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Process Safety in the Laboratory

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Content

- Background
- Overview of the Sour Laboratory
- What is process safety and why this is applicable
  - Process Hazard Review - scope of study
  - Explanation of key concepts - ALARP, LOPA,
- What we learned
- Benefits and outcomes

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Sour laboratory

Properties of H_2S Gas

- **Very toxic** by inhalation
- May cause damaging effects to central nervous system, metabolism and gastrointestinal tract.
- Prolonged exposure to small concentrations may result in pulmonary oedema.
- Exposure limit value:

Substance	CAS number	Workplace Exposure Limit			
		Long-term exposure limit (8-hour TWA reference perid)		Short-term exposure limit (15 minute reference period)	
		ppm	$mg.m^{-3}$	ppm	$mg.m^{-3}$
Hydrogen Sulphide	7783-06-4	5	7	10	14

- **Extremely flammable**
- Exposure to fire may cause containers to rupture/explode.
- If involved in a fire sulphur dioxide (toxic and/or corrosive) fumes may be produced by thermal decomposition

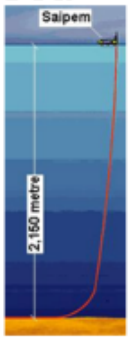
What is Pipeline / Linepipe?

Pipe operating under pressure for the purpose of transporting quantities of fluid (liquid and / or gas) over relatively large distances, from a few km to thousands of km

Onshore – Trans Alaska

1300 km long

Offshore – Bluestream under Black Sea



1210 km total length inc. 375 km subsea section

Major European Gas Trunklines

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Examples of other types of tube and pipe

Structural

Wembley Stadium

Blackpool Rollercoaster

Ascot racecourse

Examples of other types of tube and pipe

Process plant

Picture courtesy of Alan Clements

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Critical Pipe Properties

- **Strength**
  - Yield stress
  - Tensile strength
- **Toughness**
  - CTOD Tests
  - Battelle Drop Weight Tear Test
  - Charpy V-notch impact energy
  - Test temperature
- **Composition**
  - Low CEV for weldability

- **Special Properties**
  - Sour Gas Resistance

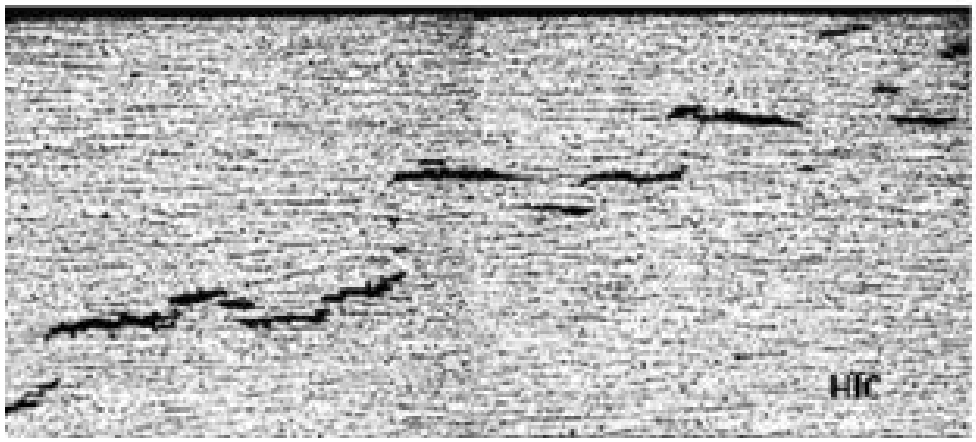
Terminology

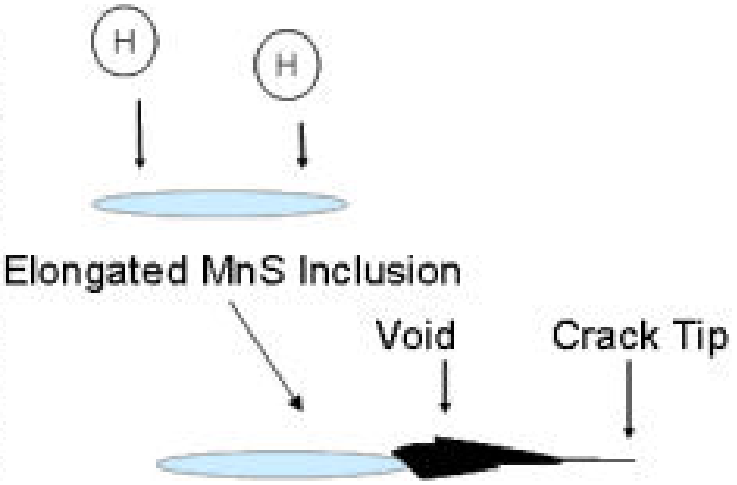
- **Sweet Corrosion**
- Carbon dioxide and water present produce carbonic acid
  - predictably reduces the pipe wall thickness

