



The IAEA Nuclear Energy Management School  
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# Radioactive Waste Management

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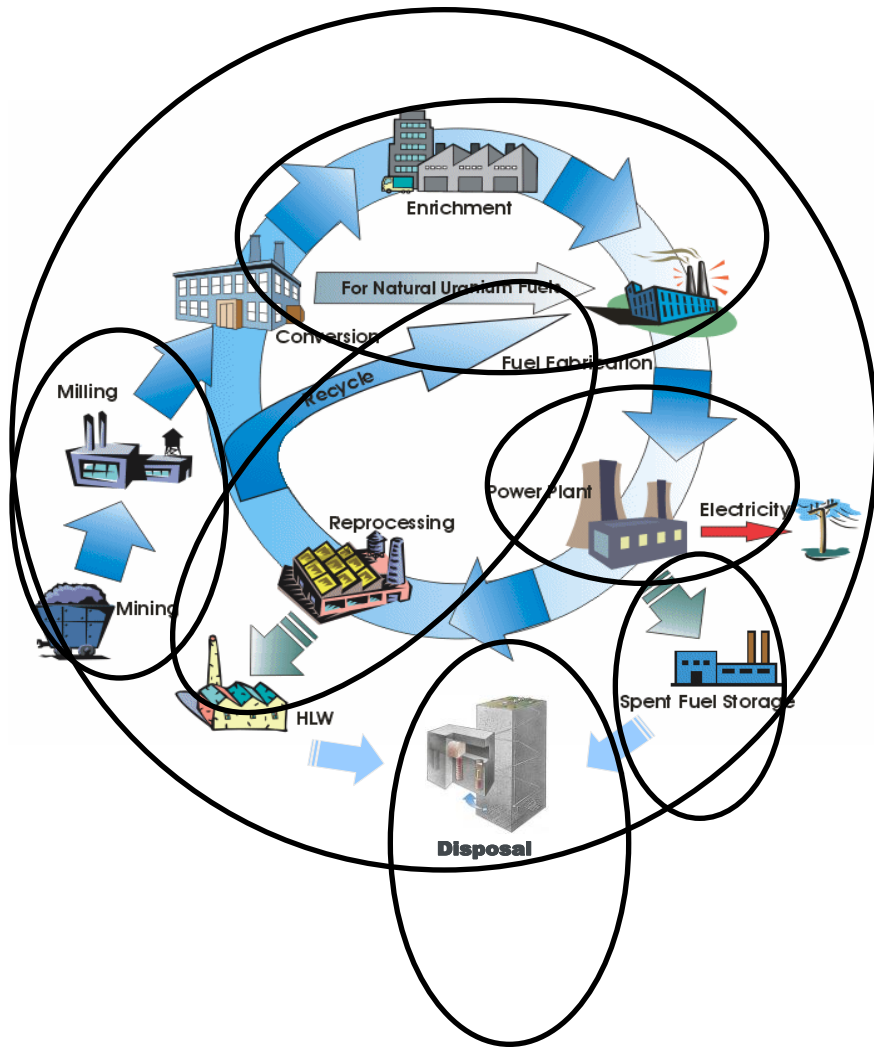
# Content

- About RWM (principles and goals)
- Policies and strategies for RWM
- Options and technologies for RWM
  - Predisposal phase (L/ILW)
  - Disposal (L/ILW)
  - Spent Fuel (SF) disposal
- IAEA role and activities
- Conclusions

# What is radioactive waste?

- Waste is material for which no further use is foreseen
- The waste can be in gaseous, liquid or solid form.
- Radioactive waste is a waste that contains or is contaminated with, radionuclides at concentrations equal to or higher than clearance levels established by the regulatory body (definition for legal and regulatory purposes)

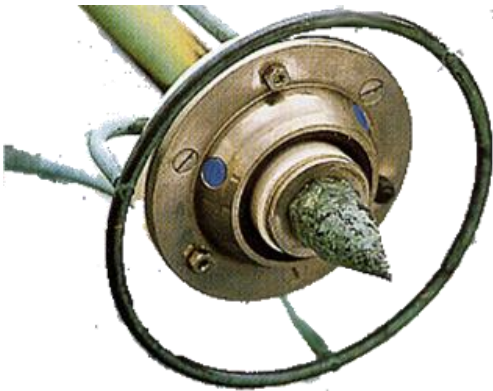
# Nuclear Fuel Cycle and Waste



- Uranium production
- Fuel fabrication
- Power production
- Spent fuel storage
- Spent fuel recycle
- Decommissioning of facilities
- Environmental remediation activities

# Non-Nuclear Fuel Cycle Waste

- Application of radioactive material in medicine, industry, agriculture and research
- Research reactors
- Non-nuclear industry (mining of ores, oil industry, phosphate industry, etc.)



Lightning conductor



Radioisotope thermoelectric generator - RTG



Teletherapy machine

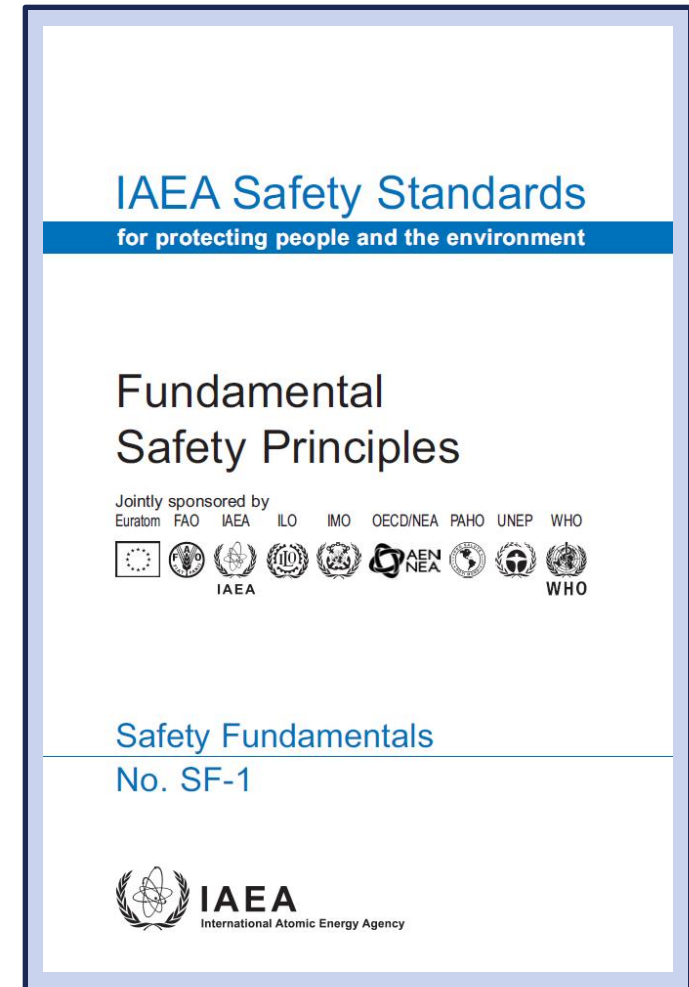
# RWM Needed in Many Countries

- 30 countries with NPP
- Between ~ 7 – 15 newcomers by 2030
- Majority of MSs using radioactive sources
- All these countries have or will have radioactive waste and need solutions for this waste
- Development of RWM infrastructure is particularly challenging for:
  - small nuclear programmes,
  - countries with nuclear applications only and
  - newcomer countries



# Radioactive Waste management (RWM)

- All activities, administrative and operational, that are involved in the handling, pretreatment, treatment, conditioning, transport, storage and disposal of radioactive waste
- The primary Goal of RWM is to protect people and the environment from the harmful effects of ionizing radiation, now and in the future and without an undue burden on following generations



# Policies and Strategies for RWM



# What is needed for consistent RWM?

- Adequate legislative and regulatory framework for RWM and SFM
- Adequate RWM system
  - Clear allocation of responsibilities for RWM
  - Necessary capabilities (facilities, human resources)
  - System for financing RWM



National RWM policy



RWM Strategy

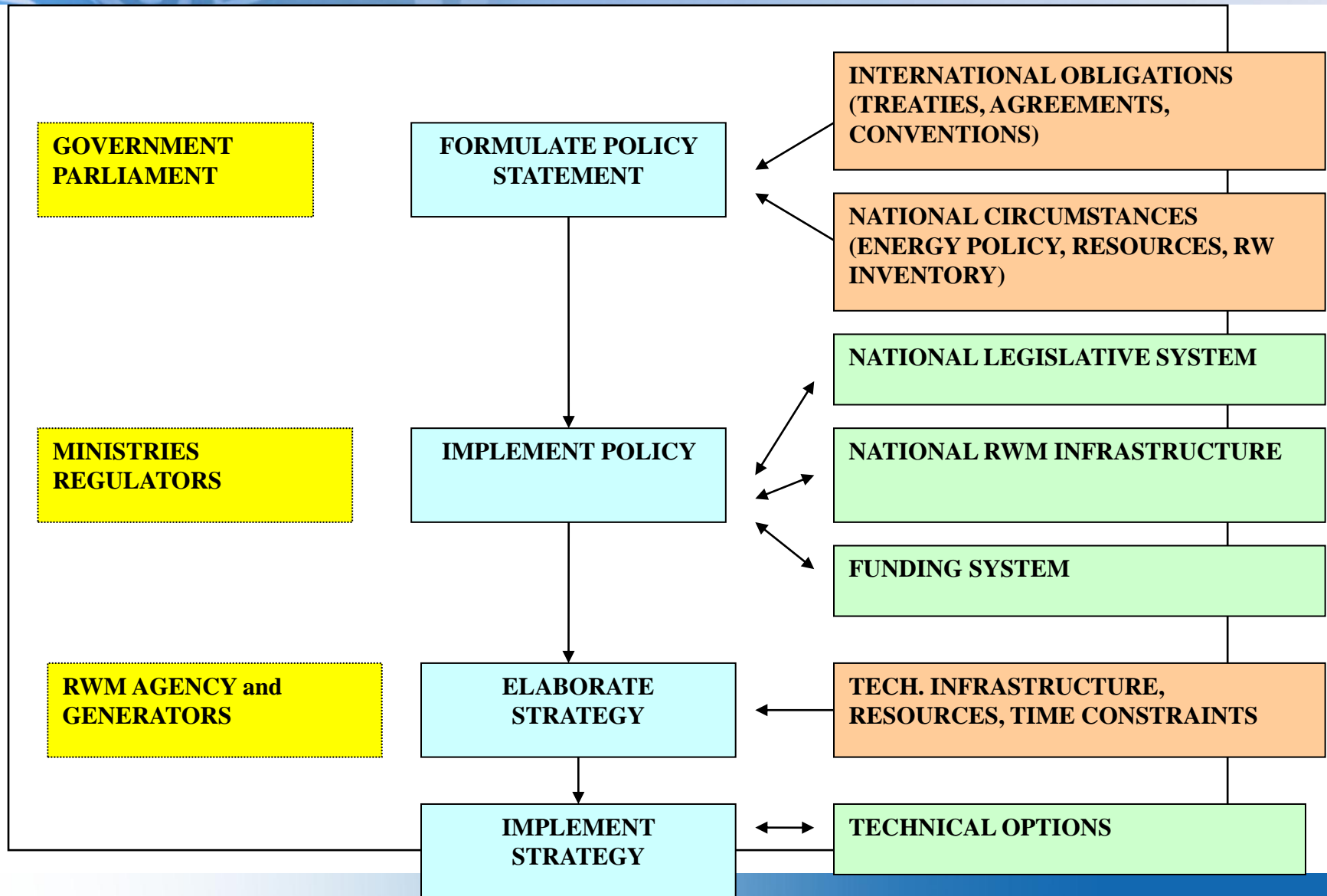
# What is RWM policy?

