PennState
College of Engineering

*NucE 497: Reactor Fuel Performance*

# Lecture 37: Fuel Cycle

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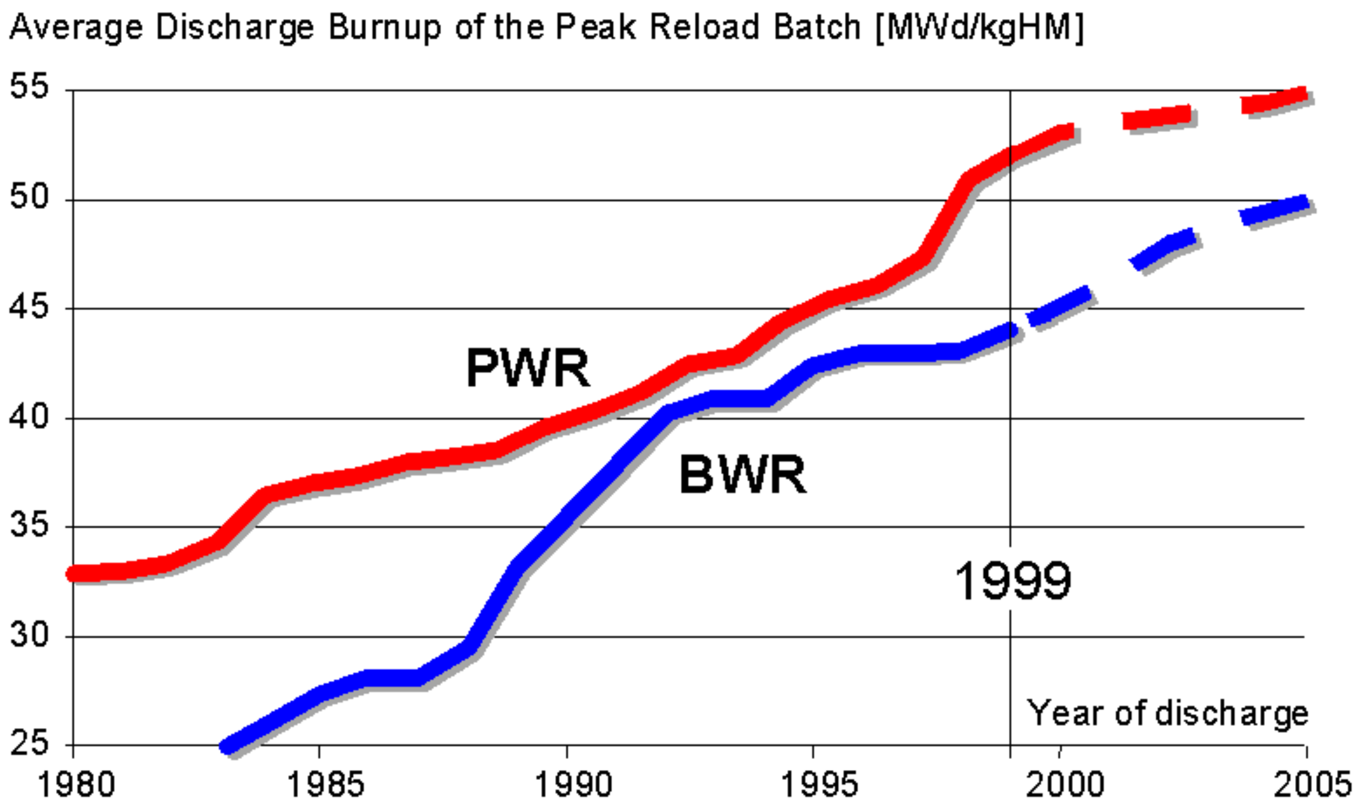
# Today we will discuss the fuel cycle and used fuel disposition

- Module 1: Fuel basics
- Module 2: Heat transport
- Module 3: Mechanical behavior
- Module 4: Materials issues in the fuel
- Module 5: Materials issues in the cladding
- Module 6: Accidents, used fuel, and fuel cycle
  - Reactivity insertion accident
  - Loss of coolant accident
  - Accident tolerant fuel
  - **Fuel cycle**
  - **Used fuel disposition**

# First, lets review from last lecture

- In a loss of coolant accident,
  a) The heat generation rate Q suddenly increases
  b) The fuel thermal conductivity suddenly decreases
  c) The coolant inlet temperature suddenly increases
  d) The fuel suddenly falls apart
- The purpose of accident tolerant fuel is to
  a) Design a reactor that is passively safe
  b) Add passive safety to an LWR
  c) Create fuel that will not fail during an accident
  d) Extend the time before catastrophic things happen after an accident

