The Role of Accelerators in the Energy Problem

IPAC10

TUZRA01

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Outline

- **Case for an increase in the use of nuclear power and the main concerns**
- Used fuel management – a major impediment to increasing nuclear power usage
- Path to increasing the public acceptance of used nuclear fuel – solving the americium problem
- SMART: Subcritical Minor Actinide Reduction by Transmutation

Nuclear Power Addresses Key National Security Issues

- In the United States, the 104 operating nuclear reactors:
  - Currently produce about 20% of the U.S. electricity.
  - Provides greater than 70% of the U.S. emission-free electricity.
- The fuel for nuclear reactors is sufficient for the next 50 to 100 years.
- The fuel comes from politically stable countries.

Nuclear Power Is The Best Present Choice For Emission-Free Power

- **A 1 GW electric nuclear power plant without recycling used nuclear fuel produces 20 tons, mostly U-238, (~2m^3) of used fuel per year with no significant airborne emissions.**
- **For comparison, a 1 GW electric coal-fired plant burns 3,400,000 tons of coal per year and produces:**
  - copious quantities of emissions:
    - CO_2 (7,400,000 tons)
    - SO_2, NO_x (20,000 tons each)
    - Hg vapor (250 lbs)
    - Radon
  - 340,000 tons of solid waste:
    - 27 tons of radioactive material, mostly U-238 and Th-232
    - toxic compounds of arsenic, copper, barium, cadmium, chromium, lead, mercury, nickel, and thallium
- **Nuclear power in the U.S. has the highest operating availability, > 90%, of all the present electric power sources.**
  - For comparison, geothermal is 75%, coal with 73%, wind is 27%, and solar is 19%.
  - Availability determines the base grid support required, either through stored power or alternative power sources, to make up for times of low production.

Nuclear Fuel Appears Ideally Suited To Recycle

- **Only a few percent of the available energy in the fuel is extracted on a single pass and the majority of the "problem wastes" can be burned in fast-neutron spectrum systems.**

- **Most of the remaining wastes have half-lives of less than a hundred years and can be safely stored in man-made containment structures (casks or glass).**

- **A geologic repository can handle the very small amount of remaining long-lived waste.**

