VISION Simulations of Advanced Fuel Cycles for Commercial Nuclear Energy

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Which future do we want?

How do we get there?

- How can we even get started?

How do we wade through the myriad of options?

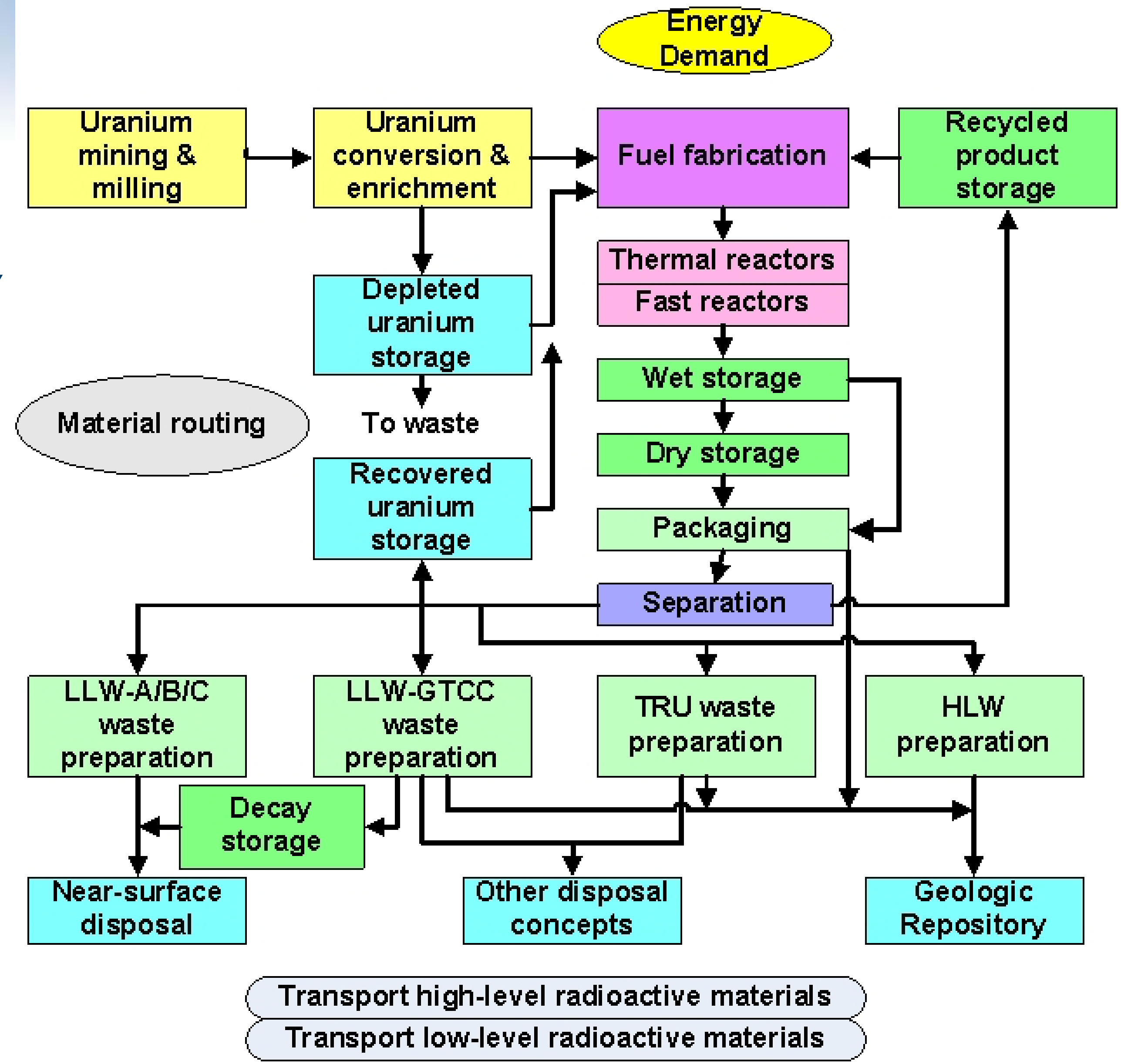
- Which options are important? When? Why?
- *NOTE: Fuel Cycle Technology is an R&D program, all options are on the table during the "Discovery" phase.*

When can we get there?

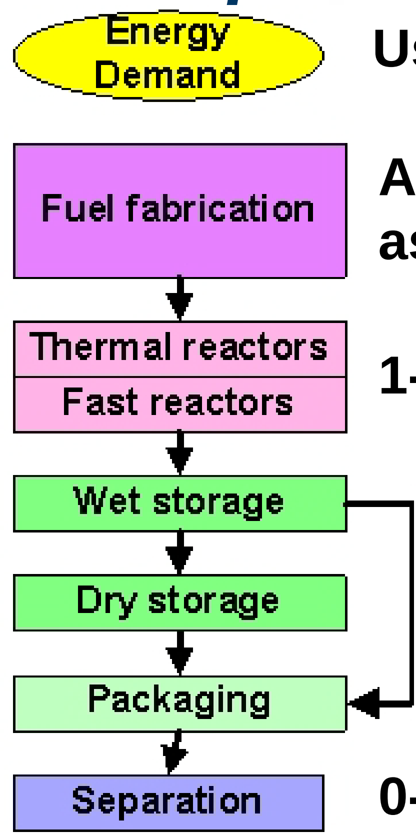
What happens between here and there?

*VISION is a **tool** to help answer such questions by simulating the entire fuel cycle*

NOTE: non-commercial wastes are not addressed



Some of VISION's capabilities



User specs for nuclear energy

As many U/TRU fuel recipes as you want

1-10 reactor types

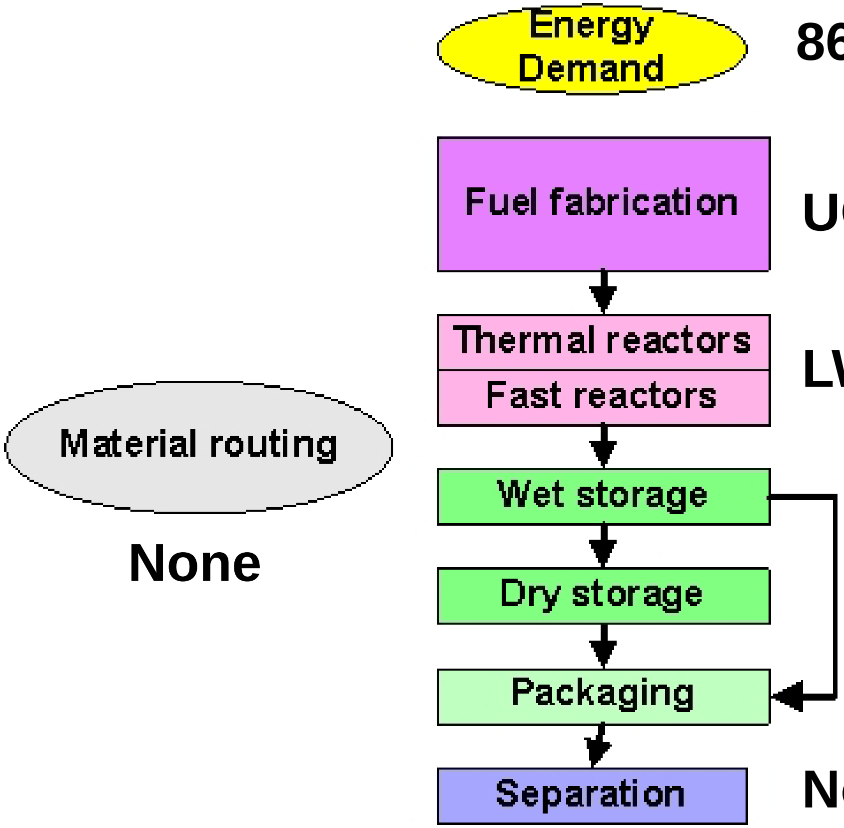
Each can be changed each year of the simulation