- **Sour Corrosion**
- Hydrogen sulphide gas and water present result in absorption of atomic hydrogen
  - embrittlement leading to catastrophic failure

Hydrogen Induced Cracking

- Hydrogen diffuses to inclusions / segregation
- Hydrogen diffuses to hard regions
- Cracking occurs when pressure exceeds local threshold





Mechanism of Hydrogen Induced Cracking, HIC

Need hydrogen sulphide gas and water present in pipeline fluid

$$H_2S + H_2O \longrightarrow HS^- + H_3O^+$$

$$HS^- + H_2O \longrightarrow S^{2-} + H_3O^+$$

$$2H_3O^+ + 2e \longrightarrow 2H_2O + 2H$$

Cathodic Reaction

$$Fe \longrightarrow Fe^{2+} + 2e$$

Anodic Reaction

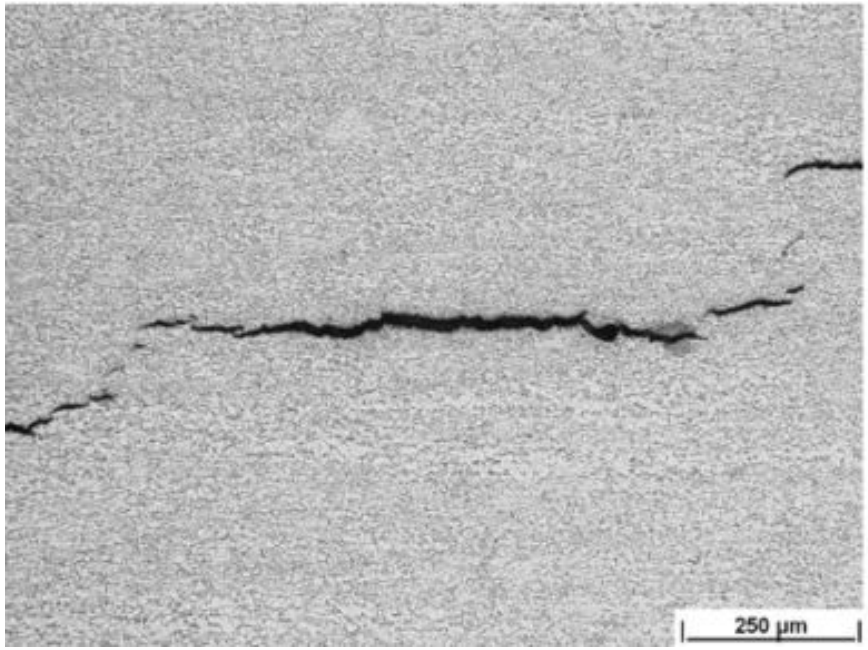
$$Fe + H_2S \xrightarrow{H_2O} FeS + 2H$$

