Global Nuclear Energy Partnership (GNEP) Waste Treatment Baseline and Integrated Waste Management Strategy

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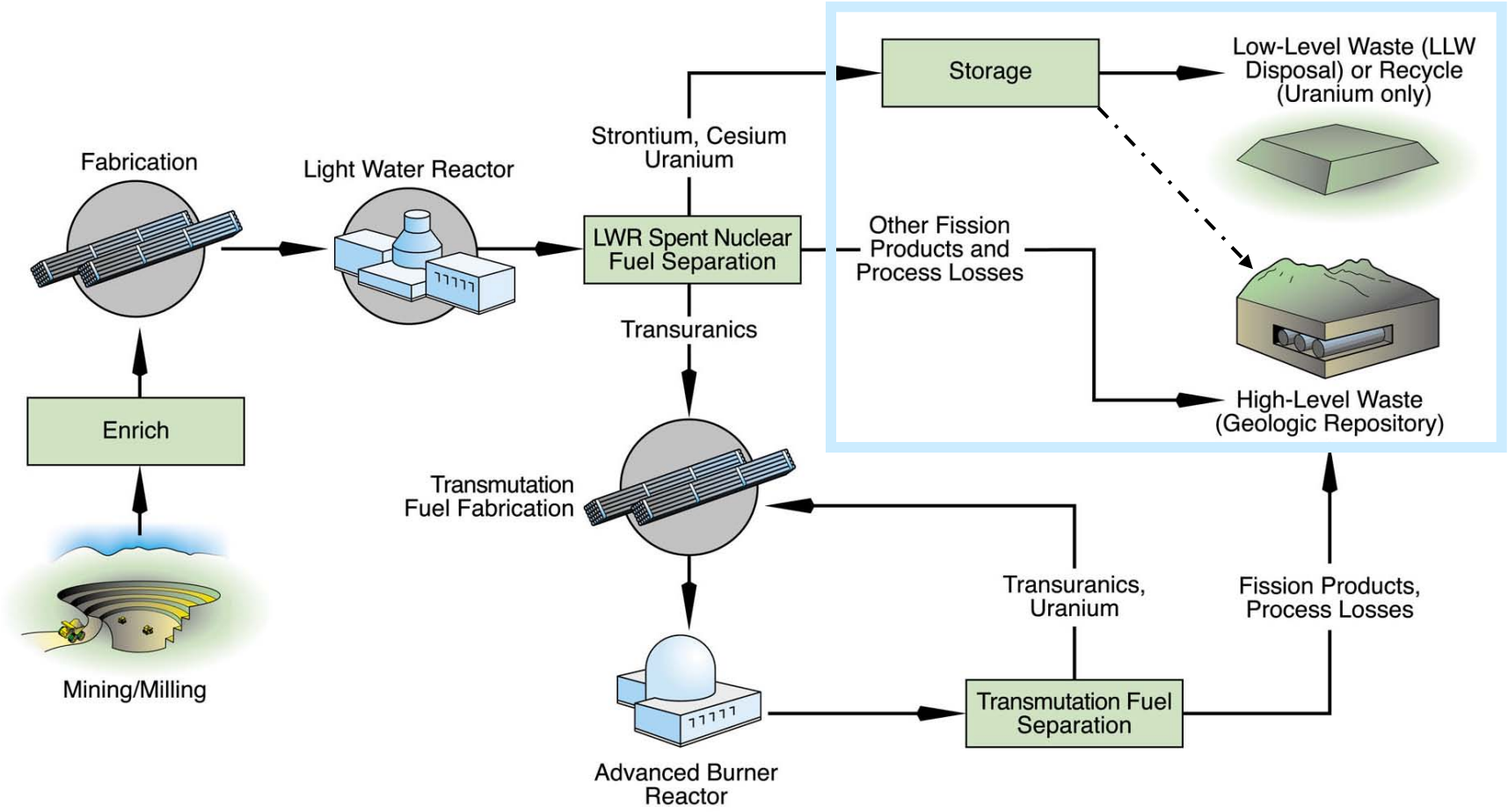
Presentation Outline

- **Waste Treatment Overview**
  - Waste Streams
  - Evaluation Criteria
  - Recommended Waste Form Baseline
  - R&D and Trade Studies
- **Integrating Waste Management**
  - Integrating the fuel cycle
  - New concepts for risk based regulations & collaboration
  - Details of a strategy for managing all radioactive wastes
- **Concluding Points**

GNEP Overview

- **Reduce America's dependence on fossil fuels**
- **Provide abundant energy without generating carbon emissions or greenhouse gases**
- **Recycle used nuclear fuel to minimize waste and curtail proliferation concerns**
- **Safely and securely allow developing nations to deploy nuclear power to meet energy needs**
- **Assure maximum energy recovery from still-valuable used nuclear fuel**
- **Reduce the number of required U.S. geologic waste repositories needed for the remainder of this century**

Closing the Fuel Cycle



Optimize Repository Disposal

Significantly reduce the long-lived nuclear waste to be disposed of in a geologic repository making disposal less complex and minimizing the need for additional repositories

- **Repository needed in all cases**
- **One repository may meet U.S. needs this century with GNEP**

Treatment Baseline Report Scope

- Technical Recommendations to Stabilize:
  - UDS
  - Tc
  - Metals – hulls/hardware
  - Fission products