0-10 separation types

1-15 routing matrices from reactor to separations

0-40 separation matrices (how much of what goes where)

Typical year-2000 initialization



86 GWe-year

UOX

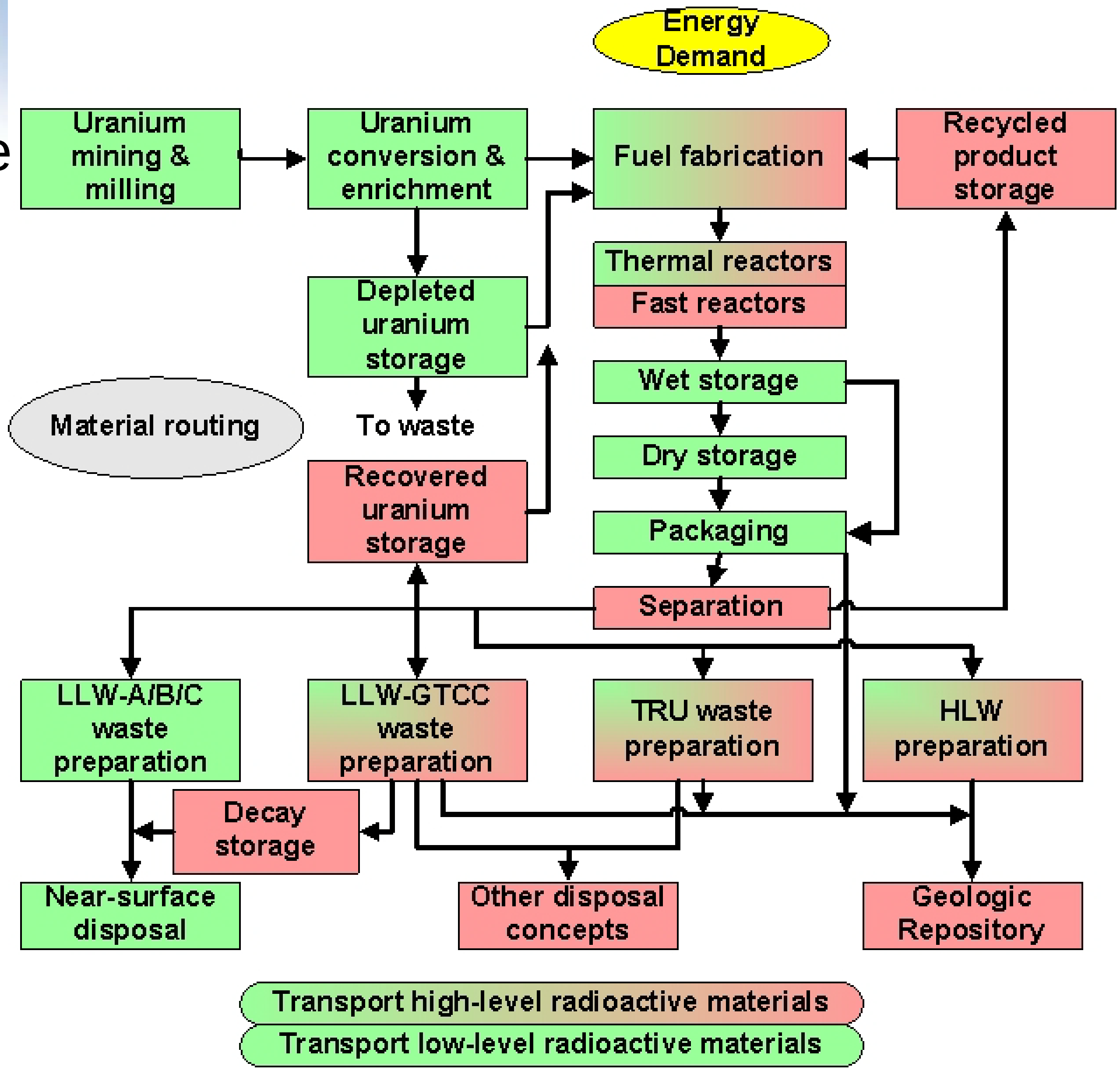
LWR, lifetimes to 60 yr

None

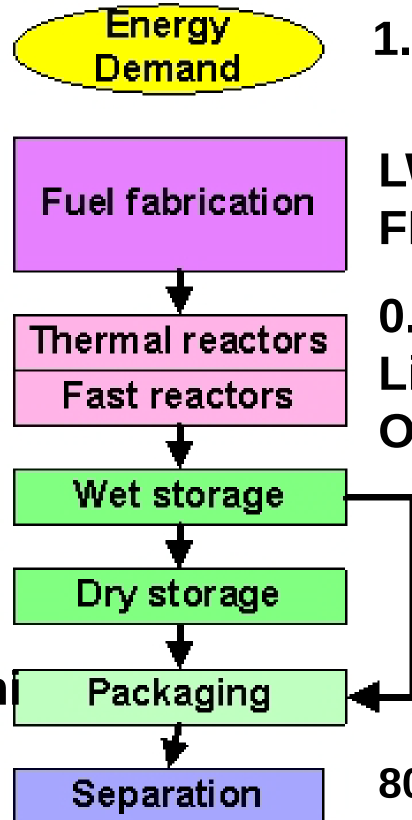
42,600 tonnes-UOX in storage

No separation

Challenge - how to sequence facilities and functions that do not exist in the current incomplete once-through cycle?