- Policy is a set of established goals or requirements which normally define national rules and responsibilities
- Policy is established by the national government
- Policy:
  - Is often codified in the national legislative system
  - provides principles, infrastructure and formal requirement for its implementation and
  - provides principles, infrastructure and formal requirement for the development of appropriate strategies

# What is RWM strategy?

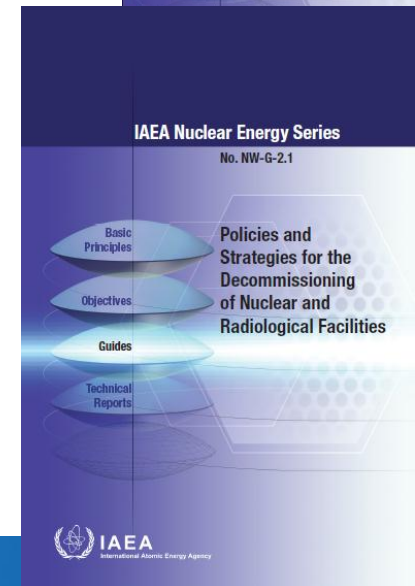
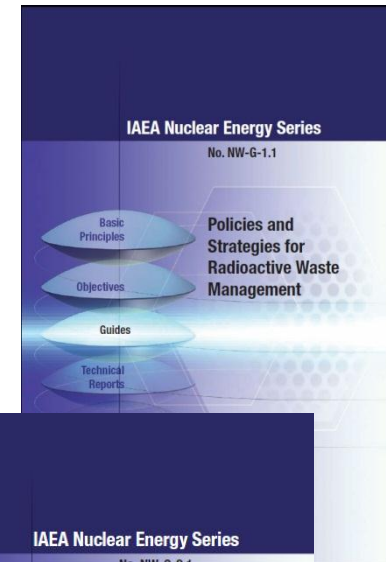
- Strategy is the means (organizational, technical) for achieving the goals and requirements set out in the national policy
- Strategy:
  - Is formulated from a national perspective, usually by waste management organization
  - More than one strategy may be developed to cover the goals and requirements of the national policy
  - The individual strategies may address different types of waste (e.g. reactor waste, decommissioning waste, institutional waste, etc.) or waste belonging to different owners
- The line separating policy from strategy is not sharp and sometimes mixtures exist

# Policy & strategy scheme



# RWM Policies and Strategies

- Policies & strategies needed for:
  - countries with existing nuclear programmes
  - countries with only nuclear applications
  - in countries embarking on nuclear
- IAEA guidance document:
  - Policies and Strategies for RWM, (NE Series, 2009)
  - Policies and Strategies for decommissioning of nuclear and radiological facilities, (NE Series, 2011)
  - Policies and Strategies in ER (in preparation)



# Main Policy elements

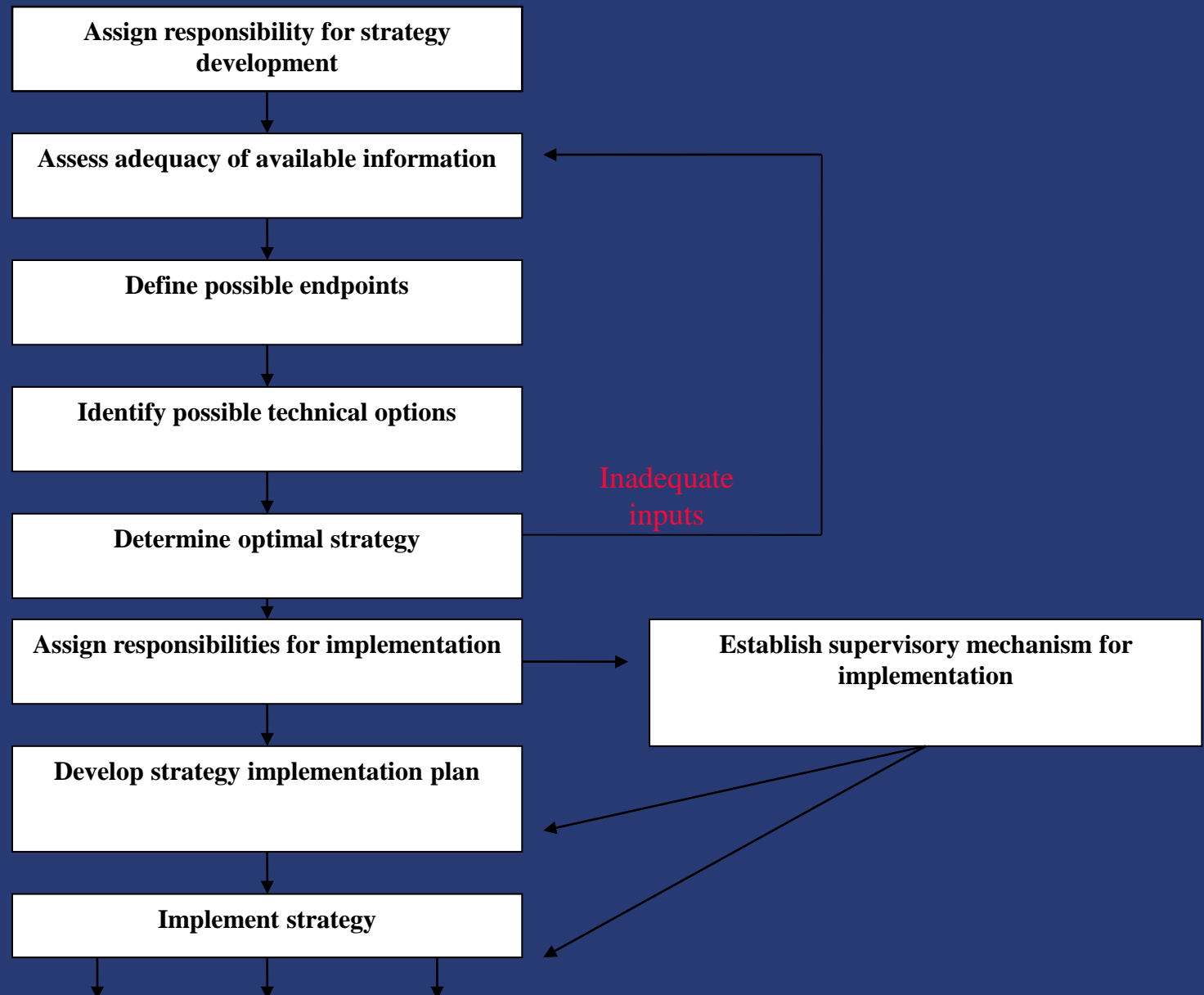
- Allocation of responsibilities (legislation, regulatory body, WMO)
- Provision of resources (human and financial)
- Safety and security objectives
- Waste minimization (recycling, clearance concept)
- Export/import of radioactive waste
- Management of spent fuel
- Management of radioactive waste (incl. disuses sealed sources, NORM?)
- Public information and participation



# Strategy development

- The following considerations are important when developing the strategy:
  - Strategic approaches (recycling, immediate or deferred disposal, multinational facilities)
  - Compliance with policy (waste recycling, clearance, environmental protection, export/import, SF as a resource or waste, return of disused sources, NORM waste,...)
  - Graded approach
  - Resources (financial, human, technical)
  - Generic technical options (shared, centralised, mobile facilities)
  - Country specifics (population, climate, neighbours)
  - Constraints on strategy selection (non- and nuclear)
  - Public sensitivity
  - Uncertainties

