Construction Safety in Hard rock Tunnelling

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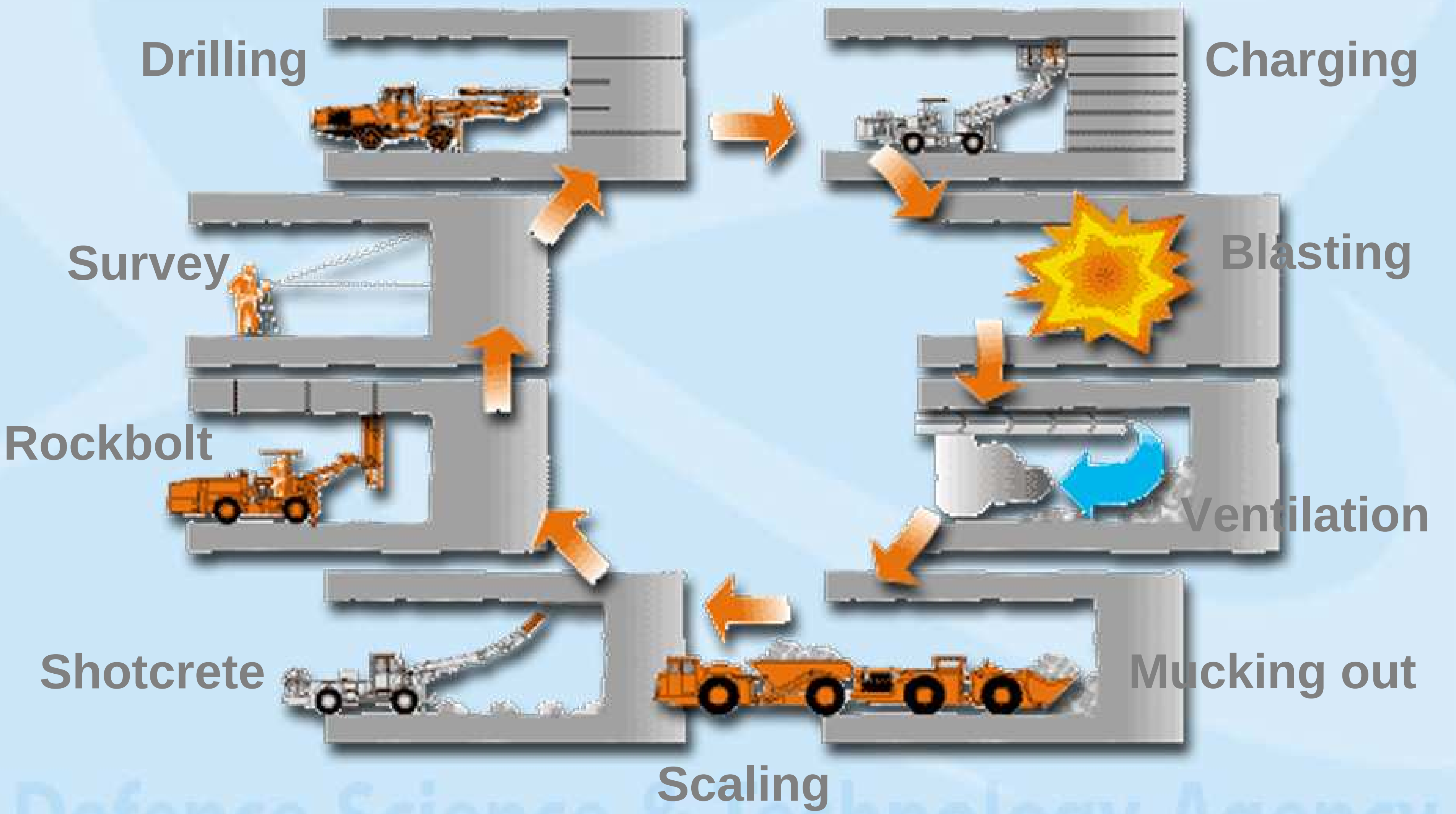
Method of Construction

- Drill and Blast Method
  - Method of rock cavern excavation with the use of explosives.
- Most suitable for hard rock with complex layout and geometry
- Unique hazards due to need for blasting
- Work is carried out in a cyclic manner

The Tunnel Cycle



Factors Unique to Tunnelling

- Uncertainty in the nature and variability of ground conditions (rock quality, ground water, gas, etc) - *need for adequate site investigations prior to and vigilance during tunnelling*
- Confined space of tunnel environment (limited access, escape, air quality control)
- Difficulty in communications (sound and signal barriers)
- Work in compressed air (soft ground)

Types of Emergency

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- Ground collapse (need we say more?)
- Support failure
- Flooding
- Gas explosion
- Oxygen deficiency
- Fire (encountering inflammable gas)
- Accidents : moving plants
- Plant and power failure
- Stoppages

Principal Causes of Accidents

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- Falling from heights or falling on level (tripping/slipping)
- Materials falling from height or from stacks or vehicles
- Burial by fall of material (rock collapse or stacking collapse)
- Flooding or inrush of water
- Machinery related (cranes, excavators, etc)
- Vehicles (excavators, dump trucks)
- Electrical installations
- Fire and explosions (gas and explosives)
- Air pollution (oxygen deficiency, toxic fumes & radon gas)

Hazards Related to Blasting

- Blasting a “way of life” in hard rock tunnelling
- Fly rock
- Airblast and ground shock
- Toxic fumes
- Accidental explosions

