The Global Nuclear Energy Partnership: *Transmutation Fuel Development*

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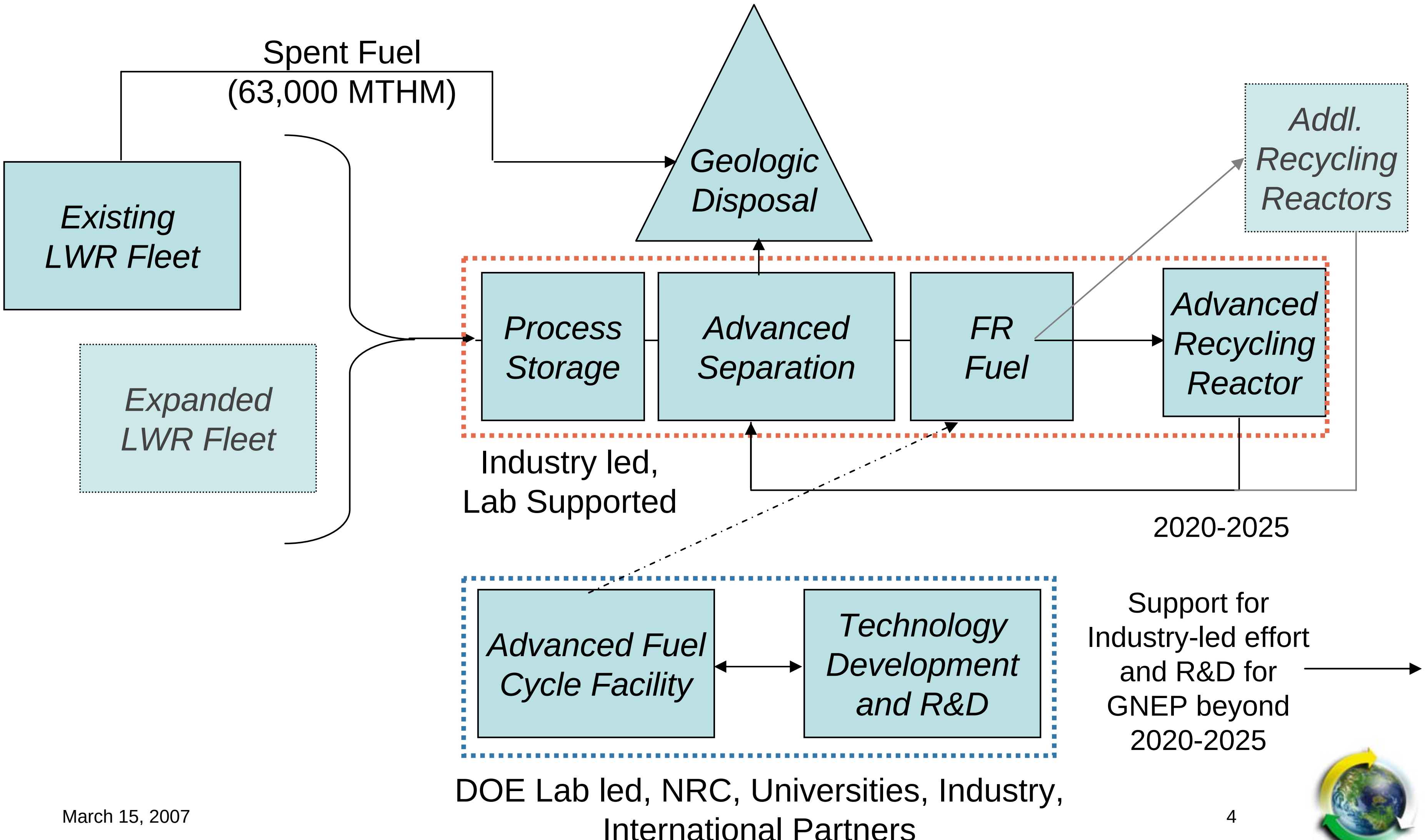
Outline

- **Transmutation Qualification Basics**
  - Background & Key Dates
- **Status of Transmutation Fuel Development**
  - State of Knowledge, Leading up to LTAs
- **Qualification Strategy for Transmutation Fuels**
  - Challenges
- **Summary and Conclusions**

