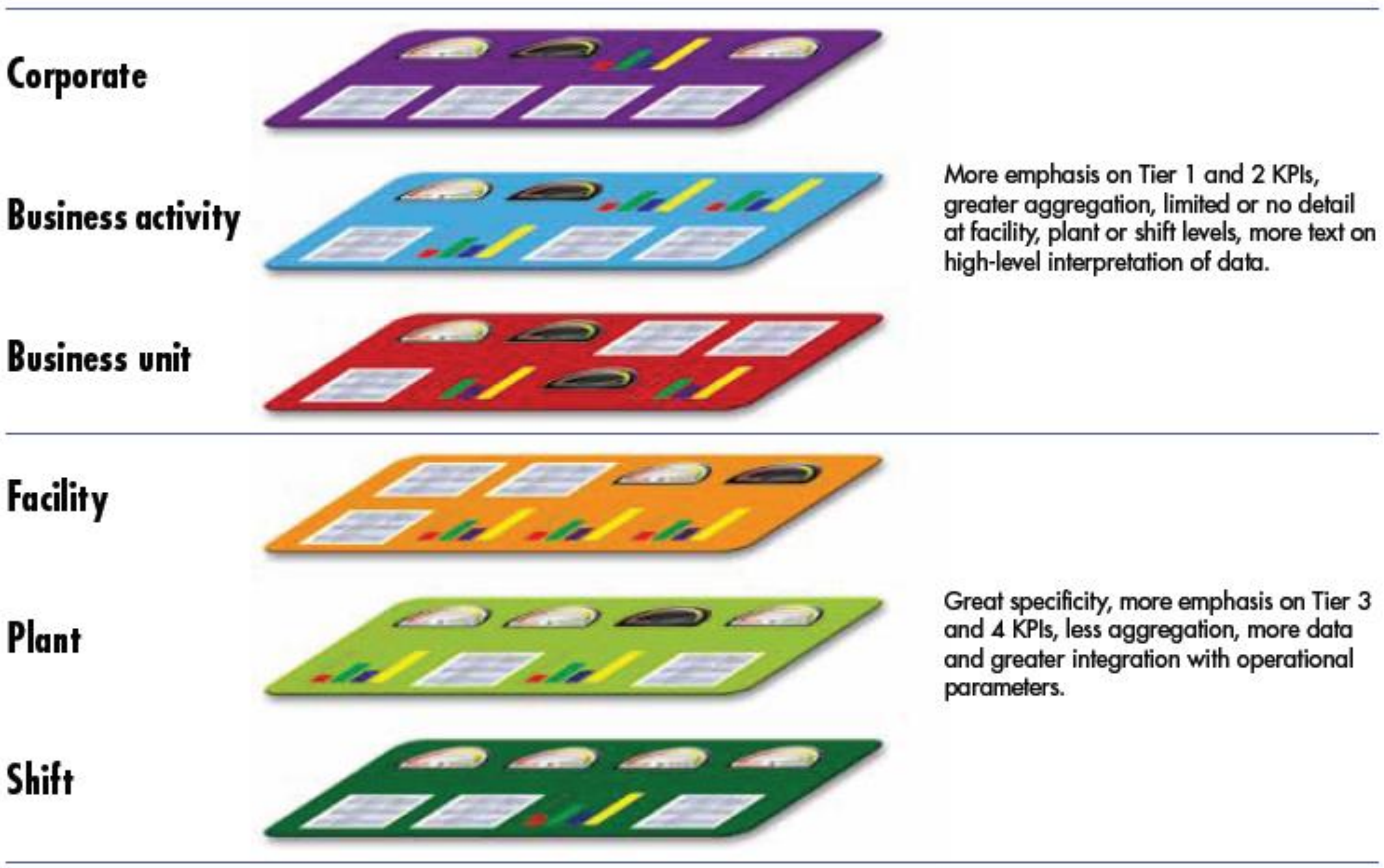
API RP 754

- API RP 754 is titled “Process Safety Performance Indicators for the Refining and petrochemical Industries”, the first edition of which came out in April 2010.
- With reference to Safety life Cycle of ISA 84.00.01, this RP is applicable during the Operation and Maintenance phase.
- The purpose of the Recommended Practice (RP) is to identify leading and lagging indicators in the refinery and petrochemical industries whether for public reporting or for use at individual facilities including methods for the development of Key Performance Indicators (KPI).
- As a framework for measuring activity, status or performance, the RP classifies Process Safety Indicators (PSI) into four tiers of leading and lagging indicators. Tiers 1 and 2 are suitable for public reporting while Tier 3 and 4 are meant for internal use at individual sites.

API RP 754


Tier 1
LOPC Events of
Greater Consequence
Tier 2
LOPC Events of
Lesser Consequence
Tier 3
Challenges to Safety Systems
Tier 4
Operating Discipline & Management System
Performance Indicators
Lagging Indicators
Leading Indicators

Key Performance Indicators (KPI)



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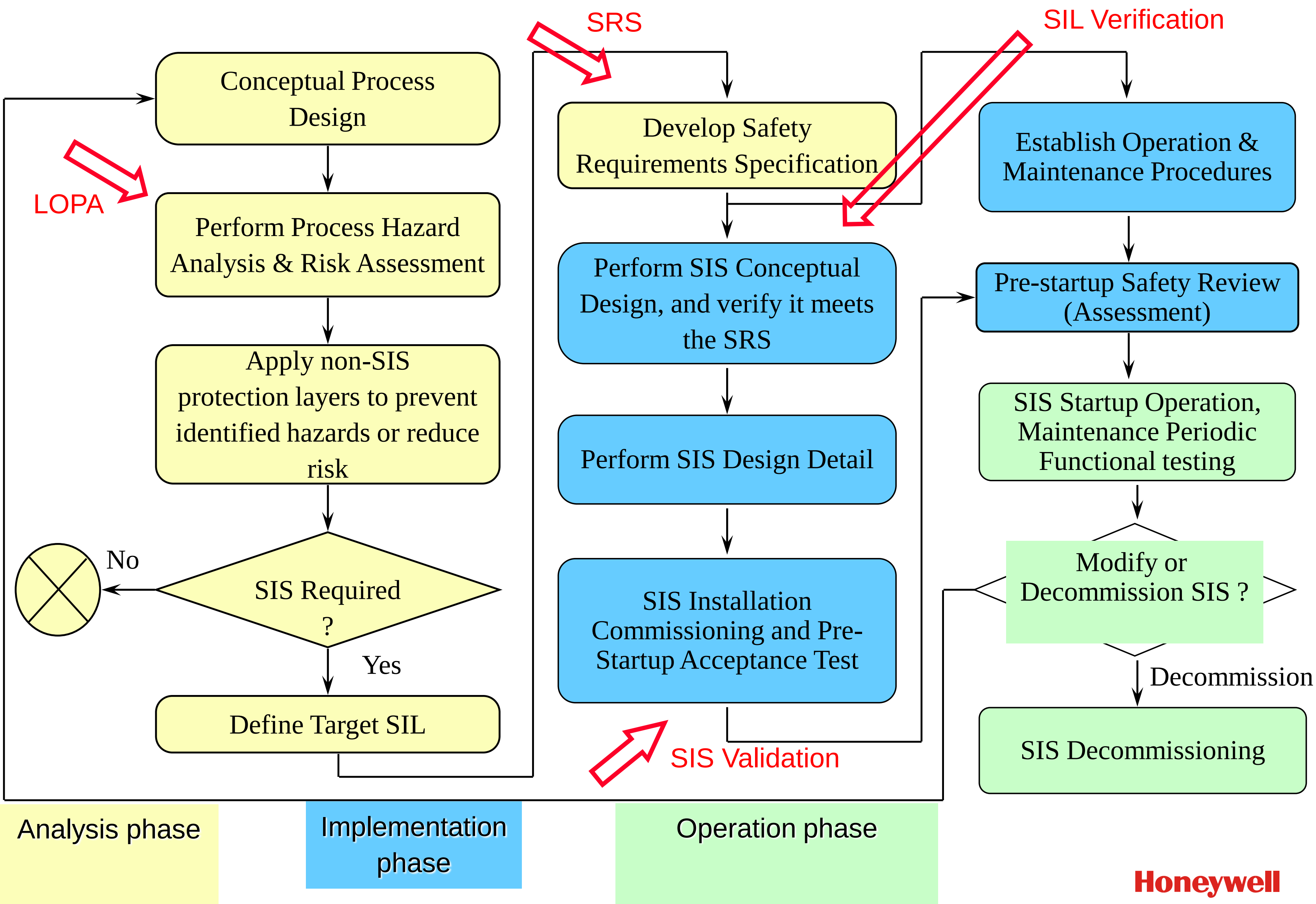
The Safety Life Cycle as defined in ISA84.00.01



