Getting the LFTR Off The Ground

Computational Physics For Liquid-Fueled Thorium Reactors

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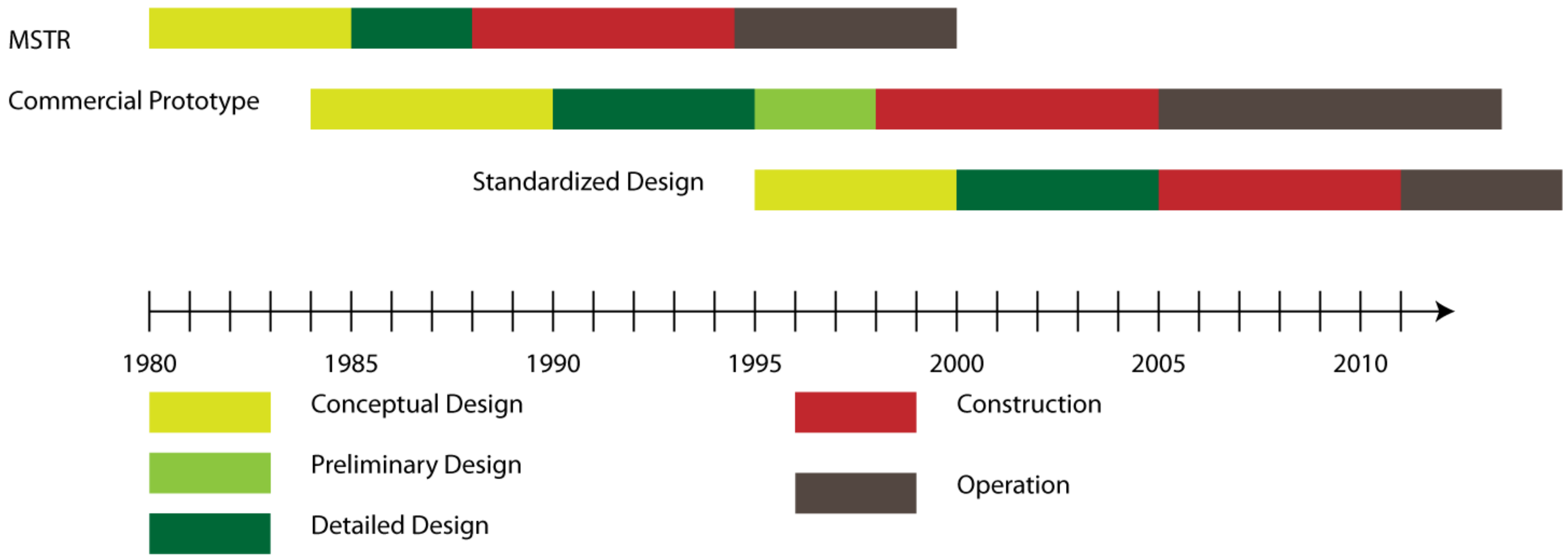
"… Generation IV Systems are expected to become available for commercial introduction in the period between 2015 [to] 2030 or beyond"

