The application of *waste-informed decommissioning* in the UK nuclear industry

Bill Miller　　ビル・ミラー

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bill.miller@jacobs.com

Introduction

- Decommissioning waste management is a large topic, so I can't cover everything. But I hope you find this presentation interesting and useful
- Two main topics today:
    1. Brief history of decommissioning and waste management in the UK up to the present day
    2. The concept of *waste informed decommissioning* and the benefits it brings
- I do not want to suggest that Japan should do all the same things as the UK. But there are some good practices and lessons learned (and a few mistakes) that could be useful to decommissioning and waste management in Japan
- I would welcome your comments and questions, because it is always good to talk and share ideas
- You may contact me by email after the presentation if you wish

bill.miller@jacobs.com

1. Brief history of decommissioning and waste management in the UK up to present today

A complicated journey with many lessons learned

UK nuclear development

- UK adopted nuclear power very early and had an extensive research programme to test different reactor designs
- First generation Magnox power reactors built in the late 1950s and 1960s
  - 26 reactors on 11 sites (but each one slightly different)
  - Calder Hall, world's first commercial power reactor opened by the Queen in 1956
- Second generation Advanced Gas Cooled reactors (AGR) built in the 1960s and 1970s
  - 14 reactors on 7 sites (but each one slightly different)
- Multiple research and development reactors
  - Dounreay fast breeder reactor (DFR) first criticality in 1959
  - Dounreay prototype fast reactor (PFR) first criticality in 1974
  - Winfrith steam generating heavy water reactor (SGHWR) first criticality in 1967
- Plus uranium enrichment and U-metal fuel fabrication facilities

Sellafield

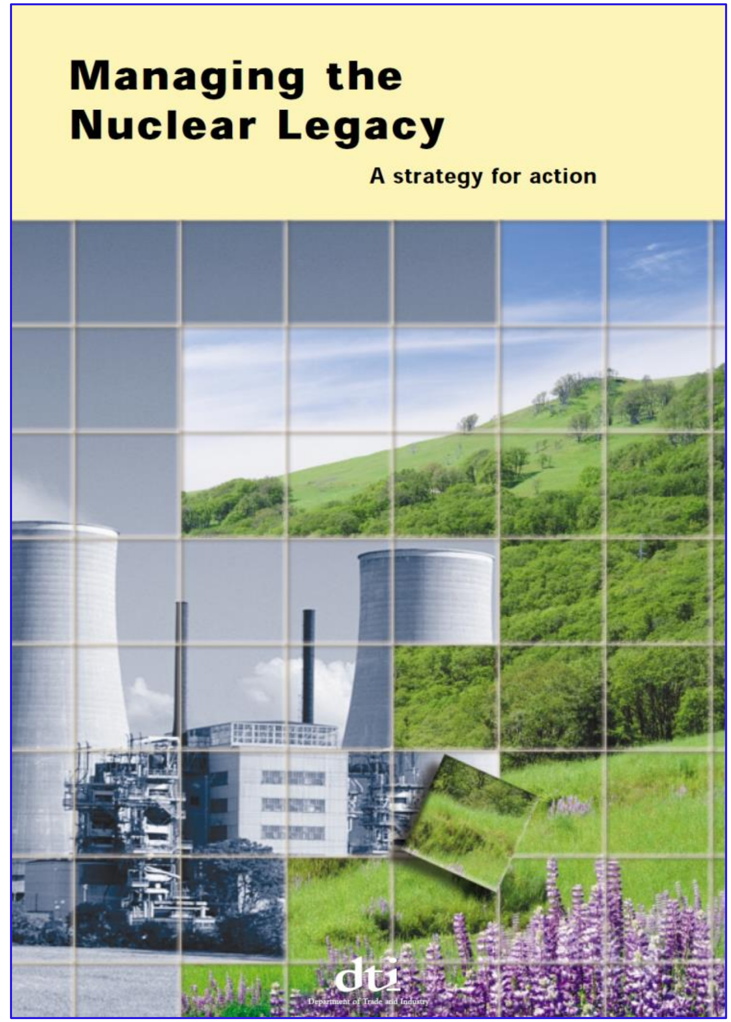
- Sellafield is the largest nuclear site in Europe with mix of legacy and operational facilities
- Started nuclear operations in 1947 (reprocessing Magnox fuel)
- Complex site, containing several early experimental reactors, fuel reprocessing facilities and old waste silos
- Site of the Windscale "Pile 1" reactor that first went critical in 1950 but caught fire in 1957
- More modern reprocessing facilities (THORP) that closed in 2018, and a vitrification plant that is still operational

LLW Repository

- Close to Sellafield, this is the UK's only national LLW repository that opened in 1959 (LLWR, previously called "Drigg")
- It has old disposal "trenches" and modern "vaults"

Early planning for decommissioning

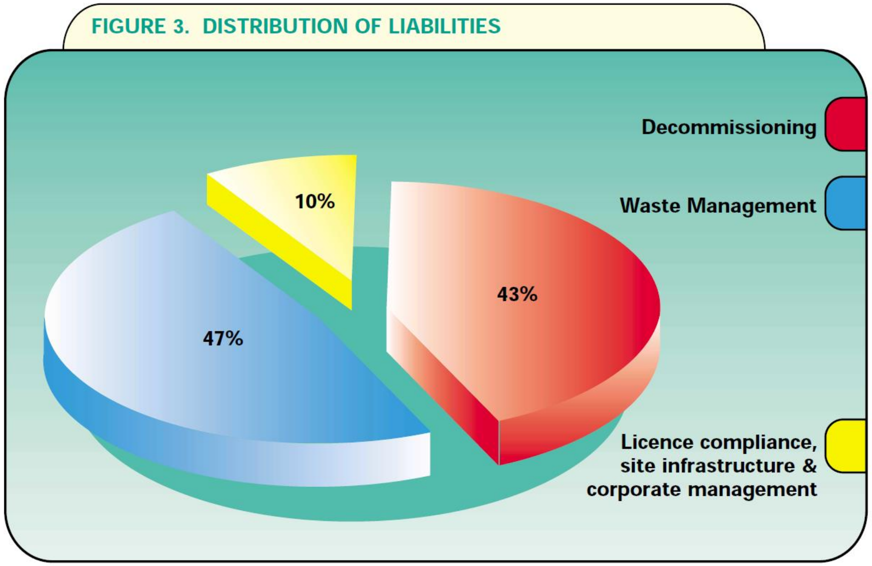
- The early reactor development programme meant the UK had to deal with complex decommissioning problems before most other countries
- By the year 2000:
  - 4 Magnox stations (8 reactors) had already closed
  - Winfrith experimental reactors stopped in 1990
  - Dounreay fast breeder reactors stopped in 1994
- All other Magnox reactors planned to close by 2015
- In 2002, UK Government published first national strategy for decommissioning
  - *"Managing the nuclear legacy. A strategy for action"*
- Very influential report:
  - Government accepted full financial liability
  - included first full cost estimate for decommissioning and waste management
  - identified lack of waste disposal capacity and urgent need for new waste management plan

