Implications for Waste Handling of the Energy Multiplier Module

by
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GENERAL ATOMICS

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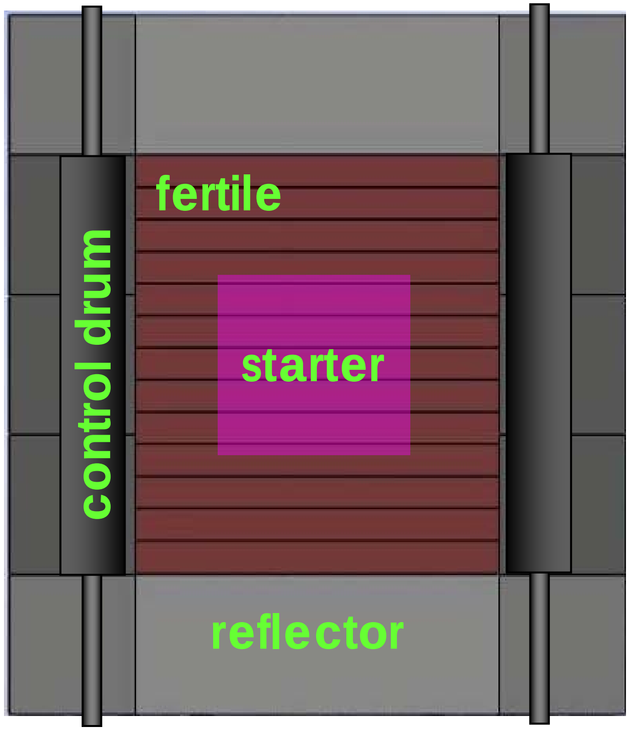
Changing the Game for Nuclear Energy

Key National Issues	EM² Goals
1. Economics	– To reduce capital investment and power cost by 30% compared to ALWRs
2. Used Nuclear Fuel	– To consume & reduce used nuclear fuel inventory, i.e. minimize need for long-term repositories
3. Non-Proliferation	– To reduce need for uranium enrichment; eliminate conventional fuel reprocessing
4. Energy Security	– To advance electrification through site-flexibility & process heat applications; to reduce foreign energy imports
5. Human Dimension	– To attract eager young minds to a challenging new enterprise

EM² is a Fast Gas-Cooled Reactor in which Fuel is Made and Burned in situ

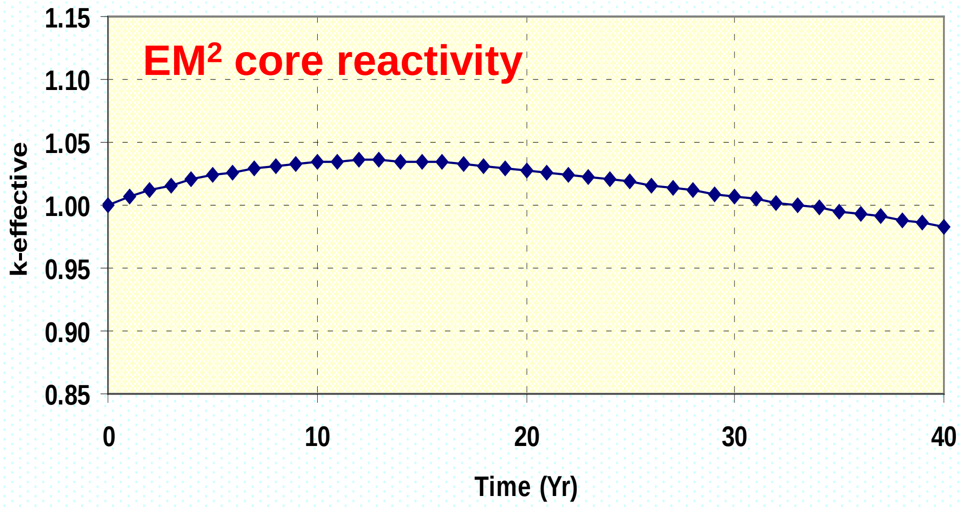
Schematic EM² core



Argonne National Laboratory predicted longer core life and lower excess reactivity

