US Activities on Fuel Cycle Transition Scenarios

Kathryn McCarthy

Deputy Associate Laboratory Director
Nuclear Science & Technology
Idaho National Laboratory

AFCI Systems Analysis Campaign Director

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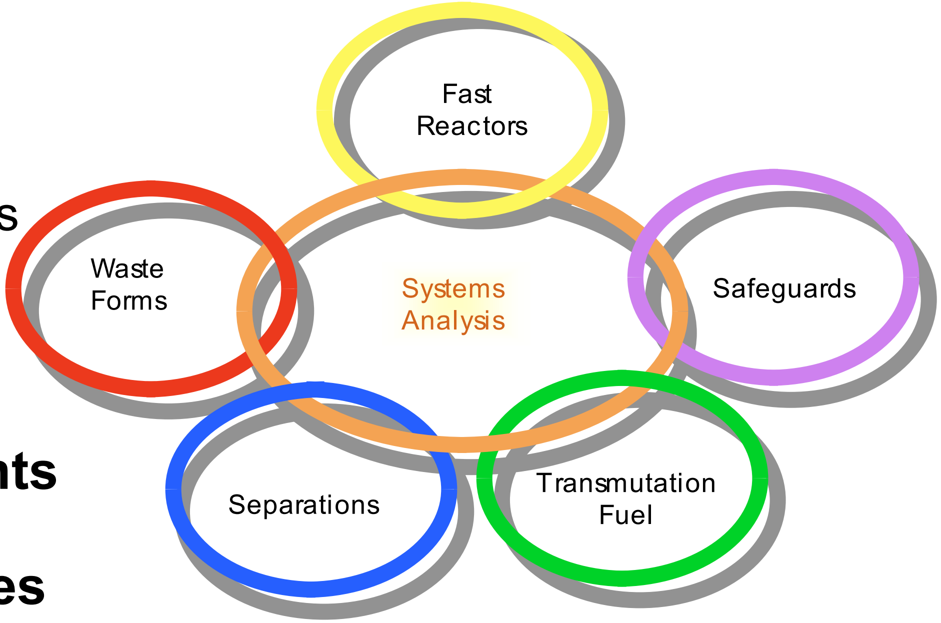
The US is analyzing fuel cycle options - The Systems Analysis Campaign provides guidance

- **Integrates information from the diverse technology development and R&D efforts**
- **Enables examination of a diverse set of scenarios**
  - Evaluate technology alternatives
  - Examine deployment options
  - Understand dynamics
  - Evaluate off-ramps
- **Used to define the requirements for the development and deployment of the technologies that are necessary to meet a mission**

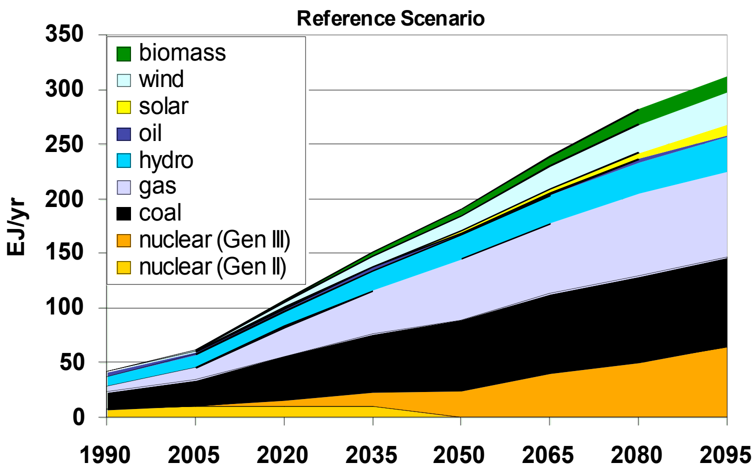


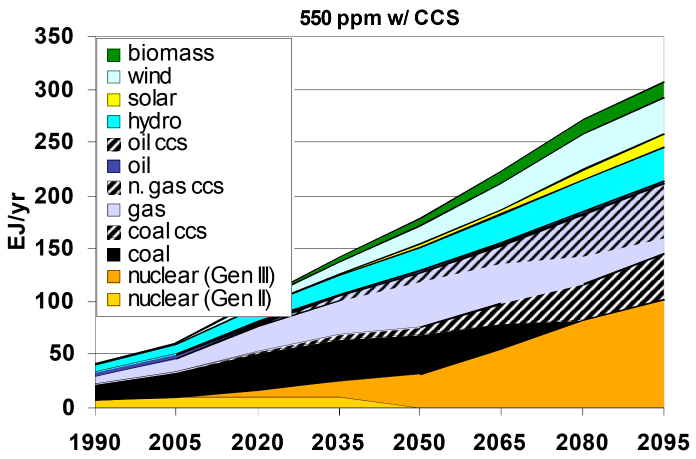
Recent systems analysis activities are focused on system performance during transition to a closed fuel cycle

