NUVIA

International Experience of Environmental Restoration of Sites from $^{134/137}Cs$ Contamination

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September 2013

together @ VINCI

Introduction

- Approaches to decontamination and remediation
- Key factors in management strategies
- Applicable case studies
- Current status
- Lessons learnt

The Environmental Restoration Stages

- Review the history of the problem/site, potential contaminants and contaminative processes
- Investigate to determine nature and extent of contamination
- Develop conceptual models of contamination spread/evolution
- Identify potential remediation options
- Assess risks (workers, public, environment now and in future) and the cost-risk reduction benefits of management options and sensitivities
- Interact with regulatory authorities
- Select and design preferred management options, including clean-up
- Implement preferred options
- Monitor and certify achievement of clean-up standards
- Close out of works and demobilise

Key Considerations

- Spatial scale
- Uniformity of distribution
- Depth distribution
- Levels of contamination
- Significance of gamma dose rates
- Nature of material contaminated, including soils
- Current and potential land use
- Human receptors, number, locations,
- Exposure pathway significance
- Flora and fauna impacts
- Socio-economic impacts
- Regulatory and other stakeholder positions

Remediation Approaches

1. **Removal of source to a more suitable disposal or storage site**

   - bulk separation, conventional earth moving, scrapping, turf removal

   - selective separation, e.g. physical methods (gravity settling, screening, settling, flotation), soil washing, chemical extraction, electro-remediation, phyto-remediation

- **Containment on site**

  - partial or complete encasement, e.g. capping, sub-surface barriers, purpose-built vaults

  - immobilisation, e.g. cement-based solidification, chemical fixation, in-situ vitrification

- **Source dilution**

  - natural attenuation or man-made intervention

Case Studies

Historically similar problems

- **High-level waste tank explosion – Khystym (North East Urals Tract)**
- **Lake Karachai at Mayak, Russia**
- **Dispersion by high winds in 1967 of radioactive silts from the dried up dispersed over a region of approximately 3000 km^2 (measured: 1000 km^2 at contamination level >7.4 x 10^4 Bq ^{90}Sr/m^2 and 2000 km^2 at contamination level >3.7 x 10^3 Bq ^{90}Sr/m^2). ~2 x 10^{13} Bq of radionuclides (principally ^{90}Sr and ^{137}Cs) were spread over a distance of 75 km.**
- **Techa River flood plain contamination**
- **Chazhma Bay submarine reactor refuelling prompt criticality incident**
- **Unit 4 Explosion at Chernobyl**
- **Nuclear weapons test site contamination (Maralinga, etc.)**
- **Southern Storage Area at Harwell UK**
- **2012 Olympic Park, Stratford, UK**
- **Bradwell NPP and other Magnox Stations in UK**

Natural Attenuation

- Institutional controls
- Local community education/awareness
- Fencing/securing sites
- Monitored natural attenuation
- Delayed (or timed) future intervention
- Mixed strategies

In-situ Remediation Technologies

- Containment technologies
- Surface caps
- Cut-off walls
- Bottom barriers
- Hydraulic control measures
- Stabilization technologies
- In situ encapsulation
- In situ compaction
- In situ treatment technologies
- Biological treatment
- Physical/chemical treatment
- Thermal t r e a t m e n t
- Agricultural methods
- Soil inversion techniques
- Revegetation
- Soil additives
- Crop selection
- Animal production methods

Contaminated Material Removal Technologies

- Removal of vegetation
- Removal of surface soil
- Standard excavation
- Remote excavation
- Cryogenic retrieval
- Dust control
- Other methods
- Removing contamination from hard or rocky surfaces

Ex-situ Treatment Technologies

- Physical processes
- Physical retrieval
- Overpacking/repackaging
- Screening
- Soil washing
- High gradient magnetic separation (HGMS)
- Solidification
- Vitrification/ceramics
- Incineration
- Filtration/ultrafiltration
- Reverse osmosis/membrane processes
- Evaporation, including solar

- Chemical processes
- Chemical/solvent extraction
- Heap leaching
- Enhanced soil washing
- Enhanced soil leaching
- Chemical precipitation
- Ion exchange
- Electrodialysis
- Adsorption
- Aeration
- Biological processes

Selection of Decontamination Approach

Decontamination techniques are dependent on:

- Desired End Point
- Type of surface to be decontaminated
- Radiological conditions
- Safety and Environmental Impacts
- Nature of contamination present
- Extent of contamination present
- Likely nature and volume of secondary waste arisings
- Disposal Routes
- Cost Benefit to the total decommissioning process
- Availability and operability of tools and processes