Basics of the breed and burn in situ approach

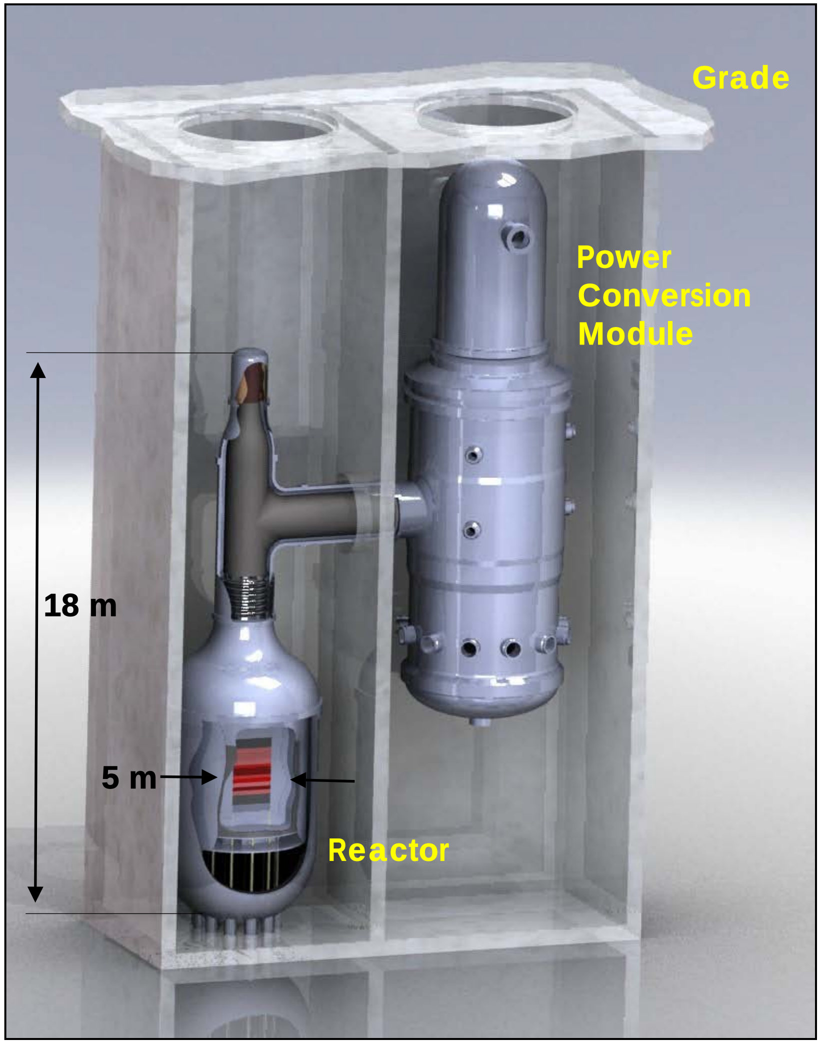
- A starter region containing fissile material provides initial criticality
- The burn spreads to the fertile region, where it is sustained by newly bred fuel
- The geometrical arrangement has low excess reactivity for decades, improving fuel utilization and simplifying control



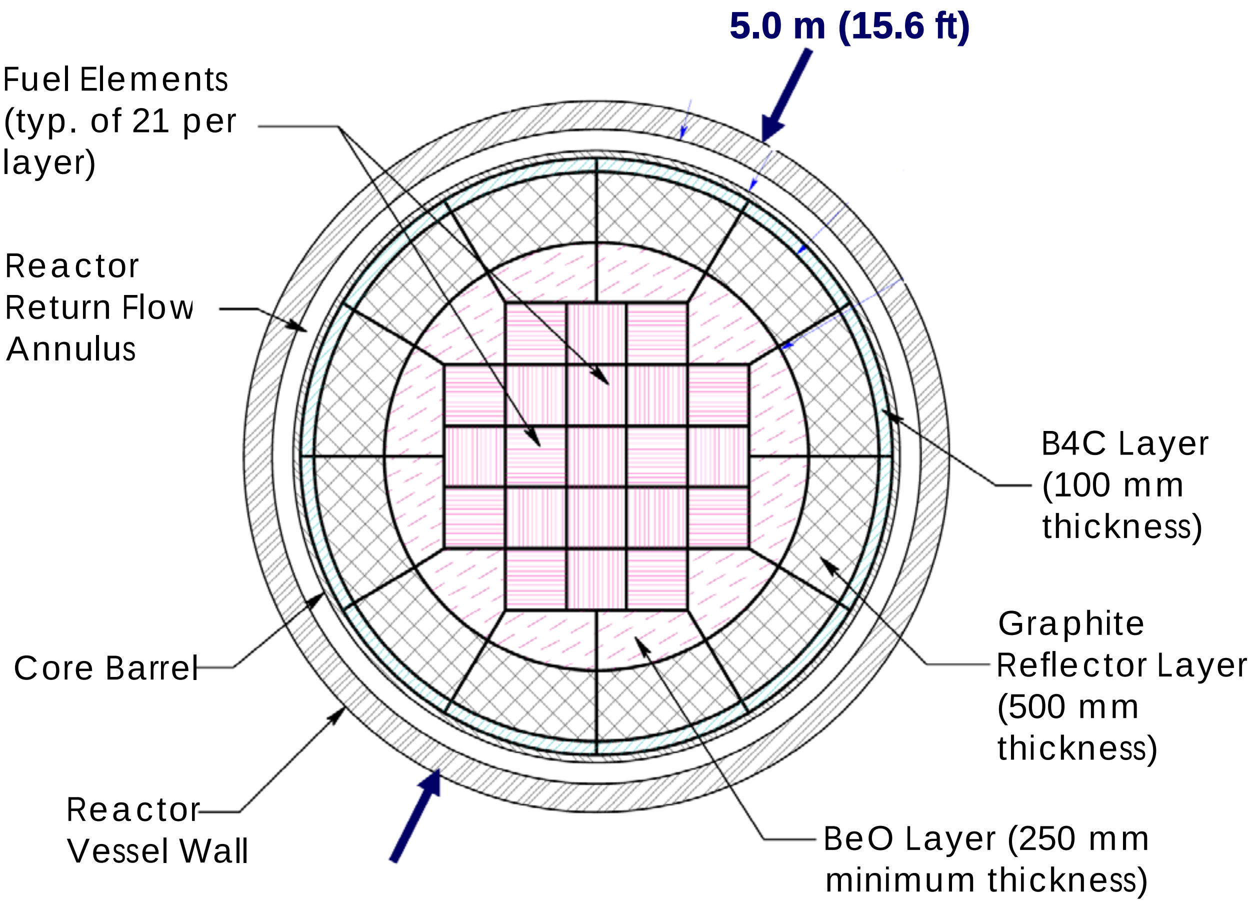
Reactor Concept

Point design features

- 500 MWt, He cooled at 850^{o}C outlet suitable for process heat applications
- 240 MW_e at ~48% net efficiency (~45% with dry cooling), at power cost comparable to natural gas at $7/Mbtu
- Burns used LWR fuel w/o reprocessing (also DU, natural U, WPu, Th admixture)
- 30^{+}-yr core w/o refueling or reshuffling; EOL core can be recycled with 30-60% fission product removal
- Passively safe, underground sited
- Modules factory manufactured & shipped by commercial trucks



