

Radioactive Waste Management

Dr Nick Evans
Loughborough University

Minerals Engineering Society Conference 2010

Overview

- Politics
- Radioactive waste
- Storage / Deep Disposal
- Geological considerations
- Other Countries
- What not to do!
- The safety case

CoRWM's Recommendations

- Geological disposal as end point for long-term management of higher activity wastes
- Robust storage in the interim
- Implementation based on willingness to participate and partnership with potential host communities
- Government accepted recommendations
- Invited local authority participation in discussions about implementation framework
 - Three authorities have 'volunteered' to talk

Who's Responsible?

Environment Agency

1. Has responsibility for authorising the disposal of radioactive wastes
2. Co-ordinating research and establishing waste management criteria

Nuclear Decommissioning Authority (NDA)

1. Responsible for decommissioning nuclear sites
2. Responsible for implementing geological disposal of higher activity radioactive waste
3. Has executive responsibility for LLW/ILW management and disposal

Sources of Radioactive Waste

1. Nuclear fuel cycle

- a) Uranium ore mining
- b) Fuel fabrication and enrichment
- c) Reactor usage
- d) Fuel reprocessing
 - Metal cladding of the fuel elements
 - Sludges from corrosion of the cladding during pond storage
 - Ion-exchange resins from effluent treatment
 - Medium-activity liquid wastes
 - High-level waste itself
 - Miscellaneous contaminated laboratory and other materials
- e) Reactor decommissioning and dismantling

2. Military use

3. Research, medicinal and industrial applications

Higher Level Wastes Inventory

Type	Packaged volume (m ³)	Radioactivity (TBq)
HLW	1,290	39,000,000
ILW	353,000	2,400,000
Plutonium	3,270	4,000,00
Uranium	74,950	3,000
Spent Fuel	8,150	33,000,000
Total	477,860	78,000,000

Intermediate Level Waste (ILW)

- Significant quantities are poorly characterised
 - Magnox sludges, historic mixtures of materials, etc.
- Significant technical challenges to remotely characterise, separate and develop wasteforms for these materials
 - Especially Sellafield Legacy Ponds / Silos
- Each 1 m³ costs £100 - £300 000 to deal with

Spent Fuel

- If UK stops reprocessing, system for encapsulating spent fuel will be needed
- AGR reactors contain UO_2 fuel pellets with stainless steel cladding
- Currently stored under both wet and dry conditions
- It is not planned to reprocess spent fuel from a new UK nuclear power stations – watch this space
- AGR and Sizewell PWR spent fuel may be declared as waste

Plutonium

- Plutonium is currently stored pending long-term management decisions
- It is currently designated as a zero-value asset
- There is a civil plutonium stock of 100 t and also a stock of military plutonium
- Currently there is no UK waste form for Pu

Graphite

- Large inventory of graphite wastes – unique to UK
 - Conditioned waste from operations and reactor decommissioning
 - Estimated total is ~ 80,000 tonnes
 - By volume, could be 30% of the (ILW) geological repository
- Irradiated graphite contains relatively high concentrations of ^{14}C and ^{36}Cl
 - May have an impact on geological repository, e.g. chloride and methane mobility
- Drigg authorisation for ^{14}C is enough for only 2% of the total graphite waste and will be reached by 2011

Waste Immobilisation

- Immobilisation is incorporation of waste into structure of a host matrix
 - e.g. ceramic, polymers, cement, bitumen or glass
- Majority of current waste already taken care of by immobilisation
 - HLW in glasses
 - ILW and LLW in cements
- Wasteform is first line of defence against escape into environment
- Often provides a long lasting barrier, e.g.
 - Pu: convert to ceramic and encapsulate in glass
 - U: compact as oxide in 500 l drums or 3 m³ boxes
 - Spent nuclear fuel: encapsulate in Cu canisters as Sweden

Waste Immobilisation (2)

- Some wastes remain problematic due to:
 - Their chemical reactivity
 - Radiotoxicity
 - Content of long-lived or highly mobile or bioavailable radionuclides
 - High volume
 - Being mixed (chemically and radioactively hazardous)
 - Being uncharacterised
 - Radioactively contaminated land

Why Immobilise in Cement?

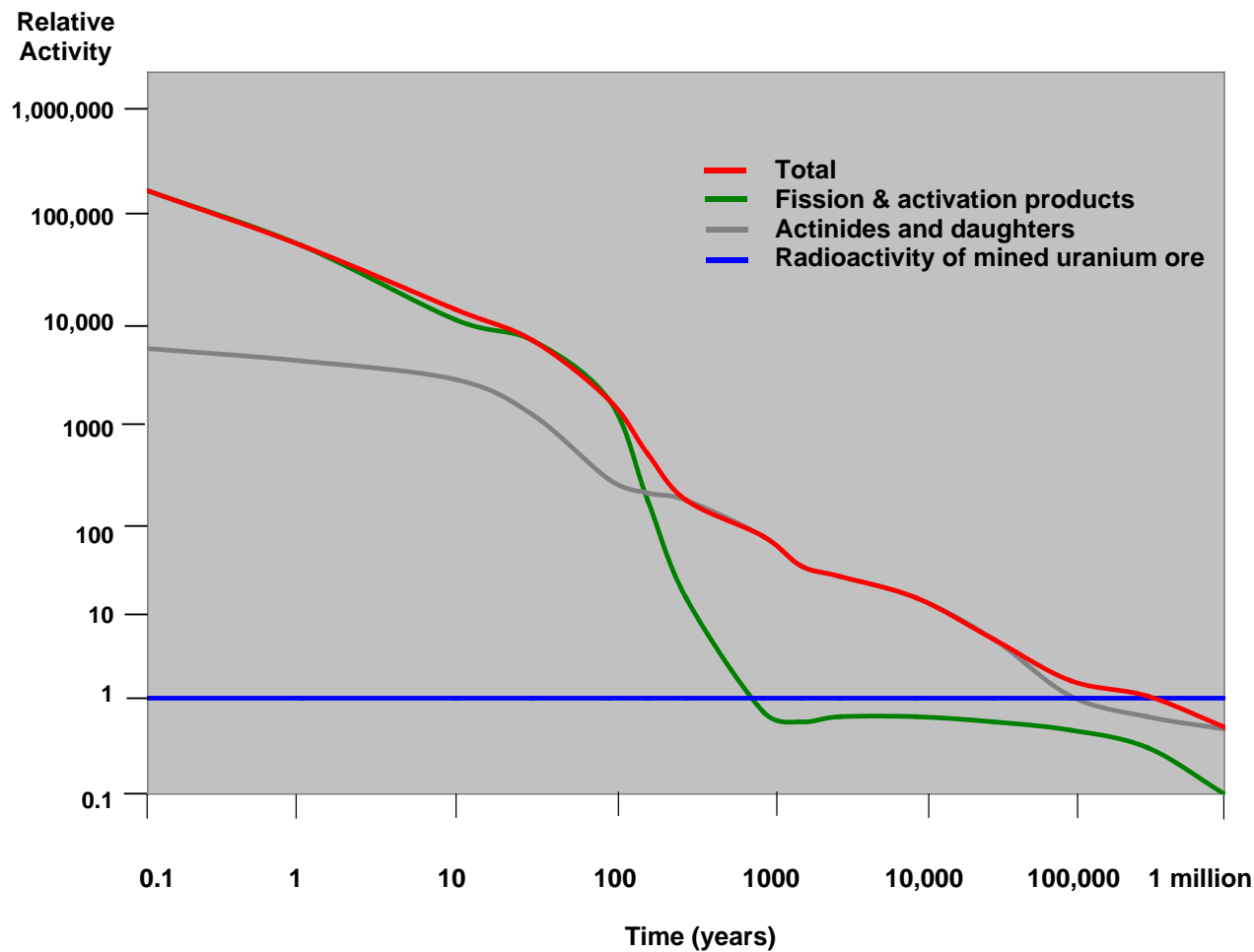
- Cheap
- Readily available
- Acts as a barrier
 - Provides sorption sites
 - Provides high pH for precipitation
- Suitable for most wastes
- Non-flammable
- Can be modified for particular wasteform
- Easily processed remotely
- Good thermal, chemical and physical stability