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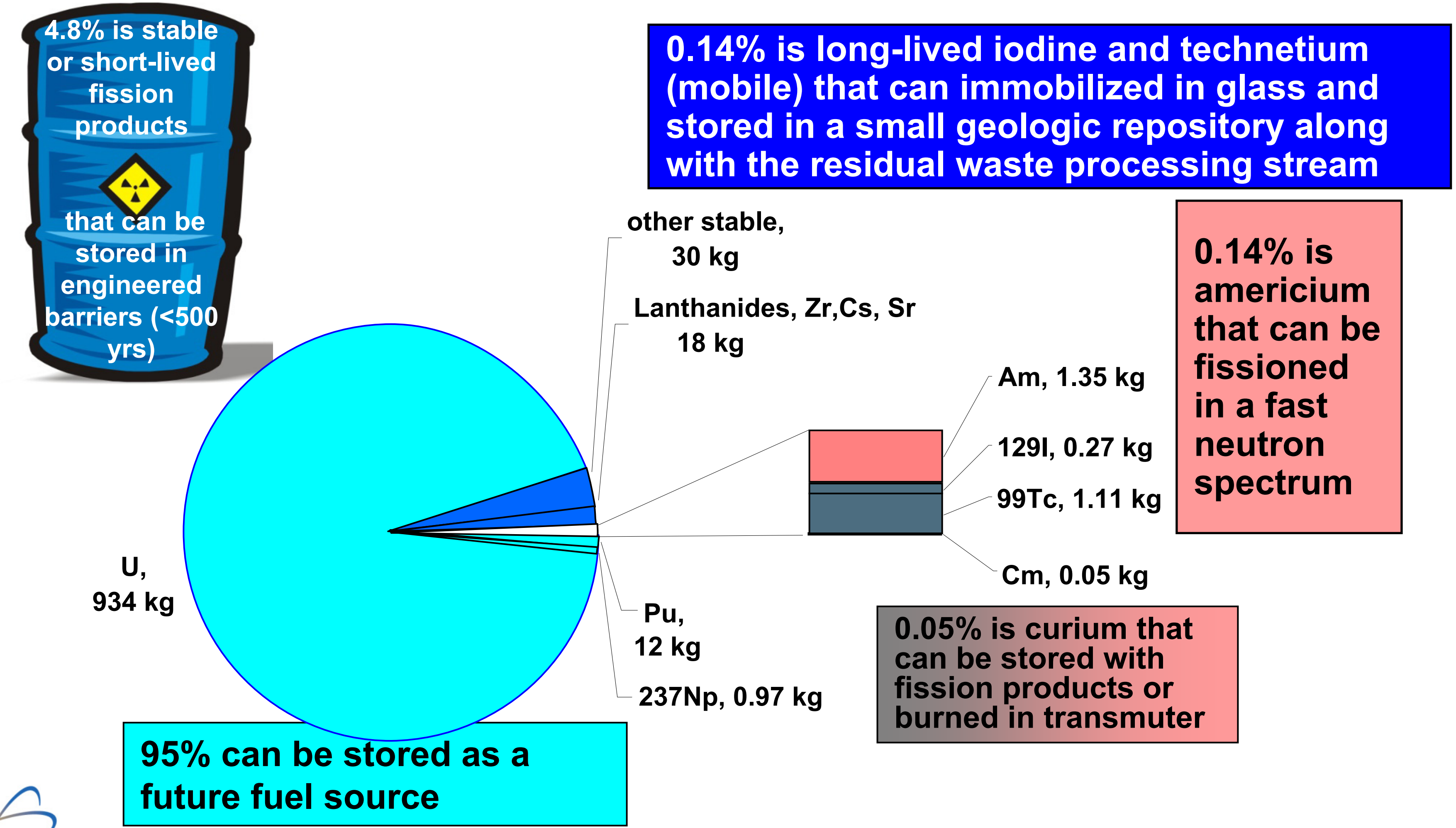
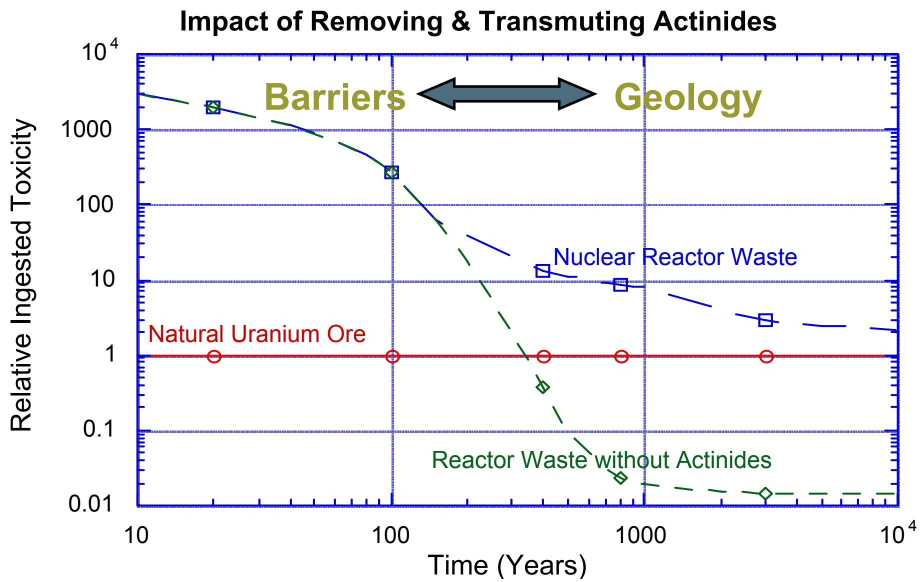
92% of Used Nuclear Fuel is U238 That Carries The Same Health Concerns Of Any Heavy Metal



High-Burn PWR 50 GW/Mt, 25-year cooling per MT of initial fuel

Need To Reduce The Isolation Time-Frame To Fit Within Engineered Barrier Limits



Unprocessed used fuel contains materials that require isolation from environment for > 1,000 years ➡ Geologic Repository

- Geologic Strategy relies on geologic characteristics to isolate wastes after containers and barriers fail
  - The repository requirements change once that the radiotoxicity and decay heat falls below natural uranium ore.
  - Current man-made containers can provide more than 300 years but less than 1000 years of certified isolation.