# Strategy formulation and implementation



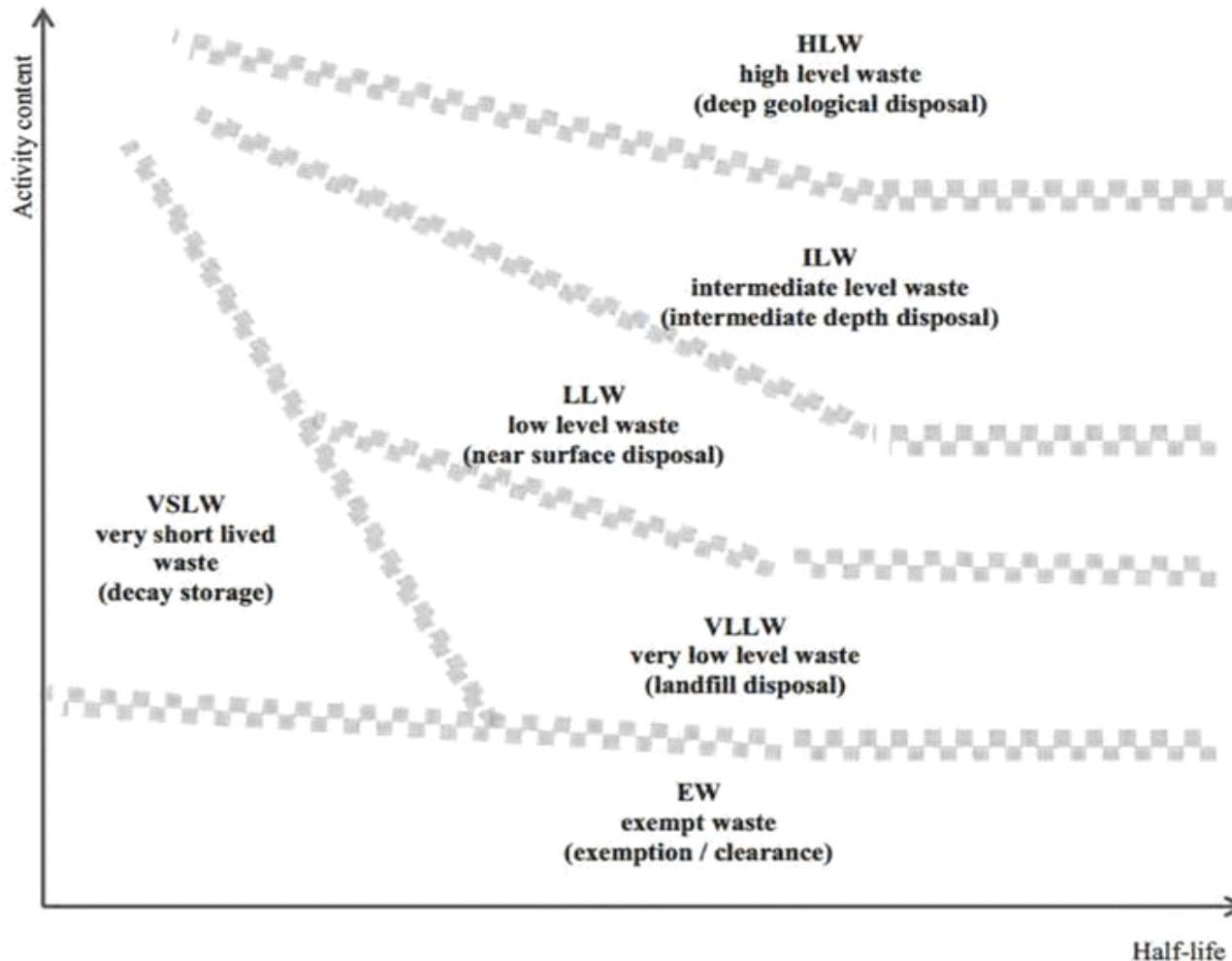
# Options and Technologies for RWM

# Approaches for managing radioactive waste

- Delay and decay
  - Waste stored until desired reduction of activity
- Collect and contain
  - Waste collected, processed, packed, stored and finally disposed of (isolation of waste)
- Dilute and disperse
  - Discharging of effluents with strict concentration and quantity limitations



# IAEA Classification of RW



IAEA Safety Standards

for protecting people and the environment

Classification of  
Radioactive Waste

General Safety Guide

No. GSG-1





# Examples of LLW, ILW & HLW



LLW includes loosely contaminated materials (e.g. paper, rags, tools, clothing, filters). Generally the waste does not require significant shielding during handling and interim storage



ILW includes e.g. resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. The waste has levels of penetrating radiation sufficient enough to require shielding during handling and interim storage.

SNF/HLW includes the fission products and transuranic elements in the fuel itself or arising from reprocessing (e.g. spent fuel bundles, liquors). It generates significant heat and requires substantial shielding





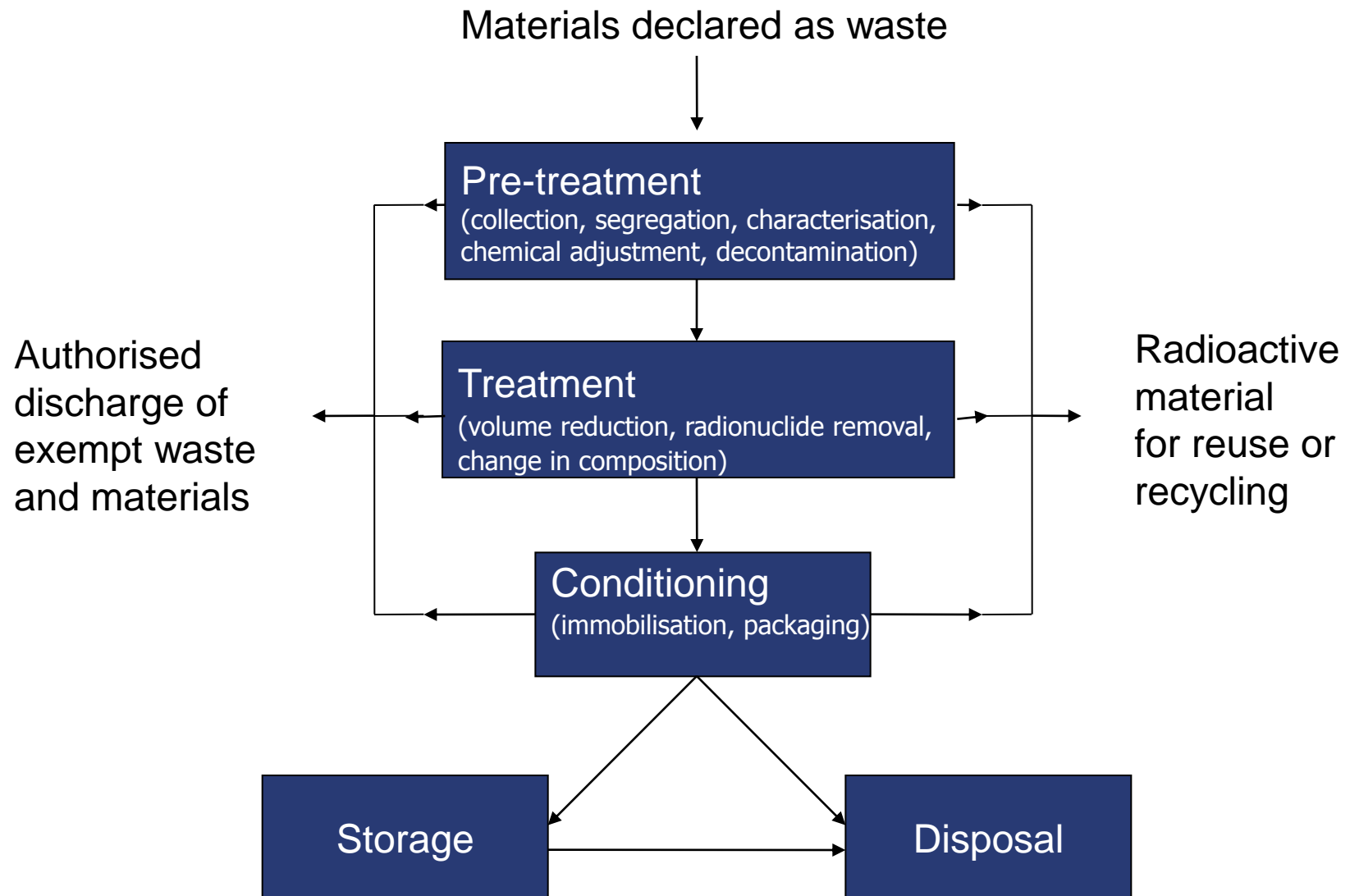
# Selection of RWM Options

- Key Technical and technological criteria
  - Waste characteristics
  - Scale of technology application (now and in the future)
  - Availability of technology, flexibility
  - Robustness of technology
  - Treated and conditioned product properties
  - Volume reduction
  - Complexity; maintenance
  - Compatibility with existing processes
  - Site availability, geological conditions

# Selection of RWM Options

- Key Non-technical factors
  - Adequacy of the national waste management system
  - National policy and strategy
  - Compliance with regulations
  - Available infrastructure, interrelations of WM steps
  - Manpower and competency
  - Resources
  - Socio-political situation
  - Potential international co-operation
  - Financial and practical feasibility
  - Cost efficiency

# The Basic Steps in RWM





RWM prior the disposal

# Predisposal steps and options

| CHARACTERIZATION |         | TREATMENT          |                    |                            | CONDITIONING   |
|------------------|---------|--------------------|--------------------|----------------------------|----------------|
| LL               | Liquid  | LIQUID WASTE       | SOLID WASTE        | GASEOUS WASTE              | Cementation    |
| IL               | Solid   | Chemical Treatment | Compaction         | Scrubbing                  | Polymerisation |
|                  |         | Ion Exchange       | Incineration       | Adsorption/Absorption      | Bituminisation |
| HL               | Gaseous | Reverse Osmosis    | Size Fragmentation | Prefiltration              | Vitrification  |
|                  |         | Evaporation        | Repackaging        | High Efficiency Filtration |                |

In most cases packaging will be required for shielding, confinement and/or for handling purposes

# Pretreatment



Waste  
collection



Checking for  
contamination



Segregation of  
waste



Sorting of waste



# Treatment by Compaction



Low pressure in-drum  
compactor



High pressure drum compactor (super-compactor)