Waste Inventory – Other Materials

- Stainless steel
- Other steels
- Magnesium and Aluminium
- Zircaloy
- Other metals
- Other materials
- Cellulosics
 - includes materials composed of polysaccharide cellulose, e.g. paper, cloth, and wood
- Halogenated plastics (e.g. PVC)
- Non-halogenated plastics, including condensation polymers (e.g. polyesters, Bakelite, nylon, epoxy)
- Other polymers (e.g. polyethylene, polypropylene, polystyrene)
- Organic ion exchange resins
- Rubber compounds, both halogenated (e.g. neoprene (polychloroprene), Hypalon (chlorosulphonated polyethylene) and non-halogenated (e.g. latex (polyisoprene), styrene butadiene)
- Other organics, (e.g. oils and other organic liquids)
- Complexing agents (e.g. EDTA, citric acid, oxalic acid)

So How Long are We Talking About?



Storage

(Interim) Storage

- *de facto* option at present and likely to remain so
- Surface stores are inherently less secure than an underground repository
- Commitment in NDA strategy to look at optimisation of interim ILW storage arrangements
 - i.e. Until GDF (repository) available
- Relative merits of long-term storage versus early disposal have been debated in a number of countries
- In Finland little enthusiasm for storage
- France and Switzerland stress importance of retrievability and prolonged period of monitoring before facility is sealed

High Level Waste / Spent Nuclear Fuel

Wet

CZ rep, Finland, Germany, Japan, Sweden, UK

Pools consist of large water filled basins with a geometrically safe (criticality) lattice of stainless steel racks

Water is circulated for cooling

Zircaloy can exist for long time

Problems with Al and Mg dissolving

Sellafield ponds!