Drilling of Charge Holes

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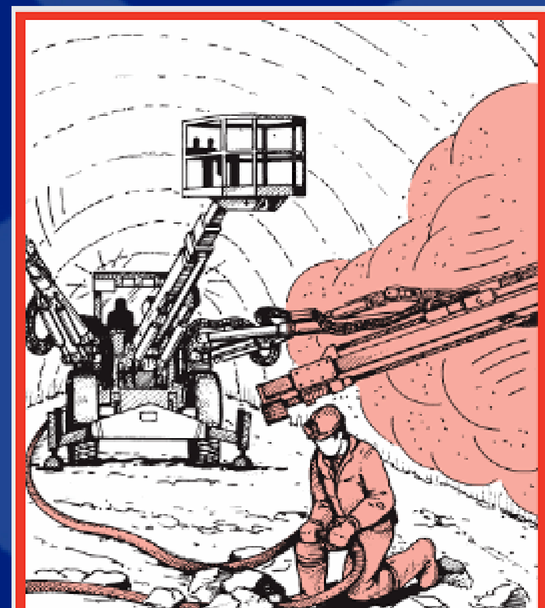
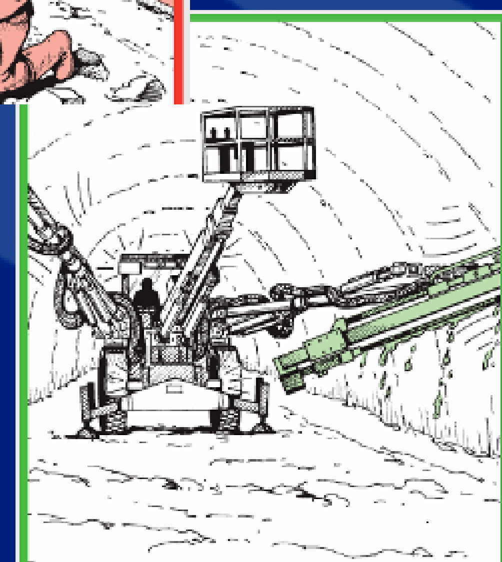
Hazards

- Being knocked over/crushed
- rock fall
- dust and noise

Protection

- Keep away from danger area
- wet drilling
- hearing protection





Warning sign to cordon off people from drilling face

Charging Explosives

Hazards

- accidental detonation by drilling into explosives
- being knocked over or crushed by drilling boom
- falling

Protection

- Only charge after the whole face has been drilled
- work can only be carried out under supervision of authorised blasting specialist
- use working platforms
- Bulk emulsion

Mobile Charging Unit

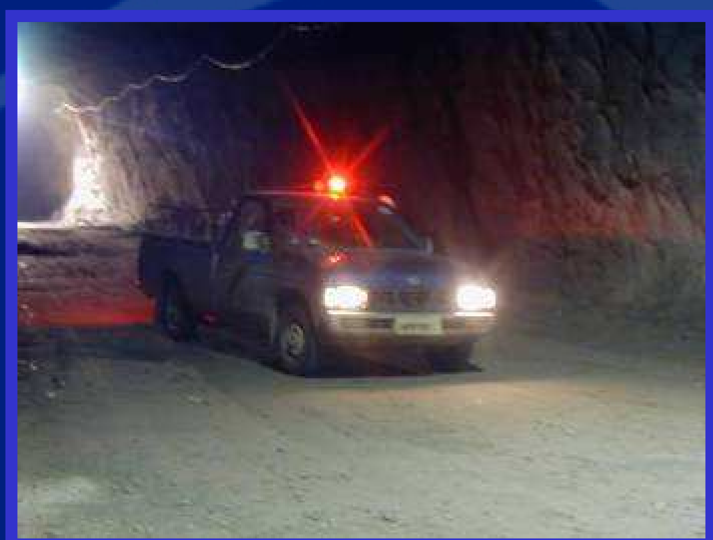
During Charging

Shotfirer will check final charged face before leaving

Signs to warn and cordon off personnel from charged face

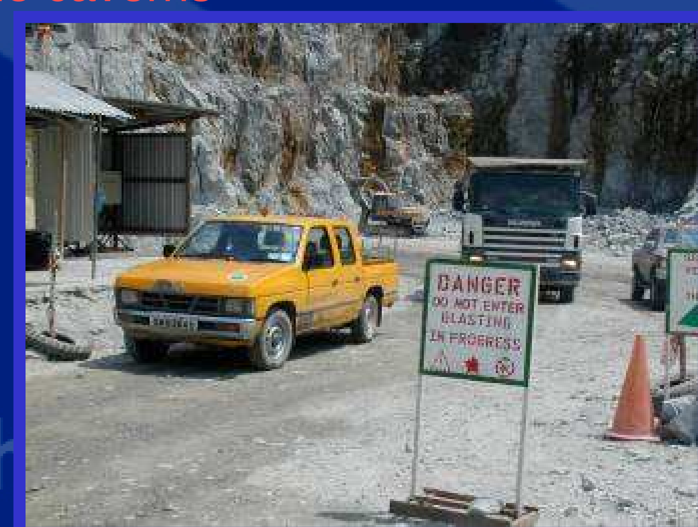
Pre-Blasting

- Responsibilities of Shot-firer in Mandai
  - Connecting the explosive charges
  - Final checking before blasting
  - Work with Tunnel Foremen & Safety Supervisor to ensure adequate safety measures are taken.