- **Transition to both 1-tier and 2-tier closed fuel cycles are being assessed**
- **Systems dynamics models are used that incorporate feedback to determine the impacts of system constraints**
  - Overall nuclear growth envelopes
  - Facility throughput restrictions
  - Material availability limitations
- **Performance metrics are provided for system costs, resource usage, waste generation**
  - Models track materials in fuels, waste streams, etc. at the isotopic level
  - Sensitivity studies are used to explore impacts of performance uncertainties
  - Sensitivity studies indicate technical performance levels needed to meet quantitative goals

Global growth for nuclear energy will increase with or without CO_2 limits

- **Global demand for all energy will grow**
  - Global electricity consumption will increase 5-fold
  - Nuclear power will expand global electricity market share by 25%
  - Nuclear growth will challenge uranium and waste disposal resources
- **Limiting CO_2 levels results in less fossil, more nuclear and renewables**
  - Carbon capture and sequestration technologies are key to fossil market shares
  - The more aggressive the CO_2 limits, the greater the importance of nuclear

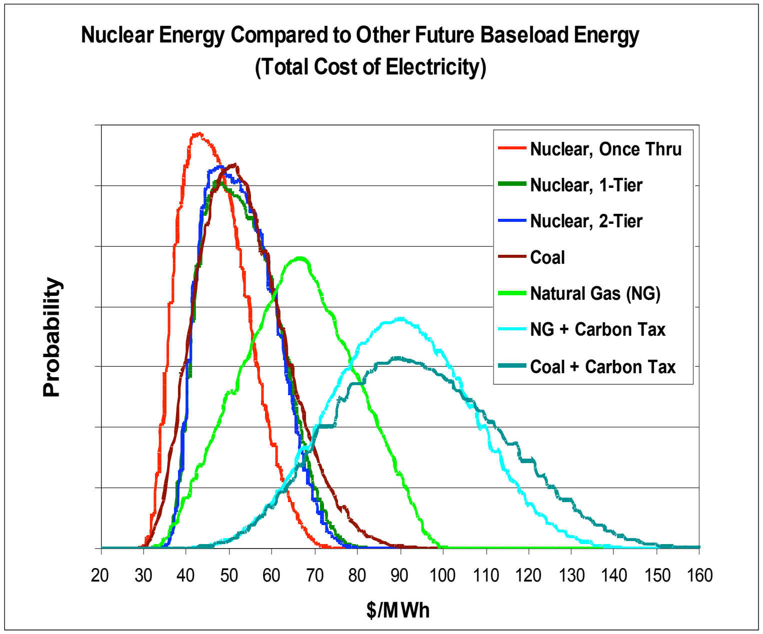




Nuclear energy is competitive with other sources with or without CO_2 taxes. Recycle does not change this finding.

- **Domestically, nuclear is competitive with fossil**
  - Once-through is potentially less expensive than coal
  - Closed fuel cycle is competitive with coal
  - Natural gas prices have greater uncertainty due to fuel costs
- **A U.S. carbon tax helps nuclear**
  - Carbon taxes will hit coal hardest
  - The uncertainty surrounding carbon taxes increases investment risk for all fossil baseload plants

