

Lessons Learned at the Magnox Swarf Storage Silo Facility (Sellafield Nuclear Site, UK) on Planning and Optimization of intervention and Clean Up Approaches

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MSSS Leak Management Approaches

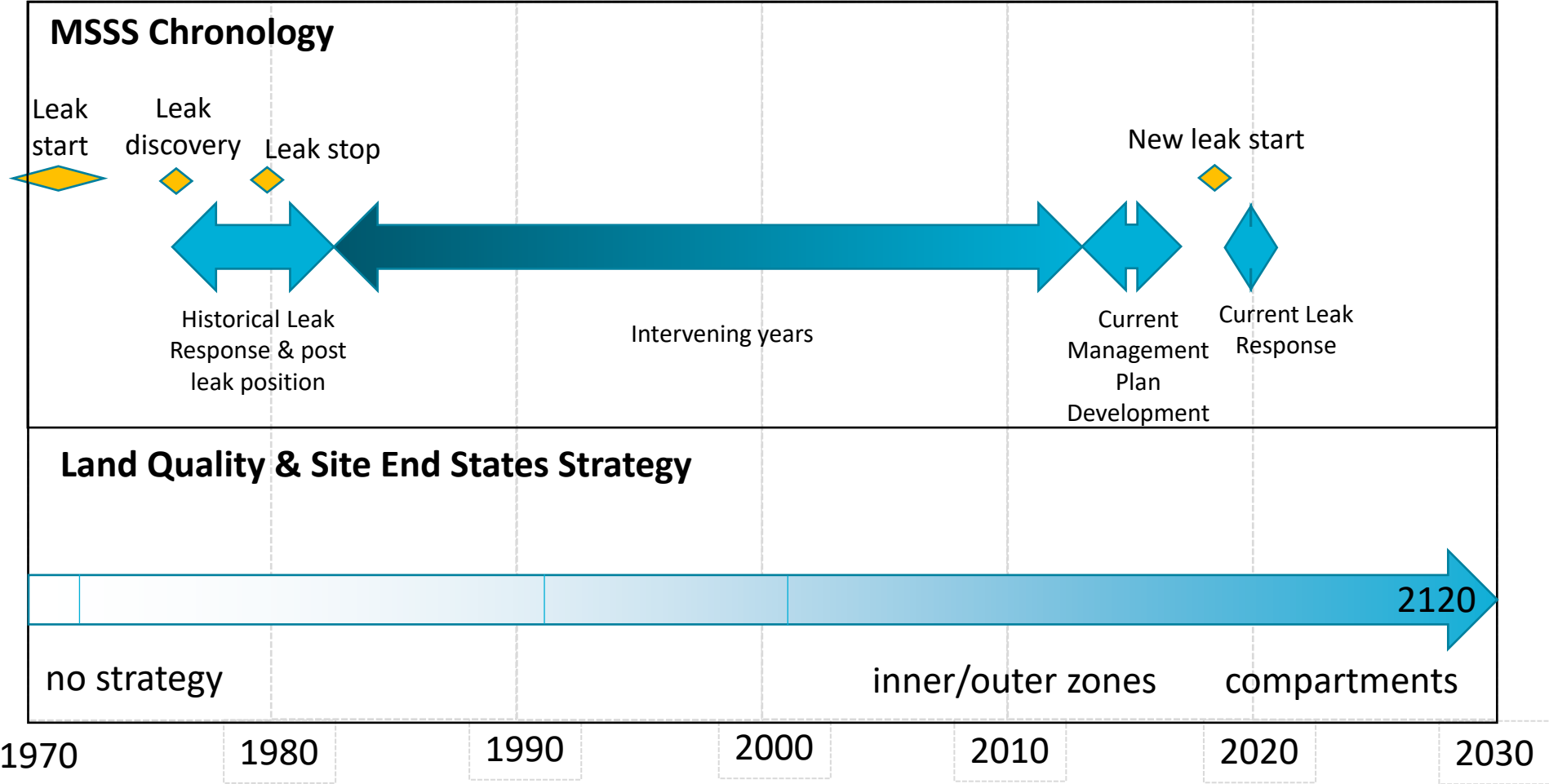
James Graham

UK National Nuclear Laboratory

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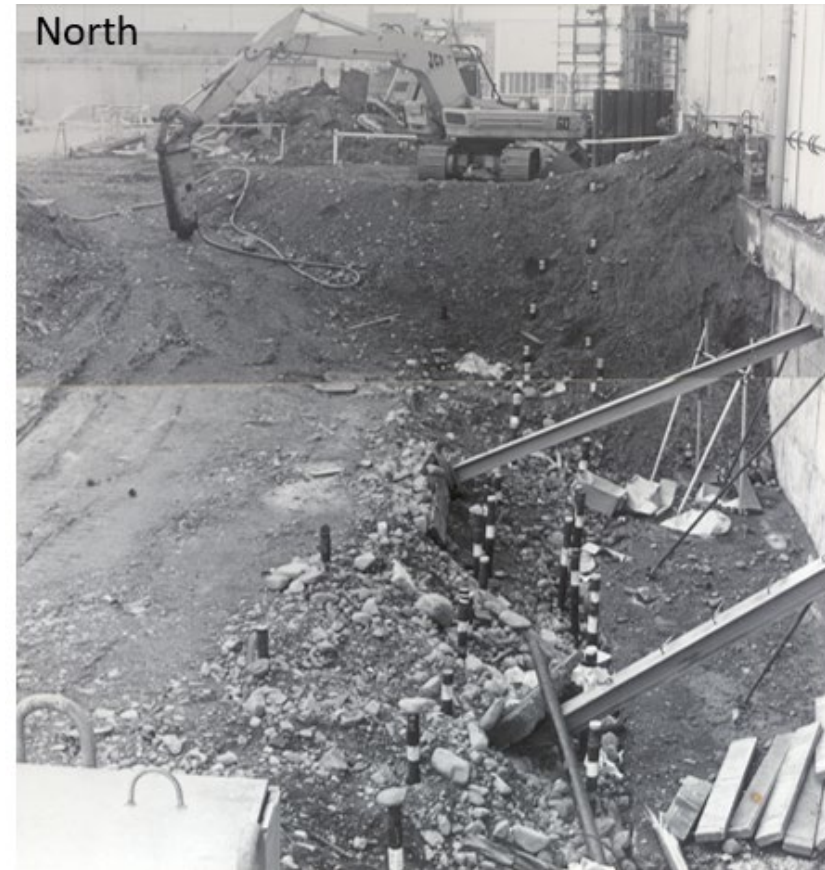
1. Historical Leak Response & post leak position
2. Intervening years
3. Current Management Plan Development
4. Current Leak Response
5. Next Steps

Timeline



Historical Leak Response & post leak position

- Attempts to find leak location in 1977
- Stopped due to excessive dose rates (up to 5 Sv/hr)
- Considered removing soil, including soil washing but calculated that even following this a proportion would still be in excess of UK LLWR limits.
- As such mostly reburied with highest activity soils placed in steel boxes within excavation.



Historical Leak Response & post leak position

Natural Attenuation R&D (1977 to early 1980s)

- Sorption experiments and gamma dose rate monitoring suggested very high sorption of main contaminant Cs-137
- Calculated $\approx 95\%$ of leak activity comprised of Cs-isotopes and held in unsaturated zone close to building
 - Consistent with contemporary R&D results from Oak Ridge
- $\approx 5\%$ (4.75% Sr-90) entered the groundwater
- Modelling/risk analysis tools predicted low offsite risk
- Estimated time to reach coast Sr-90 - 500yr (worst case 50-100yr); Cs-137 -1800yr (not including decay)
- Little discussion of other radionuclides

Historical Leak Response & post leak position

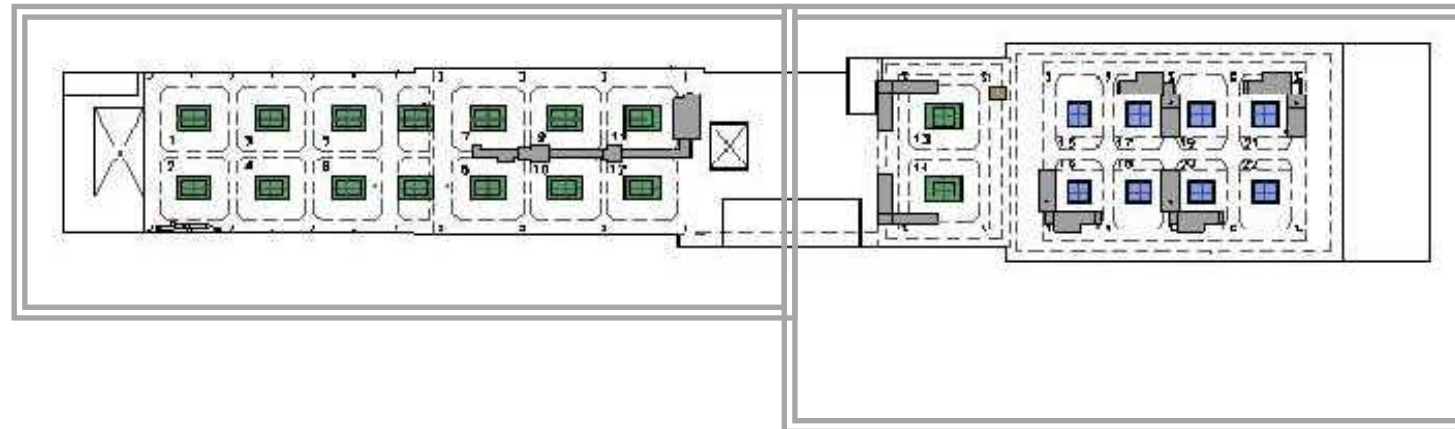
In-silo approaches

- Develop waste retrieval methods and swarf direct encapsulation
- Develop methods to minimise the leak from within the silo
 - Replacing water with gels/inert gas
 - Sealing leak e.g. bentonite injection
 - Safety Case issues

