Considerations for Fissile Material Disposition: The Role of the IAEA BRIDE Decision-Making Tool

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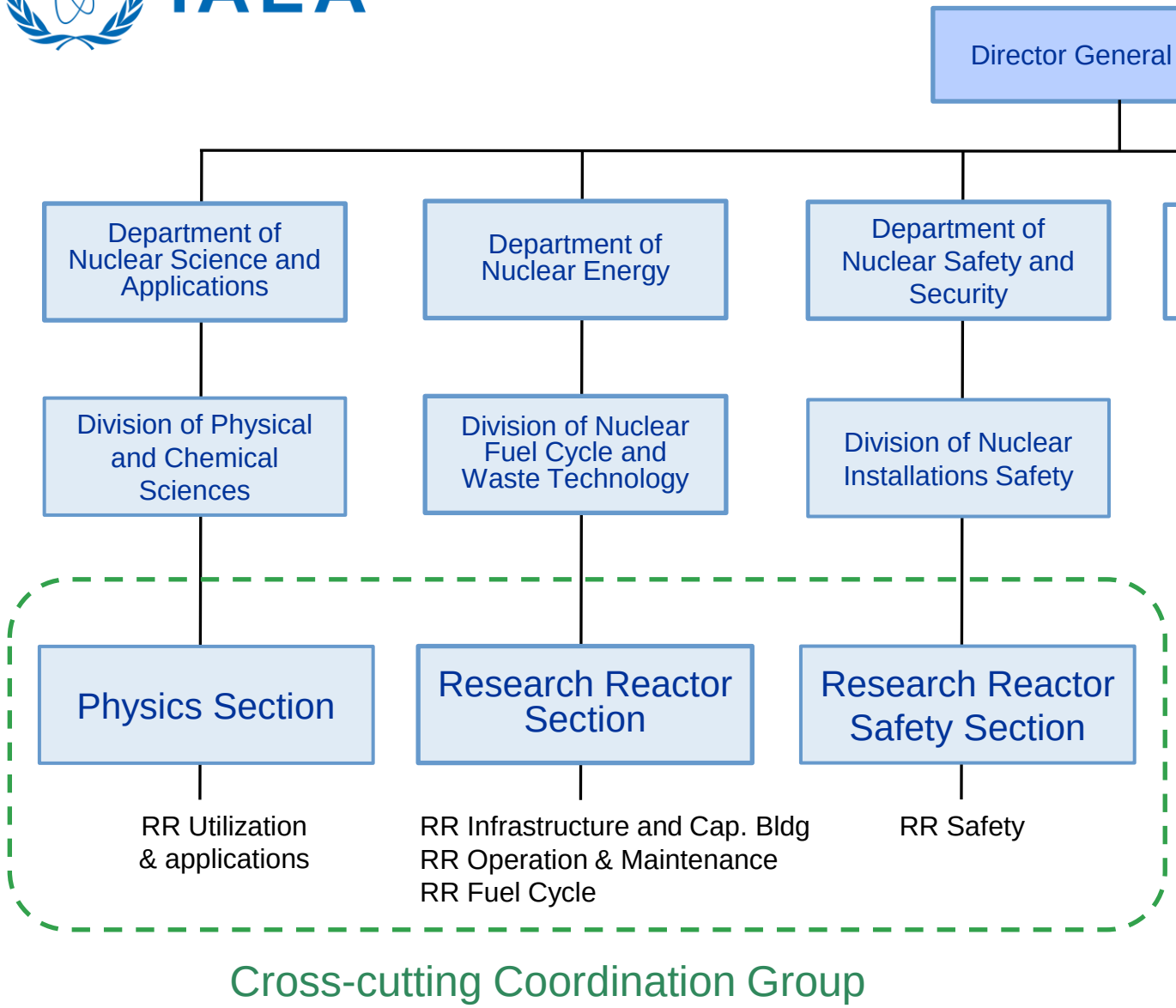


Other internal collaborations

- Nuclear Fuel Cycle
- Waste Technology
- Decommissioning
- Nuclear Security
- Safeguards
- Legal Affairs
- Technical Cooperation

IAEA work on Research Reactors: Programmatic Structure

Major Programme 1 – Nuclear Power, Fuel Cycle and Nuclear Science

Programme 1.2 – Nuclear Fuel Cycle and Waste Technology

Sub-programme 1.2.6 – Research Reactors

- **Access to research reactors, capacity building and infrastructure development**
- **Research reactor fuel cycle**
- **Research reactors operation, performance and upgrades**

Programme 1.4 – Nuclear Science

Sub-programme 1.4.2 – Research and applications with accelerators and neutron sources

- **Accelerators and neutron source applications**
- **Enhancing research with accelerators and neutrons**

Major Programme 3 – Nuclear Safety and Security

Programme 3.2 – Safety of Nuclear Installations

Sub-programme 3.2.5 – Safety of Research Reactor and Fuel Cycle Facilities

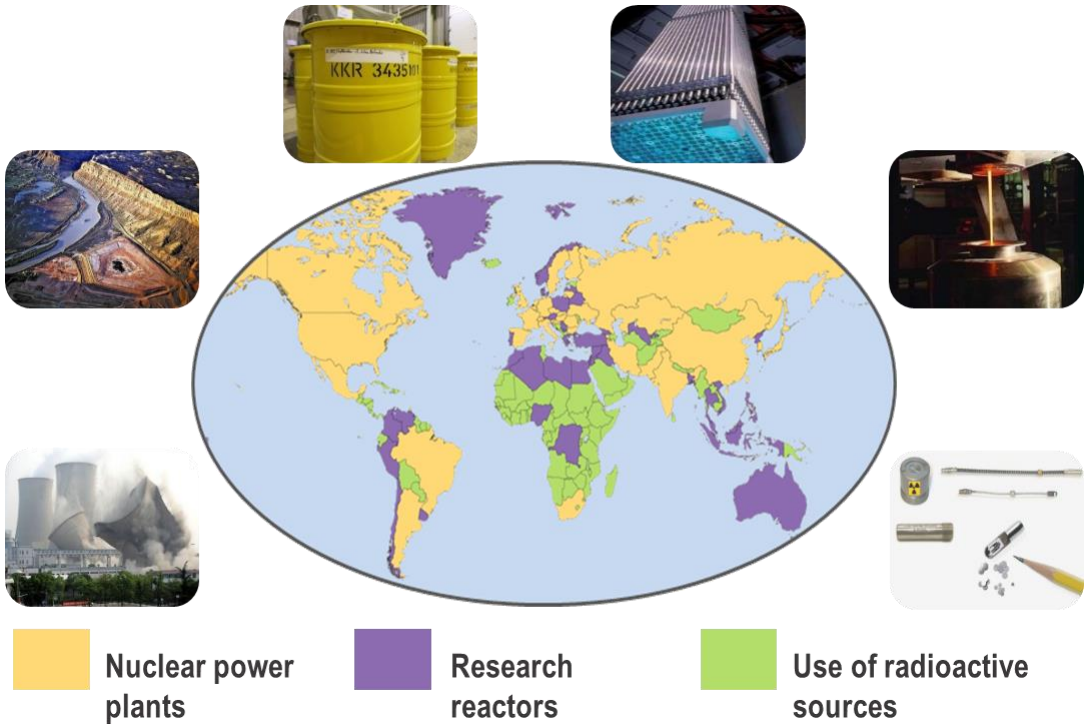
- **Safety of research reactors**

Nuclear Back-End Liability Awareness

All countries are responsible to provide solutions for the safe, secure & safeguarded management of their national radioactive waste inventories.