-- Gen IV International Forum

Timescale

1979 ORNL Proposal For DMSR Development

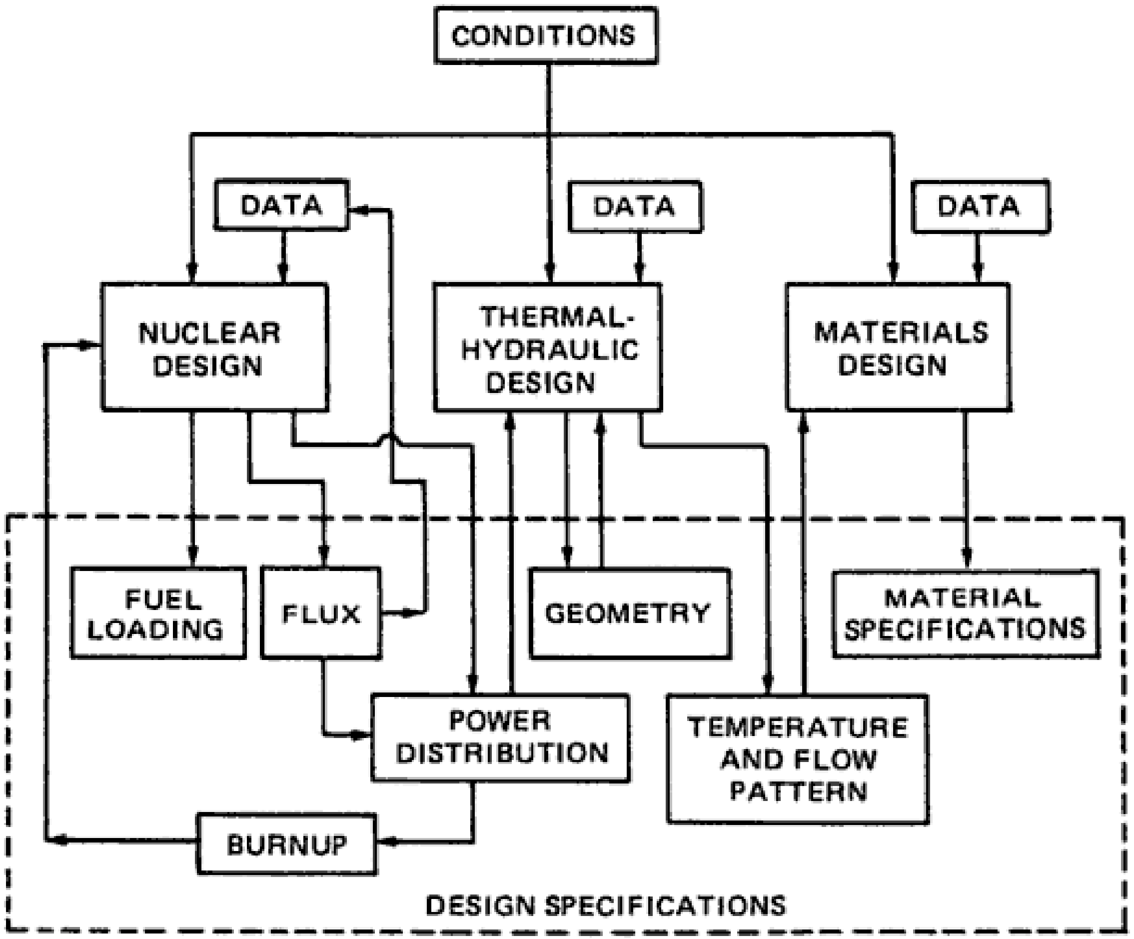


Source: ORNL-TM-6415 Figure S.2

Immediate Research Goals

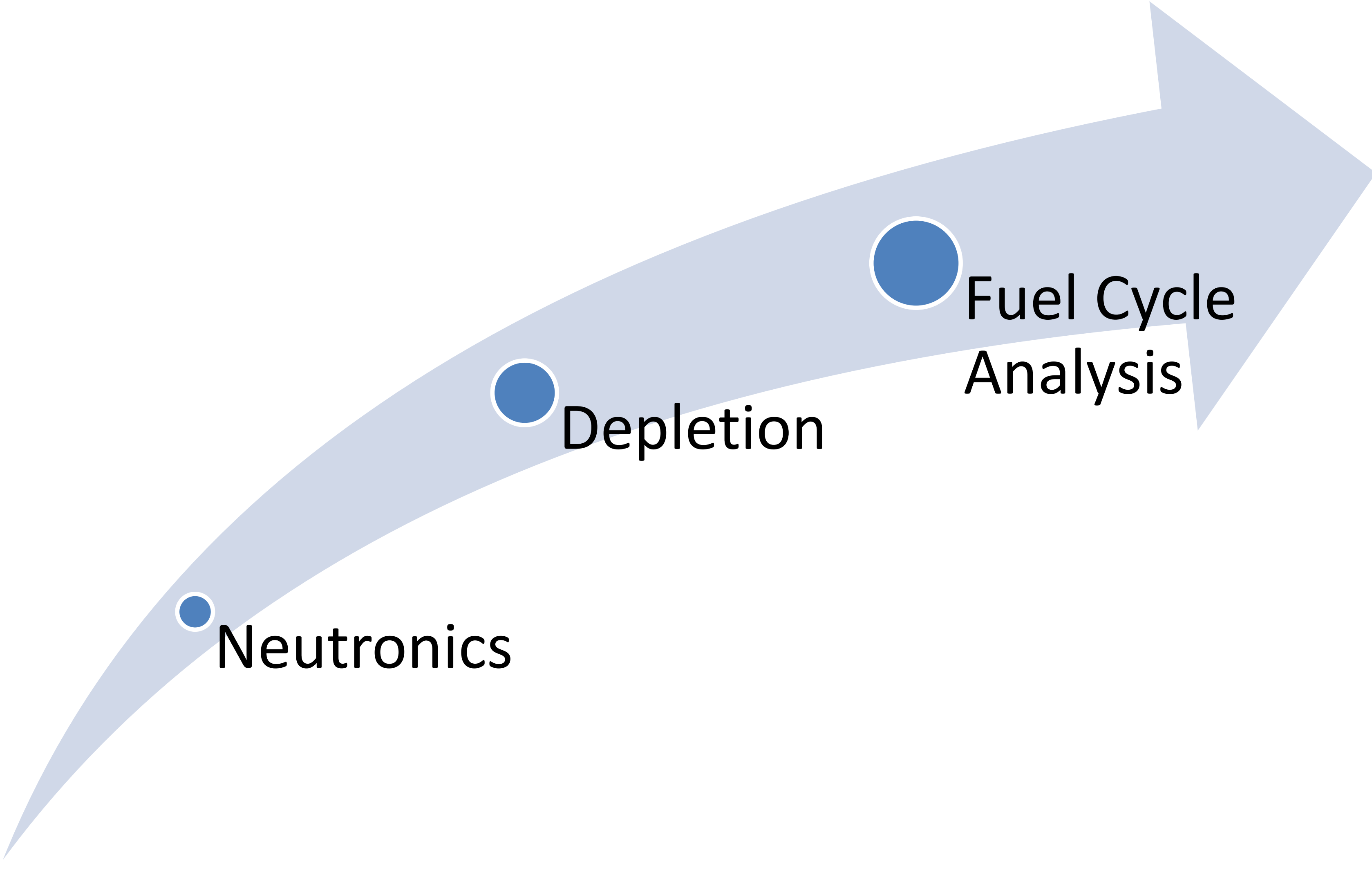
- Explore Design Space
- Quantify Benefits Of Molten-Salt Reactors
- Develop A Specific Proposal For A Test Reactor

