Aqueous Recycling of Used Nuclear Fuel

Chris Phillips
Energy*Solutions* LLC, Richland, Washington

Panel on Options for UNF Management in the USA
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Overview of the Options for Managing UNF

- Once-Through-and-Store at the individual Reactor Sites
  - Current default arrangement - the "Open Cycle"
- Once-Through-and-Store at one or more Consolidated Storage Facilities
  - Open Cycle again, but with improved security and economy
- Once-Through-and-Store in one or more National Repositories
  - The 'Yucca Mountain option'
- The Modified Open Cycle
  - as identified in the DOE Fuel Cycle R&D Roadmap
  - Recycle of certain UNF components, with limited or no separations
- Full Recycle
  - Separation of bulk uranium, uranium+plutonium, actinides and fission products
  - Recycle of the uranium and plutonium as nuclear fuel
  - 'Burning' of the actinides – conversion to lower atomic weight shorter-lived species

Commentary on these Options

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- It is not sensible to leave UNF at individual reactor sites indefinitely
  - 'Self-protection' from FPs will decrease with time
  - Each site will require increasing levels of security
- One or more consolidated UNF storage facilities are a sensible interim measure
  - Enables better security measures to be employed
  - More economic, and takes UNF off the hands of the power utilities
  - But doesn't offer a permanent solution
- A national repository will be needed no matter what is done with UNF
  - But processing the UNF will significantly reduce the volume of HL waste to be stored
  - Processing the UNF produces a more robust waste form than UNF assemblies
- The Modified Open Cycle is worthy of further R&D
  - But at the moment it poses significant problems for fuel manufacture & handling
- Full UNF Recycling should be an attractive option but has been unjustly demonized in the US
  - It is successful and economic in Europe, using 3rd generation technology
  - It significantly reduces the volume of HL waste to be stored
  - The robust vitrified waste form opens up other repository options e.g salt domes

Why isn't the US Recycling UNF?

- Recycling of UNF is routinely done in the UK (Sellafield) and France (La Hague)
  - Typical facility capacity 800-1000 tons/year
- One or more closed cycle "Consolidated Fuel Recycling Centers" were planned to be built in the USA, starting in 2009, under GNEP
- However, four objections are raised in the US that have so far discouraged recycling:
  - Suitable technology for recycling has not been developed
  - Recycling is a proliferation risk because it separates pure plutonium
  - Recycling discharges radioactive waste to the environment in unacceptable amounts
  - Recycling is un-economic

Energy*Solutions*' NUEX, & other 4th generation recycling processes, answer all these objections

The Four Generations of Recycling Facilities

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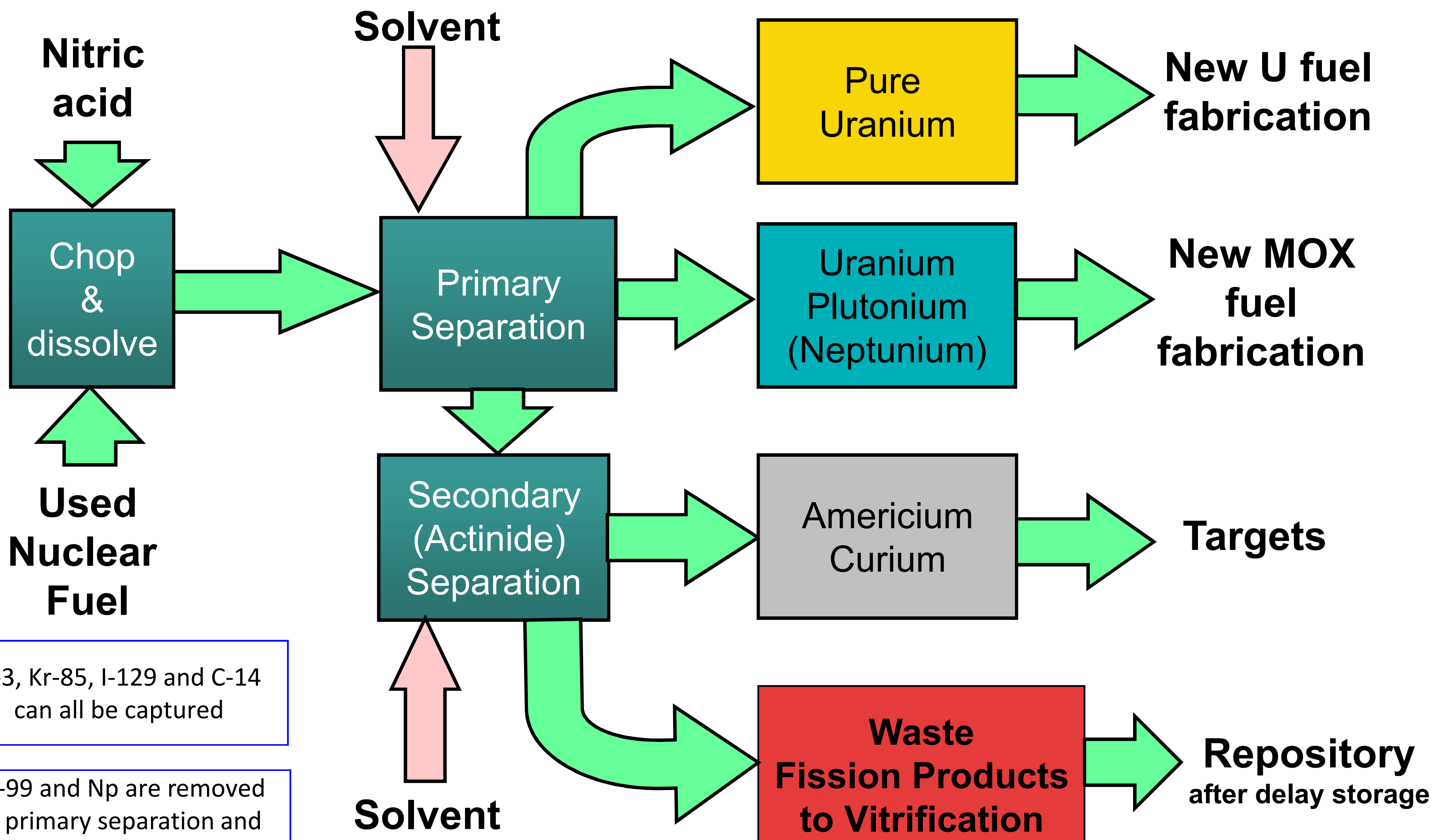
Predominately based on solvent extraction using tri-butyl phosphate in kerosene diluent