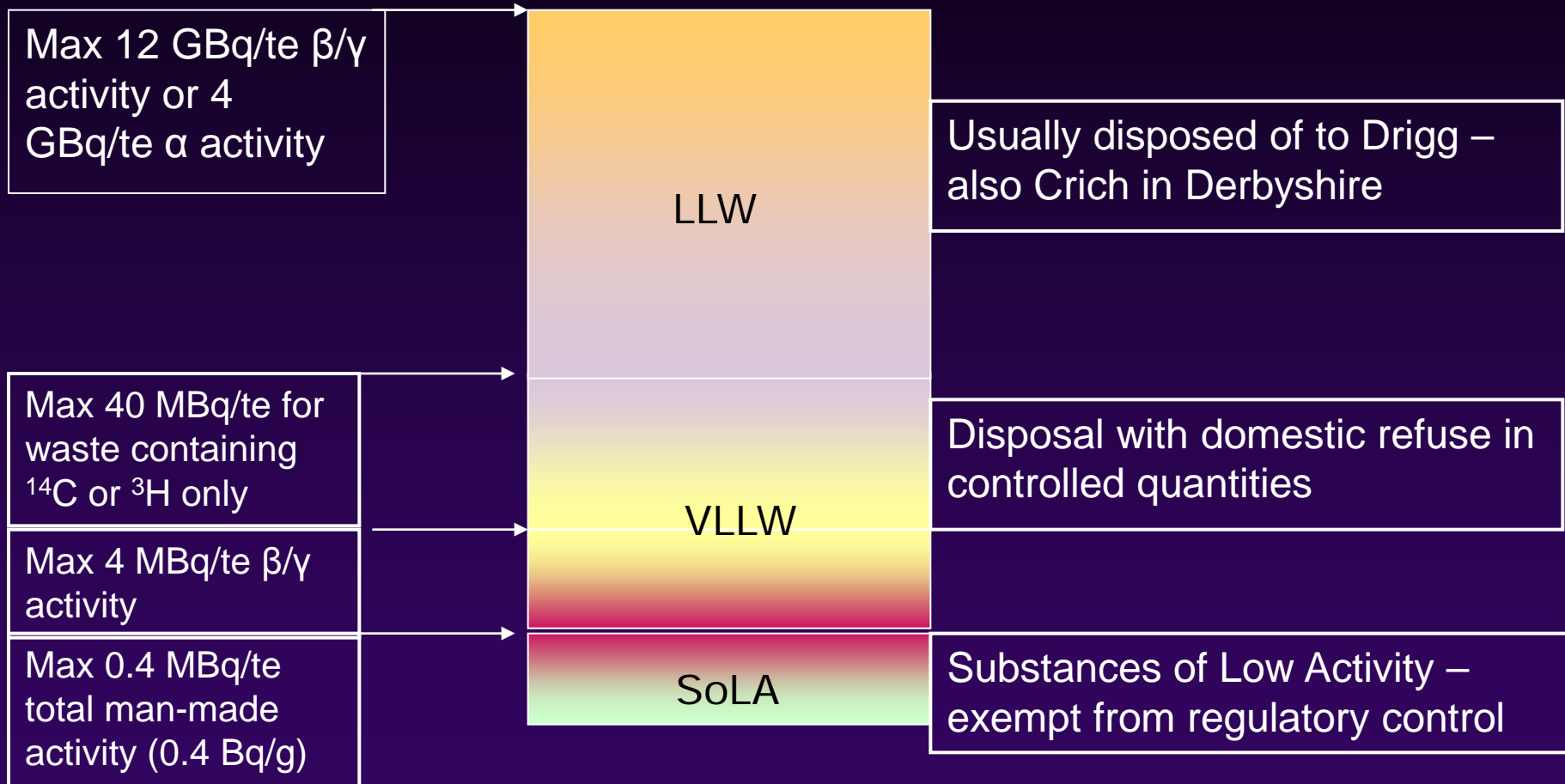
Dry

France, Germany, UK

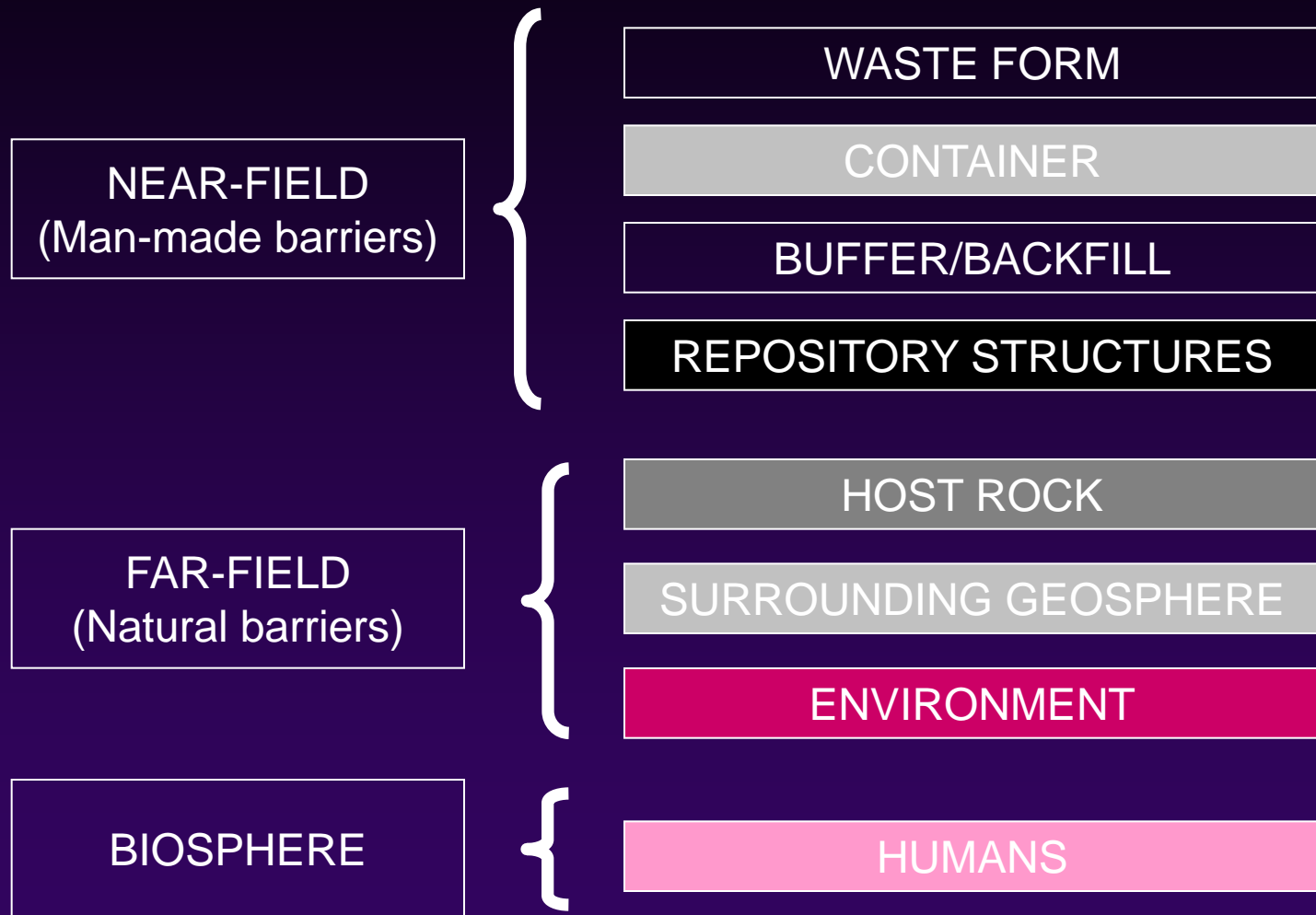
Deep Geological Disposal Safety Requirement

- Total risk to population shall be as low as reasonably achievable (ALARP)
 - Economic and social factors taken into account
 - Risk to any individual shall not exceed specified limit
 - Reflects stochastic response to low-level doses
 - Limit of 10^{-5} per year
 - Target of 10^{-6} per year
 - Maintained for 10^6 years