Components Of Reactor Design



Source: A. Seonske, *Nuclear Power Plant Design Analysis*, TID-26241, 1973

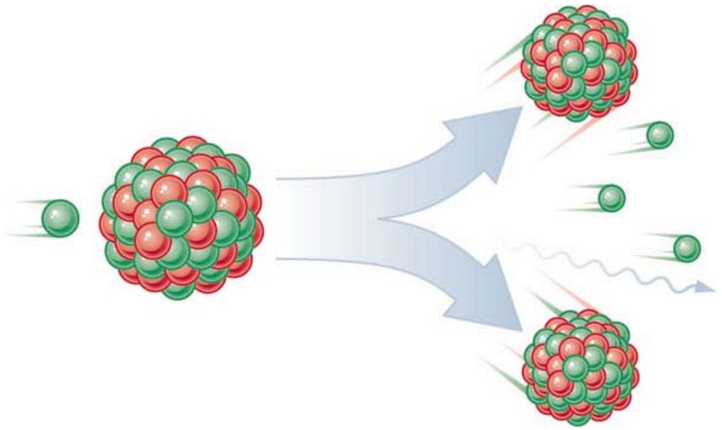
Outline



Neutronics

Two Methods of Neutronic Calculation

$$\frac{\partial \phi(\vec{r},t)}{\partial t} = \nabla \cdot \Big(D(\phi,\vec{r})\, \nabla \phi(\vec{r},t) \Big),$$



Diffusion Equation → Monte Carlo

mcnp 5

Los Alamos NATIONAL LABORATORY EST. 1943

OAK RIDGE NATIONAL LABORATORY
Managed by UT-Battelle for the Department of Energy

ADVANCED SIMULATION & COMPUTING

RSICC
Radiation Safety Information Computational Center

- Criticality Calculations
- Neutron Flux
- Nuclear Transformations
- Shielding

… in arbitrary geometry with arbitrary materials

Rez: Two-Fluid Central Core

Fuel Salt: 0.266% U_{233}

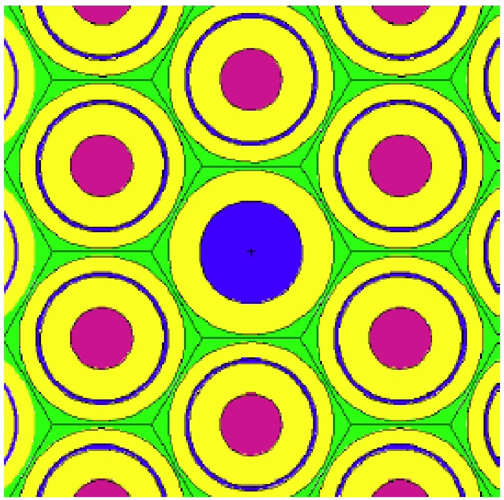


Fig. 1. Horizontal cross-section of the reactor core. Graphite (yellow), fuel salt (purple), fertile salt (blue) and helium (green).

Fertile Salt: 27% Th

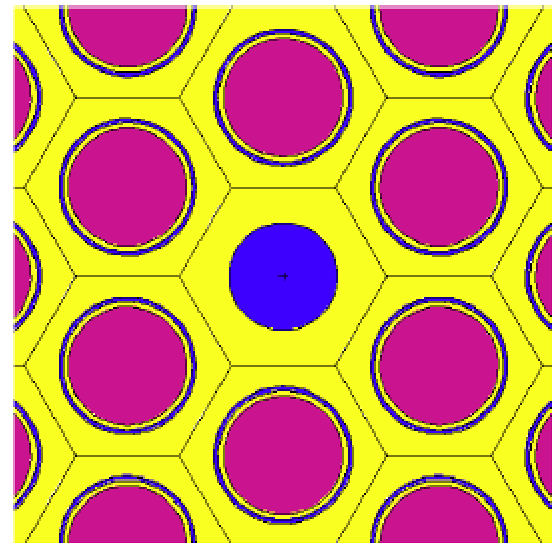


Fig. 4. Full channels (purple) with extended radius in hexagonal graphite elements (yellow). Fertile salt channels are indicated by blue color.

Critical Mass: 160-208 kg

Breeding Factor: 1.07-1.12

Doubling time: 1115-1314 **days**

Wow!

Source: J Frýbort, R Vočka, "Neutronic Analysis of Two-Fluid Thorium MSR"

Rez: Two-Fluid Blanket

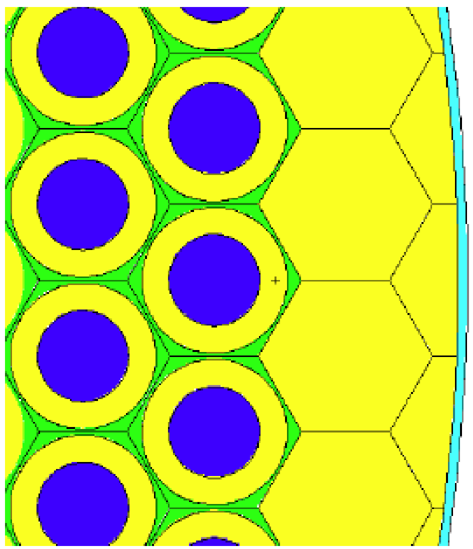


Fig. 2. Radial reflector. Graphite (yellow), fertile salt (blue) and helium (green)