  } Metal Waste Form
  - Cs/Sr — Decay Storage Waste Form
  - Lanthanides — Oxide Waste Form (possibly combining Cs/Sr with Ln)
  - Gaseous FP – I, H, C, Kr, Xe — Specialized Waste Forms

Evaluation Criteria

- **Commercial Practicability (weighted 40%)**
  - Technical Practicality, Flexibility, Scalability, Waste Loading, Processing Cost, Secondary Waste Generation
- **Technical Maturity (weighted 10%)**
  - Development Cost/Schedule to Implement,
- **Waste Form Performance (weighted 40%)**
  - Thermodynamic/Rad/Mech/Thermal Stability, Chemical Durability
- **Stream Specific Criteria:**
  - Heat transfer, RedOx Sensitivity, Resistance to degradation by decay, Resistance to radiolysis, Ability to treat more than one waste, Experience with disposal of similar materials
- **Stakeholder Acceptance (weighted 10%)**
  - All processes designed to meet standards

Treatment Baseline Report Recommendations

Waste Stream	Waste Form(s)	
	UREX+	Echem
Tc	Metal Alloy, possibly containing UDS and transition metal FP.	Metal Alloy containing UDS and transition metal FP.
Cs/Sr	Glass or Ceramic	Glass-bonded sodalite. May contain ^{129}I carried over from electro-reduction.
Ln	Glass, may be combined with Cs/Sr	Borosilicate glass or glass-bonded sodalite if combined with Cs/Sr.
FP	Included in metal waste form with Tc described above or Ln glass.	Included in metal waste form with Tc described above.
UDS	Included in metal waste form with Tc described above.	Included in metal waste form with Tc described above.
Metals—Cladding & Hardware	Compacted metal. Metal ingot if cost effective or required for disposal.	Compacted metal. Metal ingot if cost effective or required for disposal.

Treatment Baseline Report Recommendations (cont)

Waste Stream	Waste Form(s)	
	UREX+	Echem
Tritium	Grouted tritiated water (HTO).	Grouted tritiated water (HTO).
Iodine	Encapsulated silver zeolite.	Glass-bonded sodalite w/Cs/Sr and/or lanthanide FP.
Carbon-14	Grouted $Na_2/CaCO_3$ potentially including the tritiated waster.	Grouted $Na_2/CaCO_3$ with residual in glass-bonded sodalite w/Cs/Sr and/or lanthanide FP.
Kr	Decayed in fuel then released. Pressurized gas cylinder w/wo Xe if fuel storage is insufficient.	Decayed in fuel then released. Pressurized gas cylinder w/wo Xe if fuel storage is insufficient.

R&D Tasks - Technetium

- Chemically reduce and effectively capture the soluble Tc and transition metal elements from the expected aqueous solutions
- Optimize alloy formulations for waste loading to immobilize Zr, Mo, Ru, Rh, Pd, and Tc
- Evaluate alternative reductants to ferrous sulfamate in separations
- Quantify capacity of alloys to accommodate non-metallic feed materials including Zr(MoO4)2 and TcO2
- Develop a mechanistically-based model for alloy degradation

R&D Tasks - Cs/Sr (Decay Storage)

- Determine effects of transmutation and fate of the stable decay daughters.
- Optimize glass and ceramic formulations for waste loading, considering the effects of radiolysis, transmutation, thermal output, and durability during decay storage.
- Develop process for removal of Cs and Sr from Echem salts
- Develop and demonstrate flowsheets for Cs/Sr immobilization
- Evaluate benefits of heat management concepts including incorporating waste form in a metal matrix, internal or external fins, wet vs. dry storage, etc.
- Evaluate disposal options following decay storage
- Consider combination with other streams into common form

R&D Tasks - Lanthanides/FP (Oxide form)

- Optimize glass/ceramic formulations to immobilize Fe, Ln, Zr, Mo, Ru, Rh, and Pd for combined Ln/FP streams
- Optimize Ln-glass formulations
- Define operating envelope for processing glasses/ceramics in induction melter (CCIM for Ln/FP and HWIM for Ln)
- Evaluate alternative reductants to ferrous sulfamate in separations
- Develop glass/ceramic formulations for waste loading of Cs/Sr/Ln elements for processing in the CCIM
- Develop process for removal of Ln/FP from Echem salts and optimize waste form

R&D Tasks - Volatile radionuclides

- Characterize selectivity of radionuclides in gas treatment steps
- Evaluate disposal of ^{14}C and HTO as LLW
- Select baseline I capture and immobilization materials and processes
- Evaluate long-term retention of iodine on waste form
- Evaluate need for Kr capture
- Develop non-cryogenic Xe/Kr separation methods if required
- Determine tritium DF on 3A molecular sieve from very low dew point gas streams
- Develop ^{14}C waste forms for GTCC disposal

R&D Tasks - Activated Metals

- **Characterize activation of hardware components to evaluate co-disposal versus segregation of hardware and TRU contaminated cladding.**
- **Define conditions required to melt the collected hardware, including the needed additives, melting temperature**