# Conditioning of Waste

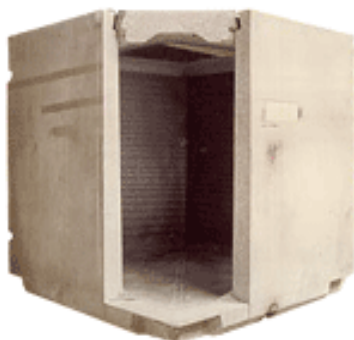


In-drum cementation facility

# Waste Packaging



**CYLINDRICAL  
CONTAINERS**



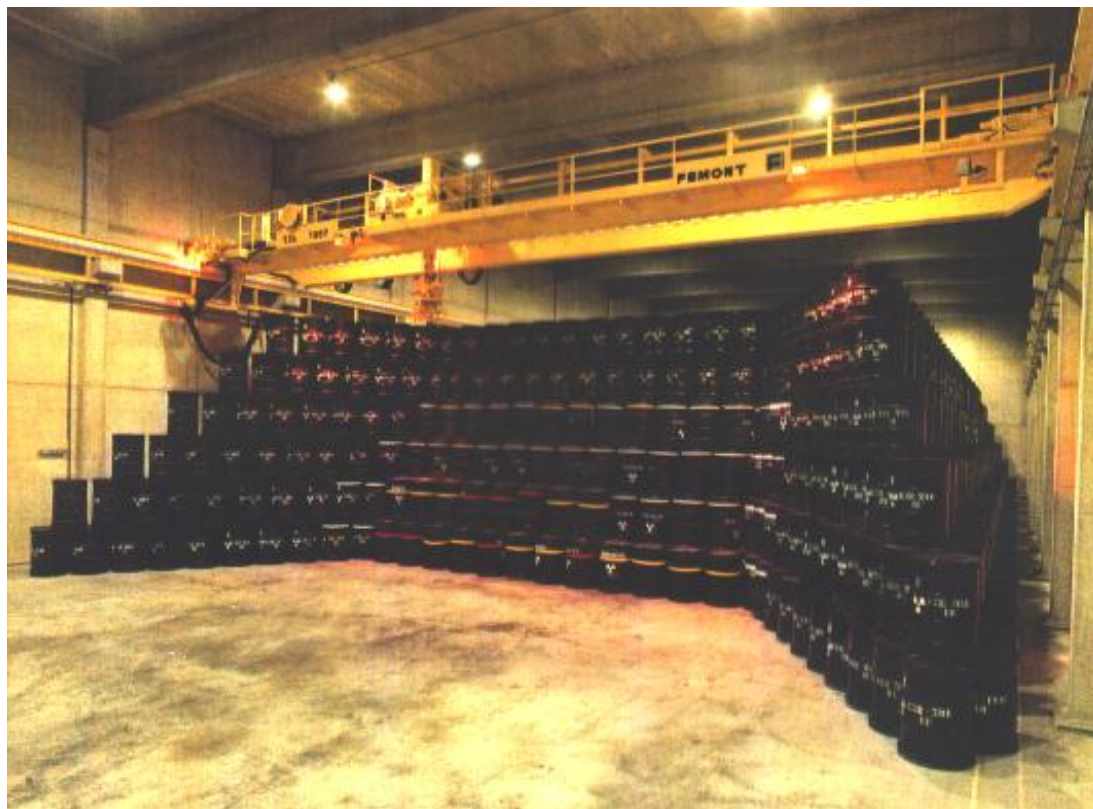
**CUBICAL  
CONTAINERS**



Transport of concrete container



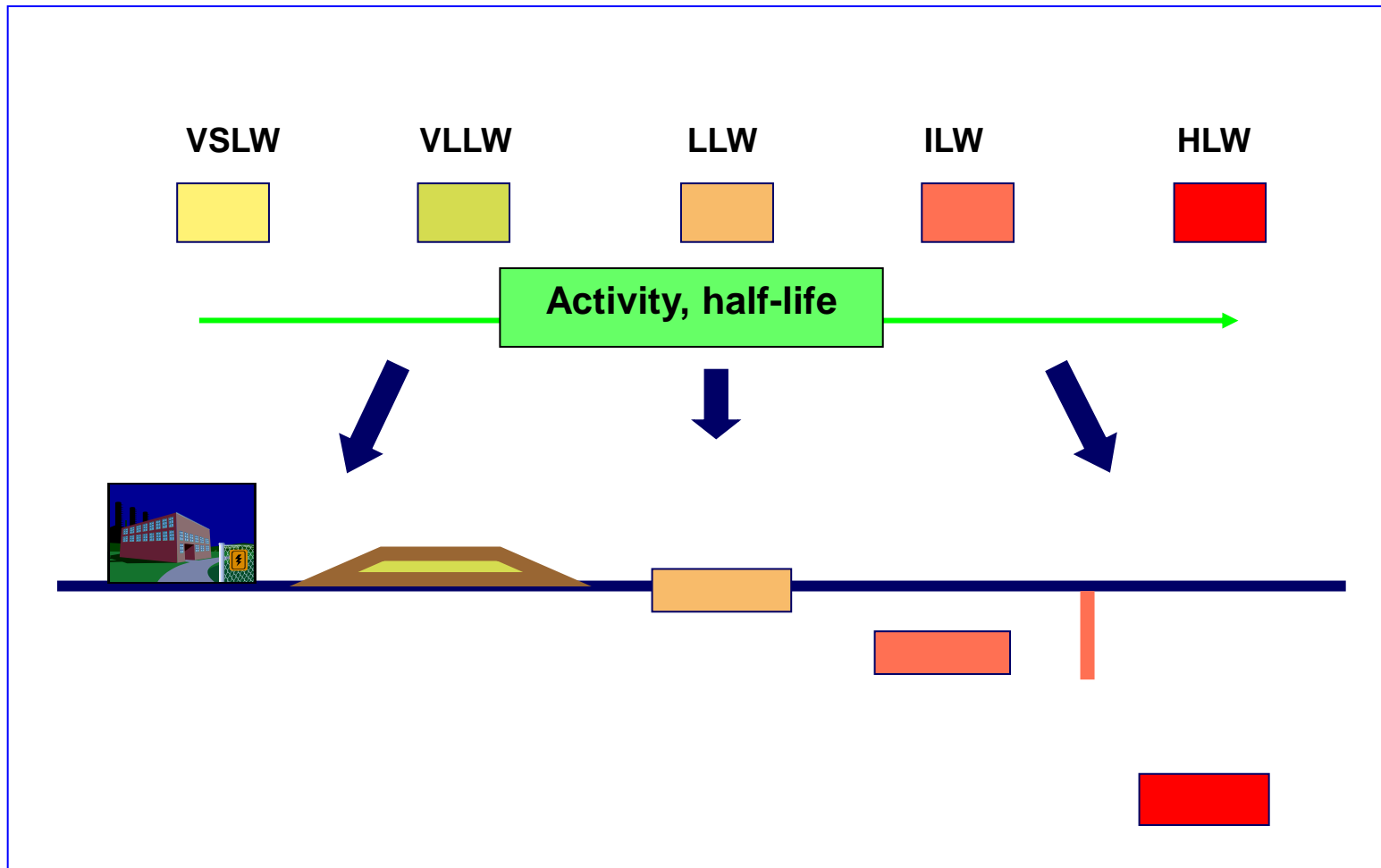
# Storage of Waste





# Disposal

# Disposal options





# Disposal of LLW

- Disposal facilities for LLW successfully operating in many countries
- Different types of repositories: surface, near surface and underground (geological)
- But many nuclear and non-nuclear countries still need to develop repositories

**EUROPE:** (Belgium); Bulgaria; Czech R.; Finland; France; (Germany); Hungary; Latvia; Lithuania; Norway; Poland; Romania; Russian F.; Slovakia; (Slovenia); Spain; Sweden; (Switzerland); Ukraine; United Kingdom

**AFRICA:** (Egypt); (Ghana); South Africa

**AMERICAS:** (Argentina); (Brazil); (Canada); (Chile); Mexico; (Peru); United States of America

**ASIA and the PACIFIC:** (Australia); China; India; (Iran); (Iraq); Japan; (Jordan); (Rep. of Korea); (Malaysia); (Pakistan); (Philippines)

# Disposal of VLLW

- For very low level waste disposal in trenches
- VLLW repositories in operation in France and Spain