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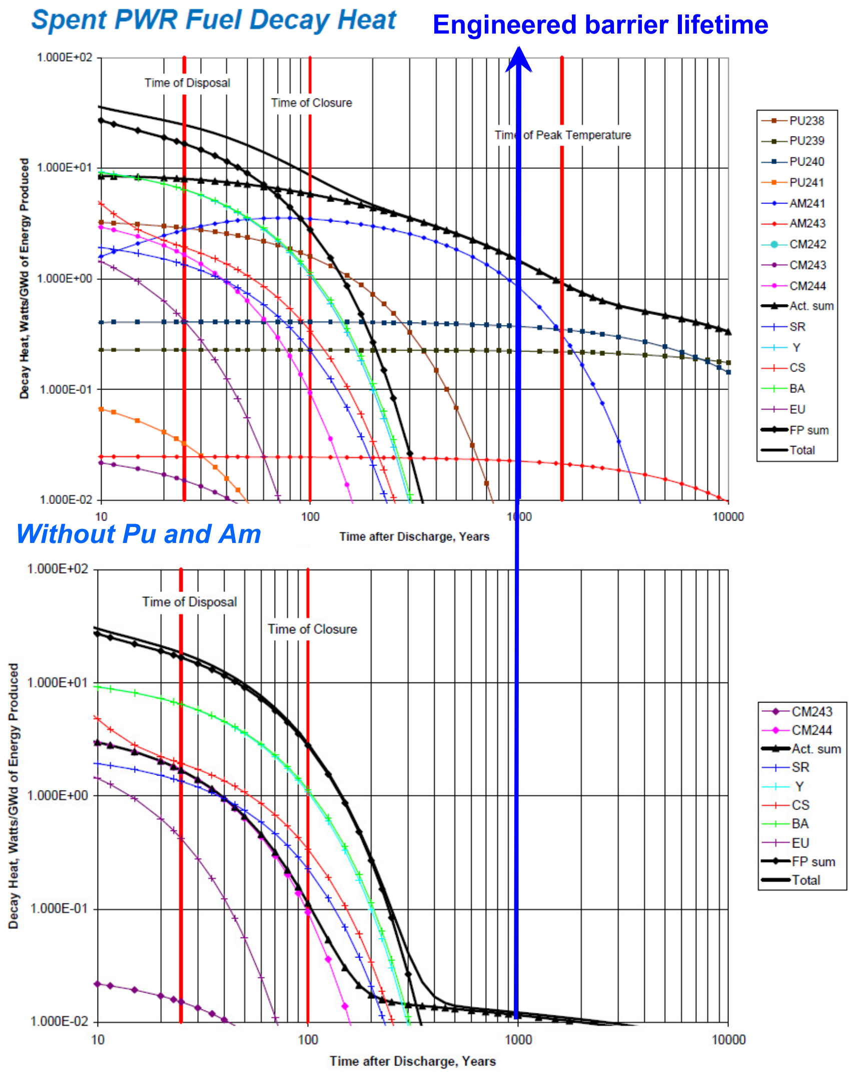
Decay Heat Has A Major Impact On Repository Licensing

Licensing is significantly impacted by the decay heat by radionuclides, in particular Am, posing many difficult-to-answer issues for engineered and natural (geologic) barrier performance, such as:

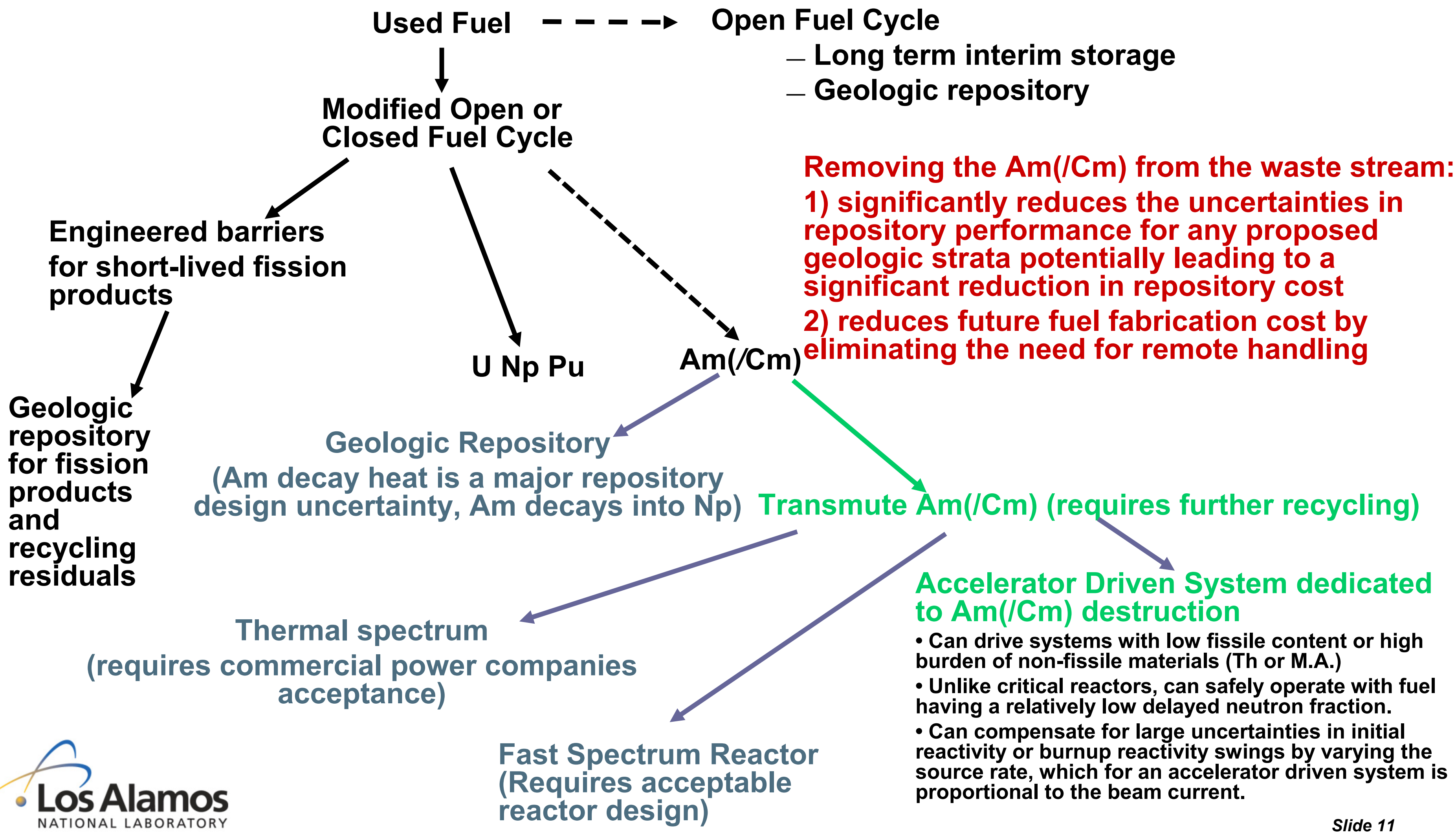
- Thermohydrologic (e.g evaporation/condensation)
- Thermomechanical (e.g. fracturing)
- Thermochemical (e.g. radionuclide solubility).

Am also impacts licensing because Am-241 decays to Np-237, a long-lived radionuclide ($t_{1/2}$ = 2 million yrs) with a relatively high solubility and tendency for aqueous subsurface transport.