# LWR Average Fuel Discharge Burnup is Increasing



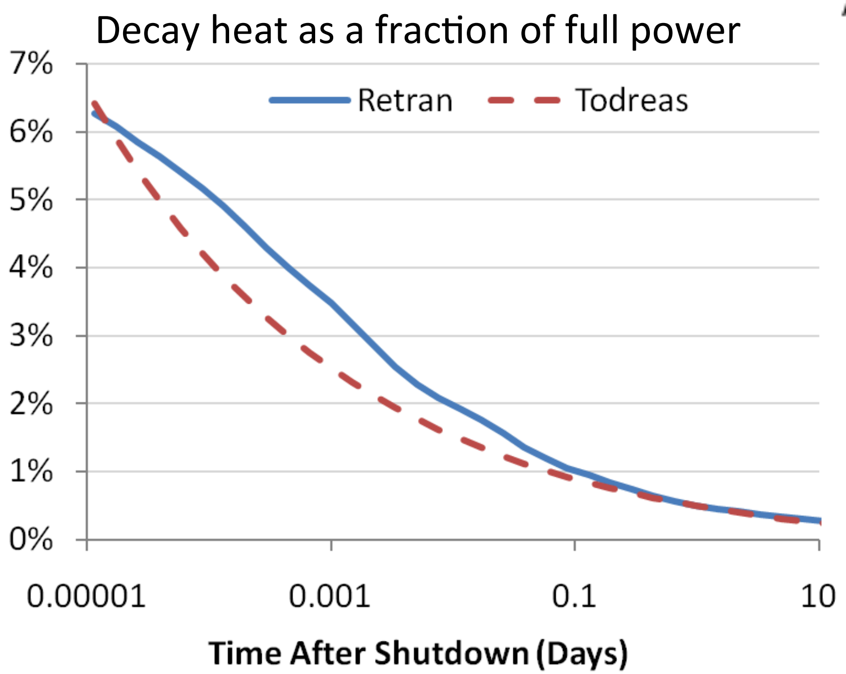

- New fuel technology and nuclear poisons make 60 MWd/gkU possible
- After this burnup, fission products poison the chain reaction

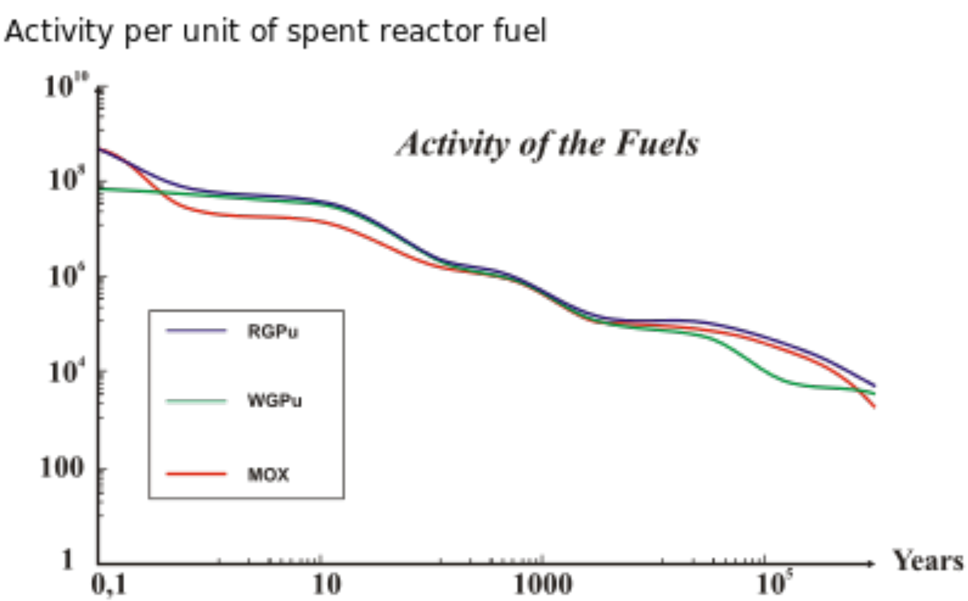
# Currently, used fuel assemblies are never used again and must be stored

- 60 MWd/kgU = 6.3% FIMA, so 93.7% of the U235 atoms never fission
- Used fuel goes through several steps before ultimate storage
  - Onsite pool storage
  - Vacuum drying
  - Dry cask storage
  - Long-term repository storage