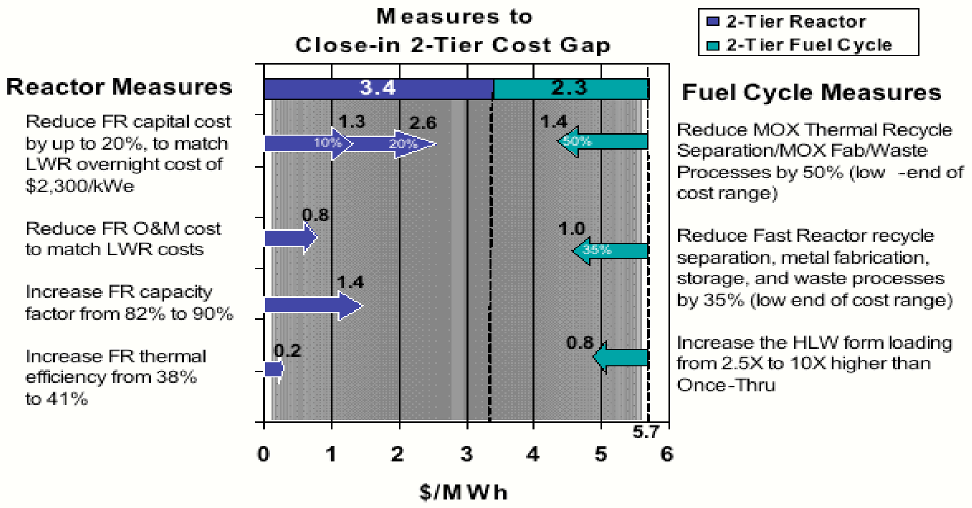
Total cost of U.S. electricity from nuclear and fossil sources



A closed fuel cycle will likely cost more than once-through

- **Closed fuel cycles appear to cost ~10% more than Once-Through**
  - Nuclear reactor and fuel cycle costs have large uncertainties
  - The cost distributions overlap

- **Measures for closing the cost gap were assessed**
  - Looked only at measures that may be controlled
  - Most involve additional R&D to improve technologies, designs

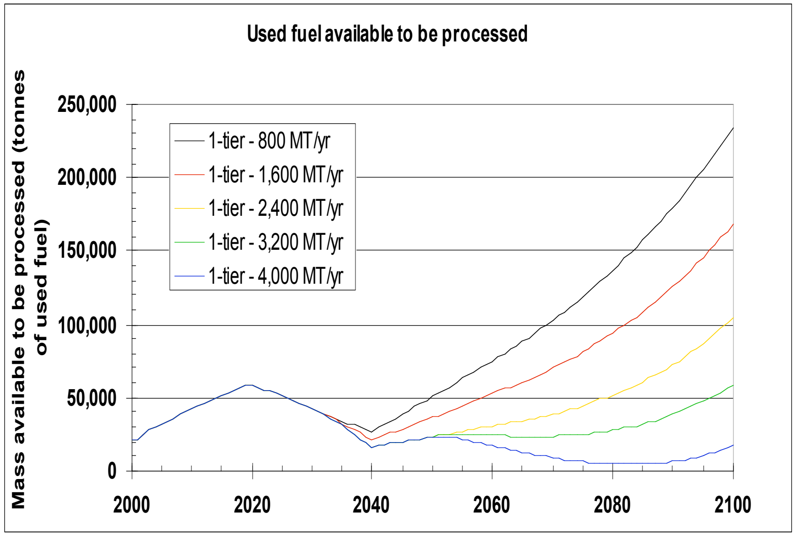


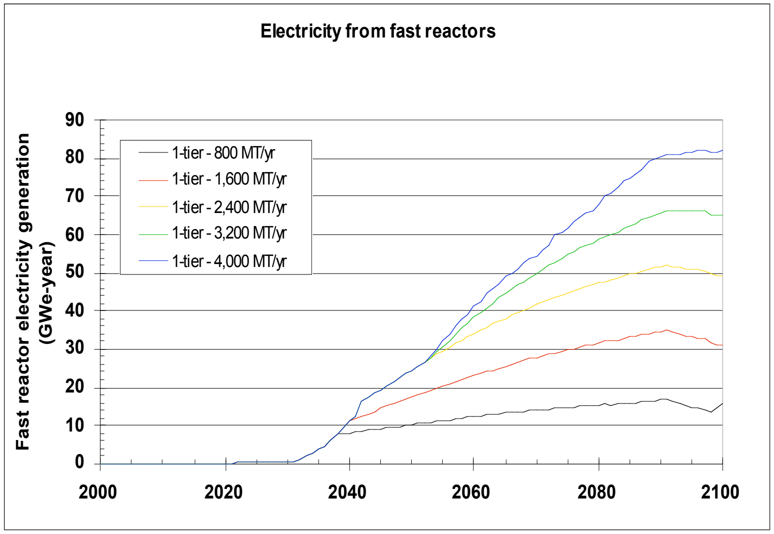
Fast reactor deployment is much slower than predicted by static calculations