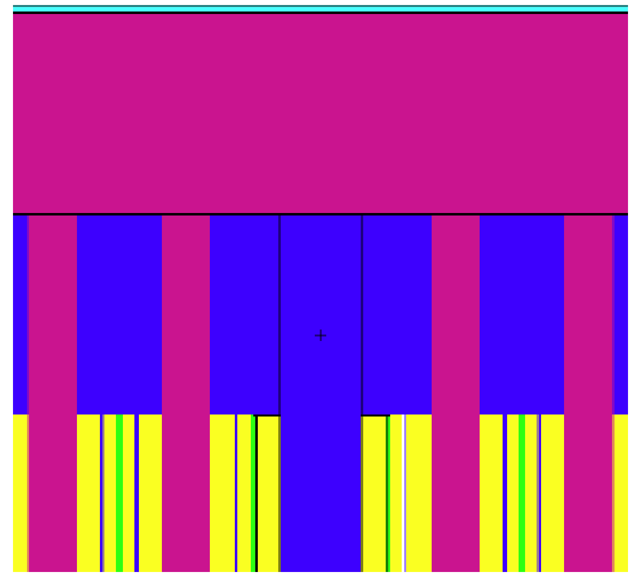


Fig. 3. Top vertical plenum

LFTR Advantage

- Proliferation Concerns Discourage External Blankets In Modern Fast Reactor Designs
- EBR-II created 250kg of “Super-grade” Plutonium (> 99% ^{239}Pu)

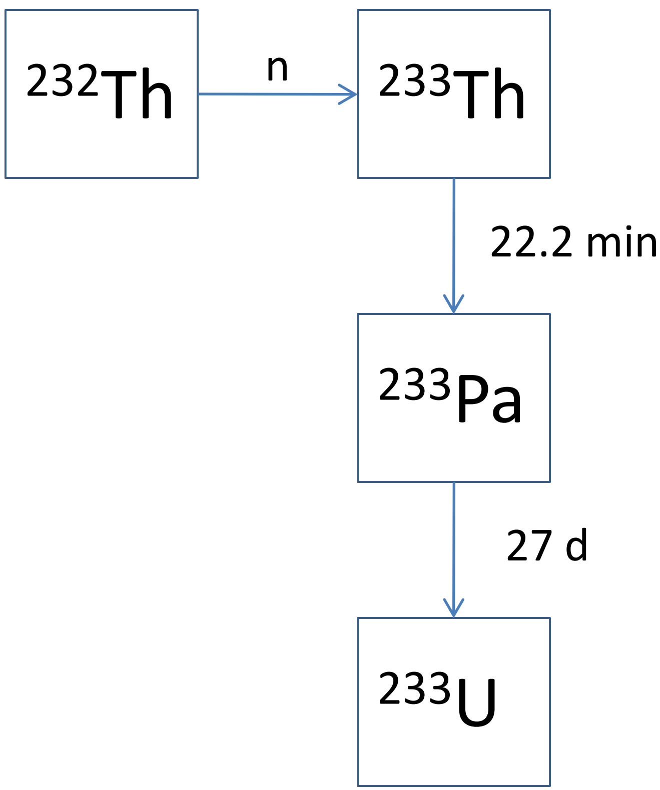
Source: H. F. McFarlane, R.W. Benedict “Management of Super-Grade Plutonium in Spent Nuclear Fuel”

Rez: What's the Catch?

- High Flow Rate
  - Up to 8 m/s
- Graphite Lifetime
  - Better Materials?
  - Reduced Power Peaking?
  - Easy replacement?
- Huge Blanket Void Coefficient
  - k=1.8
  - Hard to license if rapid insertion of k = 1.003 is possible
  - But…
    - Can we sacrifice breeding performance?
    - Depend more on external blanket?
    - Add passive reactivity control devices?

Depletion

Breeding From Thorium



But..

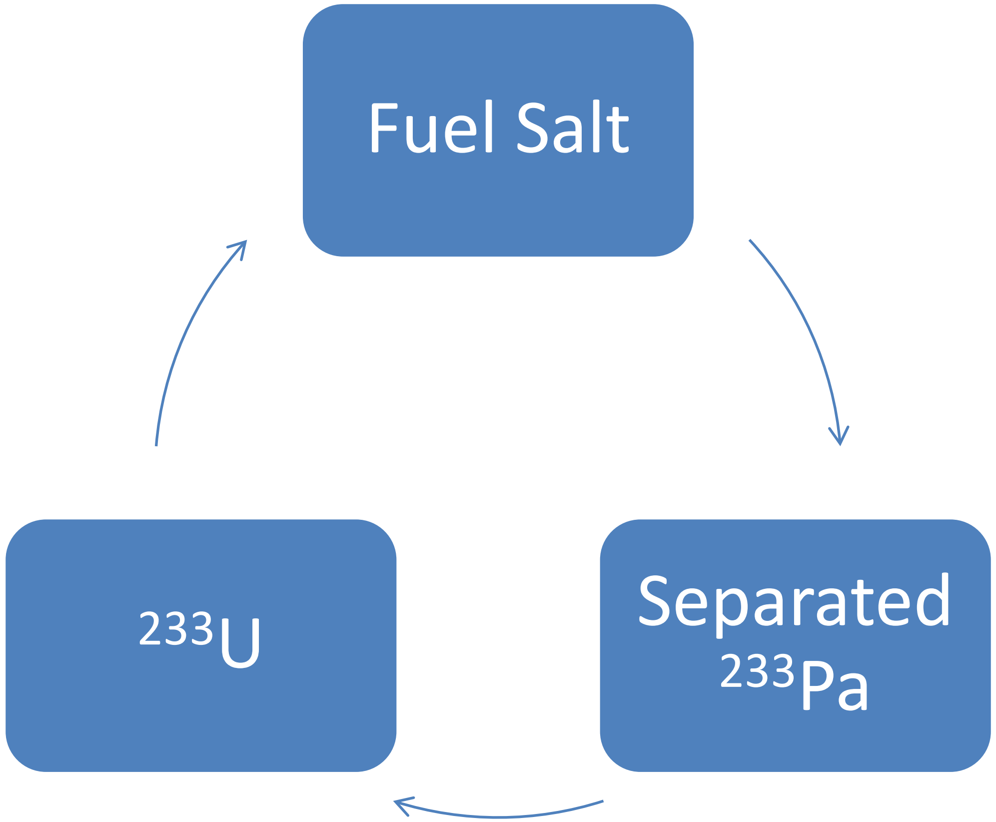
$$^{233}Pa + n \rightarrow {}^{232}Pa + 2n$$