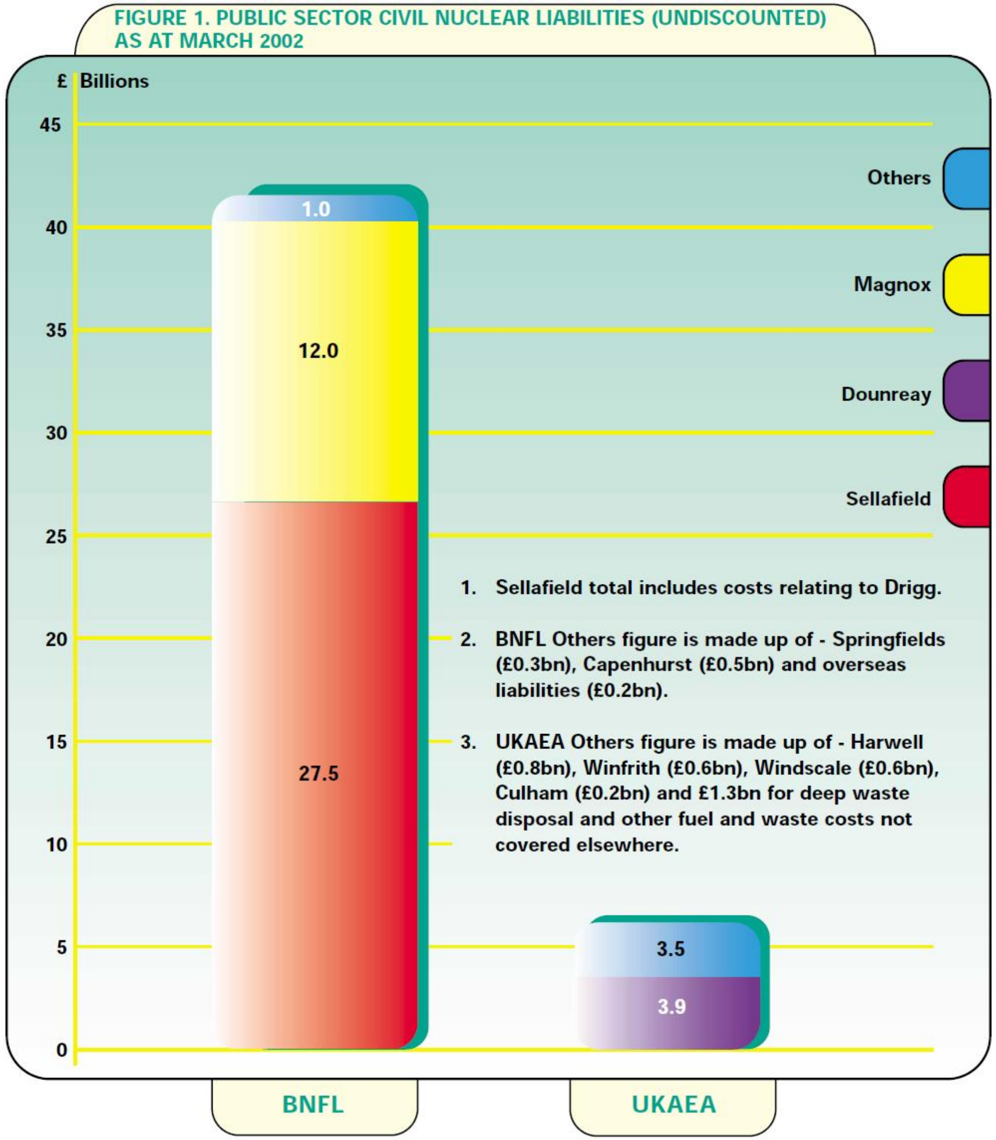


2002 cost estimate for decommissioning and waste management

GBP 48 billion
JPY 6,700 billion

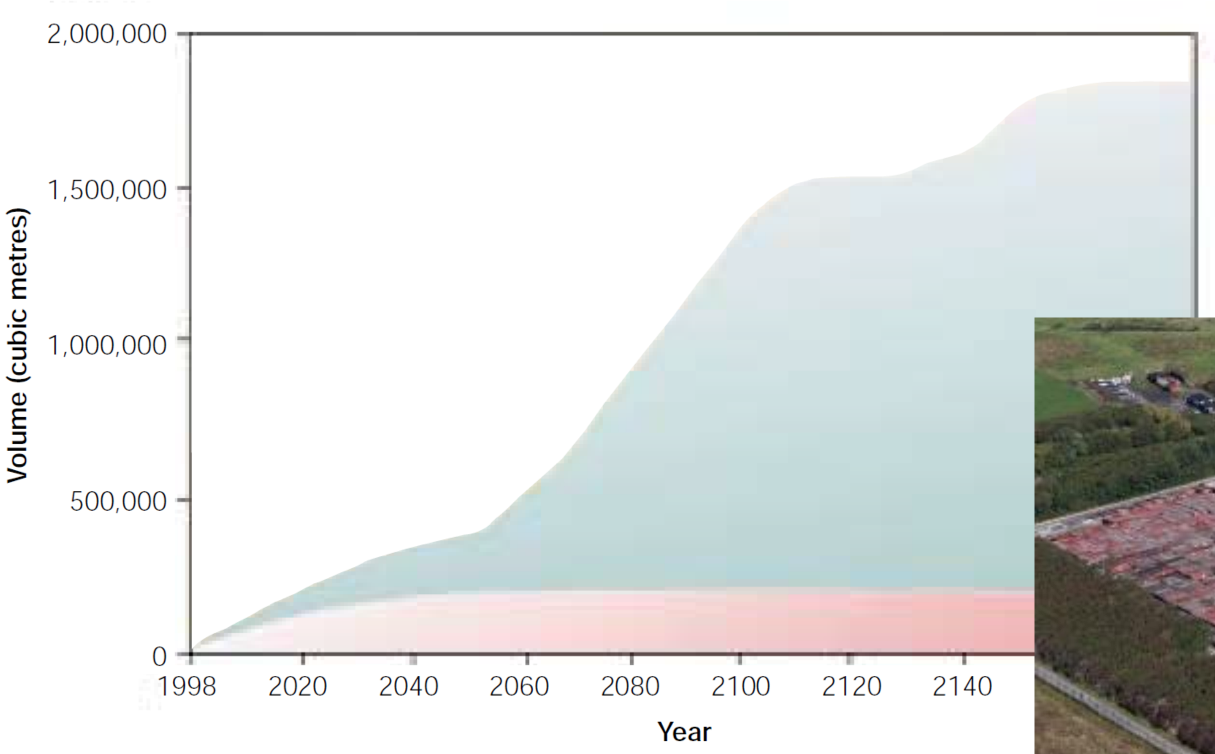
(2019 estimate GBP 124 billion)





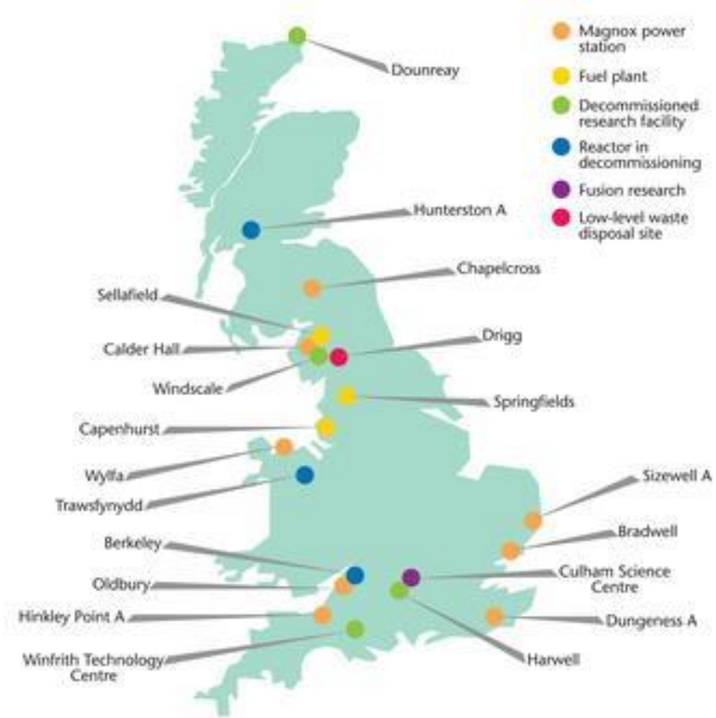
2002 estimates for waste volumes

- Decommissioning LLW volume estimate almost 2 million m^3
- But the new vault at LLWR only had capacity for around 250,000 m^3 and so would be full by 2020 - therefore urgent need for new decommissioning waste plan



New national plan

- In 2005 the UK Government published the Energy Act (law) which established the Nuclear Decommissioning Authority (NDA)
- Objective was to centralise decommissioning of all the old, legacy sites into one organisation
- Seek to find ways to speed up decommissioning but also to reduce costs and to solve the problem of waste disposal (especially for LLW)
- NDA works closely with industry supply chain to manage the decommissioning sites and to deliver waste management improvements



NDA
Nuclear Decommissioning Authority

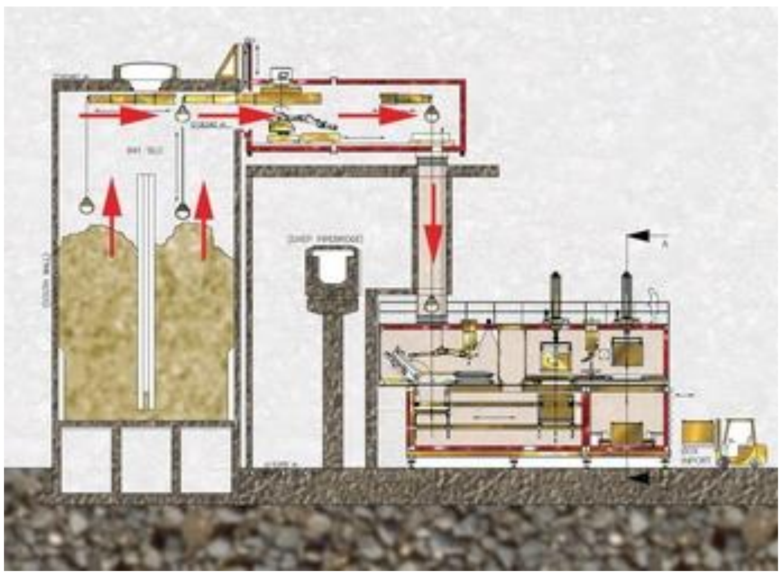
Supply Chain Charter for Nuclear Decommissioning Sites Signatory

NDA Strategy

- Government asked NDA to develop a national decommissioning and waste management strategy for all sites
- The national decommissioning strategy had to balance many factors:
  - accelerate decommissioning
  - provide waste disposal / storage routes
  - improve safety and environmental protection
  - availability of resources (money, people, skills)
  - regulator and stakeholder concerns
- Fixed budget and resource, so they have to prioritise decommissioning work
- Priority strategic work areas:
  - identify highest hazard / risk sites and facilities
  - define end-state for every site
  - detailed cost and schedule for every site
  - develop national waste management plan

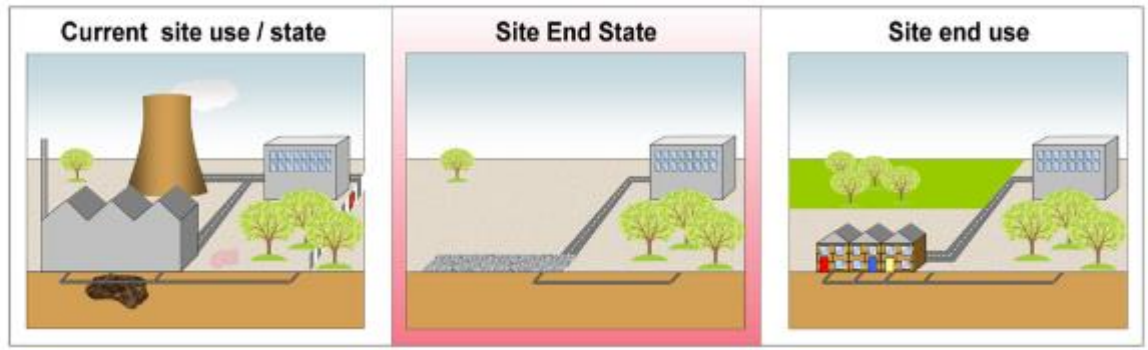
Strategic priority: risk / hazard reduction

- NDA strategic priority is to deal with older, high hazard facilities
- Highest hazard are the legacy waste ponds and silos at Sellafield
- Work now underway to retrieve the waste solids and sludges
- Wastes will be grouted and stored before geological disposal



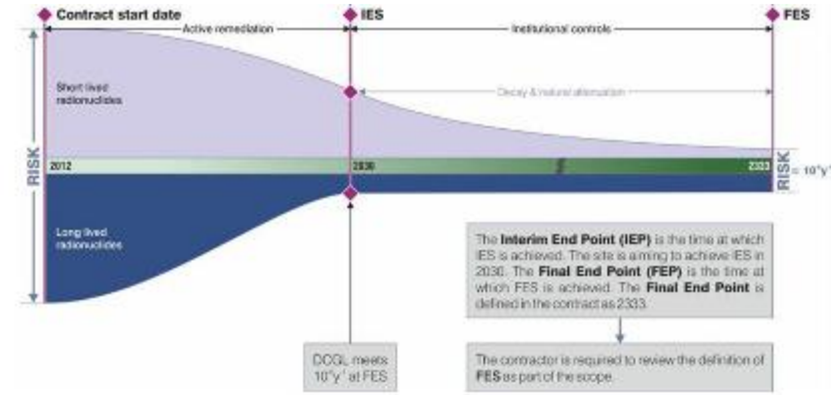
Strategic priority: define site end-states