- **Static calculations show ~60% more fast reactors**
  - At a TRU conversion ratio of 0.5, static calculations show 36% fast reactors.
  - Dynamic calculations show fast reactor shares of only ~22% by the end of the century
- **Primary factors:**
  - Separations capacity
  - Growth rates
  - Conversion ratio
  - Cooling time
    - *Fast reactor fuel type is not important – but location of recycling facilities is*

Separations capacity drives the deployment of fast reactors

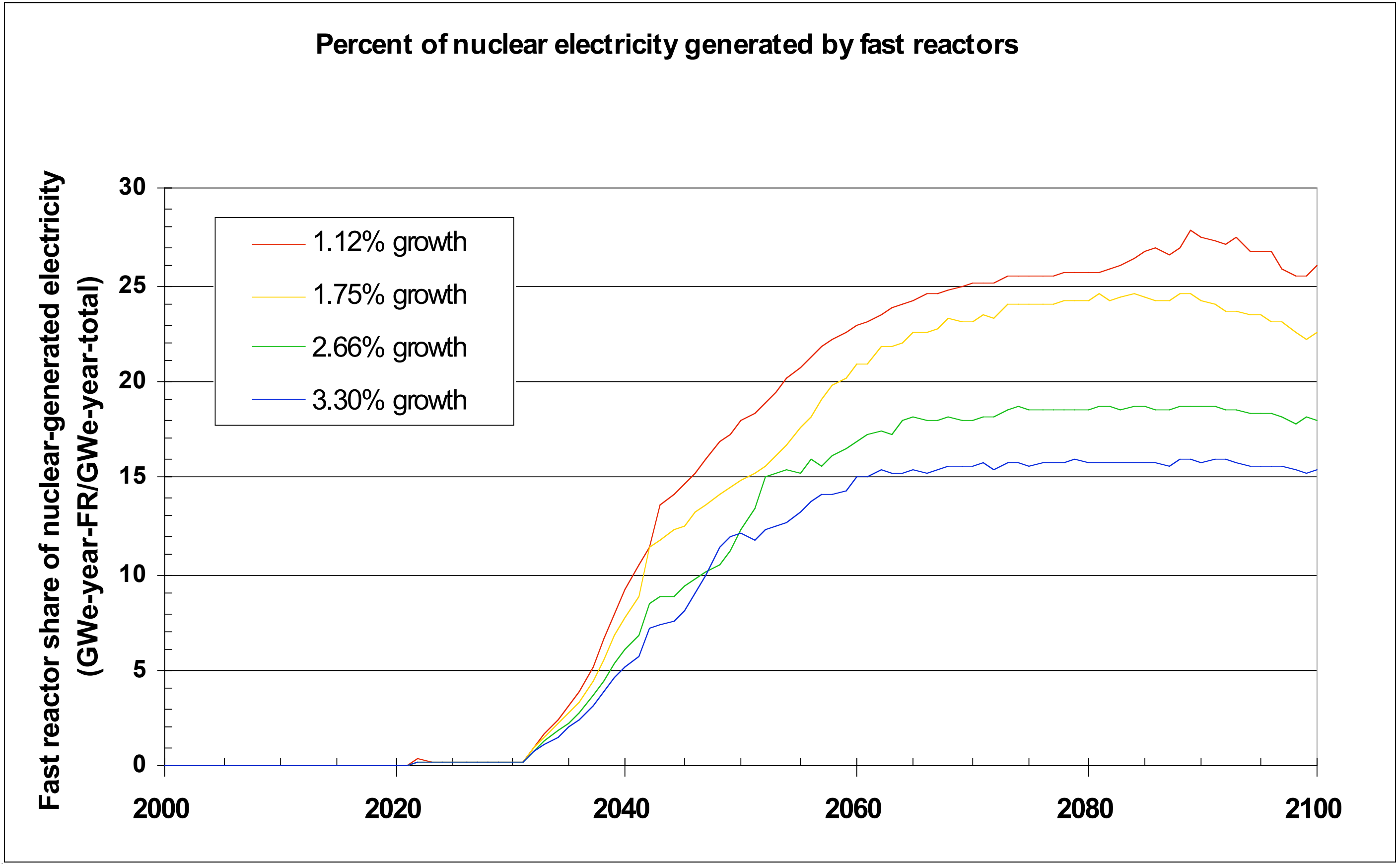
- **If LWR used fuel separations is limited, fuel is “left on the table”**
  - Nominal cases based on separating all cooled fuel by the end of the century (except for 63,000 direct disposed)
- **Separations timing is less important**