- First Generation (1940-50)
  - Hanford, Savannah River in the USA
  - Sellafield Butex in England
- Second Generation (1960s)
  - Sellafield Magnox in England
  - Marcoule in France
  - Tokai-Mura in Japan
  - Mayak in Russia
- Third Generation (1980-2000)
  - Sellafield THORP in England
  - La Hague UP3 and UP2 800 in France
  - Rokkasho-mura in Japan
- Fourth Generation (2020s?)
  - Energy*Solutions*' NUEX Facility
  - AREVA's COEX process
  - US National Laboratories' UREX process

- Steadily improved technology
- Decreasing liquid and gaseous waste discharges
- Improved solid waste treatments

- No separated plutonium
- Near-zero liquid & gaseous waste discharges
- >99% of waste radioactivity in the SNF goes to vitrified waste

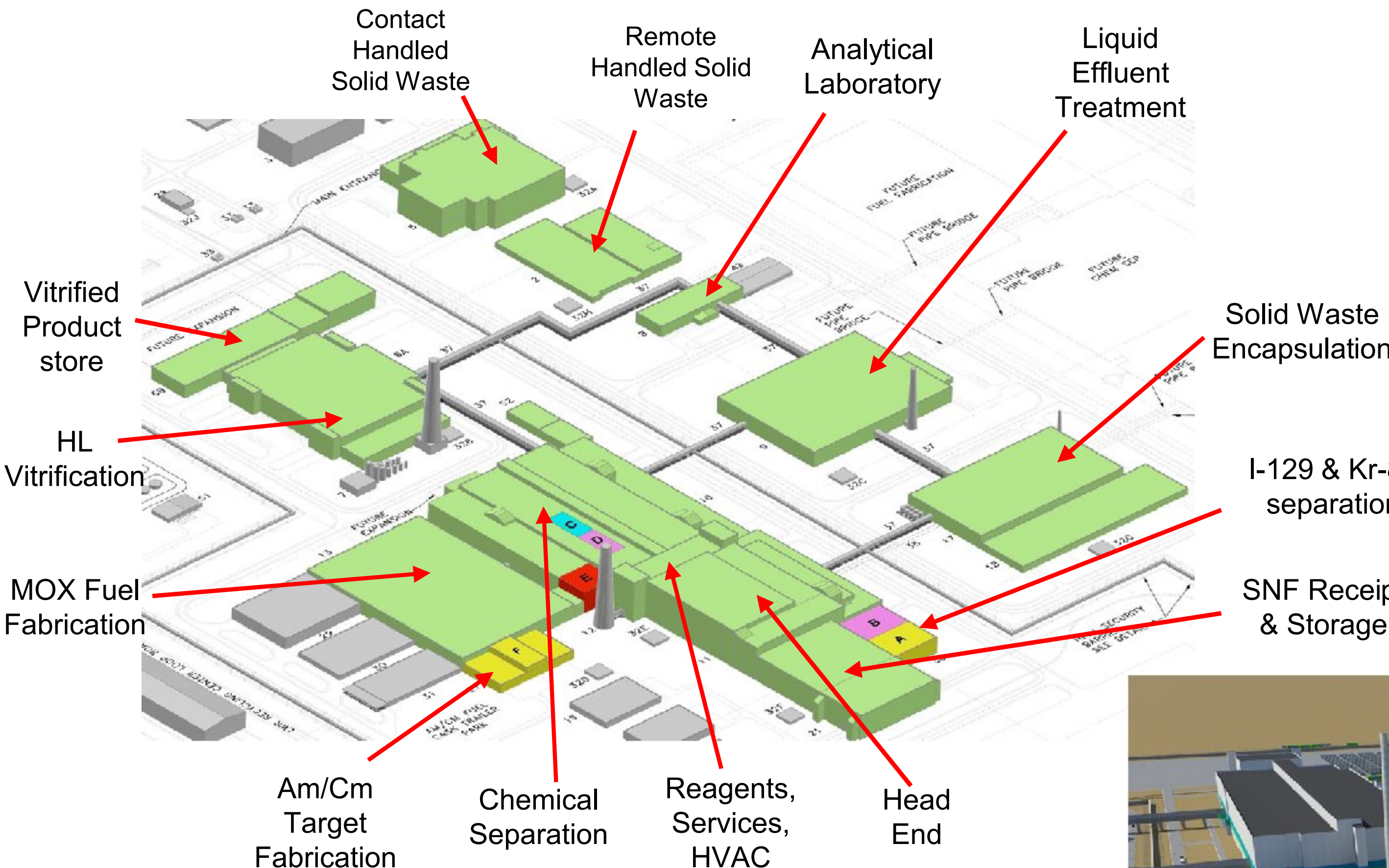
EnergySolutions' NUEX 4th Generation Recycling Process



H-3, Kr-85, I-129 and C-14 can all be captured

Tc-99 and Np are removed in primary separation and can be treated separately if required

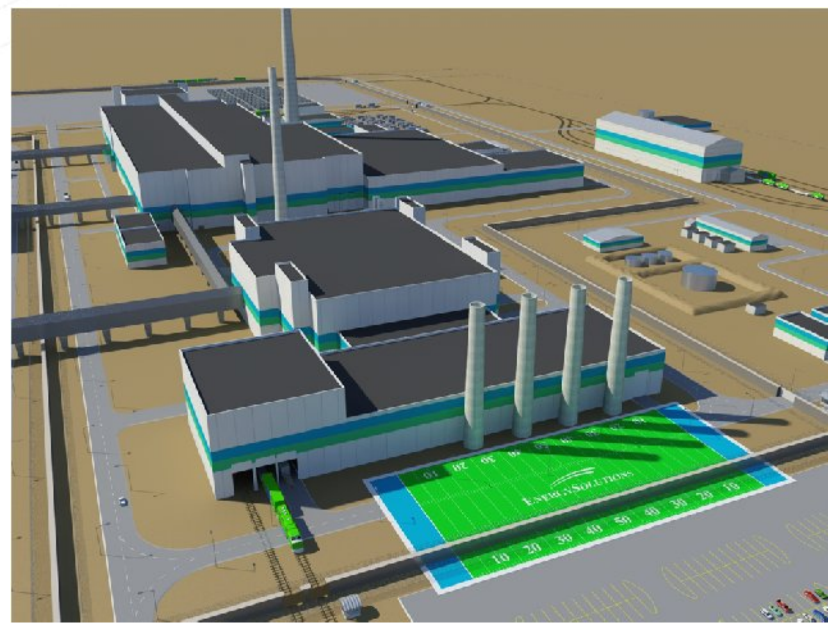
How Mature are these Recycling Processes?