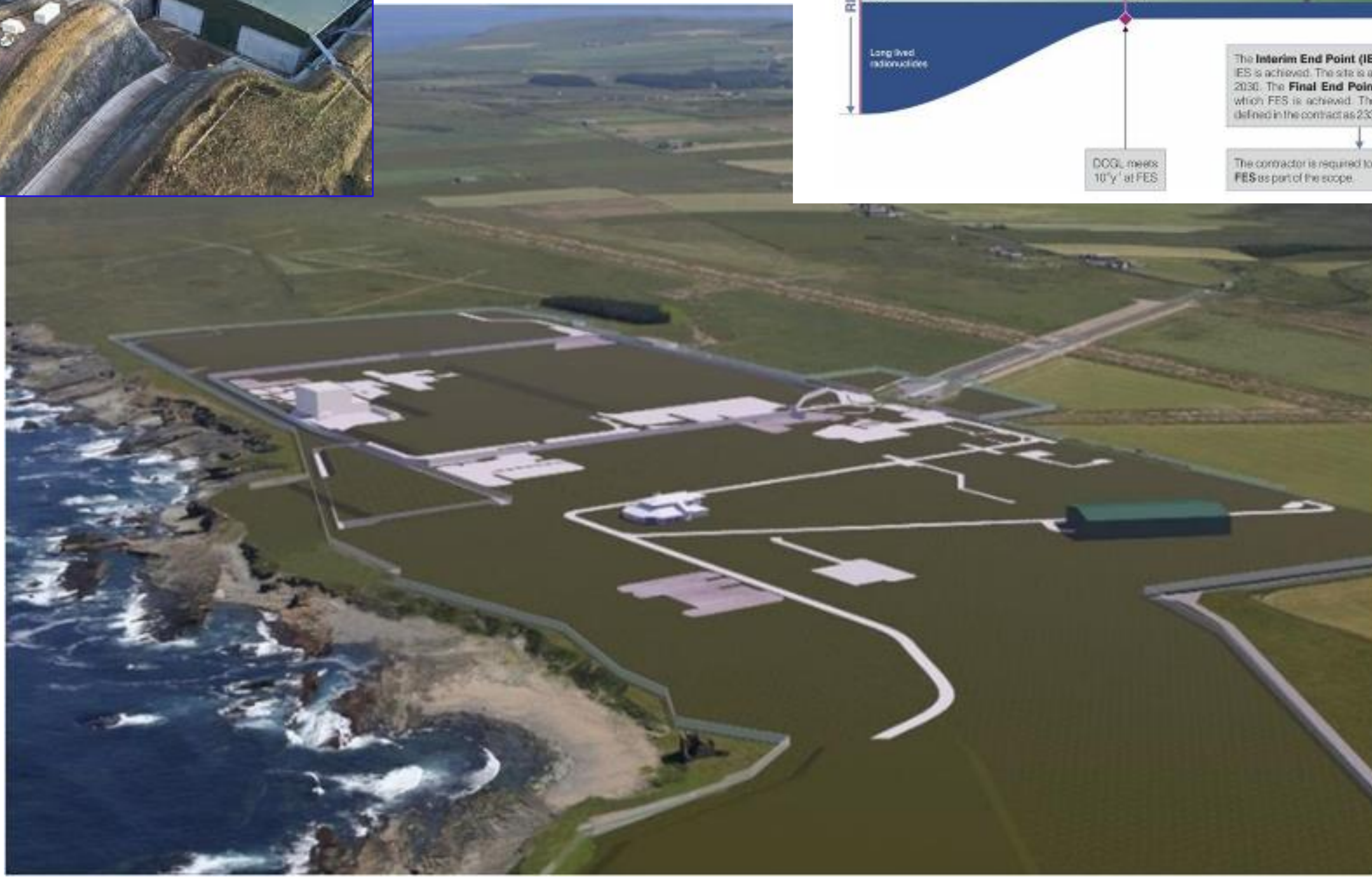
- A site end-state and potential end-use is defined for every nuclear site
  - new nuclear, industrial park, nature reserve etc.
- End-state affects the clean-up criteria and requirements
  - residual radioactive and chemical contamination
  - which buildings are left standing, landscaping
  - waste disposal facilities or waste stores on site
  - period of management control
- This affects:
  - volume and type of waste
  - cost and schedule



Dounreay current condition and future site end-state

Dounreay current condition and future site end-state





Magnox NPPs: low hazard so lower decommissioning priority

- Baseline strategy is to delay final reactor dismantling for around 60 to 85 years. *Care and maintenance* strategy.

Defueling

Reactors, cooling ponds and fuel cells containing used fuel are emptied, and the fuel is transferred off-site for reprocessing. Redundant plant can also be removed.

Care & Maintenance Preparations

During this phase hazards are reduced, buildings are deplanted and demolished. Waste is managed and maintenance requirements minimised.

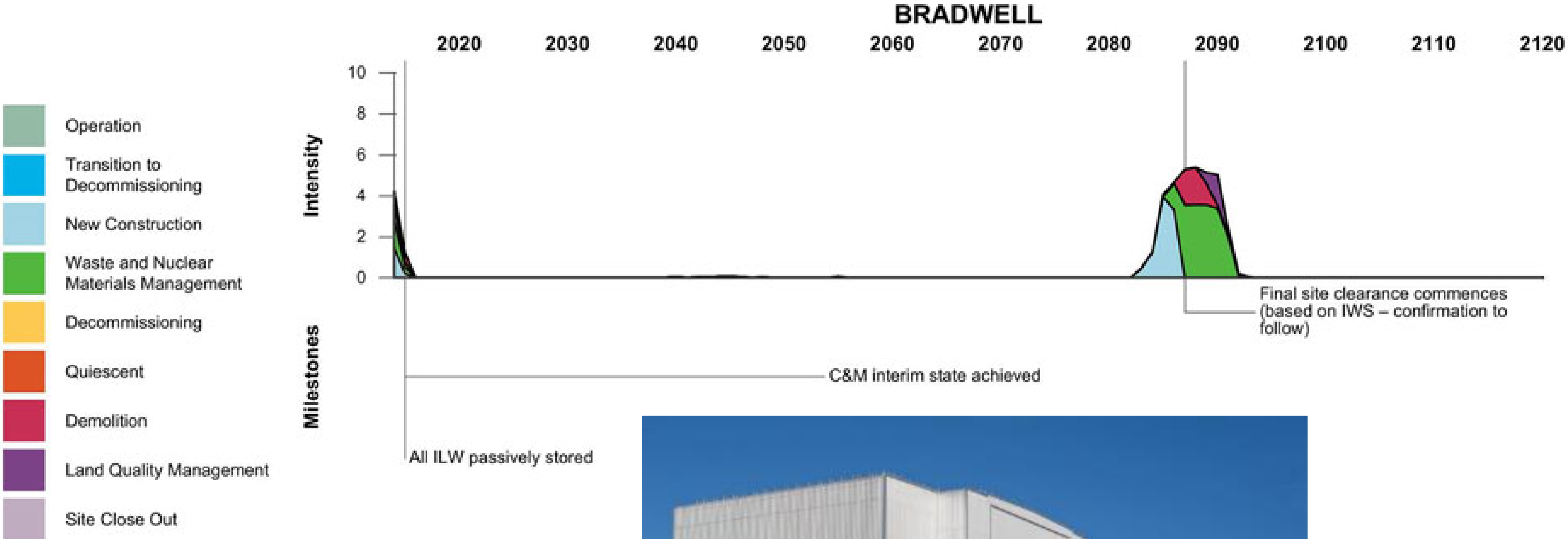
Care & Maintenance

The site is maintained in a passively safe and secure state while radiation levels are left to decay naturally.

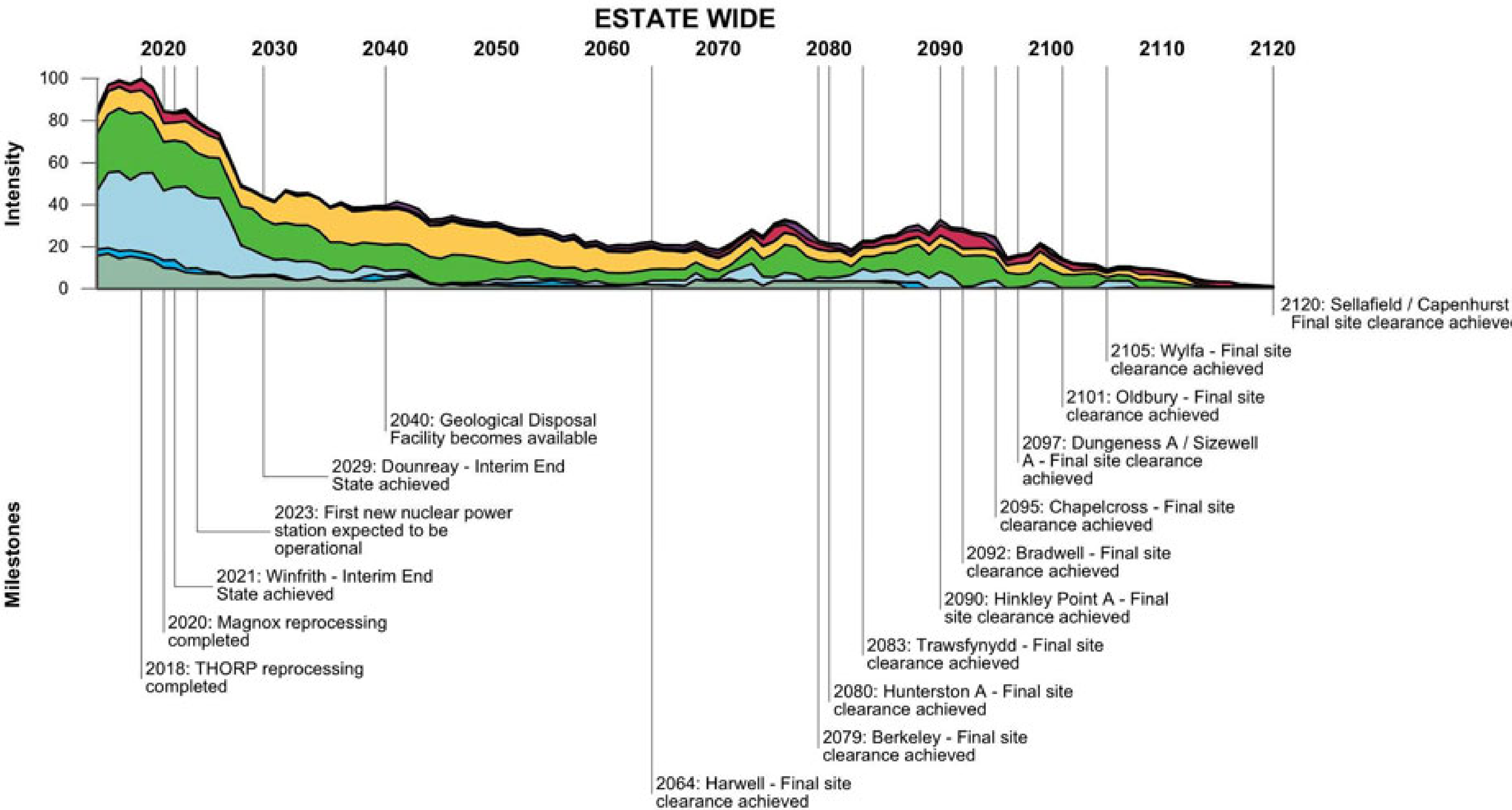
Final Site Clearance

This is the last stage in a site's lifecycle with the removal of reactor vessels and building demolition. Sites will be declassified as nuclear licensed sites.