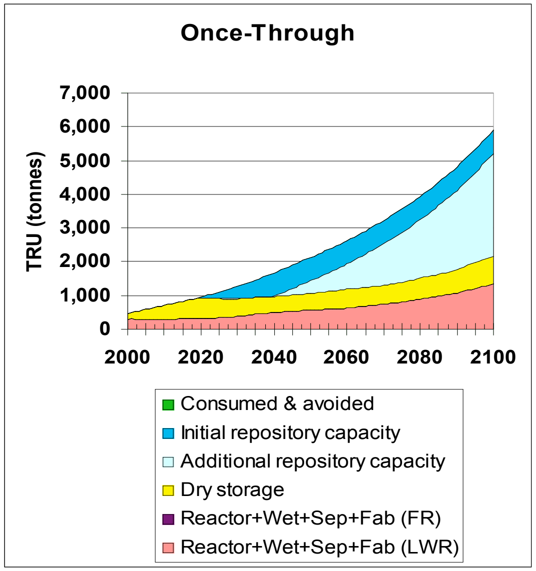
The higher the growth rate, the lower the fast reactor share

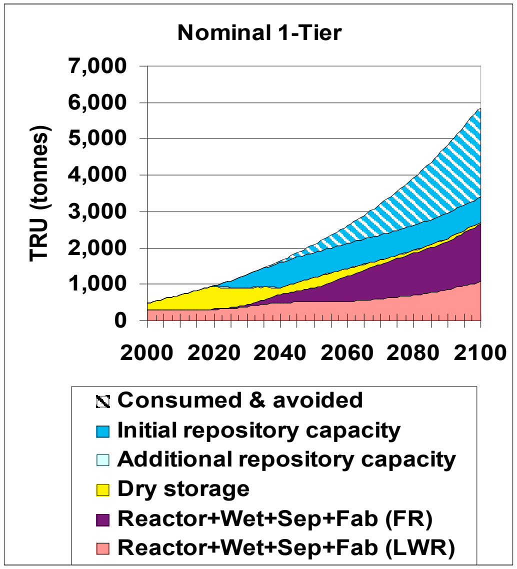
- **Fast reactor share increases while excess used fuel inventories are reduced, then levels off into dynamic equilibrium**

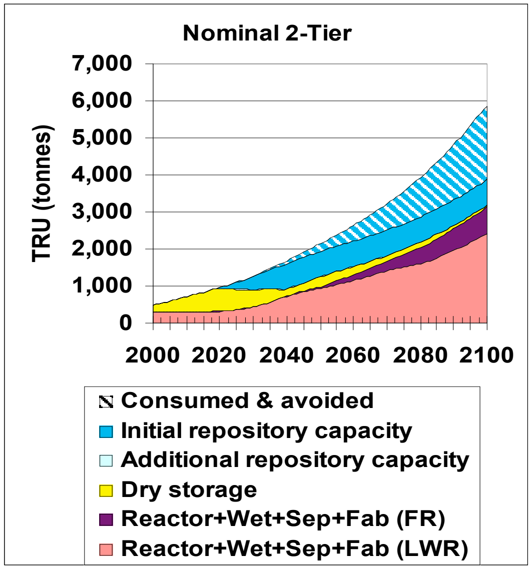


Closing the fuel cycle changes transuranics management in several ways

- **Total transuranics are reduced**
  - 1-tier reduces transuranics levels faster than 2-tier
- **More transuranics are in reactors or in storage**