Historical Leak Response & post leak position

Barrier (Diaphragm) Wall schemes

- Developed as a contingency plan (increased migration) in 1980
- Estimate of 2 man sieverts dose to install (1980); later reduced to 0.667 man sieverts after further design

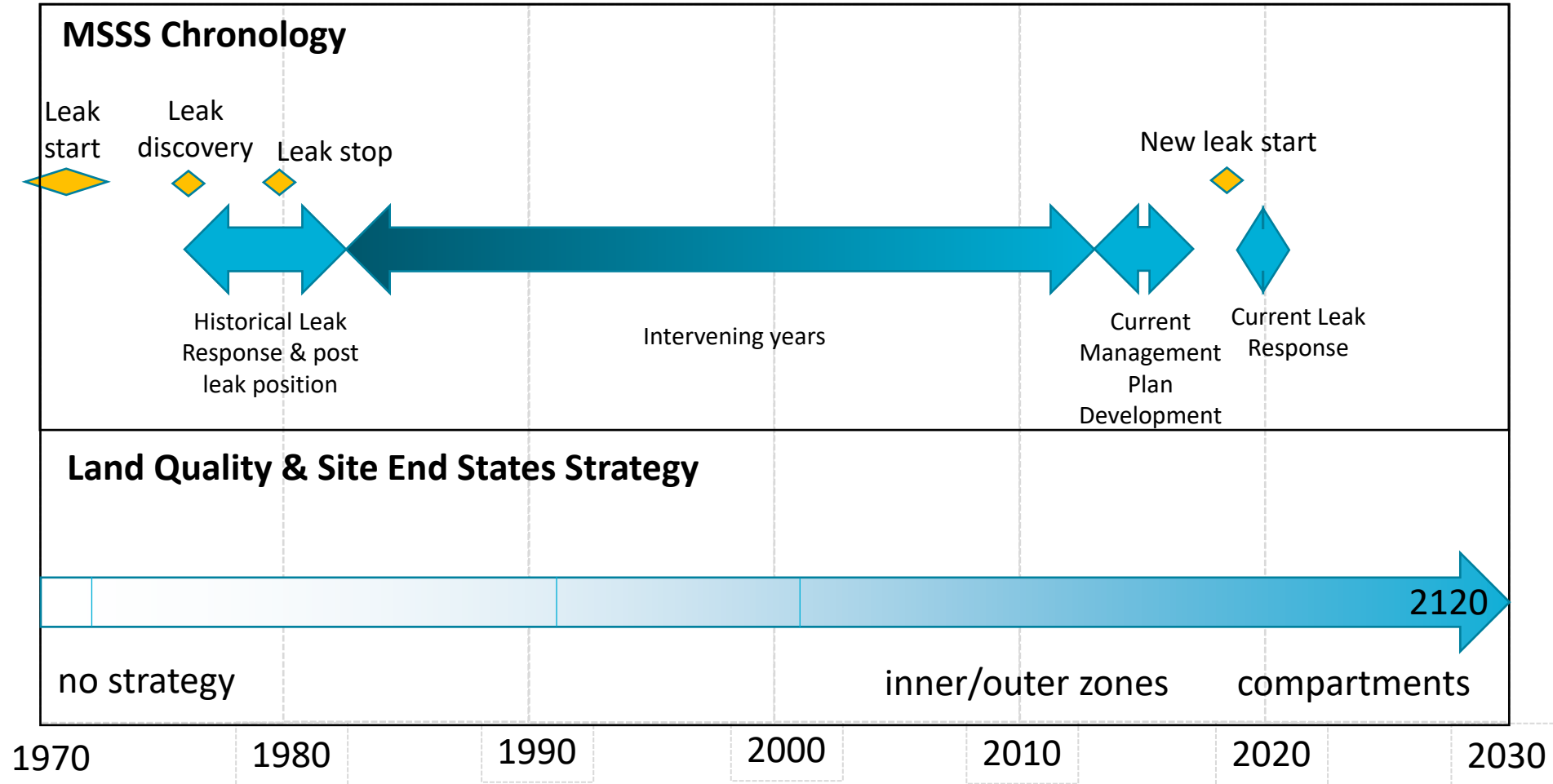


Historical Leak Response & post leak position

Conclusion

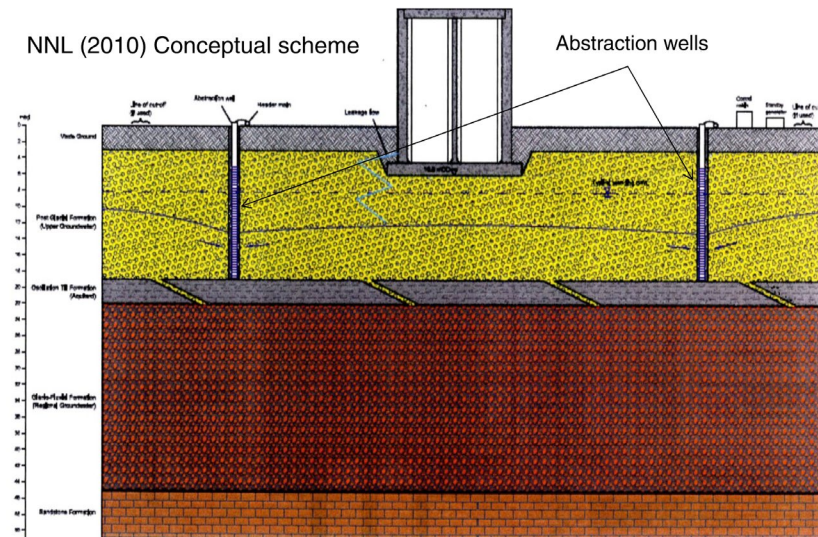
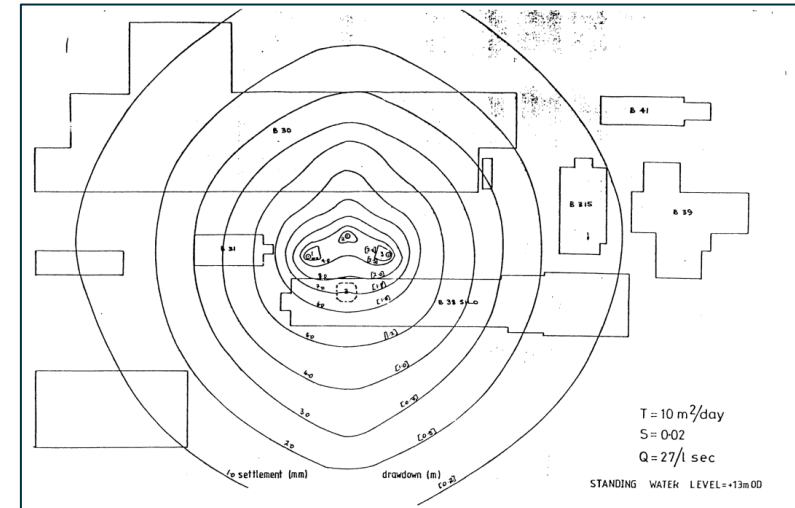
- Long estimated radionuclide travel times to the coast and low offsite risk
- High dose rates, costs and feasibility issues for barrier wall scheme installation
- Intervention not deemed to be of sufficient benefit

Timeline



Intervening years

- Some attention remained on historical leak until the 1990's
- Barrier (Diaphragm) Wall scheme 1992 'practicality plan'
 - some Sr-90 already escaped
 - Soil disposal challenges
 - Positioning issues
 - Major disruption
- Number of Optioneering Studies
- Pump and treat schemes highly ranked, but concerns regarding waste disposal and settlement
- In later years as retrievals planning matured focus turned to contingency for new leaks



Intervening years

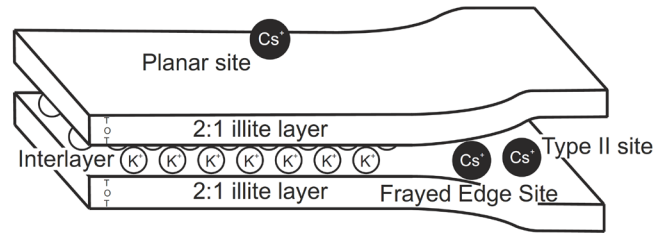


- Hard surfacing
- Surface water drainage modifications



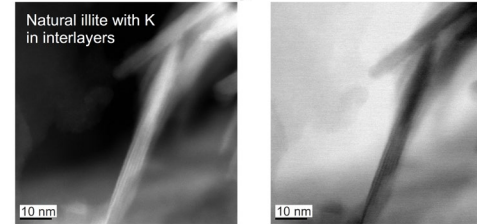
Intervening years

- Sellafield Focussed R&D on Sellafield
- University of Manchester
- University of Leeds
- Cs-137, Sr-90, Tc-99, C-14