R&D Tasks - General Studies

- Evaluate all waste/byproducts for beneficial reuse.
- Characterize recommended waste forms to support eventual acceptance to planned or conceptual disposal facilities.
- Evaluate potential for cross-contamination in waste streams and potential ramifications to disposition strategy
- Determine the optimal waste stream combinations for co-immobilization and disposal.
- Perform trade studies for LLW treatment to reduce volume, recover radionuclides, and dispose.
- Develop detailed mass balances to show radionuclide inventories in various waste streams and amounts and categories of LLW.
- Collect data to qualify waste forms for disposal

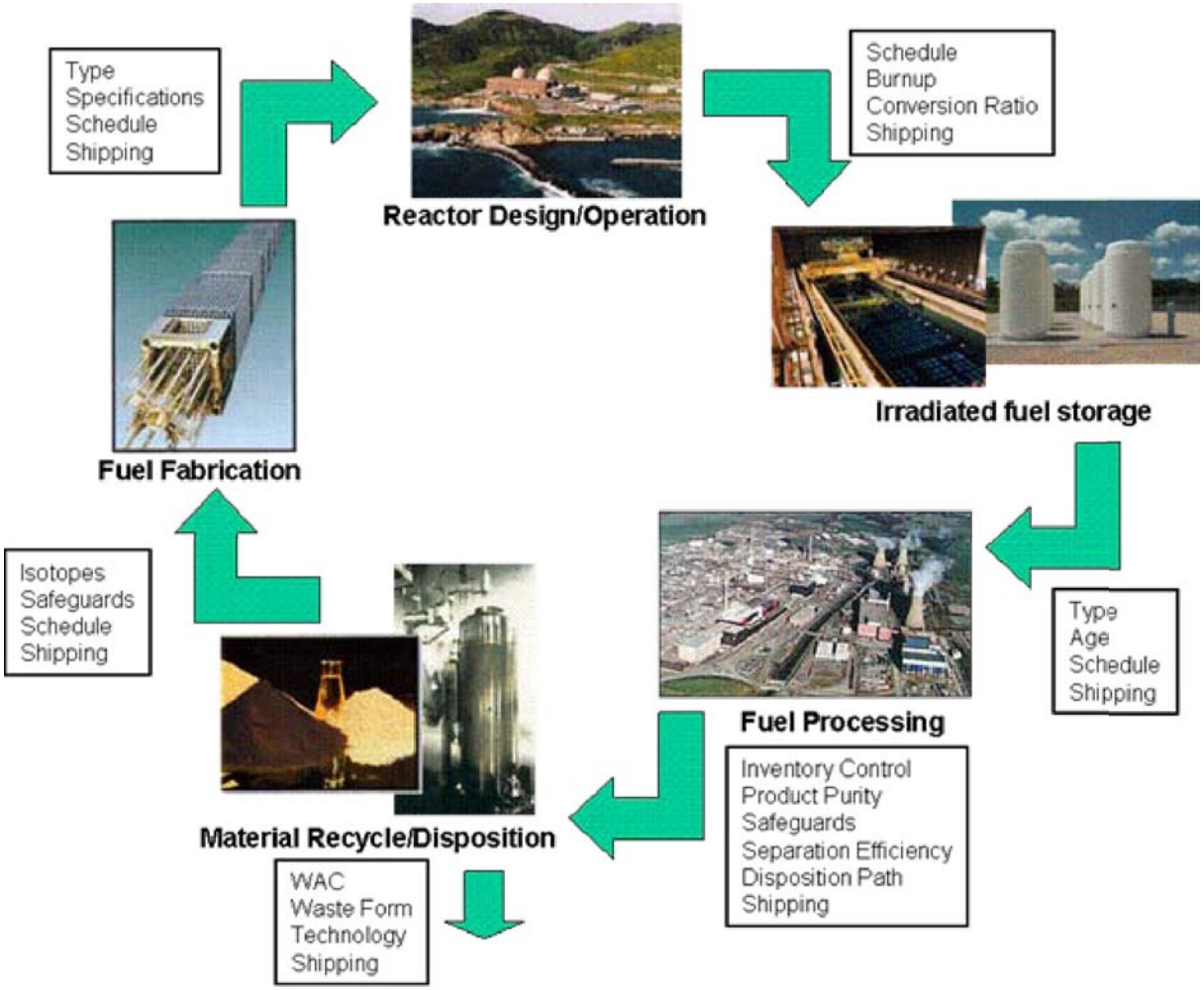
Waste Treatment Baseline Concluding Points

- GNEP Separations enable consideration of more efficient waste management strategy
- May make “HLW” classification obsolete
- Waste chemistry matched to waste form and environment to maximize durability and minimize mobility
- Many waste forms still conceptual
- Significant work needed to define characterization needs
- More work need to make waste forms and perform characterization

GNEP Integrated Waste Management Strategy

- **IWMS proposes a simpler system to dispose of all radioactive wastes**
  - Builds on a fuel cycle using advanced separations
  - Assumes 70,000 MTHM limit is lifted, or strategy applies to second repository
  - Suggests need for NWPA modification to allow risk-based waste management similar to provisions of 10 CFR 61 with added radionuclides
  - Could be applied to DOE, NRC, space, defense, medical, and diagnostic wastes
- **Emphasizes recycle and reuse, but based on economic recovery evaluation factoring in value of material and cost avoidance of disposal**
- **Considers need for industry to have a reliable system to routinely transport nuclear materials and dispose wastes**
- **Integrates current EM GTCC EIS effort**
- **Based on a collaborative approach among DOE-NE/EM/RW and NRC/EPA**