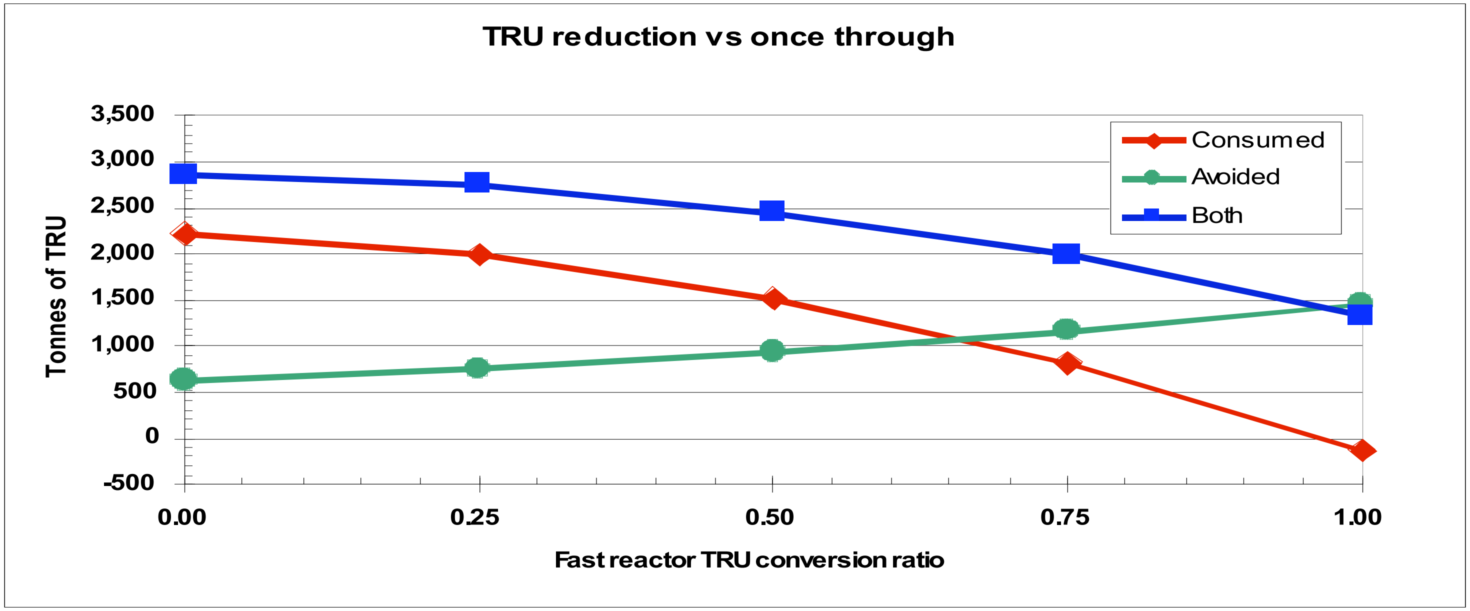






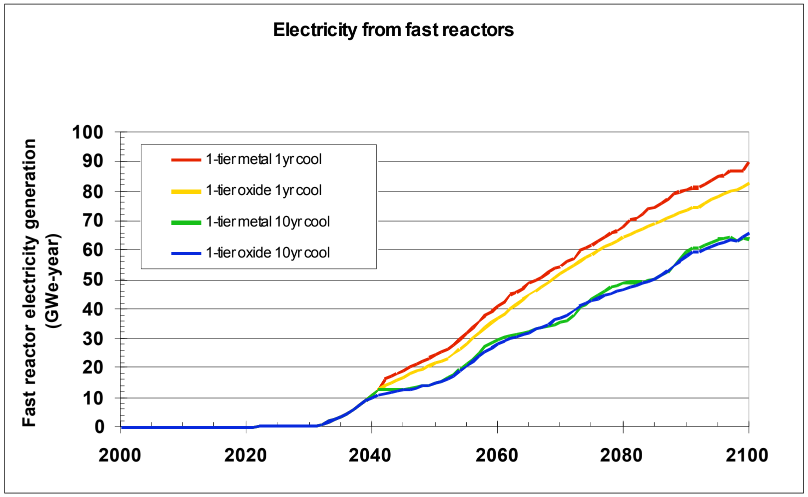
Total TRU reductions are due to both TRU consumed and TRU production avoided