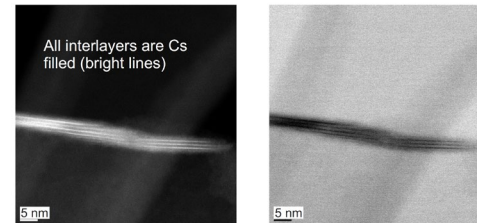


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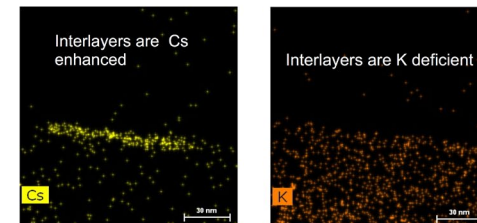
Starting material



12 months

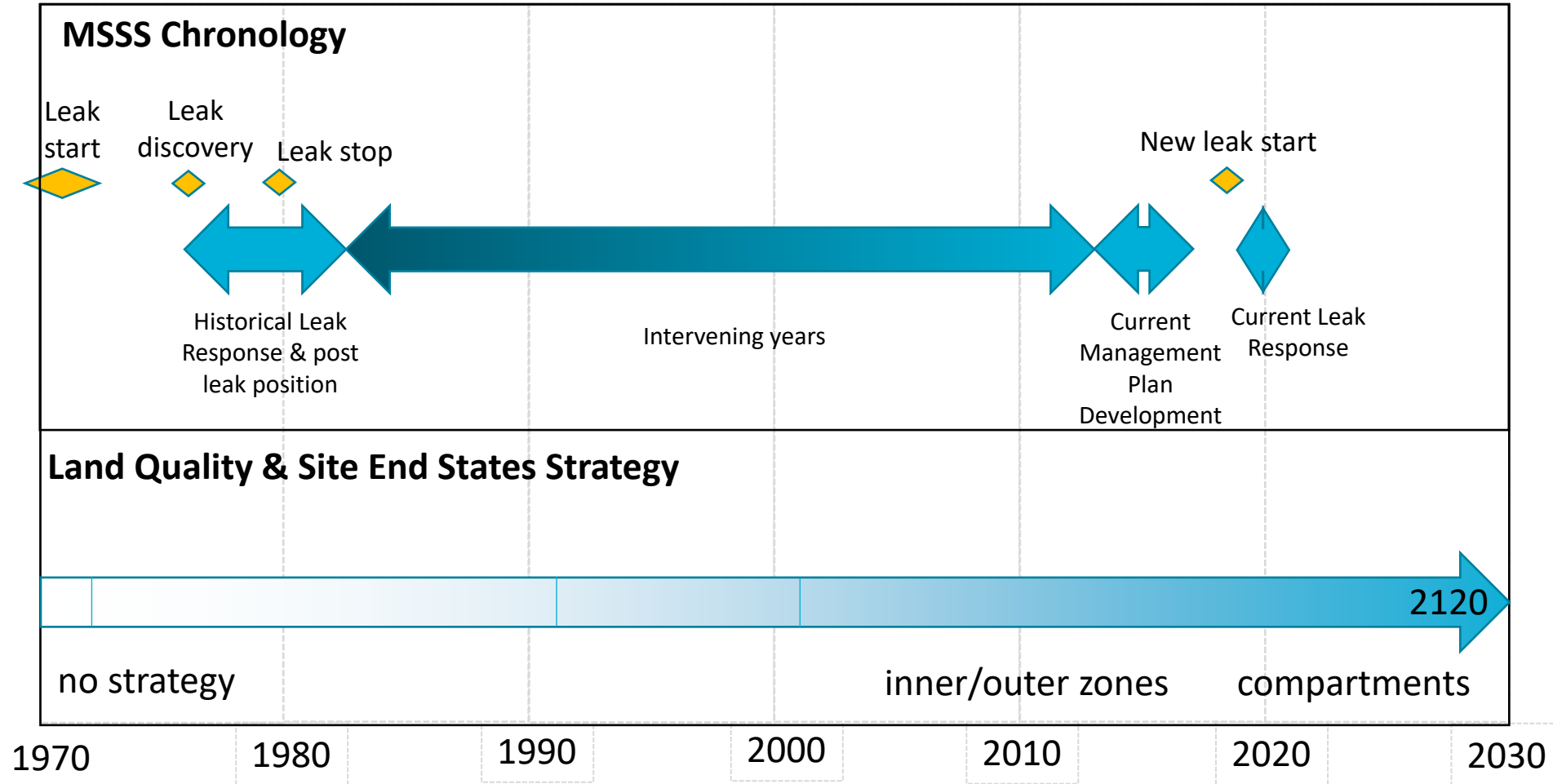


EDX



Figures from Fuller *et al.* (2013)