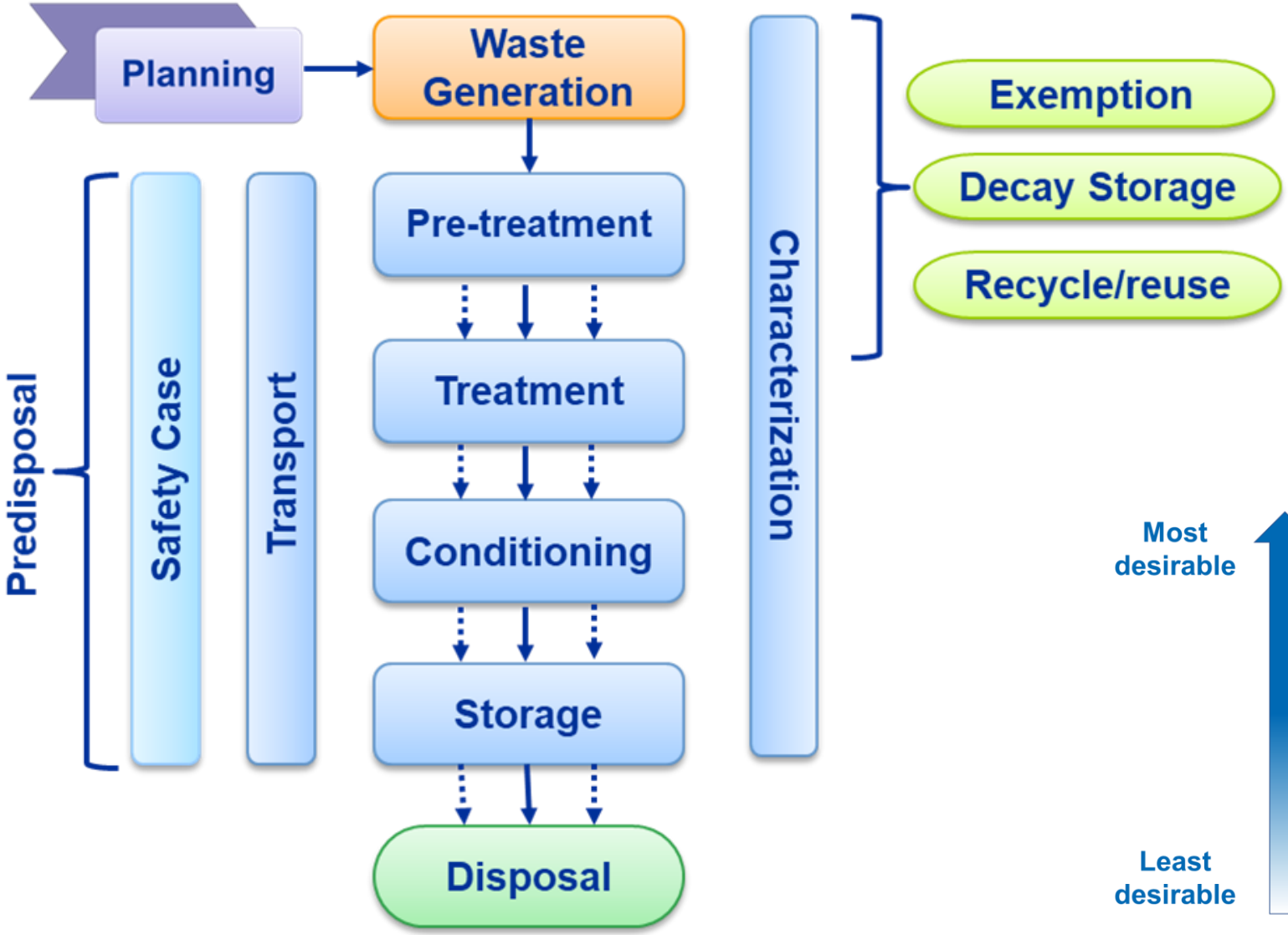
From generation to disposal:

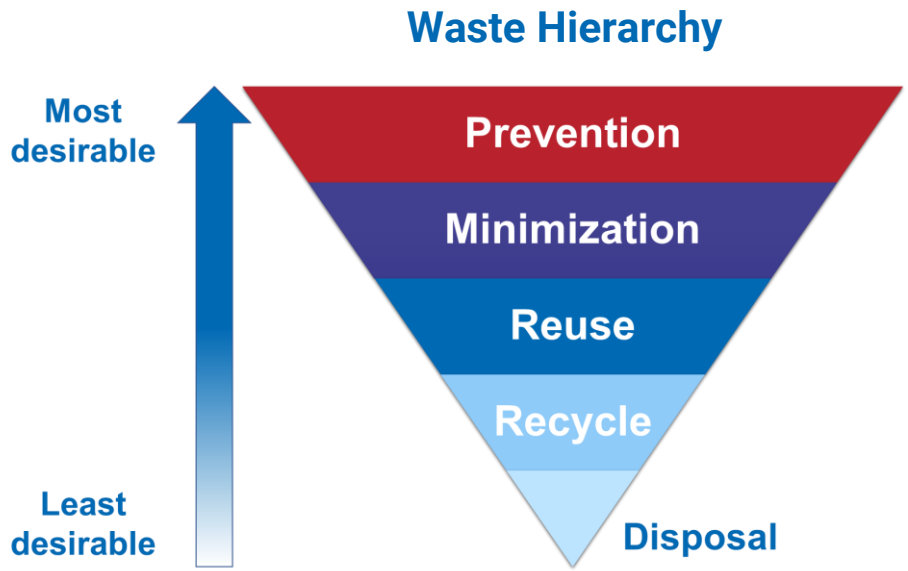
“Cradle-to-Grave”



☞Essential to provide comprehensive planning and provision for its life-cycle management from **generation** to **disposal**

How is radioactive waste managed?





Spent Research Reactor Fuel and Other Fissile Materials

Research Reactor Spent Fuel Management

- Lack of planning for spent fuel disposition
- Most research reactors store Spent Fuel (SF) in onsite pools
  - Sometimes these pools contain all the spent fuel accumulated since start of reactor operation
  - Also, they will continue to store SF with continued operation
- Little availability of back-end options for research reactor spent fuel, particularly in Non-nuclear Power Plant (NPP) countries
- Disposition options often unknown to Member State Decision Makers
  - Little experience with of what is involved in disposal of spent fuel or HLW
  - Costs for disposal unknown

→ **Leads to "No Decision" option**

Other Fissile Materials

Other Fissile Materials Share Similar Challenges to Spent Fuel

- Capacity
- Safety
- Surveillance
- Operational costs

Compatibility of Materials can Become a Factor

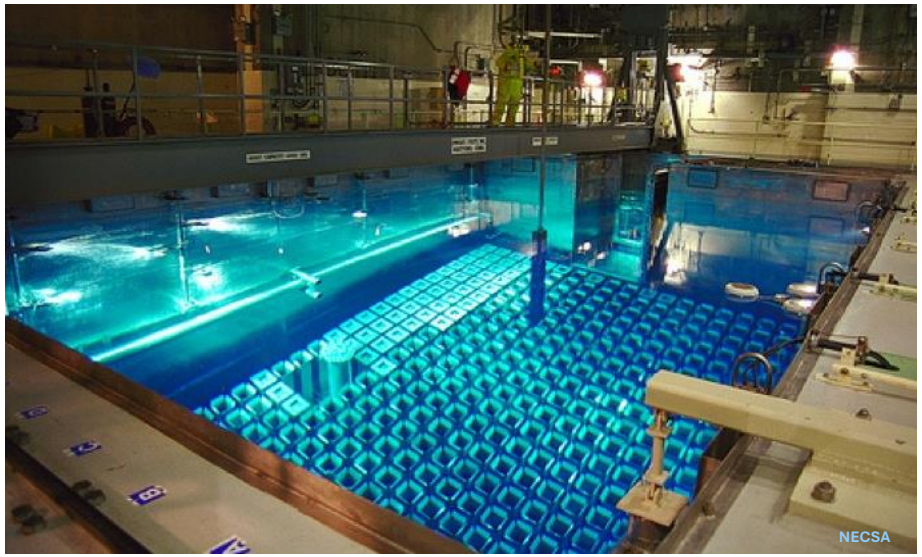
- Dissimilar metals
- Irregular Forms

Pre-Disposal Options

- **Storage**
  - The holding of radioactive materials, spent fuel or radioactive waste in a facility that provides for its containment, with the intention of retrieval for final disposal