$$^{232}Pa \rightarrow {}^{232}U + \beta^-$$

Short Doubling Time -> High Neutron Flux on ^{233}U

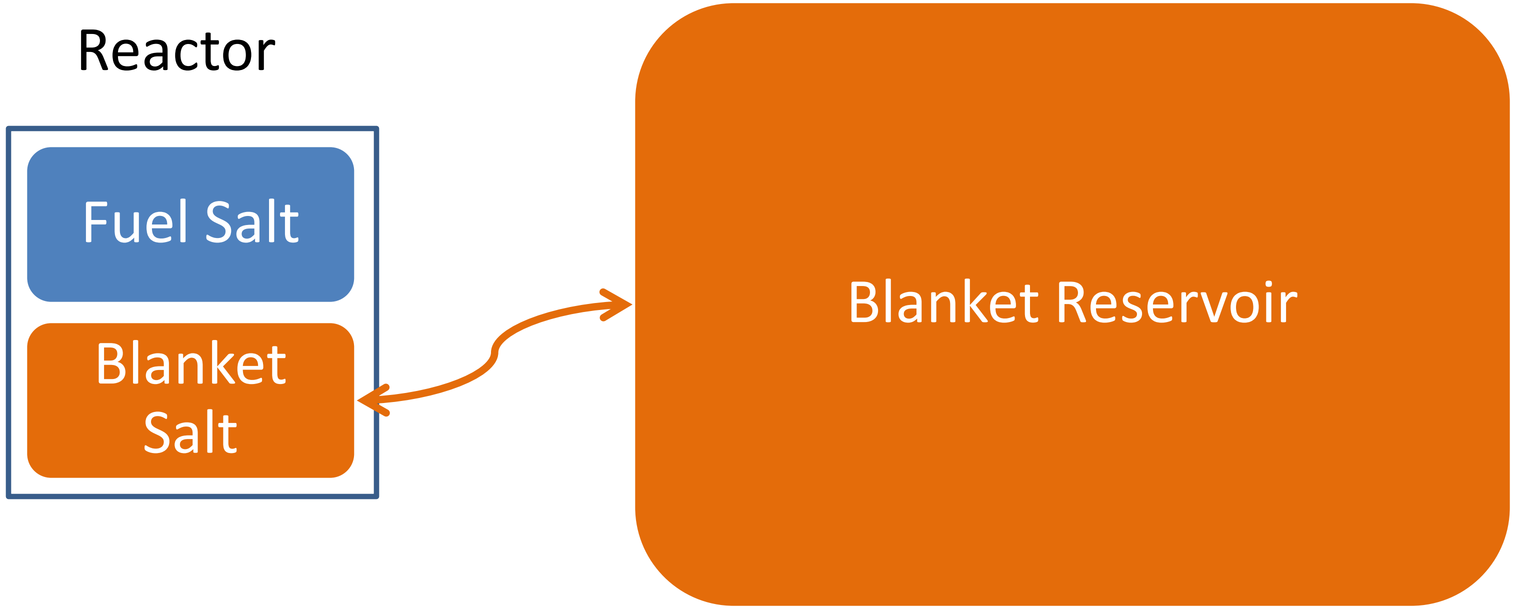
High Conversion Ratio -> Low Neutron Flux on ^{233}Pa

Single-Fluid Protactinium Solution



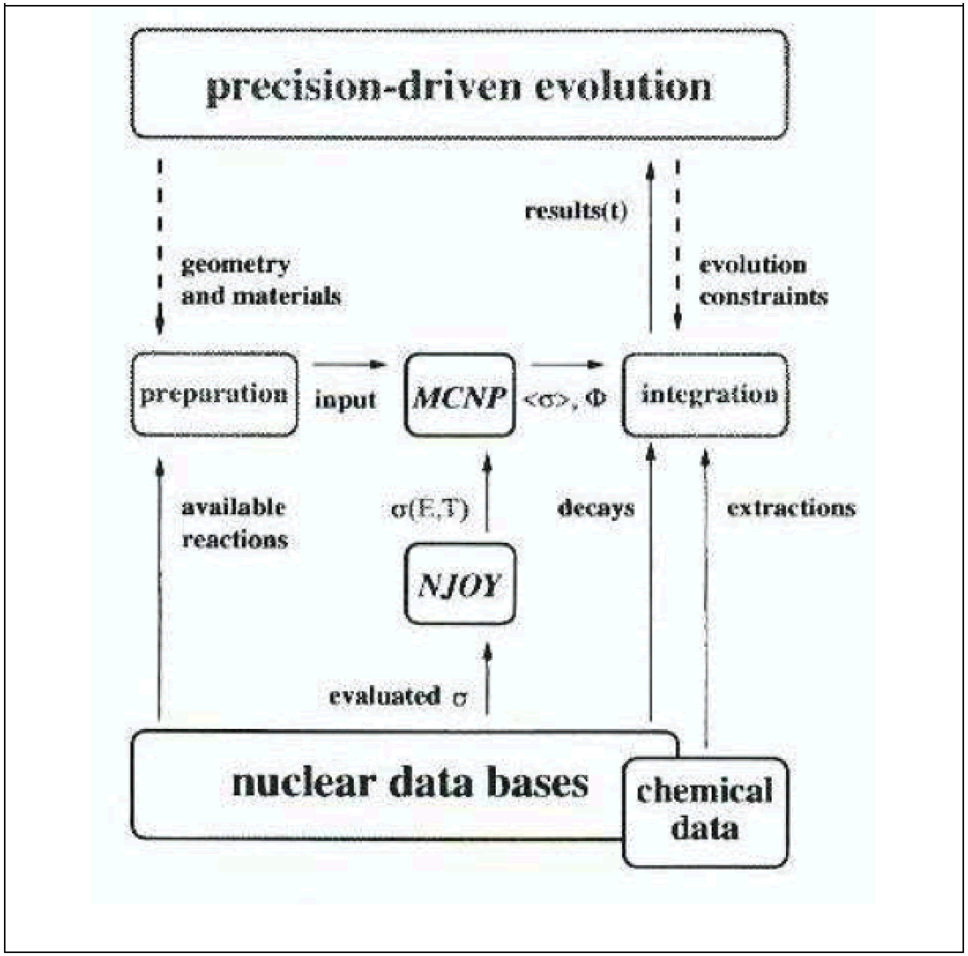
- Allows single-fluid breeding, but..
    - Requires advanced fuel processing (practical?)
    - Concerns about proliferation