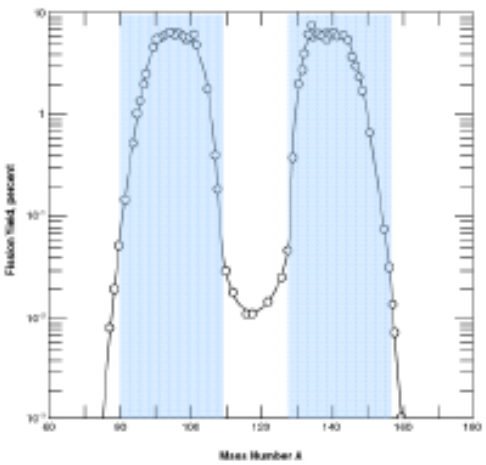
Nuclear Fuel Cycle Integrating Waste Management



Separations and Stabilization by Chemical Family

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	L	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	A															

Thermal Neutron Fission of U-235

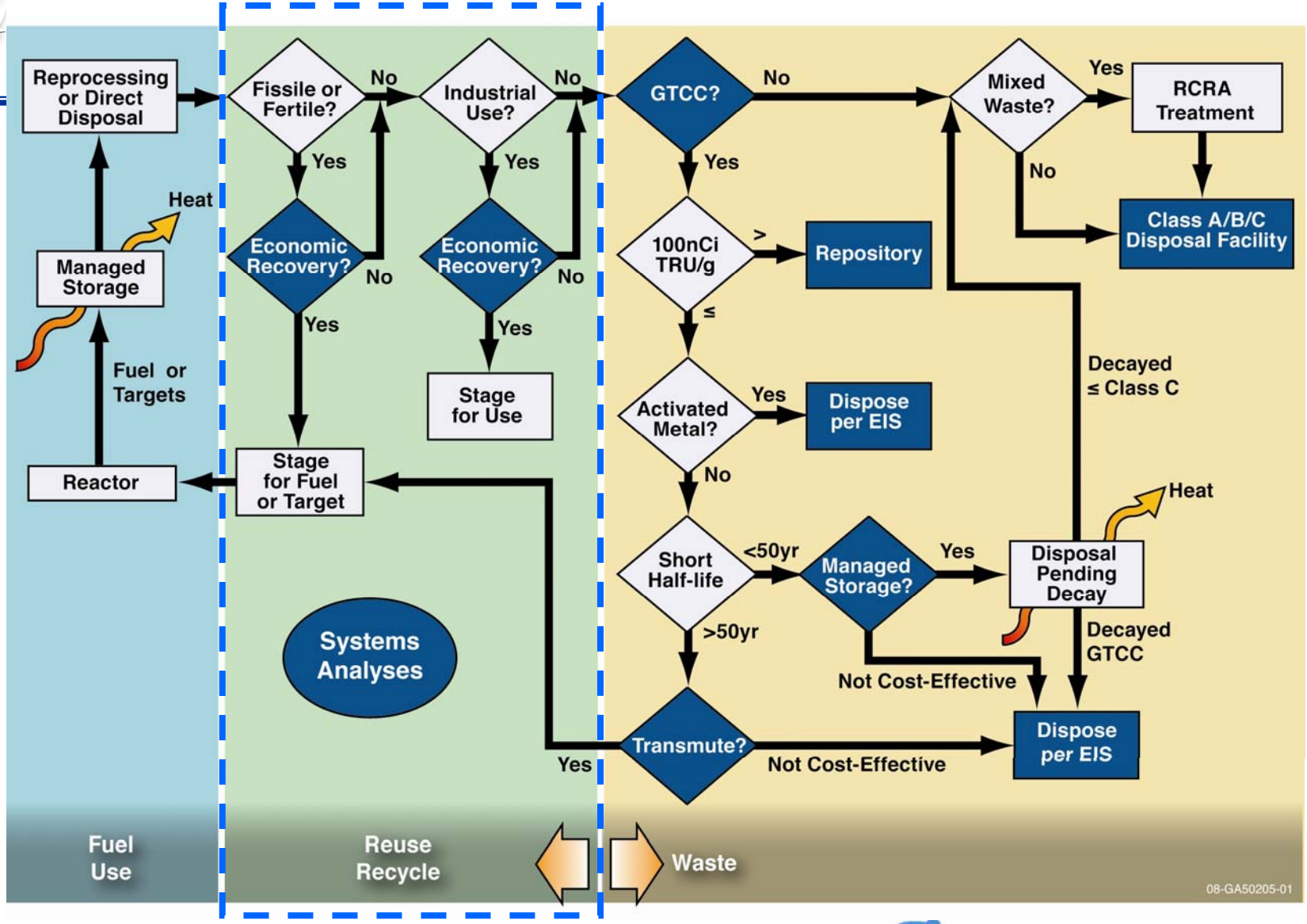


La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Advanced Separations Enables New WM Strategy
New wastes = New Options = New Strategy

- **Consider useful materials and radionuclides for recycle/reuse**
  - Fissile isotopes
  - Commercial use of radionuclides
- **Expand technical bases for additional waste forms**
- **Designation of a routine disposal pathway for GTCC not requiring a case-by-case performance assessment.**
  - $\geq$100 nCi TRU/g
  - Activated metals
  - Short and long half-life radionuclides
- **Consideration of the concept of "decay storage" in secure storage facilities to reduce heat impacts of radionuclides such as ^{137}Cs, ^{90}Sr, ^{3}H, and ^{85}Kr to decay to LLW/release limits.**