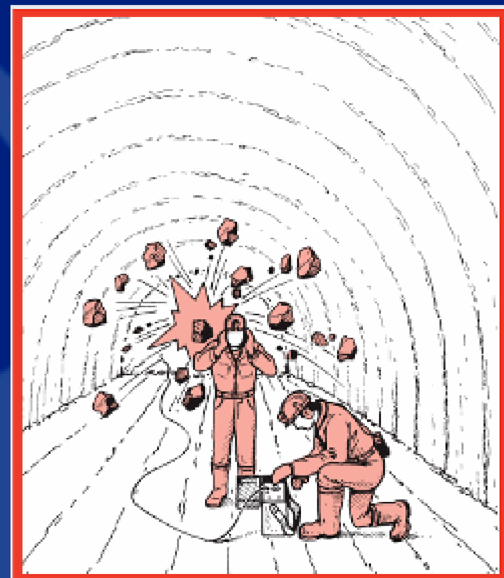


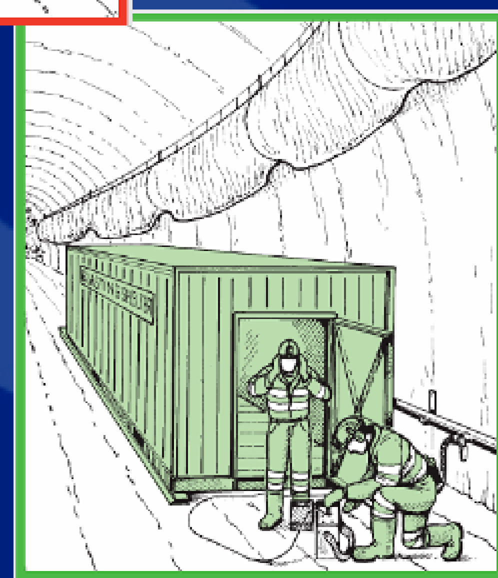
Safety vehicle with light siren evacuating personnel in cavern

Ample warning (E.g. sirens) outside the caverns



Blasting





Hazards

- Fly rock and airblast
- toxic fumes

Protection

- keep away from area
- switch off ventilation completely before firing
- switch on ventilation at full capacity after blasting
- evacuate team or provide shelter(containers or niches)

Use of rubber-tyre mats and concrete blocks to minimise rock throw during blasting open areas

Inspection of Blast Results

- Check for Misfires, Dangerous and Loose Rocks Conditions
  – Shotfirer and Tunnel Foreman will inspect the area cautiously for dangerous signs

- Safety Supervisor to ensure SF/TF carry out inspection
  – Should there be no initiation of explosives, minimum re-entry time must not be less than 30 mins.
  – After initiation, minimum retry time must not be less than 15mins (after ventilation)
  – Blast inspection team shall enter tunnel with appropriate breathing apparatus.

Use of Explosives

On-site Storage

- Licensed magazine to store detonators and booster charges in temp cavern on site
- Reduced transport hazards to public

Use of Bulk Emulsion

- Non-explosives until being charged.
- Less toxic fumes
- Mechanised charging minimises human exposure at drilling face

Detonators stored in cavern

Storage magazine guarded by 24 hour Cisco guards

Mobile Charging Unit

Control of Dust and Fumes

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- Ventilation
- Gas/dust monitoring
- Minimum entry time after blasting (with ventilation)

Air Quality Underground

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- Oxygen deficiency
- Dust
- Toxic gas (CO, CO_2, NO)
- Heat and fire

Measurement Limits for Air

- Parameters for Air Monitoring
  - Oxygen – 19.5 to 23%
  - Nitrogen Dioxide – Less than 5ppm
  - Lower Explosive Limit – Less than 10%
  - Carbon Monoxide – Less than 25ppm
  - Dust – Less than 10mg/m3 (Long term)

Typical Results in Tunnels (Average readings after blasting)

Time of the day	O2 (%)	NO2 (PPM)	LEL (%)	CO (PPM)	Remarks
Daily	20.3 – 20.9	0-2 2-5*	1-5	2-5 5-21*	*During mucking-out operation, the levels of NO_2 and CO tends to be higher

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Radon Gas Underground

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- Naturally occurring in rock and soil
- Radon and radon daughters are radioactive and can cause adverse health effects (lung cancer)
- Is released by exposed surface, blasted rock, groundwater, from outside air
- Conditions improve with proper ventilation

Radon Gas Underground

- Measured levels in UAF: 94.5 - 142.5 Bq/m^3
- Internationally accepted levels: 200-500 Bq/m^3
- 1 pCi/L= 37 Bq/m^3

Radon Level [a] Lifetime Risk of Lung Cancer Death (per person) from Radon Exposure in Homes [b]

Source: US EPA Website

pCi/L	Never Smokers	Current Smokers [c]	General Population
20	36 out of 1,000	26 out of 100	11 out of 100
10	18 out of 1,000	15 out of 100	56 out of 1,000
8	15 out of 1,000	12 out of 100	45 out of 1,000
4	73 out of 10,000	62 out of 1,000	23 out of 1,000
2	37 out of 10,000	32 out of 1,000	12 out of 1,000
1.25	23 out of 10,000	20 out of 1,000	73 out of 10,000
0.4	73 out of 100,000	64 out of 10,000	23 out of 10,000

a Assumes constant lifetime exposure in homes at these levels.
b Estimates are subject to uncertainties as discussed in Chapter VIII of the risk assessment.
c Note: BEIR VI did not specify excess relative risks for current smokers.