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SIL Analysis

SIL – Safety Integrity Level

Major parts to the process of SIL Analysis

Analysis phase:

- SIL determination (LOPA) – Determine the extent of risk and indicate it in the form of a number, SIL1 to SIL4. The higher the number, the higher the risk. Identify potential protection layers to reduce this risk.
- SRS - Generate a document (or set of documents) which identifies the Integrity and Functionality of all identified SIFs.

Implementation phase :

- SIL verification – By reliability calculations and instrument selection, design SIFs which are sufficient to meet the required risk reduction.
- SIL validation – Check if the SIFs are functionally working per the SRS.

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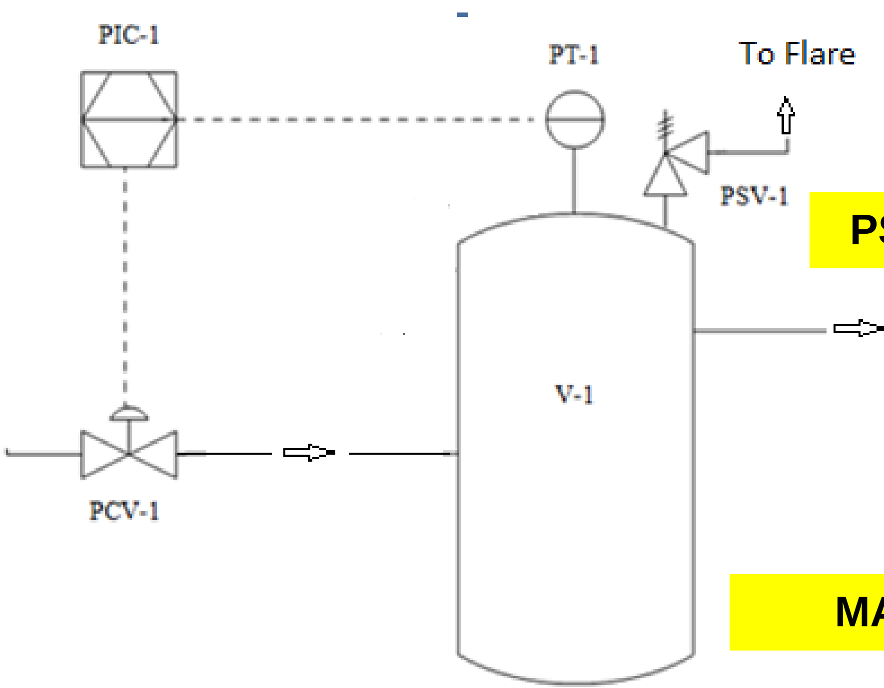
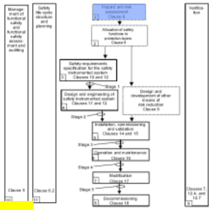
SP= 3 BAR





PSV SP = 4.0 BAR

MAWP of V-1 = 5 BAR

- **Node:** Vessel V-1
- **Guideword:** HIGH PRESSURE
- **Consequence:** High Pressure, possible vessel rupture & fire
- **Cause of failure:** PIC-1 (BPCS), Control valve (PCV-1) stuck open
- **Existing Safeguards :** PSV-1
- **Additional Protection Layers :** No recommendation

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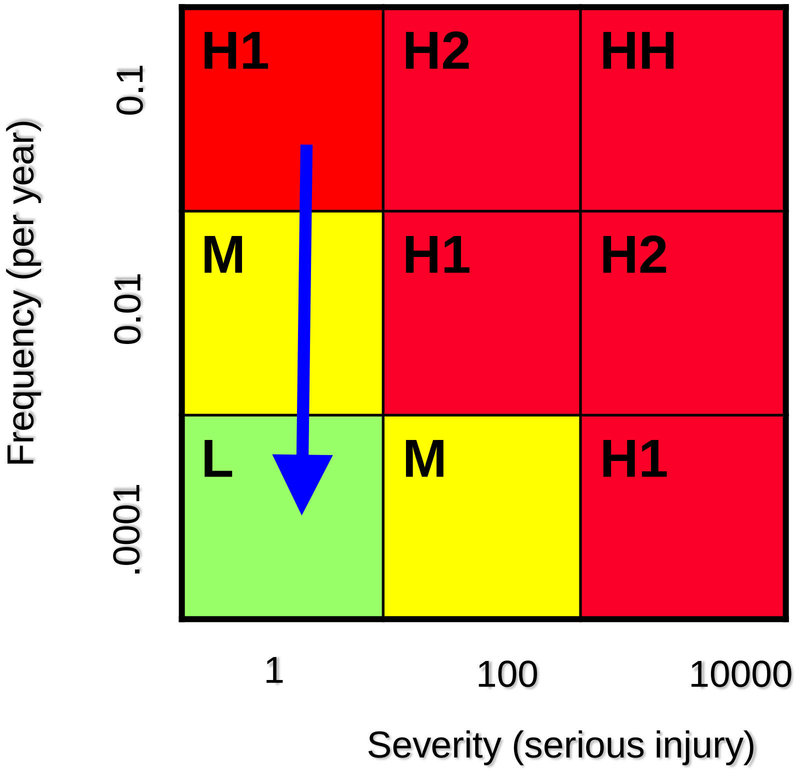
Required Risk Reduction

From the HAZOP risk matrix for this Process, the team decided :