Overall Reaction

Consequence of HIC

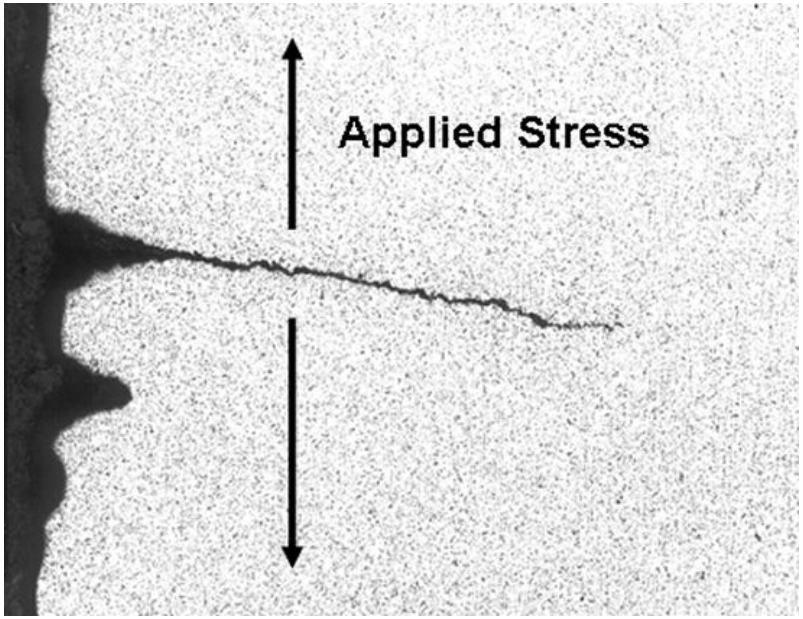
Macro-scale

Micro-scale



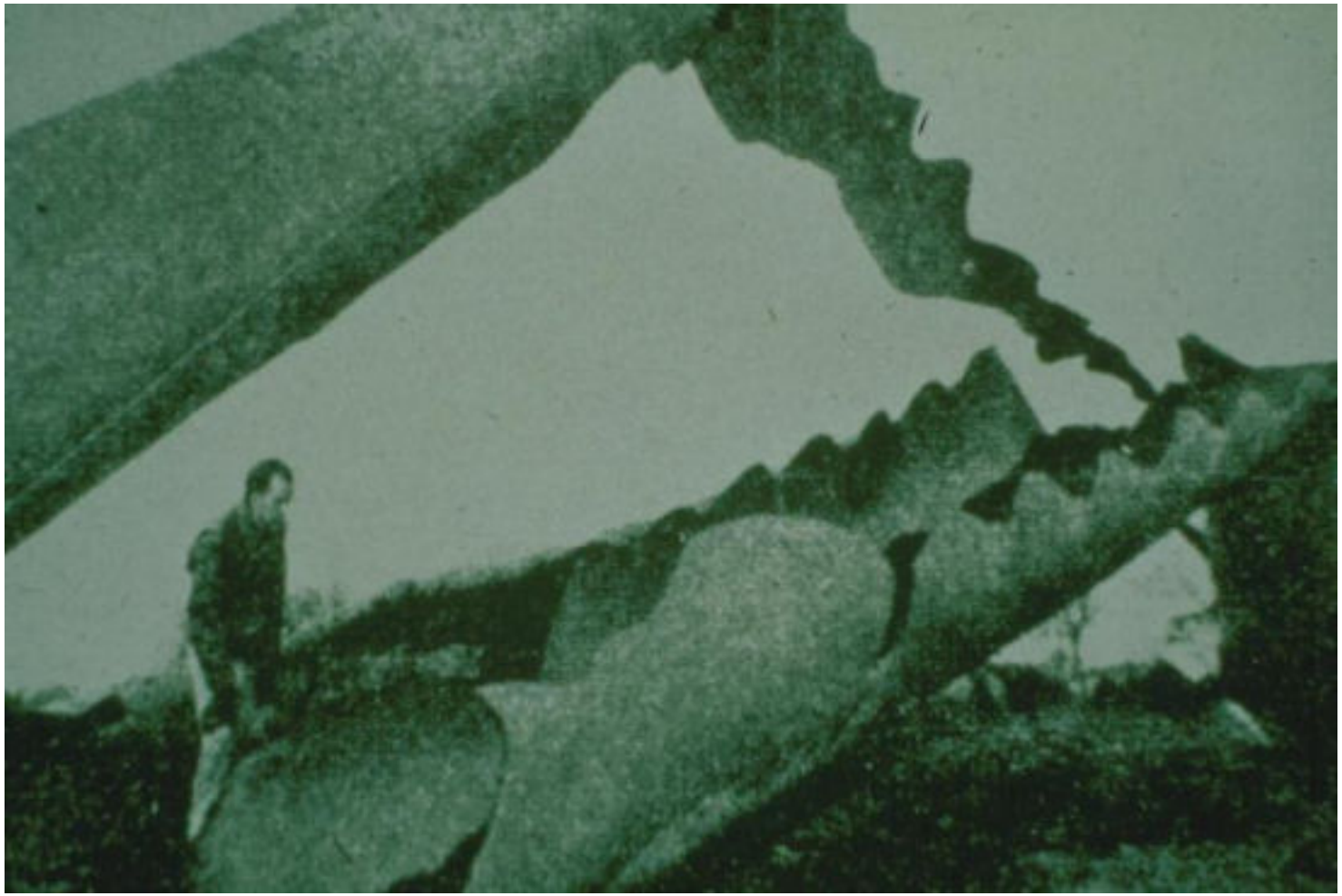
Sulphide Stress Corrosion Cracking - SSCC

- **Need an external stress**
- Pits form due to corrosion
- H diffuses to high tensile stress regions
- Local embrittlement takes place
- Crack extends by increments
- Generally occurs in higher strength grades
- Highly sensitive to microstructure