Mucking Out

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Hazards

- Being struck or crushed
- Falling Material
- Dust and Noise
- Tripping and falling

Protection

- Do not enter into loading area
- Keep running surface in good condition
- Do not overload dumper
- Good lighting to work area

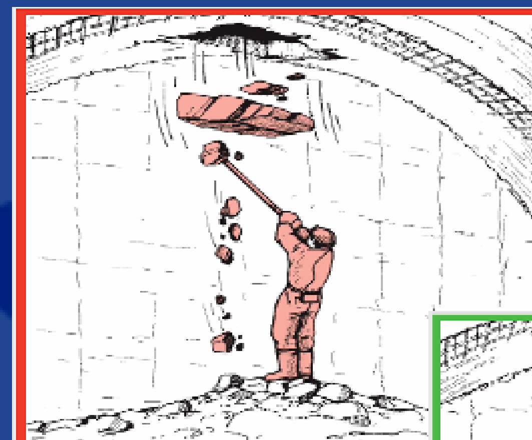
Scaling

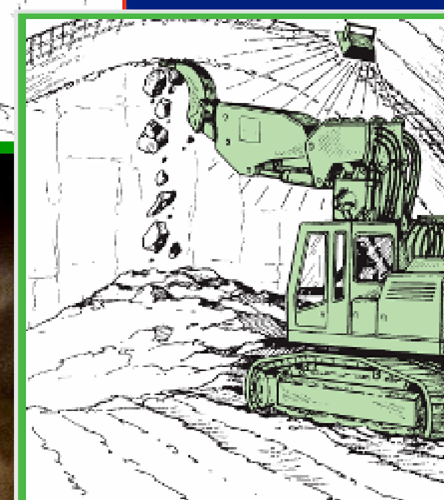
Hazards

- Rock fall
- Collapse as result from instability of exposed rock surface

Protection

- Use machine for rock scaling
- Do not enter danger zone before scaling is completed
- Lighting adequately





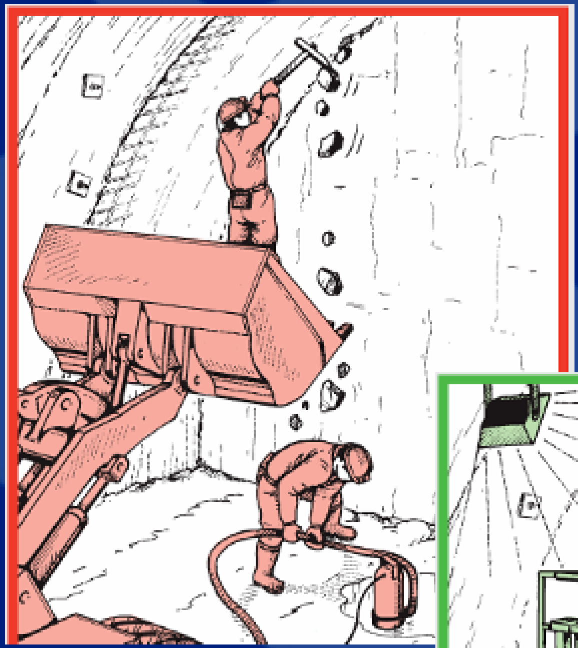
Manual Scaling

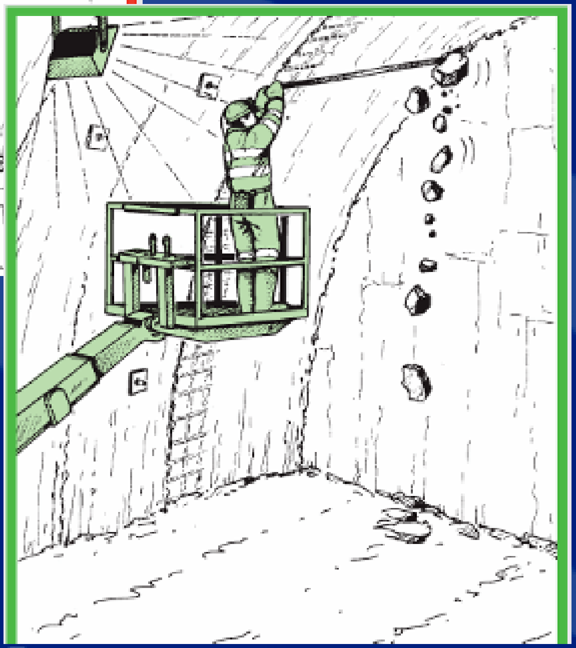
Hazards

- Rock fall
- Falling from heights
- Being crushed

Protection

- Only work from a safe area
- Use working platforms
- Light the area adequately





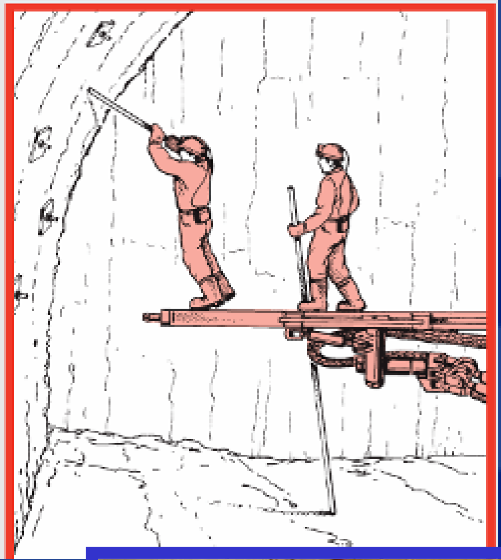
Installing Rock Bolts

Hazards

- Falling from heights
- Noise

Protection

- Use working platforms
- Use eye and hearing protection



Shotcreting

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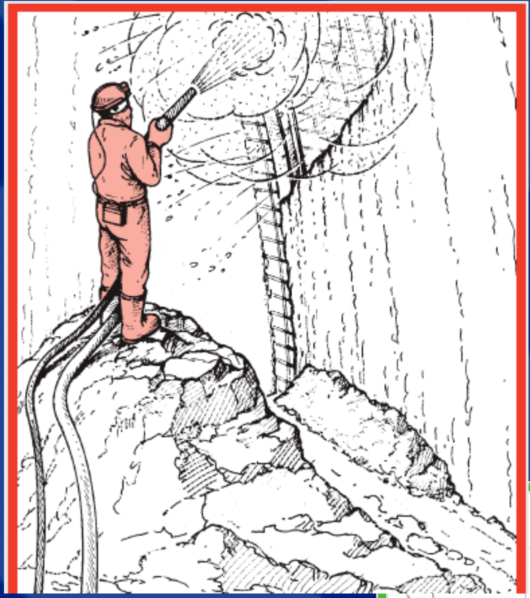