# Currently, used fuel assemblies are never used again and must be stored

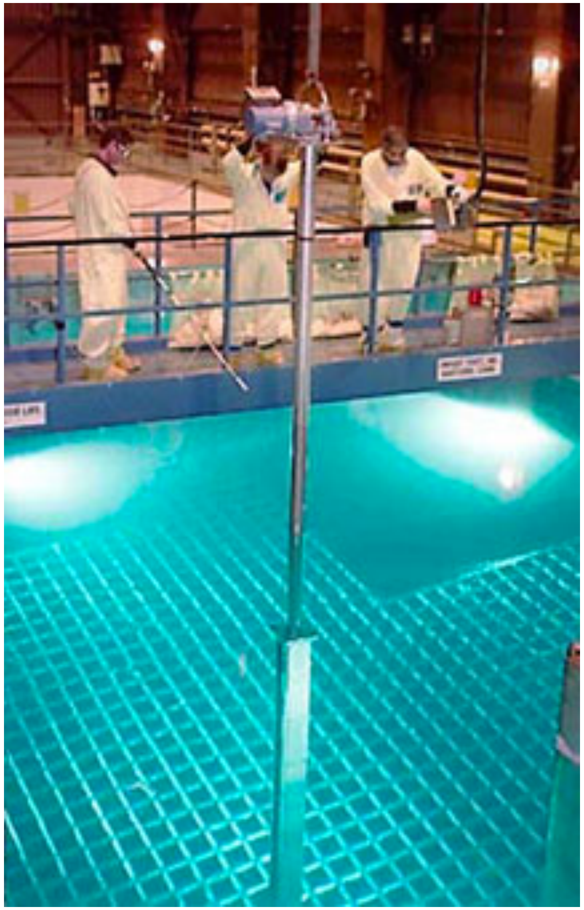
- 60 MWd/kgU = 6.3% FIMA, so 93.7% of the U235 atoms never fission
- Used fuel is hard to deal with due to decay heat and its reactivity

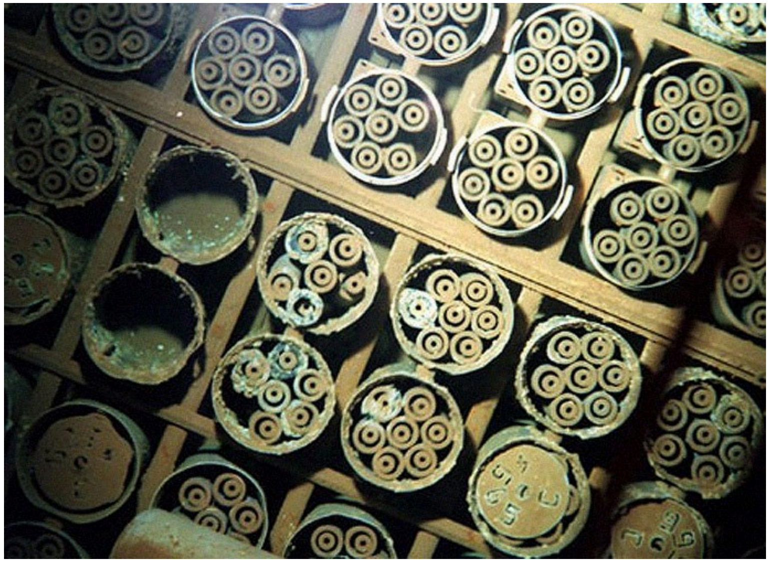


# After being taken from the reactor, the fuel is stored in onsite pools for several years

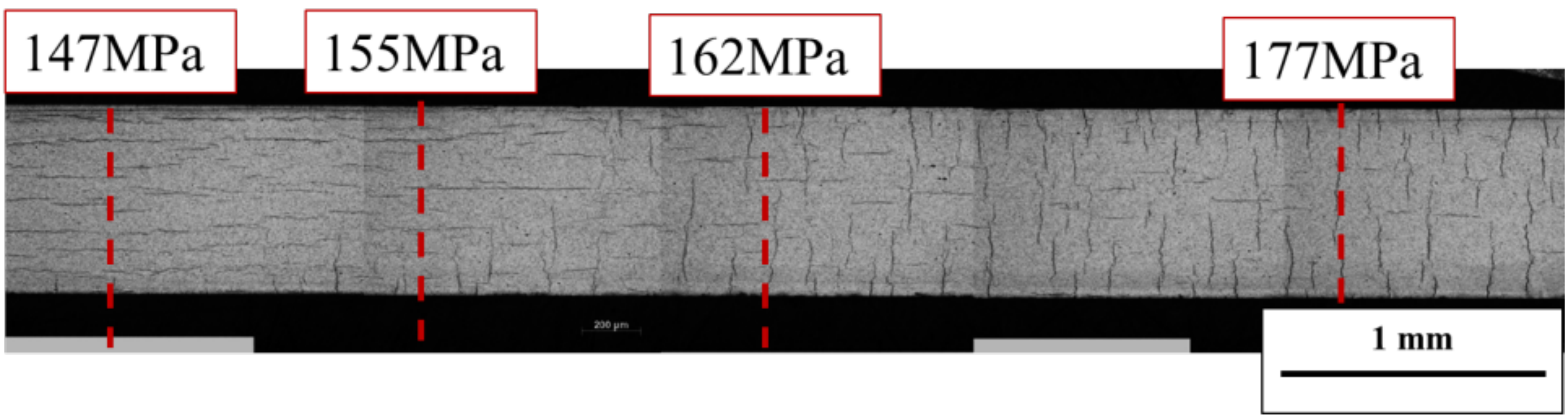
- They are stored to reduce radioactivity
- Plants have to be very careful to maintain subcriticality
- Loss of storage water caused major issues at Fukishima