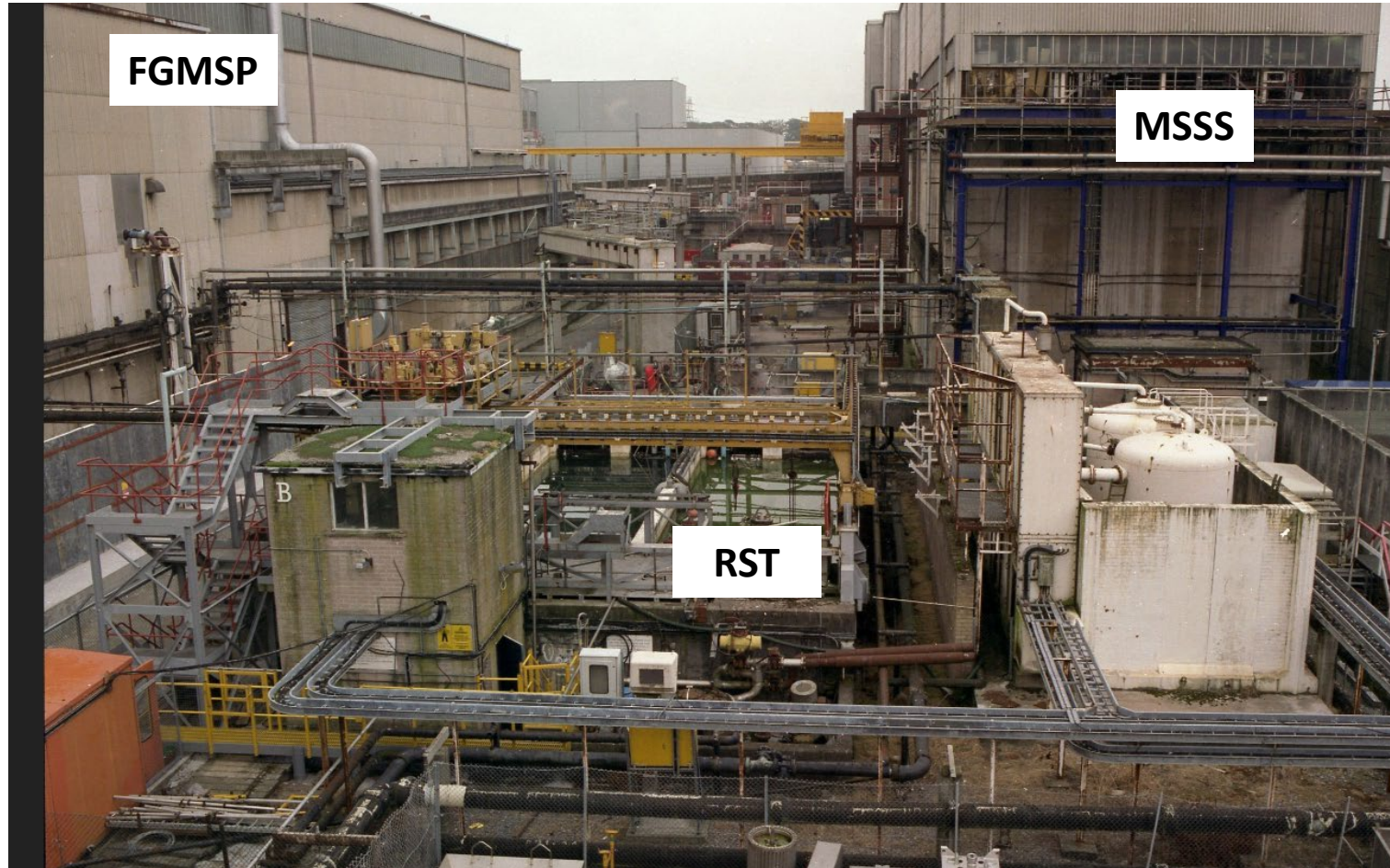
Timeline



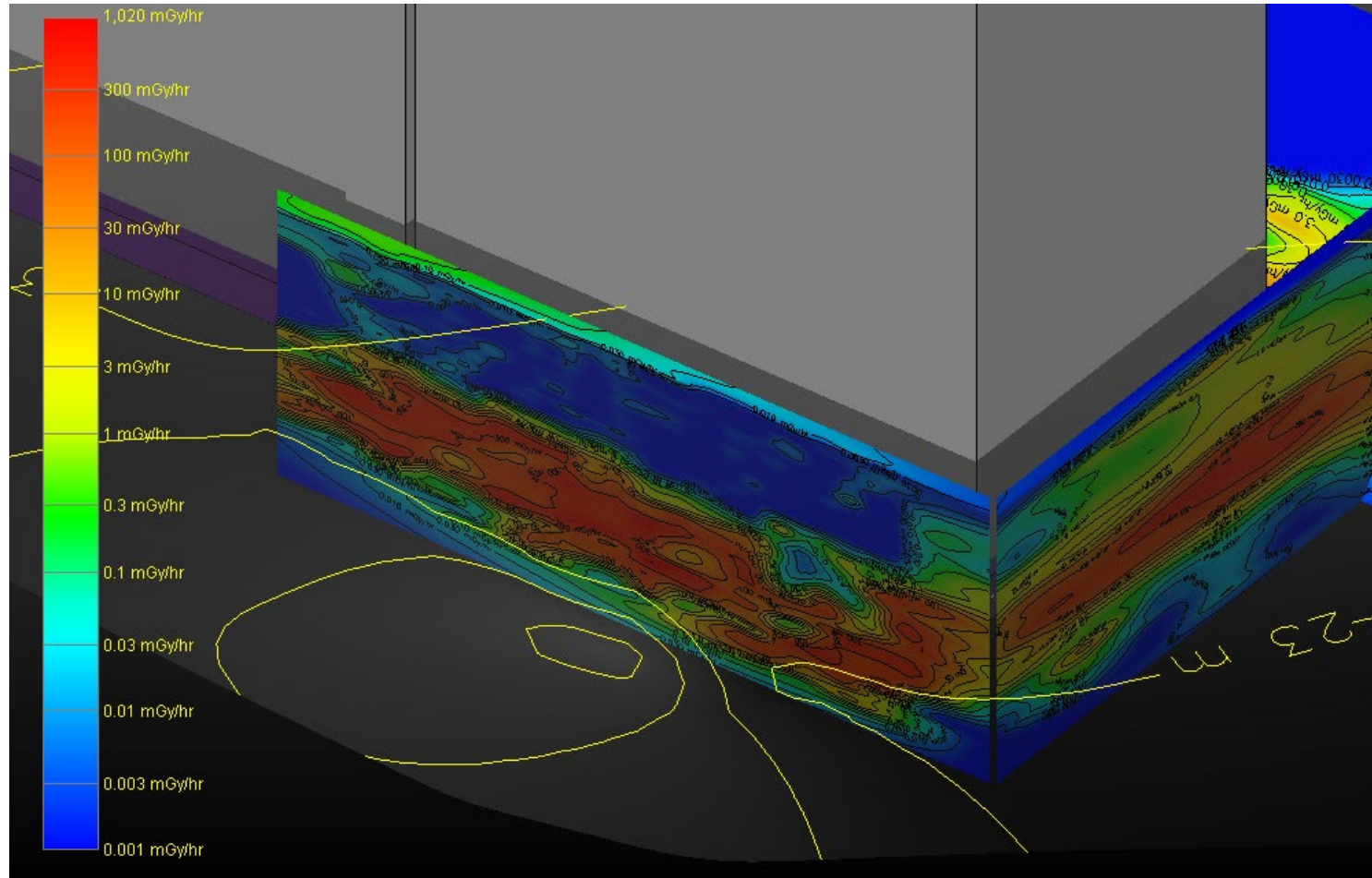
Current Leak To Ground Management Plan

- Developed as part of the Ground Environmental Management Scheme (GEMS) Study - 2013 - 2017
- Best Available Technology (BAT)
- Remplex Seminar Series, May 2021. Development of Options to Limit Groundwater Impacts from Silo Leakage

MSSS Mitigation Constraints



MSSS Mitigation Constraints



MSSS Mitigation Constraints



Current Leak To Ground Management Plan

1. GEMS Identified Contaminants of Concern (COCs) based on:

- Silo Inventory
- Results of previous environmental risk assessments;
- Soil characterisation data from the MSSS area; and
- Groundwater characterisation data from the MSSS area.

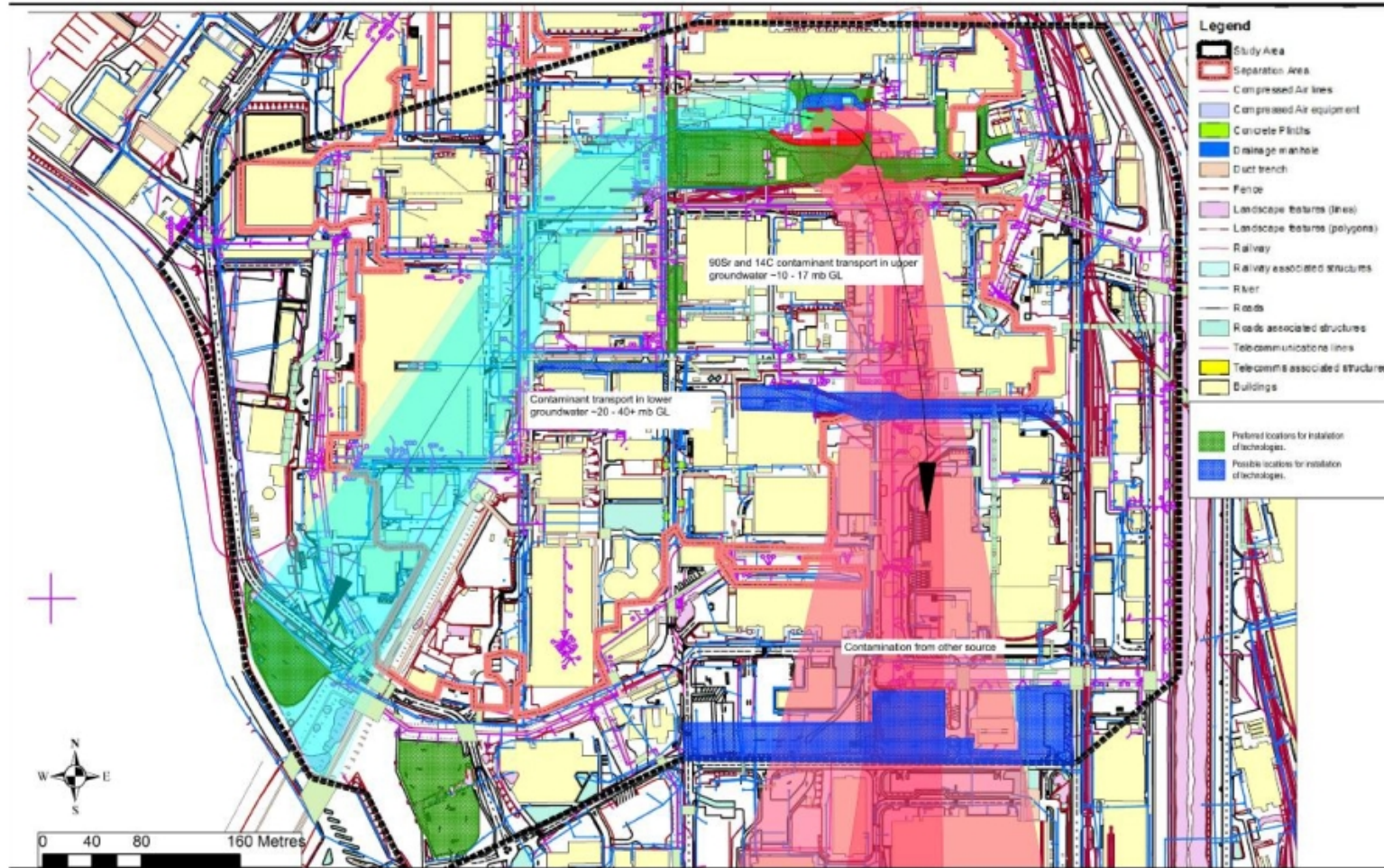
	COC Element	Associated Isotopes	
1	Sr	Sr-90	✓
2	Tc	Tc-99	✓
3	Cs	Cs-137, Cs-134	
4	C	C-14	✓
5	I	I-129	
6	Cl	Cl-36	
7	Pu	Pu-241, Pu-239 (Pu-238, Pu-240)	
8	Am	Am-241	
9	U	U-238, U-235 (U-234, U-233)	
10	H	H-3	✓

Current Leak To Ground Management Plan: Considered Intervention Technologies

GEMS Initial Groups	GEMS Long List	Phase 1	Phase 2	Study Conclusions
Cut-off Walls & Barriers	✓	✓		
Permeable Reactive Barriers	✓	✓	✓	
Chemical In-situ Treatment Zone (ITZ-C)	✓	✓	✓	✓
Bio-enhanced Retardation	✓	✓		
Surface Capping	✓	✓		
Pump & Re-inject	✓	✓	✓	
Pump & Treat	✓	✓	✓	✓
Containment and/or Stabilisation	✓	✓		
Surfactant Enhanced Aquifer Remediation	✗			
Electrokinetics	✗			
Vitrification	✗			