1. Frequency of Initiating Event (IE) – Once per 10 years
2. Severity – 1 serious injury



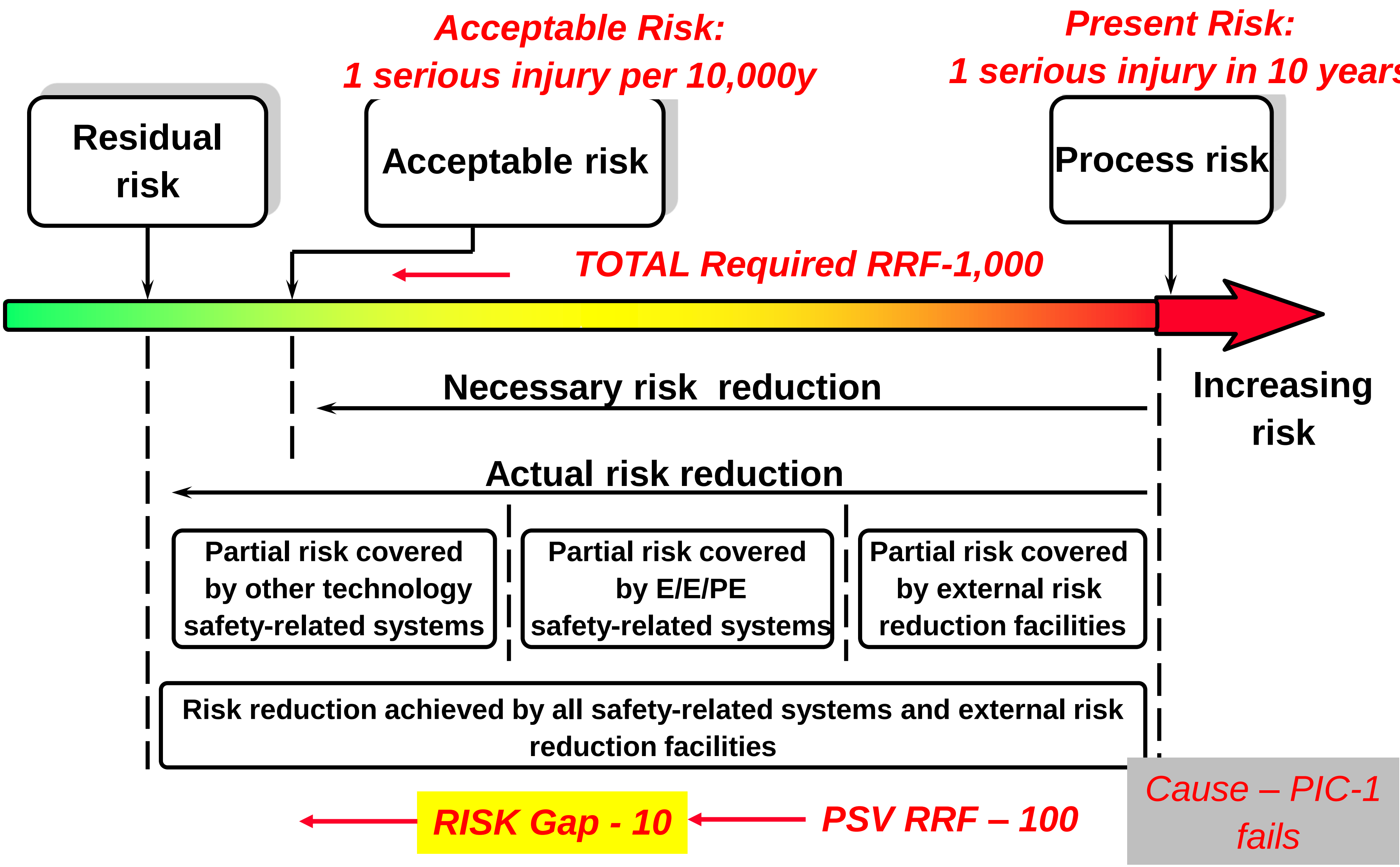
Present Risk "H1" = 0.1 (1 Serious injury in 10 years)

Acceptable Risk "L" - .0001 (1 Serious injury in 10,000 years)

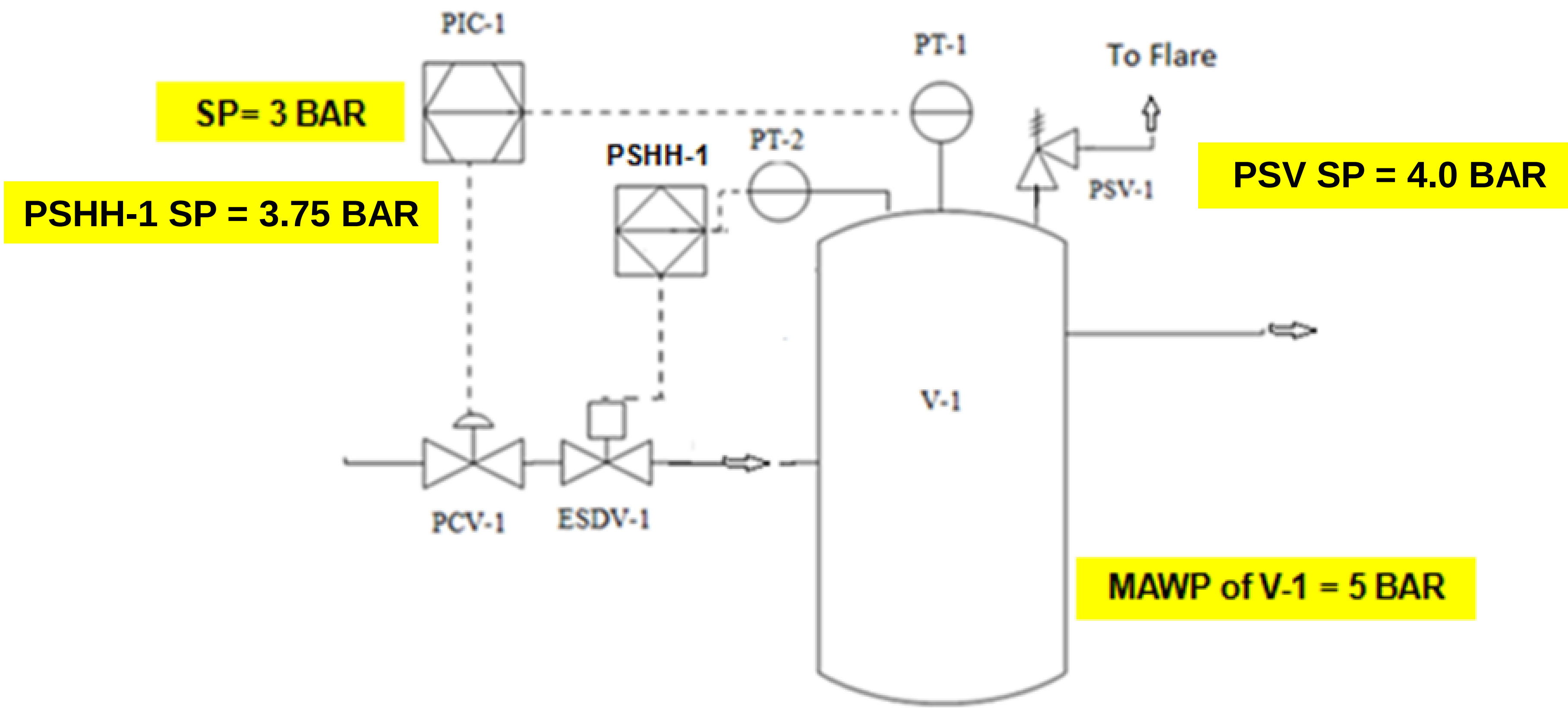
Risk Reduction Factor = 0.1/0.0001

Total Required RRF = 1,000

Risk and Risk Reduction



Case Study, Add a SIF (SIL1, RRF-10)