The Decontamination process usually needs a range of technologies

Fundamental Rule – Keep it simple

Available Structural Decontamination Techniques

Chemical Approaches

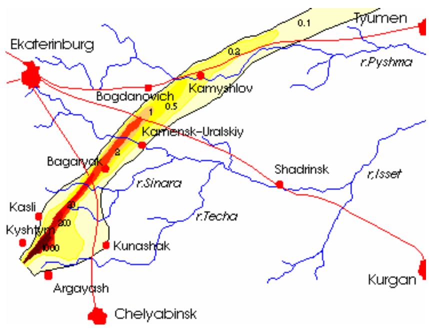
- Chemical Solutions
- Electro-chemical polishing
- Foam
- Gels
- Microbial

Mechanical Decontamination

- Mechanical Vacuuming/scrubbing
- Strippable coatings
- Steam cleaning
- High pressure water lancing
- Abrasive decontamination
- Grinding
- Scarifying/scabbling
- Surface shaving
- Ultrasonics
- Thermal ablation (laser, microwave, etc.)

Kyshytm (29/9/1957) – East Urals Radioactive Trace

- Some 15,000 - 20,000 km² contaminated to >3.7 kBq/m² of ^{90}Sr. Contamination density of 74 kBq/m² of ^{90}Sr established as the intervention level for population evacuation. This delineated ~1000 km² of the East Urals Radioactive Trace (EURT). Maximum close to the site of the explosion itself at ~150 MBq/m² ^{90}Sr.
- ~90% of 740 PBq mixed fission products released deposited as particulate material within 5 km of facility. Remaining 74 PBq deposited as dry fallout over an area 30-50 km in width and ~300 km in length stretching NNE of the Mayak facility
- At accident time, 63% area used for agriculture, 20% forested with 23 rural communities. 10700 people evacuated over 22 month period. Use of area temporarily banned.
- 1961 reclamation initiated. Today, ~180 km² near the site still officially off-limits.



Kyshtym - Radiological Risk Drivers for Remediation

- In early phases external doses to humans from gamma radiation was greater than doses from ingestion. Post >270 days external and internal doses equalised. Thereafter external doses decreased relative to the internal.
- Internal dose was delivered to the gastrointestinal tract via the consumption of contaminated foodstuffs and agricultural products. A radiation dose to bone was also delivered via the incorporation of ^{90}Sr into bone tissue. Immediately post accident, the main pathway for contamination to humans was via bread made from fallout contaminated grain harvested in the area. Later the soil-plant transfer system became more important and contamination of humans with ^{90}Sr was primarily as a result of ingestion of milk, bread and from potable water from small reservoirs.
- Food intervention limits were introduced concerning the content of radionuclides (^{90}Sr) in foodstuffs to protect the public from radiation exposure at a dangerous level.
- Eight years after the accident, milk continued to be a main pathway for contamination into the human diet, constituting up to 50% of ingested radioactivity. By 1987, the intake of ^{90}Sr to humans had decreased by a factor of 1300 relative to the intake in the period immediately after the accident and by a factor of 200 relative to one year after the accident. Reduction of the levels of contamination in the human diet was due to a combination of
- - radioactive decay of contaminants;
- - natural environmental processes that reduce the availability of contaminants; and
- - implementation of a wide range of countermeasures designed to limit the uptake of contaminants in the food chain and humans.

Kyshytm (EURT) Remediation Approach

Remediation Approach

- **1957 -1959 >10,000 te of agricultural products destroyed.**
- **>60 km² of agricultural land subjected to deep ploughing decontamination, the surface layer of heavily contaminated soil buried to a depth >50 cm, lower than the penetration depth of the roots of many crops. This served to reduce uptake via root systems.**
- **In 1958-1959 over 200 km² of EURT was ploughed to reduce uptake of contamination by plants and to decrease the exposure to gamma radiation.**
- **590 km² of land removed from agricultural use n Chelyabinsk region and 470 km² in Sverdlovsk region.**
- **By 1990 vast majority of land back in agricultural use.**

Range of methods to reduce the transfer of contamination to animals via feed crops implemented. These included:

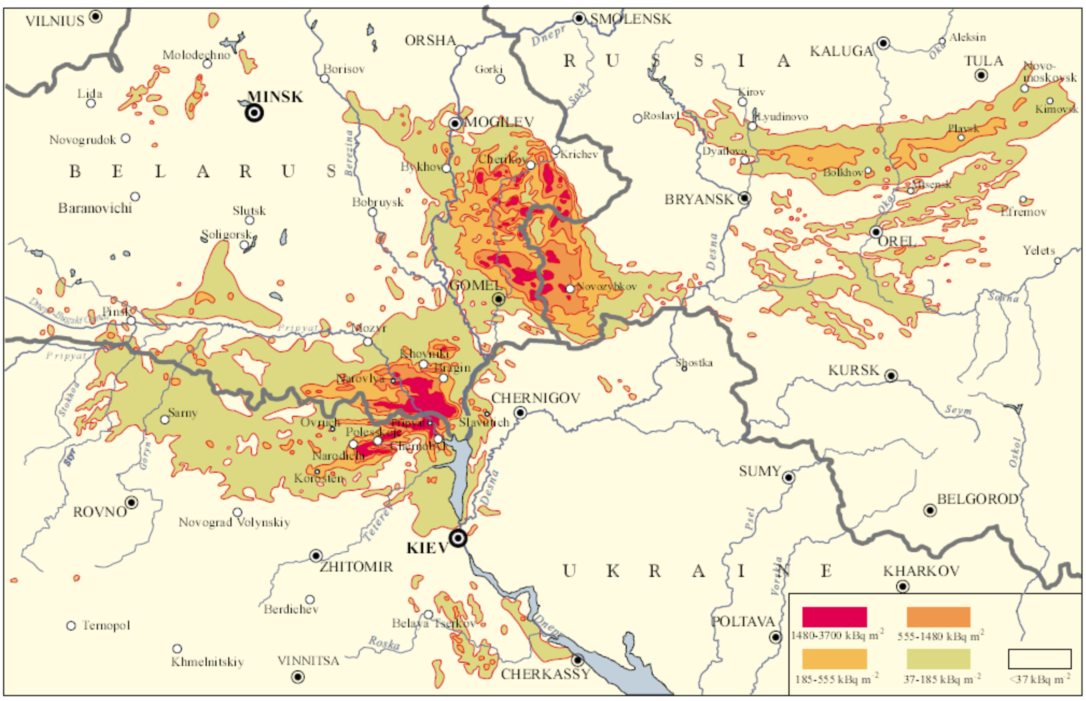
- **the removal of contaminated soil layers;**
- **deep ploughing;**
- **addition of fertilisers and ameliorants to reduce contaminant uptake;**
- **the use of crops exhibiting low uptake of strontium; and**
- **addition of nutrient supplements, mainly calcium, to animal feeds to ensure low assimilation of contaminants in body tissues.**

The implementation of these methods served to reduce uptake in plant species by factors between 5 and 15.

Chernobyl Contamination Remediation in Russia, Ukraine and Belarus

- Institutional controls (i.e. restricting living and economic activities of the inhabitants;
- Self-cleaning processes;
- Containment of runoff from radioactively contaminated flood plains;
- Deep ploughing arable lands to remove contamination from the surface and the root zone;
- Promoting natural or introduced vegetation;
- Use of potassium and phosphorous fertilizers;
- Selective separation of radionuclides from the soil matrix;
- Removal of vegetation and/or top layer of soil containing most of the contaminants;
- Use of uncontaminated feed for cattle and poultry, and
- Addition natural sorbents or substances to animals diets in order to bind ^{137}Cs so, when eaten, the activity will not be absorbed into animal flesh.

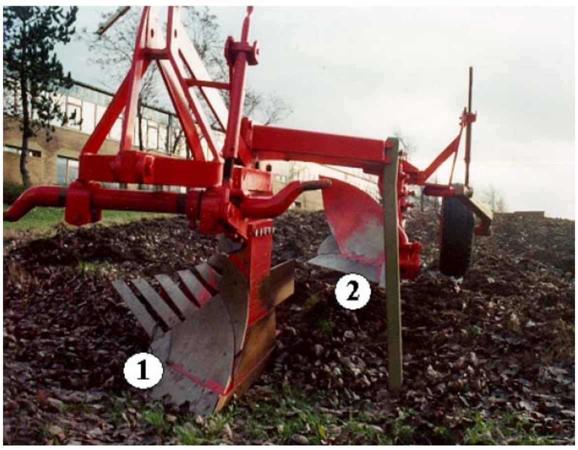
Chernobyl Contamination in former Soviet Union States