Shortlisted	✓
Supporting only	
Screened out	✗

Current Leak To Ground Management Plan: Potential Deployment Locations

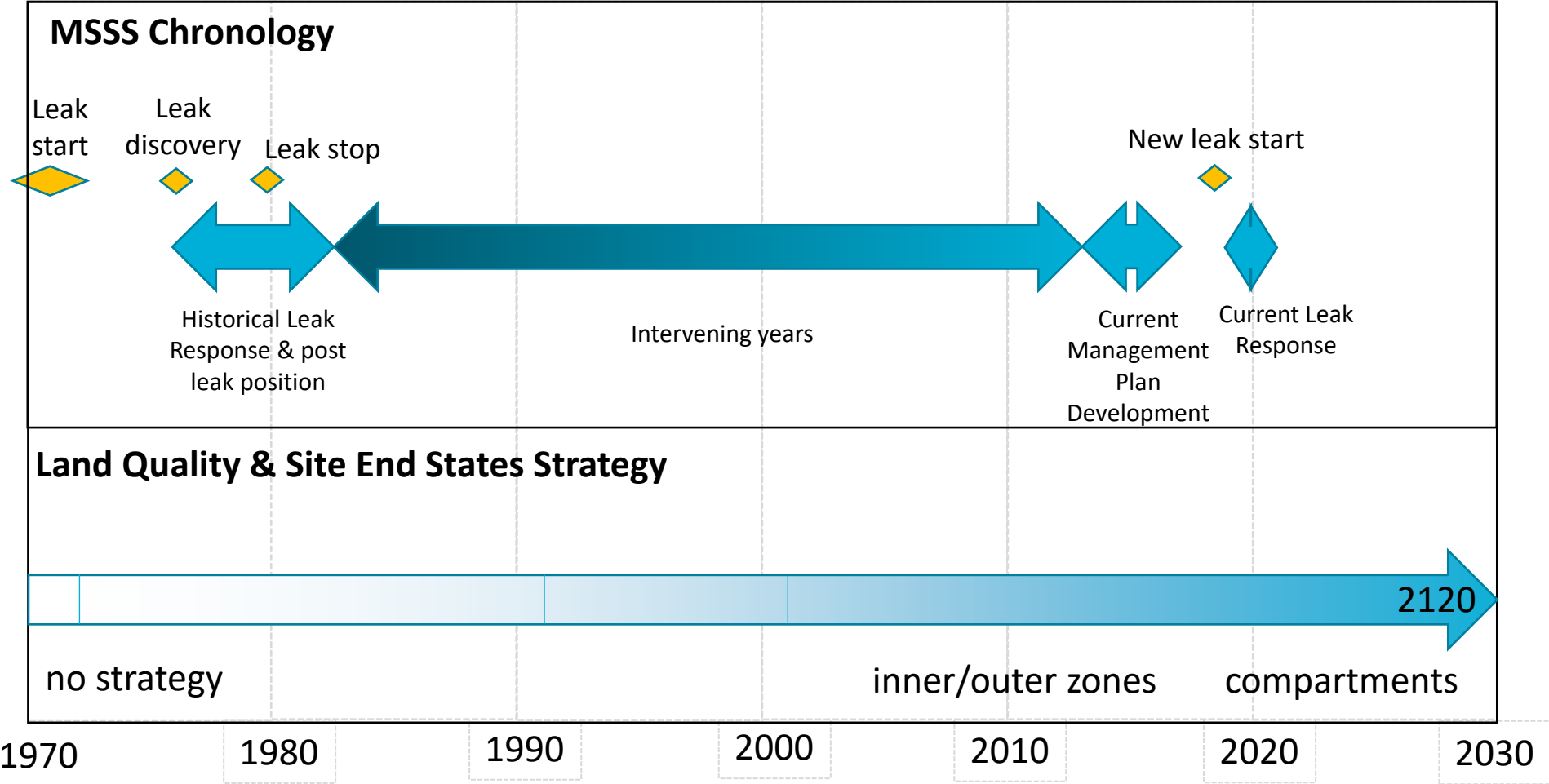


Current Leak To Ground Management Plan

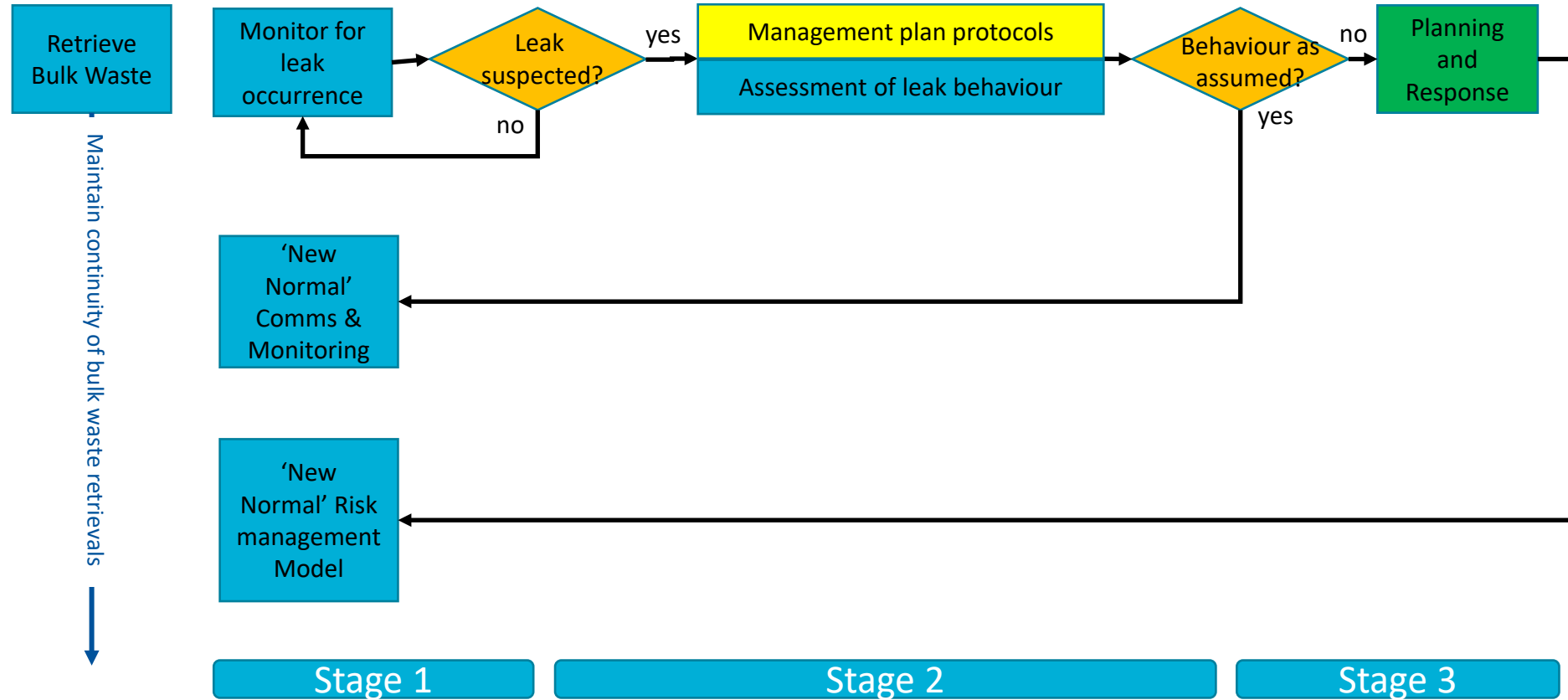
Conclusions and Strategy

- Important role of natural attenuation in limiting migration.
- Offsite risk estimated to be low from anticipated future leak scenarios.
- The current site wide strategy for the management of contaminated land based on monitoring, characterisation and assessment was also adopted as BAT for the baseline for management of MSSS future leaks.
- Decision to deploy an intervention technology only to be made if in the event of leak impacts were greater than previously predicted.
- Technology Development plans created for In-situ Chemical Treatment and Pump and Treat as contingencies.
- 3 Stage response plan developed

Timeline



Current Leak Response



Current Leak Response

- ‘Can we change our approach to leak mitigation’ – focus on technical options
- ‘Should we change our approach to leak mitigation’ – focus benefits/detriments

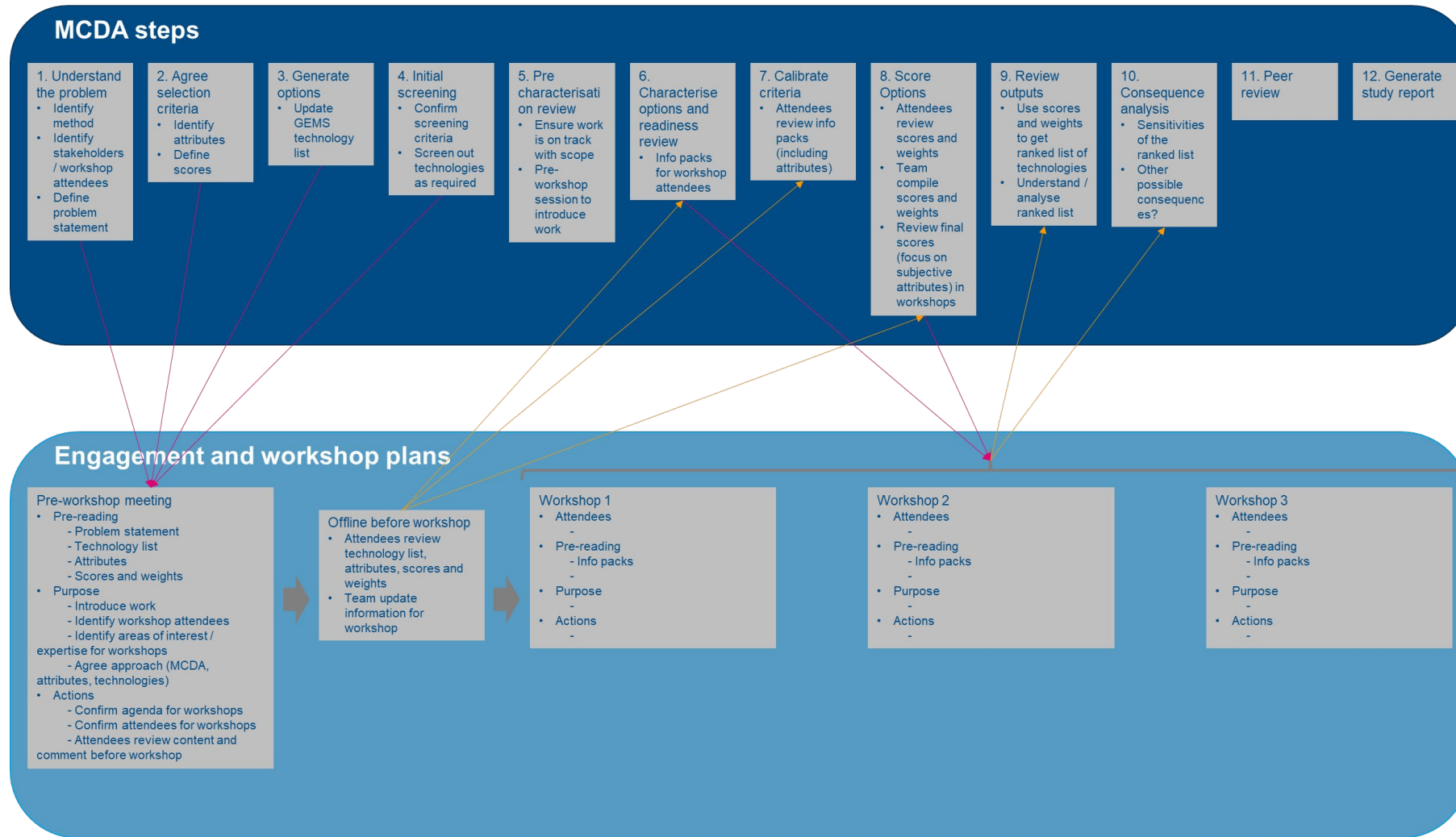
- Considering both In-Silo and In-Ground approaches