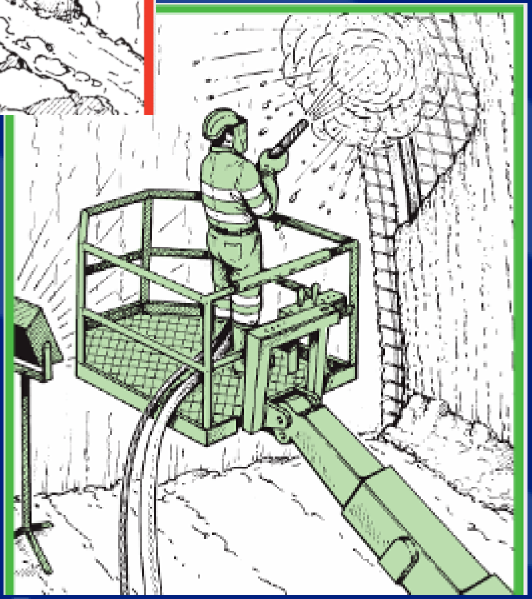

Hazards

- Falling from heights
- Rebound & dust
- Chemical additives

Protection

- Use working baskets
- Use protective clothing
- Use shotcrete robot where possible
- Wear protective hardhat for shortcreting
- Wear respiratory protection

Shotcreting Robots

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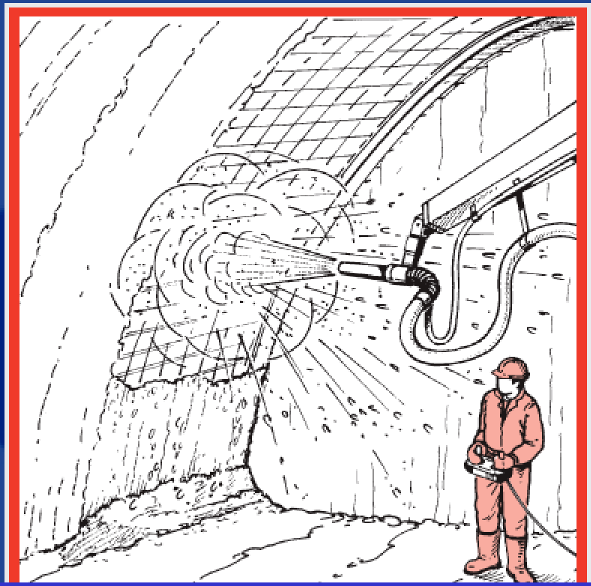
Hazards

- Being crushed
- Rebound & dust
- Burst of concrete hose

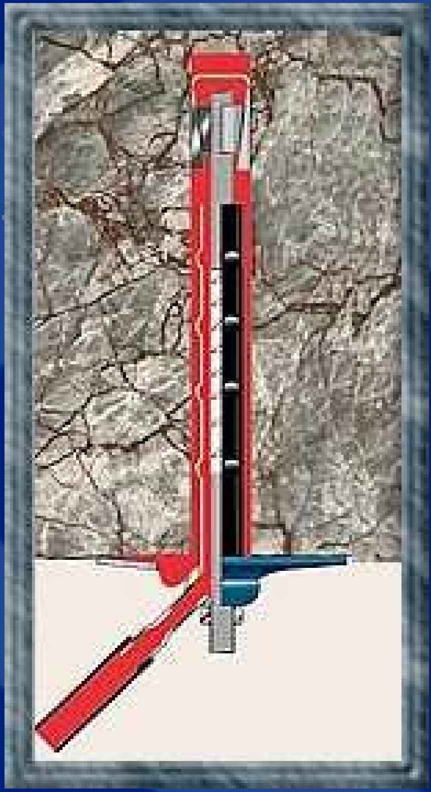
Protection

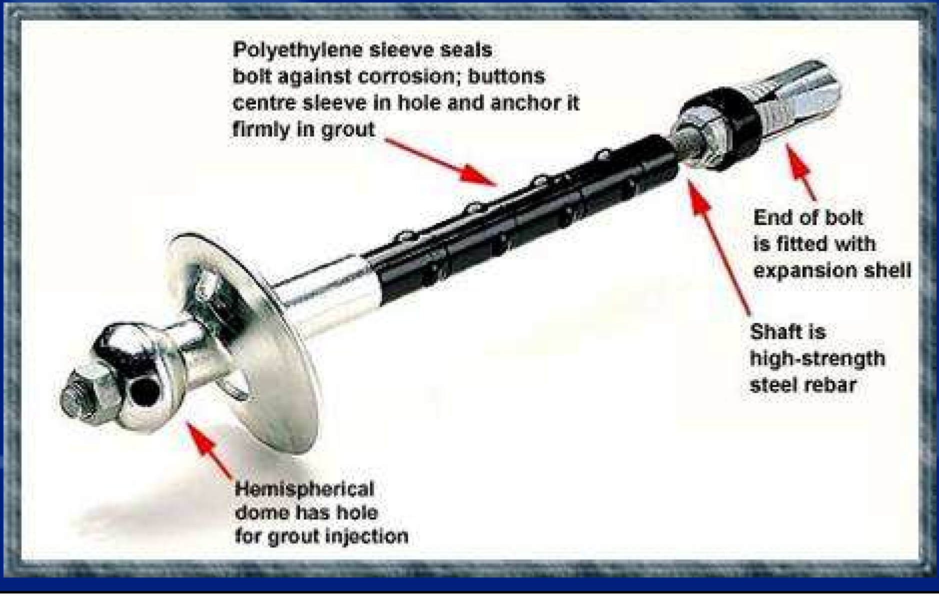
- Do not enter danger zone
- Distance between nozzle & wall <1.5
- Wear shotcrete protective helmet
- Wear respiratory protection
- Wet mix with alkali free additive to reduce dust & air pollution