Example GNEP-era assumptions



1.75%/yr growth, start in 2015

LWR UOX
FR TRU conversion ratio=0.5

0.38 GWe demo FR in 2022
Limited construction 2032-42
Only fuel limited thereafter

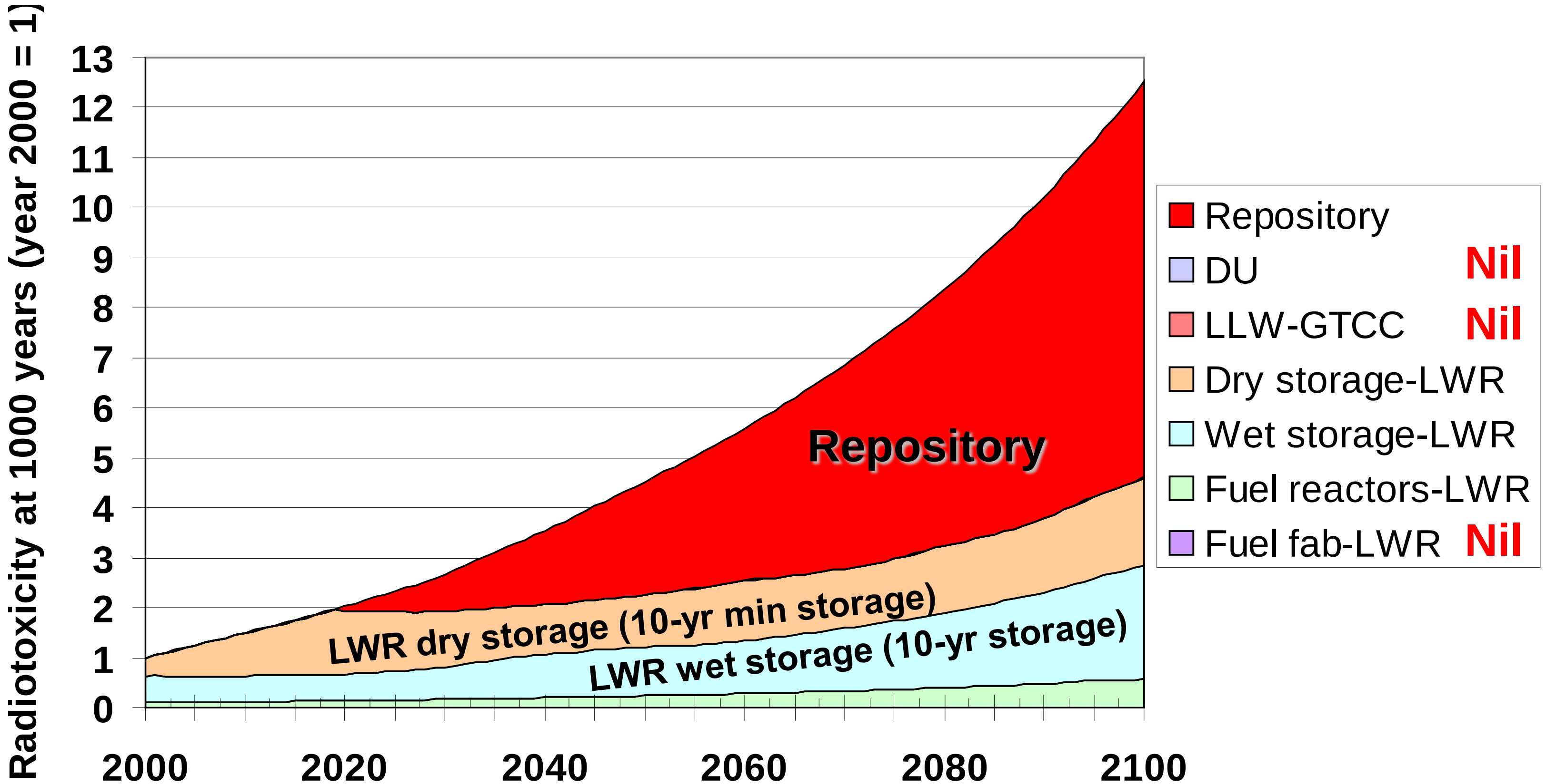
LWR→aqueous separation
FR→electro-chemical sep

Offsite (LWR): 10-yr wet storage + 1-yr processing
Onsite (FR): 1-yr wet storage + 1-yr processing

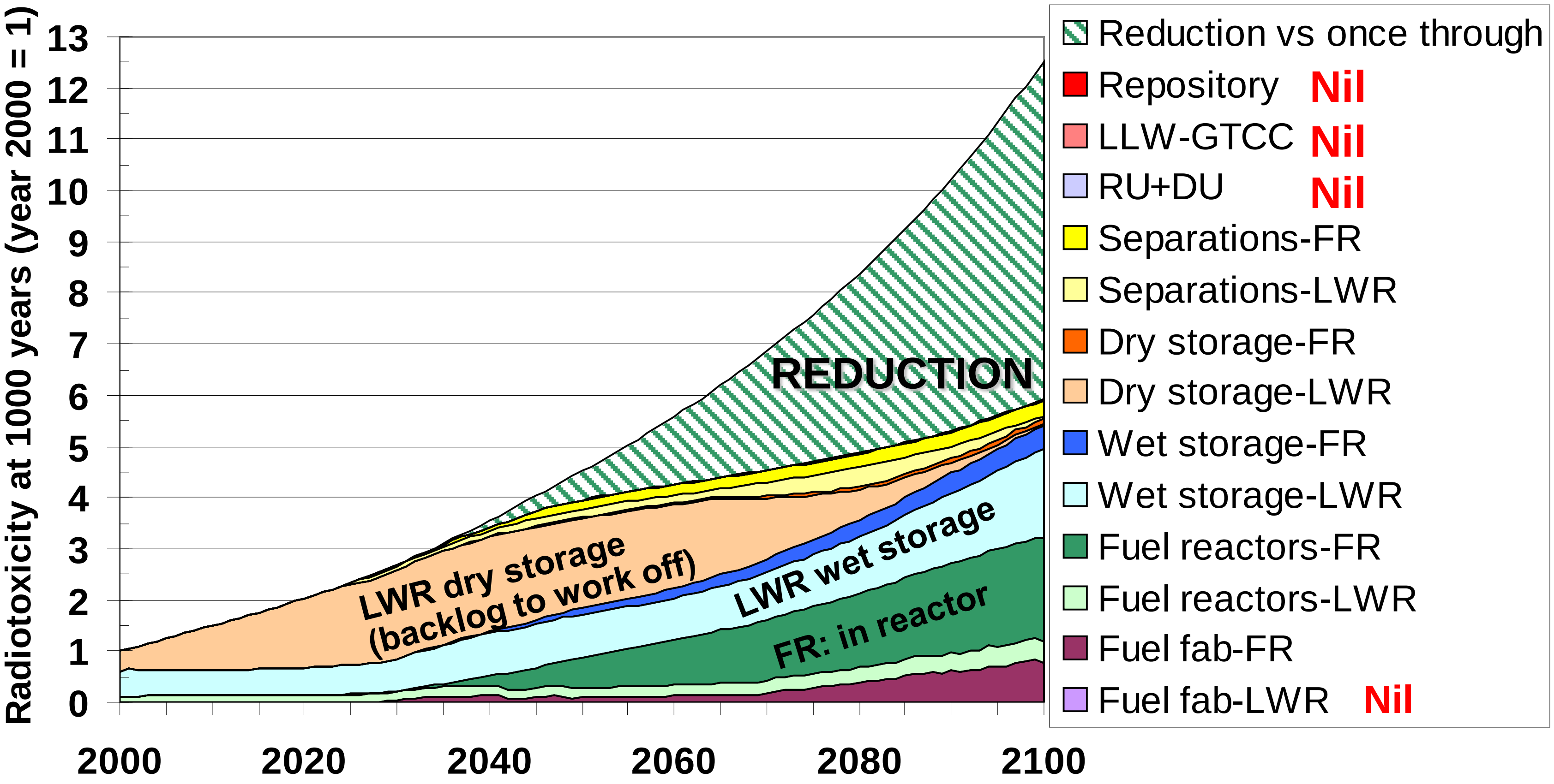
800 tonnes-UOX/yr in 2020, later 1600 tonne-UOX/yr plants to eliminate backlog by 2100, FR sep as needed

Take used fuel completely apart

Radiotoxic material resides in many locations
Case: Once through (LWR, 50 MWth-day/kg-iHM burnup)