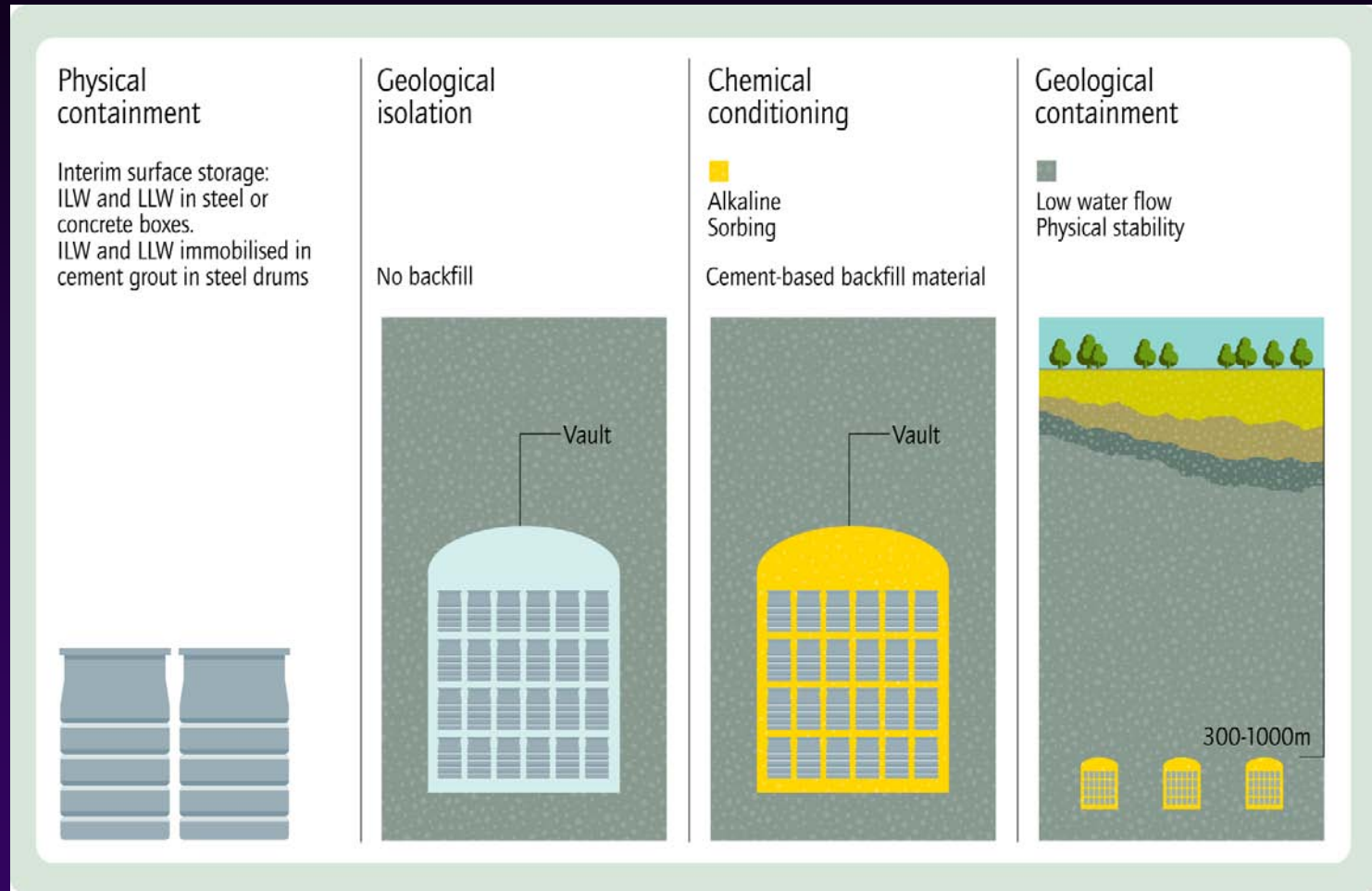
Current UK LLW Management Strategy



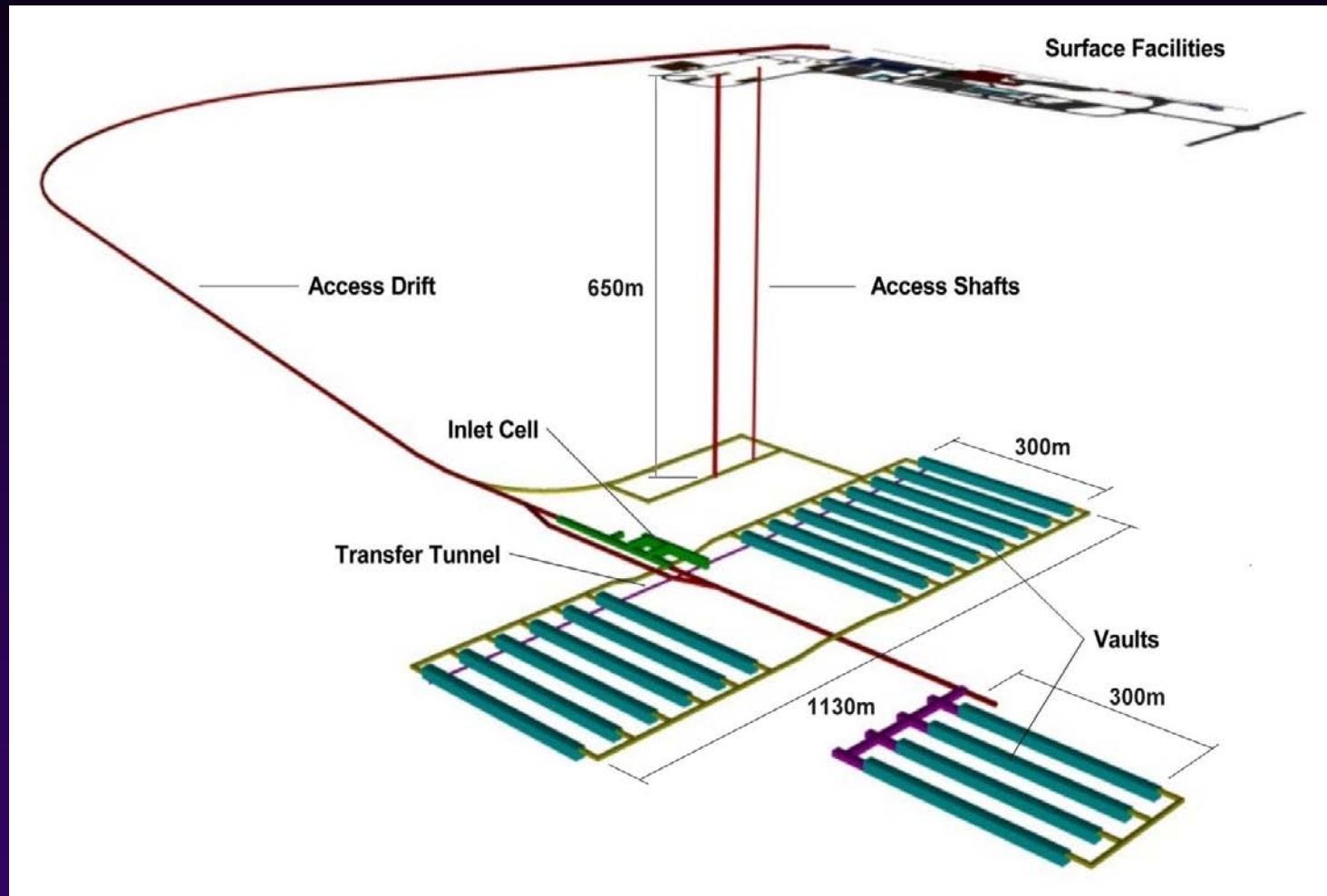
Multi-Barrier Containment (ILW)



Phased Geological Repository Concept



Basic Layout



Possible Fate of Some Radionuclides

Decay in Packages	Decay in Near Field due to Chemical Confinement	Decay in Geosphere	Escape into Environment
^3H	^{14}C	^{59}Ni	^{36}Cl
^{63}Ni	^{94}Nb	^{79}Se	^{226}Ra
^{90}Sr	^{128}Sn	^{93}Zr	^{238}U
^{137}Cs	^{239}Pu	$^{93\text{m}}\text{Zr}$	^{99}Tc
^{238}Pu	^{240}Pu	^{135}Cs	^{131}I
^{241}Pu		^{242}Pu	

Open or Closed?

Deep
Boreholes

In-Tunnel
Emplacement

Vertical Pit Disposal

CARE-type

Closed  Open

Sealed for ever.....Monitoring and Retrievability

Scientifically safest.....More publicly acceptable

Will it be Near Me?

Geological Settings

- UK geology is varied and tectonically stable
- Several suitable settings
- Properties to be considered:
 - Land surface topography
 - Rock permeability
 - Porosity
 - Hydraulic gradient
 - Chemical composition of groundwaters
- Aquifers and zones with high groundwater fluxes, potential natural resources, and geologically-complex formations are less suitable
- Exclusion criteria have been agreed

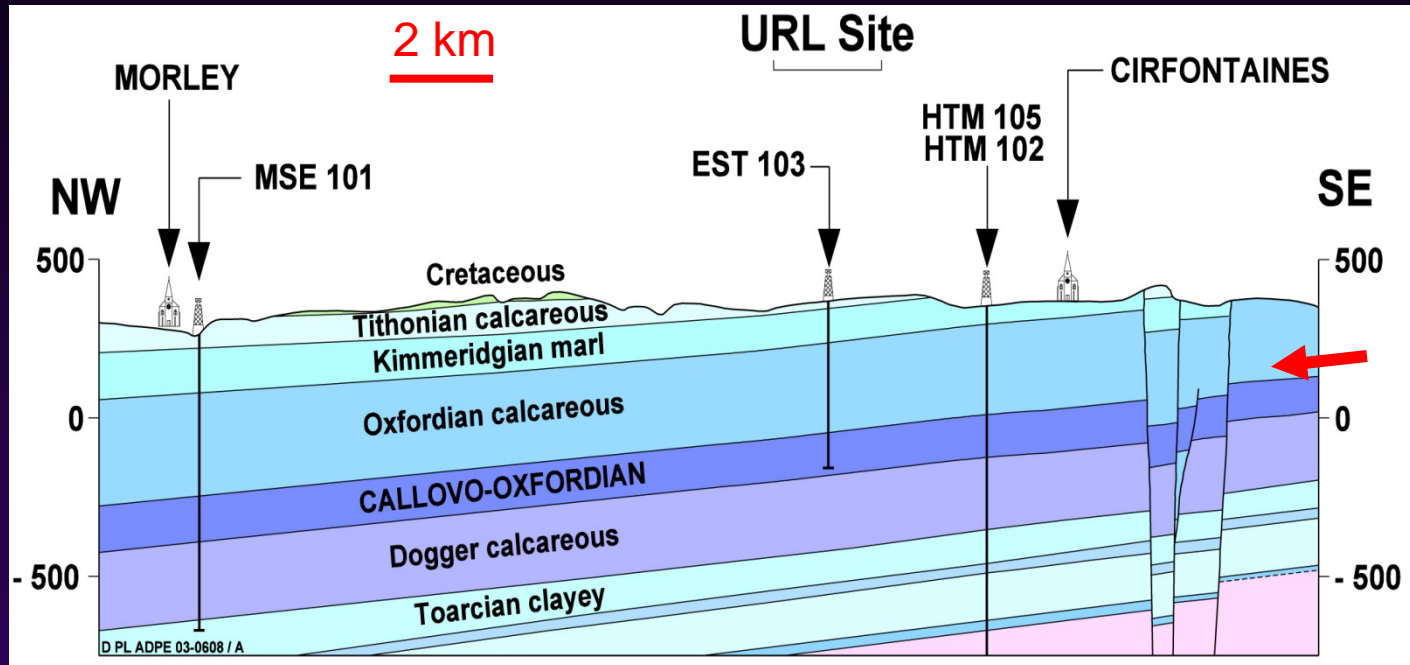
Which Rocks are of Interest?