Rock Support as Safety Measures for Construction

- Use of CT-Bolts
  - Easier to install than normal rebar bolts
  - Faster installation hence cost efficient
- Adoption of Rock Support System
  - Permanent rock bolts design adopted during construction phase
  - All tunnel crown sprayed with shotcrete to reduce hazards of spalling rocks
  - Shotcrete used as temporary support for safety





Safety Management Plan at UAF Site

- Job Hazard Analysis
  - For the various activities in the Tunnel Cycle, a detailed Job Hazard Analysis is carried out where all the potential hazards are identified for each work activity
- Safety Procedures
  - For each of the Job Hazards in each construction phase identified, safety procedures have been identified for work personnel to adopt.

Safety Management Plan at UAF Site

- Safety Control
  - Safety control measures are then put in place to minimise or avoid the job hazards i.e. regular safety meetings, briefings, seminars & audits.

- Safety Review
  - Contractor together with the Client conducts regular review of the Safety Measures. Safety is also standing agenda item in bi-weekly co-ordination meetings

- Improvements
  - Corrective measures and improvements are done where there are shortcomings.

Communications, Communications!

- Active participation of site team in contractor's weekly safety meetings
- Safety & health a standing item in biweekly co-ordination meeting involving DSTA programme Managers, QP's, and contractors project managers
- Everybody's an expert/student (training conducted by DSTA, specialists, and contractors)

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UAF OHSE Organisation Chart

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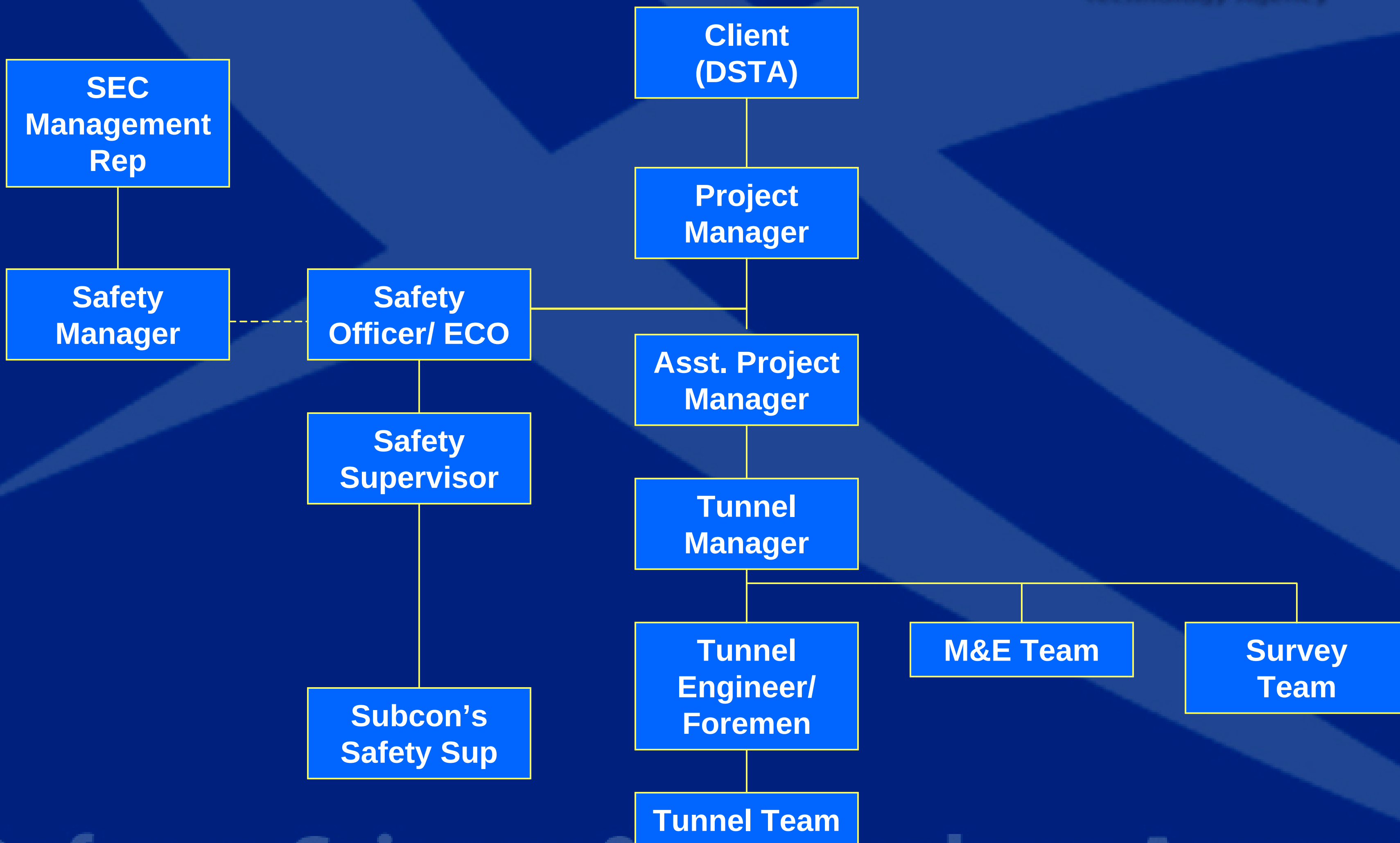

System Safety

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- A systematic process of identifying, evaluating, and controlling all hazards throughout the life cycle of a project or system (safety influences design and construction)