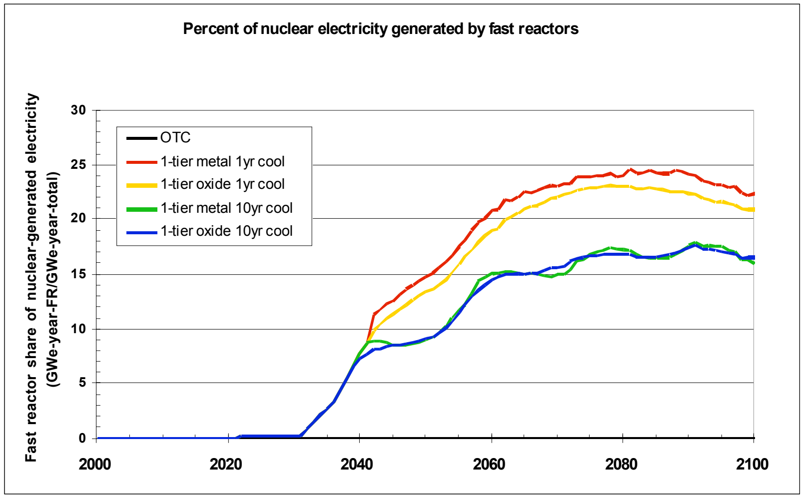
- **As conversion ratio increases, TRU avoided becomes dominate**
  - As growth rate increases, total TRU reductions are less sensitive to CR (the blue line is flatter)



Cooling used fuel longer before recycling reduces TRU available for fast reactors

- **Fast reactor fuel type is less important than location of fast reactor fuel recycling facilities**
  - Transportation constraints require much longer cooling times for centralized recycling facilities, tying up TRU in storage instead of in reactors

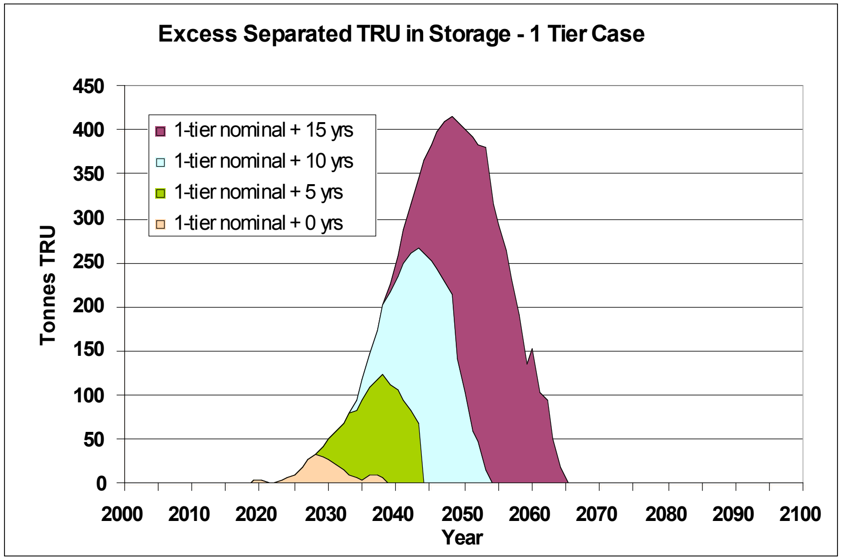




Coordination is needed to avoid excess separated material inventories at the start of the transition

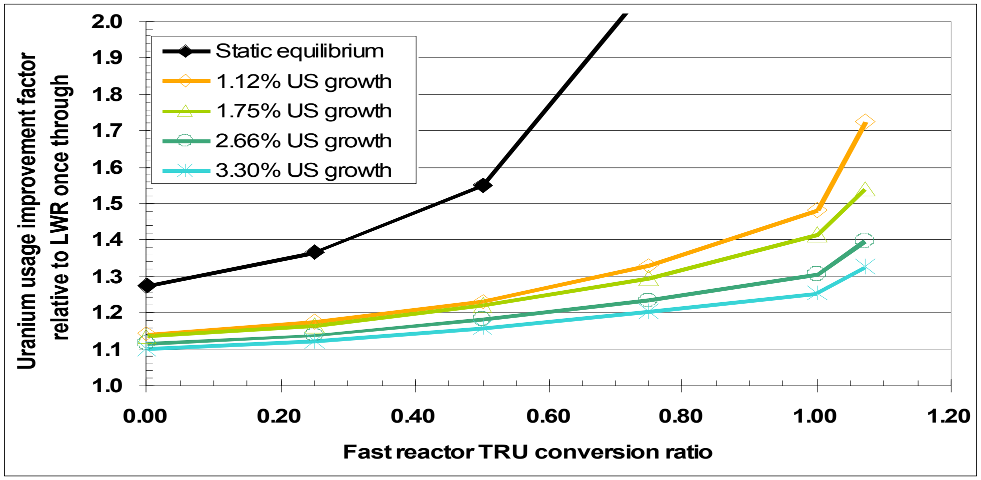
- **Facility sizes can produce material flow mismatches when total facility numbers are small**
- **Technology, regulatory and funding uncertainties can impact timing**
  - Delays in separations, fabrication, or transportation can result in fuel shortages
  - Delays in reactor fielding can result in inventory bubbles
  - Facility ramp rates, learning periods also important
- **Flexibility is an important tool**
  - Buffer storage
  - LWR MOX capacity
  - Temporary facility closures
  - Etc.