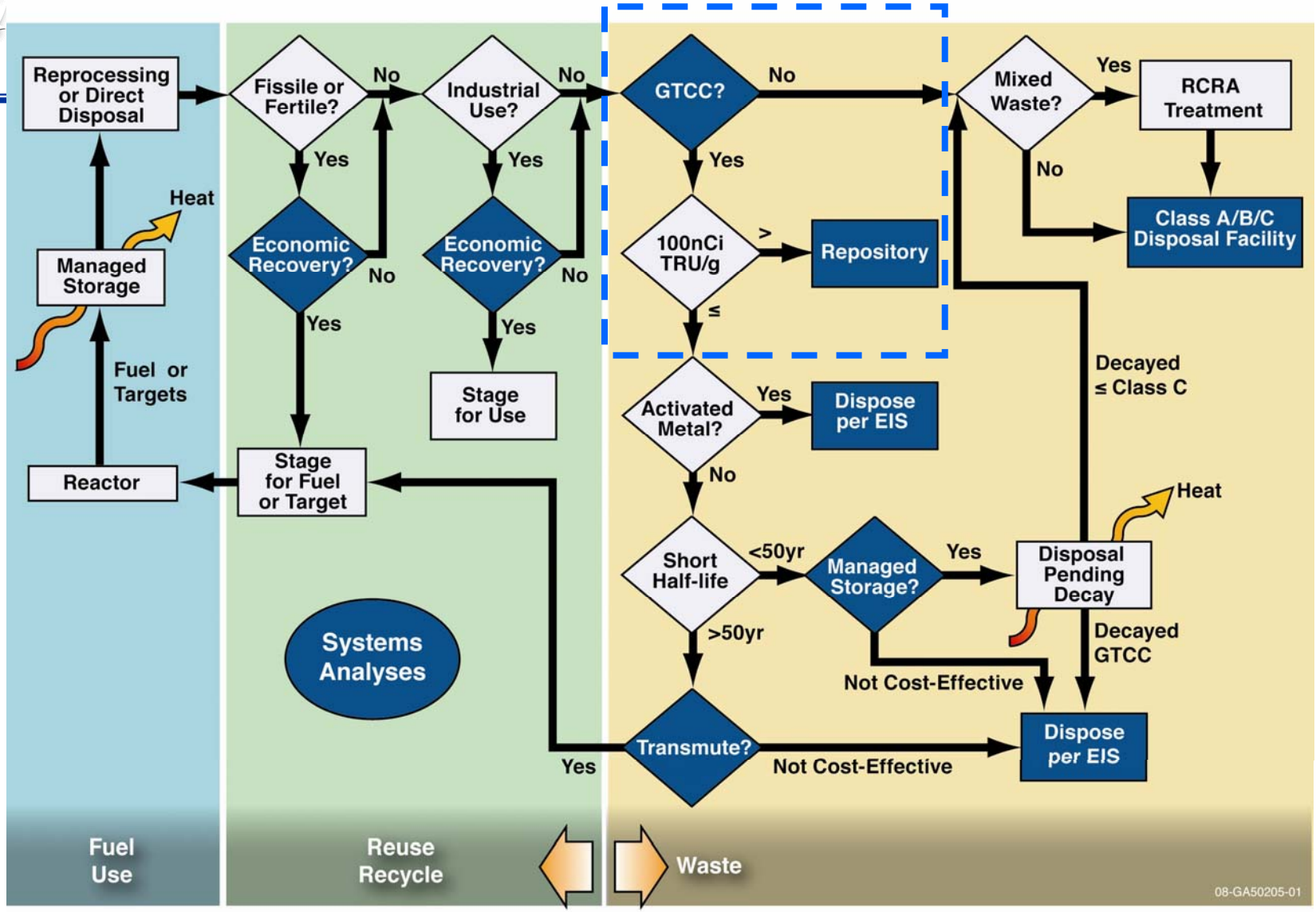
Integrated Waste Management Strategy Logic Diagram



Recycle/Reuse of Byproducts/Wastes

- **Similar to Rocky Flats Economic Discard Limit for Pu**
  - Considered value of uranium
  - Considered reactor time
  - Did NOT consider waste management
- **Economic Recovery Limit**
  - Value as fuel or industrial application
  - Cost of recovery/purification
  - Reduction to repository source term (inventory/duration) and heat
  - Fuel/target fabrication/irradiation/recycle costs
  - Remote vs. glovebox operations
  - Secondary waste generation
  - Potential for diversion and accidents