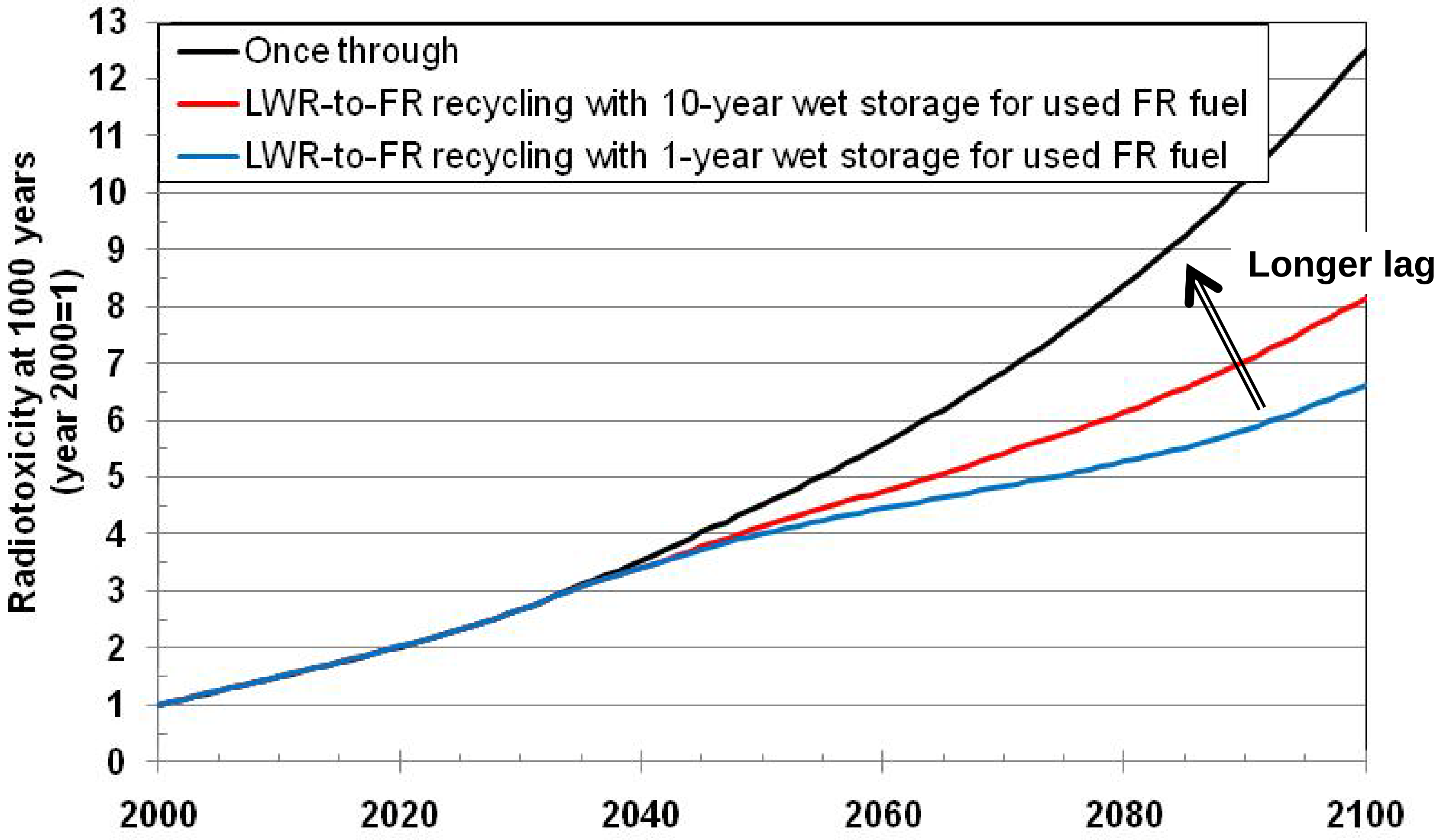
Radiotoxic material resides in many locations
Case: LWR feeds fast reactors (transuranic CR=0.50)



Two valid ways of expressing a key result Case: LWR feeds CR=0.50 fast reactors

- The radiotoxic inventory requiring deep geologic repository disposal (HLW) by 2100 has dropped by **factors 300 to 1000** relative to once through.
  - Optimistic assumption 0.1%/recycle of TRU into waste
  - New types of waste are generated.
- The total radiotoxic inventory in the system has dropped by a **factor of 2** by year 2100 relative to once through.
  - Assumption of 1-yr wet storage of used FR fuel.
  - Faster reduction possible if faster introduction of LWR separation plants versus LWR-dry storage backlog.
  - More radiotoxic inventory “in service”, to extract value from it.

Longer time lags ➔ less reduction in system radiotoxicity



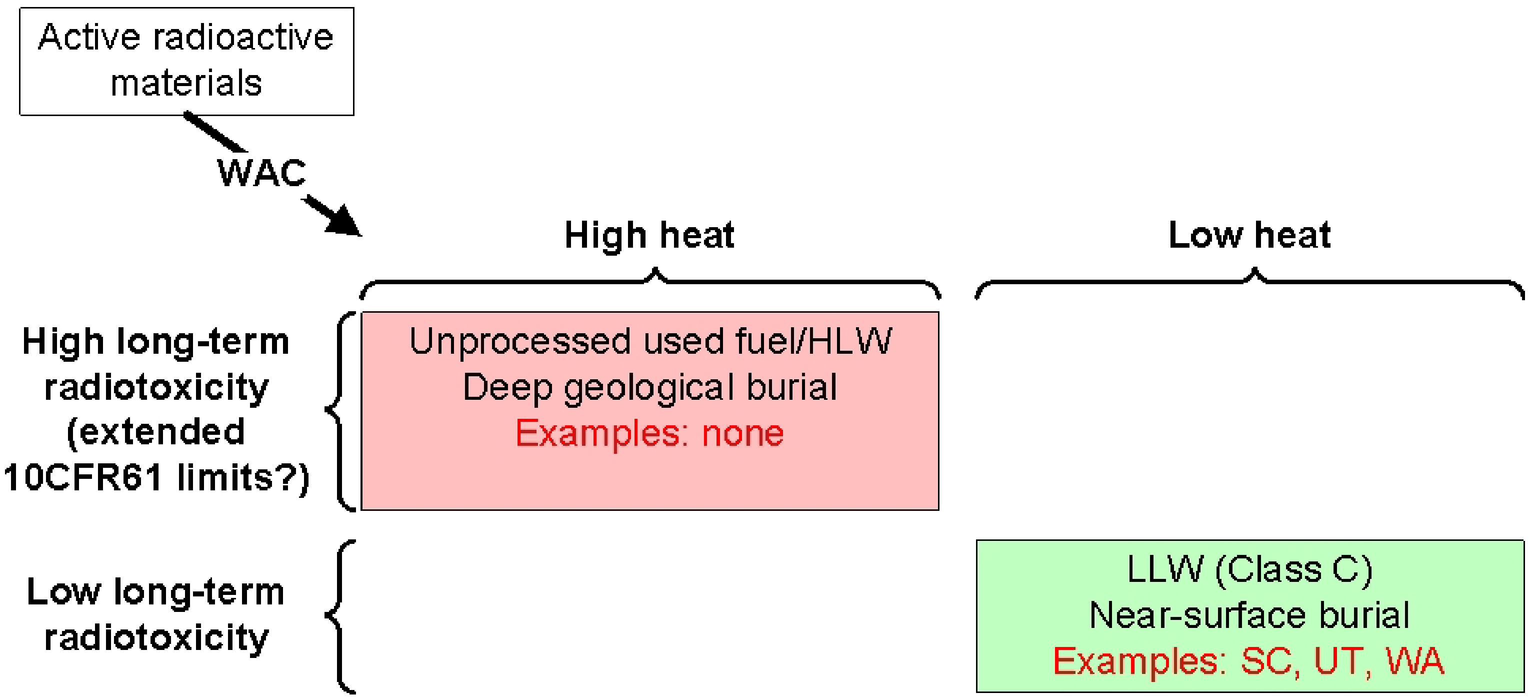
Is keeping material “in service” a problem or part of the solution?