- Hard (in the engineering sense), crystalline rocks
 - Finland, Switzerland, Sweden, Canada, Japan, UK?
- Low permeability sedimentary rocks
 - Belgium, France, Switzerland, UK?
- Evaporites (e.g. halite)
 - USA, Germany?

Hard, Crystalline Rocks

- High strength allows construction to great depth
- Main purpose of rock is to provide environment with:
 - Relatively low groundwater flow
 - Suitable geochemical conditions
 - Mechanical protection of the Engineered Barrier System
- Beware fractures!

Low Permeability Sedimentary Rocks



- Rock provides good physical and chemical barriers to flow
- Very low permeability - diffusion-controlled transport
- 40,000 years for radionuclides to migrate 1 m in clay at depth
- Detailed lithology can be traced over tens of km
- Lower strength means that disposal depth may be more limited

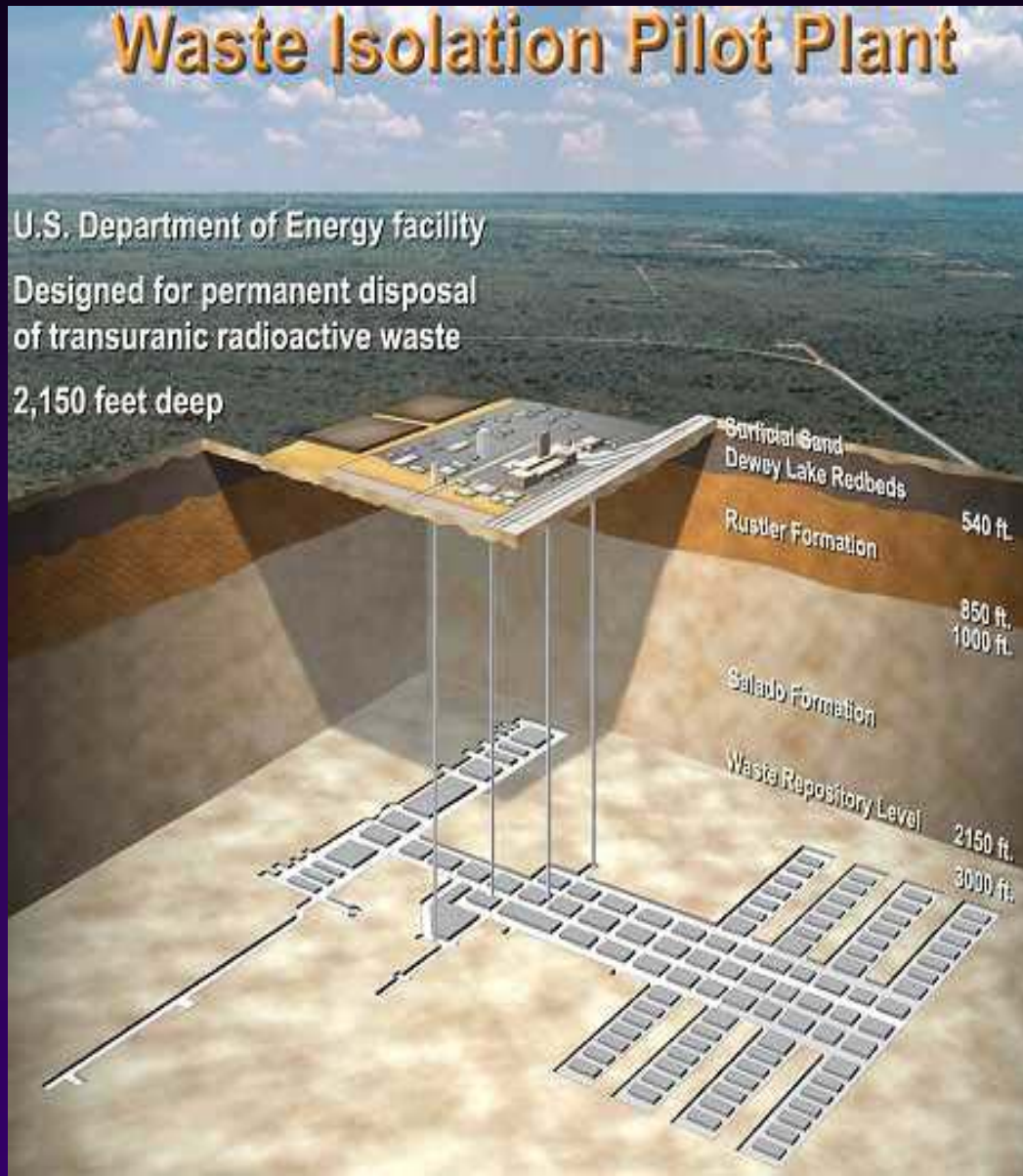
National Programmes

- Consensus exists that geological disposal is preferred method of ensuring long-term safety
- ILW geological repositories have been in operation for a number of years in Finland (crystalline rocks) and the USA (salt)
- Underground research laboratories at repository depths have been built in clays (Belgium, France and Switzerland)
- Decision of Finland and Sweden to site repositories in crystalline, igneous rocks is out of geological necessity
- Considerable resources could be expended unnecessarily in seeking 'the best site' for disposal
- Social, political and economic factors will intervene
- Local acceptance is crucial
- Key lesson from abroad is that site need not be ideal from a geological perspective
- But it should meet certain pre-defined criteria

The WIPP (New Mexico, USA)

- Waste Isolation Pilot Plant is a U.S. Department of Energy facility
- USA's first geological repository for permanent disposal of transuranic (TRU) waste
- Congress authorised development in 1980 to demonstrate safe disposal of radioactive waste
- Various sites were shortlisted
- Site was seismically stable in an area of low population density
- The local community volunteered on basis of economic incentives
- Introduction of new industry and significant job opportunities in the area