- High Pressure Trip PSHH-1 added
  - Shuts off ESDV-1 when PT-2 detects Pressure in Vessel V-1 > 3.75 BAR
  - ESDV-1 will be a De-energized To Trip (DTT) Fail Close valve, Open when Pressure is less than 3.75 BAR

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Identification of IPLs

The two IPLs identified in this scenario are (assuming PIC-1 fails) :

1. SIF-1 – the PSHH-1 interlock
2. PSV-1 – the Pressure relief valve to flare

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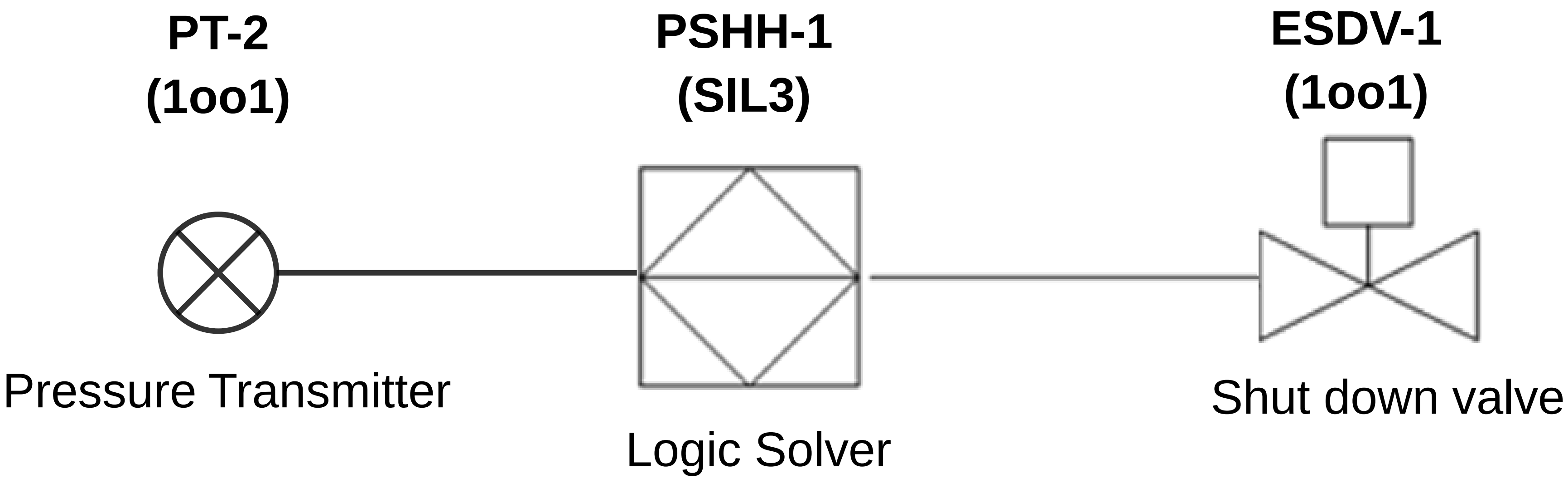
Reliability Block Diagram (RBD) of SIF-1



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PFDavg equations on 1oo1 voting

1. $\lambda_D = \lambda_{DU} + \lambda_{DD}$ $\lambda_{DD} = \lambda_D DC$ $\lambda_{DU} = \lambda_D(1 - DC)$

2. $$t_{CE} = \frac{\lambda_{DU}}{\lambda_D}\left(\frac{T_1}{2} + MRT\right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

3. $$PFD_{AVG} = (\lambda_{DU} + \lambda_{DD}) t_{CE}$$

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Table B.4 from IEC-61508-6

Table B.4 — Average probability of failure on demand for a proof test interval of 2 years and a mean time to restoration of 8 hours

Architecture	DC	λ = 1.0E-07			λ = 5.0E-07			λ = 1.0E-06		
		β=1%	β=5%	β=10%	β=1%	β=5%	β=10%	β=1%	β=5%	β=10%
1oo1 (see note)	0%	4.4E-04			2.2E-03			4.4E-03		
	60%	1.8E-04			8.8E-04			1.8E-03		
	90%	4.4E-05			2.2E-04			4.4E-04		
	99%	4.8E-06			2.4E-05			4.8E-05		
1oo2	0%	9.0E-06	4.4E-05	8.8E-05	5.0E-05	2.2E-04	4.4E-04	1.1E-04	4.6E-04	8.9E-04
	60%	3.5E-06	1.8E-05	3.5E-05	1.9E-05	8.9E-05	1.8E-04	3.9E-05	1.8E-04	3.5E-04
	90%	8.8E-07	4.4E-06	8.8E-06	4.5E-06	2.2E-05	4.4E-05	9.1E-06	4.4E-05	8.8E-05
	99%	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.2E-07	4.6E-06	9.2E-06
2oo2 (see note)	0%	8.8E-04			4.4E-03			8.8E-03		
	60%	3.5E-04			1.8E-03			3.5E-03		
	90%	8.8E-05			4.4E-04			8.8E-04		
	99%	9.6E-06			4.8E-05			9.6E-05		
1oo2D	0%	9.0E-06	4.4E-05	8.8E-05	5.0E-05	2.2E-04	4.4E-04	1.1E-04	4.6E-04	8.9E-04
	60%	3.5E-06	1.8E-05	3.5E-05	1.8E-05	8.8E-05	1.8E-04	3.6E-05	1.8E-04	3.5E-04
	90%	8.8E-07	4.4E-06	8.8E-06	4.4E-06	2.2E-05	4.4E-05	8.8E-06	4.4E-05	8.8E-05
	99%	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.2E-07	4.6E-06	9.2E-06
2oo3	0%	9.5E-06	4.4E-05	8.8E-05	6.2E-05	2.3E-04	4.5E-04	1.6E-04	5.0E-04	9.3E-04
	60%	3.6E-06	1.8E-05	3.5E-05	2.1E-05	9.0E-05	1.8E-04	4.7E-05	1.9E-04	3.6E-04
	90%	8.9E-07	4.4E-06	8.8E-06	4.6E-06	2.2E-05	4.4E-05	9.6E-06	4.5E-05	8.9E-05
	99%	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.3E-07	4.6E-06	9.2E-06