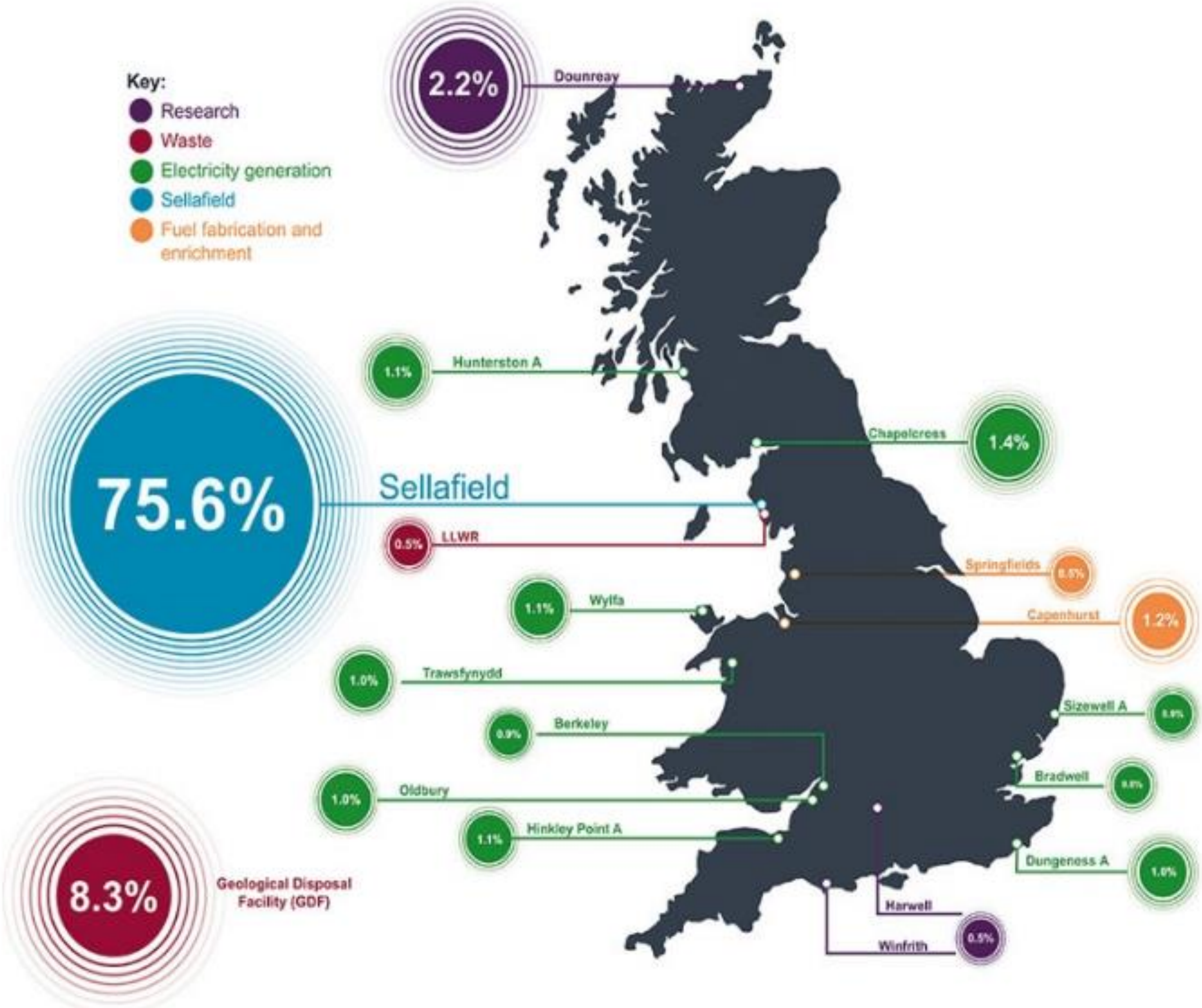
Magnox decommissioning schedule example – Bradwell site



100 year decommissioning schedule for all NDA sites

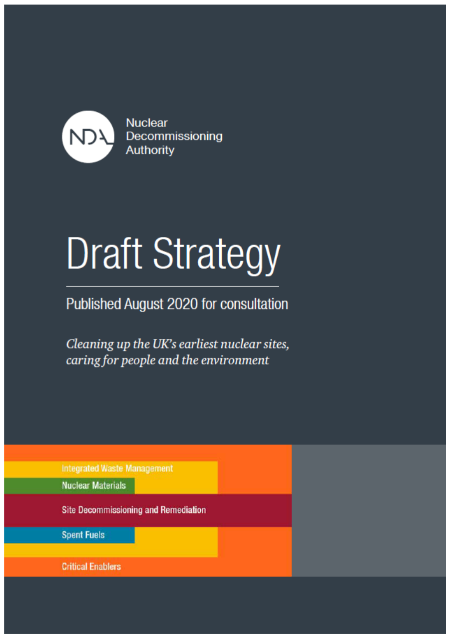


2019 decommissioning cost estimate - GBP 124 billion



What has been achieved so far with decommissioning

- The UK decommissioning strategy has been successful in many ways:
  - realistic schedule of work across all sites, and reliable cost estimates
  - partnership working with industry has been developed
  - lots of preparation work being done e.g. construction of waste stores etc.
  - decommissioning work is now progressing on the most hazardous, old facilities
  - other sites achieving interim end-states, entering care and maintenance stage
  - NDA strategy reviewed every 5 years to reflect new developments

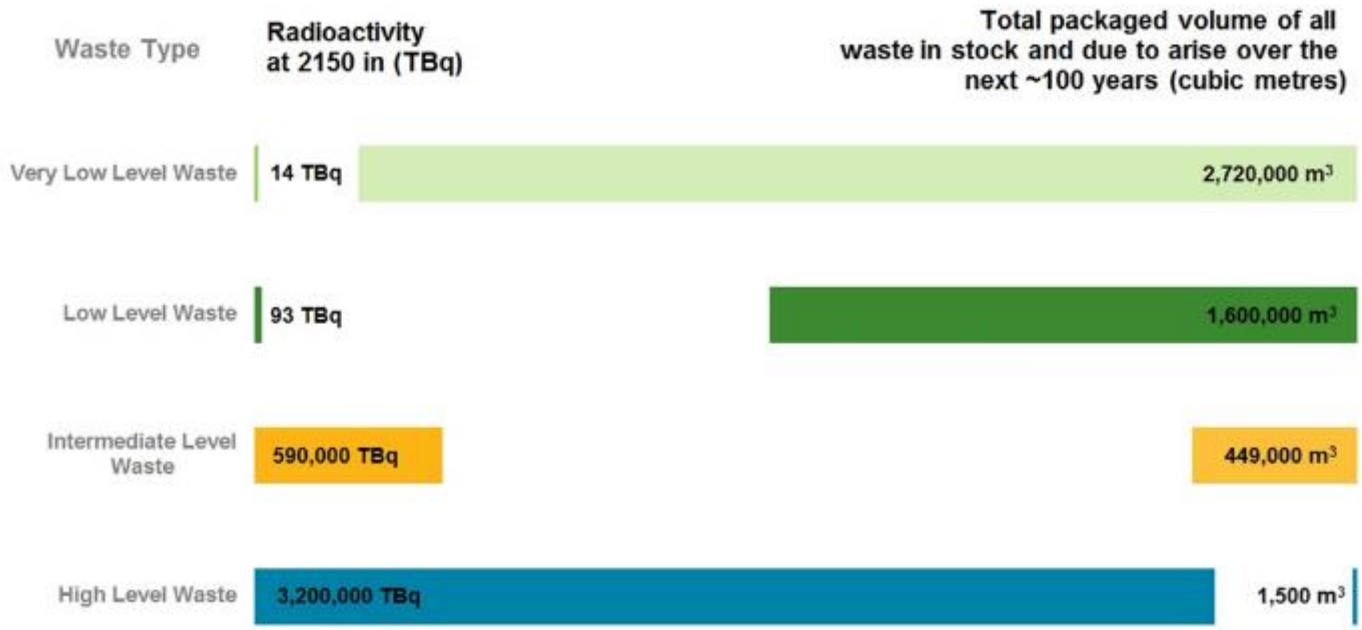


But some unintended consequences for waste management

- Some poor waste management decisions:
  - waste not well characterised, sorted and segregated
  - limited disposal routes or waste acceptance criteria (WAC)
  - caused problems for storage and treatment
  - wastes disposed as LLW that could have been cleared
- Why this happened:
  - often limited integration between decommissioning and waste management activities
  - work planned and performed by separate teams of people without a common site strategy
  - decommissioning contracts and financial incentives did not support good waste management
- Sometimes the benefits gained by faster decommissioning were lost due to unexpected extra costs for additional waste management
- This led to need for improved national approach for decommissioning waste management

2. Waste informed decommissioning

A practical plan to manage all wastes

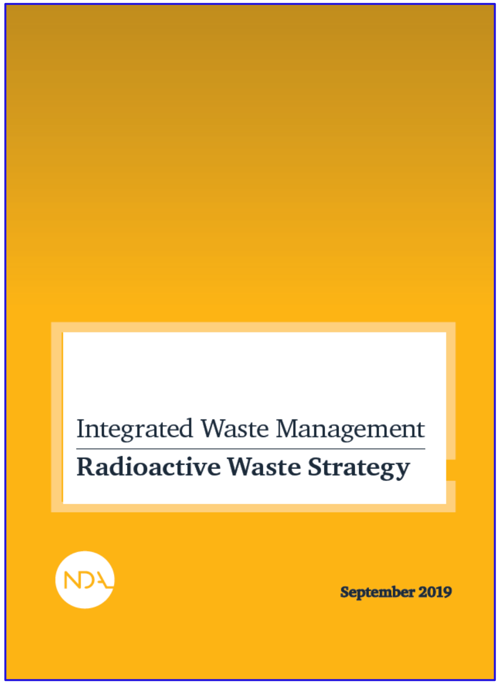


What is waste informed decommissioning ?

- An approach for joint and integrated planning and delivery for both decommissioning and waste management to achieve an optimised outcome
- Objectives:
  - national scope
  - place greater emphasis on waste management and disposal
  - decommissioning is not delayed
  - no wastes are generated without a management plan
  - radioactive waste volumes are reduced and more waste is cleared as non-radioactive
  - more management and disposal routes for LLW are available to increase flexibility
  - ILW (sludges, resins etc.) can be treated and packaged before a repository is available

Important new developments to improve waste management

1. Change of culture to prioritise waste management and planning
2. Improved waste characterisation and inventory data
3. Integrated waste management strategy at every site
4. New approaches to LLW management to avoid disposal to the LLWR
5. Disposability assessment to allow ILW to be treated and packaged



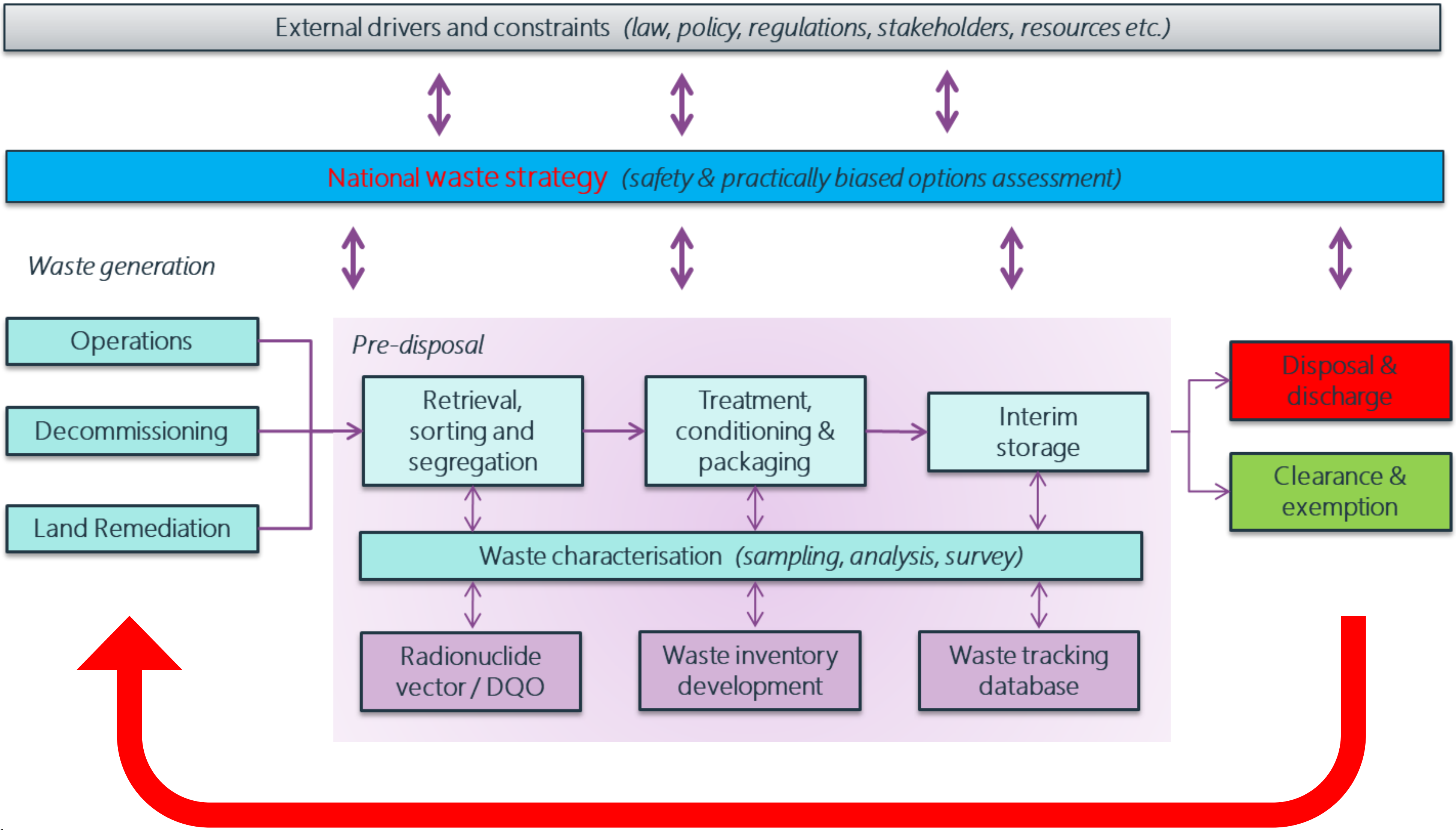
1) Culture change: decommissioning is a waste generation activity