The 30 km Exclusion Zone around Chernobyl



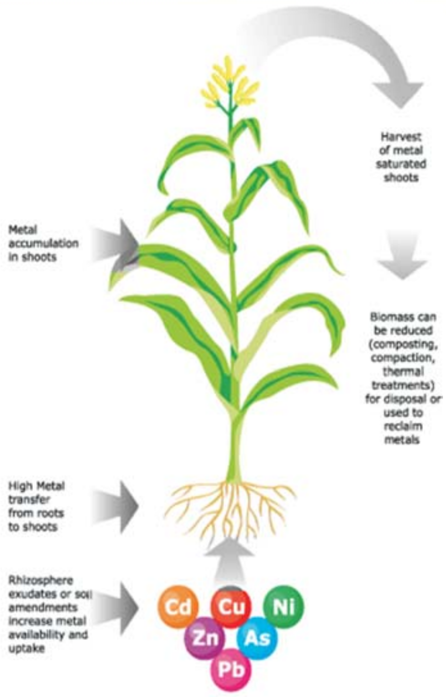

Skim and Burial Deep Ploughing for Chernobyl



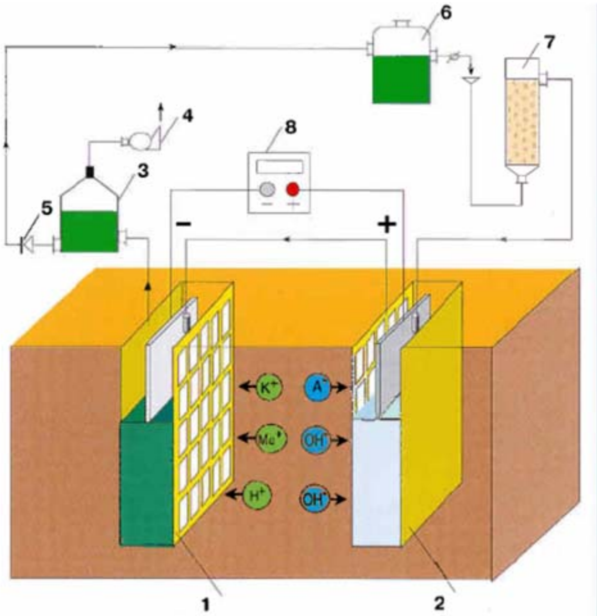


Waste Disposal - Buryakovka

Long-term Approaches - Phytoremediation



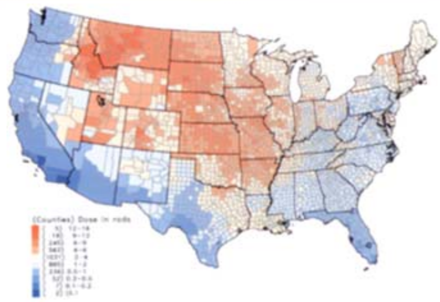
Long-term Approaches - Electrokinetic Remediation



Dounreay Nuclear Establishment in Caithness

Former Russian Navy nuclear Submarine spent Fuel and radioactive Waste Storage Facility at Andreeva Bay near Murmansk

Nevada Nuclear Test Site



Semipalatinsk Nuclear Weapons Test Site, Kazakhstan

Case Study – Southern Storage Area

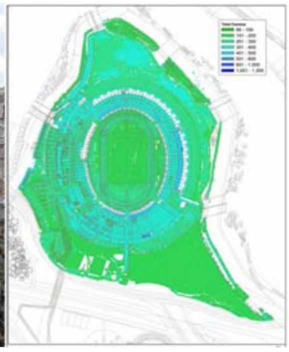
The Southern Storage Area (SSA) was a 7 ha site munitions storage compound (WWII), which was later used for the packaging of LLW and for the storage and disposal of chemical and radioactive wastes.

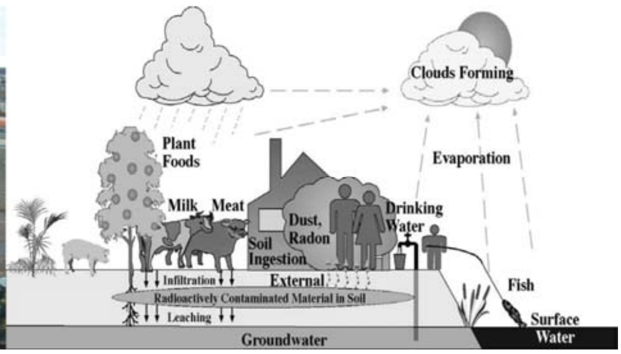
The project required:

- Location of all chemical and radioactive contamination existing above independently defined risk-based clean-up levels (RBCL) on the site.
- Segregation of the contaminated material into controlled, special, exempt and low-level waste categories.
- Packaging the waste and removing it from the site to licensed disposal facilities.
- Surveying and sampling the site to check clean-up quality.
- Landscaping and replanting grass on the site to allow unrestricted public access. Part of the site is now a new housing development (Chilton Fields)