- It is sometimes said that recycling TRU and U is just a way to “hold up” the material rather than admitting that you have to dispose of it.
- Options for TRU, U, Zr, etc.
  - Keep “in service” as long as beneficial to extract value and reduce ore consumption
  - Dispose before the value is exhausted and then consume new virgin material
- Waste minimization
  - Minimize use of virgin materials
  - Turn liabilities into assets

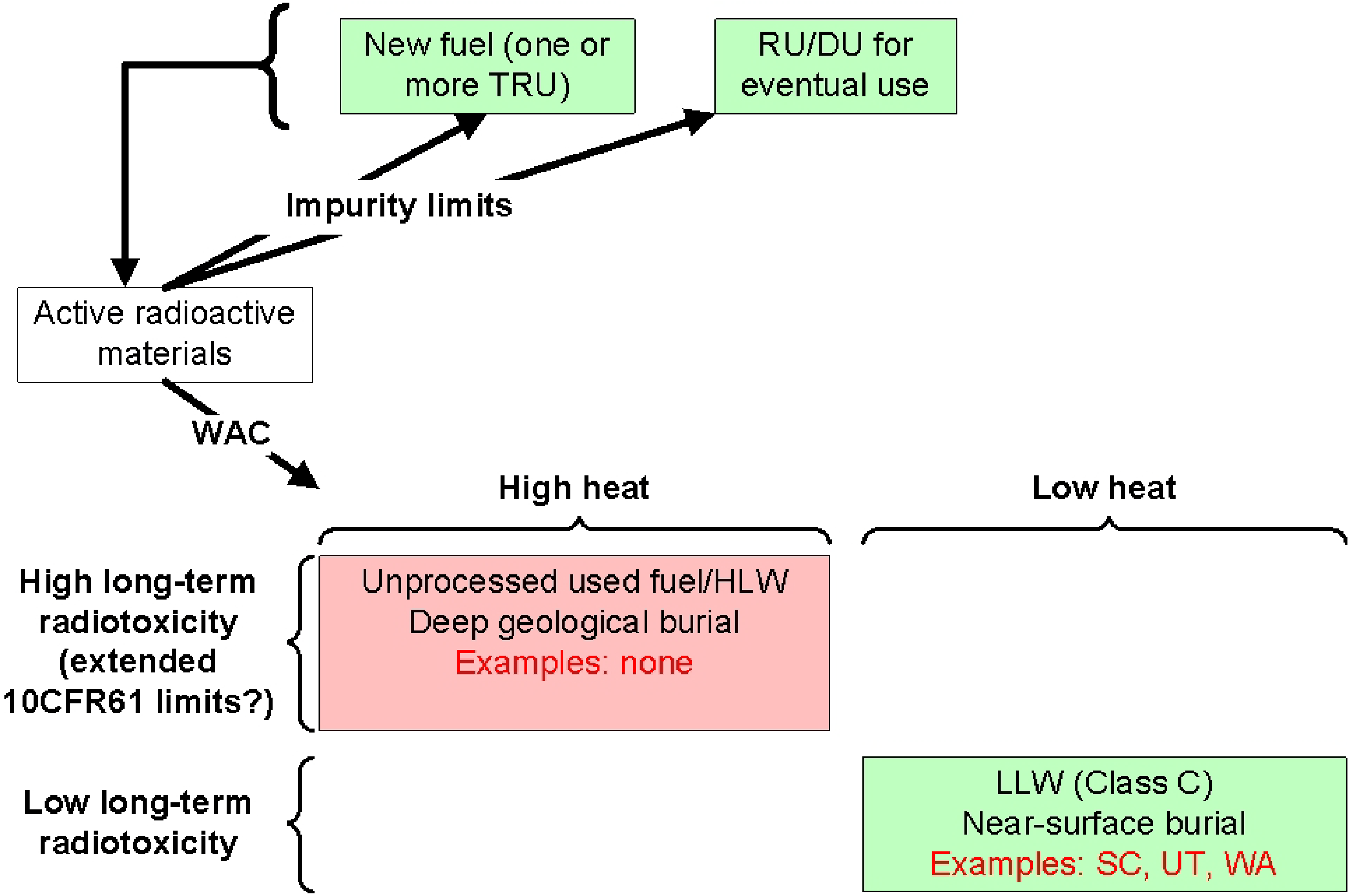
All mass must be dispositioned, it is not just about the used fuel going to a repository