# Surface disposal of LLW



# Disposal in Trenches

## LLW Disposal in Richland, Washington





# LLW in Vaalputs, South Africa



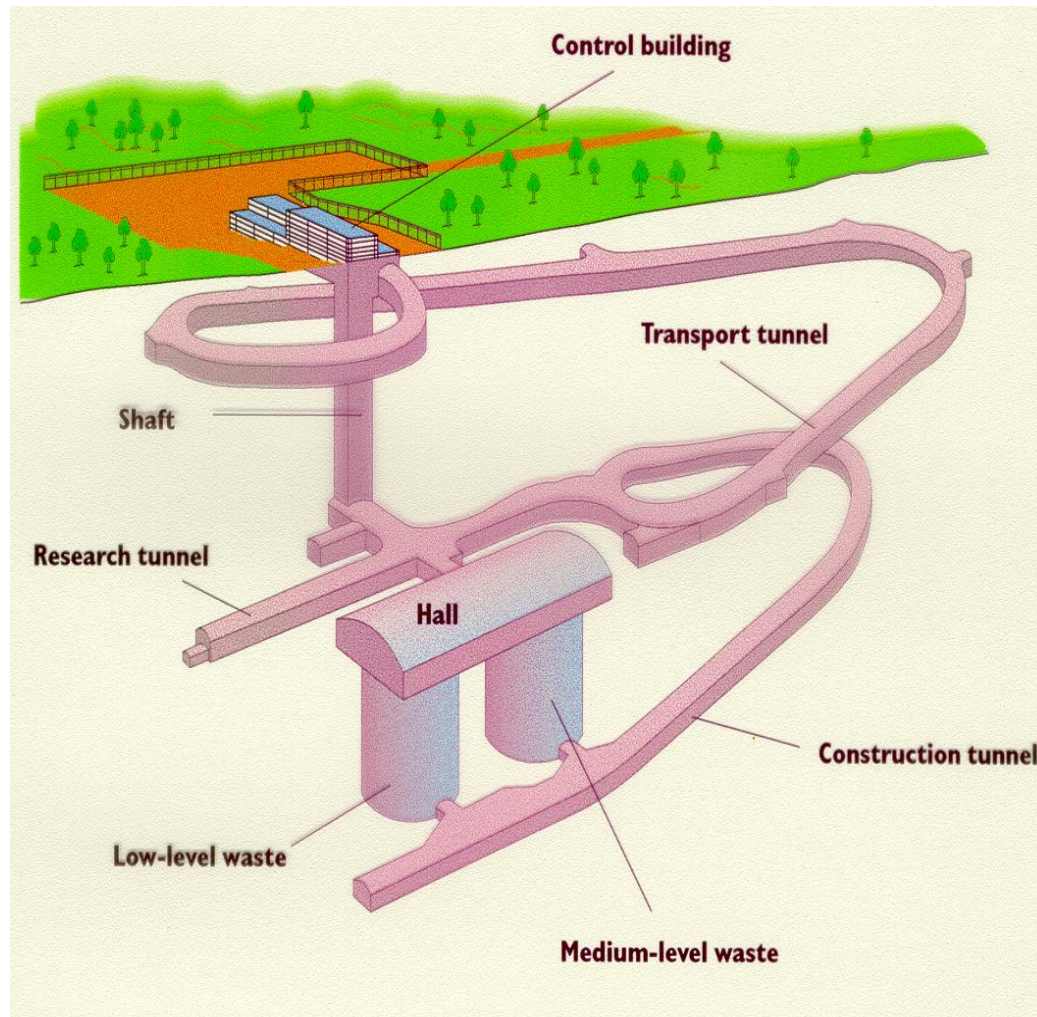
# Surface disposal in Japan



Rokkasho



# L/ILW disposal in Olkiluoto





# L/ILW in SFR Forsmark



# Surface disposal in France

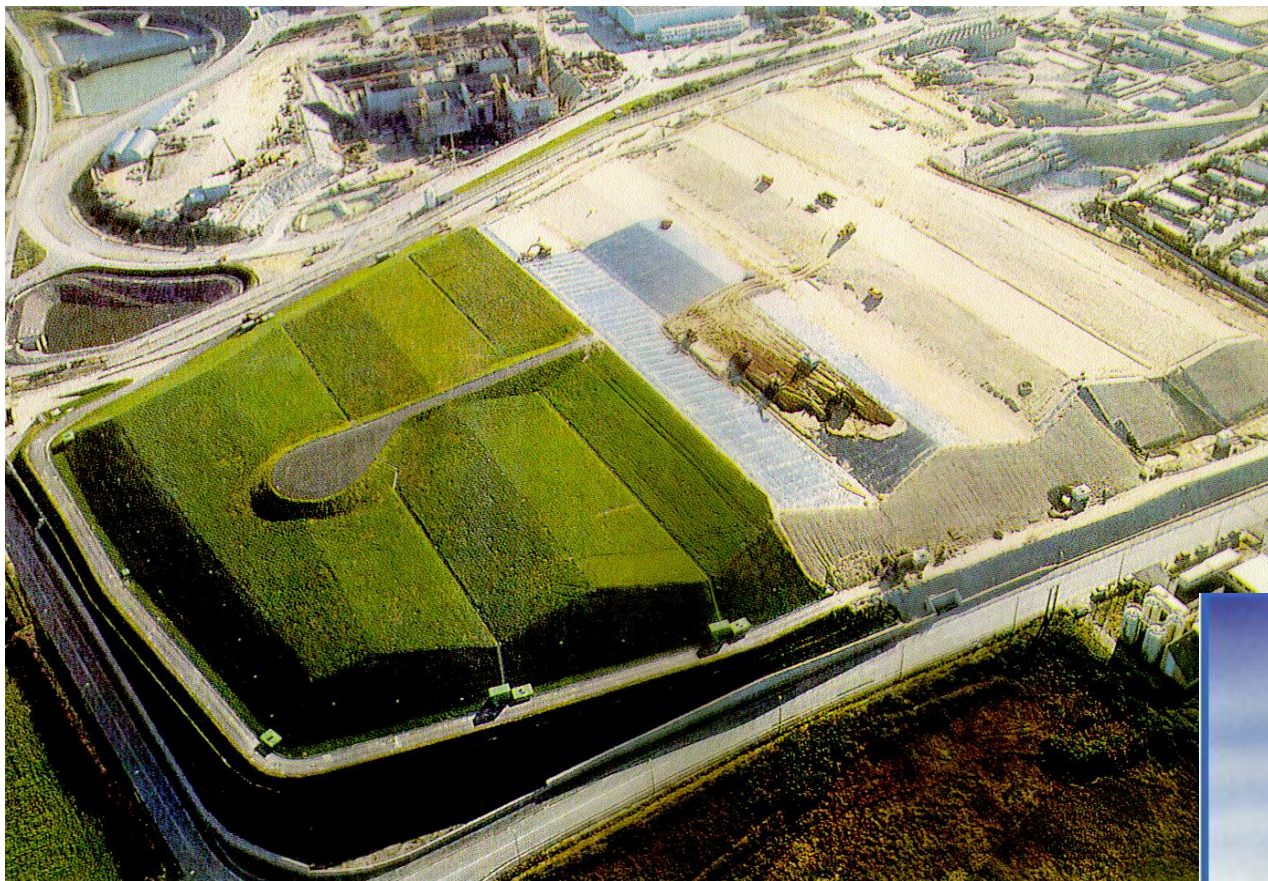


Centre de l'Aube





# Centre de la Manche, France



Closure of the repository





# Non-heat generating waste in Morsleben



Morsleben



# Non-heat generating waste in Konrad



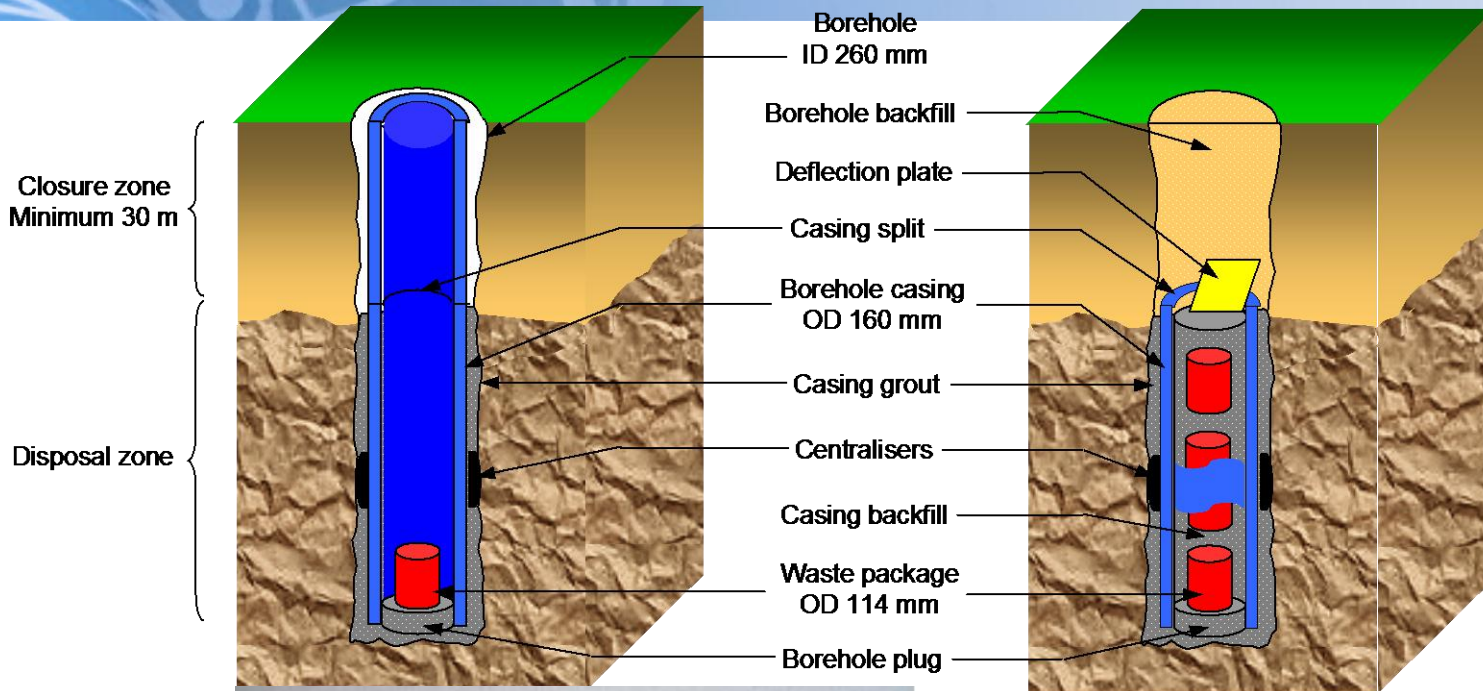
Konrad, Germany

# Disposal of TRU waste in WIPP, USA





# Concept of Borehole Disposal



For small volumes of waste (DSRS)