Transmutation Fuel - Historical Background

- **1960 – 1990: The Oxide/Sodium Cooled Development Generation**
  - Southwest Experimental Fast Oxide Reactor (SEFOR), Stickler, Arkansas, 1969 - 1972, 20 MWth
  - Clinch River Breeder Reactor, Oak Ridge, Tennessee, announced in 1972, not built, 350 MW(e)
  - Fast Flux Test facility (FFTF), Hanford, Washington, 1980-1993, 400 MWth
  - Foreign Fast Reactors: Phenix, 233 MW(e) & Superphenix, 1240 MWe, France; Joyo, 100 MWth & Monju, 280 MWe, Japan; BN 350, 350 MWe & BN-600, 600 MWe, Russia
- **1985 – 1995: Metal Fuel Comes of Age**
  - Built on liquid metal cooled fast reactor development since 1946,
    EBR-I & II, (1951-1994), Fermi (1963 - 1972), and the FFTF (1980-1993)
  - Integral Fast Reactor (IFR) project of early 1990’s proposed to burn actinides
- **2000: Start of the AFCI/GNEP Era**
  - Accelerator Transmutation of Waste program – 2000
  - Advanced Accelerator Applications program - 2001
  - Advanced Fuel Cycle Initiative program - 2003
- **2007: GNEP International/Industrial Participation Expansion**

Supporting the GNEP Strategy Requires New Facilities, Technology Development and R&D



Some Reference GNEP Dates

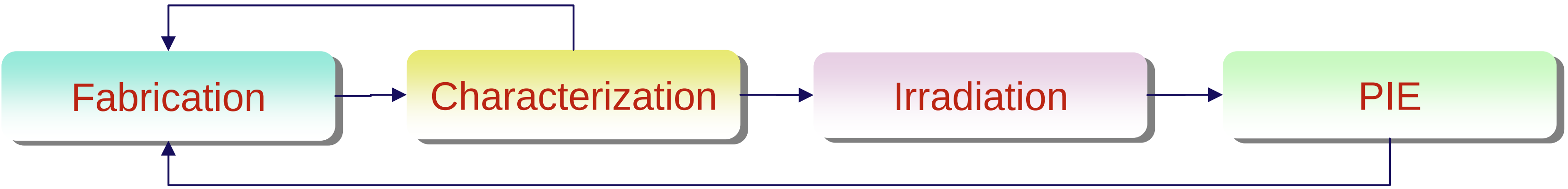
- **2007: Program Authorized**
- **2008: Secretarial Decision on GNEP Path Forward**
- **2018: Advanced Fuel Cycle R&D Facility Operation (AFCF)**
- **2020: Advanced Burner Reactor Startup with Non-Transmution fueled Driver Core (ABR)**
- **2020-2025: Commercial-scale Recycle Facility Operational**
- **2020 – 2030: Transmutation Fuel Qualification Period (~10 yrs)**

What Does advanced fuel "Qualification" Mean?

Basically, sufficient data on a new fuel type has been generated over the range of normal and design transient conditions, as well as sufficient analysis of beyond design conditions to support a license, by test, application with the NRC. The strategy that will be applied to the ABR in GNEP, driven by the anticipated dates, is:

- **Plan on initial ABR startup with a common fast reactor driver fuel, such as that developed in the U.S. for the FFTF and Clinch River**
- **After successful initial power operation of the ABR, use transmutation fuel-bearing Lead Test Assemblies fabricated in the AFCF in the ABR to generate sufficient data to support the license of full-core operation with such assemblies in about ten years**
- **The acceptable rate of transmutation fuel bearing assembly insertion into the ABR will be decided as part of the ABR licensing process**

Fuel fabrication process will be developed using existing facilities prior to large-scale demonstration.