Core Composition and Arrangement



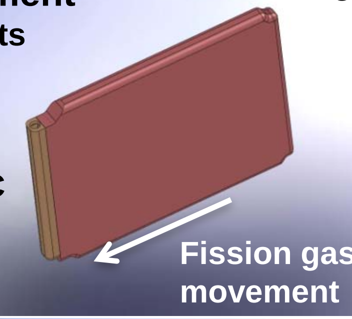
Material irradiation data is encouraging about the life of SiC structure

Fuel Element

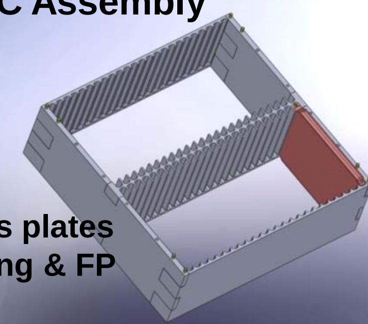
5.19kg

17,136 units

SiC-SiC clad porous UC plate



SiC-SiC Assembly Frame

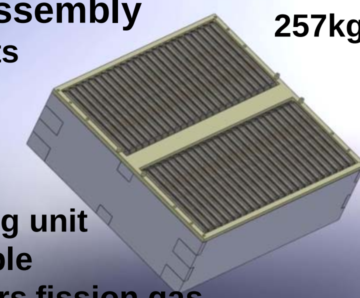


Positions plates for cooling & FP control

Fuel Assembly

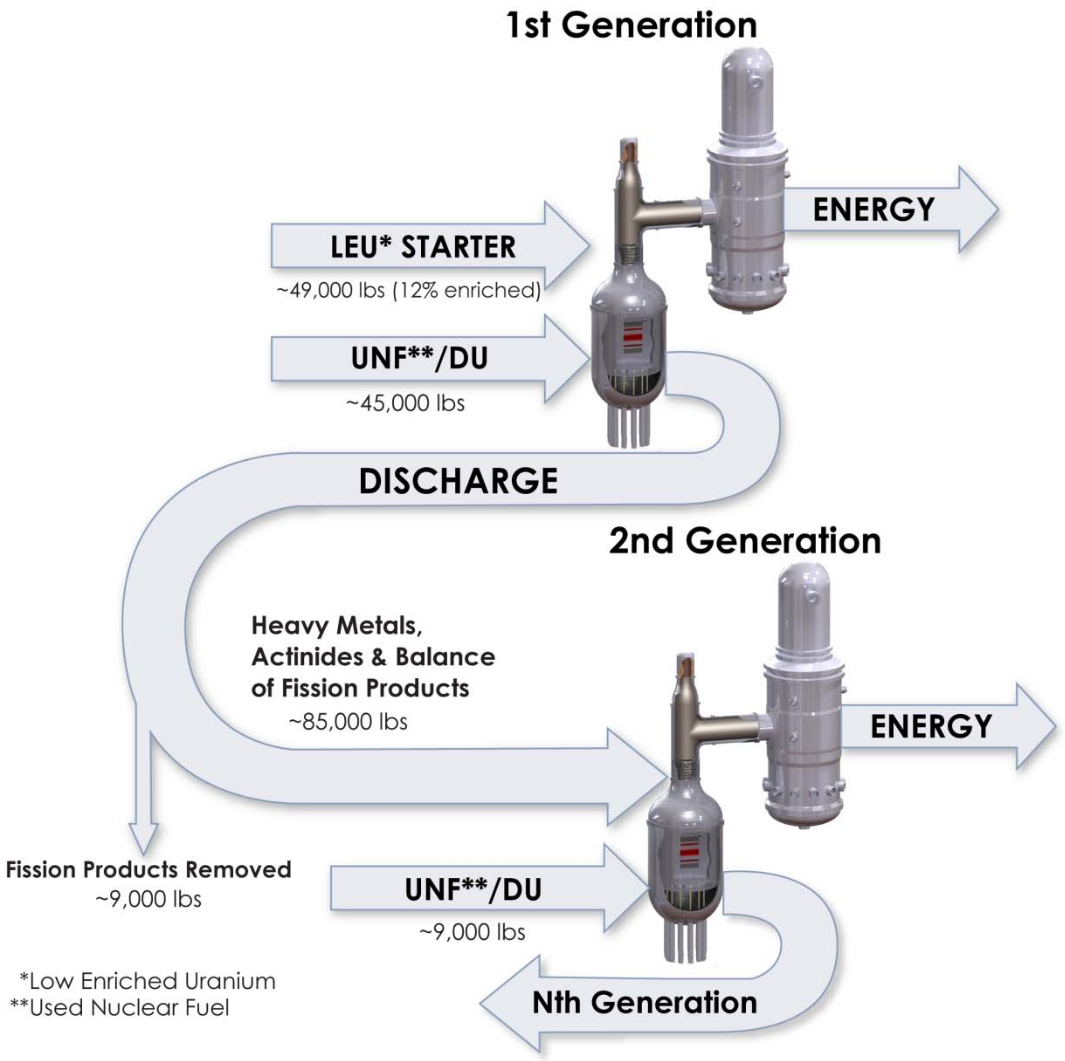
357 units

257kg

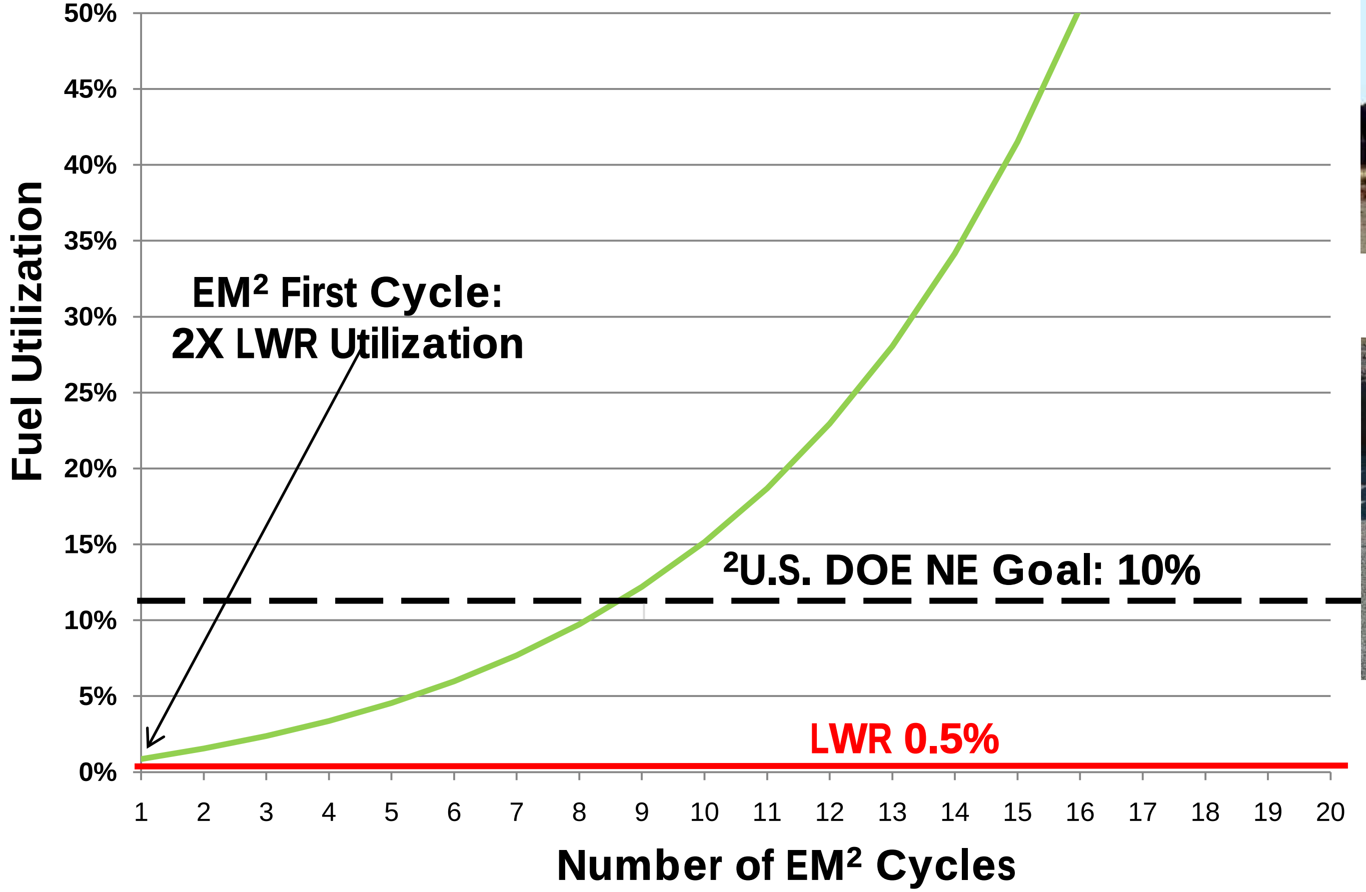


- Handling unit
- Stackable
- Transfers fission gas

Used Nuclear Fuel/DU and Partial Closing of the Fuel Cycle



Energy Security: Fuel Utilization[1] Improves with Number of Cycles



U.S. SNF inventory: 61,000 t

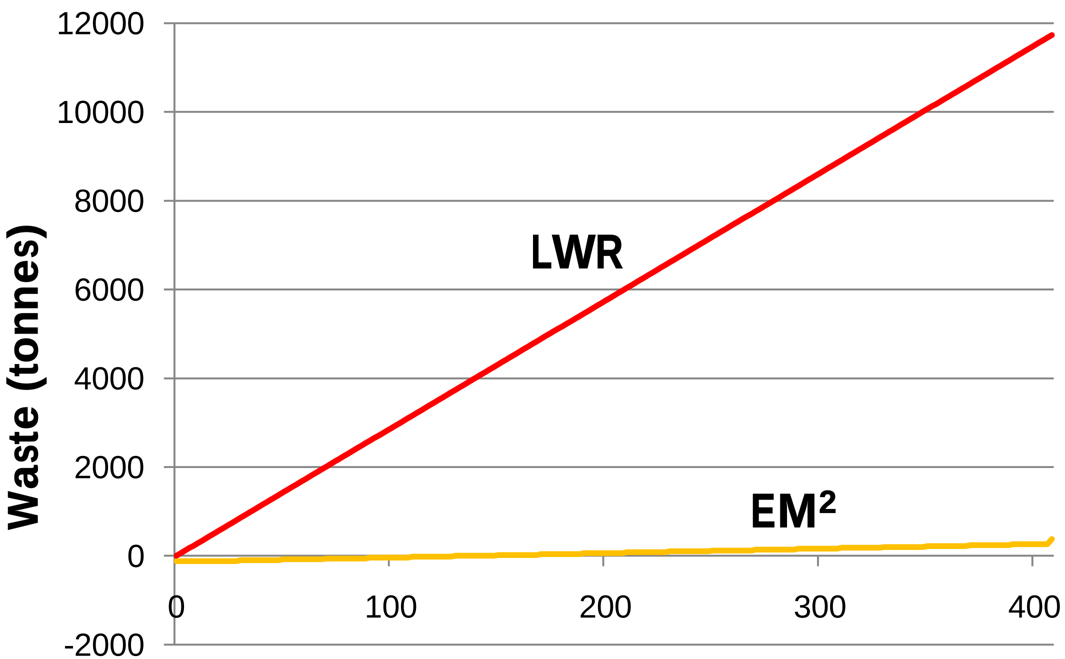
U.S. DU inventory: 700,000 t