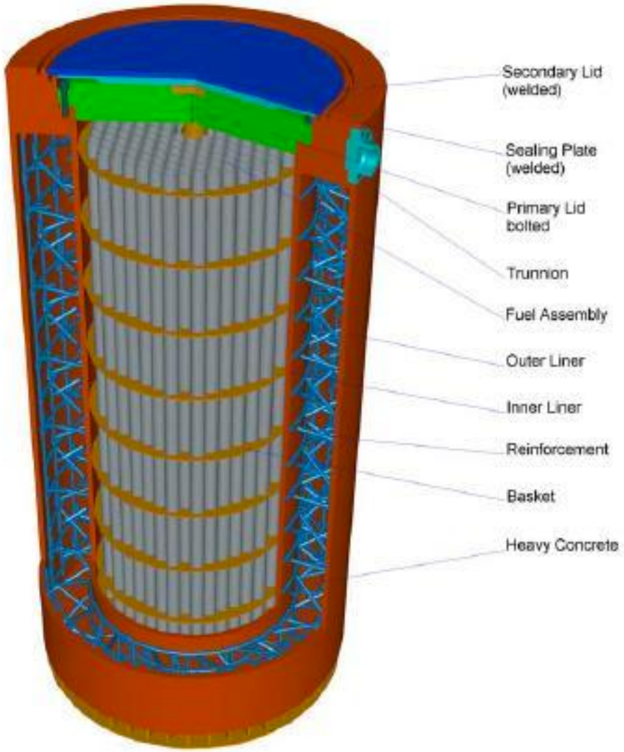
# Between pool storage and dry cask storage, the assemblies have to be dried out

- The assemblies are dried using a mechanical pumping system to remove the water
- Decay heating causes the cladding to heat up during this process, put the hydrogen into solution
- Additional fission gas release can increase the internal cladding pressure
- It is after this time that hydride reorientation could occur



# Used fuel is stored in dry casks onsite and for transportation

- Casks were designed to store fuel for 40 yrs
- The casks may need to be used for significantly longer
- The assemblies need to be able to be removed from the casks without exposure
- They are tested to ensure they don't breach