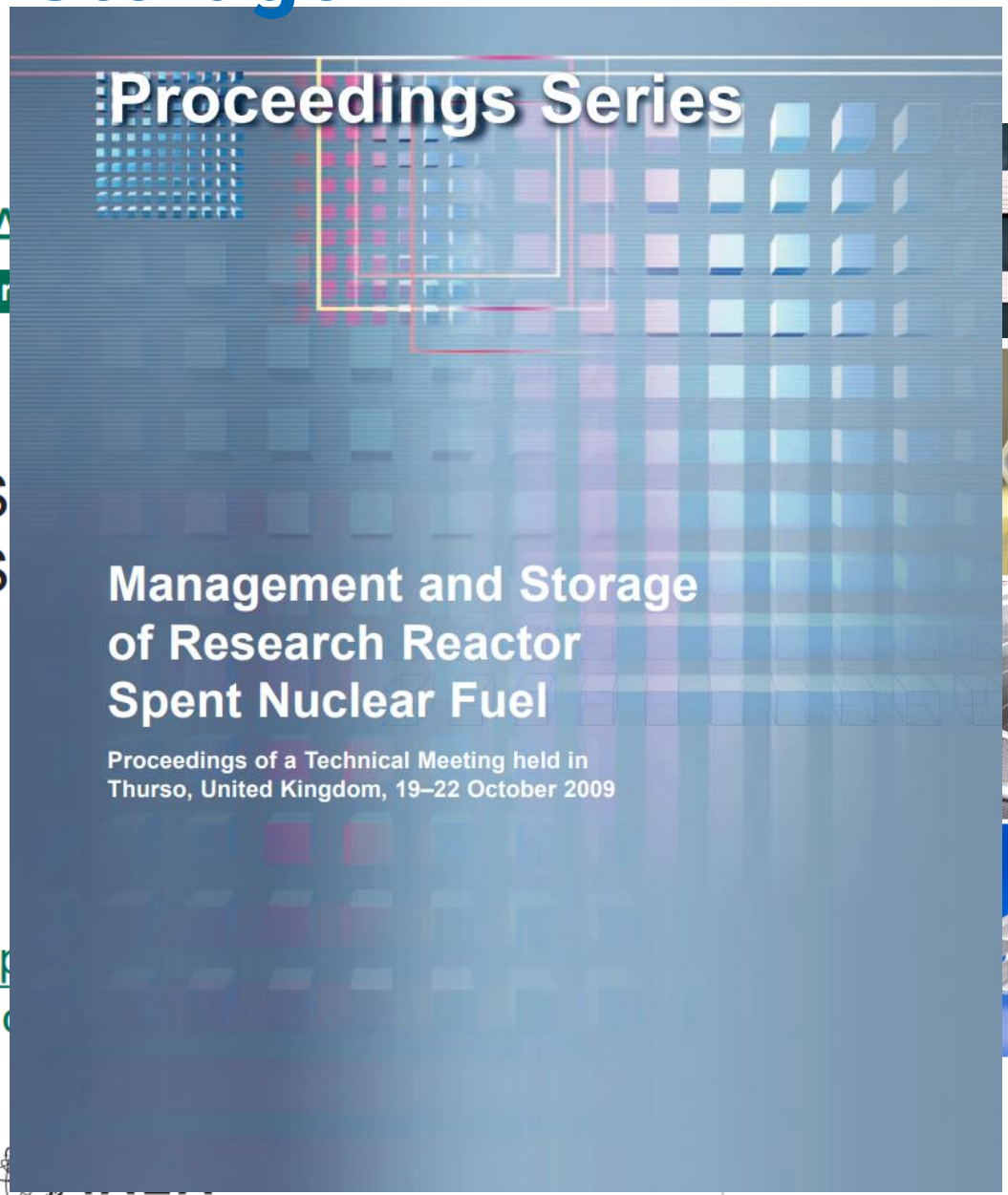
- **Pre-Disposal**
  - Any waste management steps carried out prior to disposal, such as pre-treatment, treatment, conditioning, storage and transport activities

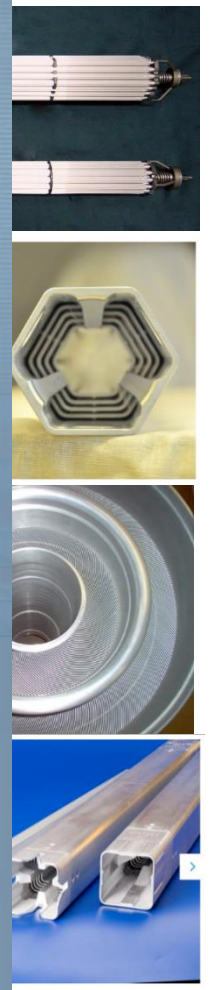
Spent Fuel Storage



Issues with Spent Fuel Storage

- How much can be stored a
- For how long can it be safe
- What surveillance of the fu
- What does it cost to maint
- Will we need to construct
- Should the additional stor
- What form of dry storage?
- How soon can fuel be mov
- What is the cost to transiti





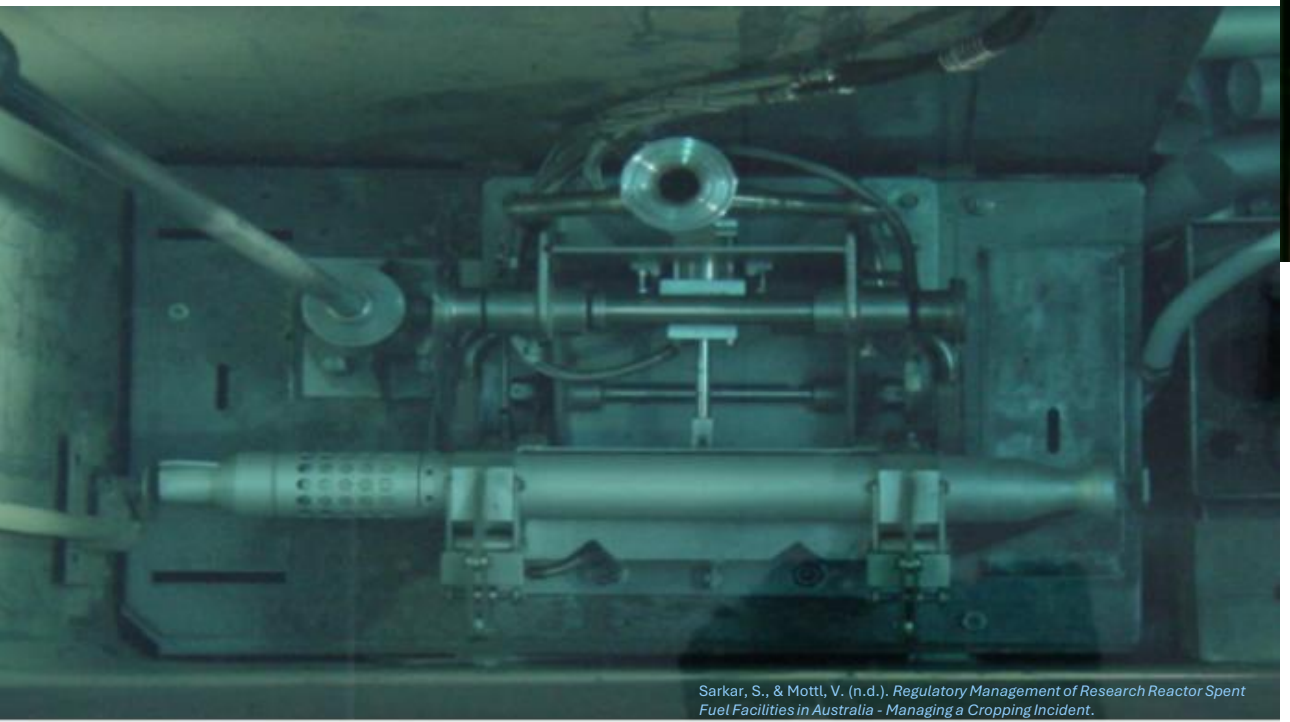
Pre-Disposal Options

- **Treatment -** Operations intended to benefit safety and/or economy by changing the characteristics of the waste
  - Volume reduction
  - Removal of radionuclides from the waste
  - Change of composition
- **Conditioning** – Those operations that produce a waste package suitable for handling, transport, storage and/or disposal
  - Conversion of the waste to a solid waste form
  - Enclosure of the waste in containers
  - Provision of an overpack (if necessary)