Energy in U.S. SNF & DU inventory is 5 x world's proven oil reserves

[1]Percent of mined heavy metal that is fissioned

[2]U.S. Department of Energy, Nuclear Energy

Quantity of Waste Produced



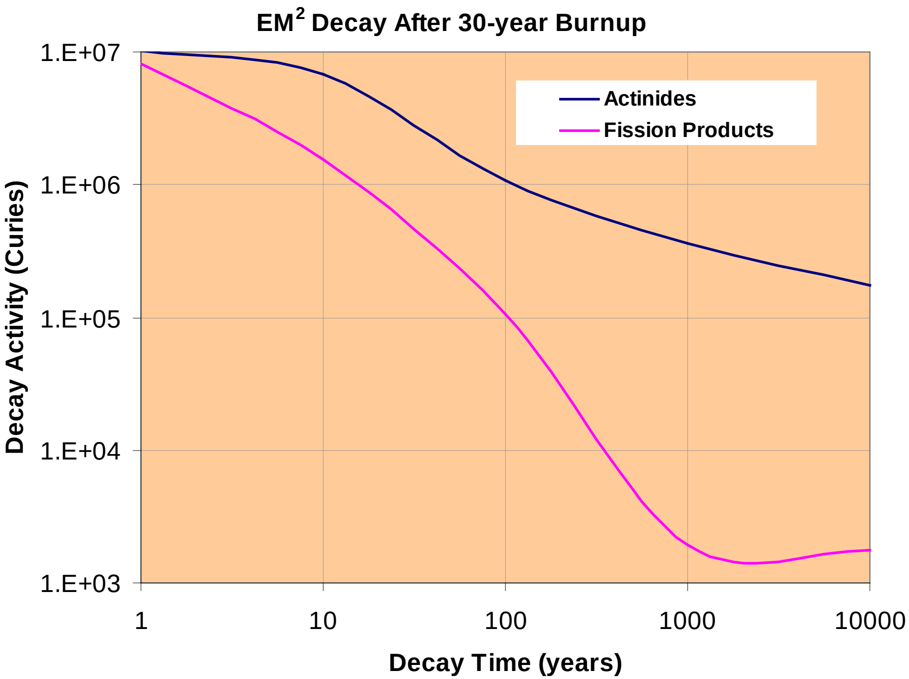
Waste vs years of operation for a continuously operating1.2 GWe plant

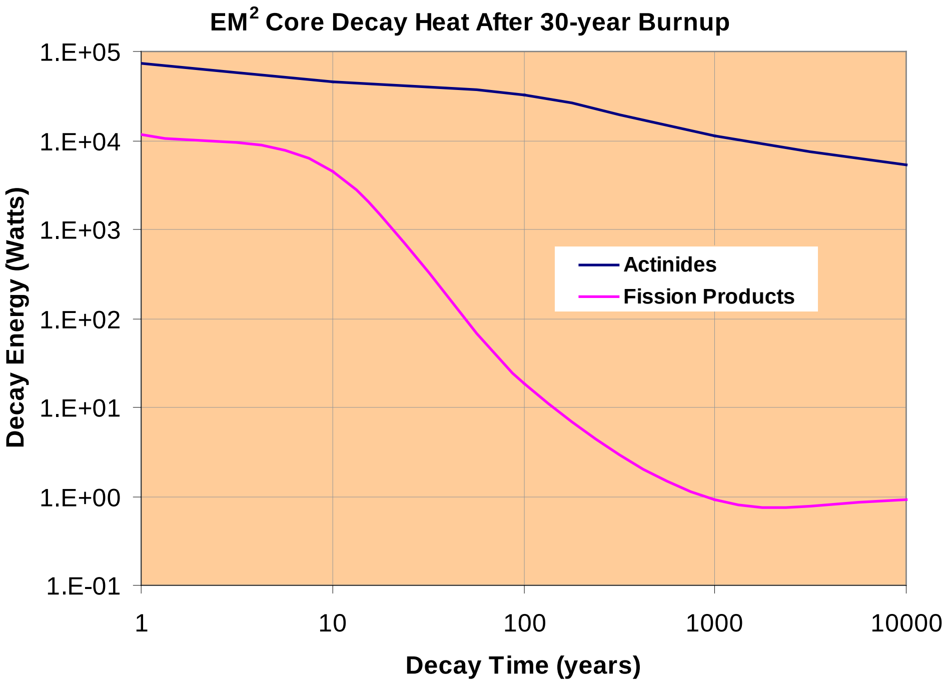
Impact on repository sizing (stated on a per unit energy supplied basis)