Fabrication

- Glove-box fabrication very slow
- Hot-cell facility needed.
- Stockpile materials limited (Am, Np, Reactor Grade Pu)
- Actual separated and co-precipitated materials needed

Medium schedule risk

Characterization

- Additional state-of-the art characterization equipment needed

Irradiation

- Domestic fast-spectrum irradiation capability does not exist.
- ATR/HFIR irradiations with cadmium filter.
- More aggressive collaboration agreements (Joyo, Monju, BOR60)

High schedule risk

PIE

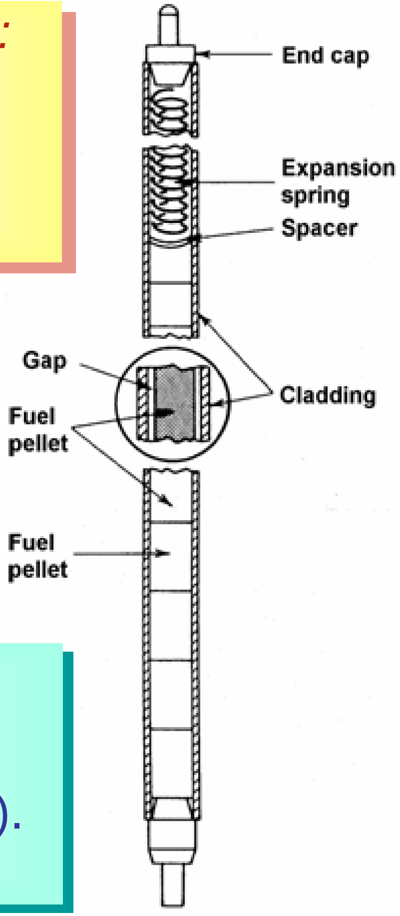
- Infrastructure requires serious refurbishment
- e.g. shielded microprobe, thermal characterization of hot fuels

Fuel performance prediction requires integral understanding of multiple phenomena.

- Microstructure
- Initial distribution of species
- Initial stoichiometry
- Thermal conductivity
- Thermal expansion
- Specific heat
- Phase diagrams
- Fission gas formation, behavior and release
- Materials dimensional stability
  - Restructuring, densification, growth, creep and swelling
- Defect formation & migrations
- Diffusion of species
- Radial power distribution
- Fuel-clad gap conductance
- Fuel-clad chemical interactions
- Mechanical properties

