Spent Fuel Reprocessing: Dirty, Dangerous, Expensive … and Utterly Ineffective

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Should we “recycle” spent fuel?

- Sven Bader spoke last week about “recycling” spent nuclear fuel. Isn’t it good for the environment to recycle waste?
  - **Not if the recycling process itself causes more harm than directly disposing of the waste, which is the case for spent nuclear fuel.**

"RECYCLING" vs. REPROCESSING

- Reprocessing alone is NOT "recycling"
  - Most of the content of spent nuclear fuel is not usable as fuel and still requires geologic disposal
  - Generates separated plutonium and reprocessed uranium, most of which is not re-used today
    - The United Kingdom reprocesses spent fuel but has not "recycled" a single kilogram of plutonium
    - Reprocessed uranium, which is > 95 percent of spent fuel, is a waste product that is not currently being recycled and will be too expensive to reuse for the foreseeable future
  - "Recycling" entails the entire chain of processes needed to convert the usable components of spent fuel into fresh fuel, including plutonium fuel fabrication
    - Each process introduces additional waste streams and risks (safety and security) that direct disposal does not have

The only thing about reprocessing that is effectively recycled …

… is misleading information about how great it is

- Every 10-15 years, interest in reprocessing spent fuel spikes, sort of like the solar cycle, largely driven by Department of Energy laboratories and their supporters
- However, these efforts have not succeeded
  - Largely because neither government nor private industry have been willing to shoulder the huge cost of establishing a new fuel cycle based on reprocessing and recycling, without any clear benefit for waste management or resource conservation

Reprocessing: Dirty, dangerous, expensive …

- Reprocessing is
  - ***Dirty***: Transforms spent nuclear fuel, a relatively stable waste form, into multiple, hard-to-manage waste streams—including gaseous and aqueous radioactive effluents—greatly increasing the volume of wastes requiring secure disposal
  - ***Dangerous***: Industrial-scale reprocessing plants separate thousands of bombs' worth of plutonium annually, greatly increasing its vulnerability to theft by terrorists
  - ***Expensive***: DOE's very optimistic 2017 estimate of aqueous reprocessing cost is $1,300 per kilogram of spent fuel in 2023 dollars: over $100 billion to reprocess the current US spent fuel inventory
- The additional steps needed to recycle plutonium (fuel fabrication, transportation, reactor operation) only add cost and risk compared to the once-through cycle

National Academies of Science, Engineering, and Medicine (NASEM) study

- **"Finding 9: As proposed for some advanced reactor closed fuel cycles, reprocessing and recycling of spent nuclear fuel introduces additional safety and environmental considerations over the management of open-cycle light water reactor oxide fuels."**
- **"Recommendation D: The current U.S. policy of using a once-through fuel cycle with the direct disposal of commercial spent nuclear fuel into a repository should continue for the foreseeable future."**
  - "*Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors*," 2023.

But doesn't France safely recycle its nuclear waste?

- Only a fraction of the plutonium separated from spent fuel in France is converted to mixed-oxide (MOX) fuel and reused in reactors
  - At the end of 2021, France's stockpile of domestic separated plutonium was **85 metric tons**: the equivalent of 10,000-20,000 nuclear weapons
  - Although the inventory has been steadily increasing because France separates more plutonium than it can use as fuel, a breakdown in the MOX fuel fabrication process has contributed to the recent increase of 4-5 MT per year

But doesn't reprocessing save money by reducing nuclear wastes?

Not if you account for ALL the wastes: total volume increases

- High-level waste (HLW)
  - liquid, highly radioactive waste that must be solidified for safe storage and disposal
  - Other highly active process waste streams
- Low-level waste (LLW) classes A, B and C
- Greater-than-class-C LLW
  - Contains more than 100 curies per cubic meter of certain "transuranic" isotopes (plutonium-239, etc)
- Reprocessed uranium (RepU)
  - Far less desirable than natural uranium for fuel fabrication
- Plutonium with or without other "actinides (neptunium, americium, curium)
  - Will require long-term storage even if an effective system for "transmuting" these isotopes is developed
- 300-year storage of cesium and strontium (if separated from HLW)

Nuclear fuel cycle industry in France
A major contribution to energy sustainability

Uranium and conversion ≈ 8000 t/year → Enrichment ≈ 5,5 MUTS/year → UO2 Fuel fabrication ≈ 1060 t/year
2000 assemblies/yr (45 GWd/t average, max 52 GWd/t

→ time period 20 years

430 TWh /an

58 EDF NPPs
22 units loaded with MOX
2 with REPU

Spent Fuel: 1200 tons /year (UOX et MOX)

Spent Fuel Transportation to La Hague, interim storage in cooling pools 1200 tons/year

Recycling: MOX fuel 100 t/year on 22 units 900 MW (30% core) --> 40 TWh/yr

MELOX Fuel Fabrication plant

8,5 t /yr Separated plutonium (1%)

Reprocessing : 850 t / year

La Hague

Reprocessed uranium: ~ 810 t/yr (U235 content 0,8%)
1/3 re-enriched and recycled on 2 units 900W (100% core)
or 40 t/yr --> 15 TWh/yr
to be extended to 4 units