- Higher burnup and higher efficiency mean lower end of life fuel mass & volume
- These amounts are reduced further (linearly) by the number of times fuel is reused
- These figures of merit are further improved if spent LWR fuel is used as fuel

Total waste in 400 years: LWR 12,000t, EM^2 < 400t

Implications for Nuclear Waste





FP radiological data

- FP makeup quite similar to that of LWRs except that Cs is removed from the core during the burn
- After 300 yrs, primary FPs are ^{99}Tc & ^{151}Sm, two weak beta emitters; FP heat load is few W/core

Actinide radiological data

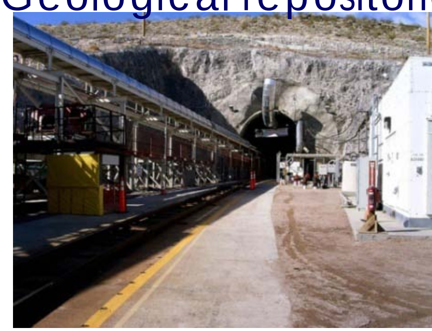
- If restricted to one burn cycle, actinide content per unit energy produced is similar to that of LWRs and is reduced linearly with the number of cycles
- Long core residence postpones repository need

Non-Proliferation

Dry cask storage

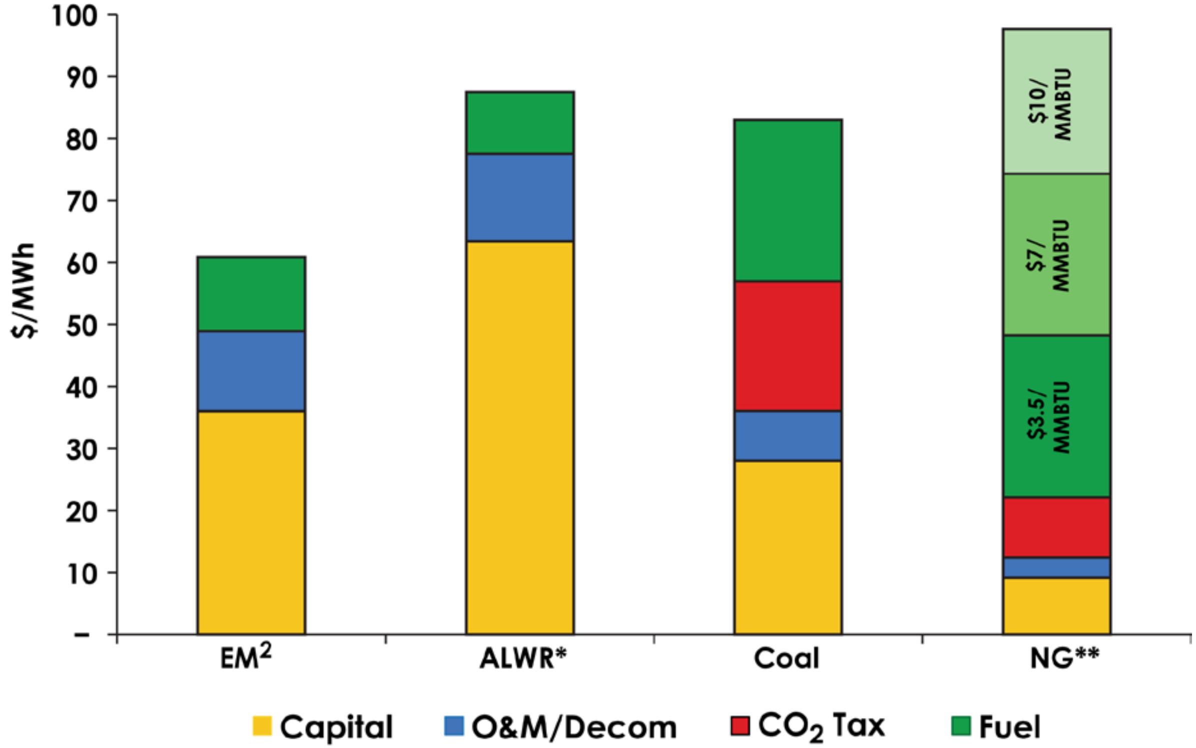
Uranium enrichment

Geological repositories



1. Reduces fuel handling and eliminates long-term storage of spent fuel containing significant Pu.
2. Eliminates need for conventional reprocessing (heavy metal chemical separation).
3. Both discharged and refabricated EM^2 fuel meets self-protection requirements for 20 yrs.
4. Below-grade reactor core is inaccessible without special remote handling equipment.
5. Low excess reactivity- core cannot be easily reconfigured for material insertion/extraction

Comparative Power Generation Costs



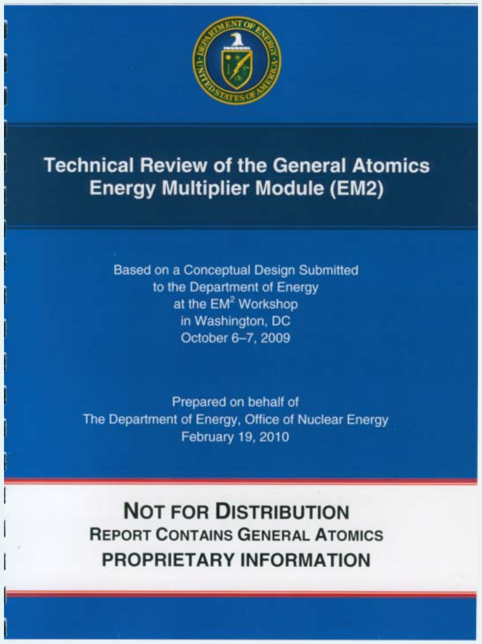
*Advanced Light Water Reactor
**Natural Gas