- Application of engineering and management principles, criteria and techniques to optimise safety (*compare to compliance safety*)

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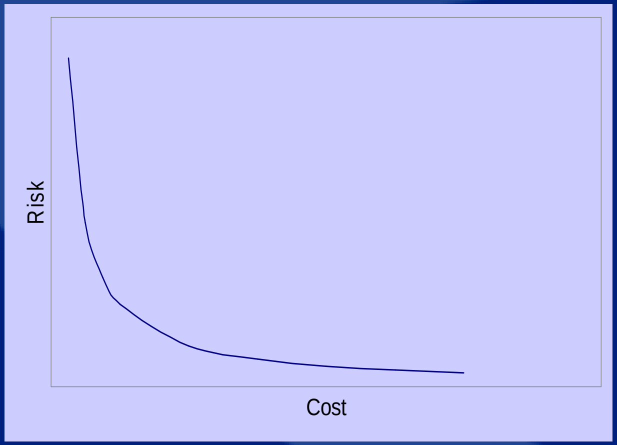
System Safety Objectives

- To achieve maximum safety within the constraints of operational effectiveness, time, and money
- Should preferably be incorporated at the inception of a project

Safety Principles



- Absolute safety does not exist
- Safety must be planned
- Safety is everybody's responsibility
- Safety efforts cost money, so do accidents (or if you think safety is expensive, try an accident!)

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Safety Design Precedence

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- Design to eliminate hazard if possible
- Design to reduce hazard
- Incorporate safety devices
- Provide warning devices
- Develop procedures and training

System Safety Activities

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- Preliminary hazard identification
- Preliminary hazard analysis
- Sub-system hazard analysis
- System hazard analysis
- Operating hazards analysis
- Occupational health and hazards assessment
- Software hazards analysis
- Hazard tracking

Risk Ranking

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Severity / Probability	Catastrophic	Critical	Marginal	Negligible
Frequent	1	3	7	13
Probable	2	5	9	16
Occasional	4	6	11	18
Remote	8	10	14	19
Improbable	12	15	17	20

1 – 5	High	R1
6 – 9	Serious	R2
10 – 17	Medium	R3
18 - 20	Low	R4

Important: Need to define risk acceptance authority

Risk Acceptance Criteria

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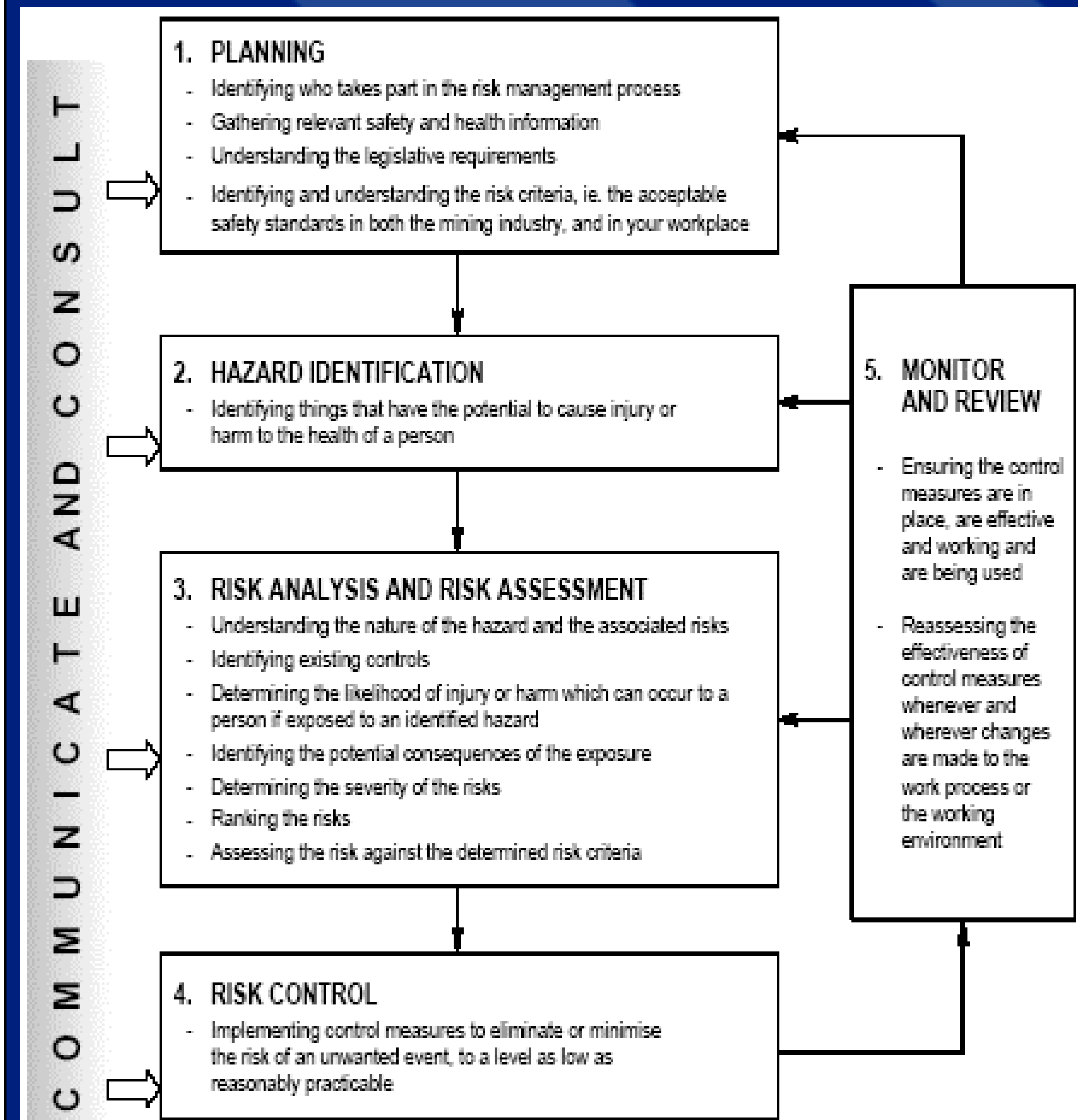
Example from US MIL STD 882