Simple technology

Cost effective



South Africa Demo



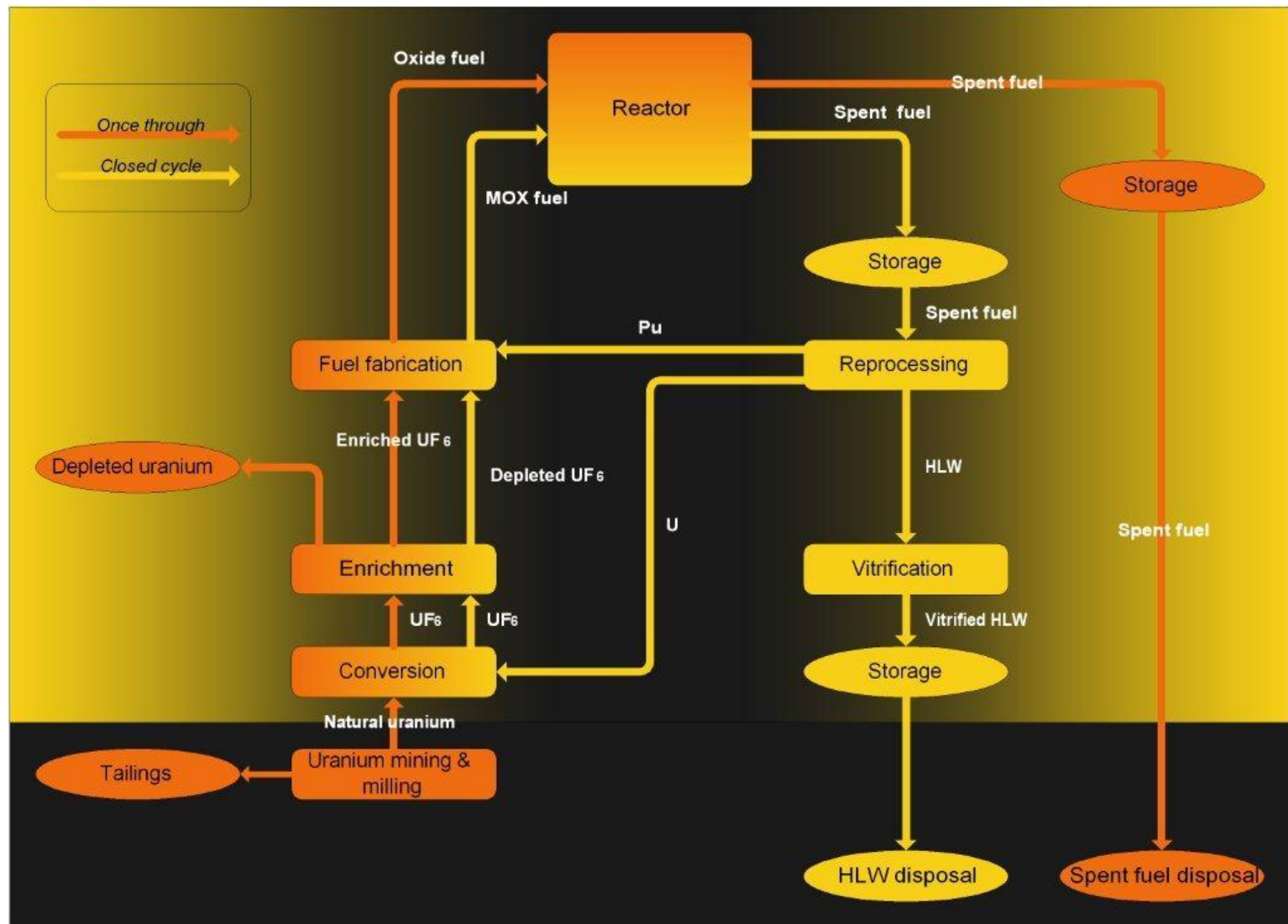


# Spent Fuel and HLW Disposal

# Basic options for SF management

- Once-through cycle – spent fuel stored and then disposed of → Direct disposal of SF
- Closed fuel cycle – reprocess SNF, Pu + U recycled and waste disposed of → Disposal of HLW and L/ILW from reprocessing

# The Nuclear Fuel Cycle



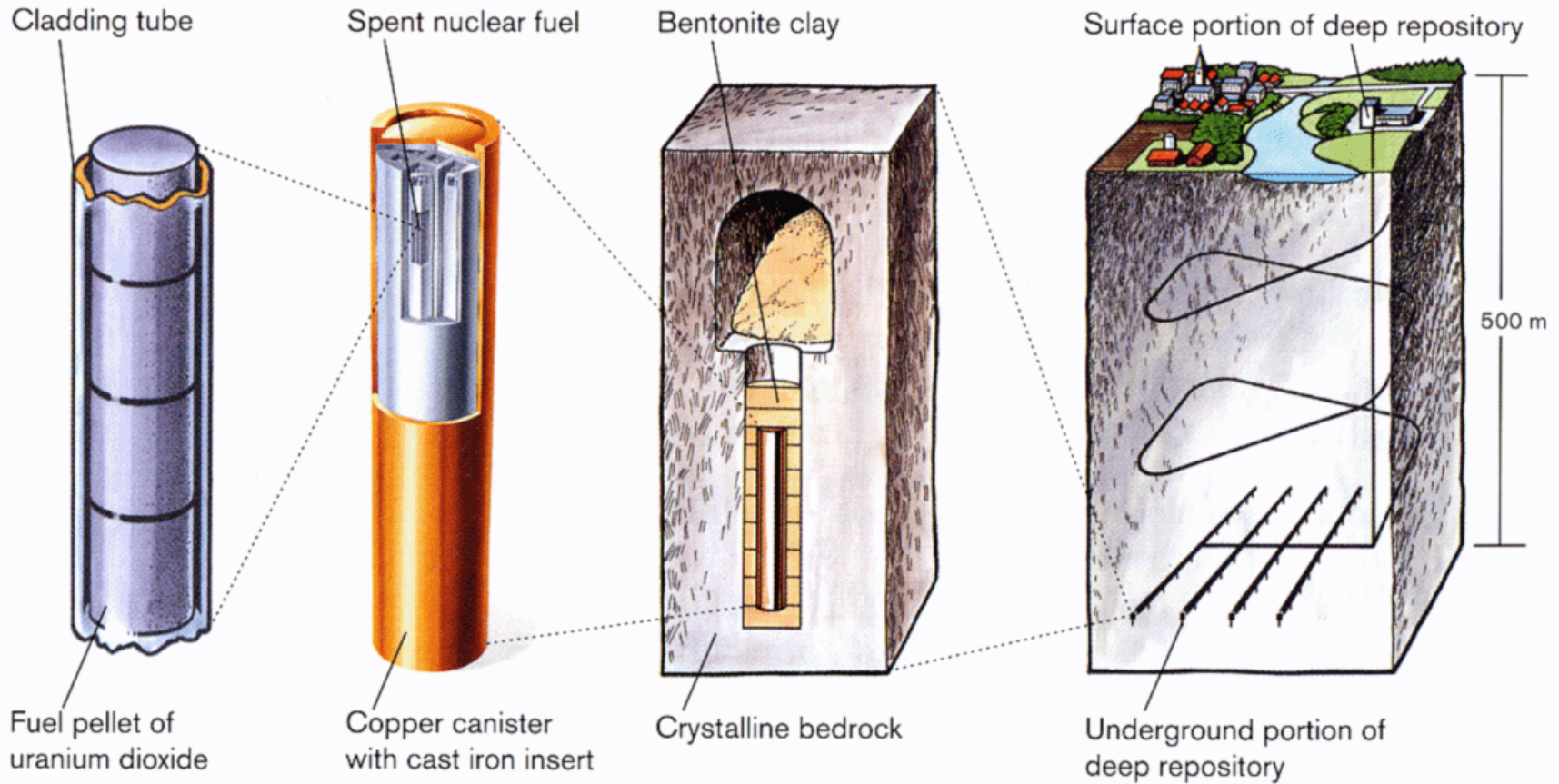
# Comparison: once-through – closed fuel cycle

|                           | Once-through cycle<br>(for 1 GW year) | Closed fuel cycle<br>(for 1 GW year)  |
|---------------------------|---------------------------------------|---|
| U-ore extraction          | 205 t                                 | 130 t   |
| Tailings                  | 58 000 m <sup>3</sup>                 | 38 000 m <sup>3</sup>   |
| Conversion and enrichment | 30 m <sup>3</sup> L/ILW               | 20 m <sup>3</sup> L/ILW   |
| Fuel production           | 40 m <sup>3</sup> L/ILW (long-lived)  | 25 m <sup>3</sup> L/ILW (long-lived)  |
| Production of MOX fuel    | -                                     | 30 m <sup>3</sup> L/ILW (long-lived)  |
| Reactor operation         | 80 m <sup>3</sup> L/ILW               | 80 m <sup>3</sup> L/ILW   |
| Fuel reprocessing         | -                                     | 4 m <sup>3</sup> HLW,<br>20 m <sup>3</sup> L/ILW (long-lived),<br>84 m <sup>3</sup> L/ILW |
| Spent fuel                | 10 – 12 m <sup>3</sup> SF             | -   |

# Geological disposal

- Technical solutions for geological disposal available
- Geological repositories designed as passive facilities
- Safety based on multi-barrier approach
  - Natural barriers
  - Engineered barriers
- Possible host rock: granite, clay, salt...