Southern Storage Area at Harwell

2012 Olympic Park at Stratford UK





The “Soil Hospital” at Olympic Park, Stratford

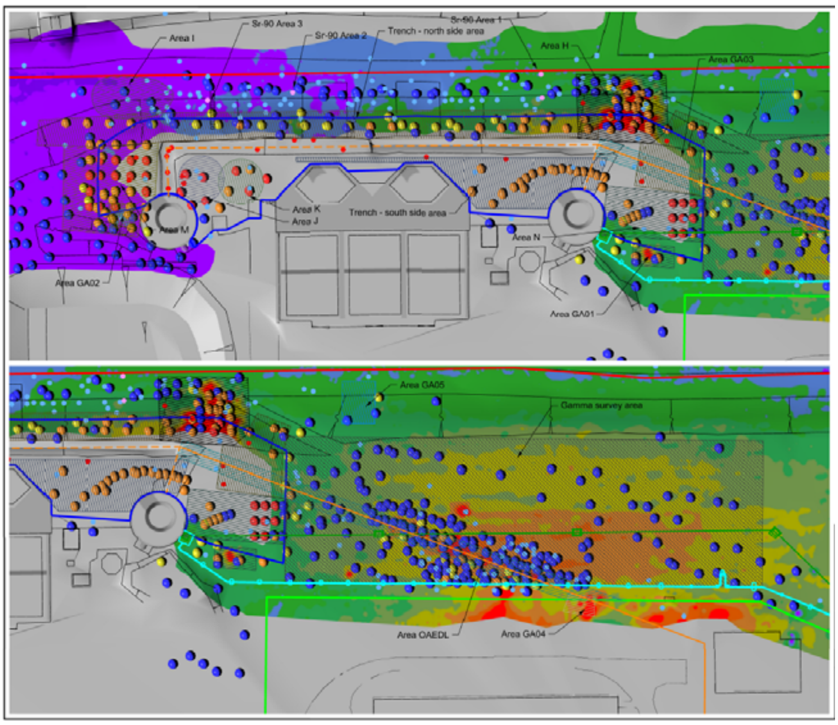
Olympic Park – Conveyor Monitoring for Artefacts

Old radium painted dials

Olympic Park – Spoil Monitoring

- HRGS established a fingerprint, enabled the use of a gross gamma technology
- Gamma Excavation Monitor (GEM) System
- Increased throughput from 50 tonnes per day, to 350 tonnes per day
- Proportion of bucket loads put into bags for validation monitoring using the HRGS

^{137}Cs Contamination Distribution at Bradwell NPP, UK



Engineering Aspects of Containment Options

- **Removal and or capping of areas of surface ^{137}Cs contamination warranting contamination control measures under the IRRs**

  The IRRs state that an area must be designated where:

  - External dose rate >7.5Sμv/h (average over working day)
  - There is a significant risk of spreading radioactive contamination outside working area