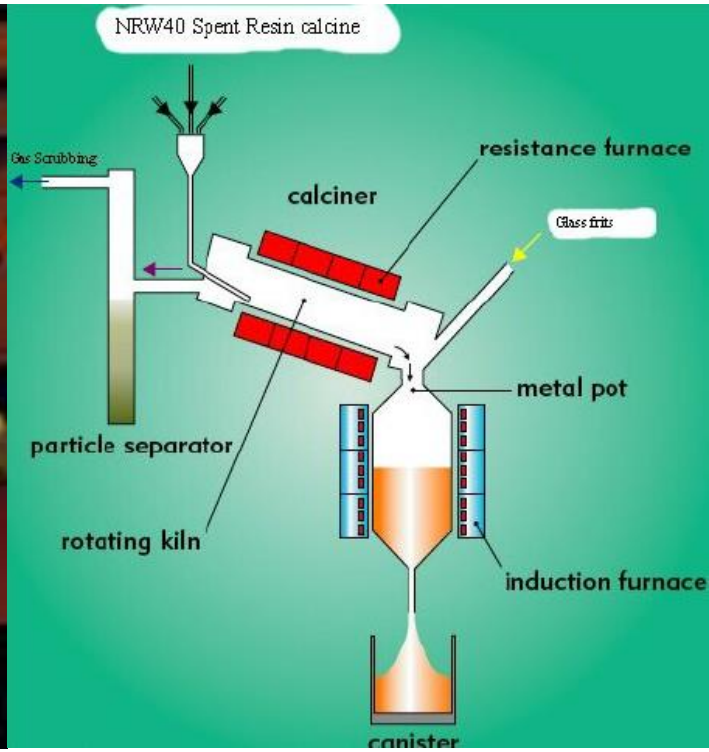
Treatment and Conditioning of Spent Fuel

Consolidation

- Reduces volume
- Criticality limitations
- Heat generation considerations



Sarkar, S., & Mottl, V. (n.d.). *Regulatory Management of Research Reactor Spent Fuel Facilities in Australia - Managing a Cropping Incident.*



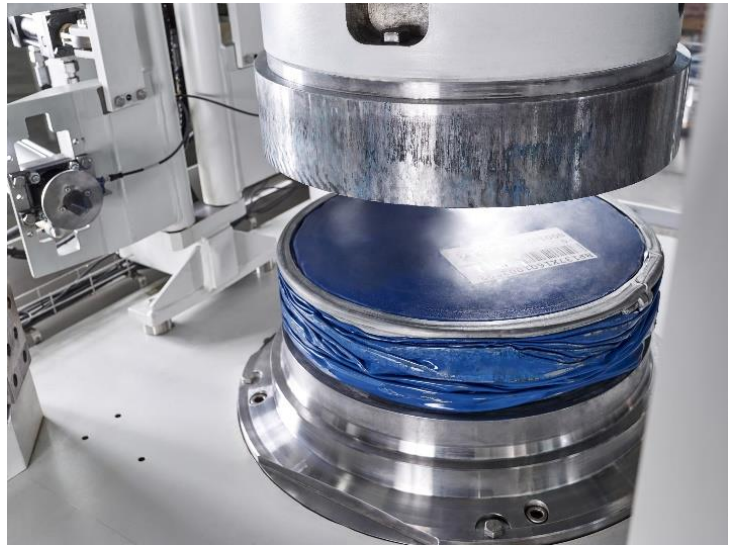
Hamodi, Nasir & Iqbal, Yaseen. (2009). Immobilization of Spent Ion Exchange Resin Arising From Nuclear Power Plants: An Introduction. J Pak Mater Soc. 3.

Reprocessing

- Most comprehensive management option
- Substantially reduces volume
- Reduces reactivity and results in durable waste form
- Commercially available – very expensive

Treatment & Conditioning Options For Other Fissile Materials

Waste Forms:
Grout, Metallic,
Vitrification,
Supercompaction,
Hot Isostatic Pressing



Waste Processing & Storage Options

Pre-treatment

- **Collection**
- **Sorting & segregation**
- **Size Reduction**
- **Surface Decontamination**

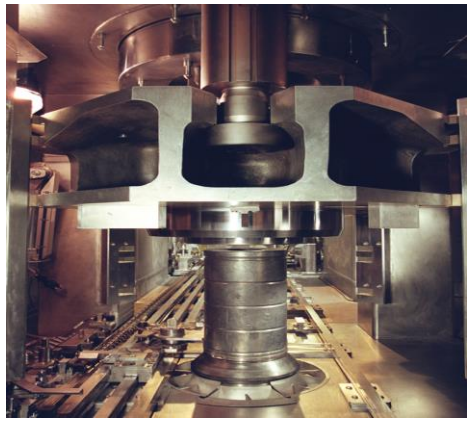




Treatment

Solid Waste
- Low-force compaction
- Supercompaction
- Incineration
- Metal Melting
- Pyrolysis

Liquid Waste
- Ion exchange
- Filtration
- Chemical Separation
- Evaporation
- Membrane methods



Conditioning

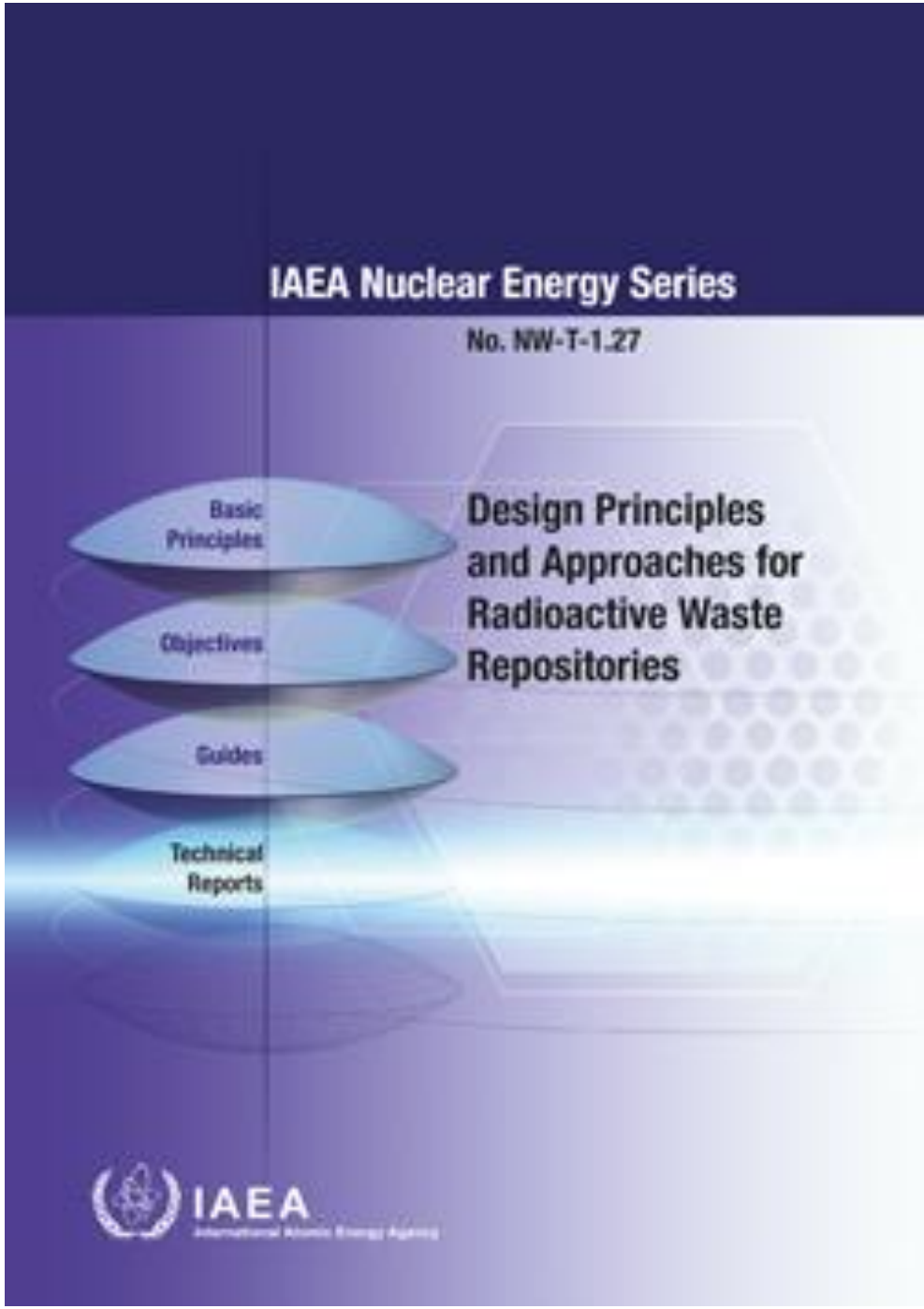
Solid Waste
- Cementation
- Geopolymer
- Ceramic
- Vitrification
- Polymer