Current Leak Response

Key Assumptions/Constrains:

- The leak location is not currently known.
- In undertaking the optioneering process it was assumed the leak is from a below ground wall location rather than a baseslab leak.
 - Evidence from historic ground contamination and civil engineering analysis

Current Leak Response : Optioneering Process



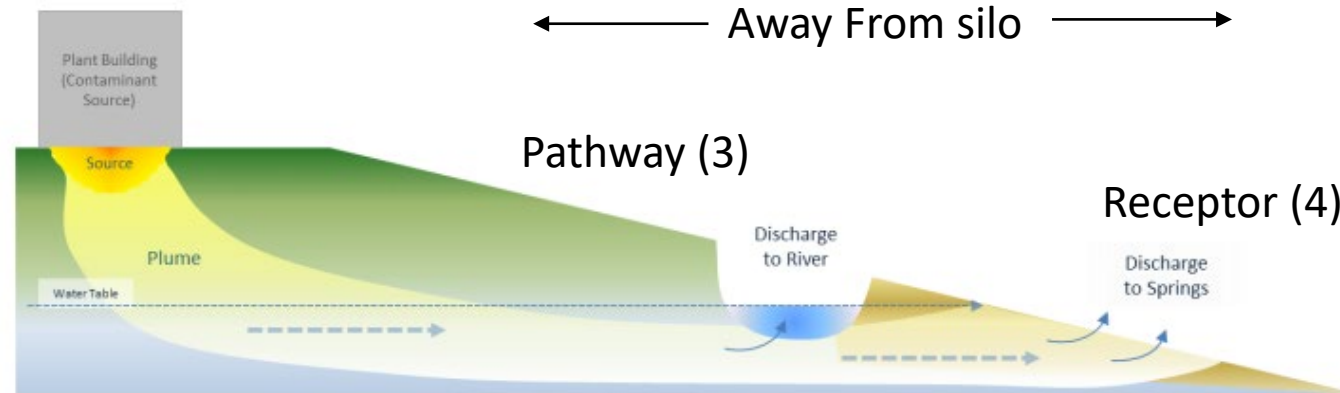
MCDA Step 3&4 Generate Options List and Screen

Long-List	New Idea/New Deployment Concept	New Long->Short List
Low Permeability Barriers (Away from Silo)		✓
Low Permeability Barriers (Near Silo)	✓	✓
Permeable Reactive Barriers		✓
Chemical In-situ Treatment Zone (ITZ-C)		✓
Air Sparging and Soil Vapour Extraction	✓	✓
Biological In-situ Treatment Zone (ITZ-B)		✓
Surface Capping		S
Pump & Treat		✓
Containment		S
Stabilisation		✓
Surfactant Enhanced Aquifer Remediation		✗
Electrokinetics		✓
Vitrification		✗
Direct Excavation		✗
Phyto-Remediation		✗
Ground/wall local freezing (to stop leak)	✓	✓
Grout/chemical treatment (to stop leak)	✓	✓
Pore-water extraction	✓	✓
Land Use Controls (LUCs)	✓	✓

Technology Aims

1. Stop leakage (external)
2. Prevent/minimise migration to groundwater
3. Prevent/limit migration in groundwater
4. Protect receptors

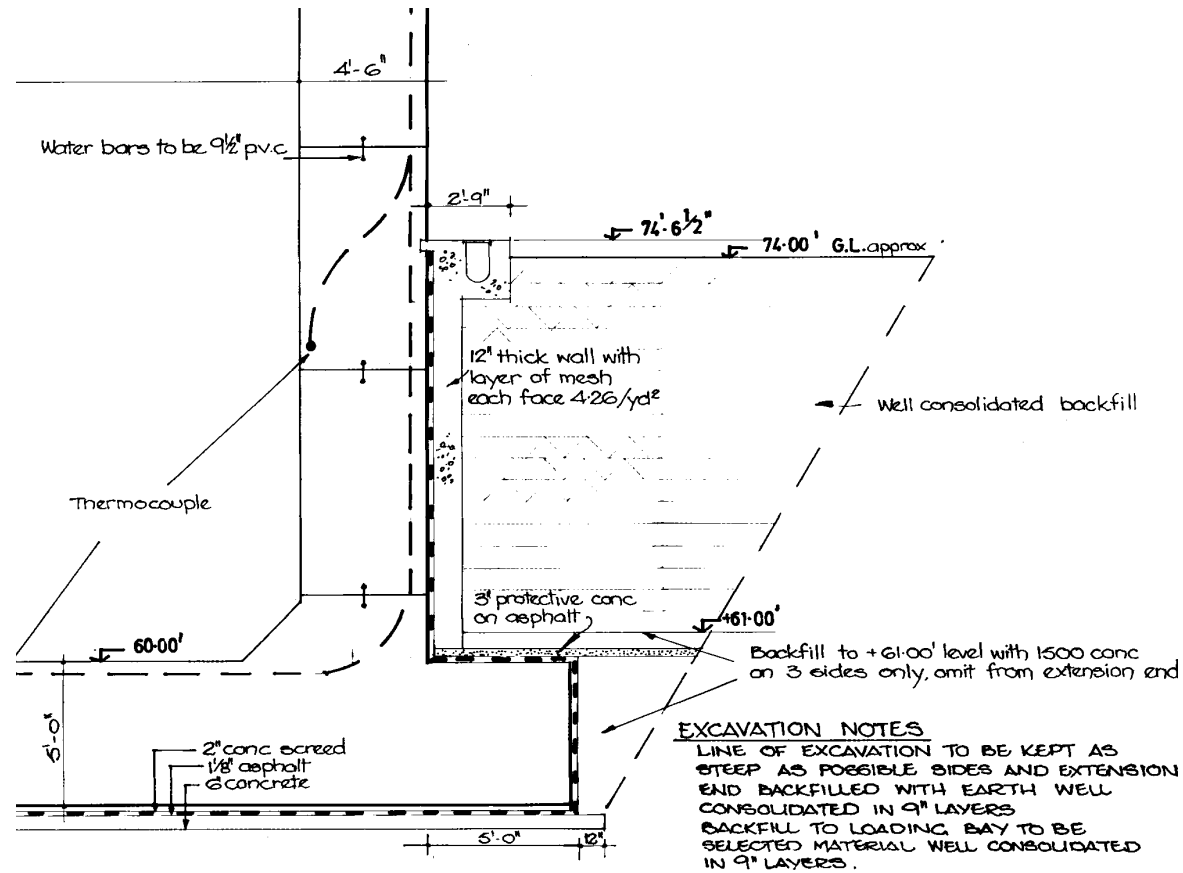
Near Silo/Source
(1,2,3)



Optioneering Output

Aim	Technology	Baseline 'GEMS'/LMP Technology	'Can We' Technologies	Dormant/ Parked	Rejected
Stop the leak	Ground/wall local freezing				✘
	Grout/chemical treatment		✓?		
Prevent migration to groundwater	Low permeability barriers - small scale (plus effluent pumping/recovery)		✓?		
	Low permeability barriers - large scale (plus effluent pumping/recovery)			✓	
	Pore-water extraction			✓	
	Stabilisation		✓?		
	Electrokinetics			✓	
Prevent migration in groundwater	Pump & Treat	✘		✓	
	Chemical In Situ Treatment Zone (ITZ-C)	✓			
	Air Sparging and Soil Vapour Extraction		✓?		
	Permeable Reactive Barriers			✓	
	Biological In Situ Treatment Zone (ITZ-B)			✓	
	Electrokinetic Barriers			✓	
Protect receptor	Pump & Treat/GW Abstraction			✓	
	Electrokinetic Barriers			✓	
	Air Sparging and Soil Vapour Extraction			✓	
	Low permeability barriers			✓	
	Land Use Controls			✓	