# Multi-barrier system



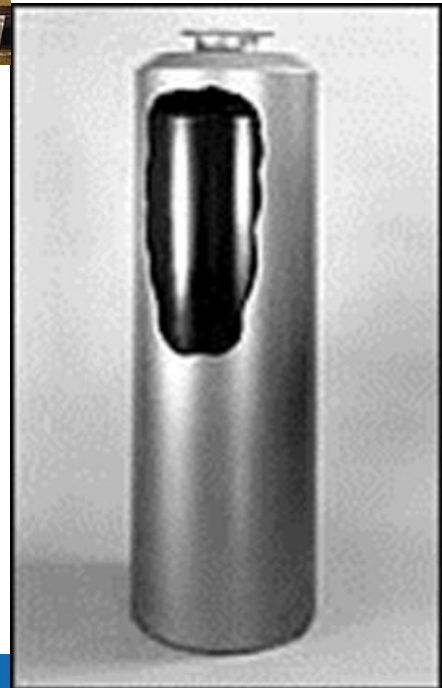


# Encapsulation of SF and HLW

Copper canisters for SF

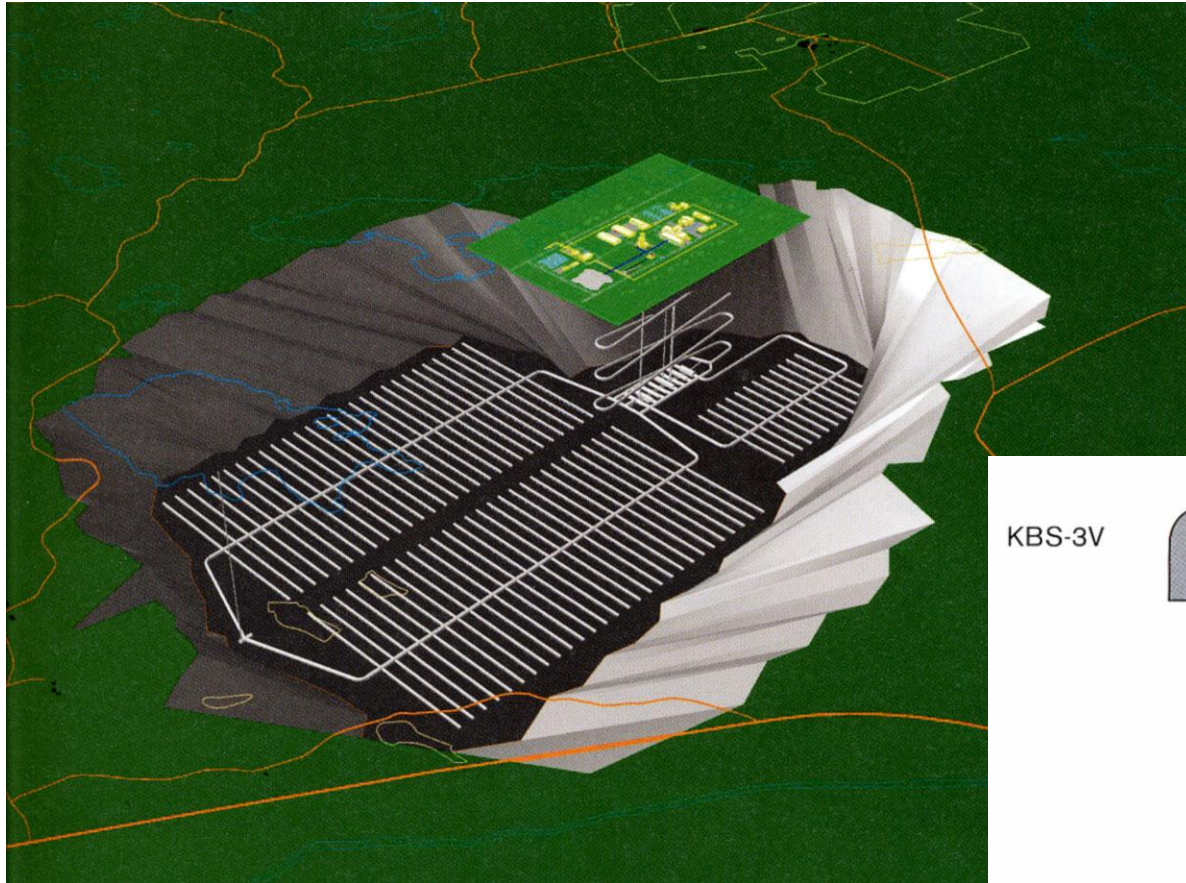


Pouring of  
glass and HLW  
to container



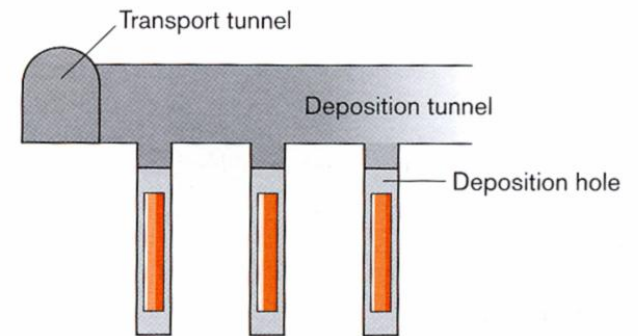


# Getting close to first operating repositories

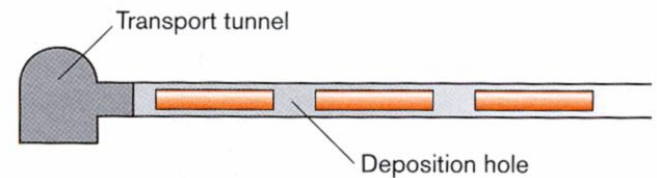


Geological disposal  
in Sweden

KBS-3V

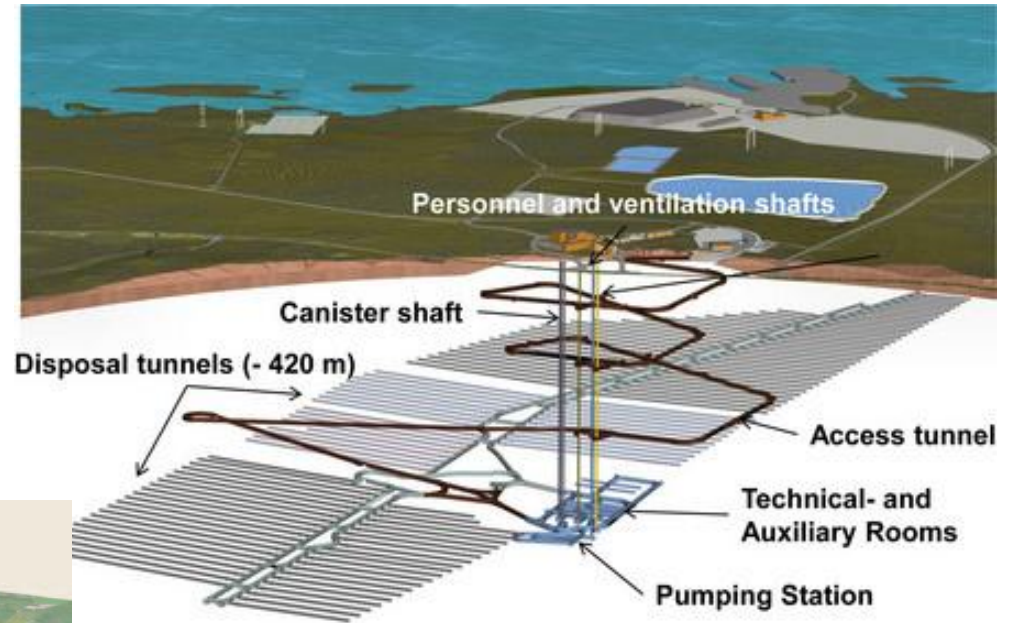
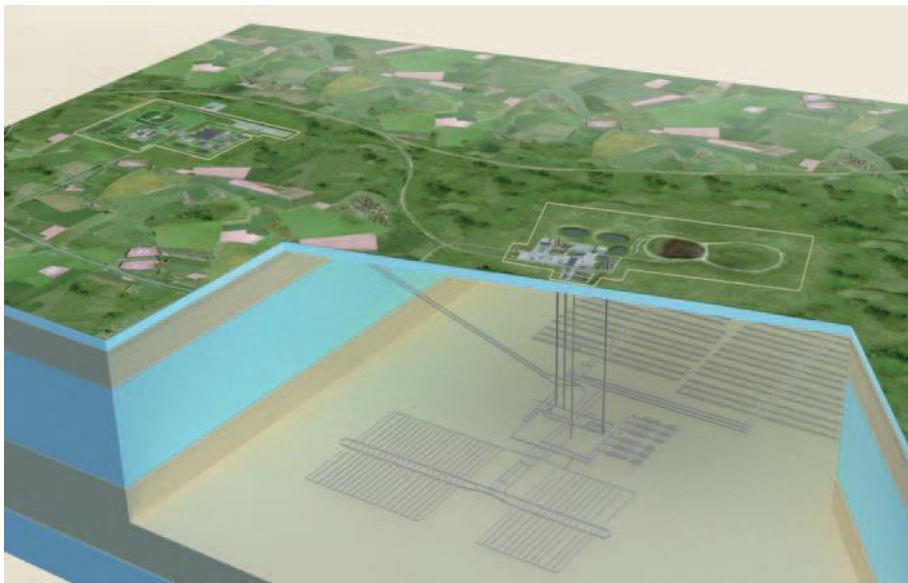


KBS-3H



# Getting close to first operating repositories

Disposal concept in France



Geological repository in Finland.