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PFDavg calculation of SIF-1

From Table B.4, **IEC61508-6**	‘λ’ Failures per hour	‘PTI’ Proof Test Interval in months	‘MTTR’ Mean time to repair in hours	‘DC’ in percent	PFD_{avg}
1oo1 Sensor (Pressure transmitter)	1×10^{-6}	24	8	90	4.4×10^{-4}
Logic Solver (SIL 3) (data NOT from table B.4)					5×10^{-4}
1oo1 Final element (On-off valve)	1×10^{-5}	24	8	0	4.4×10^{-2}

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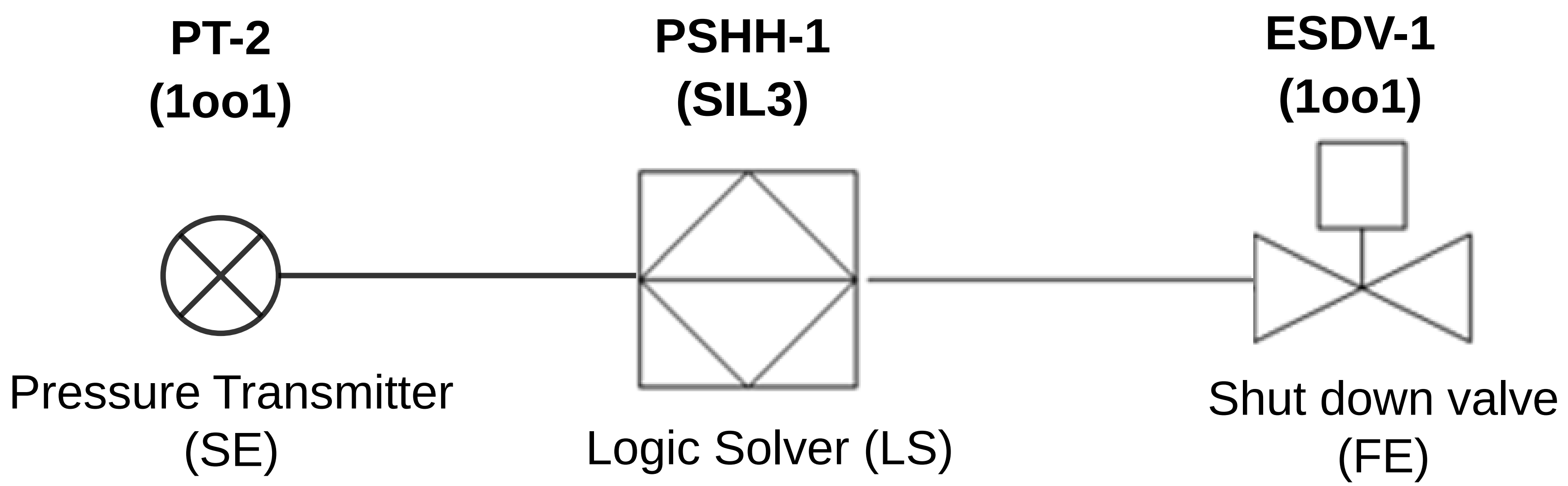
PFDavg calculation of SIF-1



$$PFD_{avg}(SIF\text{-}1) = PFD_{avg}(SE) + PFD_{avg}(LS) + PFD_{avg}(FE)$$

$$PFD_{avg}(SIF\text{-}1) = 4.4 \times 10^{-2} \text{ (approx.)}$$

$$RRF = I/PFD_{avg} = 22.7$$

PFD_{avg} of both the IPLs put together

PFD_{avg} (of all IPLs) = PFD(IPL1) x PFD(IPL2) x .. x PFD(IPLn)

In our example :

PFD_{avg} (SIF-1 and PSV-1) = $4.4 \times 10^{-2} \times 0.01 = 4.4 \times 10^{-4}$

RRF = I/PFDavg = 2272

(note - from industry standard books, the PFD_{avg} of a PSV is 0.01)

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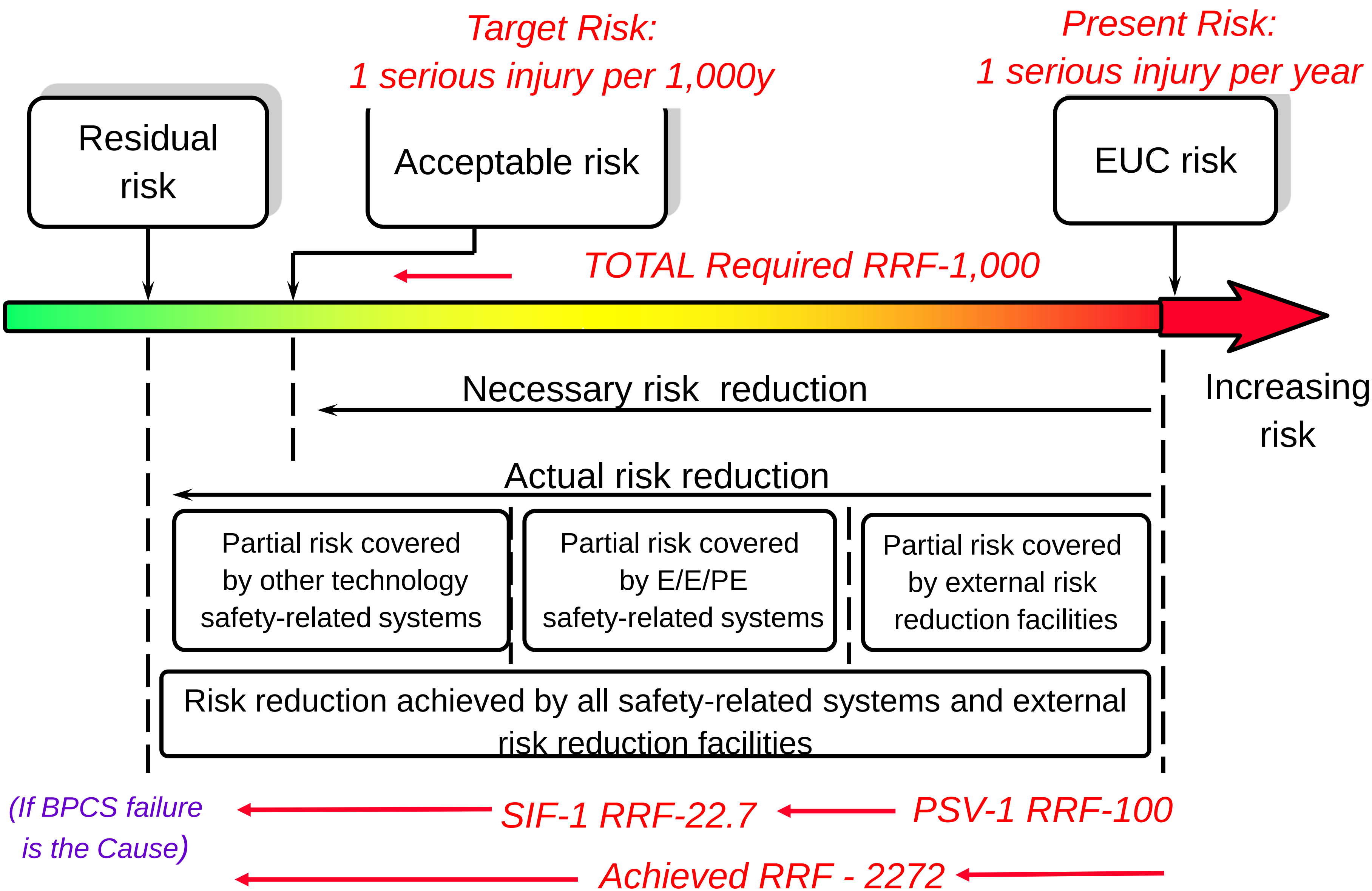
Risk Reduction based on SIF-1 design