# Permanent storage will occur at a national repository

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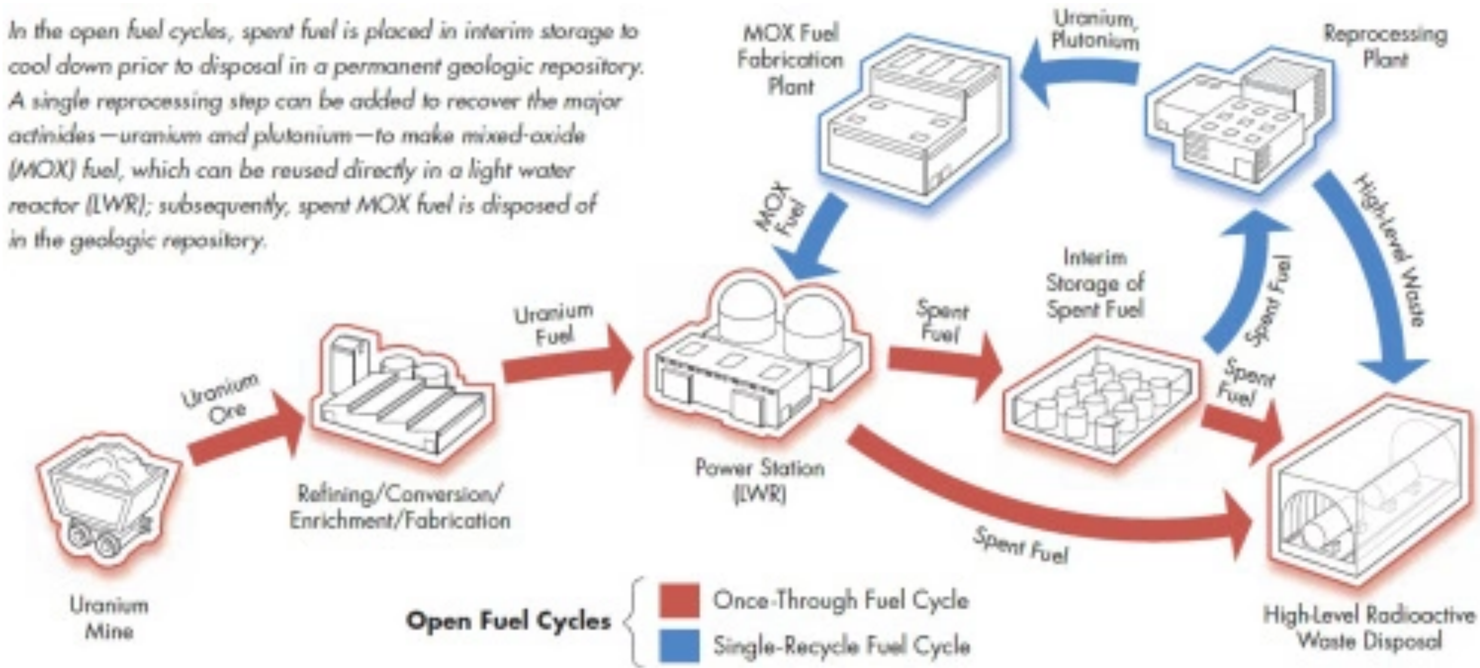
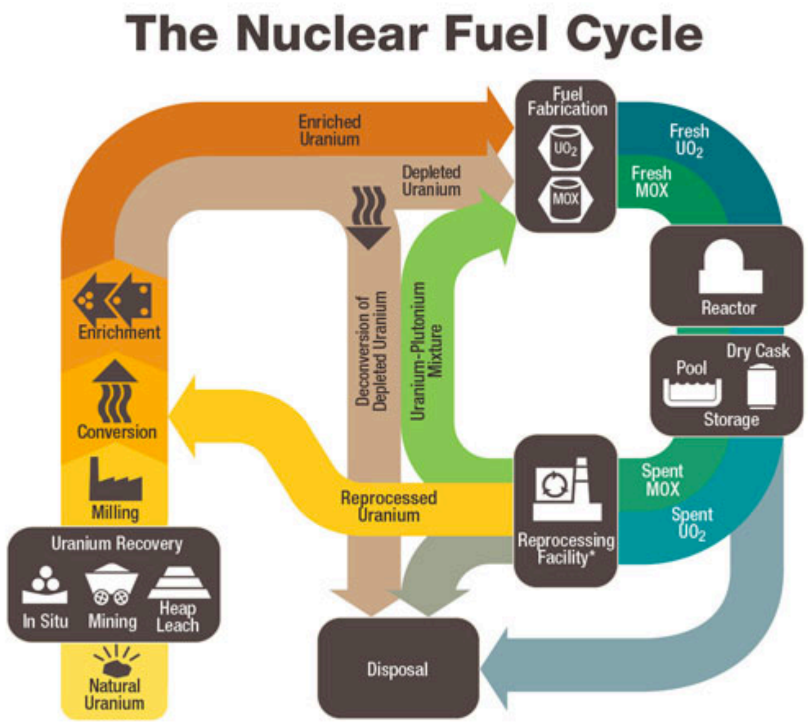
# Fuel reprocessing would allow us to use significantly more that 6% of the uranium

- We currently use a once-through cycle, without reprocessing
  - The used fuel must be stored for 250,000 years
- Reprocessing would allow the fuel to be reused
  - The final fission products would have shorter half lives
  - More power would be generated



# In a plutonium cycle, Pu and U are removed from the used fuel and used to make mixed oxide fuel

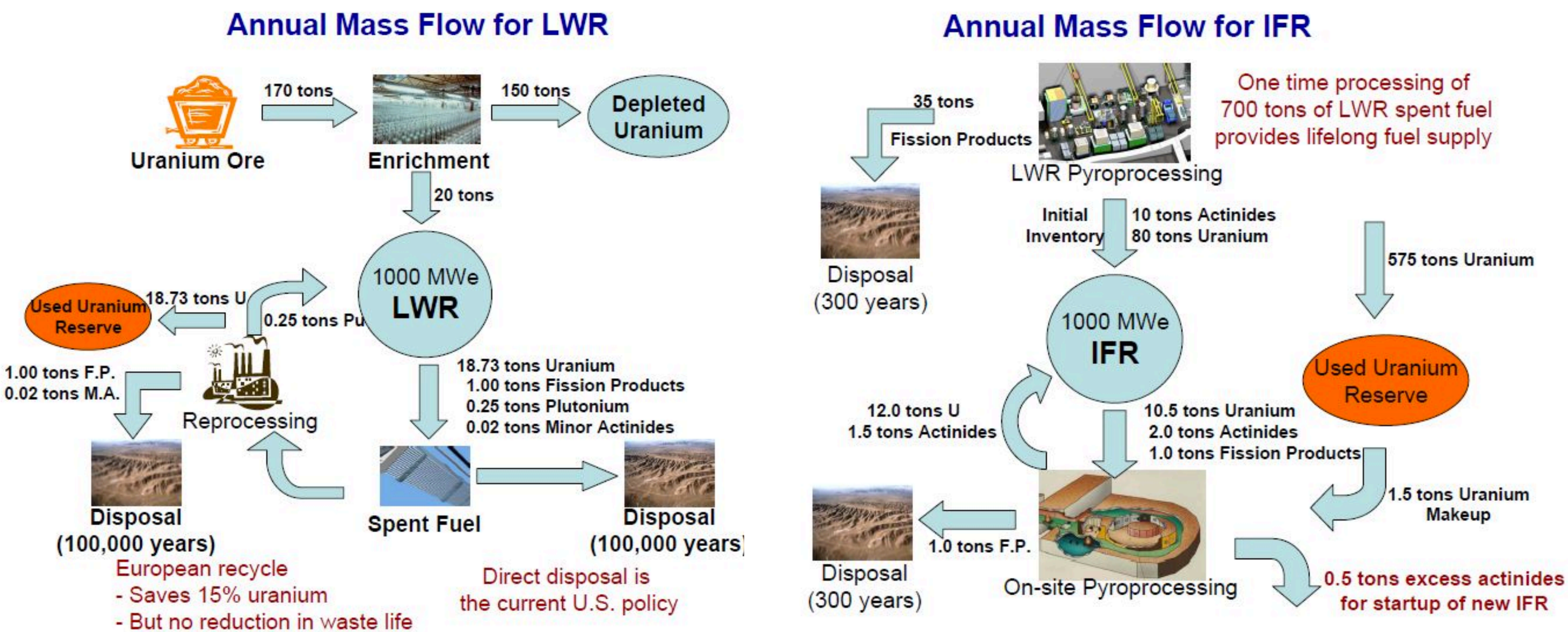
- The Pu (and U) are separated from the fission products, minor actinides, and activation products
- The U and Pu are used to make MOX fuel pellets
- MOX pellets are typically not reprocessed