30% cost reduction is a result of the following attributes

- Less materials
- Factory labor
- Shorter construction time
- Smaller facility footprint
- Higher efficiency
- Decades of life — no refueling/no shuffling
- Simple control
- Bankablility of fuel

ALWR, coal and natural gas data source: MIT 2009 Cost Update; EM[2] model estimate.
All power generation costs evaluated for a 30-yr levelization period

DOE-NE Comprehensive EM^2 Peer Review


Technical Review of the General Atomics Energy Multiplier Module (EM2)

Based on a Conceptual Design Submitted to the Department of Energy at the EM^2 Workshop in Washington, DC October 6–7, 2009

Prepared on behalf of The Department of Energy, Office of Nuclear Energy February 19, 2010

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REPORT CONTAINS GENERAL ATOMICS PROPRIETARY INFORMATION

- Core physics and depletion
- Core thermal hydraulics
- Fuels
- Fission product transport
- Used fuel management
- Structural materials
- Balance of plant
- Safety
- Non-proliferation
- Cost/economics

Key findings:

- **Most significant risks are associated with 30-yr core in fast neutron fluence, including fuel thermal-chemical performance and dimensional stability, SiC clad integrity, and fission product transport**
- **Report affirms the reactor physics design and that EM^2 supports all five DOE-NE goals**

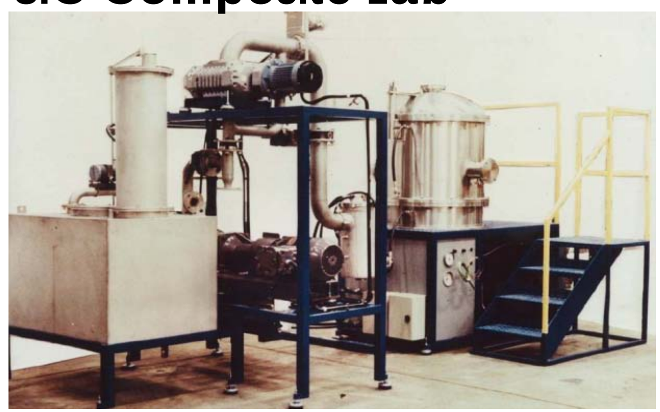
GA's Internally-Funded Program Addresses Fuel and Power Conversion

CY2010 GA-Funded Work

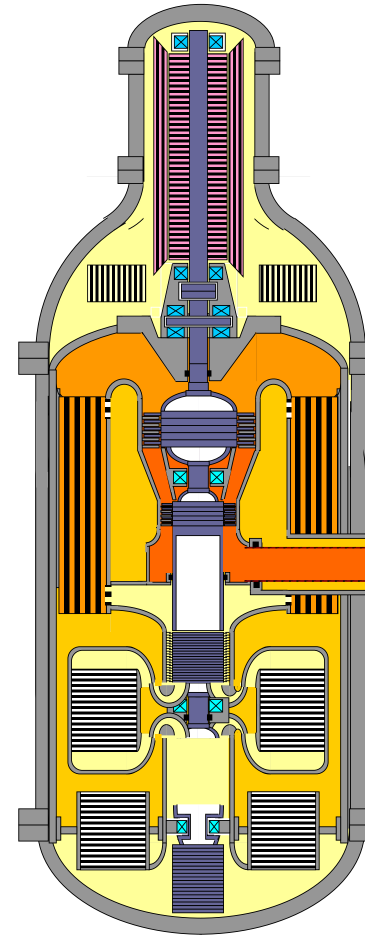
- Bench-scale UC fab facility
- Bench-scale SiC fab facility
- Fuel fab process optimization
- Physics methods upgrade
- Reactivity control design
- EM^2 fuel metrology lab
- High-speed generator
- High-voltage inverter
- Reactor concept optimization
- Power conversion design
- Selected accident analyses
- FP transport component fab