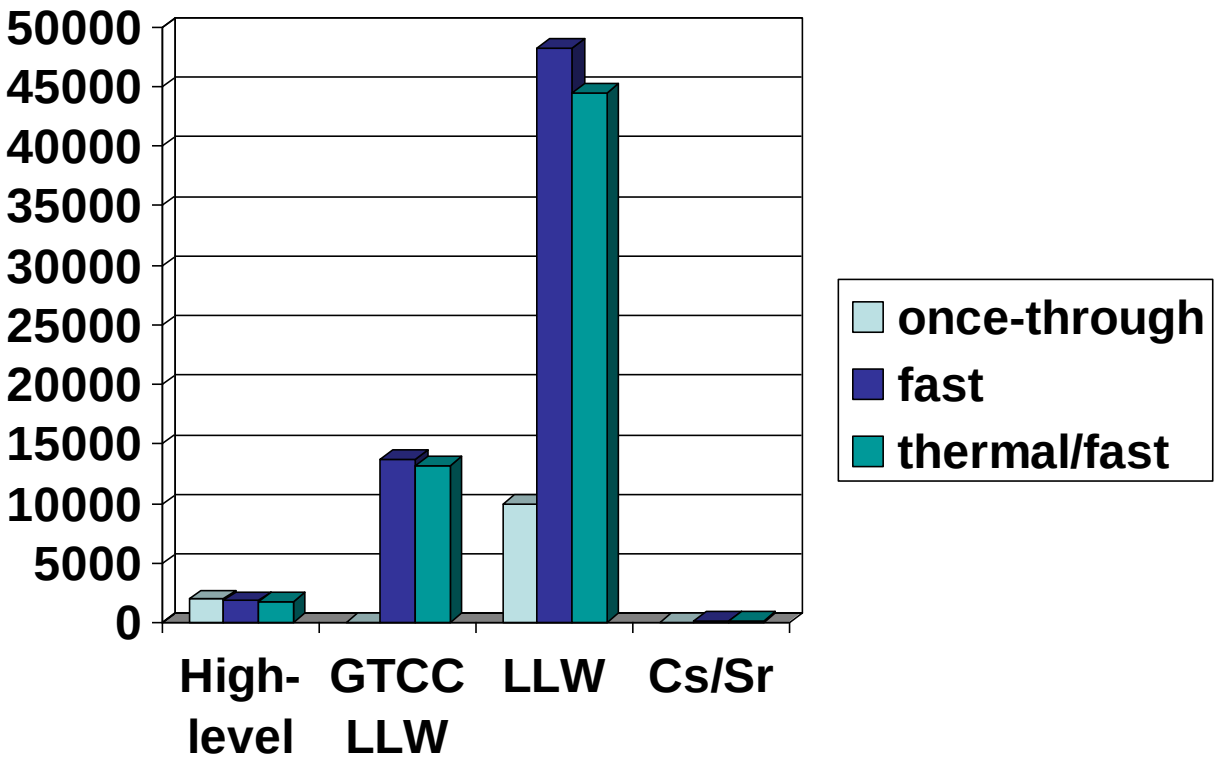
Vitrified High level Waste
Interim passive storage
Disposal optimisation

110 to 130 m³/yr vitrified HLW
122 m³/yr compacted ILW

Impact on repository

- Reprocessing 850 MT of spent fuel (360 cubic meters) annually results in 110-130 cubic meters of vitrified high-level waste and 122 cubic meters of “intermediate-level” waste
  - Total volume reduction only a marginal 36%
  - But volume isn’t typically a limiting factor for repository capacity anyway; heat load is (and reprocessing alone doesn’t change that)
- INCREASE in low-level waste volume will have an impact (in the wrong direction)

ANNUAL WASTE GENERATION (m^3)



Department of Energy Draft Global Nuclear Energy Partnership Programmatic Environmental Impact Statement, DOE/EIS-0396, October 2008

Don’t advanced reprocessing technologies reduce proliferation and terrorism risks?

No.

- Some claim that replacing conventional PUREX reprocessing with processes that would not separate pure plutonium but would keep it mixed with other actinides and fission products, such as “pyroprocessing”
- These ideas date to the 1970s, but were judged then not to be effective (and since that time the capabilities of terrorists and outlaw states have only increased)
- Analyses continue to confirm that these processes would not mitigate the proliferation or security risks of reprocessing/recycling—but the myth persists

NASEM report

- **“Finding 20: All … advanced reactor fuel cycles will require rigorous measures for safeguards and security commensurate with the potential risks they pose.**
  - Fuel cycles involving reprocessing and separation of fissile material that could be weapons usable pose greater proliferation and terrorism risks than the once-through uranium fuel cycle with direct disposal of spent fuel.”

But won't advanced reactors run on spent fuel and recycle their own wastes?

No.

- Only a small fraction of the waste from reprocessing can be reused in reactors: namely, plutonium and other "transuranic" elements
- Significant reductions (factor of 10 or more) in these materials can only occur if the complex system works perfectly, at an unrealistically high level of performance, for thousands of years: In other words, it can only work on paper (or computer)
  - Only a small fraction is actually fissioned per cycle
  - Even small material process losses to waste can accumulate over time and undermine the system's ability to reduce the overall waste burden

So why are we still talking about reprocessing?

- In my opinion, the periodic resurgence of reprocessing talk (and funding) is a symptom of the ongoing failure of government and industry to develop a safe long-term spent fuel disposal strategy, especially in the face of plans to build new reactors
  - Polling shows radioactive waste is one of the biggest areas of public concern regarding nuclear power
- All should be wary of claims that a technical panacea to the nuclear waste problem is on the horizon.
  - The promise of false solutions is a recipe for more inaction, which will only delay progress on a deep geologic repository and a path to get spent nuclear fuel out of Vermont (and every other state with decommissioned reactors)

Further reading

- https://www.ucsusa.org/resources/advanced-isnt-always-better
- https://nap.nationalacademies.org/catalog/26500/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors