Using Depleted Uranium as Fuel in a Traveling-Wave Reactor

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Traveling-Wave Reactors

- Also known as breed-and-burn reactors
- Start with subcritical (k_∞<1) fertile feed fuel (low enriched uranium, natural or depleted uranium, thorium)
- Use leakage neutrons from critical region of core to breed fissile Pu-239/U-233, make feed fuel critical (k_∞>1)
- Breeding new fuel causes burning region to move, or *travel*
- Use bred-up feed fuel to sustain reactor criticality, allowing more fresh feed fuel to be bred
- ***Not a new idea!***

Examples of Breed-and-Burn Reactor Concepts

CANDLE reactor (Sekimoto 2008)

MIT B&B GFR (Yarsky, Driscoll, Hejzlar 2006)

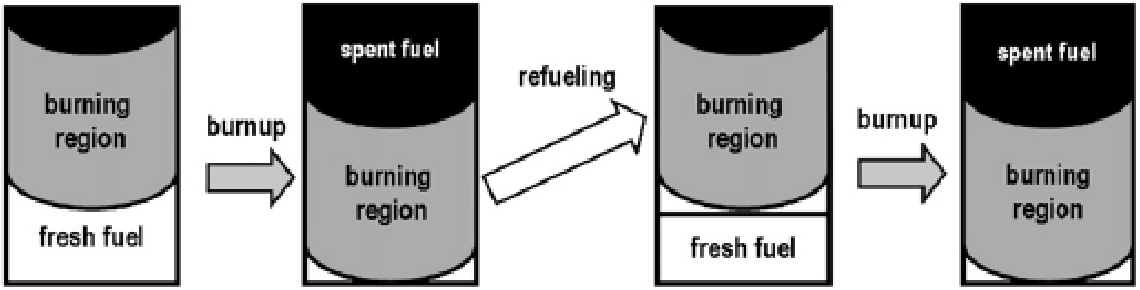
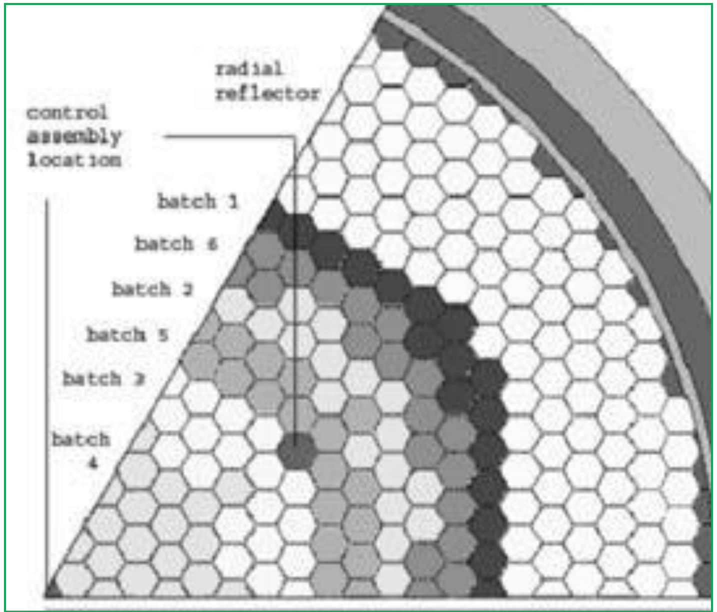


Fig. 1. CANDLE burnup and its refueling scheme.



Self-Fuel-Providing LMFBR (Toshinsky 1999)

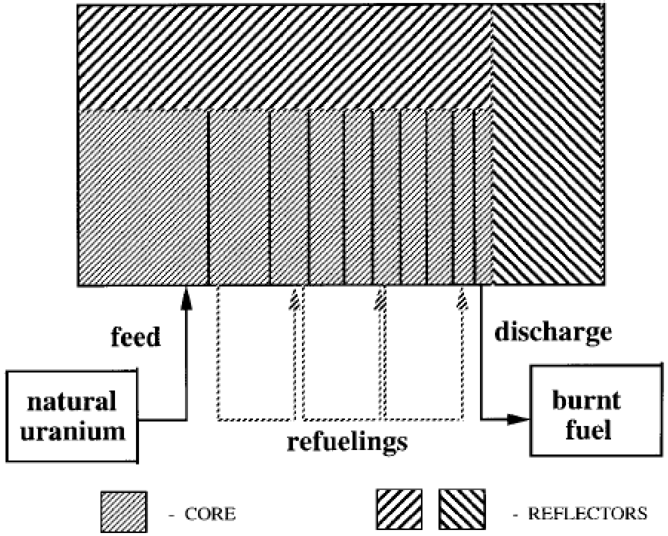
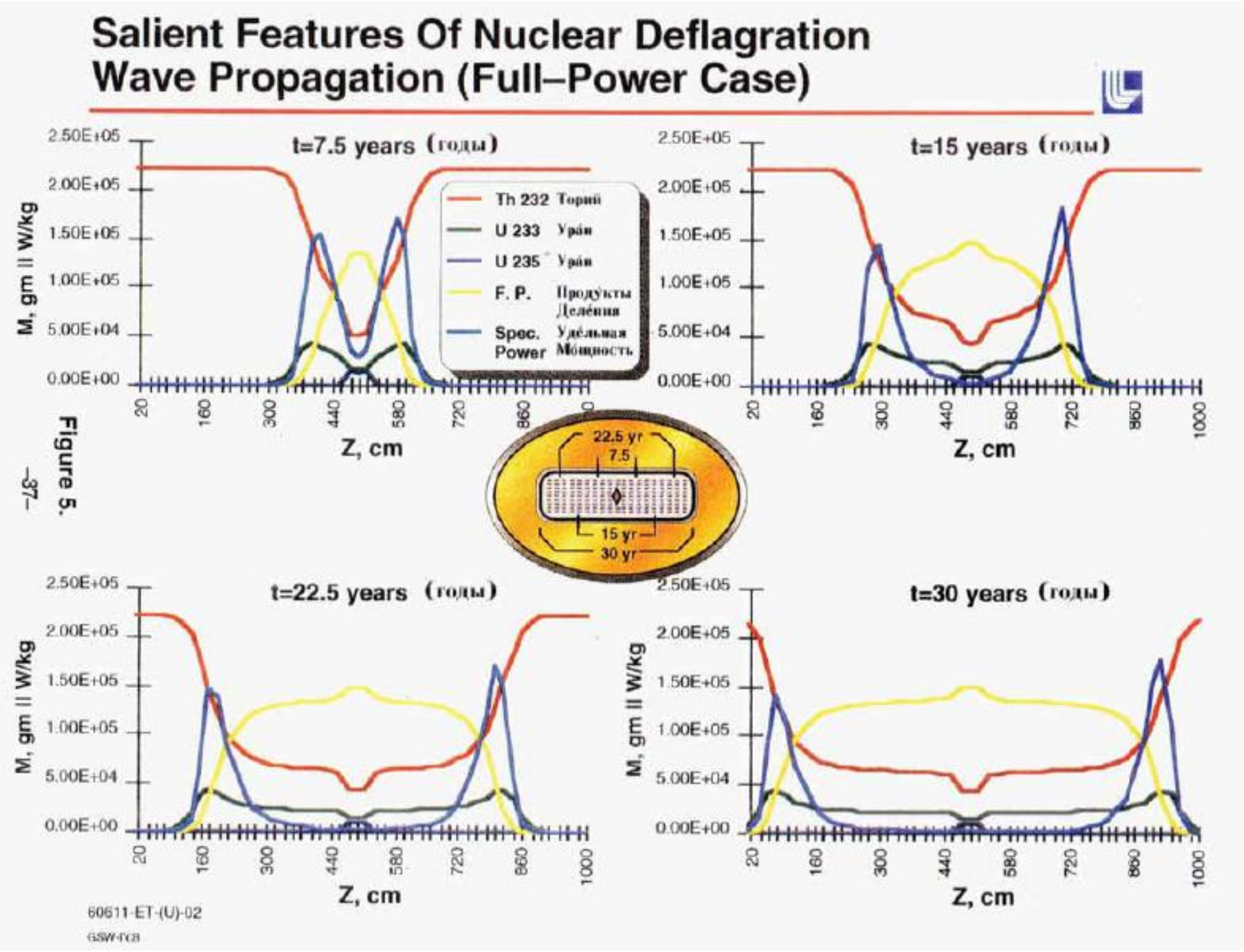


Fig 1. Operation mode of Self-Fuel-Providing LMFBR

Examples of Breed-and-Burn Reactor Concepts (II)

Thorium fueled, gas cooled TWR (Teller 1996)



Salient Features Of Nuclear Deflagration Wave Propagation (Full–Power Case)

Major Question in TWR Design

For a given feed fuel composition, what is the minimum burnup required to sustain critical breed-and-burn operation?

Neutron Excess Concept: Introduction

- Two ways to answer this question:
  - 1) Model a full breed-and-burn reactor, with a complex distribution of materials and fluxes, and compute equilibrium-cycle reactivity
  - 2) Model depletion of the feed material, estimate reactivity based on net number of neutrons produced, aka *neutron excess*

Neutron Excess Definition

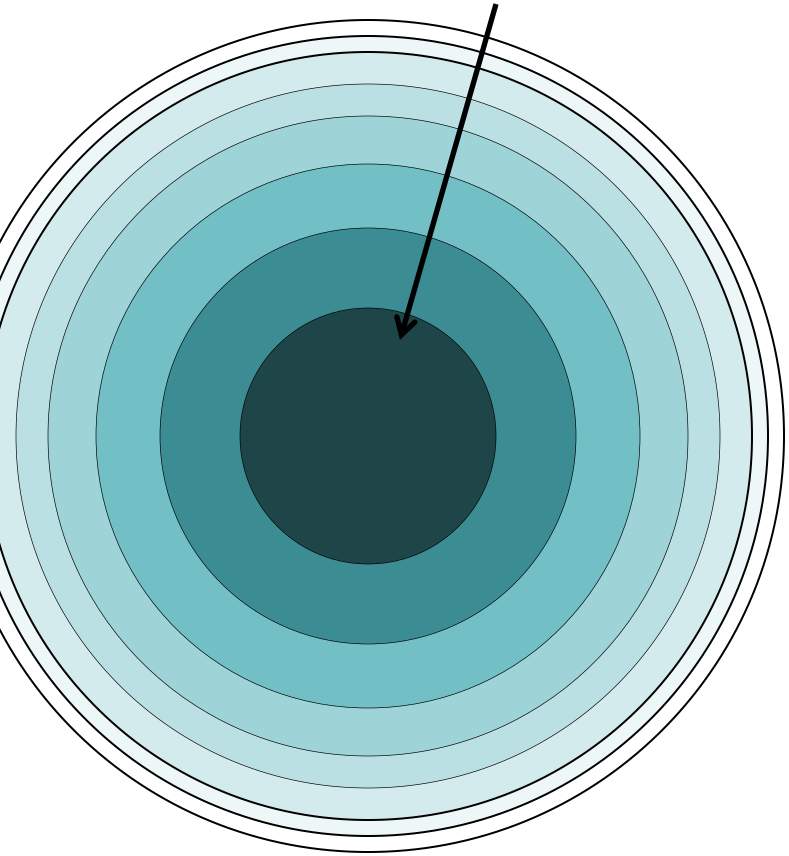
- Neutron excess of a material (ΔN) is defined as:

$$\frac{dN}{dt} = \phi(\nu\Sigma_f - \Sigma_a) \qquad \Delta N = \int dt\,\phi(\nu\Sigma_f - \Sigma_a)$$

- Has units of neutrons/volume; meaning is the net number of neutrons produced by or lost to a material
- Similar to neutron excess is total neutrons absorbed (ΔA):

$$\frac{dA}{dt} = \phi\Sigma_a \qquad \Delta A = \int dt\,\phi\Sigma_a$$

"Thought Experiment" Picture of a Breed-and-Burn Reactor



- Arbitrarily thin, equal volume spherical shells
- Feed fuel is flowed into central burn region, discharged from center
- Equilibrium cycle with fixed power and volume flow rate
- Feed fuel blanket absorbs neutrons leaking from burn region

Reactivity of Idealized Reactor

$$k = \frac{neutron\ creation\ rate}{neutron\ loss\ rate} = \frac{\int dV \phi \nu \Sigma_f}{\int dV \phi \Sigma_a} = \frac{\int dV \phi \Sigma_a k_\infty^{'}}{\int dV \phi \Sigma_a}$$

- K-infinity prime is a material + spectrum property: the ratio of neutron production rate to absorption rate, but evaluated at the local (rather than infinite medium) neutron spectrum
- Neutron excess (ΔN) is related to neutrons absorbed (ΔA) through k-infinity prime:

$$\Delta N = \int dA\left(\frac{\nu \Sigma_f}{\Sigma_a} - 1\right) = \int dA\left(k_\infty^{'} - 1\right)$$

Neutron Excess Relationships

$$k = \frac{\int dV \phi \Sigma_a k_\infty^{'}}{\int dV \phi \Sigma_a} = \frac{\int dA k_\infty^{'}}{\int dA} = \left.\frac{\Delta N}{\Delta A}\right|_{discharge} + 1$$

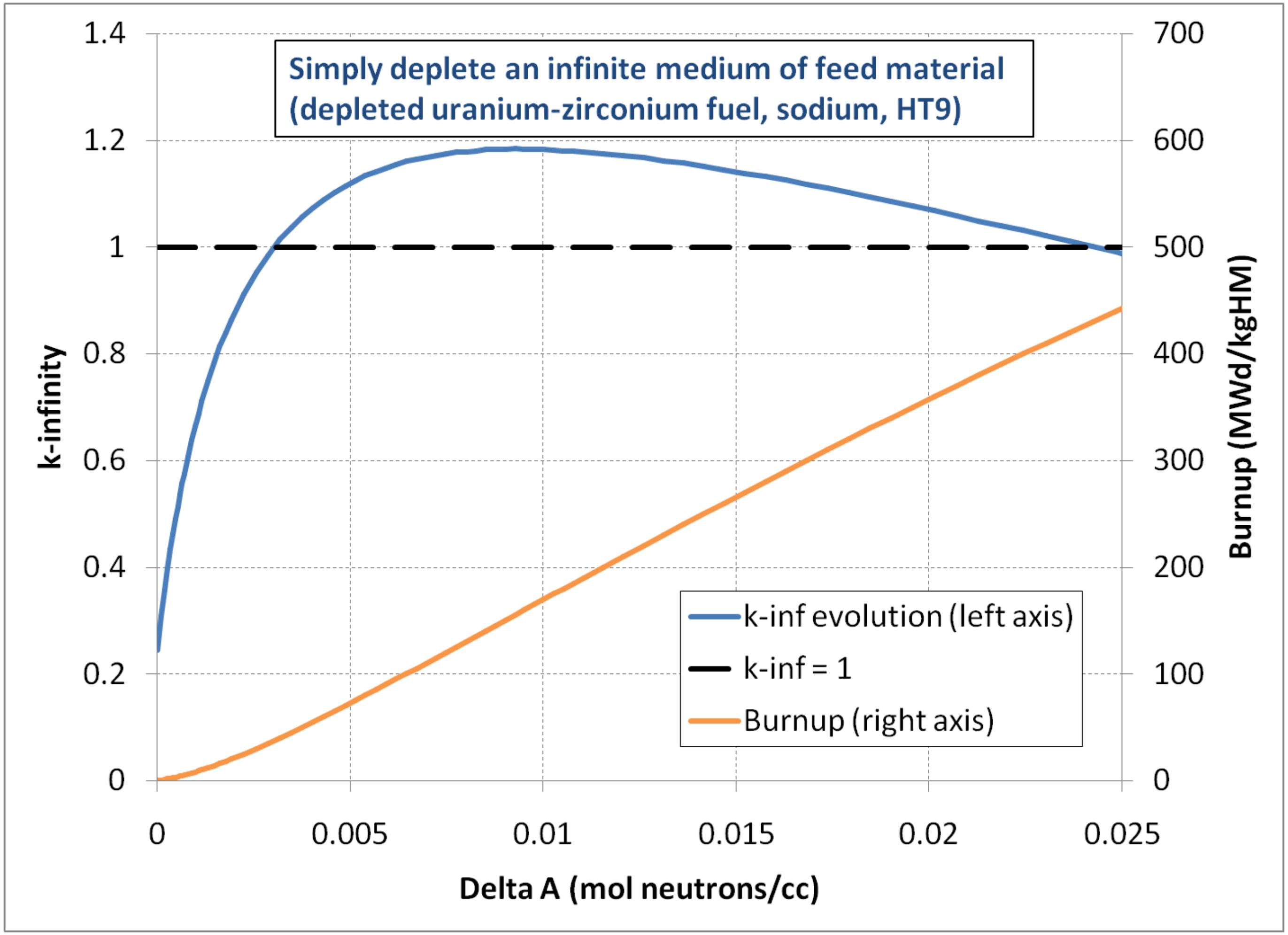
- From substituting:

$$dV = \frac{dV}{dt} dt = \dot{V} \frac{dA}{\phi \Sigma_a} \qquad \Delta N = \int dA (k_\infty^{'} - 1)$$

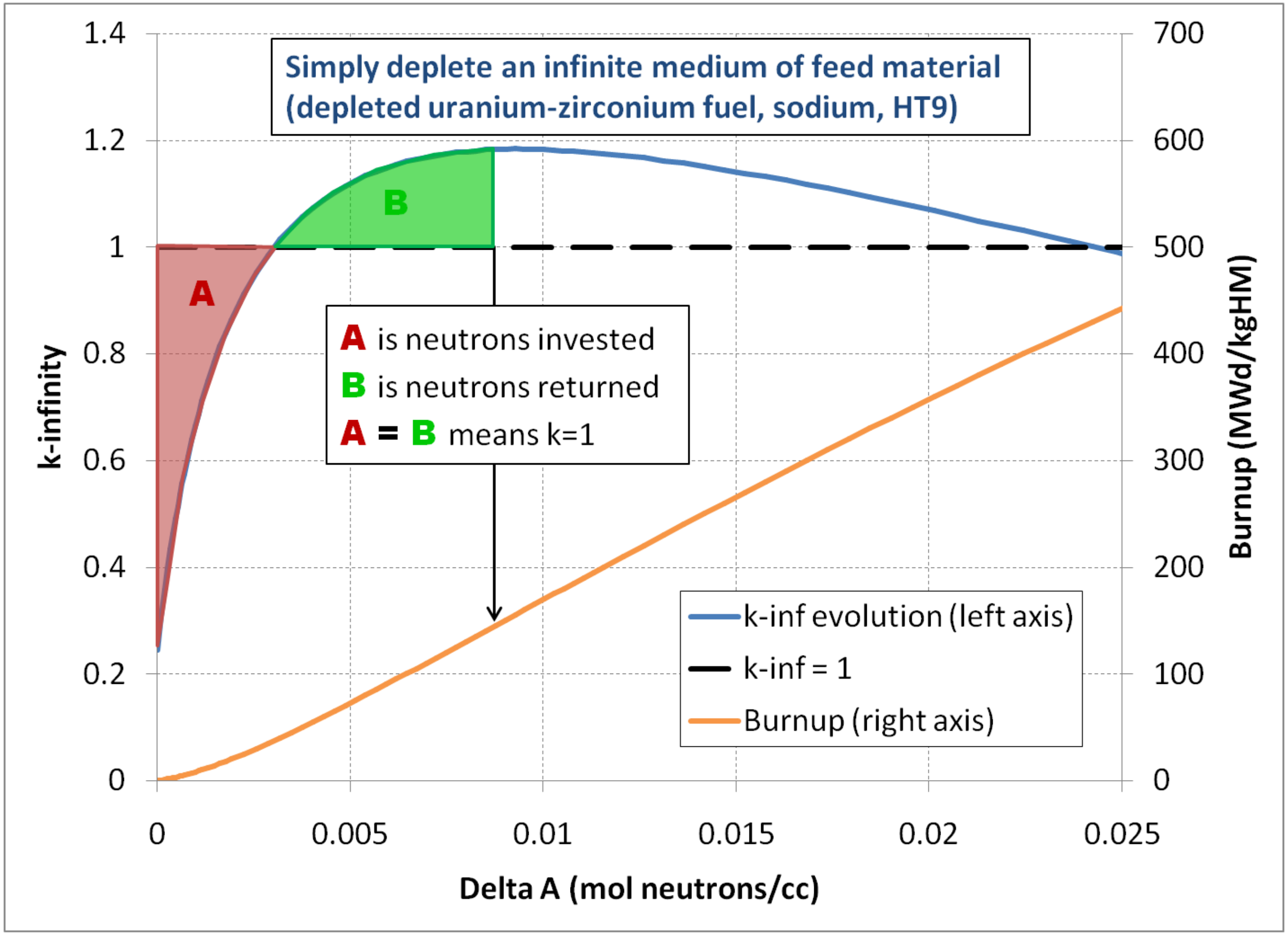
- From these equations one sees that k-effective can be represented in terms of the function:

$$k_\infty^{'}(\Delta A)$$

Simple $k'_{\infty}(\Delta A)$ Approximation



Simple $k'_{\infty}(\Delta A)$ Approximation



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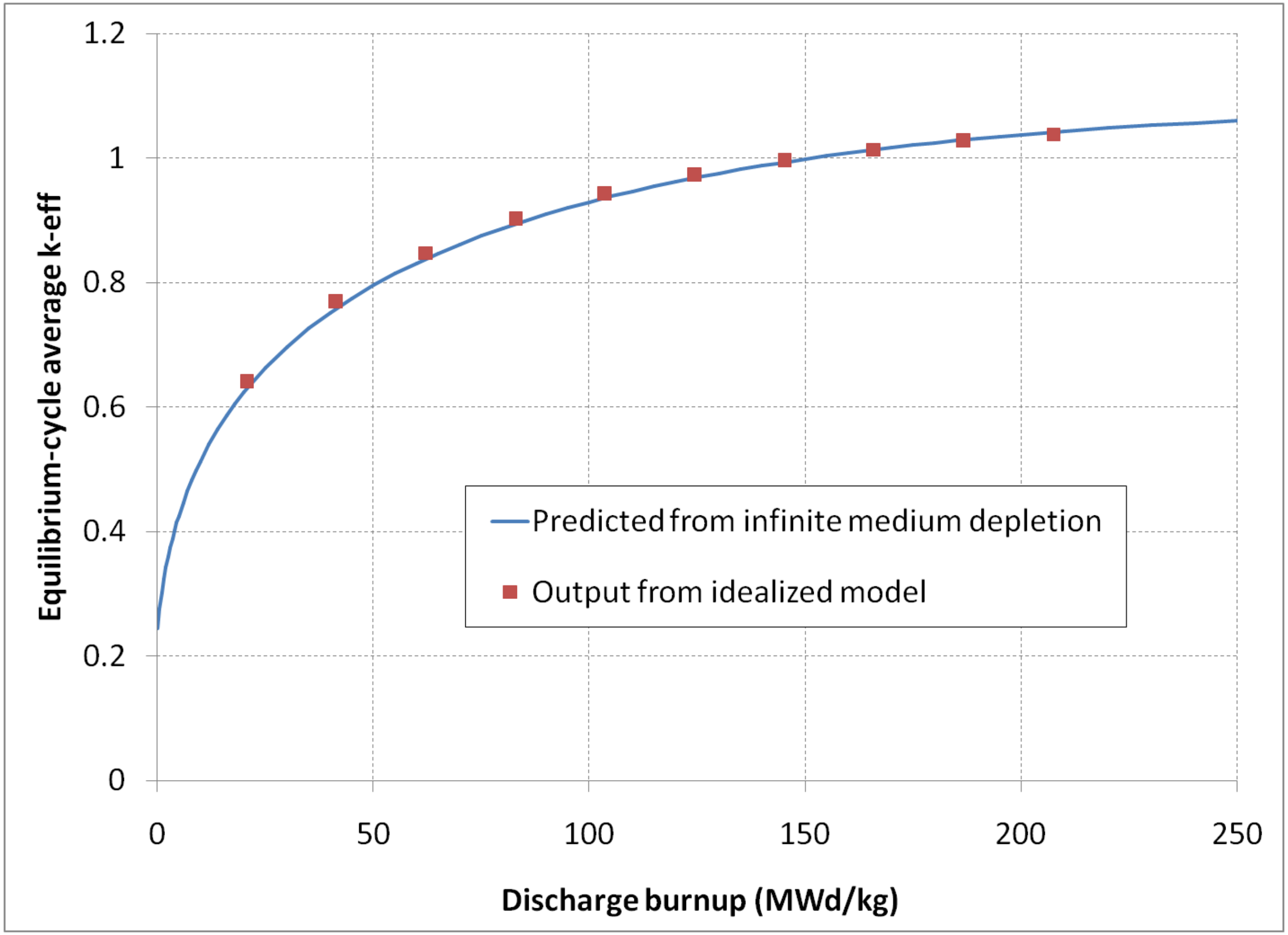
Predicted vs. Modeled k-effective



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More about Neutron Excess Estimate

- Theoretical minimum burnup required for k=1:

  150 MWd/kg
- Prediction gives an accurate estimate of middle-of-cycle k-effective, insensitive to:
  - Geometry (planar, cylindrical, spherical, hexes)
  - Cycle length
  - Equilibrium cycle shuffle path(s)
- Factors like control and leakage can be included
- Incorporating effect of axial peaking within an assembly requires an extension of the concept

Another Neutron Excess Relationship

- It can be also shown:

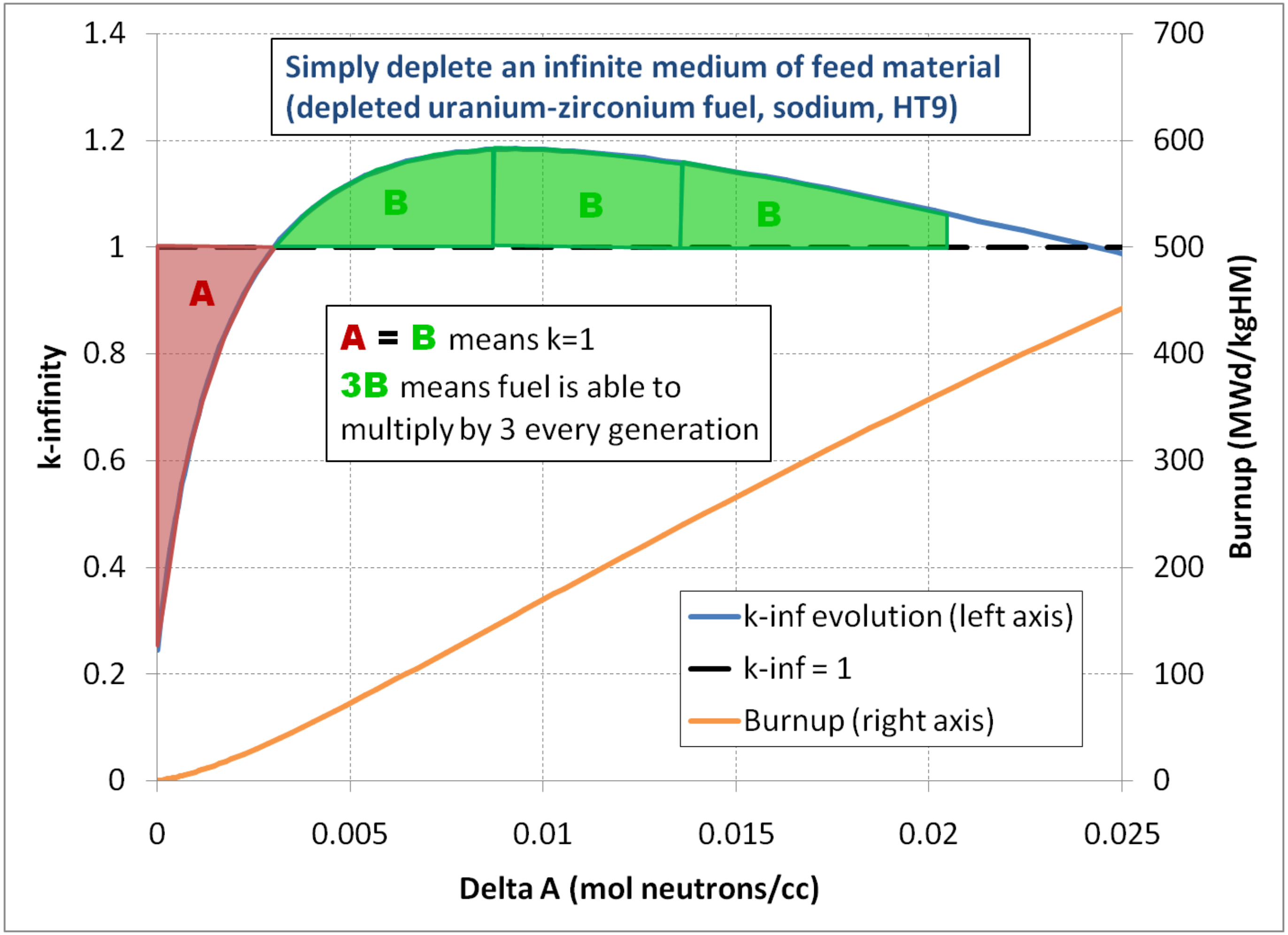
$$\int dt[(k-1)\int dV\phi\Sigma_a] = \int dV\Delta N$$

- Or for a critical reactor with k=1:

$$\int dV\Delta N = 0$$

- I.e. neutrons (and neutron excess) is conserved
- This can be used to predict how much starting fissile material is needed to initiate a breed-and-burn equilibrium cycle

One Interesting Consequence



A Note on Modeling

- TerraPower studies full 3-D models of our reactor geometry
  - Detailed axial resolution
  - Detailed fuel shuffling of individual assemblies
  - Moveable control elements
  - Homogeneous and fully resolved models
- Two different modeling tools:
  - MCNPXT (modified MCNPX-CINDER90) using ENDF/B-VII cross section libraries with 213 FPs
  - REBUS and MC**2 using ENDF/B-V