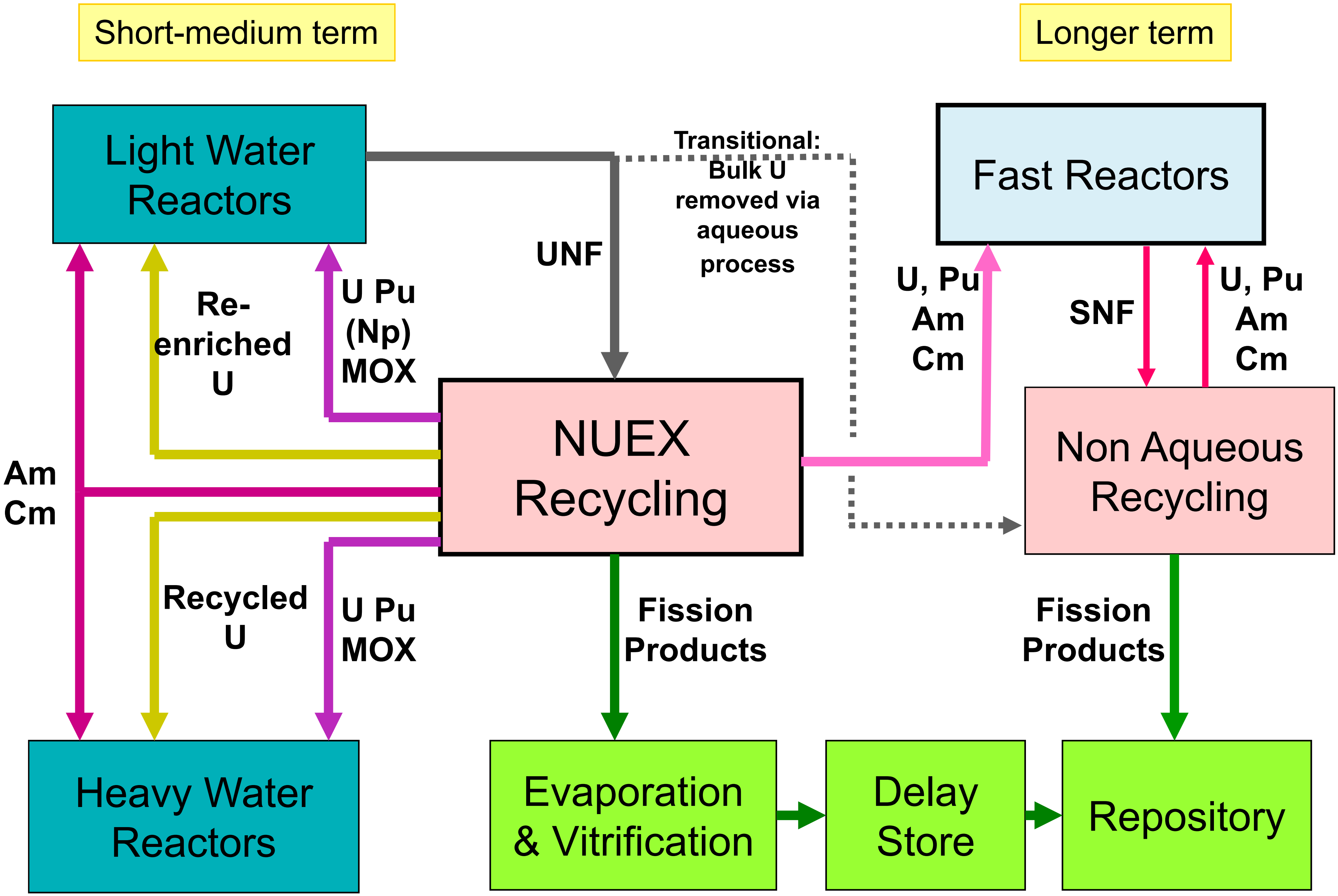
Conceptual Design for a 1500 ton/year Recycling Facility with Vitrification, MOX Production, MA Target Production, Wastes Handling

TRL 8 or 9

- Over 90% of the technology is ready to deploy
Process equipment is proven in industrial use
- Chemistry enhancements are needed to provide new separations and improve environmental performance
- Detailed design could start immediately

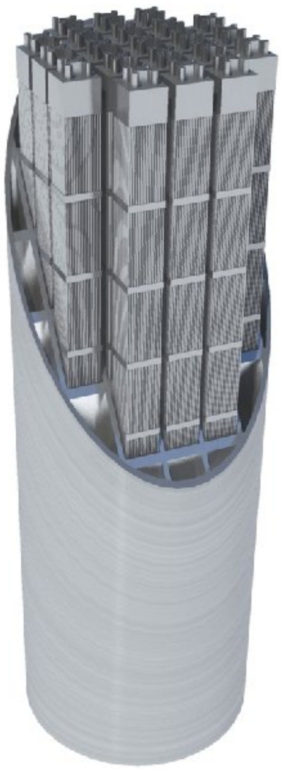


How does NUEX fit into an Overall Recycling Scheme?