Packaged radioactive
waste for disposal

Non-radioactive waste
for recycling

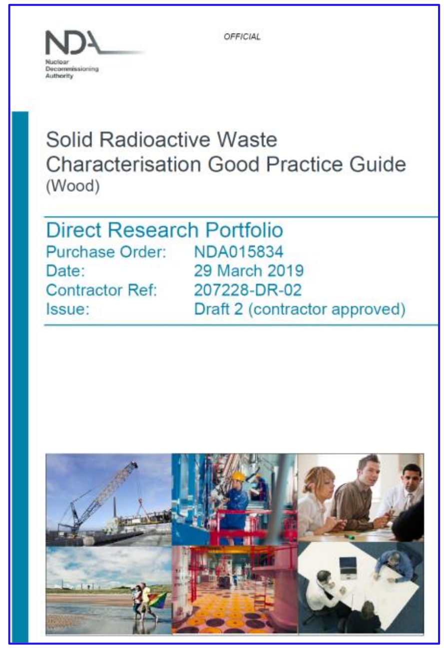
Remediated site
for reuse

1) Culture change: plan backwards – put waste management first



2) Improved waste characterisation and inventory data

- Waste characterisation is the starting point for planning
- Need good quality and comprehensive information:
  - radionuclide composition
  - material type and chemical composition
  - volumes and geometry
  - schedule for generation
  - uncertainties
- Ideally characterise buildings before they are demolished so waste plans can be prepared
- Also require confirmation monitoring for clearance, segregation or to meet waste acceptance criteria
- Requires detailed and efficient waste characterisation:
  - Jacobs analytical laboratory measures 15,000 waste samples each year
  - laboratory measurements to define radionuclide vector "fingerprint" and on-site gamma spectrometry

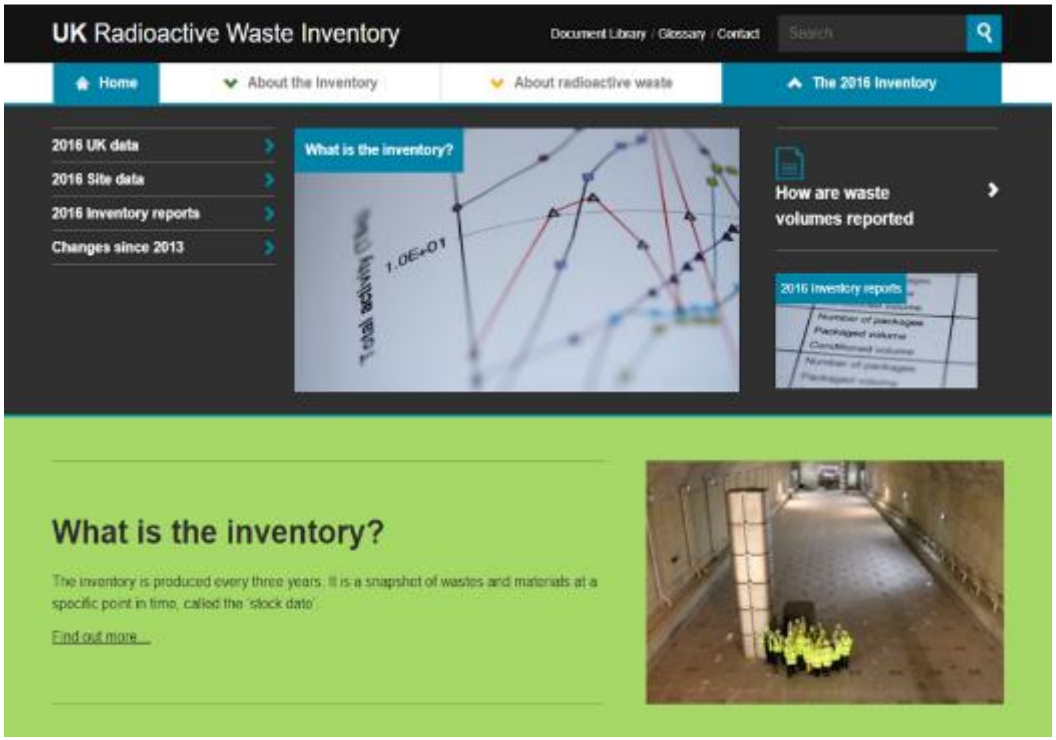

NDA Nuclear Decommissioning Authority
OFFICIAL

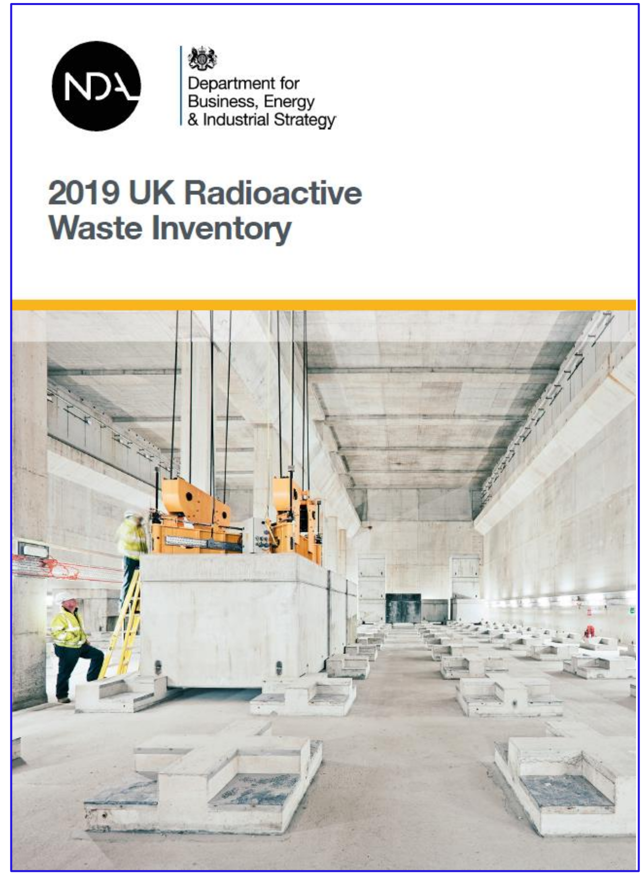
Solid Radioactive Waste Characterisation Good Practice Guide
(Wood)

Direct Research Portfolio
Purchase Order: NDA015834
Date: 29 March 2019
Contractor Ref: 207228-DR-02
Issue: Draft 2 (contractor approved)

2) Improved waste characterisation and inventory data National UK radioactive waste inventory (UKRWI)

- Publicly available information https://ukinventory.nda.gov.uk/
- Reports data for each site at waste stream level
  - approximately 1300 separate data sheets





WASTE STREAM	**2C308 Concrete (Reactor and Non-Reactor) LLW**

SITE	Chapelcross
SITE OWNER	Nuclear Decommissioning Authority
WASTE CUSTODIAN	Magnox Limited
WASTE TYPE	LLW

WASTE VOLUMES

		Reported
Stocks:	At 1.4.2016....................	0 m³
Future arisings -	1.4.2089 - 31.3.2095..........	34903.1 m³
Total future arisings:		34903.1 m³
Total waste volume:		34903.1 m³

Comment on volumes: It has been assumed that the whole of the bioshield will be knocked down and disposed of as LLW. There will be no segregation of waste. Final Dismantling & Site Clearance is assumed to commence in 2089. Volumes and radioactivity have been calculated for 85 years after reactor shutdown, i.e. 2089.

Uncertainty factors on volumes:	Stock (upper): x	Arisings (upper) x 1.2
	Stock (lower): x	Arisings (lower) x 0.8

WASTE SOURCE Concrete wastes from dismantling of reactors and associated plant.

PHYSICAL CHARACTERISTICS

General description:	A wide variety of concrete and reinforced concrete items (reinforcing steel is described in waste stream 2C307).
Physical components (%vol):	Concrete and reinforced concrete (100%), mostly from reactor bioshield.
Sealed sources:	-
Bulk density (t/m³):	1.4
Comment on density:	The density is of the waste as cut for packaging assuming 20% in blocks and 80% as rubble.

RADIOACTIVITY

Source:	Activation of the concrete and impurities. There may be some contamination.
Uncertainty:	The values quoted were derived by calculation from available material specifications and are indicative of the activities that are expected. The major source of uncertainty is the impurity levels.
Definition of total alpha and total beta/gamma:	Total beta/gamma is defined as the sum of the listed activities of all nuclides other than alpha emitters. All alpha emitters are insignificant.
Measurement of radioactivities:	The specific activities have been estimated using a neutron activation calculation.
Other information:	The activities quoted are those at 85 years after reactor shutdown, i.e. in 2089. There may be some contamination by Cs137.

Nuclide	Mean radioactivity, TBq/m³				Nuclide	Mean radioactivity, TBq/m³			
	Waste at 1.4.2016	Bands and Code	Future arisings	Bands and Code		Waste at 1.4.2016	Bands and Code	Future arisings	Bands and Code
H 3			2.77E-05	C C 2	Gd 153				8
Be 10				8	Ho 163			1.93E-09	C C 2
C 14				8	Ho 166m			3.22E-09	C C 2
Ce 144				8	Cf 249				8
Pm 145				8	Cf 250				8
Pm 147				8	Cf 251				8
Sm 147				8	Cf 252				8
Sm 151			3.4E-07	C C 2	Other a				
Eu 152			1.91E-06	C C 2	Other b/g				
Eu 154			1.03E-08	C C 2	Total a	0		0	
Eu 155				8	Total b/g	0		3.73E-05	C C 2

Bands (Upper and Lower)
A a factor of 1.5
B a factor of 3
C a factor of 10
D a factor of 100
E a factor of 1000

Note: Bands quantify uncertainty in mean radioactivity.