The WIPP (New Mexico, USA)



- Waste disposal in halite at 650 m depth
- Extremely low permeability
- In safety case only way to obtain radionuclide transport to the biosphere is via human intrusion

Finland - Decision-in-Principle (2001)

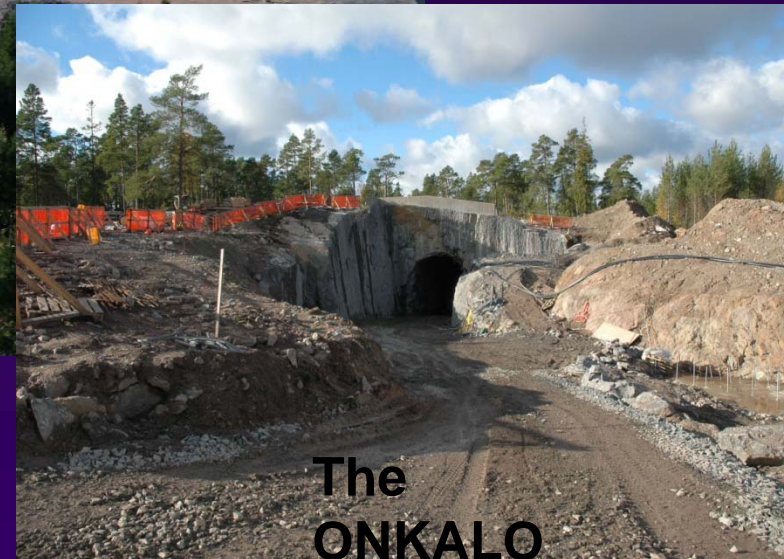
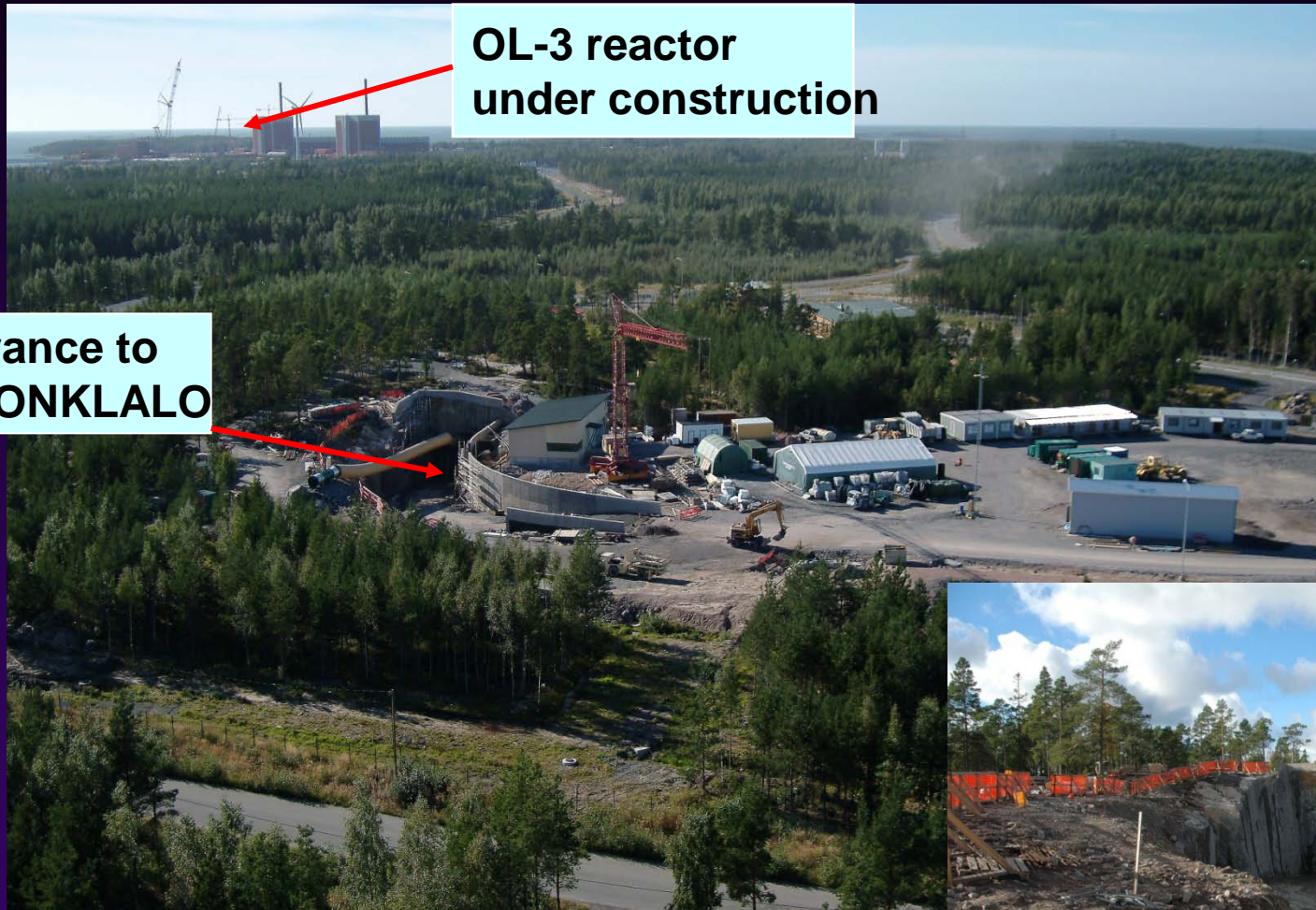
”Construction of the final disposal facility for spent nuclear fuel produced during operation of the existing Finnish nuclear power plants, in such a form as described in the application with regard to the main operating principles of the facility and the structures aimed at ensuring its safety, at Olkiluoto in the municipality of Eurajoki, is in the overall interest of society.”

Finnish Parliament, 18 May 2001

Site Selection Process: Stakeholder Discussion

- 1980's – early 1990's: informing the local decision-makers, media and public about investigations
- Nuclear Energy Act of 1987: introduction of local veto
- Early 1990's: first serious attempts at dialogue started
 - Societal aspects of waste issues acknowledged
- Late 1990's: public dialogue in the context of Environmental Impact Assessment
- Late 1990's: contacts with municipalities on possibilities for enhanced cooperation
- Early 2000's: national debate (Parliament)