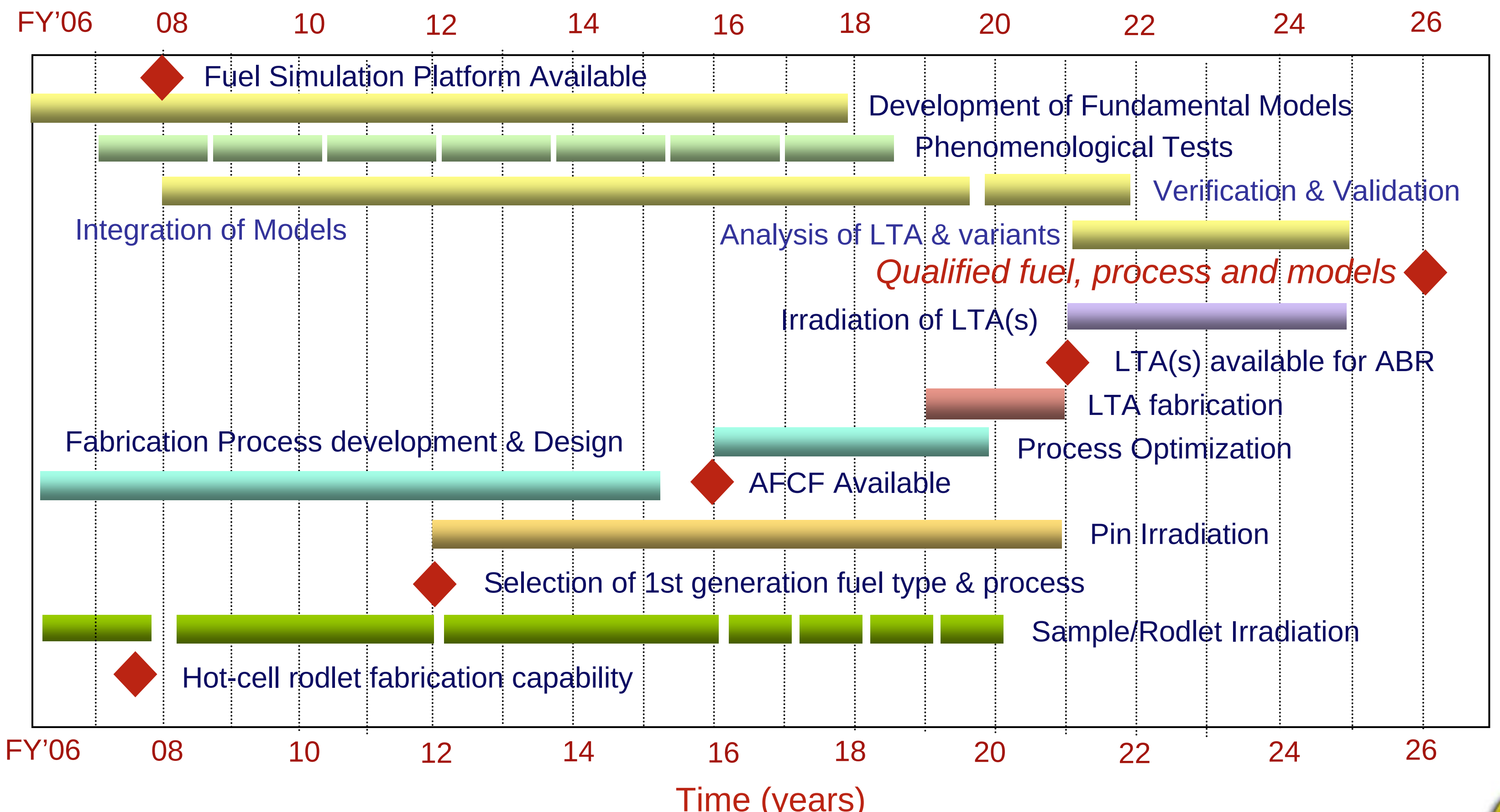
Dynamic properties:
Changes with irradiation, temperature, and time.

Nonlinear effects:
Initial condition dependence (fabrication route).