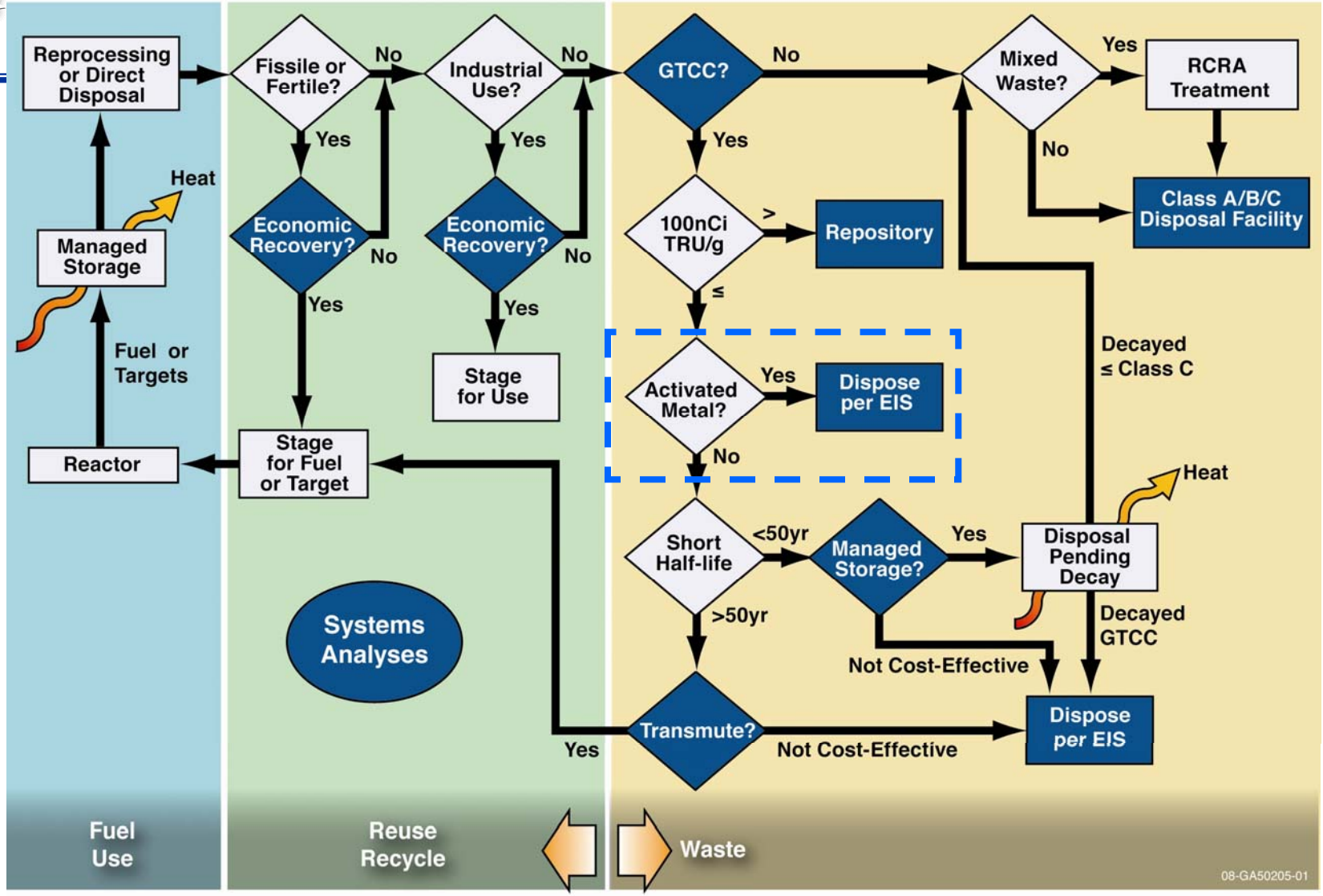
Integrated Waste Management Strategy Logic Diagram



GTCC ≥ 100 nCi TRU/g

- **Source of materials**
  - Contaminated cladding
  - Separations losses
  - Fuel fabrication losses
  - HVAC & process filters, maintenance, job-control, and balance-of-plant
- **Value of reconsidering contamination limit**
- **WIPP precedent for defense wastes**
- **Japanese definition of TRU is long-lived, low heat**
  - Actinides
  - Technetium
  - Iodine
- **Pending EIS IWMS assumes WIPP precedent for defense-TRU**