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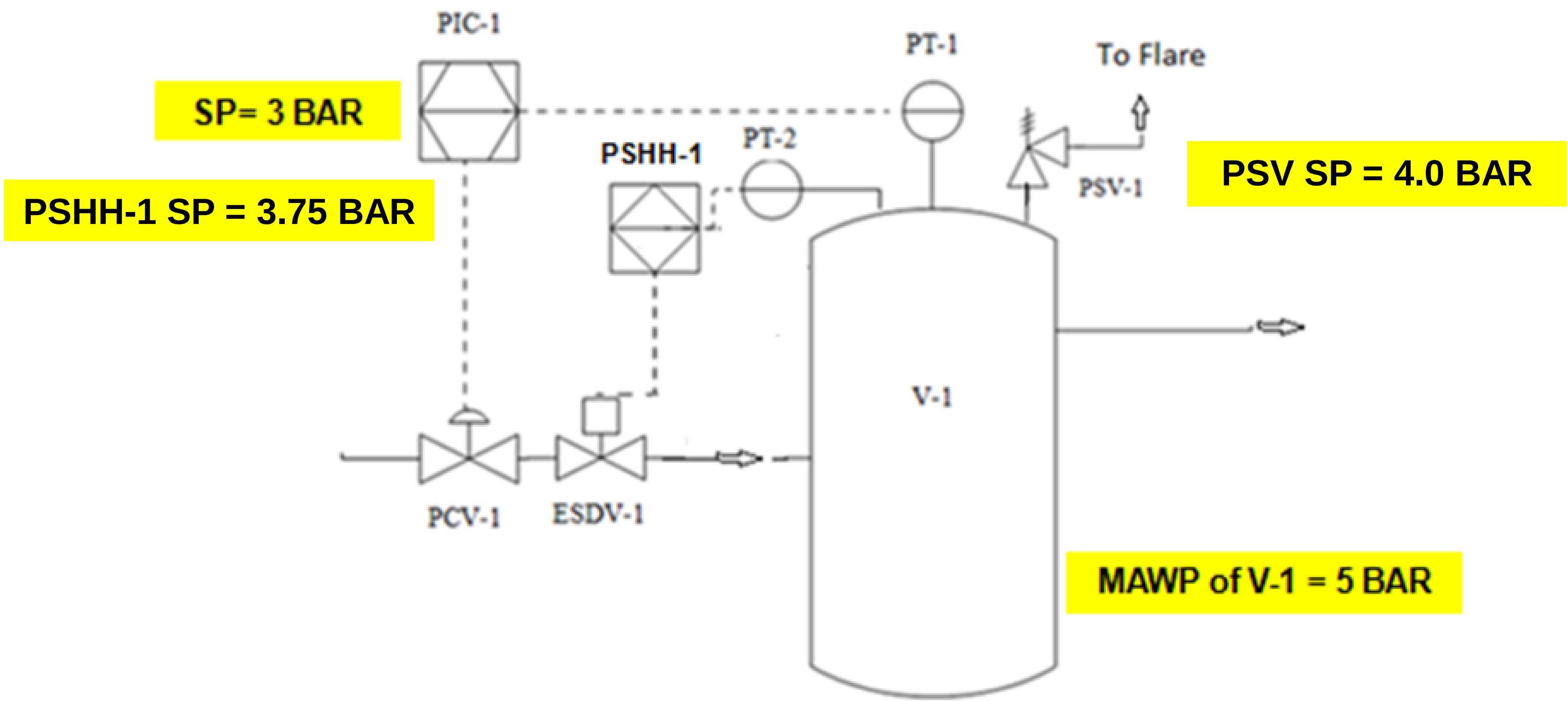
Case Study, Add a SIF (SIL1, RRF-22)



- High Pressure Trip PSHH-1 added
  - Shuts off ESDV-1 when PT-2 detects Pressure in Vessel V-1 > 3.75 BAR
  - ESDV-1 will be a De-energized To Trip (DTT) Fail Close valve, Open when Pressure is less than 3.75 BAR

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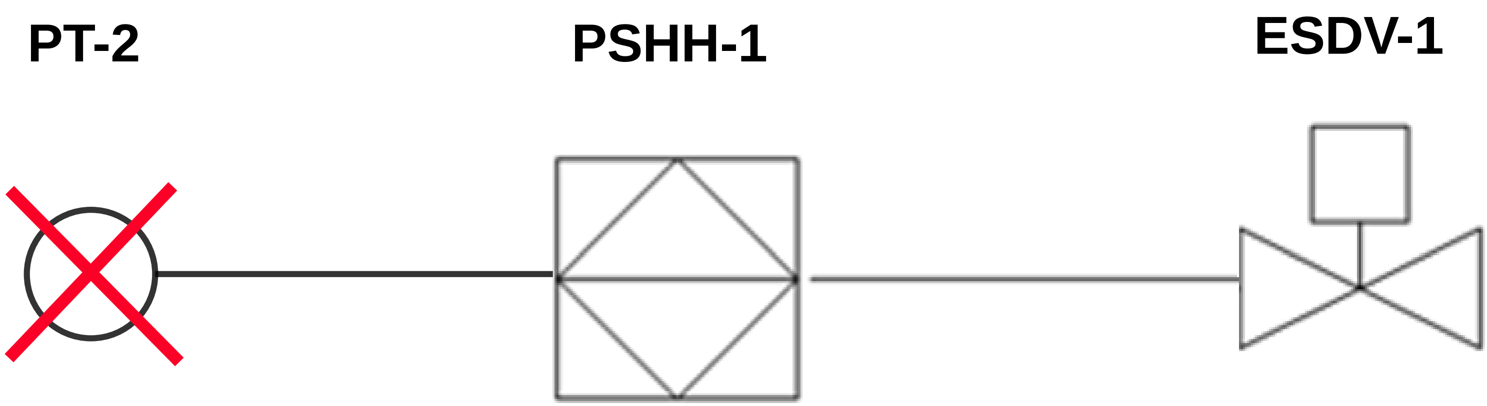
Use of KPIs in our example

- **Release of PSV-1 to Flare (KPI 1)** –This would mean both the DCS and SIS loop had failed to maintain the pressure in the vessel below dangerous levels. This would be a lagging indicator and could be classified as Tier 1 or 2 by the individual site based on amount of gas released to flare.
- **SIF-1 exercised (KPI 2)** –This would mean that the Pressure in the vessel was not controlled by DCS and reached a limit where SIF-1 had to shut the Hydrocarbon inlet line. This would be a Tier 3, leading indicator as far as LOPC is concerned but a lagging indicator in terms of Process Availability.
- **Audit findings (KPI 3)** - If an Audit finding indicates that the SIF-1 field instruments are not being Proof Tested once every 2 years (as was considered during the SIL verification calculations), this will be informed to the individual site management as a Tier 4 leading indicator.
- **SIF component detected failure (KPI 4)** – One of the components of SIF-1 fails and is detected, the SIF is now running in a degrade mode. The component needs to be fixed and restored so that SIF-1 can give the full risk reduction it was designed for. This would be a Tier 4 leading indicator.