The Olkiluoto Site, Finland



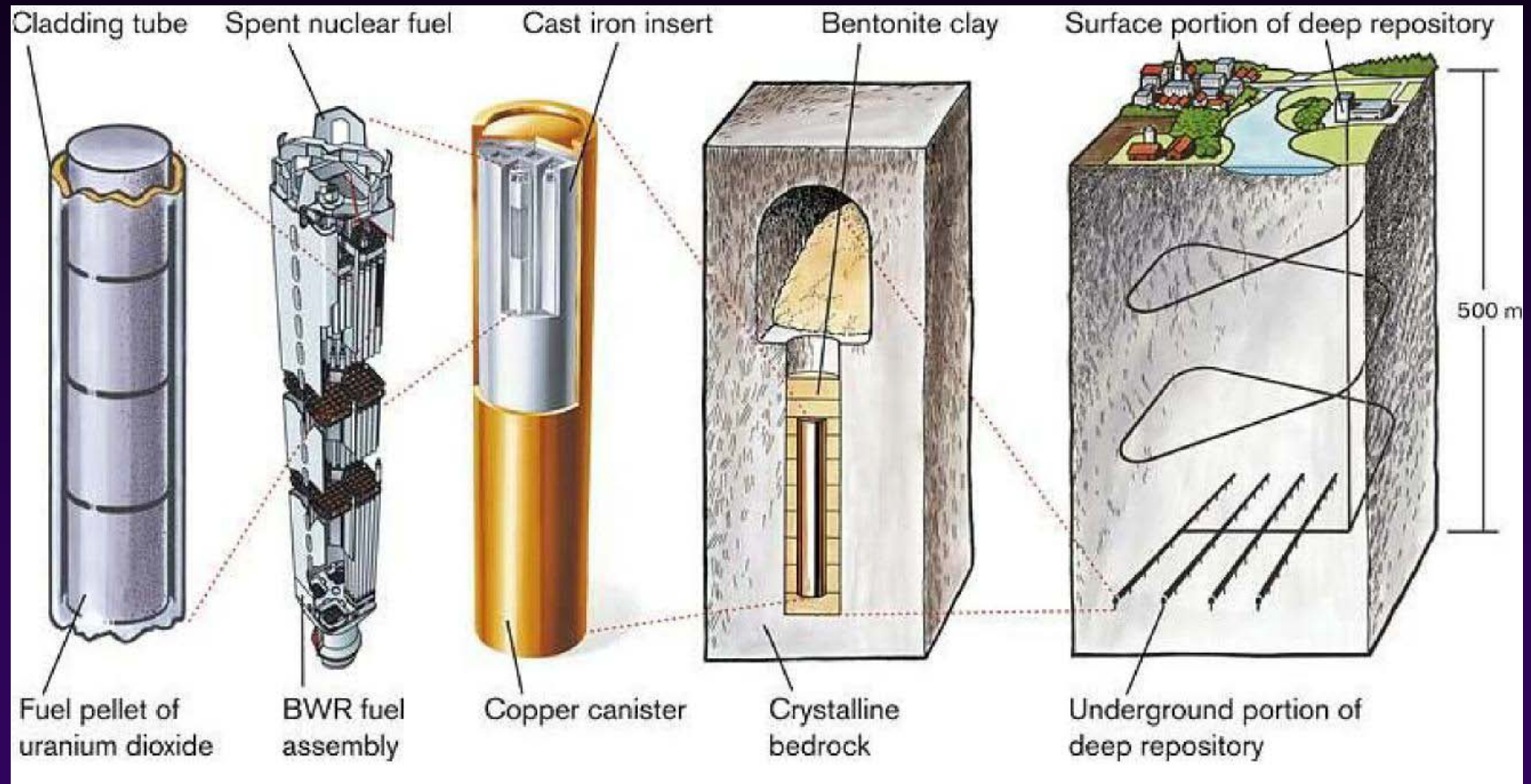
Onkalo



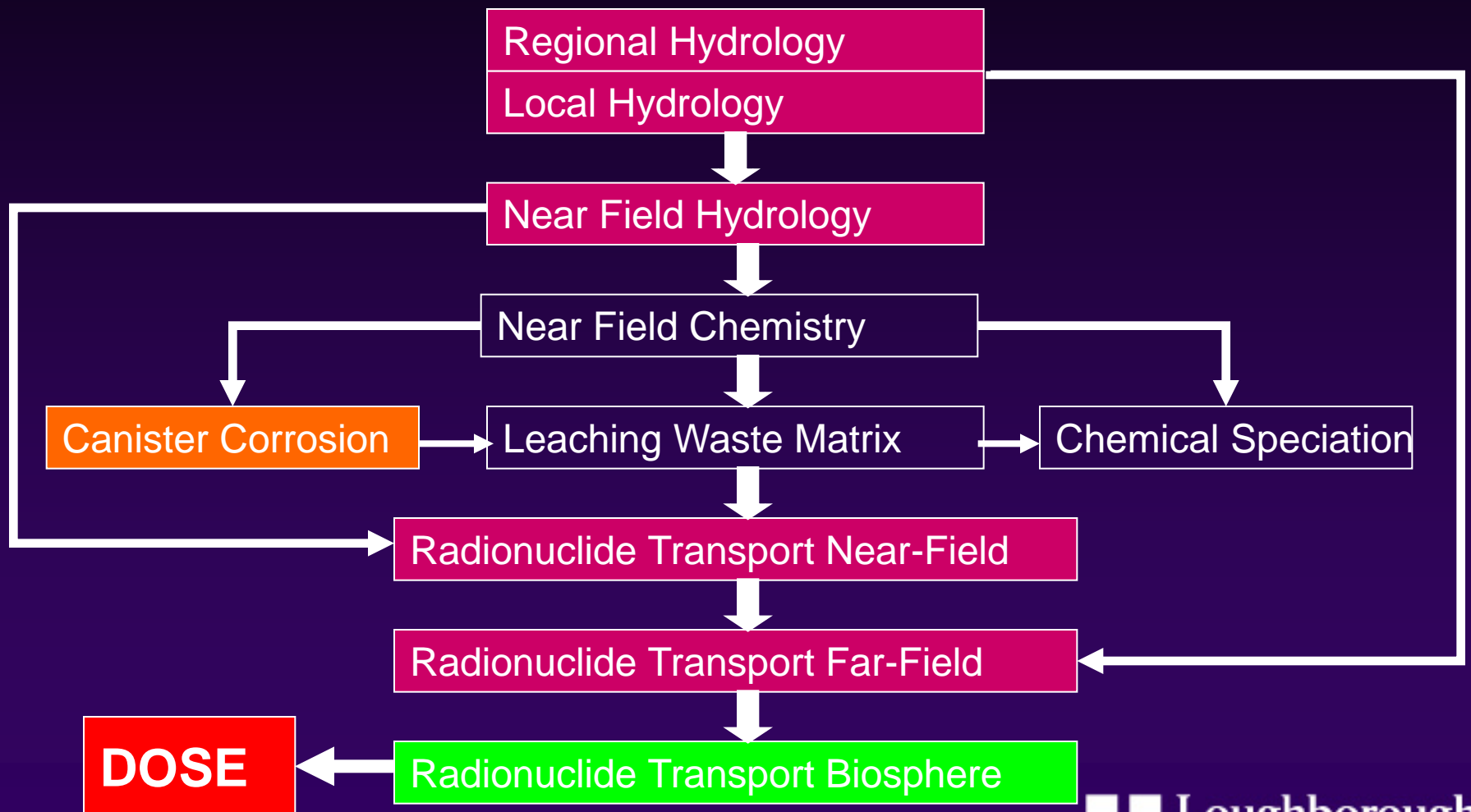
Sweden

- Disposal of all types of waste in crystalline rocks of Scandinavian shield, at various depths
- Stripa underground research laboratory is situated in central Sweden
- Underground store for 3000 t of spent fuel has been constructed at a coastal site (Oskarshamn)
- LLW and ILW wastes are to be disposed of in a repository currently under construction at Formsmark
- Hundreds of metres offshore, at a depth of 50 m below the sea-bed
- Access by inclined tunnels from coast
- Estimated start date 2020