- **Emplacement of a low permeability cap over current C2 area**

  Consideration of the materials used, topography, thickness and overall design

- **Installation of cut off walls**

  Consideration of the materials used, design, thickness, length and depth

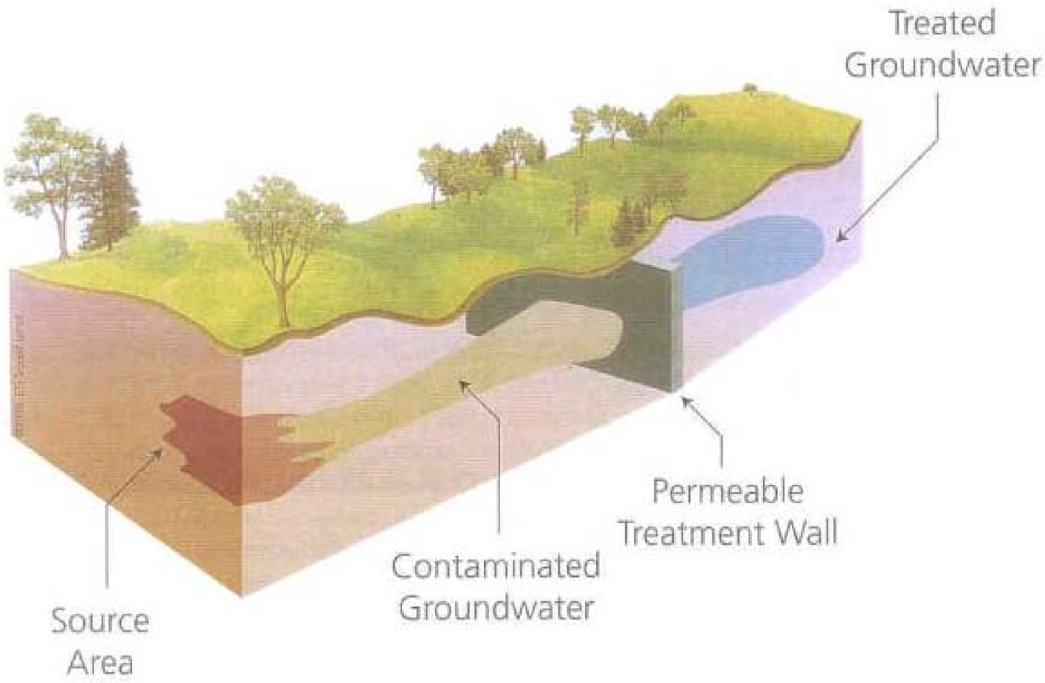
- **Subsurface interception drain**

  Consideration of the materials used, design, thickness, length and depth

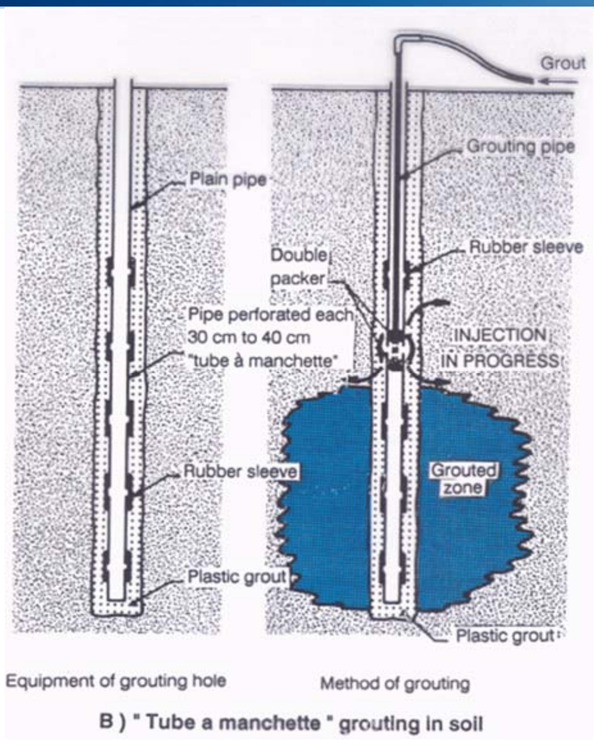
Initial Thoughts on Methods & Constraints

- **Deep Soil Mix Walls**
  - **Provide reasonably defined physical barrier**
  - **Quality controls are simple**
  - **K <$1x10^{-8}$ or better**
  - **No or limited quantity of spoil at surface**
- **Against**
  - **Large rigs giving access problems**
  - **Proven to 20m depth in dense soils**

Permeable Reactive Barriers – General Principle

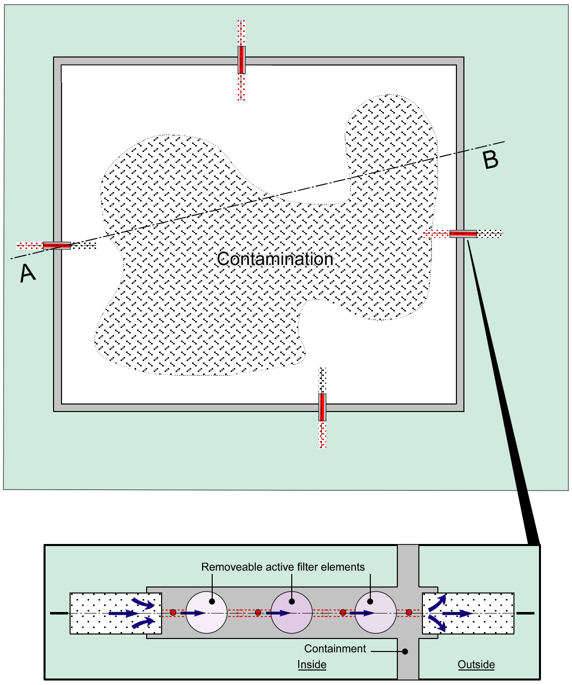


Permeation Grouting



- low viscosity grout (30-32 seconds Marsh)
- relatively low injection pressure
- particle size of grout adapted to the soil voids
- substitution of the free water contained in the soil by a grouting material with minimal distortion of the soil structure