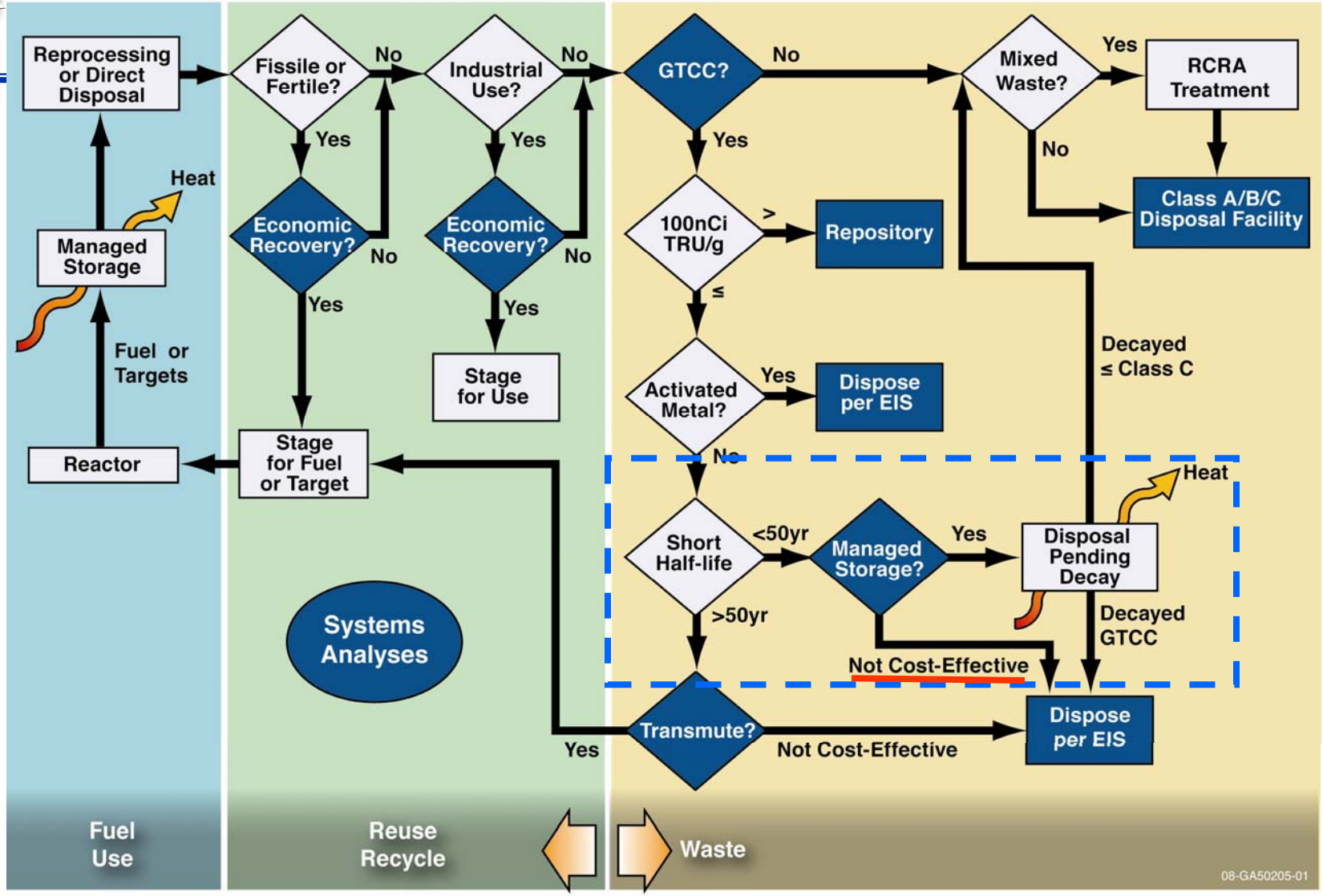
Integrated Waste Management Strategy Logic Diagram



Activated Metals

- **A Primary Category in the DOE-EM GTCC EIS**
- **GNEP sources of materials**
  - Fuel cladding
  - Non-fuel-bearing hardware
  - Pressure vessels (other D&D metals)
- **EIS options**
  - Enhanced Surface Disposal
  - Borehole
  - Geologic Repository
- **Pending EIS IWMS**

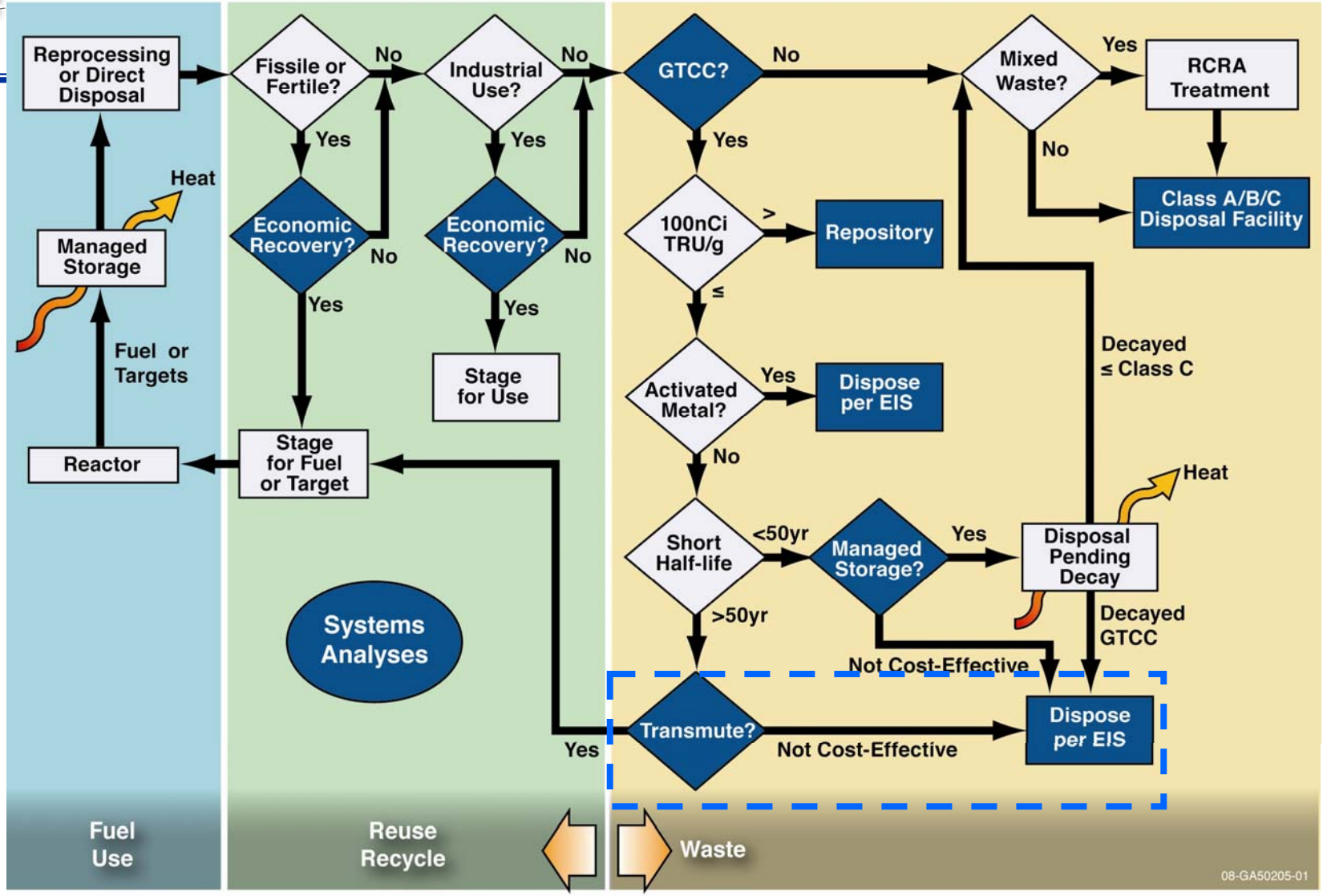
Integrated Waste Management Strategy Logic Diagram