Wigeland 2006

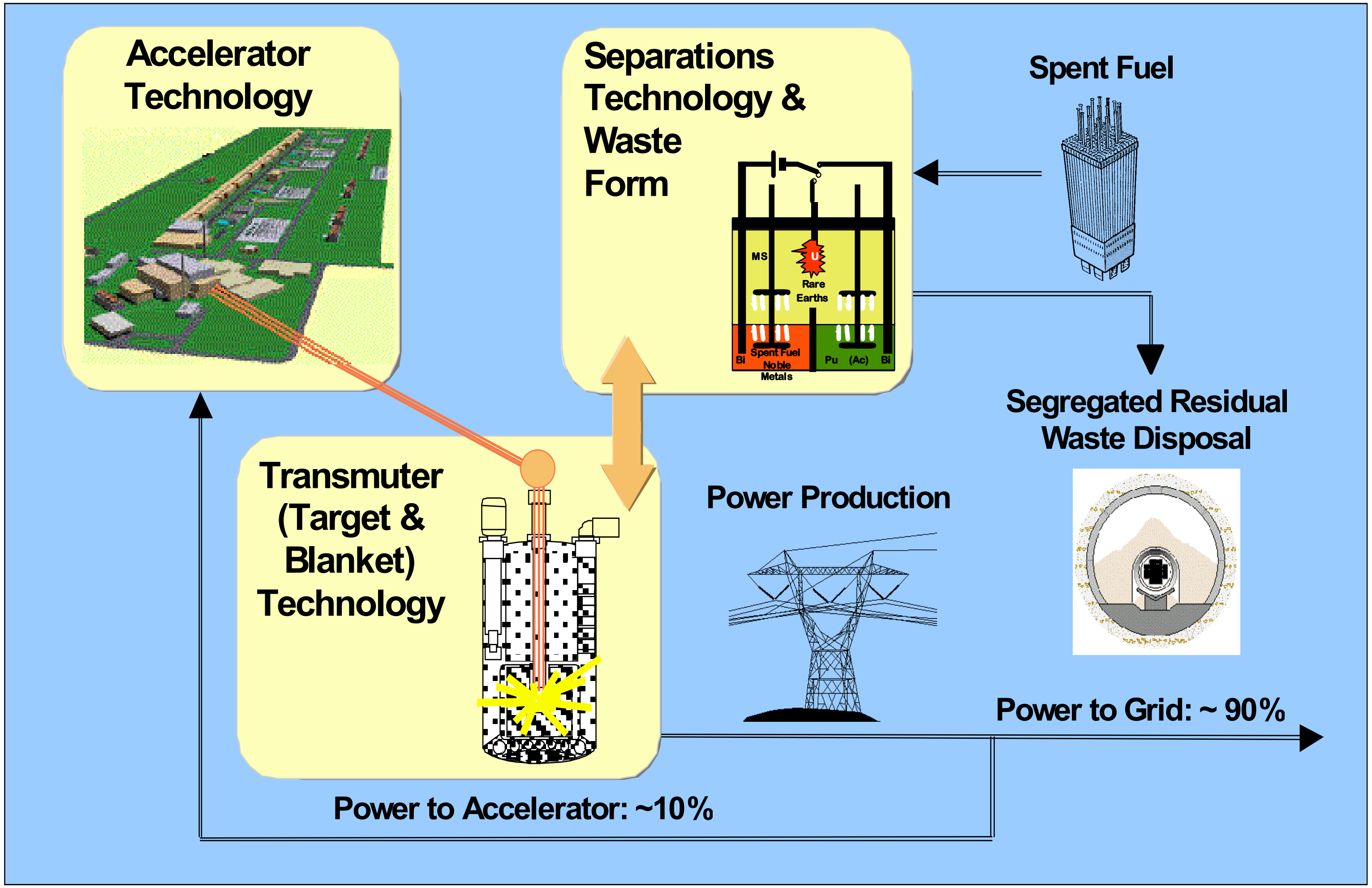
Which Used Fuel Deposition Options Directly Address The Am Issue?



What are appropriate (licensable) disposal paths for waste streams?