Active Containment Scheme



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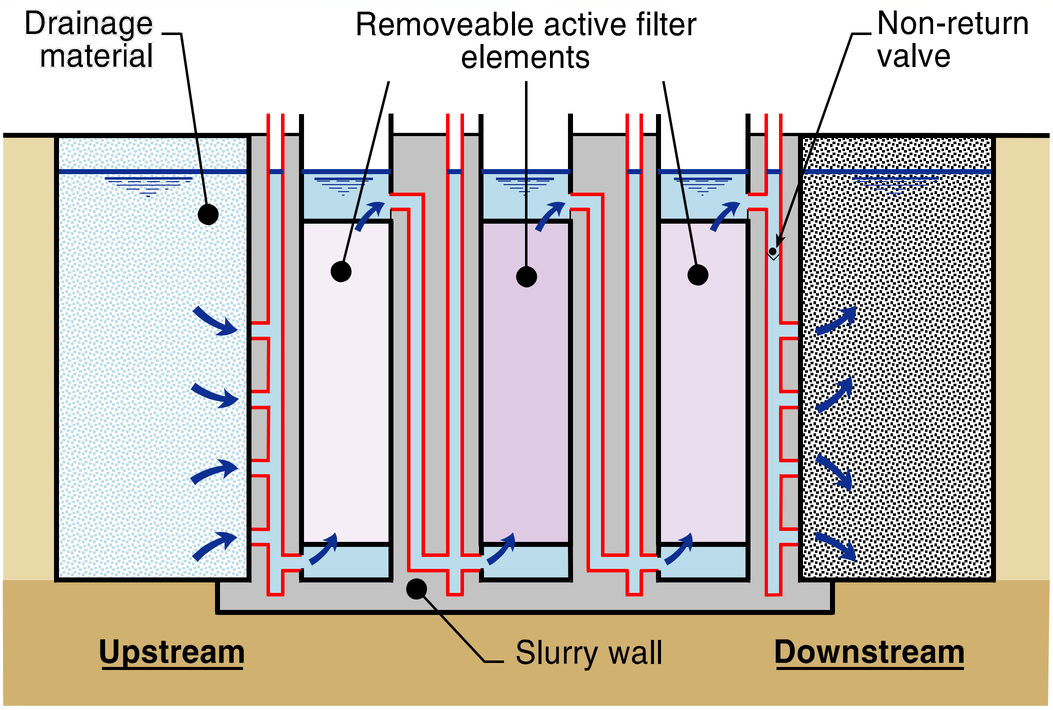
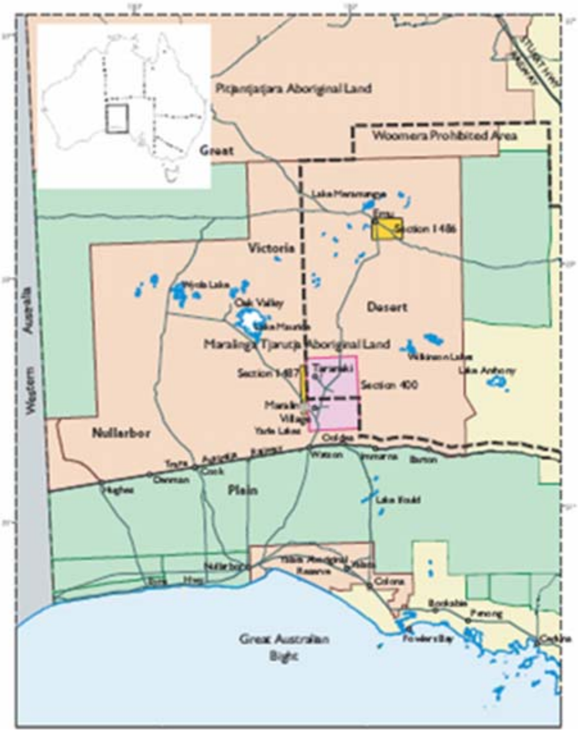
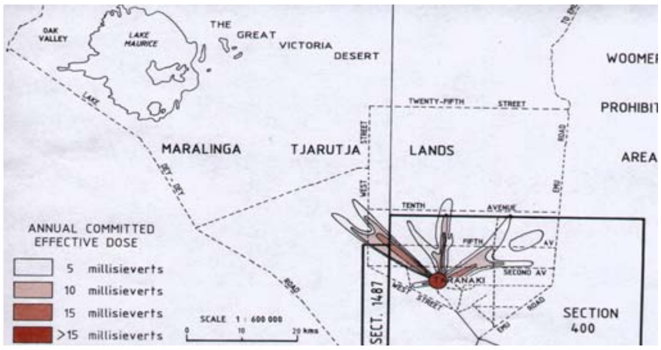


Commencing Digging

Wolf Creek, USA - 125m Cut-off

Maralinga Nuclear Weapons Site ^{137}Cs Contamination





Routes to Exposure and Factors influencing Risk

1. Inhalation of contaminated dust, resuspended from the surface by wind and raised as a result of human activities.
2. Ingestion of food which contains radioactive material or has been contaminated by active soil and dust during its preparation.
3. Entry into body of radioactive materials through open flesh wounds and abrasions.
4. External exposure to ionising radiation emitted by radioactive material or in the ground.

Factors influencing Significance of each Pathway for local population

1. Sleeping and eating practices
2. Hunting and food gathering
3. Food preparation practices
4. Sources of food items, including the mixture of local and imported foods and seasons when local foods gathered
5. Recreation activities, e.g. children playing on ground
6. Health practices, e.g. rubbing wounds with dirt and leaves
7. Cultural practices