1-tier scenario excess separated transuranics with later fast reactor deployment and no change in separations



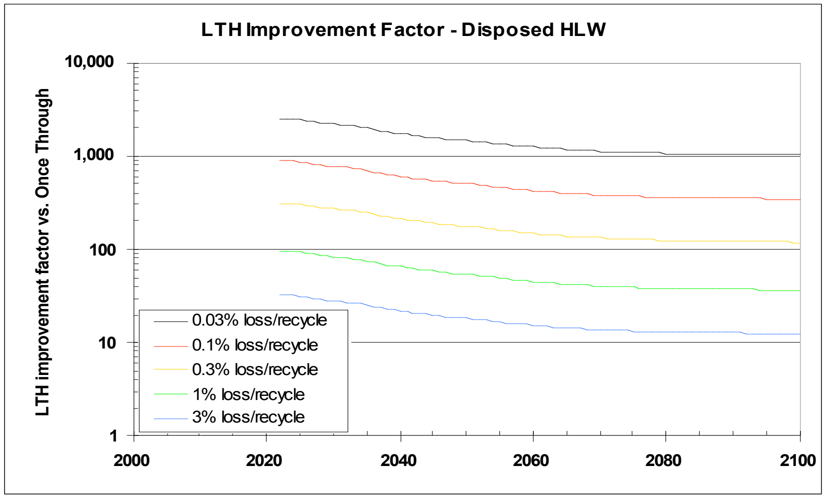
Uranium savings are limited during the transition period

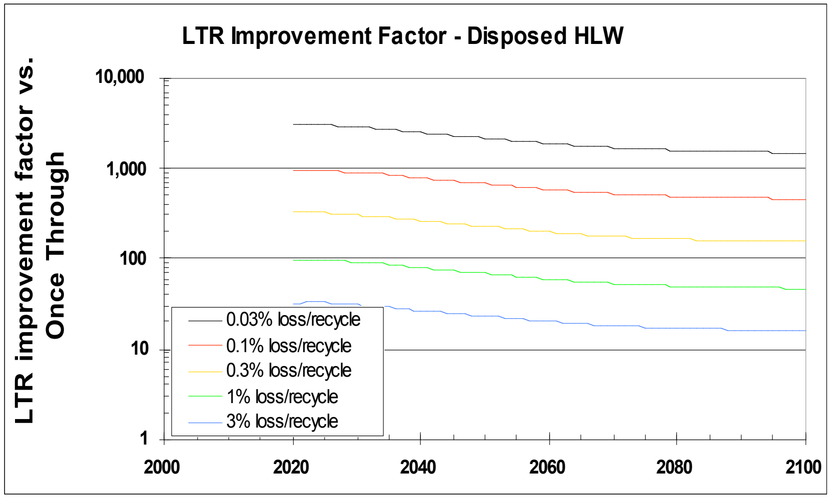
- **Closed fuel cycles do not save much uranium by end of century**
  - Transition rates are too slow to have major impacts
  - Dynamic transition again much less than predicted by static calculations
- **Fast reactor deployment is the most significant factor**
  - Higher nuclear growth rates equate to lower uranium savings
  - TRU conversion ratios have greatest impact above 1.0



System loss rates during recycle impact waste benefits

- **Quantitative waste parameter improvement goals are met at system loss rates per recycle below 0.3%**
  - Cost/benefit analysis of loss rates is needed





These studies are being used to inform follow-on studies

- Assessing the impact of advanced fuel cycle cost differentials on domestic and global projections of nuclear energy growth
- Assessing phased fuel cycle transition options, including the initial fielding of mature technologies followed by a later phase-in of advanced technologies
- Supporting major technology decisions and requirements development through integrated analyses
  - Minor actinides storage vs. disposal trade-off study
  - System losses trade-off study
  - Waste trade-off studies
- Extending the types and scope of analyses provided
  - Impacts of expansion of nuclear energy beyond electricity generation