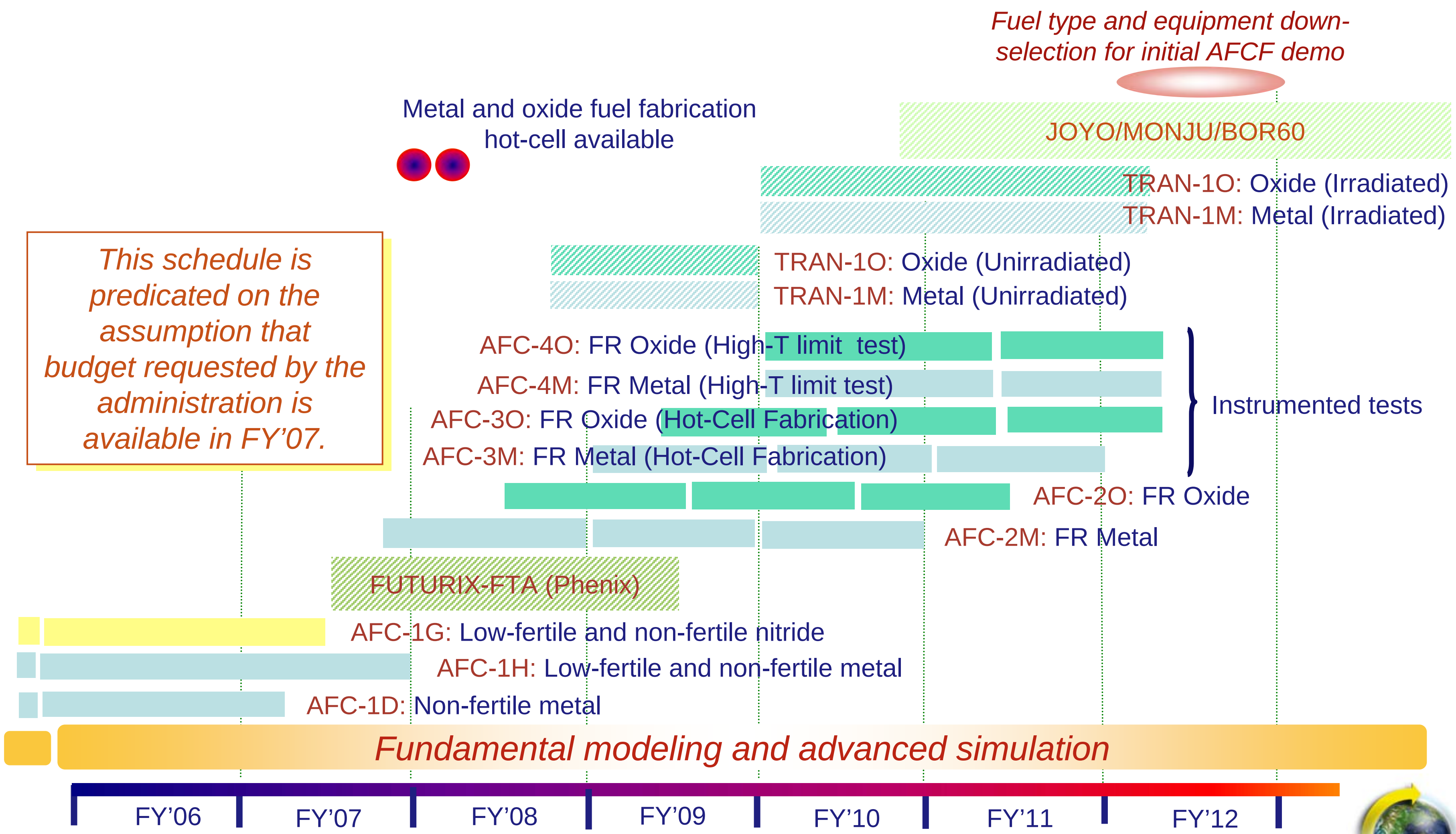


A parallel analytic and experimental development assures implementation shortly after the first LTAs.

This schedule is predicated on the assumption that budget requested by the