What if PT-2 Transmitter Fails ?



If PT-2 Fails, then there is no active SIF

PFD_{avg} of both the IPLs put together

In our example :

PFD_{avg} (SIF-1 [degrade] and PSV-1) = 1 x 0.01 = 0.01

RRF = I/PFDavg = 100

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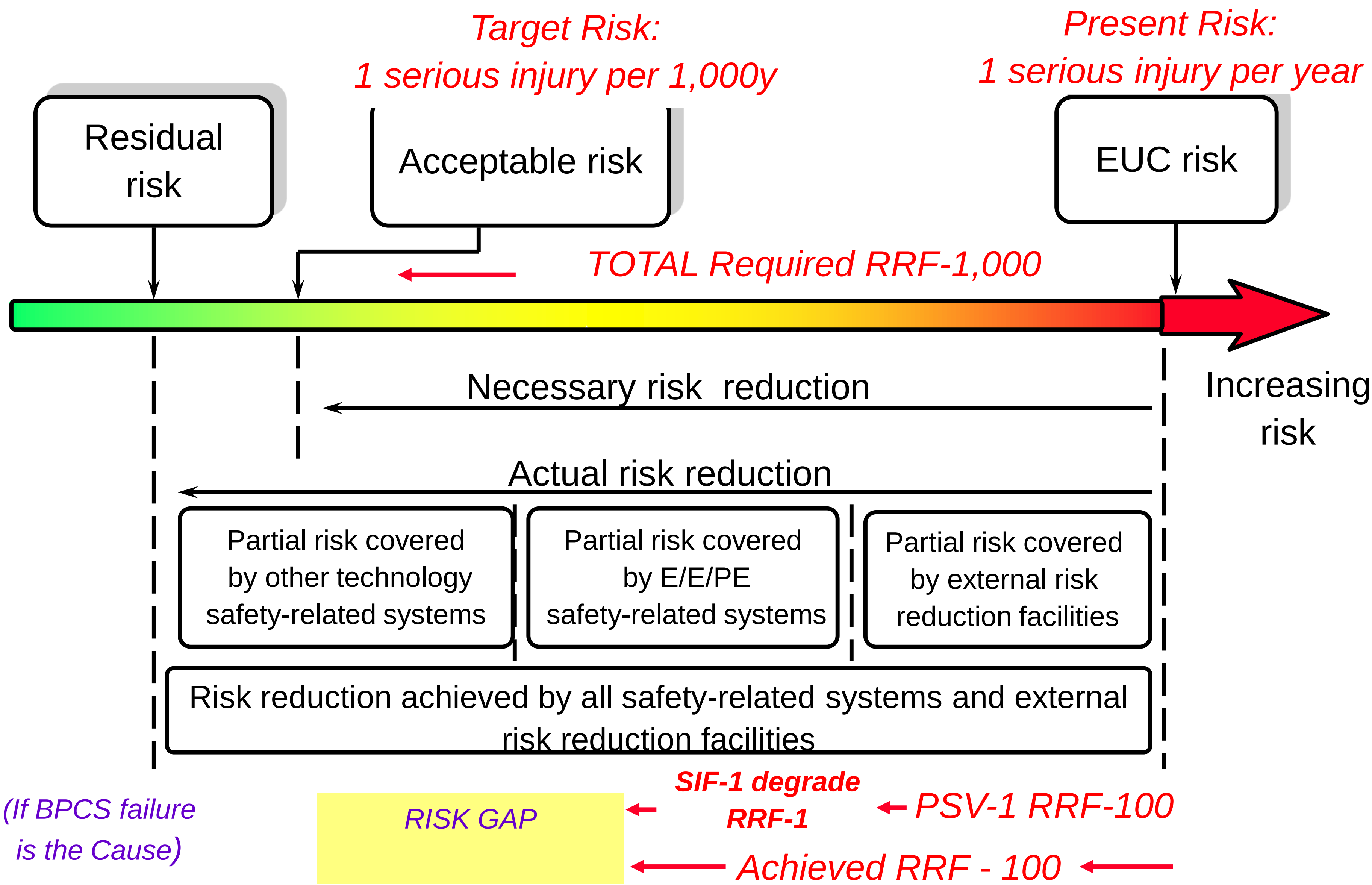
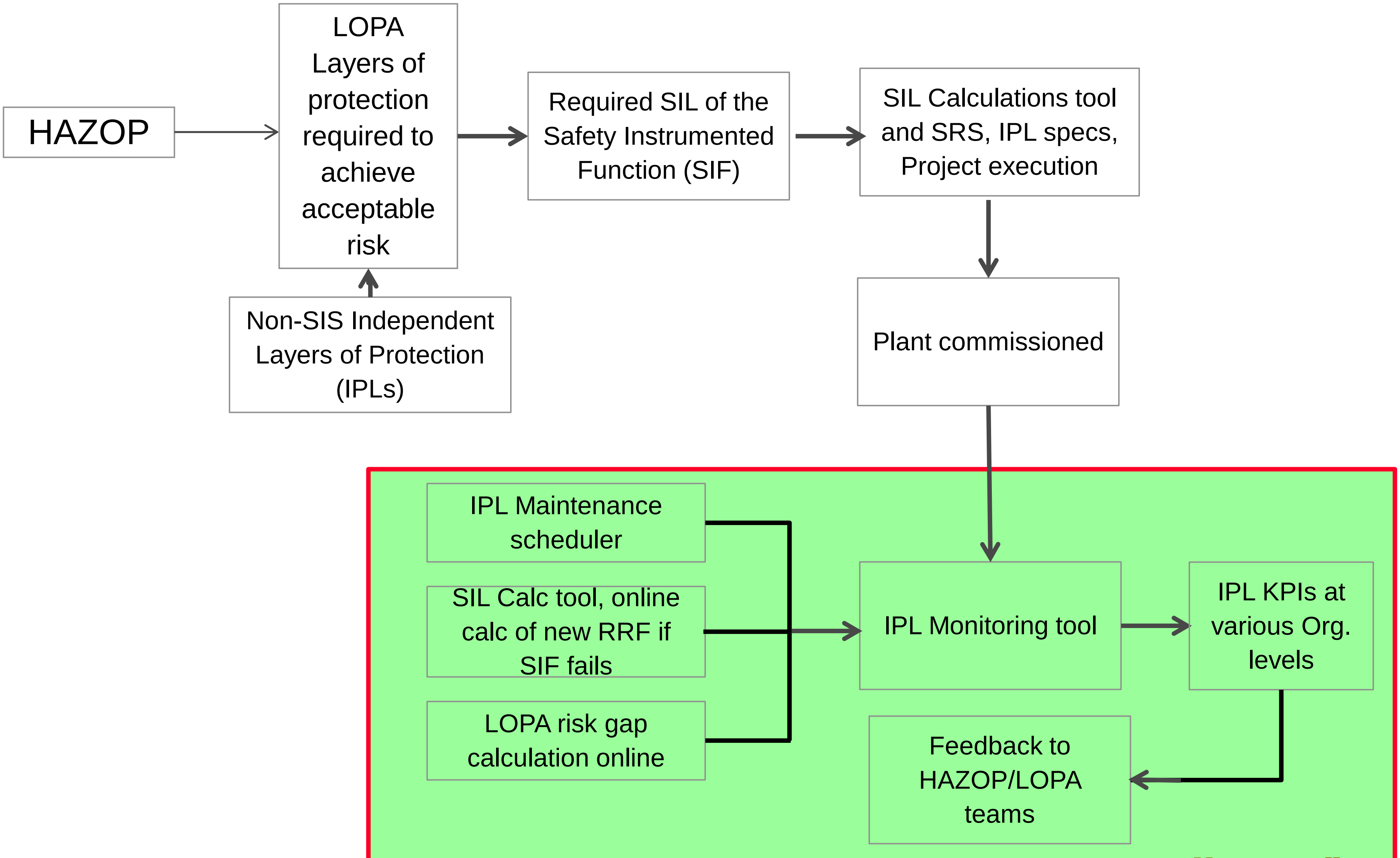
Risk Reduction based on SIF-1 (degrade mode)