Active radioactive materials

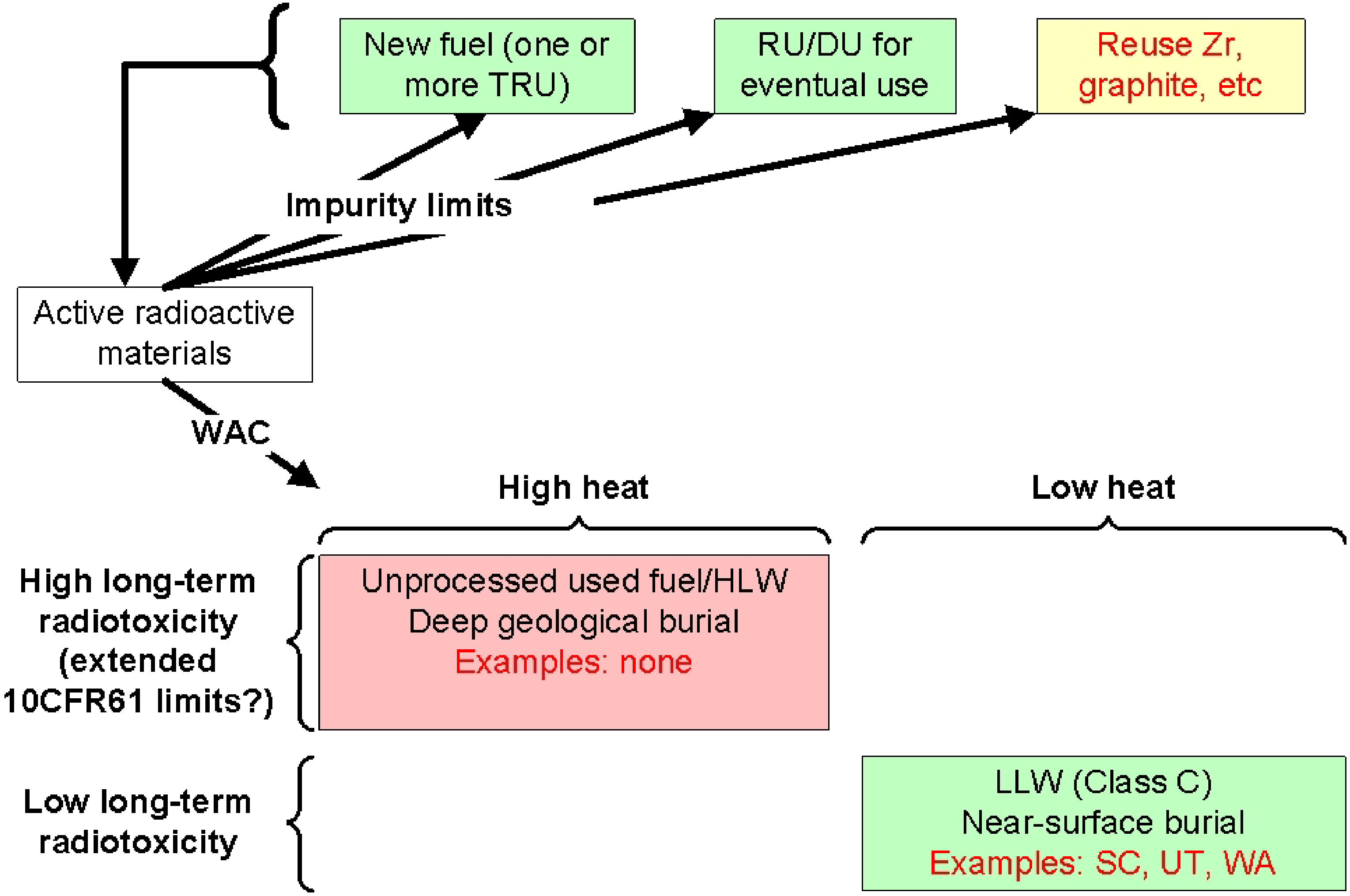
All mass must be dispositioned, it is not just about the used fuel going to a repository



Recycling TRU and U would add options



Can we add more options to reduce HLW?



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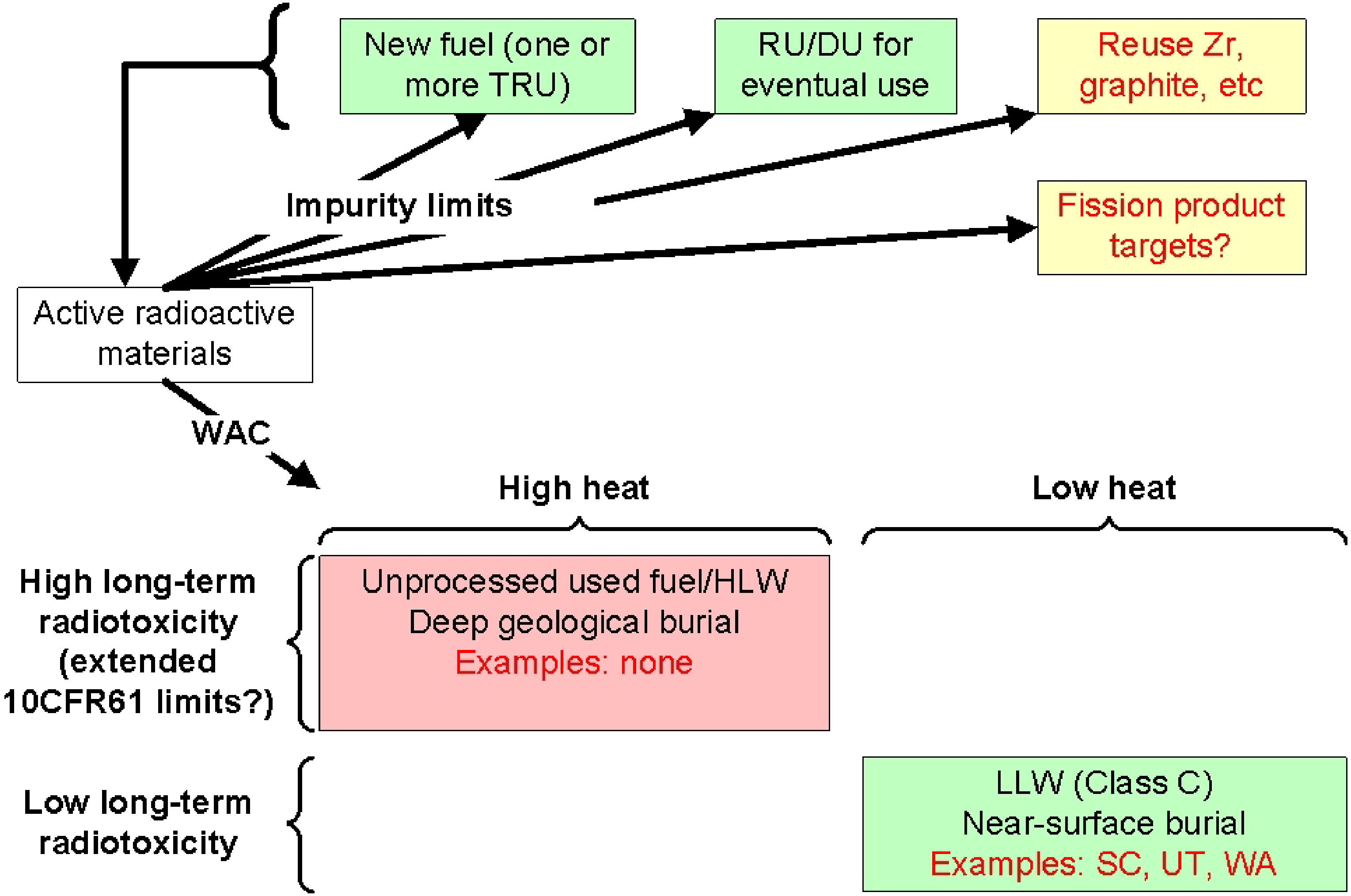
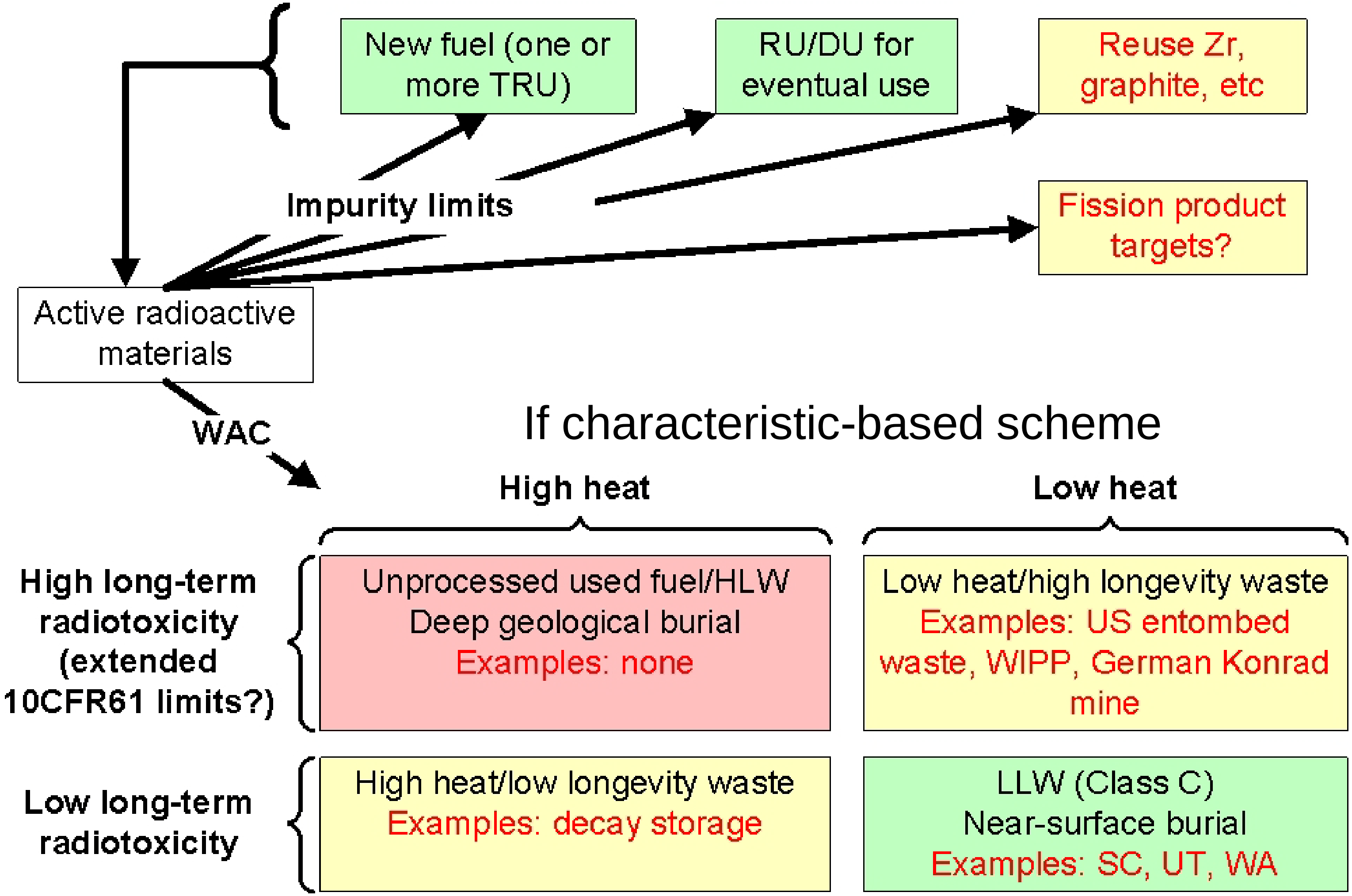