administration is available in FY'07.



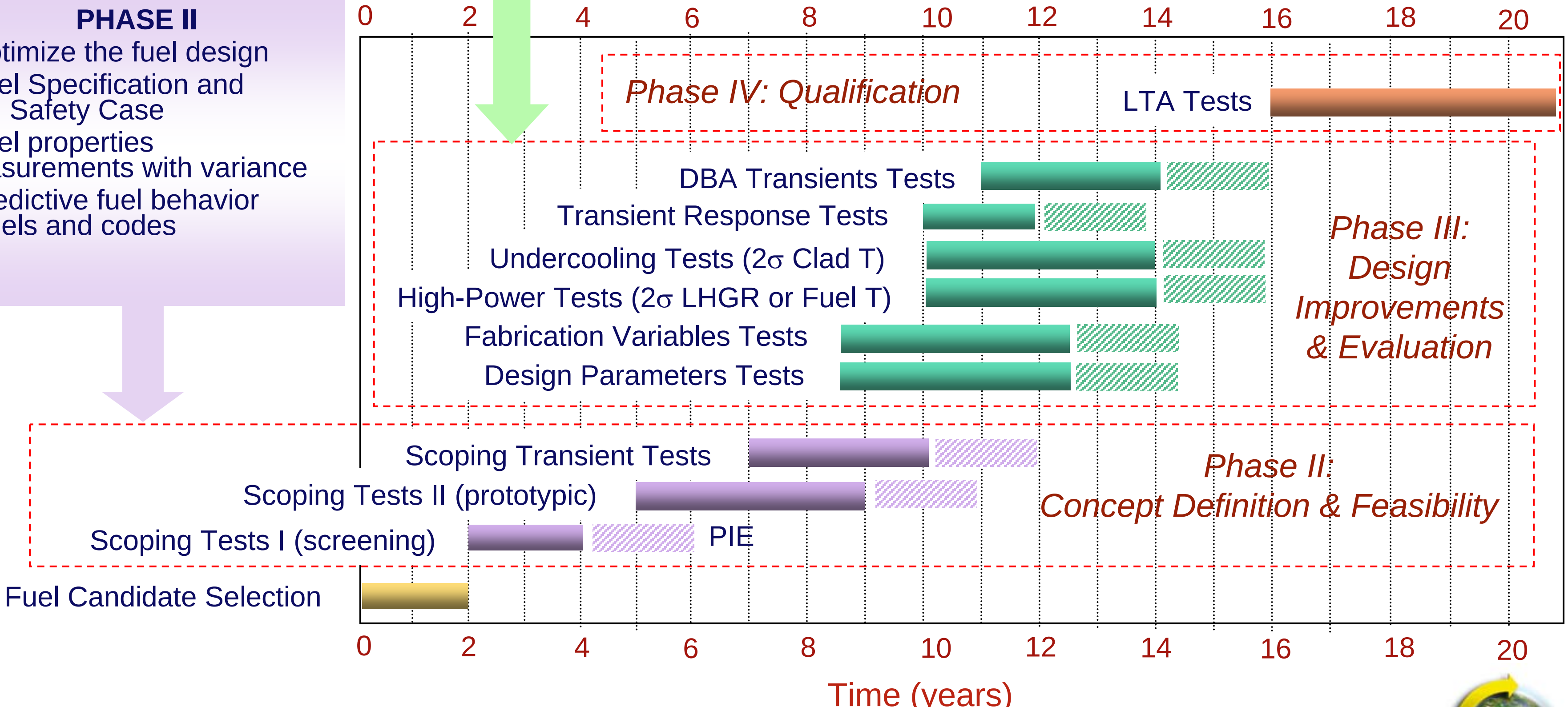
Near-Term irradiation schedule reflects emphasis on fast-reactor transmutation fuel down-selection in 2012 for the initial demonstration.