Importance of Pipeline Toughness

Propagating brittle fracture



Importance of Pipeline Toughness

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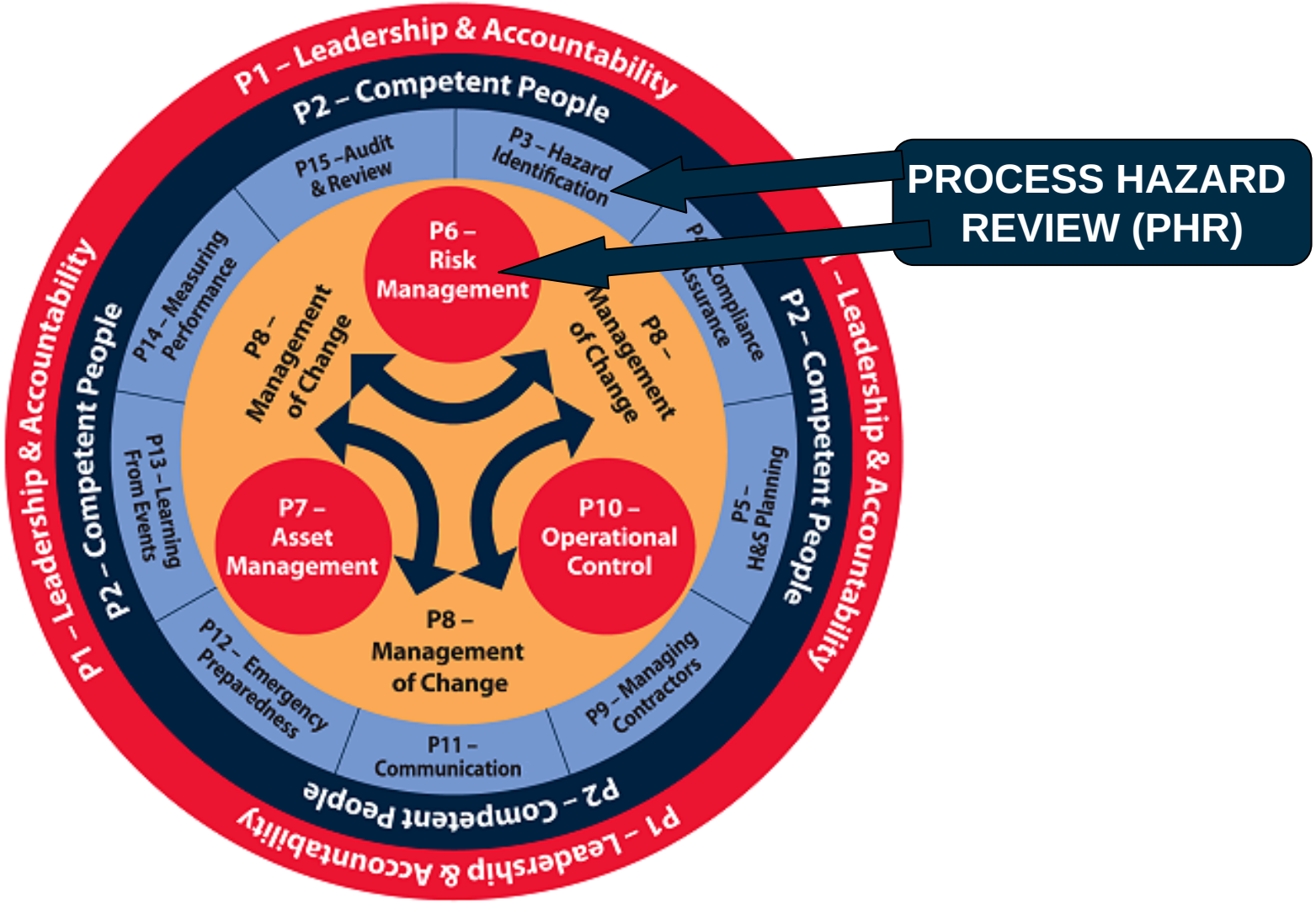
Process Safety

Process Safety - background



PHR methodology

- Team-based hazard ID and risk evaluation methodology
- Specialist and independent facilitator
- Team comprising experienced operators, engineers and technical staff
- Uses checklists and guide diagrams to:
  - Identify credible losses of containment (or energy releases)
  - Understand the consequences
  - Assess need for remedial measures
- Key issues are identified more quickly
- Risk-based improvement plan
- PHR re-validation