Code
1 Measured activity
2 Derived activity (best estimate)
3 Derived activity (upper limit)
4 Not present
5 Present but not significant
6 Likely to be present but not assessed
7 Present in significant quantities but not determined
8 Not expected to be present in significant quantity

3) Integrated waste management strategy (IWS) at every site

- Every site has to develop an IWS that is consistent with the decommissioning plan and site end-state
- And every project has to develop a separate *waste management plan*
- This is planning tool to identify every waste stream and plan its management route
- Decisions on *what*, *how*, *where* and *when* to treat, store and dispose of wastes
  - characterisation requirements
  - waste management infrastructure (stores etc.)
  - estimate of schedule and costs
- IWS is essential for effective schedule planning and cost estimation

Corporate logo

Document reference number
Issue number – Date

SECURITY CLASSIFICATION

PROJECT WASTE MANAGEMENT PLAN

< Project Name >

< Site name or location >

1. PROJECT SCOPE

Description & scope of the project (not the scope of the waste) Include: • What? • Where? • How?	
Anticipated date when waste arisings will start	

2. PROJECT WASTE MANAGEMENT PLAN ENDORSEMENT

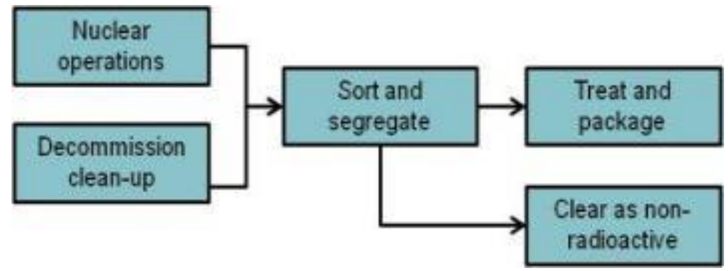
Document author	Print Name: .... Signature: .... Date: ....
Engineer / Waste Manager	Print Name: .... Signature: .... Date: ....
Declaration	
The Project Manager will take all reasonable steps to ensure that: a. All waste from the project is dealt with in accordance with Section 7 & 8. b. All relevant persons (contractors, site engineers, etc.) are made aware of the location and requirements of this PWMP and any supporting documentation.	
Project Manager	Print Name: .... Signature: .... Date: ....

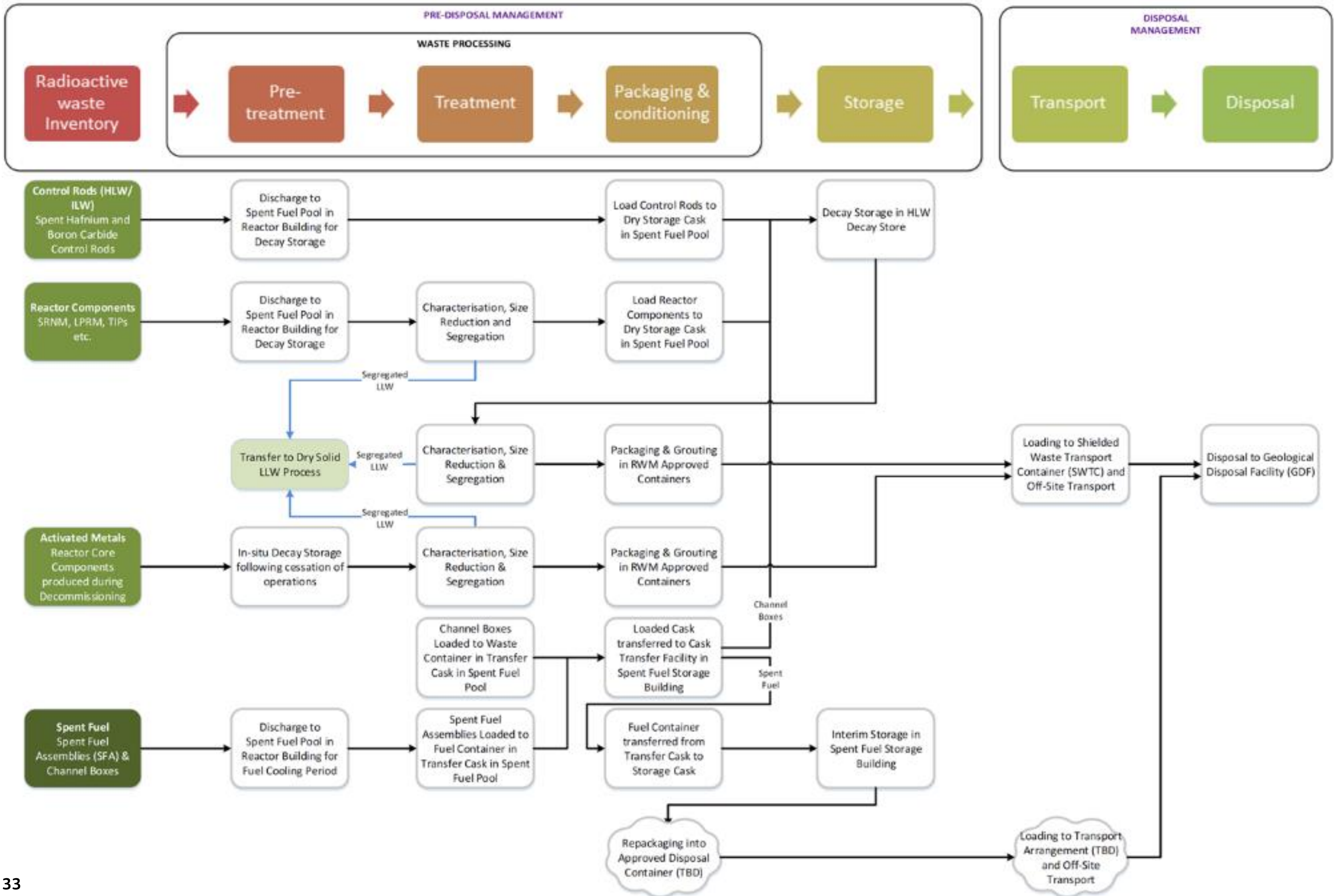
SECURITY CLASSIFICATION

1

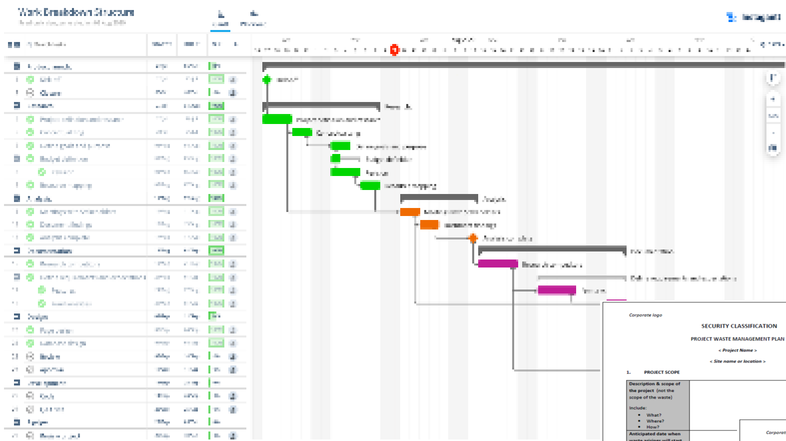
3) Integrated waste management strategy (IWS) at every site

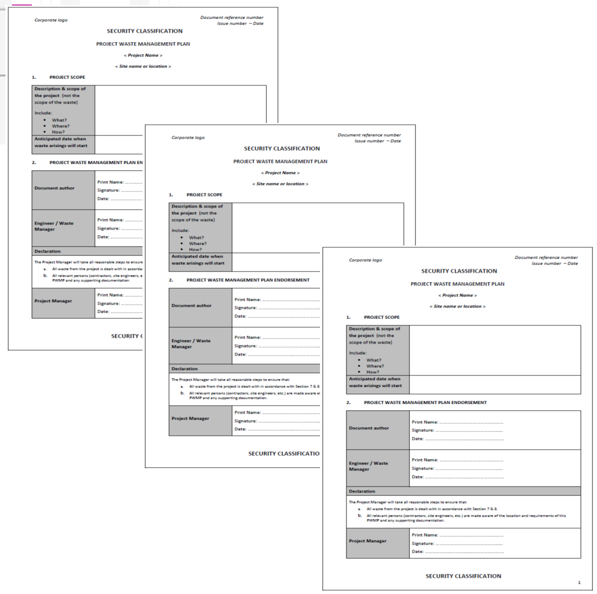
- Benefits from IWS:
  - reduce the overall cost and effort for waste management
  - reduce waste volumes / minimise need for disposal
  - optimise the waste plan for <u>all</u> wastes (avoid duplication)
  - identify dependencies and economies of scale
  - allow long-term planning / identify infrastructure requirements
  - increase regulator and stakeholder support
  - drive use of clearance & exemption and reuse and recycling options
- Described in IWS report and waste route-map
- Revised every 3 years to reflect new developments

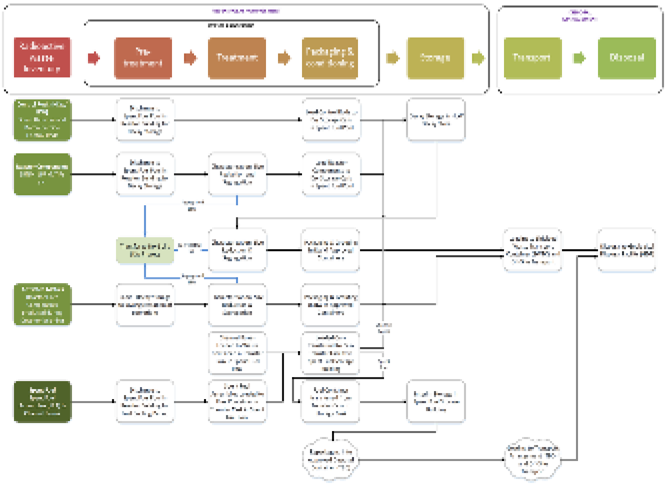



PRE-DISPOSAL MANAGEMENT
WASTE PROCESSING
DISPOSAL MANAGEMENT
Radioactive waste Inventory
Pre-treatment
Treatment
Packaging & conditioning
Storage
Transport
Disposal
Control Rods (HLW/ ILW) Spent Hafnium and Boron Carbide Control Rods
Discharge to Spent Fuel Pool in Reactor Building for Decay Storage
Load Control Rods to Dry Storage Cask in Spent Fuel Pool
Decay Storage in HLW Decay Store
Reactor Components SRNM, LPRM, TIPs etc.
Discharge to Spent Fuel Pool in Reactor Building for Decay Storage
Characterisation, Size Reduction and Segregation
Load Reactor Components to Dry Storage Cask in Spent Fuel Pool
Segregated LLW
Transfer to Dry Solid LLW Process
Segregated LLW
Characterisation, Size Reduction & Segregation
Packaging & Grouting in RWM Approved Containers
Loading to Shielded Waste Transport Container (SWTC) and Off-Site Transport
Disposal to Geological Disposal Facility (GDF)
Segregated LLW
Activated Metals Reactor Core Components produced during Decommissioning
In-situ Decay Storage following cessation of operations
Characterisation, Size Reduction & Segregation
Packaging & Grouting in RWM Approved Containers
Channel Boxes
Channel Boxes Loaded to Waste Container in Transfer Cask in Spent Fuel Pool
Loaded Cask transferred to Cask Transfer Facility in Spent Fuel Storage Building
Spent Fuel
Spent Fuel Spent Fuel Assemblies (SFA) & Channel Boxes
Discharge to Spent Fuel Pool in Reactor Building for Fuel Cooling Period
Spent Fuel Assemblies Loaded to Fuel Container in Transfer Cask in Spent Fuel Pool
Fuel Container transferred from Transfer Cask to Storage Cask
Interim Storage in Spent Fuel Storage Building
Repackaging into Approved Disposal Container (TBD)
Loading to Transport Arrangement (TBD) and Off-Site Transport