Two-Fluid Protactinium Solution



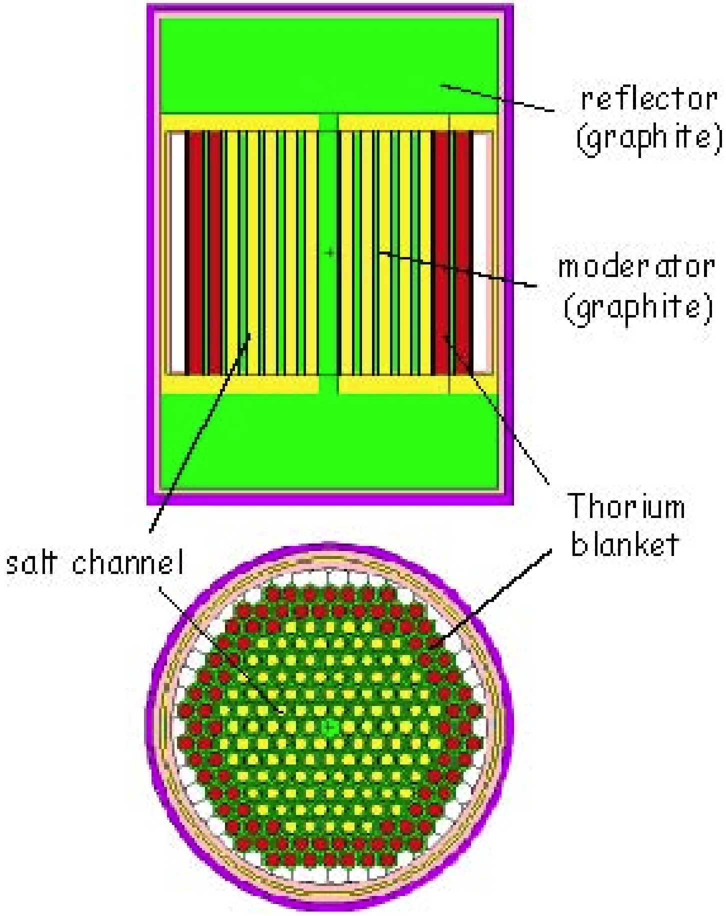
- Simple Fuel Processing
- Optimal System Parameters
- Highest Breeding Ratio, Shortest Doubling Time

Coupled Analysis Of Fluid Fuel Reactors



Source: C. Le Brun, L. Mathieu, D. Heuer, A. Nuttin "*Impact of the MSBR Concept Technology on long-lived radiotoxicity and proliferation resistance*"
See Also: ORNL-TM-4210