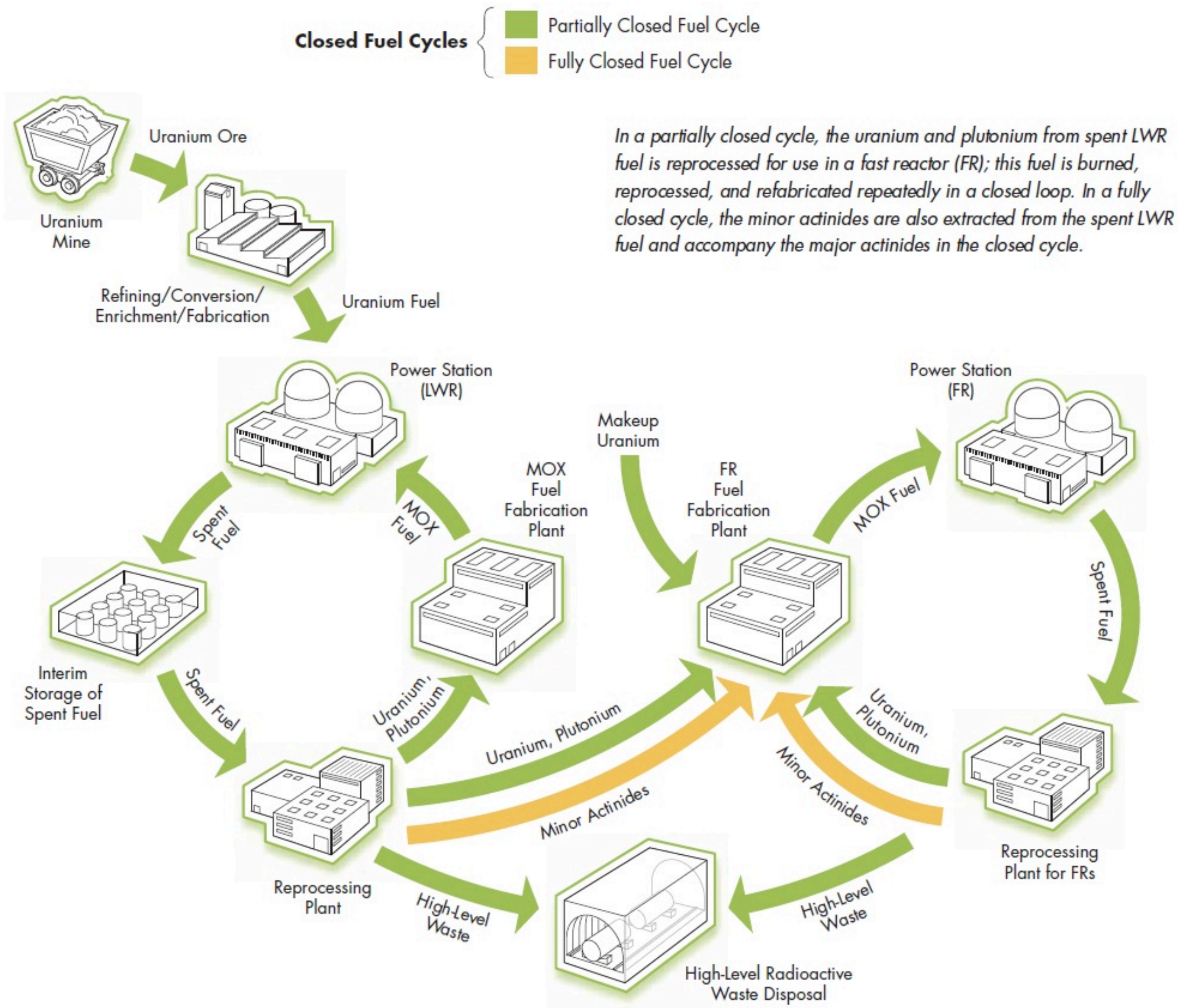

* Reprocessing of spent nuclear fuel including MOX is not practiced in the U.S.
Note: The NRC has no regulatory role in mining uranium.