- Dispose of the short-lived (<500 years) fission products.
  - Do we bury (deep or shallow) or store above ground?
  - What types of engineered barriers are suitable?
- Dispose of the long-lived waste isotopes (>100,000 years) into a geologic repository.
  - — LWR residual long-lived fission products
  - — Reprocessing plants effluents
  - What type of geologic repository is required (salt, clay, granite, etc.)?
  - Is more than one kind of geologic repository needed?
  - Is further separation required to make the repository(ies) easier to license?
- ***Will need to destroy the Am – a sub-critical accelerator burner is the most efficient since the equilibrium feed-stream can be entirely Am***

Accelerator-Based Transmutation Includes Four Major Technology Elements: Accelerators, Transmuters, and Separations, Fuels and Waste Forms



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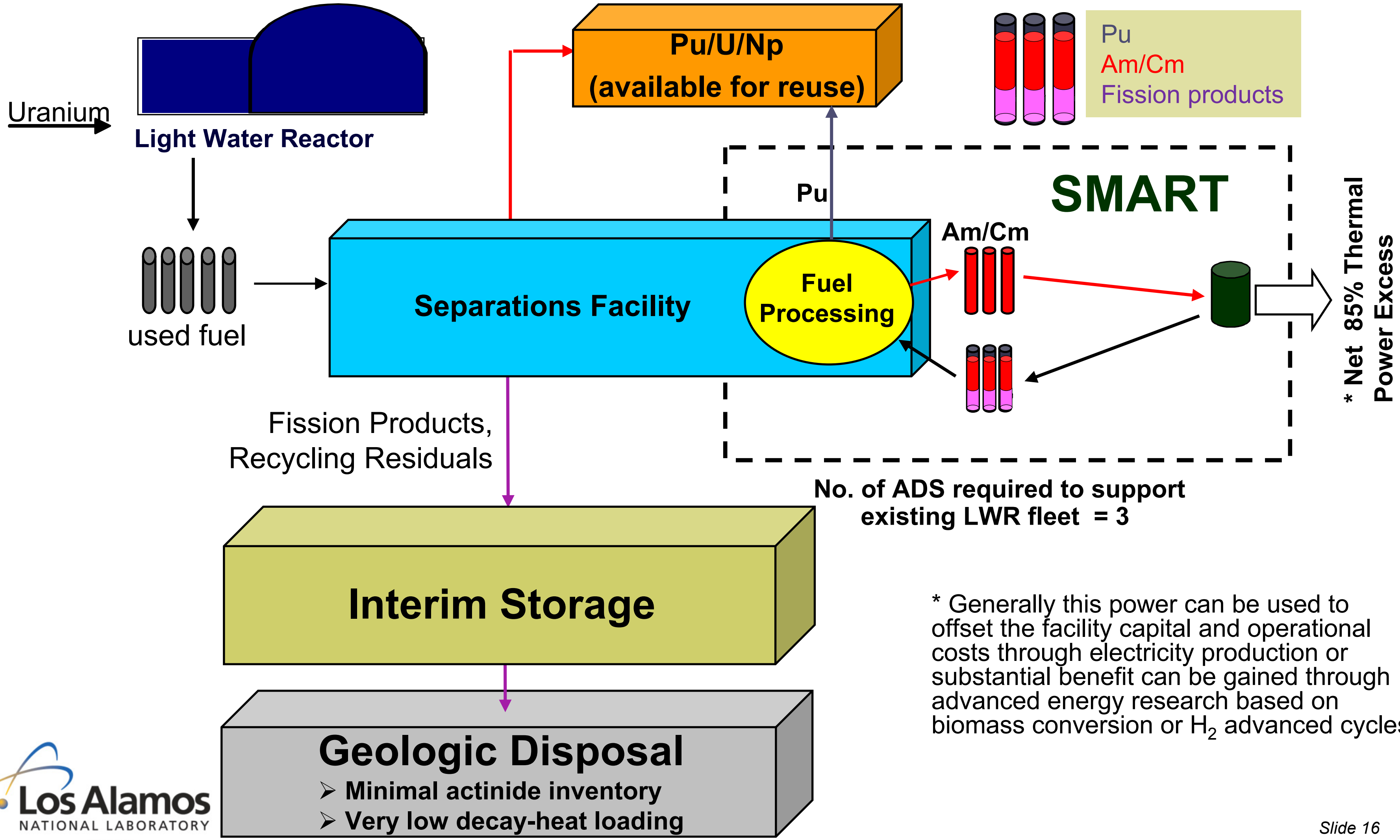
Why Am Destruction by Accelerator Based Transmutation?