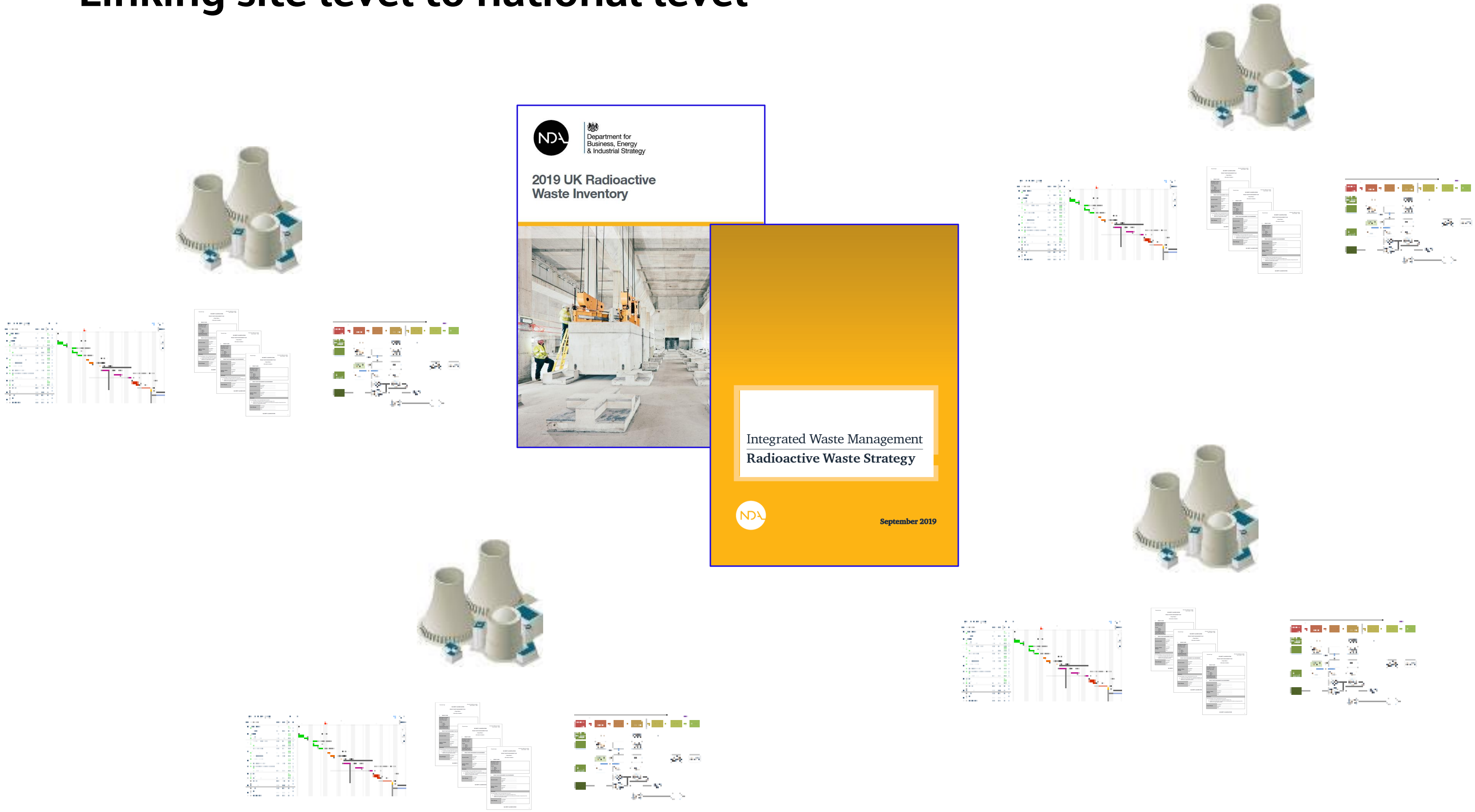
3) Decommissioning plan and integrated waste strategy at every site





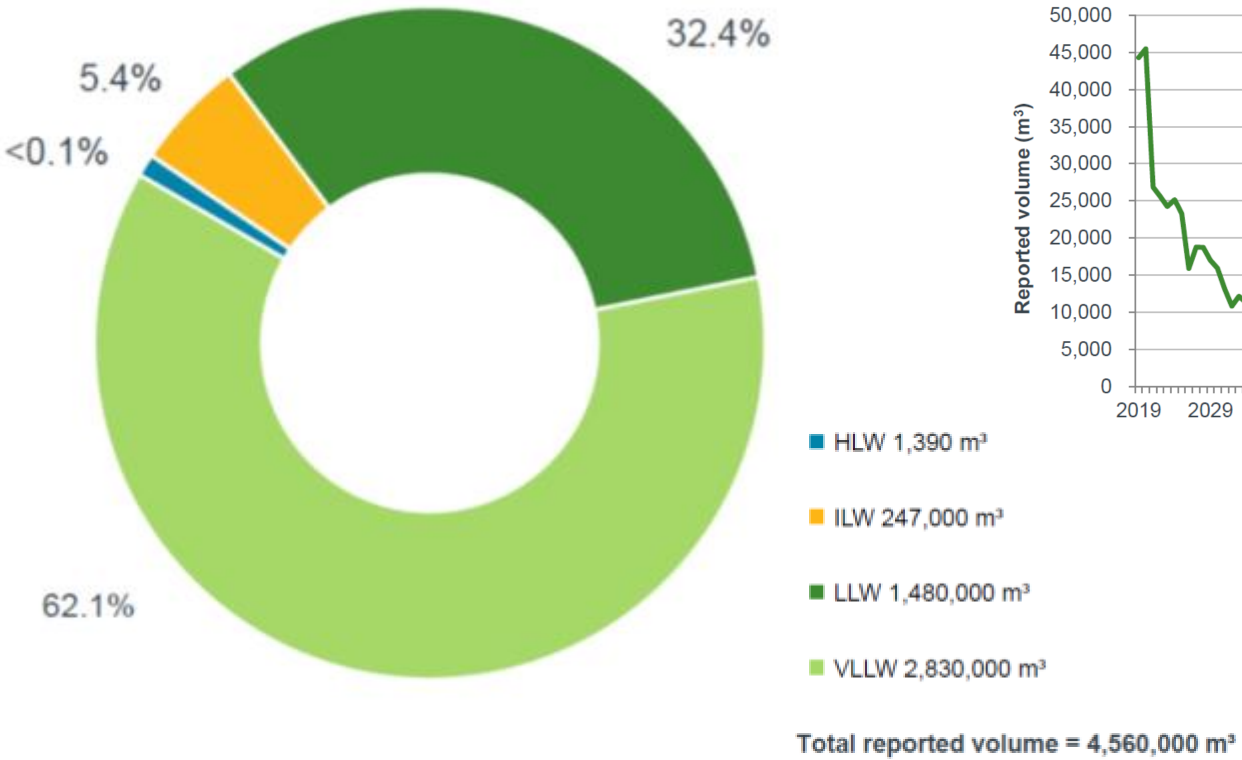


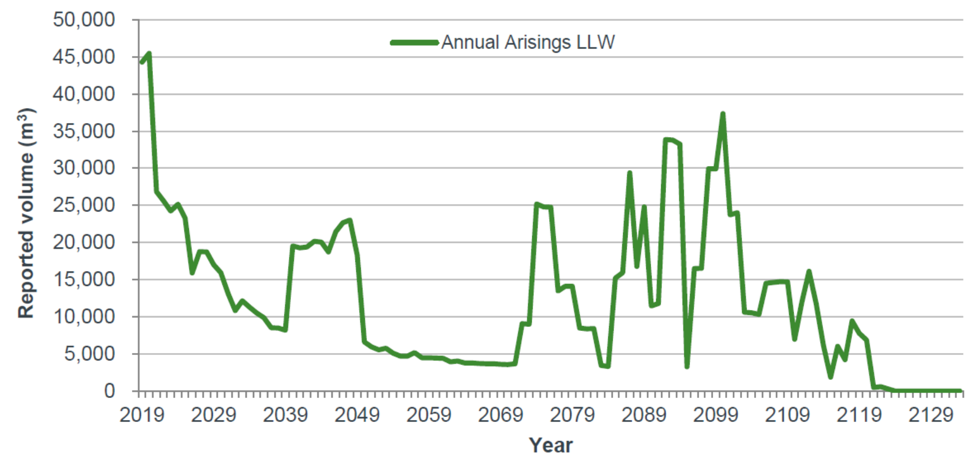
3) Integrated waste management strategy (IWS) at every site Linking site level to national level



4) New approaches to LLW and VLLW management

- LLW and VLLW presents a difficult waste management problem:
  - although low radiological hazard, exists in very large volumes
  - UK LLWR capacity is limited and Government does not want to build a new repository
  - waste is being generated now, so needs an immediate solution
  - but will continue to be generated over next 100 years



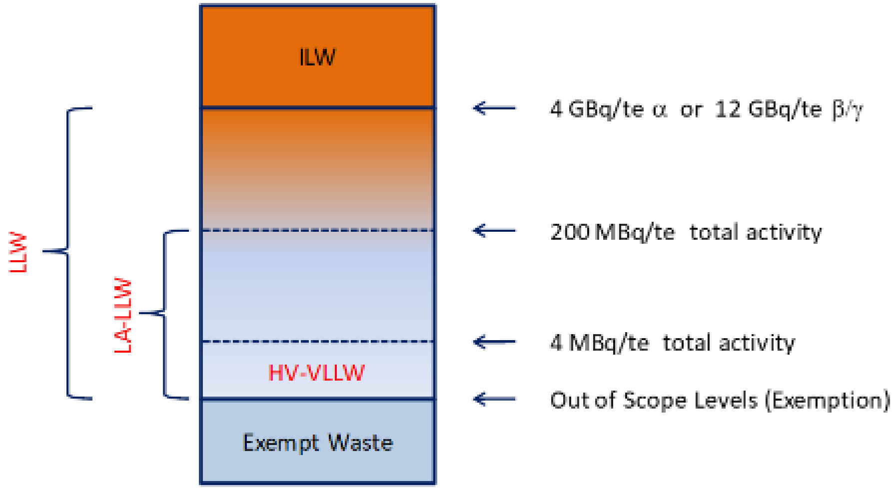


4) New approaches to LLW and VLLW management UK National LLW / VLLW Strategy

- National strategy is integrated plan for LLW from every UK site including industry, hospitals etc.
- Objective is to:
  - apply waste hierarchy
  - reduce volume disposed to LLWR
  - maximise clearance and recycling
  - find efficiencies and economies of scale
  - apply risk-based approach to disposal
- Strategy developed by Government but implemented through a collaboration between:
  - NDA
  - regulators
  - waste producers
  - waste management companies
- Updated every 3 years to reflect changes in site decommissioning plans or developments in technology etc.