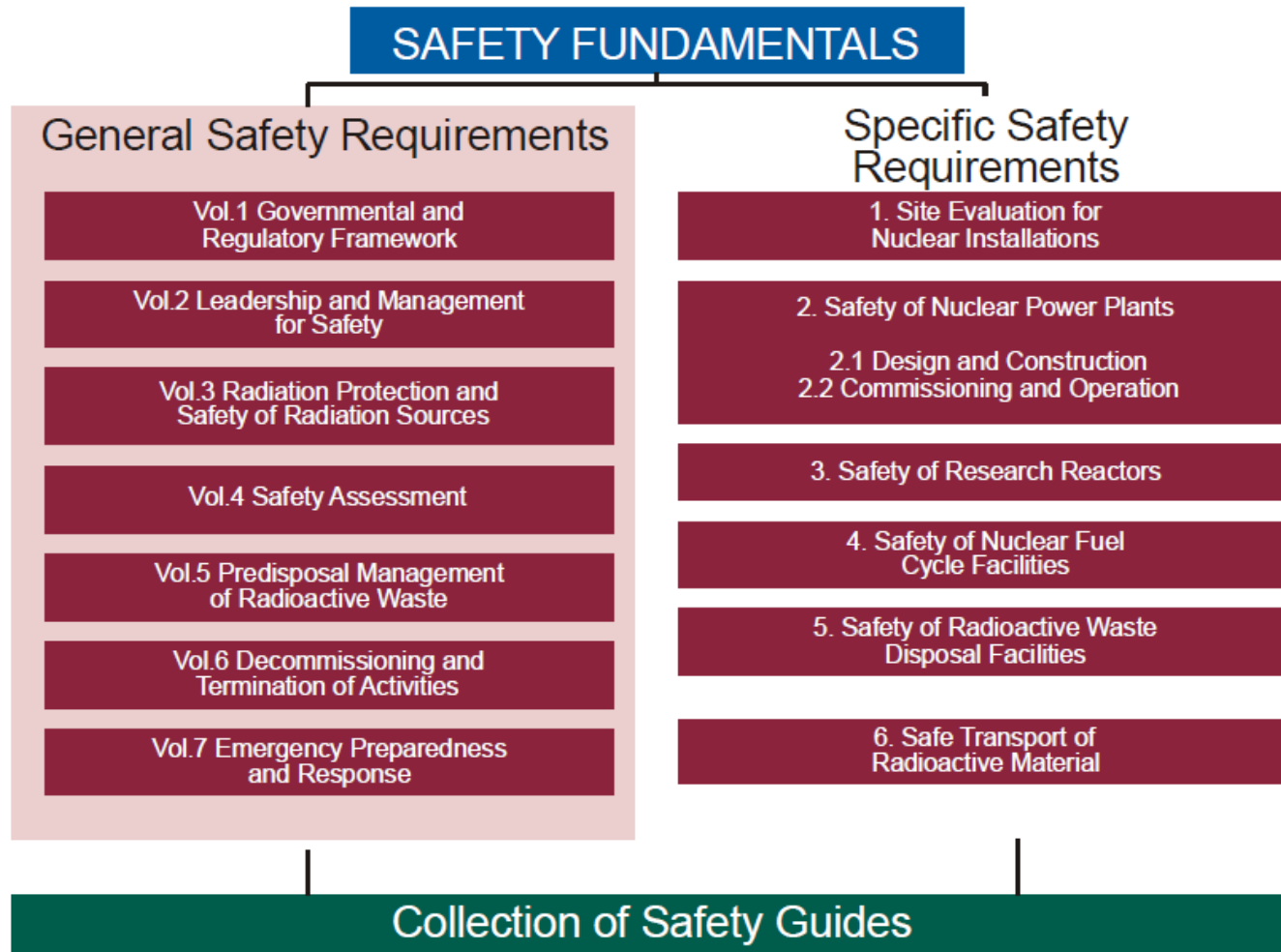
# IAEA Activities to Assist Member States

# IAEA activities

- Joint Convention, Safety Standards and guides for harmonization of safety approaches
- Facilitating international cooperation, information exchange and capacity building:
  - Technical reports and publications
  - Coordinated research projects
  - Networks
  - Databases
  - Training courses and eLearning
  - Conferences and Symposia
- Technical assistance to Member States
- Review services

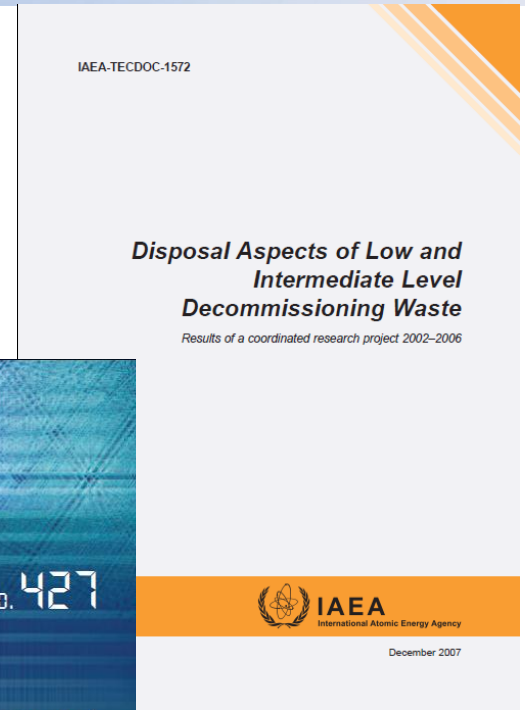
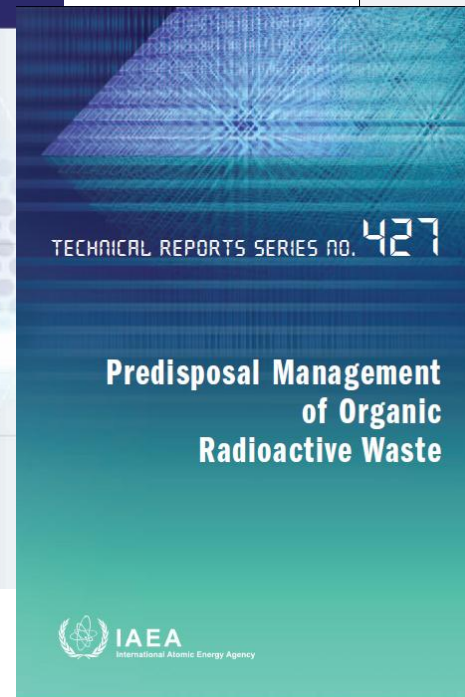
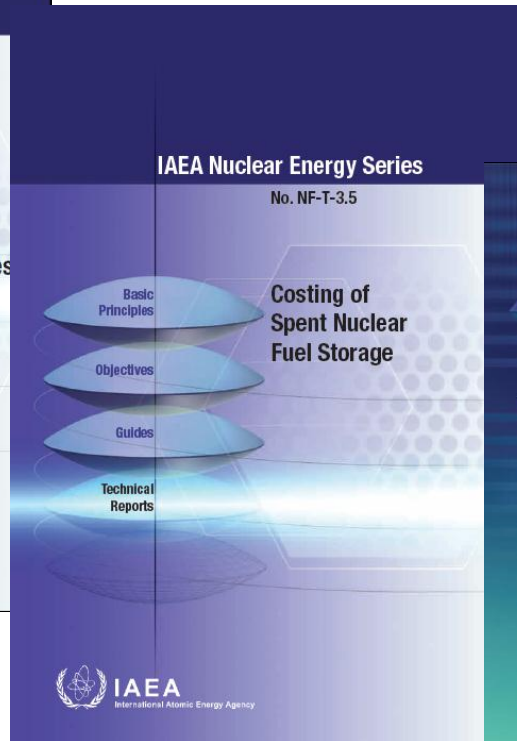
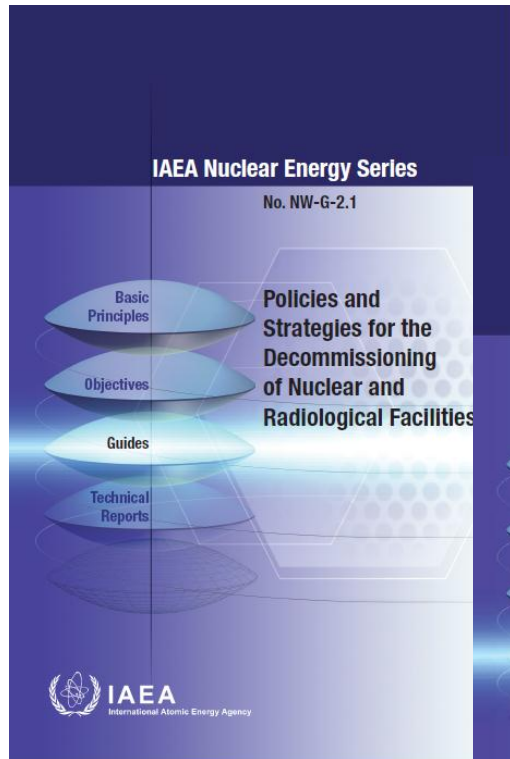


# Safety Standards and Guides





# Technical reports



<http://www.iaea.org/OurWork/ST/NE/NESeries/ClickableMap/>

# RWM Networks

- Networks are new tool to address the needs of Member States through thematic and strategically focused approaches
- Five Networks focused on the following areas:
  - Geological Disposal (**URF Network**, established in 2001)
  - Decommissioning of nuclear facilities (**IDN**, established in 2006)
  - Near-Surface Disposal of LLW (**DISPONET**, established in 2009)
  - Environmental Remediation of radioactively contaminated sites and environmental management of active sites (**ENVIRONET**, established in 2009)
  - Characterization of LILW (**LABONET**, established in 2011)

# CONNECT – Network of Networks

- Further development of Networks on-going to facilitate interactions between members and participants
- Connecting the Network of Networks for Enhanced Communications and Training in Radioactive Waste Management, Decommissioning and Environmental Remediation
- **CONNECT** allows users to communicate directly with others in near real-time, either on a one-on-one basis or with multiple users.
- Training and eLearning materials are also being developed to be available via CONNECT

# Conclusions

- Safe and efficient RWM is an important component of prosperous and peaceful use of nuclear energy and radioactive materials
- Technologies are available and being further developed
- IAEA plays an active role in developing and maintaining high standards of RWM in Member States
- IAEA is also strongly promoting international cooperation and exchange of information
- Cooperation beneficial for developing and developed programmes as well as for countries embarking on nuclear

# IAEA Assistance

- Many countries seek IAEA assistance in addressing waste issue:
  - Currently more than 80 TC projects related to RWM in 37 countries and in all regions
  - Required assistance mainly related to waste processing, storage and disposal of LLW
  - Assistance related to geologic disposal of SF and HLW mostly focused on:
    - Development of adequate policy and long-term strategy/programme for SF/HLW
    - Development of necessary infrastructure and financing schemes for SF and HLW management



# IAEA Priorities in RW and SF Management

- Encourage and support establishment of a policy for SFM and RWM and strategy for its implementation in each country using nuclear technology
- Stimulate countries introducing nuclear power to develop adequate policies and strategies at an early stage in their nuclear programmes
- Support countries with small nuclear programmes in their efforts for disposal solutions, encouraging cooperation and pooling of resources