- R1 - Unacceptable
- R2 - Must control or mitigate
- R3 - Acceptable with management review
- R4 - Acceptable without review

Safety and Health Risk Management (MOSHAB, 1999)



Risk =

Likelihood x Consequence

Risk Mitigation - the ALARP principle - As Low As Reasonably Practicable

Generic Mitigators for High-Consequence Industries

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- Public dread & resultant imposed pressure
- Organisation's clear understanding of the price to pay in getting it wrong
- Organisational commitment to a strong safety culture
- Organisational commitment to continued investment in relevant technical expertise
- Independence and empowerment of safety mechanisms
- Organisational commitment to allocating some of the best brains to safety
- Visibility to and encouragement for external challenge
- Formal external regulation
- Encouragement and recognition of early symptoms/near-miss reporting/no-blame culture
- Safety is more than on your local patch

Conclusions

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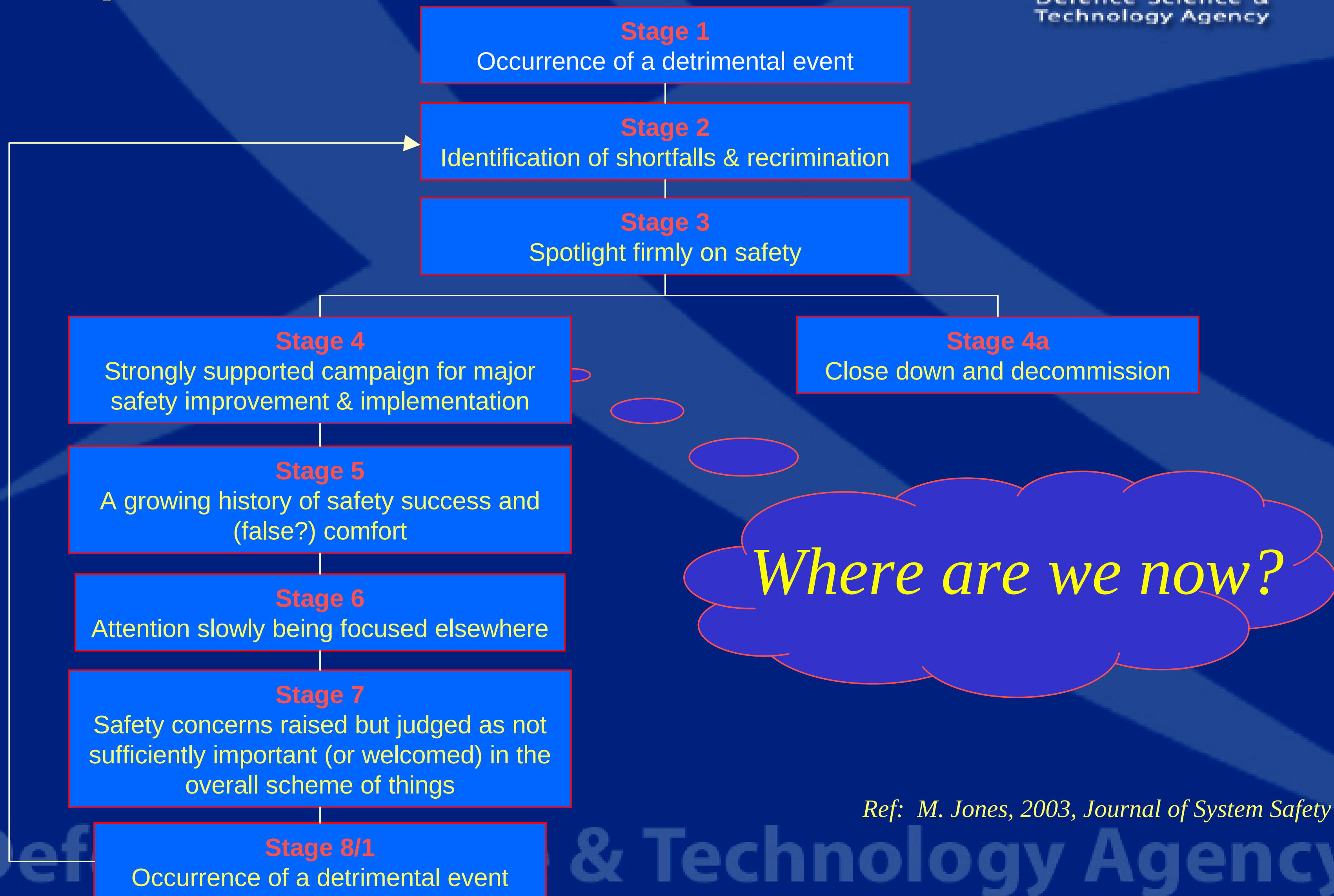
- The safety (or accident) cycle - how to reduce the magnitude and frequency

- Safety - You must believe it yourself!

The Safety Cycle (or Normal Accident Cycle)



Ref: M. Jones, 2003, Journal of System Safety

The Old Lady and the Wall

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An old lady lived near an abandoned wall next to a road. The wall looked very unstable. Everyday the old lady would sit in front of her house and warn all passers-by about the danger. But no body seemed to pay attention and they walked by the wall without any mishap. So, one day the old lady decided to check out the wall herself . . . . .

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Thank you!

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