How low can residual used fuel/HLW be?



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Score card: what is theoretically possible?

	To reactor?		Pass non-HLW criteria?		
	Recycle as fuel?	Transmute?	Low-heat High-tox	High-heat Low-tox	Low-heat Low-tox
TRU	Yes	N/A	No	No	No
RU and DU					
Zirconium					
Lanthanides					
Other metals					
CsSr					
Halogens					
Inert gases					
H-3					
C-14					
Tc-99					

Score card: what is theoretically possible?

	To reactor?		Pass non-HLW criteria?		
	Recycle as fuel?	Transmute?	Low-heat High-tox	High-heat Low-tox	Low-heat Low-tox
TRU	Yes	N/A	No	No	No
RU and DU	Partial use unless breeder	N/A	Yes	If clean	If clean
Zirconium	Maybe	Unlikely	Maybe	Maybe	Maybe
Lanthanides	No	No	Maybe	If clean	Maybe
Other metals	No	No	Maybe	No	No
CsSr	No	Unlikely	No	Maybe	No
Halogens	No	Maybe	Yes	No	No
Inert gases	No	No	Yes	Yes	Yes
H-3	No	No	Yes	If clean	If clean
C-14	If graphite	No	Yes	Maybe	Maybe
Tc-99	No	Maybe	Yes	No	No

Conclusions

- It's a system
  - Account for all facilities, all mass
  - Use materials as long as you can, reduce ore consumption
  - Tolerating more impurities in fuel → less TRU in waste
- Timing matters
  - When build new facilities?
  - System responds slowly
- Recycling leads to more types of waste, but there seem to be options and precedents on what to do with them.
  - Consume TRU → less radiotoxic burden, shorter duration
  - Can decouple high heat vs. high long-term radiotoxicity
  - Characteristic-based waste classification, especially H/L and L/H…

Waste classification		Heat	
		High	Low
Long-term hazard	High	HLW	
	Low		LLW-C

BACKUP SLIDES

References

- J. J. Jacobson, et al, "Verifiable Fuel Cycle Simulation Model (VISION): A Tool for Analyzing Nuclear Fuel Cycle Futures," (accepted by Nuclear Technology).
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- S. J. Piet, et al, "Must Advanced Fuel Cycles Produce High-Level Waste?," Integrated Radioactive Waste Management in Future Fuel Cycles, November 8-12, 2009, Charleston, South Carolina.
- J. J. Jacobson, et al, VISION User Guide - VISION (Verifiable Fuel Cycle Simulation) Model, INL/EXT-09-16645, August, 2009.
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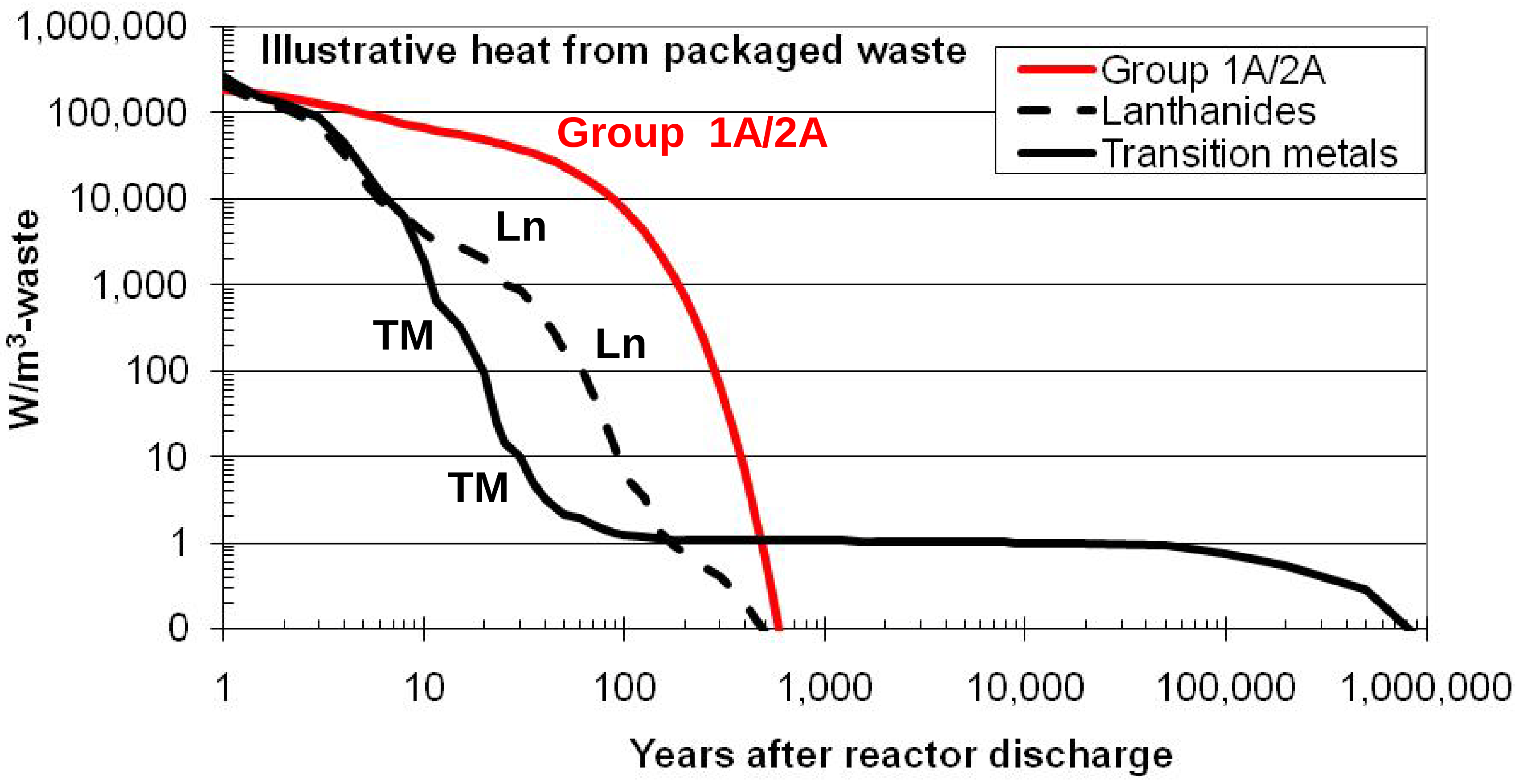
Depending on waste density, packaging, criteria, and purity, disposal of lanthanides & transition metals may not be heat-limited