KBS-3 Concept

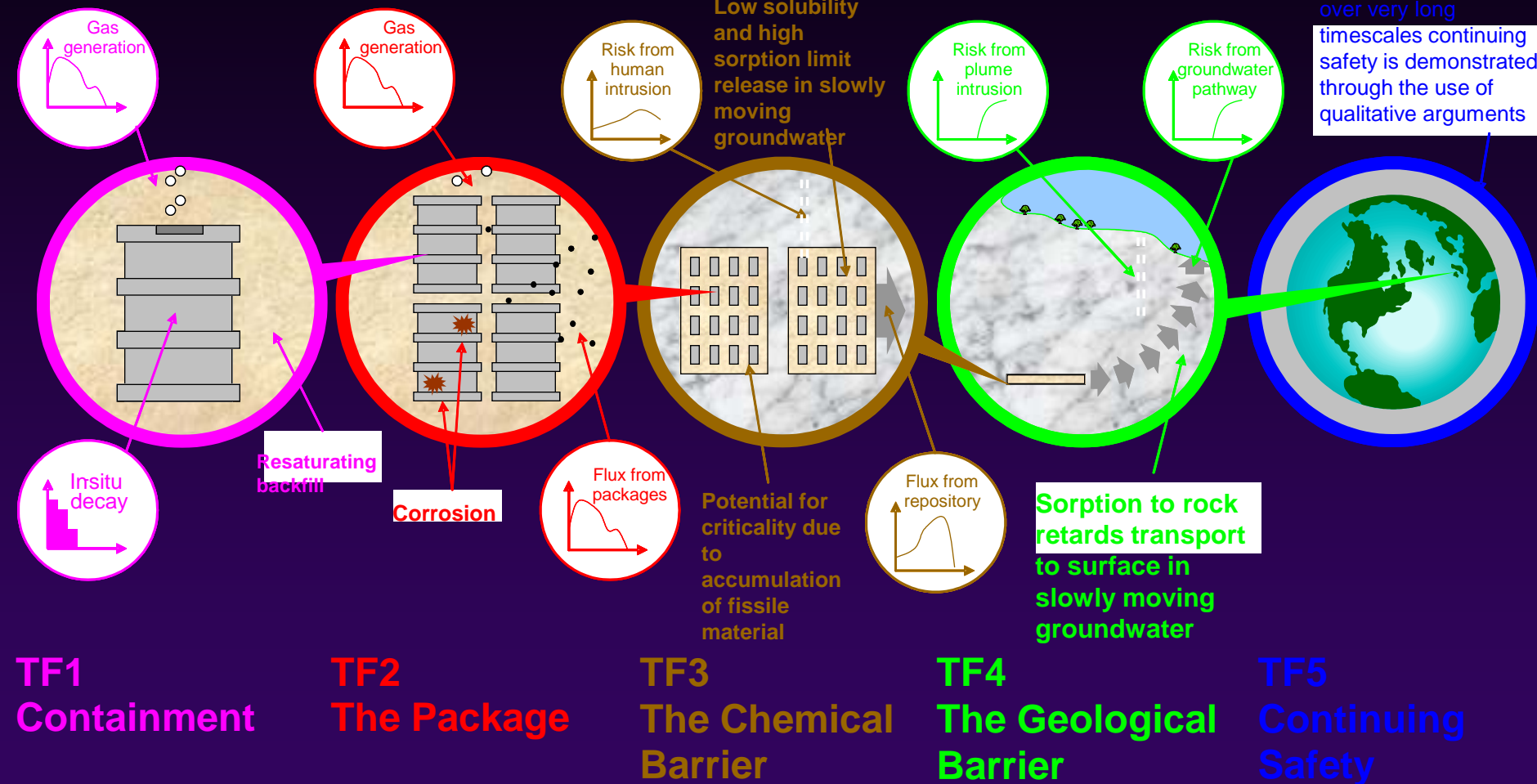


Factors Affecting Radionuclide Dose to the Public



Assessment Timeframes

Despite major change to the whole system over very long timescales continuing safety is demonstrated through the use of qualitative arguments



Conclusions

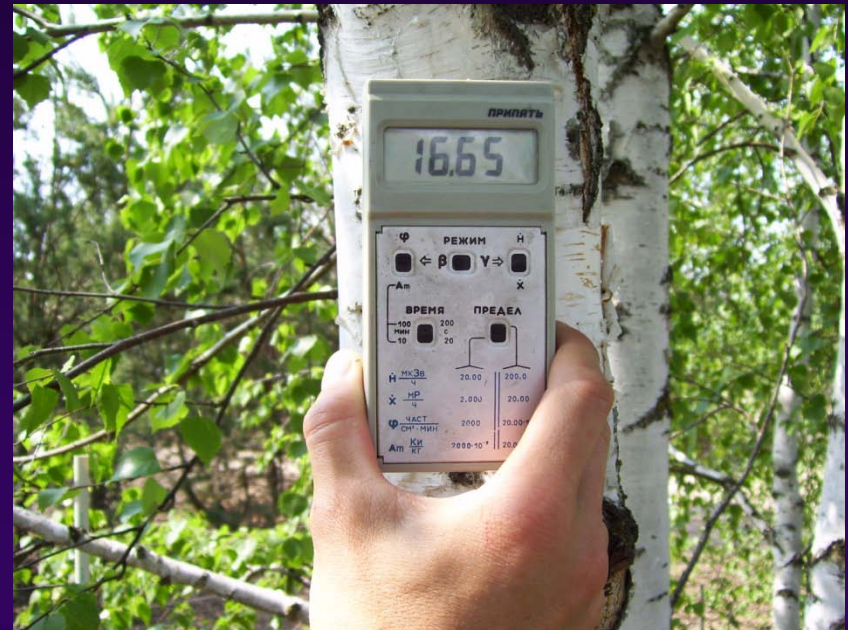
- A UK repository(s) may well happen by 2040
 - Scottish independence?
- Considerable resources could be expended in seeking 'best site'
- The science and technology is already in place for disposal of most wastes
- Closed vs. open likely to be a major debate
- Social, political and economic factors important
- Local acceptance crucial

Waste Trenches

- Approx 800 waste burial sites in exclusion zone
- Lower level sites were hastily built in sandy soil 2 to 3.5 m deep with no isolating covers or liners
- Some have trees planted on top!
- Other waste is buried in 30 large trenches 100 m x 70 m and 10 m deep
- Groundwater movement is leaching radionuclides from the trenches

A Typical Small Trench

- Low and intermediate level wastes, including trees
- French (IRSN) monitoring for ^{90}Sr movement
- Trees planted on the trenches



Bushy Pine Trees



Other Waste Trenches

Quite well hidden!



Vehicle Graveyard

- For all the transportation used in:
 - Putting out the fire
 - Building the sarcophagus
 - Transporting the waste
 - ?? million tonnes of scrap radioactive iron
 - Some is buried in the large trenches

Vehicle Graveyard



Acknowledgements

- The Radiochemistry Group at Loughborough
- Funding from:
 - NDA
 - Sellafield Ltd.
 - UKAEA
 - NERC
 - EPSRC etc.