Near Silo Environment

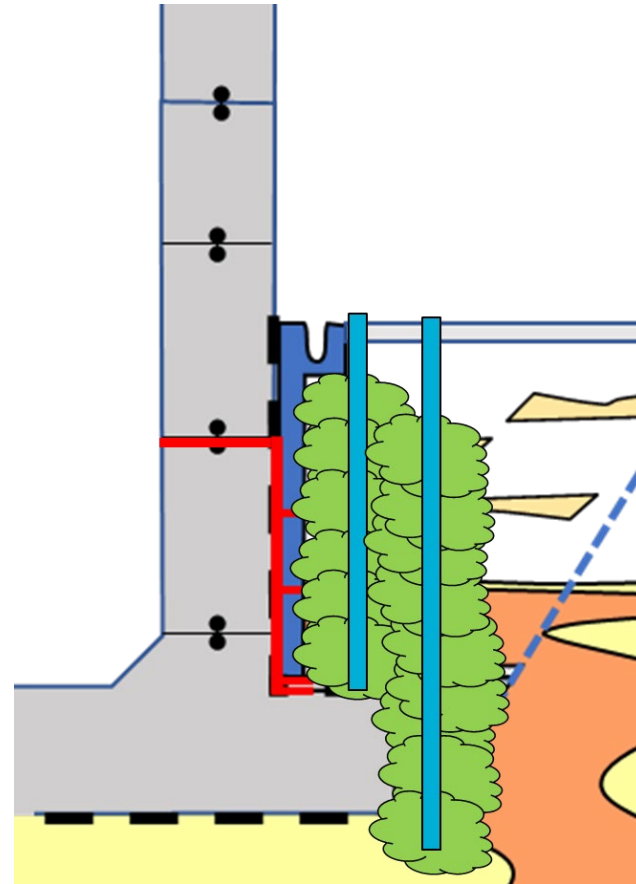


Grout/chemical treatment

- Aim to stop leak
- Anticipated permeation grouting technique

Critical Factors

- Determining defect/leak location and geometry
- Risk of liquor flow to surface
- Achieving effective sealing around complex building structure and heterogeneous ground

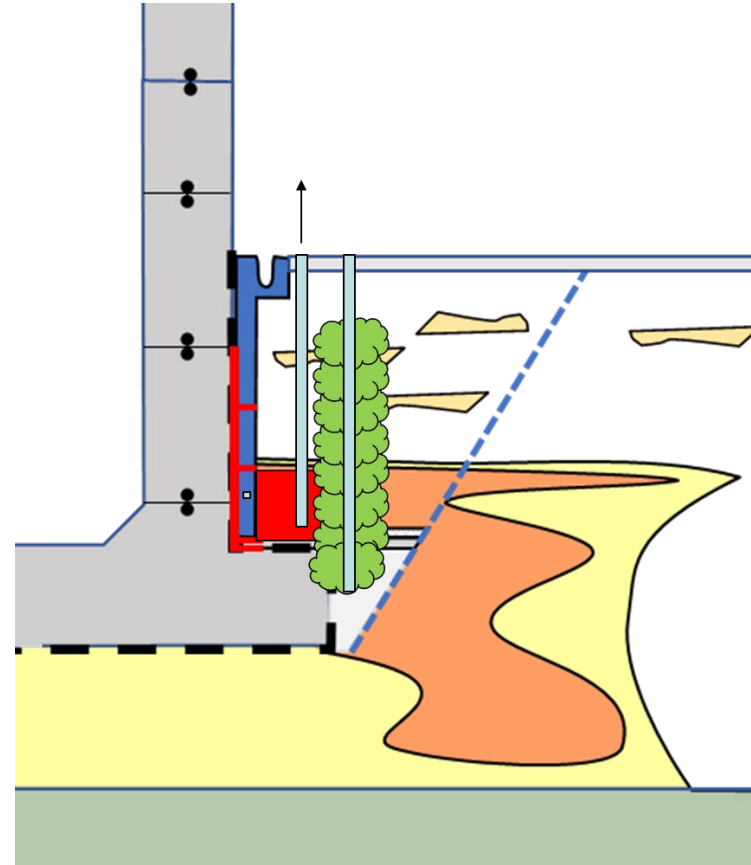


Low Permeability Barriers: Small Scale (plus effluent pumping recovery)

- Aim to prevent migration to water table and recover
- Likely permeation grouting technique

Critical Factors

- Determining defect/leak location and geometry
- Identifying viable effluent route
- Achieving effective sealing around complex building structure and heterogeneous ground

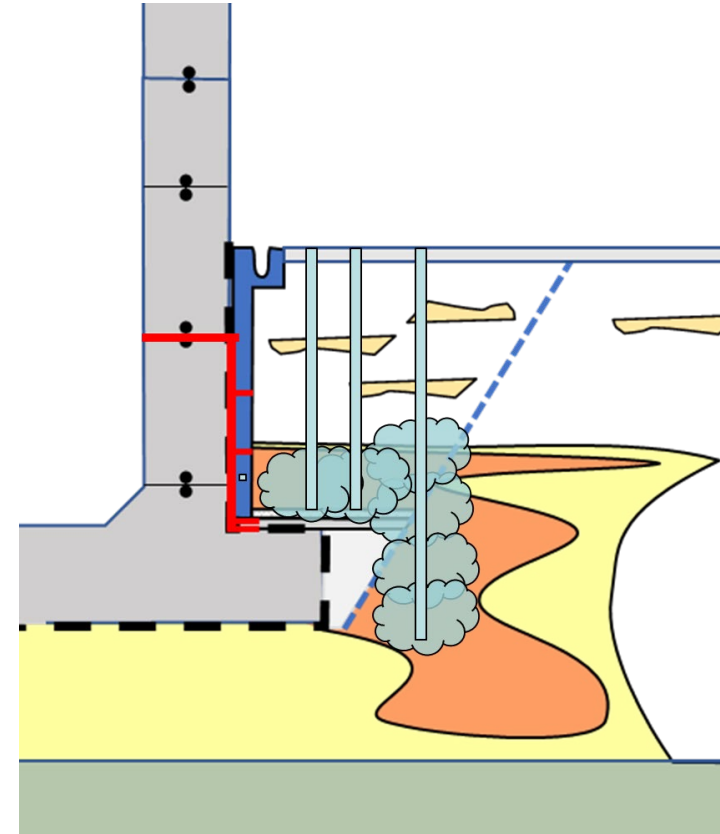


Stabilisation

- Aim to prevent migration to water table by injection of stabilising media

Critical Factors

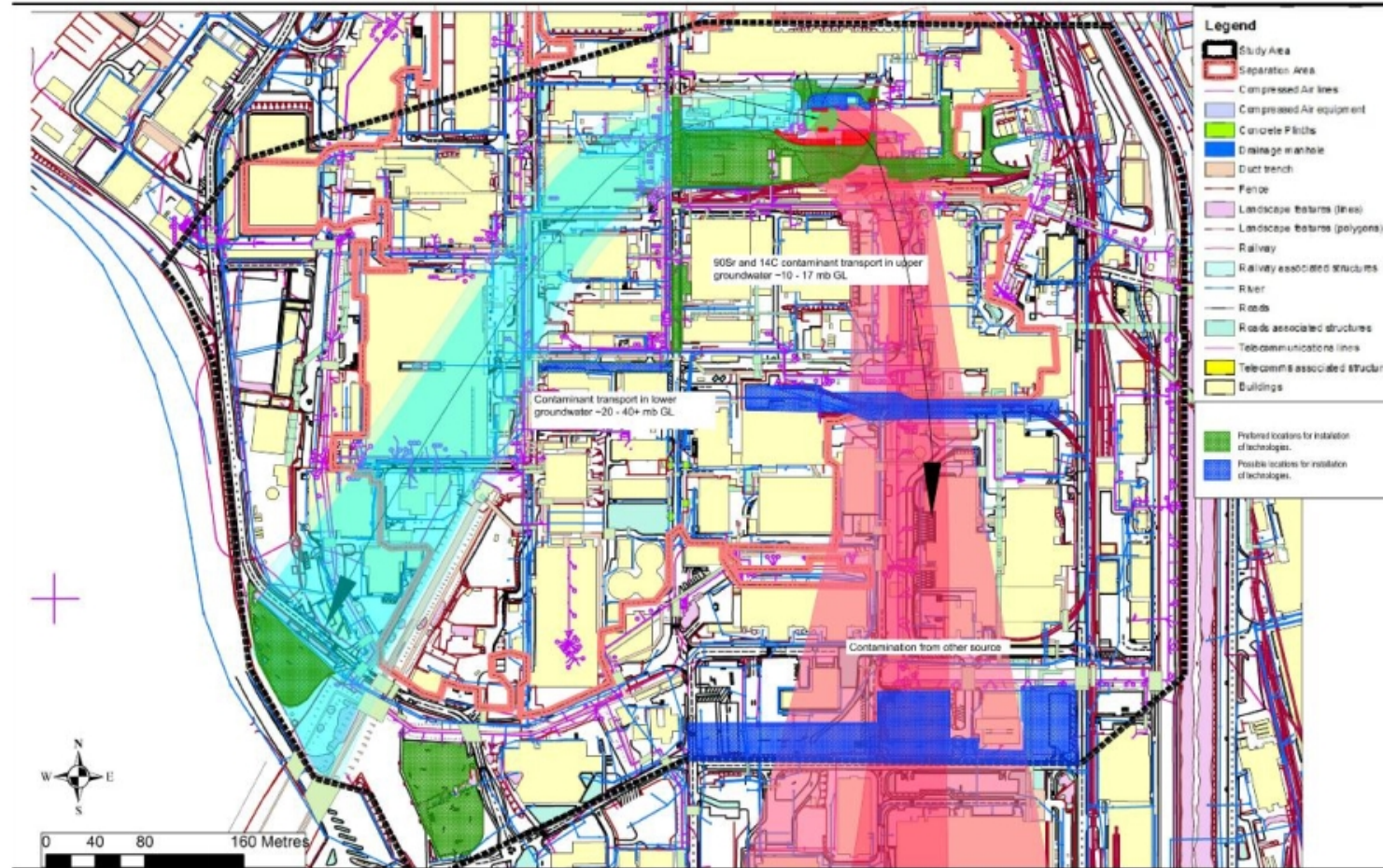
- Determining defect/leak location and geometry
- Suitable injectable media/treatments required for COCs
- Achieving effective contact between injected media and leak