4) New approaches to LLW and VLLW management Co-disposal of VLLW and industrial wastes to landfill

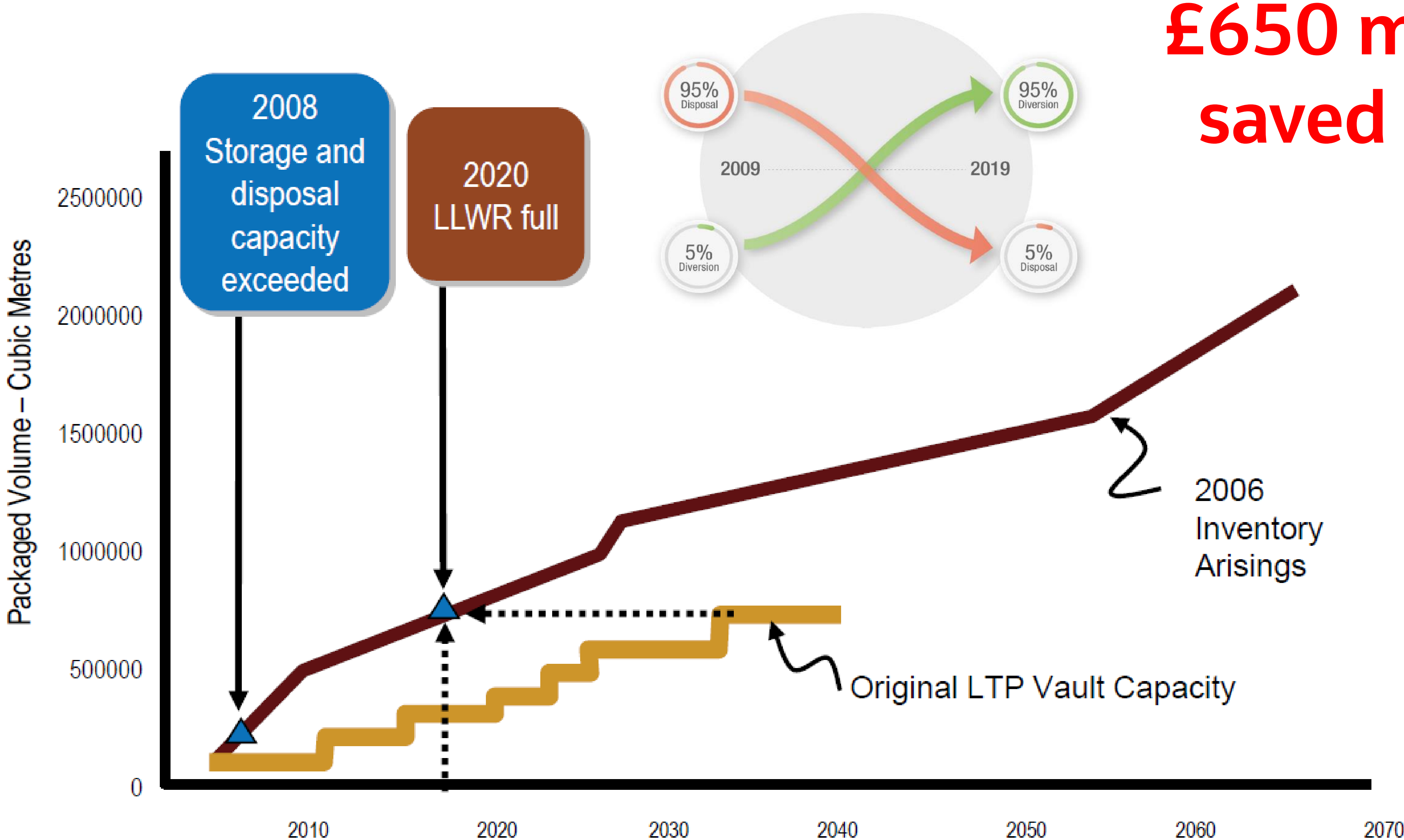
- One of the main changes in strategy is to allow VLLW to be disposed to commercially operated industrial landfills
- Apply the standard UK risk-based radiological risk constraint of 10^{-6}
- Maximum activity of 200 MBq/te



4) New approaches to LLW and VLLW management Increased use of clearance and recycling

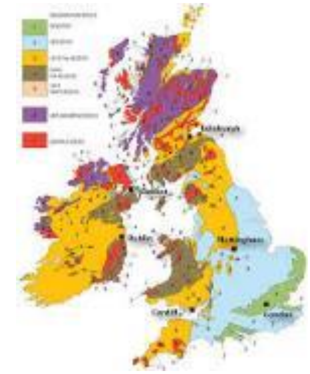
4) New approaches to LLW and VLLW management
Benefits of the LLW strategy

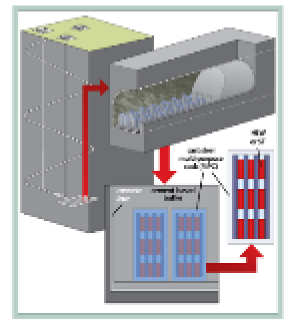
£650 m saved

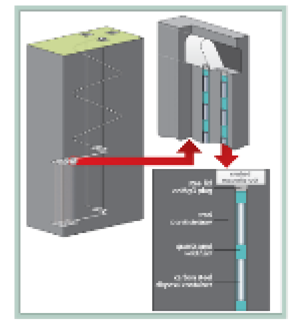


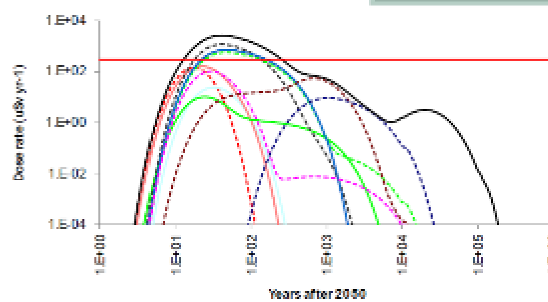
5) Disposability assessment for ILW

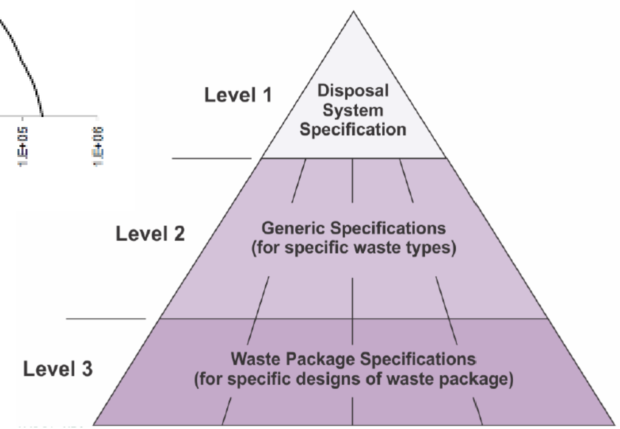
- Standard practice is not to treat wastes until a repository is available
- But that may be 50 years away, so need to treat wastes now to make safe
- Disposability assessment involves making sensible assumptions for repository design and site conditions to calculate its *safety envelope*
- This means criteria for treatment and packages can be developed
- There is project risk but it can be managed by making reasonable assumptions











Progress to 2019

Since it was established in 2005, the NDA has made excellent progress in dealing with some of the most complex nuclear risks in the world. Two of our strategic outcomes (see timeline below) have been achieved and good progress is being made with the safe management of nuclear inventory and reduction of its risks.

More strategic outcomes will be achieved with the closure of the reprocessing facilities at Sellafield and the building of new modern treatment and storage facilities to manage nuclear material and waste - ultimately working towards the final disposal of nuclear inventory and the release of land for other economic uses.

> "Our mission will be complete when we release our sites for other uses."
>
> NDA Strategy effective from April 2016, p19

953 hectares remaining

1,046 hectares of designated land on nuclear licensed sites for clean up under the Energy Act 2004

PROGRESS AGAINST STRATEGIC OUTCOMES

SPENT FUELS

ALL SITES DEFUELED OF MAGNOX FUEL	95%
ALL MAGNOX FUEL REPROCESSING COMPLETED	88%
ALL EXOTIC FUEL CONSOLIDATION COMPLETED	34%
ALL EXOTIC FUEL DEFUELED	43%

NUCLEAR MATERIALS

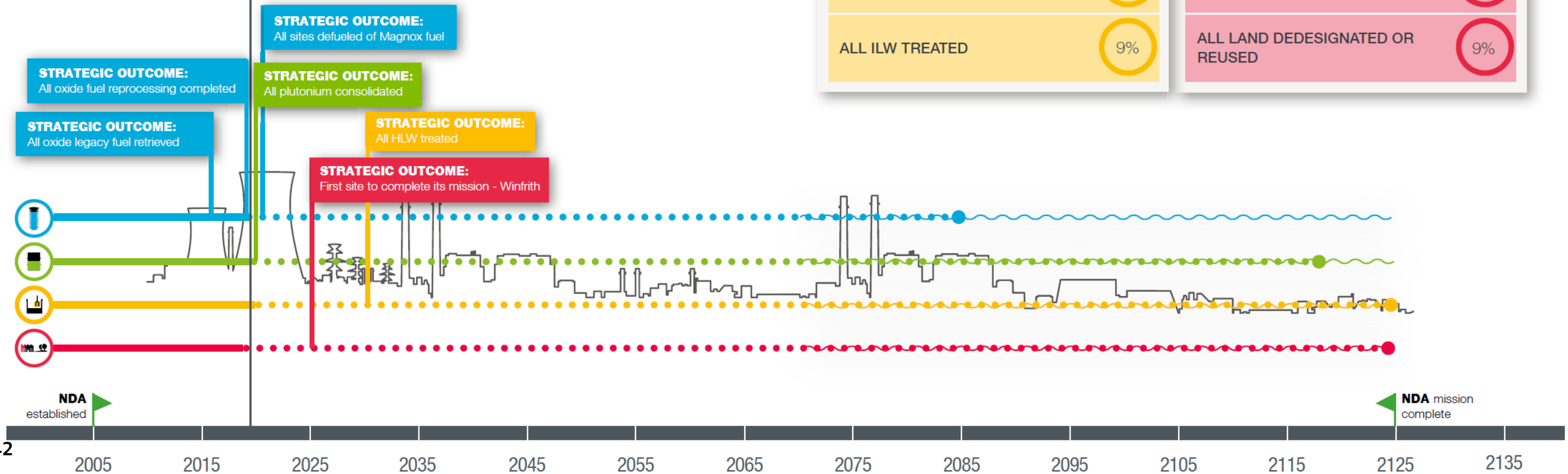
ALL PLUTONIUM PRODUCED	95%
ALL PLUTONIUM CONSOLIDATED	80%
ALL URANIUM PRODUCED	86%
ALL URANIUM CONSOLIDATED	86%

INTEGRATED WASTE MANAGEMENT

ALL HLW TREATED	70%
ALL HLW IN INTERIM STORAGE	80%
ALL WASTE REMOVED FROM LEGACY PONDS AND SILOS	6%
ALL ILW TREATED	9%

SITE DECOMMISSIONING & REMEDIATION

ALL RADIOACTIVE BUILDINGS - COMPLETED PRIMARY FUNCTION	46%
ALL RADIOACTIVE BUILDINGS - COMPLETED DECOMMISSIONING	26%
ALL RADIOACTIVE BUILDINGS - DEMOLISHED OR REUSED	23%
ALL LAND DEDESIGNATED OR REUSED	9%



The final slide – some lessons learned and suggestions for you

- Put waste at the centre of your decommissioning planning process
- Define the problem – site end-states, waste characterisation and inventory are key
- A national integrated waste strategy may bring efficiencies and economies of scale
- Disposal facilities are valuable – do not dispose what you don't have to
- Allow for flexibility with multiple treatment and disposal routes
- If you can, take a risk and treat some wastes before a repository is available
- Identify good practices and make them easy to do
- Work closely regulators, industry and supply chain - it should be a collaboration
- Always seek opportunities for continuous improvement. Keep learning !!

Thank you for listening.

If you have any comments or questions, please feel free to contact me at any time.

Bill Miller　　ビル・ミラー

bill.miller@jacobs.com