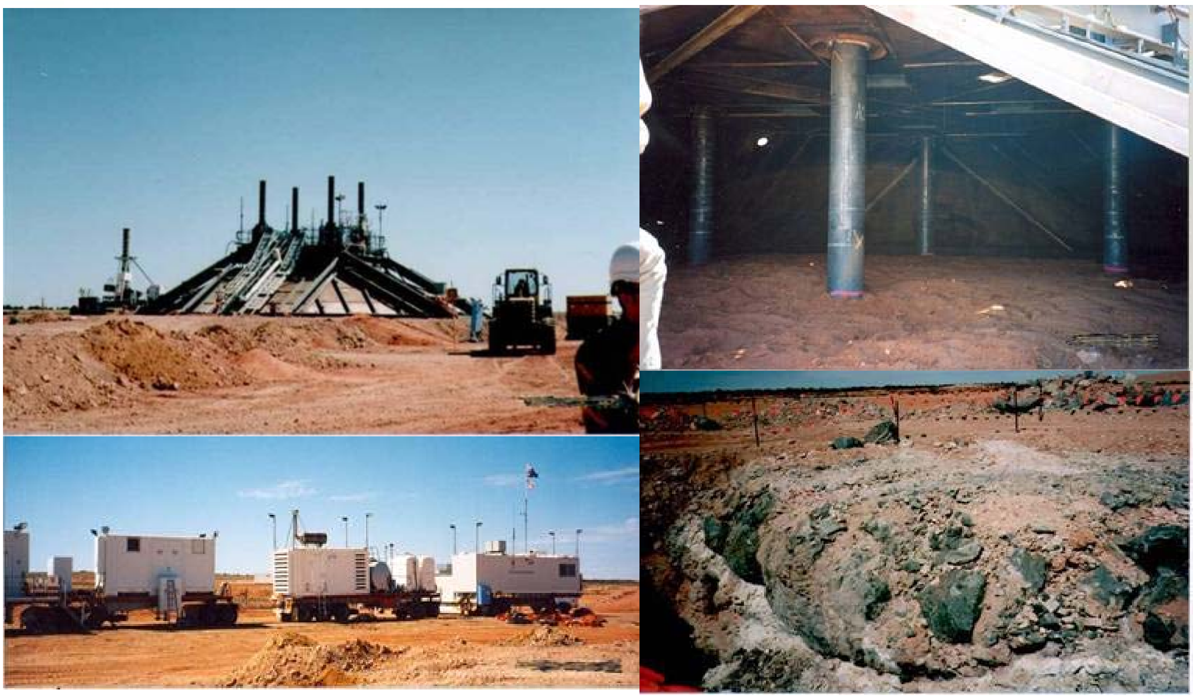
The Options, Costs and Details

Option	Cost, A$M(1990)	Area released, km^2	Detail
1	**13**	**1560**	**Construct warning fences around whole area**
2(a-d)	**13-41**	**1920**	**Fence area north of option line with pits at Taranaki, TM101/Tiekins, Airstrip Cemetery and Unnumbered pits, grout other numbered pits**
3(a-d)	**19-37**	**2020**	**Fence area north of option line and all pits bar other numbered and DC/RB pit. These are to be exhumed and reburied**
4(a-b)	**20-37**	**2155**	**Fence area north of option line, Taranaki and unnumbered pits. Exhume and bury all other pits.**
5(a-b)	**21-66**	**2820**	**Fence area north of option line and pits at Taranaki, TM101, Tiekins and unnumbered pits. Exhume and bury all other pits.**
6(a-j)	**82-653**	**2820-3120**	**Fence area north. Previously treated land remove/bury or treat by TRUclean process. Exhume/bury, grout or use ISV to treat all other pits.**
7(a-d)	**52-82**	**2430**	**Fence all contours W of Right Street. Mix soil E of Right Street. No action on Taranaki, DC/RB and unnumbered pits. Exhume/bury or grout or ISV other pits.**

Contaminated Soil Removal in the Field

Scraped Soil Removal Area at Taranaki

Stabilisation - Pit Treatment by In-situ Vitrification at Maralinga



Best Practice – UK SAFEGROUNDS Learning Network

•**SAF**ety and **E**nvironmental **G**uidance for the **R**emediation **of** **U**K **N**uclear and **D**efence Sites

- **Good practice guidance for the management of contaminated land on nuclear and defence sites. Version 2, 2009**
- **Approach to managing contaminated land on nuclear-licensed and defence sites – an introduction. June 2009.**
- **Best practice guidance for site characterisation. Version 2, 2009.**
- **Assessments of Health and Environmental Risks of Management Options for contaminated land. July 2005.**
- **Community Stakeholder Involvement (Version 2). August 2005.**
- **The UK regulatory framework for contaminated Land on nuclear-licensed Sites and Defence Sites. Discussion paper. (Version 5). October 2005.**
- **Good practice guidance for land quality records management. August 2007.**
- **Technical Options for managing contaminated Land. April 2004.**
- **Guide to the comparison of contaminated land management options. June 2009.**
- **Review and commentary on site end-points and radioactively contaminated land management. July 2005.**
- **Briefing note on the Energy Act. 2005.**

Lessons learnt

- **Technologies exist and are proven to tackle contamination situations**

Essentials

- **Detailed iterative long-term planning**
- **Total open policy with all project information/data**
- **Active engagement with all stakeholders**
- **A closed end budget and timescale**
- **Complete waste routes through to disposal**
- **Best Practicable Environment Option (BPEO) within agreed budget parameters**
- **Realism in what can be achieved in terms of clean-up levels and dose reductions. This particularly relates to the cost effectiveness of further reductions**