- **Packaging**
- **Overpacking**

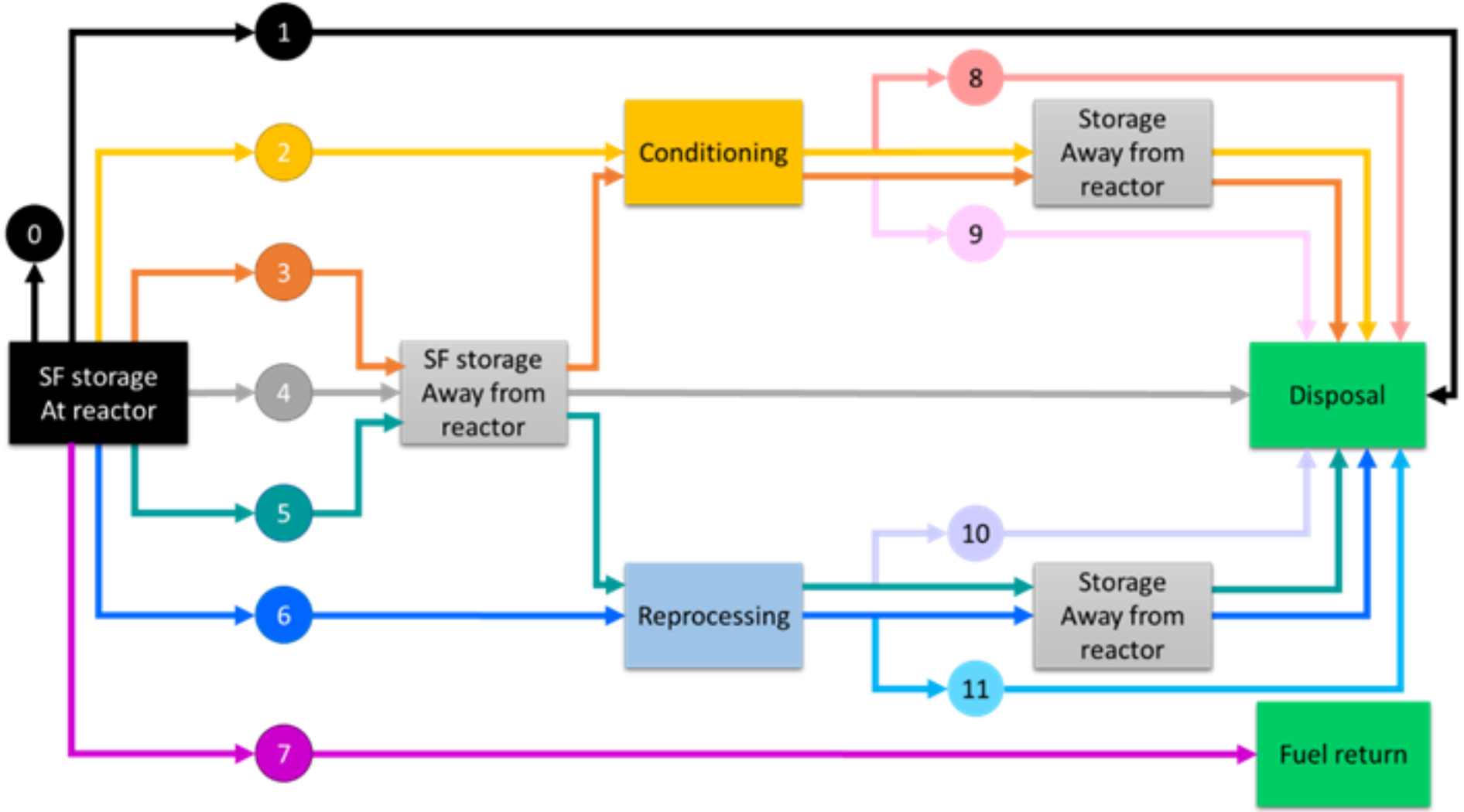
Storage

Disposal

- **Emplacement of radioactive waste or spent fuel in an appropriate facility without the intention of retrieval**



Technical Options for Fissile Materials



Governmental Decision Making

Factors

- Costs
- Technical Options
- Non-Economic Factors

- Legal and Regulatory
- Industrial and Technical
- Environmental Impact
- Human Resources
- Political Support

- Socioeconomic Factors
- Stakeholder Engagement
- Regional and International Partners
- Other Factors

IAEA Tools To Support Key Radioactive Waste Management Policy & Strategy Decisions

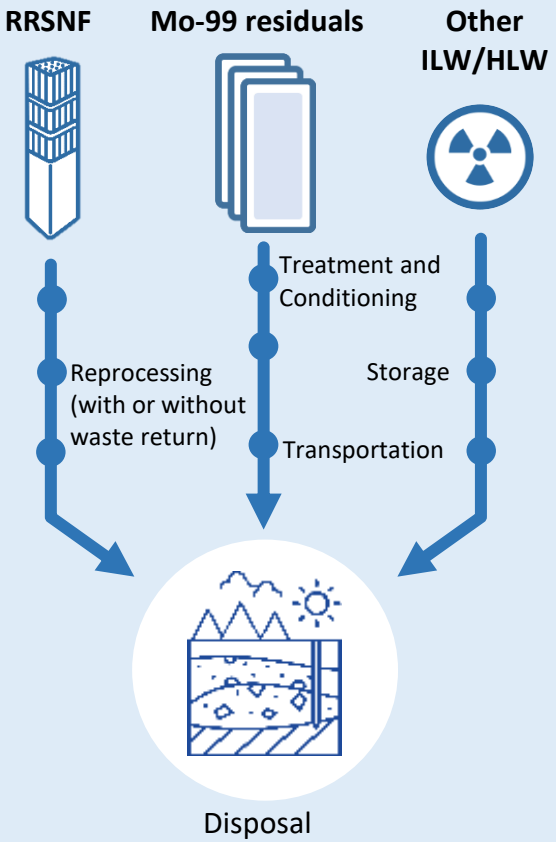
Backend Research reactor Integrated Decision-making Evaluation (BRIDE)

https://www.iaea.org/online-learning/courses/2130/nuclear-back-end-webinar-series-45-using-the-bride-decision-support-tool-to-find-the-right-solution-for-fissile-material-disposition

Multivariate Problem

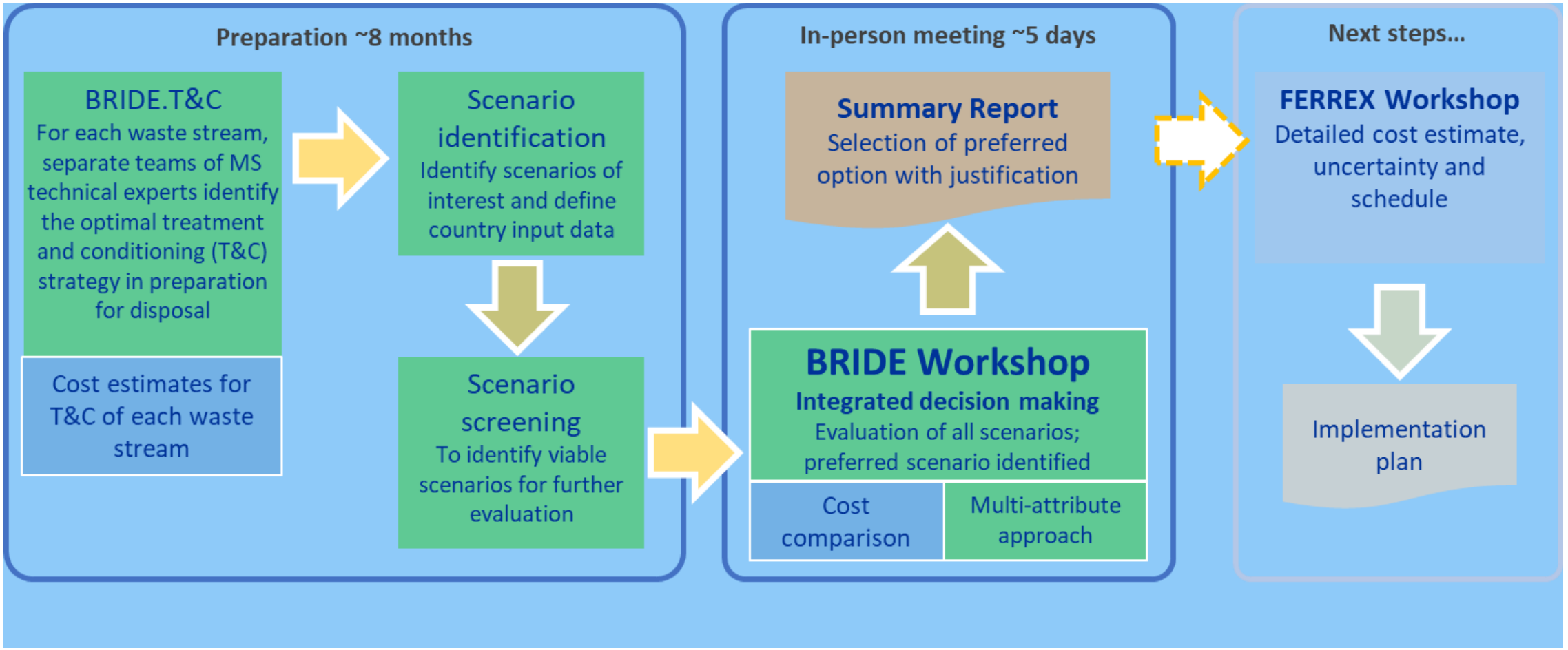
Back-end management for fissile materials