- **Accelerator-driven systems have a higher support ratio (# of systems needed to burn the Am) than fast reactors**
  - Fast reactors need U-238 in the fuel to operate safely (increases delayed neutron fraction), which breeds Pu-239 and MA's
  - Accelerator-driven systems can probably operate on a pure Am feed stream in the equilibrium cycle
- **The current US LWR fleet generates about 3 MT/yr Am (40 yrs cooling)**
- **Burning 3 MT/yr Am generates 8 GW of fission heat (about 3% of US nuclear fleet size)**
- **Three high-powered accelerators can burn the Am generated by the current US fleet**

SMART: Subcritical Minor Actinide Reduction Through Transmutation Supports LWR Economy and Preserves U, Pu, & Np as a Future Energy Resource



* Generally this power can be used to offset the facility capital and operational costs through electricity production or substantial benefit can be gained through advanced energy research based on biomass conversion or H_2 advanced cycles

Typical Questions

- **Why not just burn Am in LWRs?**
  - Studies show 50% is fissioned, while the other 50% is transmuted to higher actinides.
  - Licensing is a major concern in getting Industry buy-in for loading Am into thermal reactors

- **How do SMART costs compare to a large geologic repository and what about reprocessing concerns?**

- Reuse of U significantly reduces the environmental impact of mining.
- Legacy facilities have given the wrong impression to policy makers on the risk and cost of reprocessing facilities. Significant improvements have been made in reprocessing technology over the last several decades and modern reprocessing facilities, such as Areva, are very safe.
  - Boston consulting group (July 2006) estimated that the costs of reprocessing were comparable to the costs of a once-through strategy with Yucca Mountain disposal (ca. $ 500 per kg SNF); this is consistent with with Schneider et al., Energy Economics 31 (2009) 627-634, estimate of reprocessing costs between $ 600 – 800 per kg SNF
  - We are reviewing simplified reprocessing technologies

- **What are the proliferation concerns, and how would they be handled?**

- Providing used-fuel take back would reduce long-term storage needs and so may reduce pressure for a global expansion of new enrichment facilities
- Consolidates attractive material to small # of sites for protection
- Dilutes Pu/Np with U to reduce attractiveness to terrorists
- Reduces attractiveness of Am by mix with Cm (unlike some UREX versions)

SMART Converts The Fraction Of used Fuel That Requires Ultra-long-term Isolation, Am, Into Materials That Are Primarily Stable Or Short-lived

The ultimate objectives include:

- **Reducing isolation requirements to fit the lifetime of man-made containers and barriers.**
- **Reducing incentives and consequences of intrusions into repositories.**
- **Significantly reducing uncertainties relating to repository performance potentially leading to a substantial reduction in repository cost.**
- **Improving fuel utilization.**
- **Developing proliferation-resistant reprocessing streams.**

Most likely: In the U.S. LWR waste will be the government's problem – This is consistent with a few large ADS machines collocated with a government reprocessing facility.

What Is The Best Use Of The ~8 GWth High Grade Process Heat?

- *Will need incremental cost to have power production, but this cost will be much less than the total revenue earned*
  - *Electricity to the grid*
  - *Electricity to storage (pump water or such)*
  - *Hydrogen production*
  - *Conversion of biomass to hydrocarbon fuel*
- *Not use*

Conclusions

- Nuclear energy is a safe, cost-effective, emission-free power source.
- Disposal of used nuclear fuel is still a major hindrance in nuclear power acceptance.
- Accelerator-driven transmutation of Am addresses repository licensing issues and so can help diminish used fuel disposal as an issue in the expansion of nuclear power.