Engineered Storage for Decay

- **Potential Radionuclies**
  - ^{137}Cs
  - ^{90}Sr
  - ^{85}Kr
  - ^{3}H
  - ^{xxx}Cm
- **Heat Management Strategy Trade-Studies of Various Concepts**
  - Extended SNF aging
  - Interim waste form storage for up to 10 half-lives
  - Storage at reactor, reprocessing plant, repository, interim facility
  - Transportation, handling, processing, security, permitting issues
  - Facility M&O costs
  - Ultimate disposition of materials (cross-contamination, specific isotopes)

Integrated Waste Management Strategy Logic Diagram



Transmutation of Long-lived Radionuclides

- **Potential Radionuclides**
  - ^{99}Tc
  - ^{129}I
  - ^{xxx}Am
  - ^{xxx}Cm
- **Destruction in fuel or targets**
  - Remote fabrication
  - Irradiation costs
  - Multiple recycles
  - Waste generation

Volume Effects in Waste Management

- **Repository capacity limited by legislation, dose, heat, or volume**
  - NWPA limits first repository/MRS until second repository is in operation
  - Potential dose is ultimate functional design criteria
  - Operational design criteria has thermal limits to meet dose requirement
  - Volume is generally not a limiting factor for repository capacity
  - Waste volume affects transportation and placement operations
- **Canistered (TAD) SNF ~ 1.24-1.51 m^3/MTHM**
- **Areva reports ~ 0.31 m^3 HLW+ILW/MTHM for 40 GWd/MTHM**
  - ~0.13 m^3 glass/MTHM (Vitrified HLW MA/FP/UDS)
  - ~0.18 m3 metal/MTHM (Supercompacted ILW hulls and hardware)
- **Rokassho is similar to La Hague**

Comparison of WM volumes w/wo Reprocessing

- **IWMS suggests classification by risk using Class A/B/C, GTCC**
  - 0.013-0.060 m^3 glass/MTHM (Cs/Sr/Ln w/wo TMFP from 50 GWd/MTHM)
  - 0.007-0.004 m^3 metal/MTHM (Tc/UDS w/wo TMFP varies inversely with glass)
  - 0.020-0.064 m^3 total repository waste not including hulls/hardware or offgas wastes (iodine, ^{14}C)
  - 0.047-0.072 m^3 Hulls & Hardware
  - 0.002-0.009 m^3 Iodine concept (order-of-magnitude)
  - 0.019-0.038 m^3 ^{14}C concept (order-of-magnitude)
  - 0.088-0.183 m^3 ΣGTCC
- **Volume reduction ~2-6.5 glass + metal forms vs COEX HLW glass**
- **Volume reduction ~8-14 ΣGTCC vs. canistered SNF**

- **Primary benefit is not volume reduction, rather more durable waste forms and a strategy to increase repository capacity**

Secondary Wastes

- **Job Control (maintenance, decontamination, PPE)**
- **Balance of Plant (laboratories, waste water, utilities, filters, etc.)**
- **GTCC estimated at ~ 5-20xHLW**
- **LLW Class A/B/C estimated at ~3-5xGTCC**
- **Economics of volume reduction**
  - Limited waste disposal options
  - Industry has essentially eliminated MLLW generation
  - Waste minimization programs
  - Compaction, steam-reforming, and possibly incineration if cost-effective
- **DOE has taken responsibility for GTCC similar to SNF**
  - Limited commercial cost incentive for GTCC waste disposal

IWMS Conclusion

- **IWMS describes simplified process for managing all radioactive wastes based on risk**
- **Repository wastes grouped chemically with waste form matched to wastes**
  - Maximizes durability
  - Minimizes volume
- **Identifies trade studies to evaluate cost effectiveness of options**
- **Provides basis for collaboration among DOE-NE/EM/RW and NRC/EPA**
- **Independent of repository environment, thermal vs fast reactor recycling, fuel or target type, allows phased approach to separations including PUREX, COEX, UREX+, and Echem**

Thank you for your kind attention.

Questions?

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