Thorium MSR Core



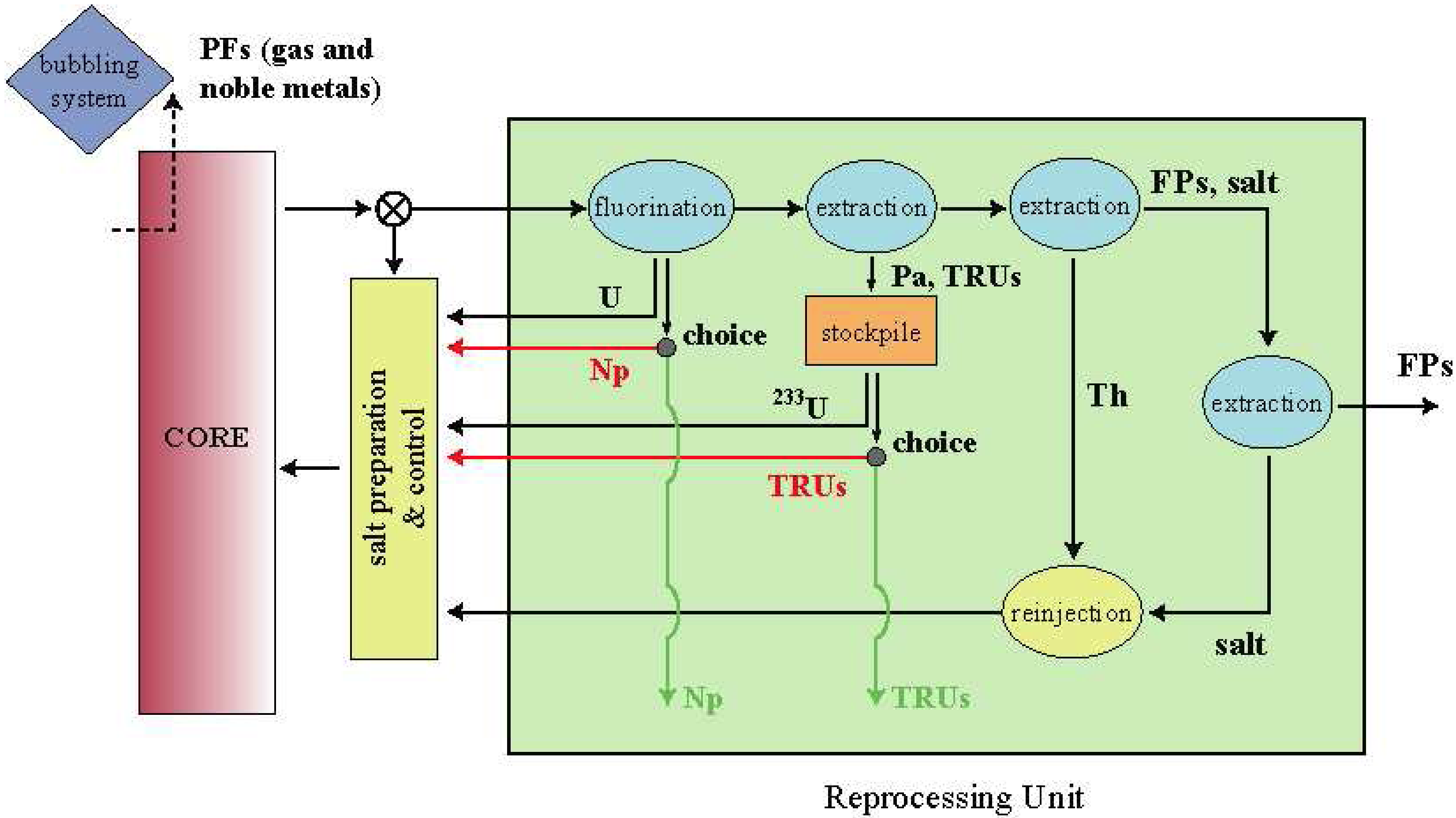
"1-1/2 fluid" reactor, variants:

- Thermal TMSR (1600 kg ^{233}U)
- Epithermal TMSR (4200 kg ^{233}U)
- Fast TMSR (8300 kg ^{233}U)

- Fuel Processing:
  - Bubbling extracts insoluble elements
  - Batch process, every six months
  - Near-unity breeding

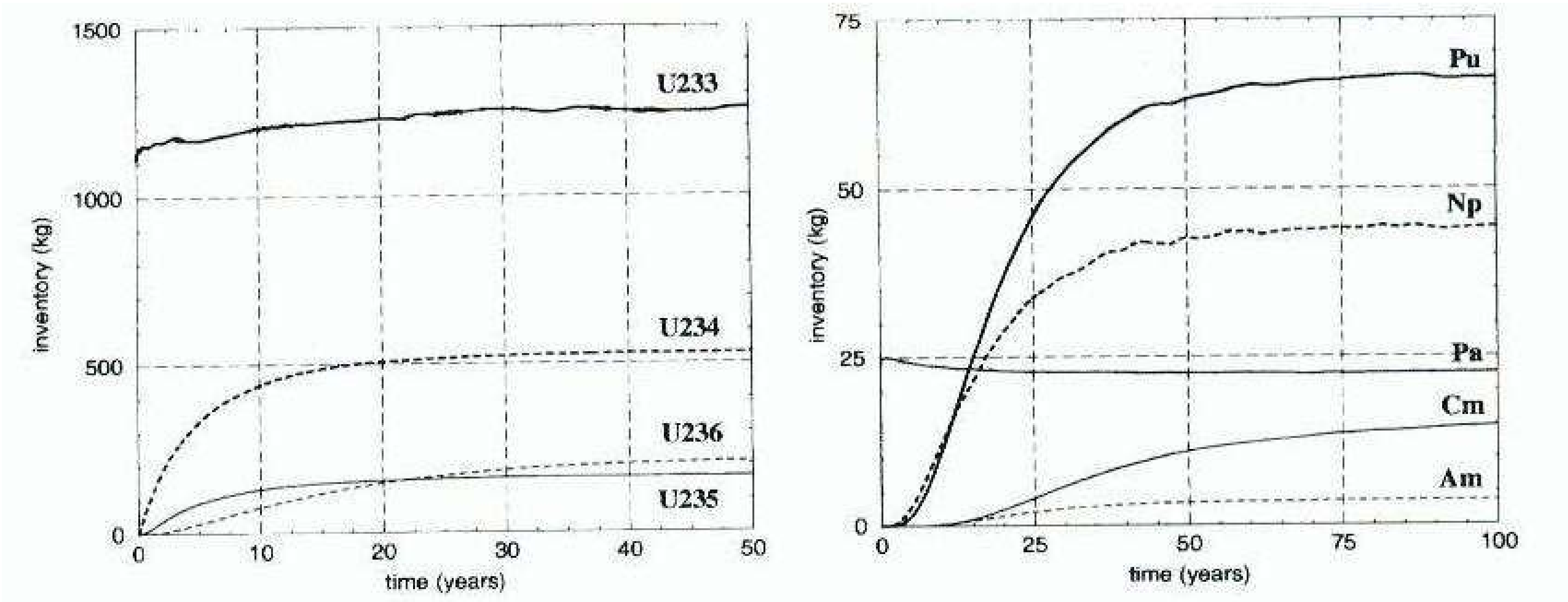
Source: C. Le Brun, L. Mathieu, D. Heuer, A. Nuttin "*Impact of the MSBR Concept Technology on long-lived radiotoxicity and proliferation resistance*"

Thorium MSR Fuel Processing



Source: C. Le Brun, L. Mathieu, D. Heuer, A. Nuttin "*Impact of the MSBR Concept Technology on long-lived radiotoxicity and proliferation resistance*"

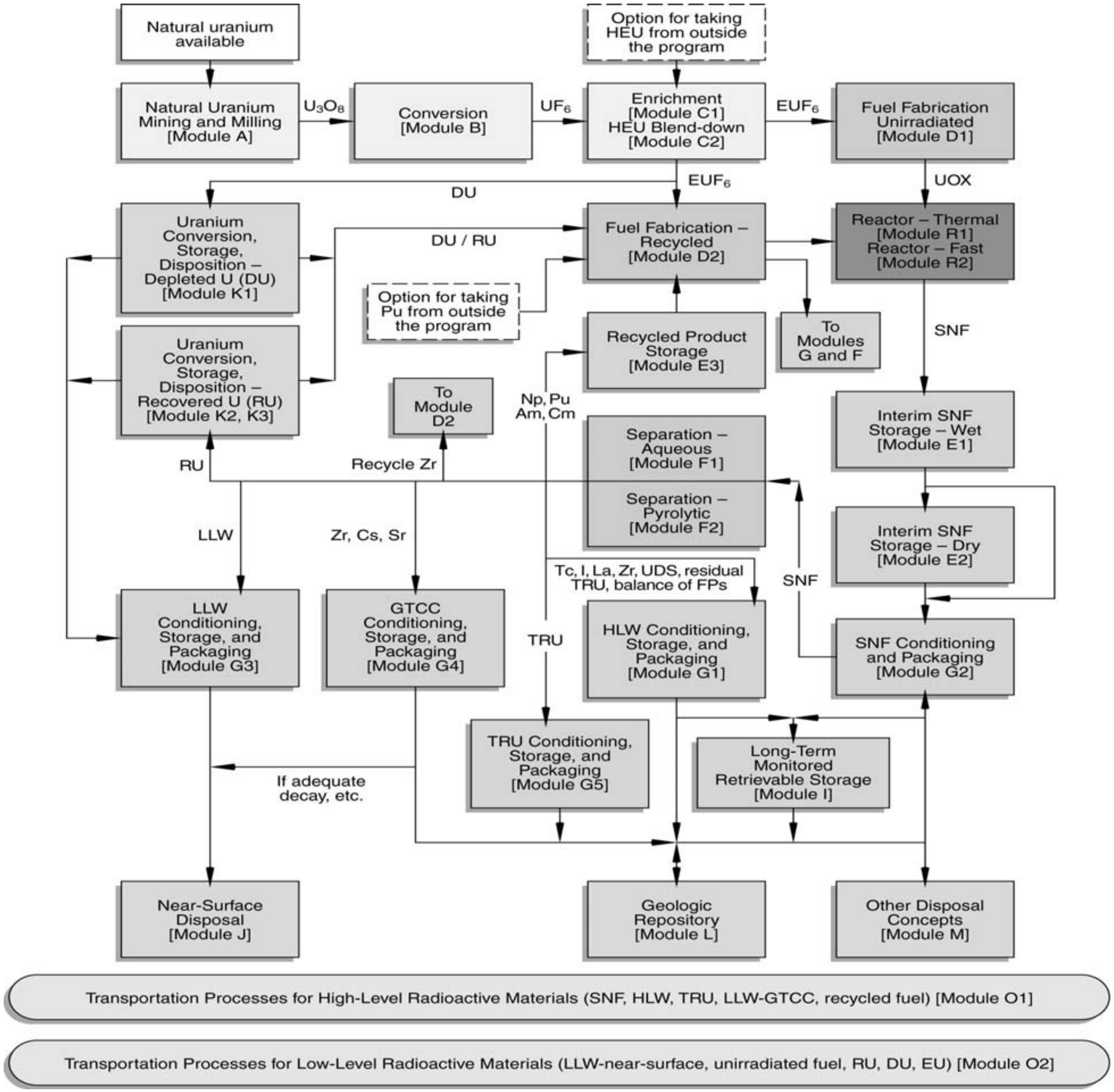
Actinide Inventory with Auto-Recycle



- MSBR-like Core (Thermal Spectrum)
- Fast spectrum produces 10x as much Pu, but still 1/10 of PWR
- Good news: Pu is > 60% ^{238}Pu (Weapons Useless)
- Equilibirum ^{3}H production about half of CANDU

Source: C. Le Brun, L. Mathieu, D. Heuer, A. Nuttin "*Impact of the MSBR Concept Technology on long-lived radiotoxicity and proliferation resistance*"

Fuel-Cycle Analysis



Source: J. J. Jacobson, A. M. Yacout, G. E. Matthern, S. J. Piet, D. E. Shropshire, "*Vision: Verifiable Fuel Cycle Simulation Model*"

Back of the Envelope…

- 400 tons of Pu From LWR -> 33 GWe of Fast Near Breeders
- Thermal MSR near breeders need ~ 1/10 the fissile inventory
- Same start charge could fuel ~ 300 Gwe of MSR Near Breeders

Sources: http://nucleargreen.blogspot.com/2009/06/s-prism-scalability-repost-for-steven.html
C. E. Boardman, D. G. Carrol, C. Ehrman, C. E. Walter, "*S-PRISM Fuel Cycle Study*"

Launching the Thorium Economy