HLW and GTCC Waste Volume Reduction Achieved by Recycling

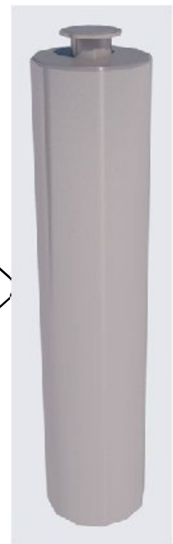
Radioactivity: 100%



Used fuel in one disposal container (MPC) 10.9m^3

RECYCLED

Radioactivity: 99%



One Vitrified HLW Disposal Canister 0.8m^3

+

Radioactivity: 1%

2.5 GTCC LL waste (RH72 B) Canisters 2.3m^3

(Mainly compacted fuel cladding)

5 GTCC LL CH Drums of I-129 Waste 1.6m^3

Vitrified product volume reduction from SNF is here shown to be about 13-fold. This allows for vitrified product containers Depending on heat-related packing factors that are assumed, this factor can fall to about 6-fold

The Business Case for Recycling

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Business model developed by Booz Allen Hamilton

- The bulk recycled uranium from Recycling can be sold as fuel to reactor operators:
  - It can be used in existing LWRs following re-enrichment
    - It is competitive with "fresh" enriched uranium given a minimum uranium market price (typically somewhat greater than $80/pound, depending on assumptions)
  - It can be used in HWRs reactors without re-enrichment
    - It is competitive now and electricity utilities in China are already testing its use
- The mixed uranium-plutonium stream can be made into MOX fuel for LWRs
  - Use of MOX fuel is already well established in Europe
  - It is competitive now with standard uranium fuels (at ~10% discount)
- Use of the existing and going-forward US waste fund adds to these product sales incomes to provide the balance of funding
  - US Utilities have been paying into this fund at 0.1 cent per kwhr of electricity generated
- Detailed design of a recycling facility could start immediately, leading to an operational facility in about ~17-20 years

Conclusions

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- Aqueous UNF recycling is a mature technology that has evolved significantly over its 50 years of use:
  - 4^{th} generation technology
  - No separation of pure plutonium
  - Near zero, or zero, radioactive waste discharges
  - Recycle of uranium and plutonium is a valuable energy source
  - Compact, robust waste forms
  - Removing transuranics from the waste vastly shortens its radioactive duration
- The four US objections to UNF Recycling are thus no longer valid for modern 4^{th} generation aqueous recycling facilities
- Creating one or two Consolidated UNF Storage Facilities is a good idea
  - But should be seen as a step along the path to recycling

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How are these Advances Achieved?

- The NUEX process builds on the industrially proven world recycling facilities (England (THORP), France, Japan)
- Flexible flowsheet: ability to make products with differing proportions of uranium, plutonium and neptunium
- Separation of pure plutonium is avoided by adjustments to solvent extraction separation chemistry. Typical products are:
  - **Bulk uranium oxide ("RU") for use in HWRs and LWRs**
  - **Mixed uranium, plutonium, neptunium oxides**
    - Proportions of U, Pu, Np can be varied by altering redox reagents, acidities, conditioning temps
    - Np can be separated if required for separate treatment or storage
    - Tc can be separated if required for separate treatment or storage
  - **Americium, curium produced for target burning in HWRs, LWRs & fast reactors**
- Uses improved "salt-free" reagents
  - **Nearly all wastes can be vitrified: >99% of the radioactivity in the SNF**
- Zero or near-zero liquid discharges
  - **Recycle of nearly all process water as reagent make-up**
  - **Purge water is cement-encapsulated**
- Gaseous tritium (H-3), krypton-85, iodine-129, carbon-14 captured
  - **Economics of krypton-85 capture under continued review**
  - **Necessity for tritium capture under continued review**

Have the NUEX – and similar - Facilities resolved the US Objections to Recycling?

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- "Suitable technology for recycling has not been developed"
  - Suitable 3rd generation technology has been developed in Europe over the last 50 years and could readily be advanced to 4th generation for use in the US
- "Recycling is a proliferation risk because it separates pure plutonium"
  - 4th generation recycling does not separate pure plutonium at any point in the process
  - Modern accountancy methods allow accurate measurement of fissile material content at any point in the process – allowing any unauthorized diversion to be quickly detected. Full IAEA approval for this
  - Recycling ultimately reduces the fissile material circulating in the fuel cycle
- "Recycling discharges radioactive waste to the environment in unacceptable amounts"
  - 4th generation recycling discharges trivial or indeed no radioactivity to the environment
  - Over 99% of the UNF radioactivity goes to glass encapsulation
- "Recycling is uneconomic"
  - A coherant business case has been produced
  - This does requires access to the Waste Fund – and a minimum price for fresh uranium