Any management strategy ends only at disposal!

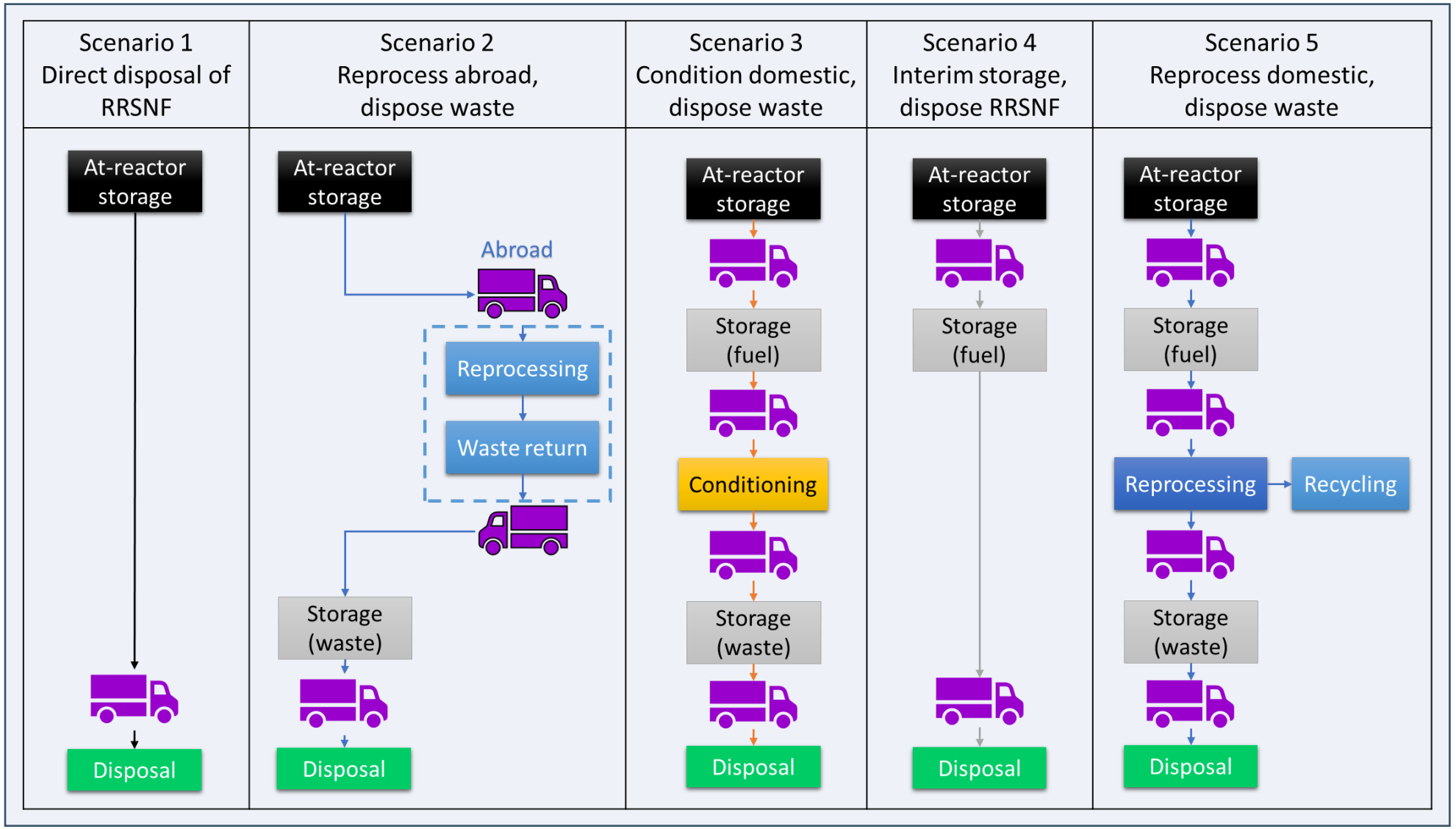


BRIDE → Integrated decision

BRIDE Workshop



The RRSNF Management Strategies



The BRIDE Excel File

The plausible strategies

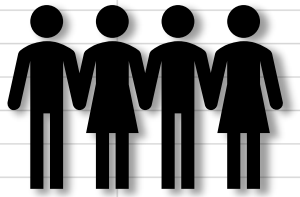
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
clude Scenario?	Yes	Yes	Yes	Yes	Yes	No	No
Short name	Domestic Direct Disposal	International Reprocessing	Domestic Conditioning	Domestic Long Term Storage	Domestic Reprocessing	TBD 1	TBD 2
Description	Near term direct disposal of RRSNF	Reprocess abroad, followed by disposal of returned products	Stabilize in domestic facility followed by direct disposal of stabilized products	Interim storage of RRSNF in monitored facility, followed by direct disposal of RRSNF	Reprocess in domestic facility, recycle fissile material, and dispose waste	TBD 1	TBD 2

Number of experts in this panel: 7

The expert panel's evaluations

Scores

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Max
Expert 1	3.59	5.83	4.77	6.02	2.81			6.02
Expert 2	5.66	5.41	5.55	5.00	2.50			5.66
Expert 3	6.42	3.59	4.04	3.59	5.22			6.42
Expert 4	5.32	2.99	6.07	6.19	4.75			6.19
Expert 5	7.04	4.95	5.81	5.00	3.58			7.04
Expert 6	7.04	5.13	6.49	4.43	3.55			7.04
Expert 7	5.98	5.84	6.10	5.01	5.87			6.10
Expert 8								0.00
								0.00
								0.00



The economic factor AND the non-economic factors

Raw Non-economical Average Score	5.87	4.82	5.55	5.03	4.04			5.87
Raw Cost Score				9.29	1.00			10.00