# Minor actinides can also be reprocessed using integratal fast reactors

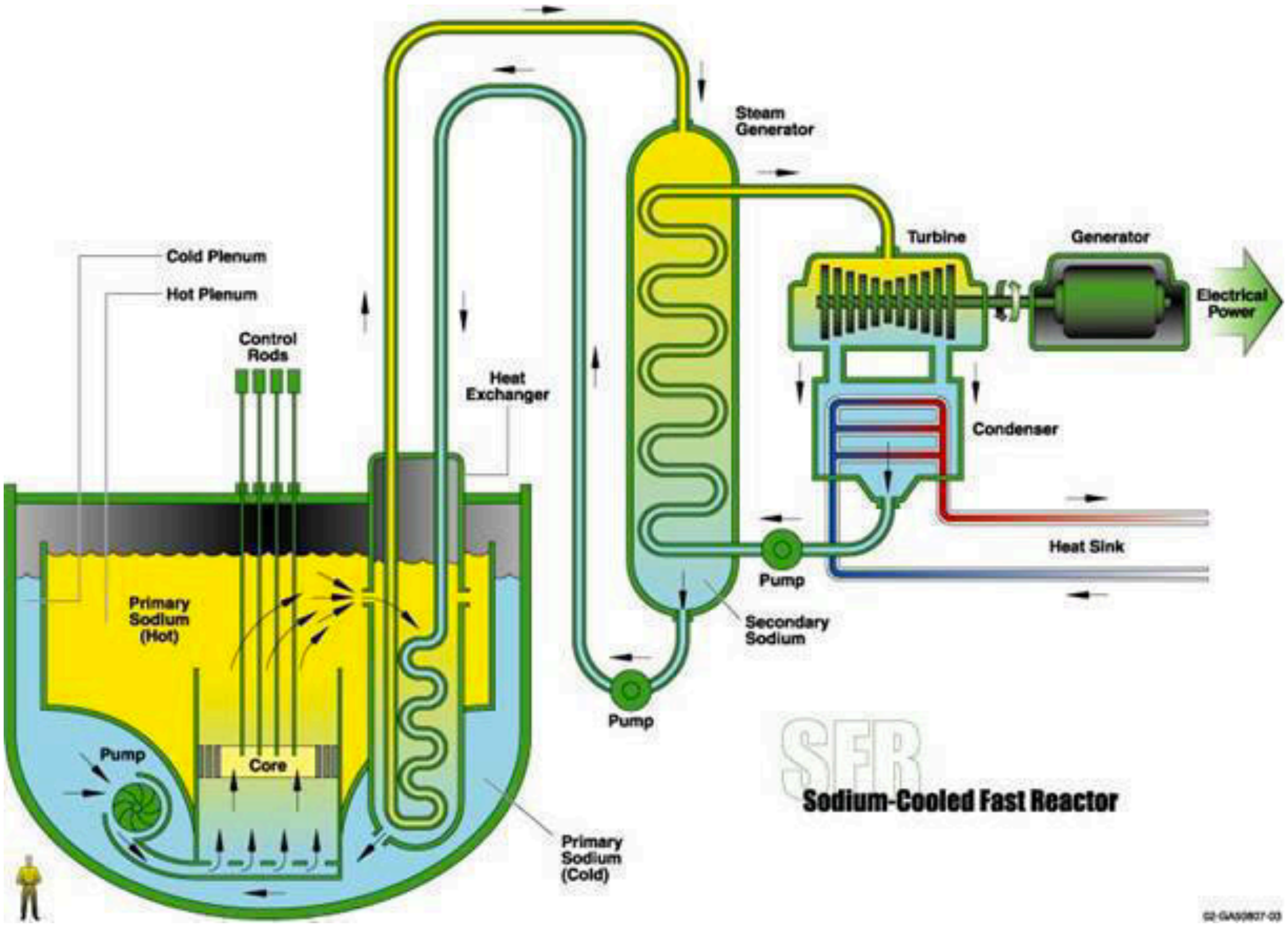
- Fast reactors can fission any actinide nucleus
- Thus, much more of the used fuel can be burnt