Identified stabilisation techniques

1. Phosphates (solid or sequestration) (**Sr-90**, U)
2. Carbonate sequestration
3. Chemical reduction (for **Tc-99** & U)
4. Biological reduction (for **Tc-99** & U)
5. Adsorption / reaction with particulates e.g. zeolites (**Sr-90**, Tc-99, U)

Away From Silo

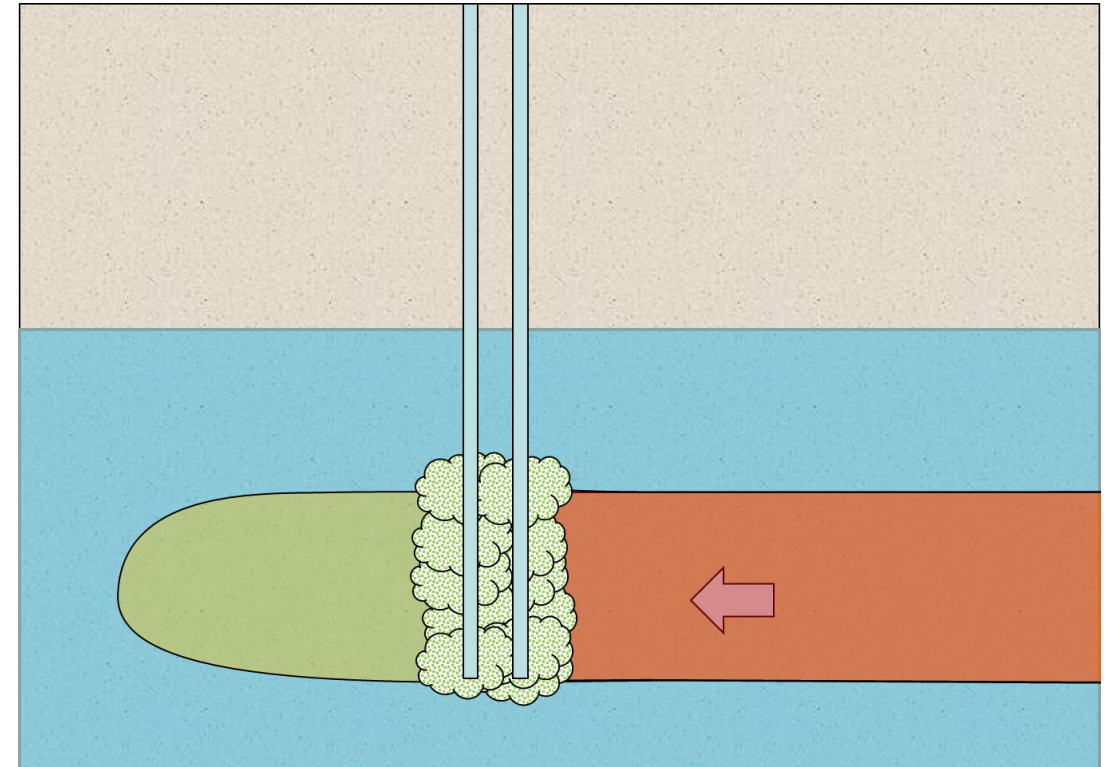


Chemical In-situ Treatment Zones

- Aim - Prevent migration of contaminants in groundwater by emplacing media (e.g. enhancing adsorption to the soil in the leak path using borehole injection).

Critical Factors

- The migration behaviour/pathway away from the building needs to be determined.
- Suitable deployment locations along the pathway need to be located/confirmed.
- Suitable injectable media/treatments required for COCs.



GEMS/LMP

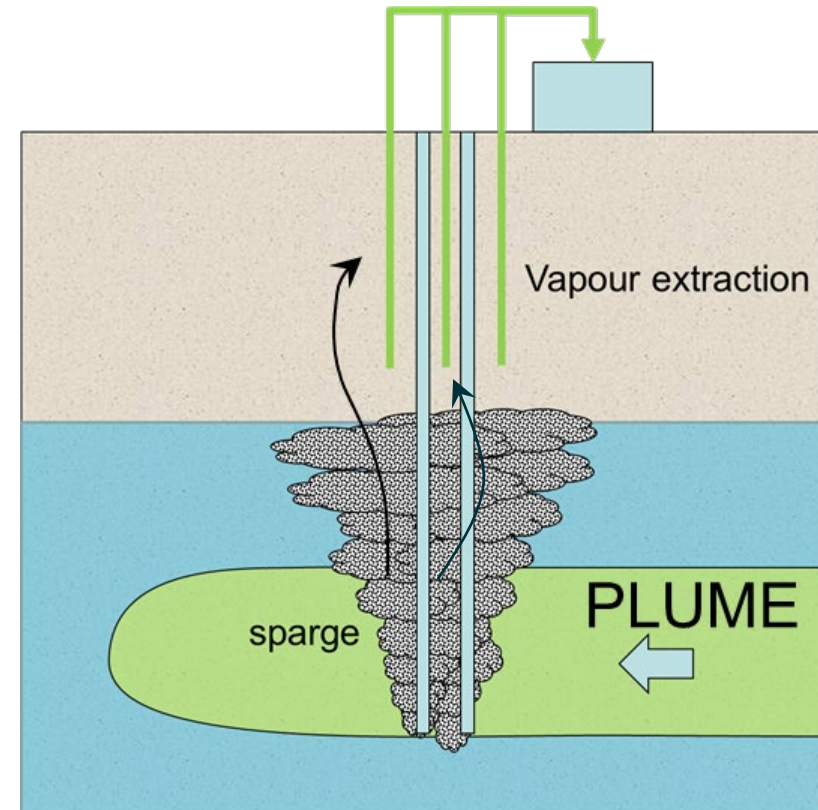
- Apatite sequestration (Sr-90, U)
- Sodium Dithionite (Tc-99)

Air Sparging and Soil Vapour Extraction

- Aim - Remove C-14 from groundwater for treatment/disposal

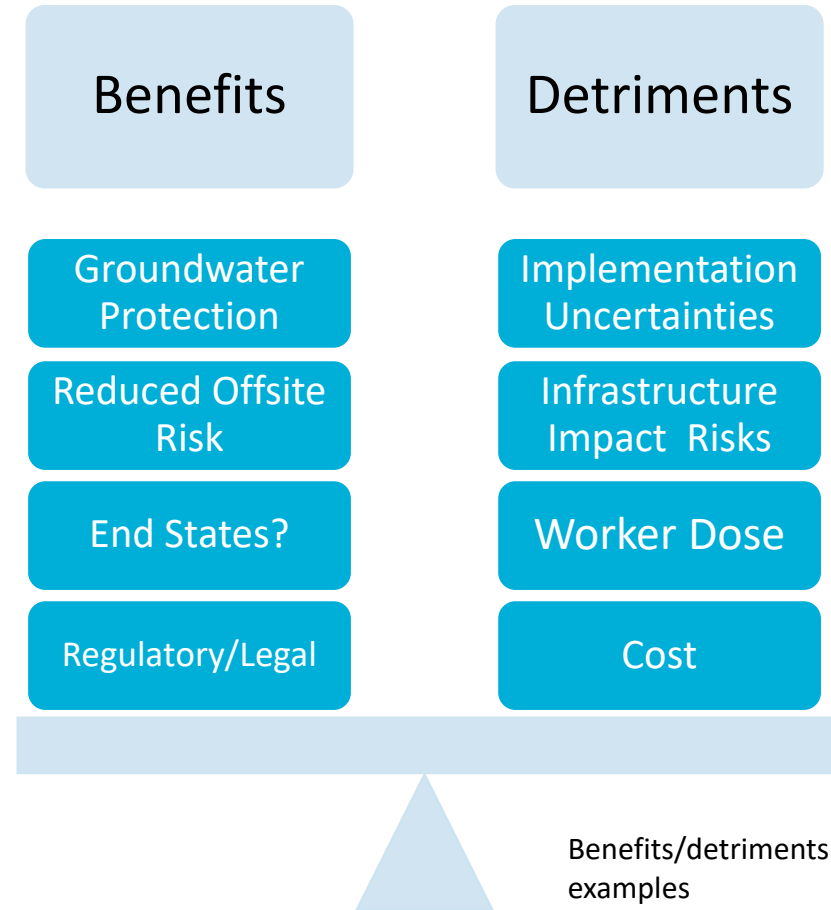
Critical Factors

- Only treats C-14
- Confirming C-14 geochemistry and behaviour
- The migration behaviour/pathway away from the building needs to be determined
- Suitable deployment locations along the pathway need to be located/confirmed
- Waste management route required



Next Steps

- Continue to follow leak management protocols including re-evaluation of options
- Transfer of focus from 'Can We' to 'Should we'
- Develop Concept Designs of shortlisted intervention technologies
- Accelerate work on critical factors e.g. leak location
- Determine which, if any COCs might require mitigate and why?
- Review position of baseline management approach of 'Characterisation, Monitoring and Assessment'



Summary

- Planning for future adverse events
- Maintaining readiness of plans/strategies/management schemes
- Engaging stakeholders to develop and maintain trust and confidence
- Learning on potential mitigations and future clean up strategies

Thanks for Listening