To achieve fuel qualification tests using LTAs, considerable developmental testing is planned.

PHASE III
- Demonstrate fabrication process
- Validate fuel performance specifications
- Validate predictive fuel performance codes

PHASE II
- Optimize the fuel design
- Fuel Specification and Fuel Safety Case
- Fuel properties measurements with variance
- Predictive fuel behavior models and codes



Metal and oxide TRU fuels are candidates for the first generation transmutation fuel.

Candidates for First Generation Transmutation (< 20 years)

Oxide Fuels (powder processing)

- Successful small-scale fabrication and irradiation on limited amount of samples (France, Japan)
- Effect of group TRU on fabrication process unknown
- Effect of lanthanides on fabrication
- Large-scale fabrication amenable to hot-cell operations must be developed
- Limitations on linear power

Metal Fuel

- Successful small-scale fabrication and irradiation on limited amount of samples
- Large-scale fabrication without loss of Am must be demonstrated
- Fuel-clad interactions at high burnup must be investigated
- **Effect of lanthanides on FCCI must be addressed**

Back-up Options for Initial Candidates

- Sphere-pac or vibro-pac fuel technology
  Risk trade-off: fabrication versus performance

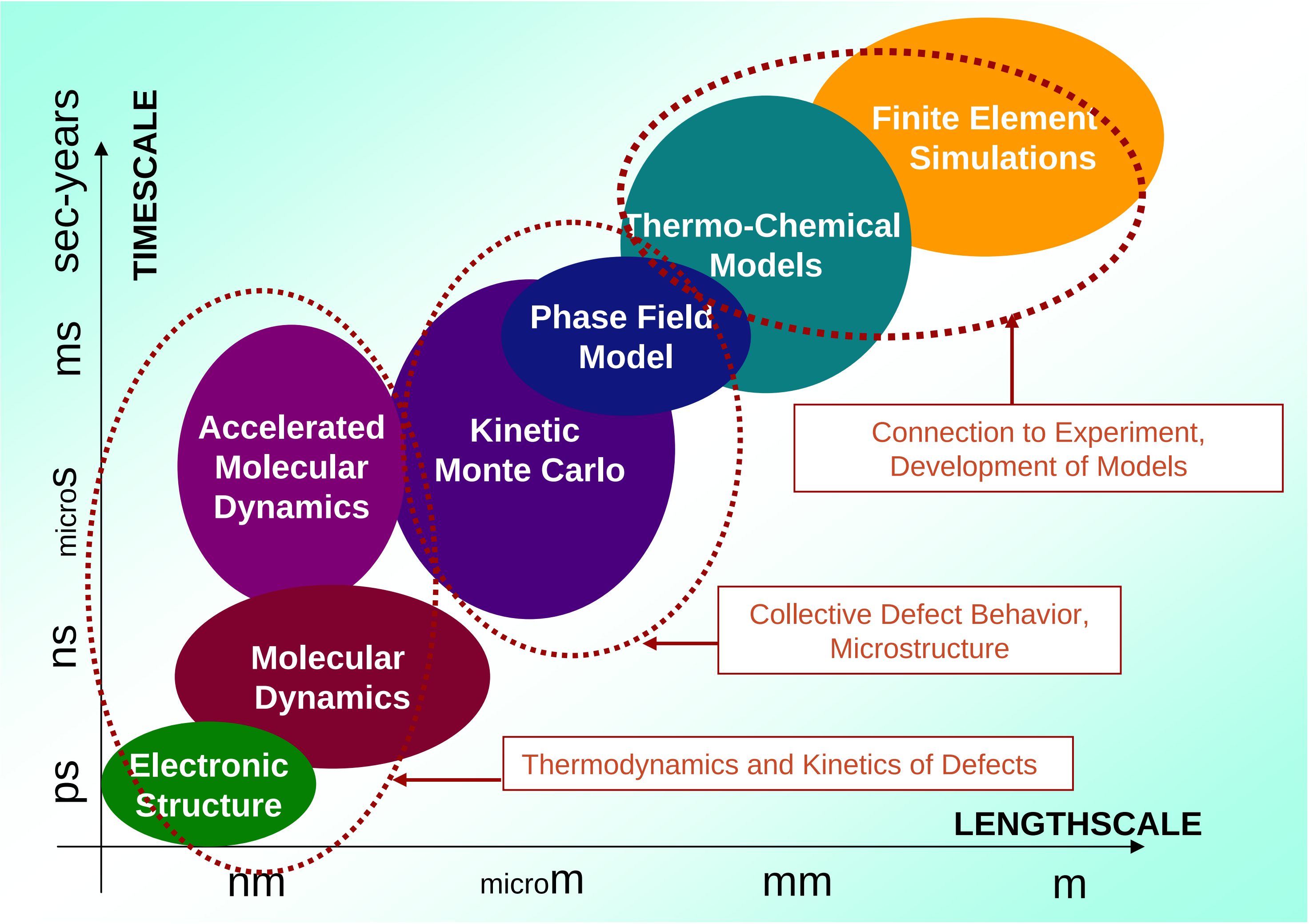
- Am recovery and use in moderated targets
- Fabrication using powder metallurgy
- Development of advanced clad materials (possibility of using liners)

Long-Term Options (2nd or 3rd Generation) for Increased Efficiency (> 20 years)