Cost scoring method: Logarithmic

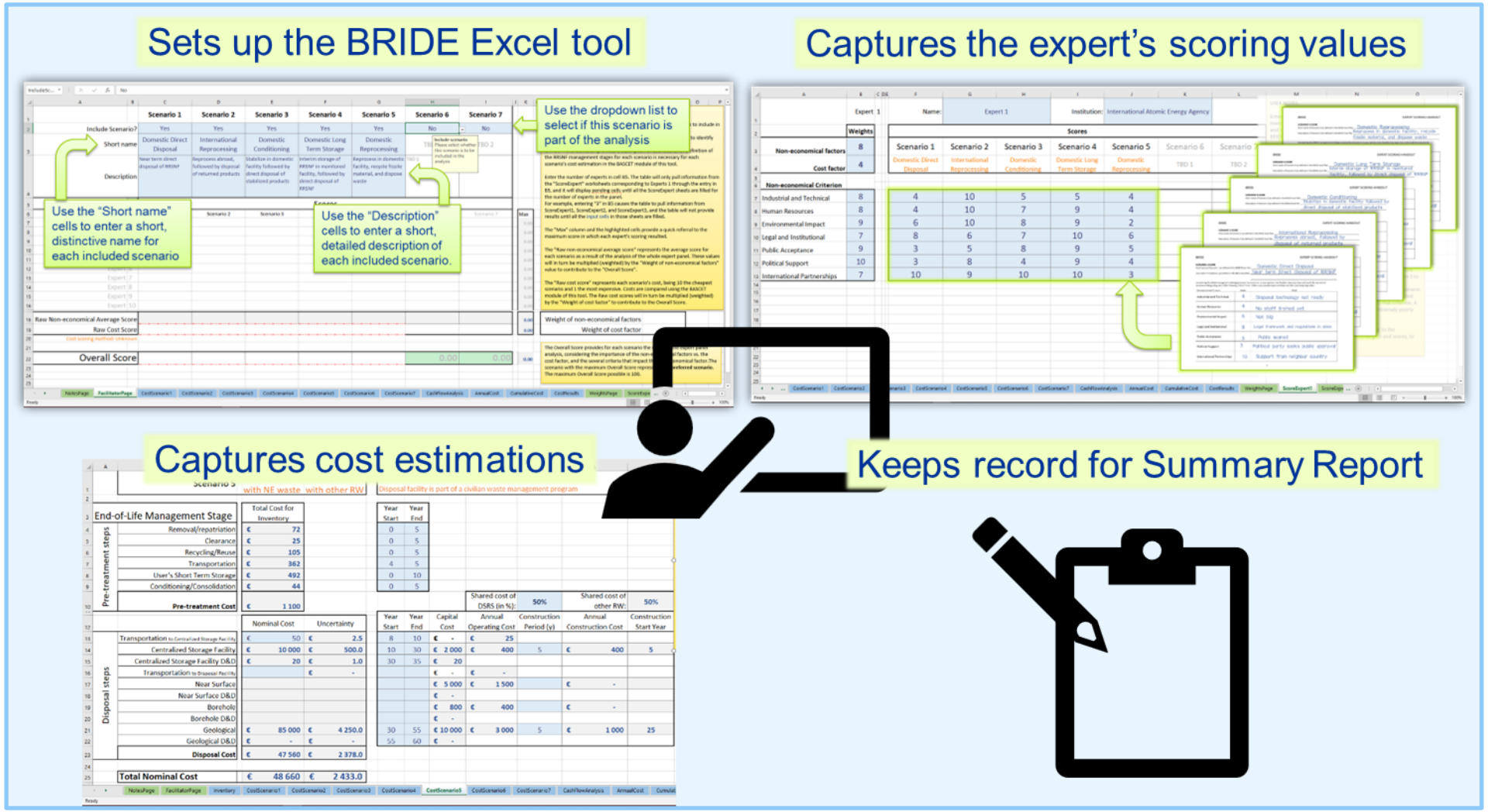
The preferred option

Overall Score	70.31	43.70	52.02	63.25	24.30	0.00	0.00	70.31

NotesPage | FacilitatorPage | CostScenario1 | CostScenario2 | CostScenario3 | CostScenario4 | CostScenario5 | CostScenario6 | CostScenario7 | CashFlowAnalysis | AnnualCost | Cumulative

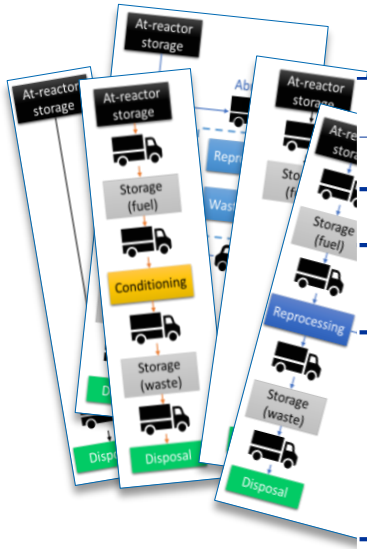
Ready

The BRIDE Excel File



The Unit Costs

For each scenario



Unit costs for each stage of scenario

RRSNF management stages Costs in €

Stage	Cost Estimate (*Example*)	
At-reactor Storage	Annual Operating Cost	200 000
Domestic Transportation	Cost	300 000
Away from reactor Storage	Annual Operating Cost	1 000 000
	Capital Cost	0 (existing facility)
	D&D	200 000
Reprocessing Commercial Services	Shipment Cost (to and from)	1 000 000
	Reprocessing Cost	40 000 000
	Disposal of return waste	3 000 000
Domestic Conditioning	Annual Operating Cost	400 000
	Capital Cost	5 000 000
	Disposal of resulting waste	1 000 000
Geologic Repository	Annual Operating Cost	3 000 000
	Capital Cost	100 000 000
	D&D/Closure	2 000 000

- Real costs vary from country to country

BRIDE Implementation – The Unit Costs

Scenario 4 — Domestic Long Term Storage

Interim storage of RRSNF in monitored facility, followed by direct disposal of RRSNF

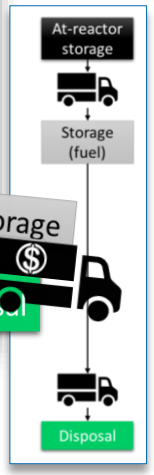
	RRSNF Management Stage	Nominal	Standard Deviation	Year Start	Year End	Capital Cost	Annual Operating Cost	Construction Period (y)	Annual Construction Cost	Construction Start Year
Domestic	At-reactor Storage	€ 1 000		0	20		€ 50		€ -	0
	SNF Storage	€ 500		20	50	€ 100	€ 13	3	€ 33	17
	SNF Transportation	€ 100		20	21		€ 100		€ -	0
	Reprocessing						€ -		€ -	0
	Conditioning						€ -		€ -	0
	Reprocessing/Conditioning Product Storage						€ -		€ -	0
	Reprocessing/Conditioning Product Transportation						€ -		€ -	0
	Disposal	€ 5 000		50	100	€ 2 000	€ 60	10	€ 200	40
	Total Domestic Cost	€ 6 600	€ -							
International	Transportation						€ -		€ -	0
	Reprocessing						€ -		€ -	0
	Dilution/Stabilization						€ -		€ -	0
	Disposal						€ -		€ -	0
	Total	€ -	€ -							
	Total Nominal Cost	€ 6 600	€ -							