IPL KPI.......

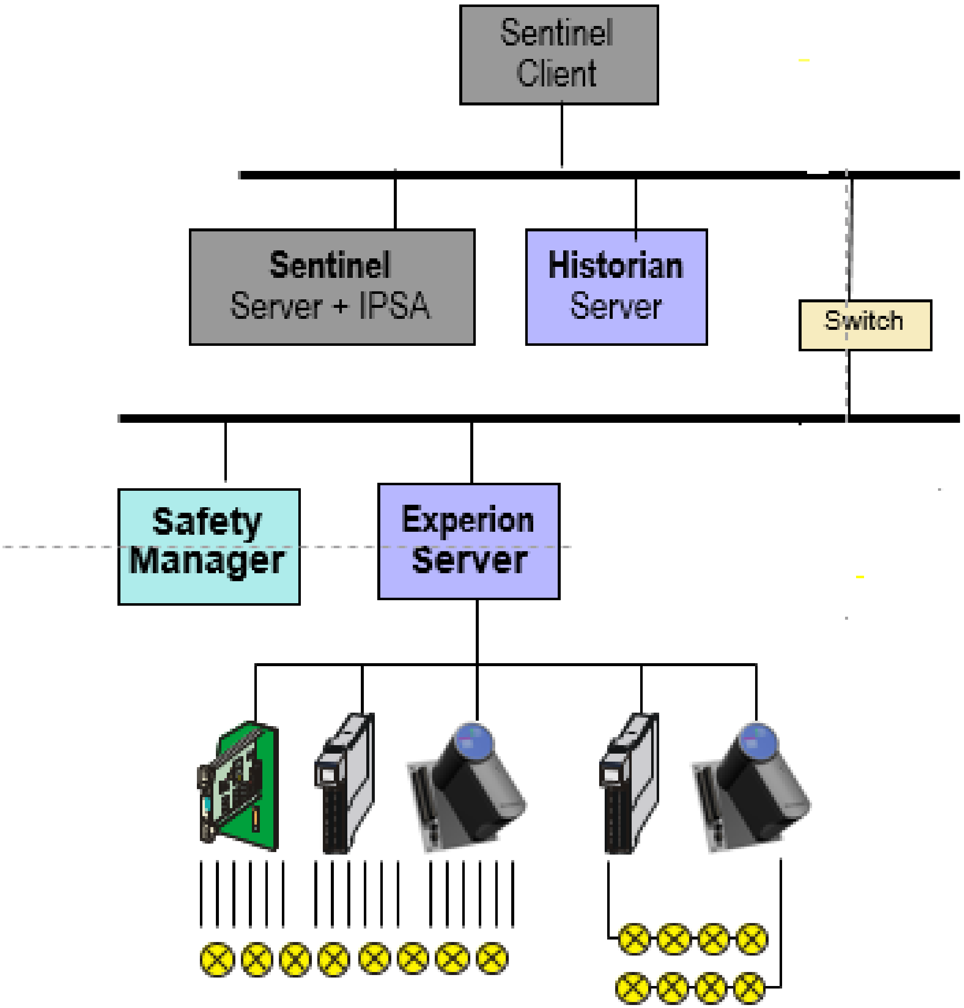

HAZOP
LOPA Layers of protection required to achieve acceptable risk
Non-SIS Independent Layers of Protection (IPLs)
Required SIL of the Safety Instrumented Function (SIF)
SIL Calculations tool and SRS, IPL specs, Project execution
Plant commissioned
IPL Maintenance scheduler
SIL Calc tool, online calc of new RRF if SIF fails
LOPA risk gap calculation online
IPL Monitoring tool
IPL KPIs at various Org. levels
Feedback to HAZOP/LOPA teams

Key Performance Indicators (KPI) summary

KPI's are a useful measure to:

- **Prevent major incidents** – Based on Tier 1 KPIs released by an individual site to the company head quarters and later nation wide, the company (and other companies in the similar business) can analyze and learn what led to the Process Safety Incident, the root cause and how this can be avoided in the future.
- **Improve Reliability –** Steps taken by a company to reduce major Process Safety Incidents help improve Reliability of Process Operations.
- **Avoid Complacency** – KPI's provide a measure of asset integrity. Just because there has been no major incident for a long time does not mean everything is fine. Leading KPI's could provide valuable information on the health of assets and indicate that it is time to do maintenance on the asset.
- **Communicate Performance –** Tier 1 and 2 KPI's could provide to the company and nation wide how the individual site is performing while Tier 3 and 4 KPI's could asses performance internal to the individual site

Honeywell offering….



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Conclusion

- The Safety Instrumented System (SIS) Safety Life Cycle (SLC) per IEC 61511 / ISA 84.00.01 starts with the Analysis and Design phase in which the requirement of Safety Instrumented Functions (SIF) and other Independent protection Layers (IPL) are Analyzed and later designed to prevent / mitigate process risk in a process plant. During the Operation / maintenance phase of the SLC, by using the KPI definitions and selection criteria as given in API RP 754, the functioning of the designed SIFs and other IPLs can be monitored.

- Use of KPIs will be helpful to let the public (based on Tier 1 and 2) know how safe the Process units are being operated in their neighborhood and the individual site management (based on Tier 1 to 4) to know how well the IPLs are keeping up to their design intent to prevent / mitigate Process Risk.

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Thank You...