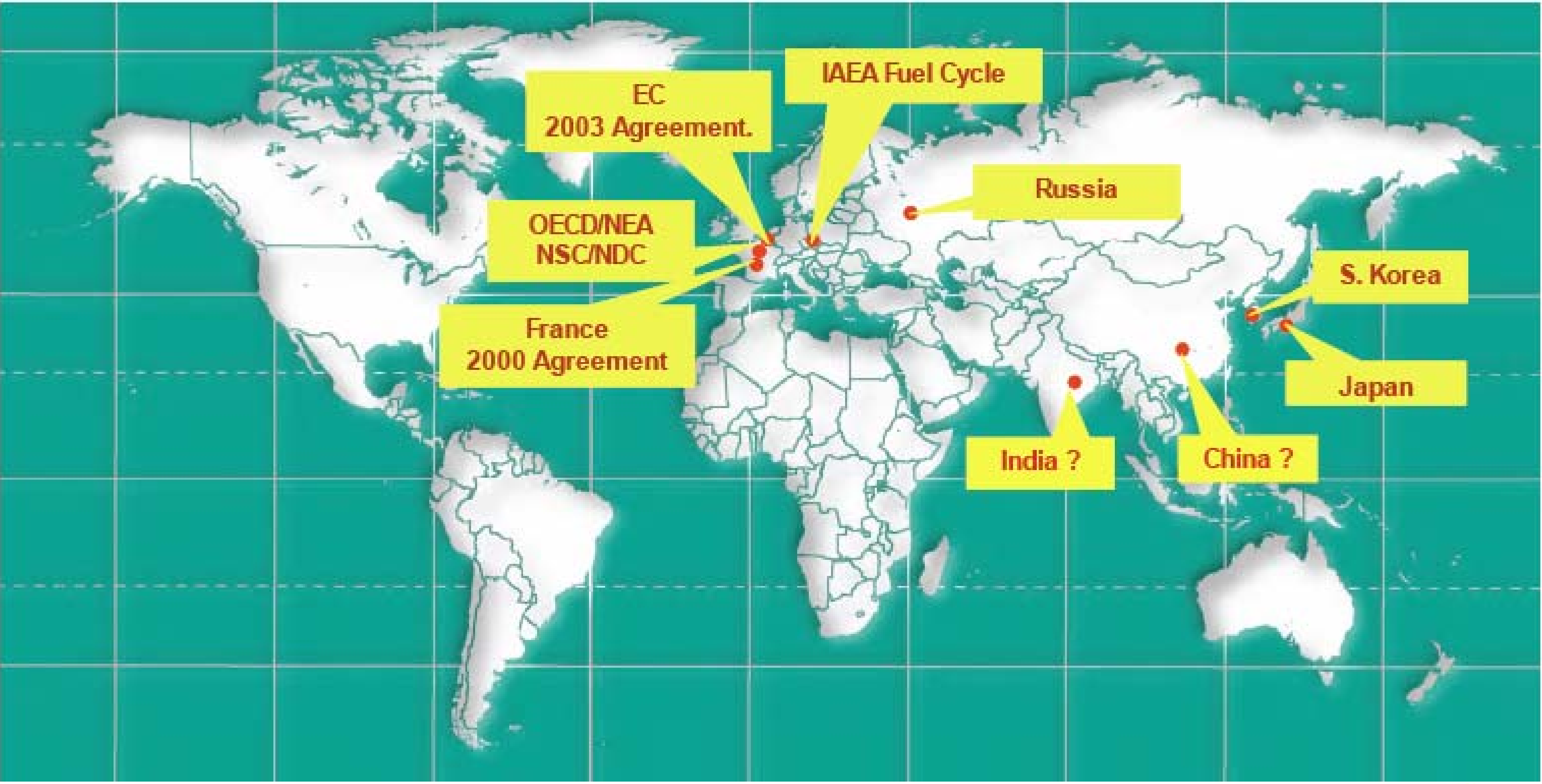
- **Nitride**
  - High TRU loading potential
  - Fabrication process requires further work
  - N-15 enrichment.
- **Dispersion**
  - High burnup potential
  - Fabrication process requires further work
  - Separations process must be developed

Multi-scale modeling approach is being used to develop fuel performance suite of codes. μ

Long-term pay off: Incremental improvements in reducing the number of tests and qualification duration



There is considerable potential for International Collaborations on GNEP Fuel Cycle Development.



Summary and Conclusions

- The AFCI research-to-date along with International collaborations has shown the technical feasibility of transmutation fuels (metals and oxides).
- The engineering feasibility requires additional development
  - Fabrication cost/ process efficiency at engineering scale
  - Burnup limits as high as possible
  - Assembly level fabrication and irradiation
- Fuel qualification even for much simpler fuel systems requires a lengthy development and testing.
- In parallel to empirically based approach for selected composition(s), a science based approach that takes credit for advanced modeling and simulation along with phenomenological testing will be used for rapid implementation after the completion of irradiation for the first set of lead test assemblies (LTAs).
- A realistic development program exists to achieve the GNEP objectives
  - Additional International collaboration is important for the implementation of the fuel development plan.