USER NOTES

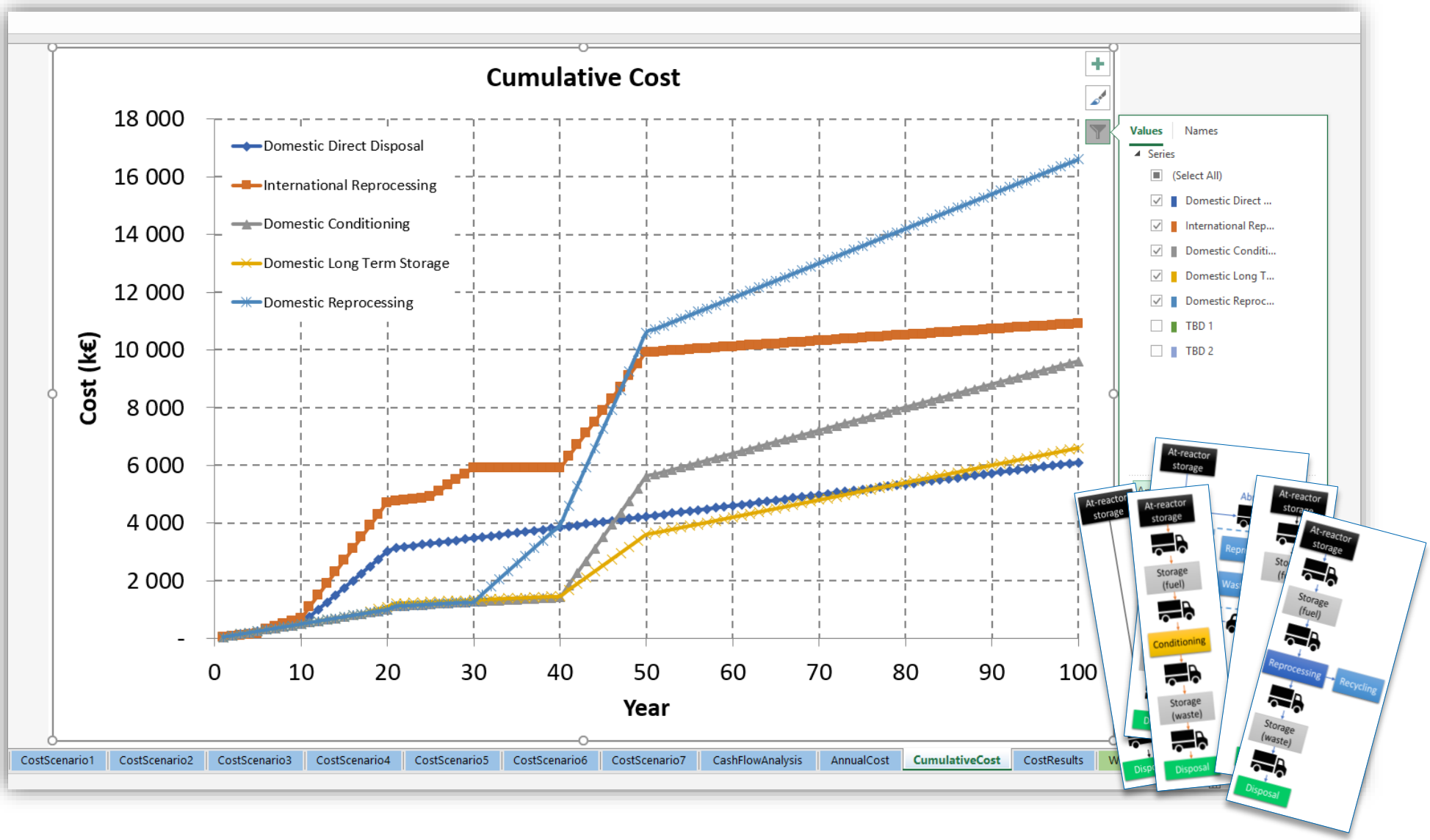
The typical RRSNF management stages are given in column A. The "Nominal" (expected) costs are entered in column D. Uncertainty estimates, if available, can be tracked in column E.
The time-based cash flow data is entered in columns G through K. The "Year Start" and "Year End" give the start and end operation period for that stage. Any related "Capital Cost" goes in column I, and the "Annual Operating Cost" is calculated as the difference between the "Nominal" cost and "Capital Cost", spread over the ope[illegible] period. The "Annual Construction Cost" spreads the construction cost over the "Construction Period".
The annual cost for each stage is calculated and displayed from year 1 until year 100 of the r[illegible]
The annual "Total nominal cost" is also calculated and displayed, and its result is used for th[illegible]
displayed in the "Annual Cost" and "Cumulative Cost" graphs along with the Total Nominal Cost [illegible]

FacilitatorPage | CostScenario1 | CostScenario2 | CostScenario3 | CostScenario4 | CostScenario5 | CostScenario6 | CostScenario7 | CashFlowAnalysis | AnnualCost

Ready

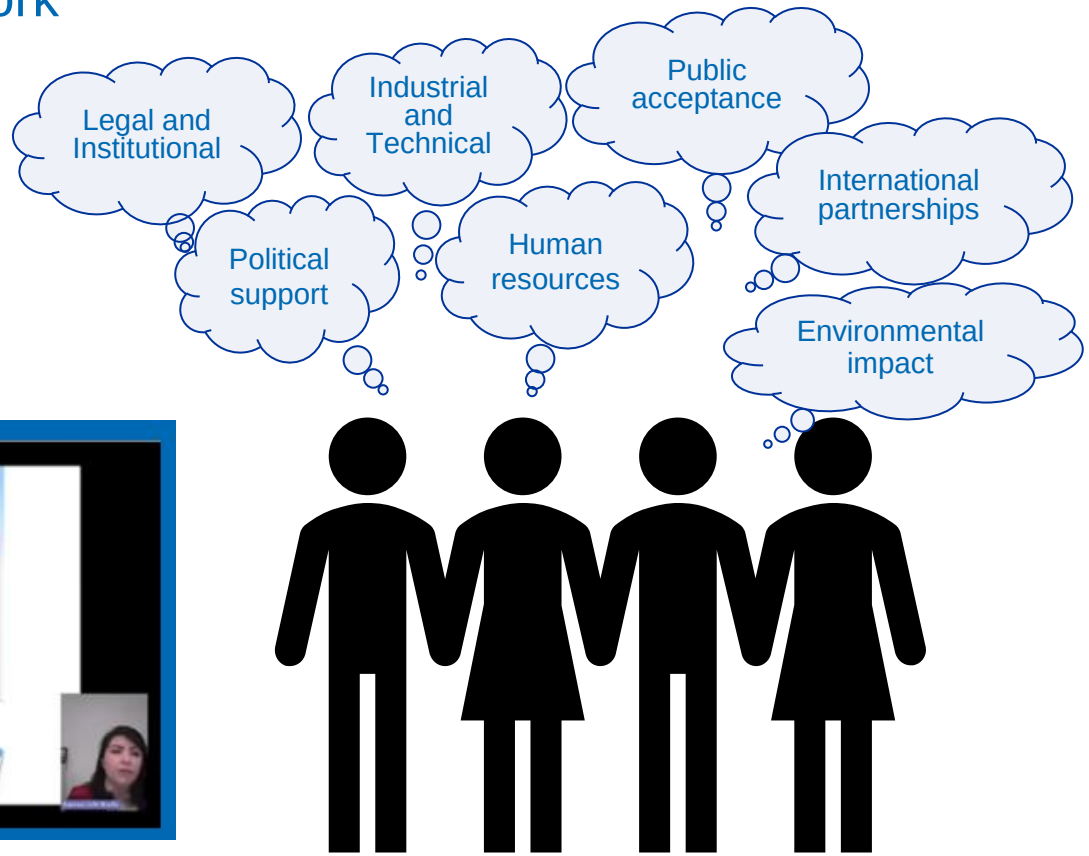


BRIDE Implementation – Cumulative Cost



BRIDE Implementation – The Expert panel

- The expert panel is conformed by individuals from a diverse background (relevant to the RRSNF management) and whose input validates the decision-making process.
- These experts will assess the advantages and disadvantages of each scenario, and their likelihood to be implemented within the national framework



BRIDE Implementation Results

The preferred option

	A	B	C	D	E	F	G	H	I
1			**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2	Include Scenario?		Yes	Yes	Yes	Yes	Yes	No	No
3	Short name		Central Long-term Storage	Near-surface Disposal	Borehole	Geologic Repository	Geologic Repository	TBD	TBD
4	Type of facility		Dedicated to DSRS	Dedicated to DSRS	Dedicated to DSRS	Dedicated to DSRS	Co-disposal with other RW		
5	Description		DSRS stored in storage facilities at a centralized waste management installation (until disposal)	DSRS stored at a centralized waste management installation until disposal in near-sruface facility	DSRS disposed in borehole	DSRS disposed in a Geologic repository built specifically for the EOL of DSRS	Geologic disposal facility is part of a civilian waste management program	TBD	TBD
6	Number of experts in this panel	7	Scores						
7			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
8	Expert	1	4.26	6.35	5.18	6.27	3.34		
9	Expert	2	6.08	5.99	5.86	5.38	3.06		
10	Expert	3	6.74	4.39	4.53	4.14	5.44		
11	Expert	4	5.78	3.86	6.31	6.41	5.03		
12	Expert	5	7.29	5.58	6.09	5.38	4.01		
13	Expert	6	7.16	5.74	6.80	5.00	3.98		
14	Expert	7	6.23	6.24	6.34	5.38	5.89		
15	Expert	8							
16	Expert	9							
17	Expert	10							
19	Raw Non-economic Average Score		6.22	5.45	5.87	5.42	4.39		
20	Raw Cost Score		8.06	8.83	10.00	1.00	8.55		
21	Cost scoring method: Logarithmic								
22									
23	**Overall Score**		**64.13**	**63.42**	**70.35**	**31.21**	**57.00**	0.00	0.00
24									

NotesPage | FacilitatorPage | Inventory | CostScenario1 | CostScenario2 | CostScenario3 | CostScenario4 | CostScenario5 | CostScenario6 | CostScenario7 | CashFlowAnalysis | Annu

The summary report

Summary

BRIDE

- Tools to bring together Stakeholders to discuss the multiple options
- Workshops are designed to evaluate the many variables
- The result is a Preferred Option as well as a Summary Report illustrating the basis for the Preferred Option
- Participants become advocates of the Preferred Option

Questions

IAEA

THANK YOU

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