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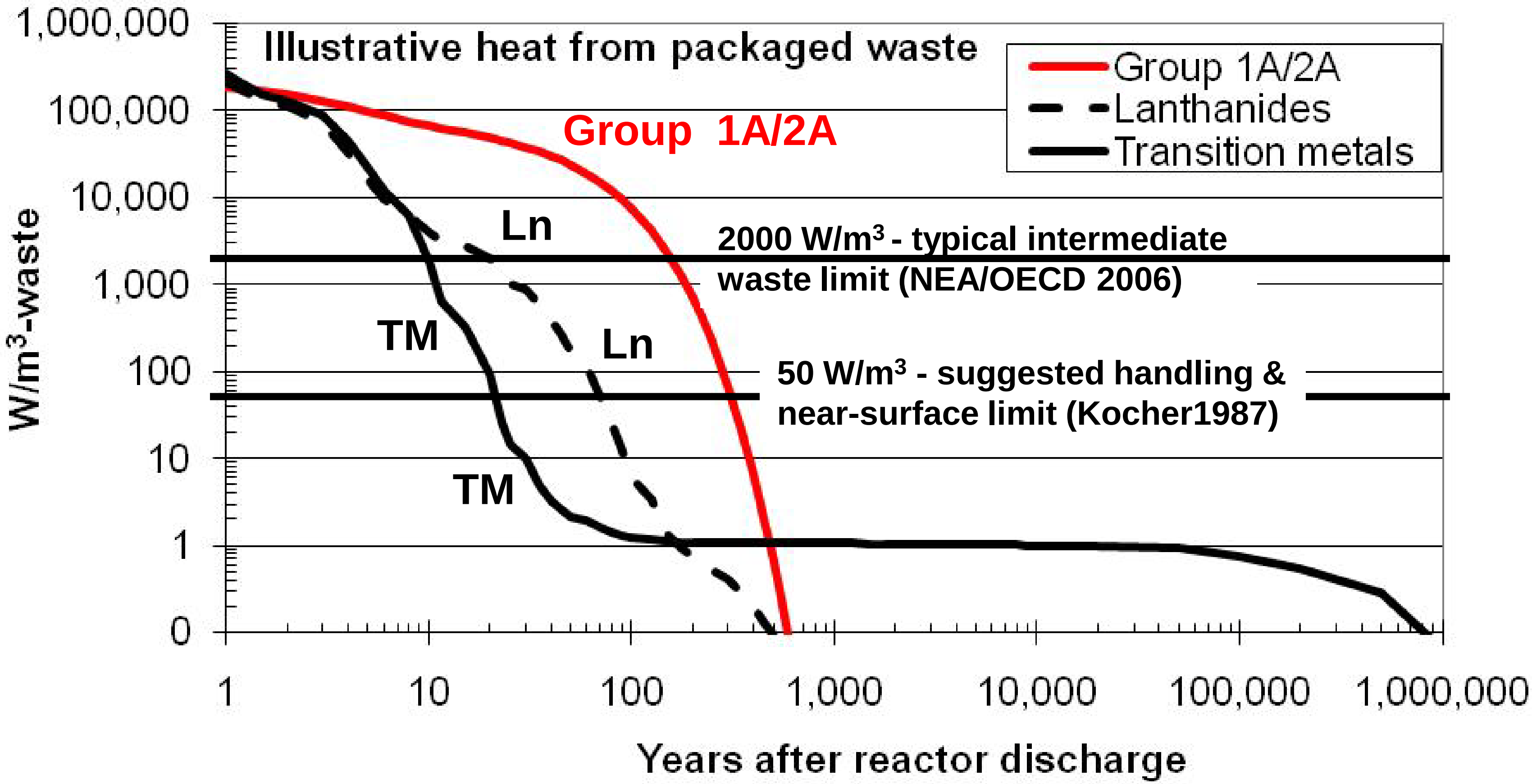

Potential radiotoxicity longevity criteria

- 100 nCi-TRU/g-packaged-waste (alpha-emitters, halflife >20 yr)
  - *40CFR191*
- 100 nCi-TRU/g-packaged-waste (alpha-emitters, halflife >5 yr)
  - *10CFR61*
- Limits for specific isotopes
  - Many potentially relevant isotopes are not in 10CFR61
  - When take the 10x metal waste form credit?
  - Fetter extended 10CFR61 analysis to all isotopes, halflife >5 yr.
    - *S. Fetter, E. T. Cheng, and F. M. Mann, "Long-Term Radioactivity in Fusion Reactors," Fusion Engineering and Design, 1988.*
    - *S. Fetter, E. T. Cheng, and F. M. Mann, "Long-Term Radioactive Waste from Fusion Reactors: Part II," Fusion Engineering and Design, 1990.*

Preliminary screening: isotope limits

- 100 nCi-TRU/g-packaged-waste (>5 yr) & limits for Pu241, Cm242 limits
  - ➔ Pu and Am constrains lanthanides and Group 1A/2A – preliminary estimate is a limit of ~0.1% Pu or Am getting into waste
  - ➔ Letting Pu241 decay into Am241 toughens constraint
- Expanded 10CFR61 isotope concentration limits
  - Constrains: U+TRU, halogens (I129), Tc99, transition metals (Sn126)
  - Maybe ok: Lanthanides (Ho166m), Group 1A/2A (what Cs135 limit?)
  - Not constrained: Inert gases, H3
- Others?