Sour Lab PHR – steps

- Team introduction
- Scope meeting
- Structured hazard identification exercise
- Qualitative risk assessment for each hazardous event considered

Consequence ranking

Categoty	Title	Description
5	Catastrophic	Off-site fatality Multiple (5 or more) on-site fatalities Very serious contamination of ground or water course, long-term loss of aquatic life Prohibition notice
4	Extremely serious	One or few major injuries off-site Few (less than 4) on-site fatalities High levels of carcinogen exposure MATTE (DETR definition) Severe fine
3	Major	One of few off-site medical treatment cases One or few major injuries on-site Distressing exposure, irreversible effects Disturbing visual evidence, fish killed Prosecution
2	Serious	Distress to off-site population One or few serious injuries on-site Release 2-5 times OEL Sustained or repeated nuisance, noise, unpleasant smell, dust fall-out, flaring or venting Exceed liquid effluent consent Warning from CA
1	Minor	Nuisance off-site One or few on-site medical treatment cases Release above OEL, unpleasant conditions Short duration nuisance, noise, offensive smell, flaring or venting Small amount released to watercourses Release notifiable to the CA

Frequency ranking

Category	Title	Description	
A	Probable	Greater than 1 per year	Has occurred in the lifetime of the plant
B	Possible	1 in 10^2 years to once per year	Could occur during the remaining lifetime of the plant
C	Unlikely	1 in 10^4 to 1 in 10^2 years	Incidents in industry on similar technology
D	Very unlikely	1 in 10^6 to 1 in 10^4 years	Foreseeable event but chance of occurring is very low, requires the failure of a number of layers of protection
E	Extremely unlikely	1 in 10^7 to 1 in 10^6 years	Equivalent to the risk of being killed by a lightening strike

PHR output – qualitative risk evaluation

- A full list of major accident hazards for the plant
- All major accident hazard events positioned on the risk matrix

Appendix B Hazardous event prioritisation summary

CONSEQUENCE CATEGORY					
CATEGORY 5				UNACCEPTABLE	
CATEGORY 4	1.4, 1.7, 1.11, 5.2, **6.2**	**1.2**, 1.6, 1.8, **3.1**, 3.5	**1.3**, **1.5**		
CATEGORY 3		4.4	**1.1**, **1.9**		
CATEGORY 2	4.1	2.2	2.1		
CATEGORY 1	4.3	11.2, 11.6 BROADLY ACCEPTABLE		4.5	TOLERABLE IF ALARP
EVENT FREQUENCY PER YEAR	E	D	C	B	A
	10^{-7} EXTREMELY UNLIKELY	10^{-6} VERY UNLIKELY	10^{-4} UNLIKELY	10^{-2} POSSIBLE	1 PROBABLE 10
	All scenario numbers shown in bold have a PHR recommendation raised against them. Risk estimation based on team judgement, sufficiently accurate for prioritisation purposes only. Further detailed analysis (LOPA) or information may lead to revised estimates.				

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PHR output – safety integrity level (SIL) determination

LOPA	Safety Instrumented Function	Target SIL	Target PFD_{avg}
1	H_2S Leak Detection and Alarm System	1	0.017

- LOPA principal steps :

  1. Identify the specific hazardous event and its severity.
  2. Identify the initiating causes of the hazardous event.
  3. Determine the target frequency.
  4. Identify independent layers of protection.
  5. Completion of LOPA Spreadsheet

PHR output – safety integrity level (SIL) determination

LOPA	Safety Instrumented Function	Target SIL	Target PFD_{avg}
1	H_2S Leak Detection and Alarm System	1	0.017

- LOPA principal steps :

Event consequences	Target event frequency for SIL assessment (per year)
Category 5	3.5×10^{-7}
Category 4	3.5×10^{-5}
Category 3	3.5×10^{-3}
Category 2	3.5×10^{-1}

PHR output – safety integrity level (SIL) determination

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  3. Determine the target frequency.
  4. Identify independent layers of protection.
  5. Completion of LOPA Spreadsheet

Summary – what we learned

- PHR review
  - Recommendations for improvement
  - Intolerable risks
  - Tolerable if ALARP
- SIL Determination
  - Assessed using LOPA technique
  - Achieved SIL assessment demonstrated that weekly functional testing achieves target PFD_{avg}
- Action plan and closure – review PHR in the event of change / 5 years

Summary – benefits

- Prevents major accidents with the potential to harm
- Part of the Risk Management toolkit
- Assurance that any possible risks are reduced to ALARP

Questions?