# LWRs with FRs can create a closed fuel cycle

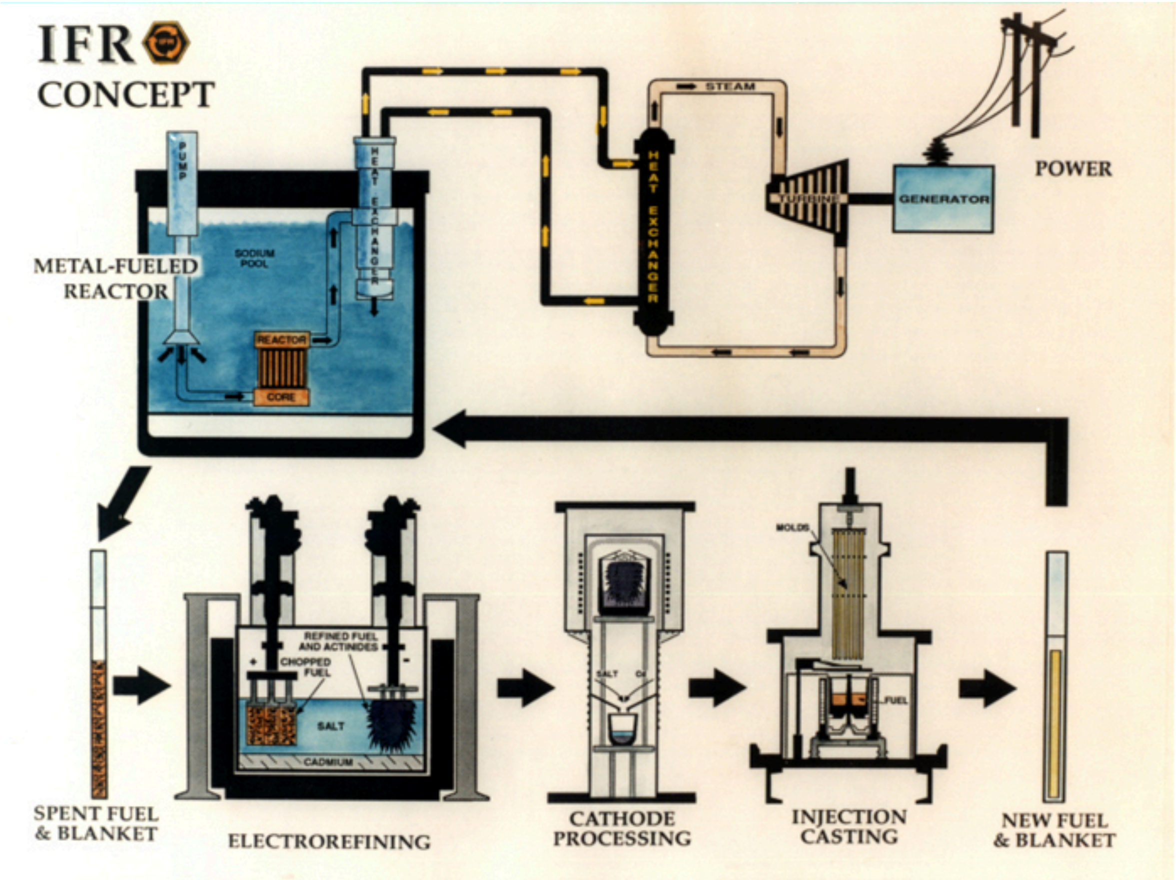


# The primary fast reactor concept is the sodium-cooled fast reactor (SFR)



# Either metal or MOX fuel could be used in SFRs, but the metal fuel has a proven fuel cycle

- Europe is pursing MOX while the US is mostly pursuing metal fuel




*Experimental Breeder Reactor II, in Idaho, which served as the prototype for the Integral Fast Reactor*

# So if fuel preprocessing completes the fuel cycle, why don’t we do it?

- Reprocessing has long been employed in France, the UK, Russia, India, and Japan
- However, reprocessing can make weapons grade Pu
- The US banned reprocessing in 1977, as an example to the world for non-proliferation
- The ban was lifed in 1981, but there was no money for development
- In 1999 the US DOE started to develop a plant, but it was never completed or used
- In addition, reprocessing is more expensive than using mined uranium

# Though we don’t have a closed cycle now, DOE is still doing lots of research and development on it

- The DOE Fuel Cycle Research and Development program conducts “research and development to help develop sustainable fuel cycles”
- It is researching three fuel cycle strategies
  - Once-through fuel cycle strategy (ATF program)
  - Modified open fuel cycle strategy (high burnup fuel, other fuel types)
  - Full recycle fuel cycle strategy (SFR, primarily metal fuel)

# Summary

- Used fuel goes through several steps before ultimate storage
  - Onsite pool storage
  - Vacuum drying
  - Dry cask storage
  - Long-term repository storage
- Various fuel cycles are in use or are being considered
  - Once through cycle
  - Plutonium cycle (twice through)
  - Closed cycle using fast reactors