UC Lab

SiC Composite Lab



SiC coater



High-speed Gas Turbine

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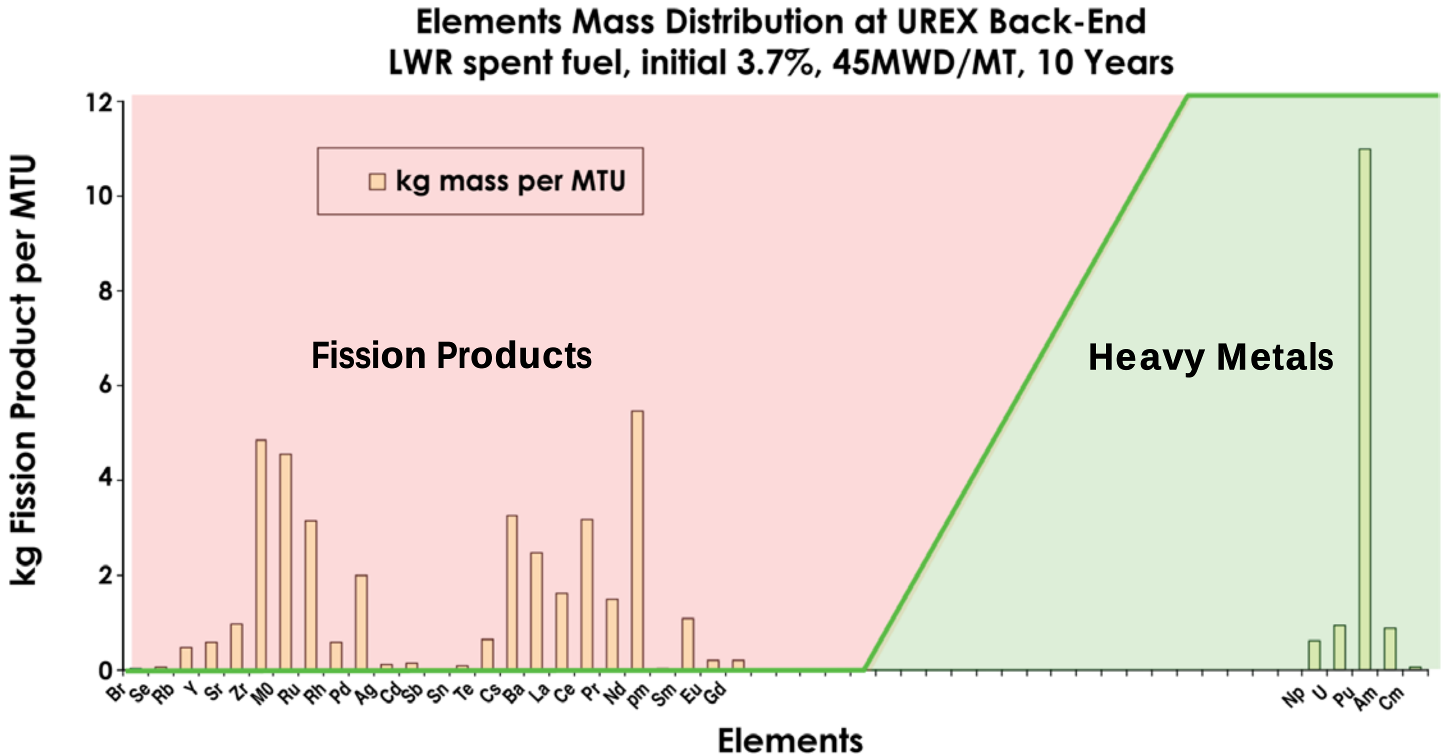
Summary

- **Significant capital & power cost reduction**
- **Reduces (and potentially consumes) the used nuclear fuel inventory, thereby easing repository requirements and possibly delaying their need**
- **Reduces long-term need for enrichment; eliminates need for conventional reprocessing**
- **Formidable technical challenges are attracting eager young minds to a new nuclear enterprise with a long-term future**

Backup Slides

EST Also Offers Promise for Used Nuclear Fuel

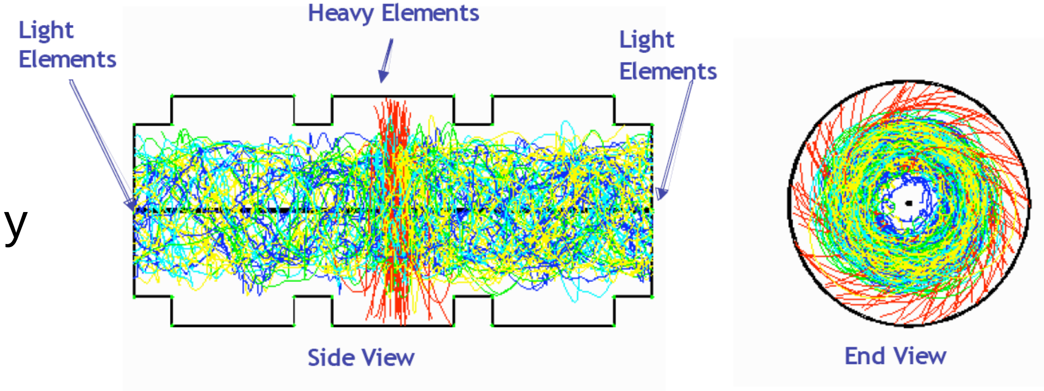


- **Uses mass gap between actinides and lanthanides**
- **Separation of trivalent actinides and lanthanides considered to be the most difficult current reprocessing steps**
  - Necessary for both repository management and recycled fuel
- **Filter throughput 30X less than wastes → much smaller size plant**

EST Technology Proof of Principle has Occurred

- **Physically separates based on mass/charge using electromagnetic fields**

- **Advantages for nuclear wastes**
  - Relatively indifferent to waste complexity
  - Excellent separation efficiency
  - Single step process
  - Reduced waste streams
  - Significant net cost savings and risk reduction



O	blue	Cr	cyan
Na	green	Sr Cs Pu	red
Al	yellow		

- **Advantages for used nuclear fuel processing**
  - Separates fission products
  - Not capable of TRU separation by element or isotopes
  - Supportive of new reprocessing-free closed fuel cycle options

Technology Needs & Research Challenges

- Efficient and effective separation of fission products from reactor discharge
- Understanding properties of materials under high neutron fluences and high temperatures
- Behavior of fuel and fission products over decades
- Defining and establishing manufacturing base to realize the cost-effective fabrication of modular reactors like EM^2

EM^2 is More Proliferation-Resistant than Alternative Reactor Concepts

Portion of Fuel Cycle	Attribute of Fuel Cycle	Light Water Reactor	Traditional Fast Reactor	EM^2
Front end	Need for enrichment?	Yes	Gen 1: yes Gen 2: no	Gen 1: yes Gen 2: no
Operations	Fuel residence time Sealed vessel?	< 5 yr No	< 5 yr No	> 30 yr Yes
Back end	Planned reuse of fuel	None	Yes, with Pu separation	Yes, without Pu separation

Proliferation vulnerability legend	LOW	MODERATE	HIGH