

**Tuesday, August 05**

**High Fidelity System Modeling for Advanced Energy Technologies: Methods Development, Concepts, Design, and Analysis**

Pavel V. Tsvetkov, Texas A&M University, College Station  
Nuclear Science and Technology Division Seminar  
10:00 AM, Research Office Building (5700), Room O-304  
Contact: Kevin T. Clarno ([clarnokt@ornl.gov](mailto:clarnokt@ornl.gov)), 865.241.1894  
Contact: Alice Rice ([riceaf@ornl.gov](mailto:riceaf@ornl.gov)), 865.576.2237

**Abstract**

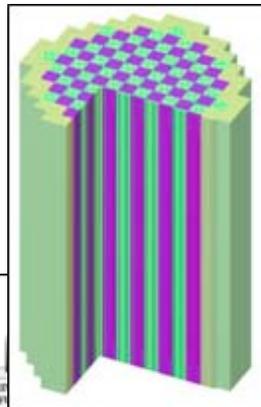
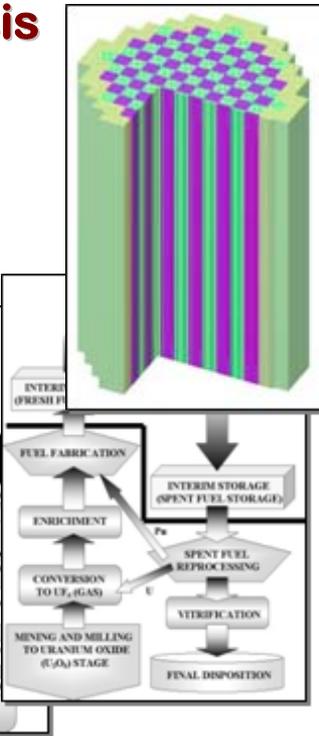
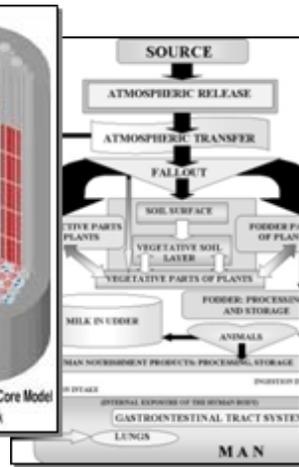
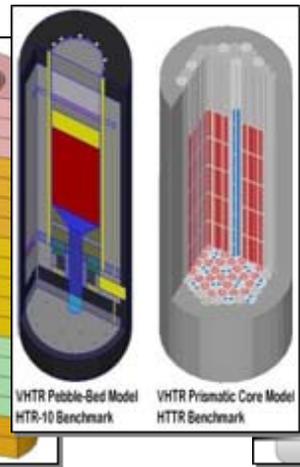
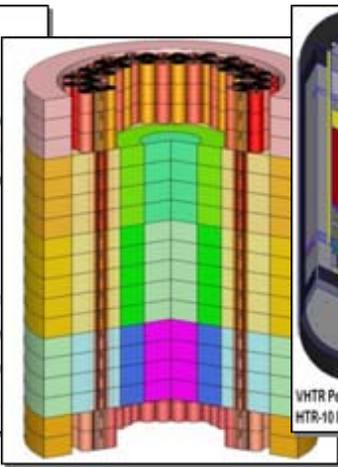
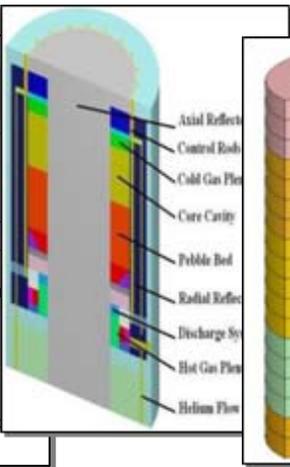
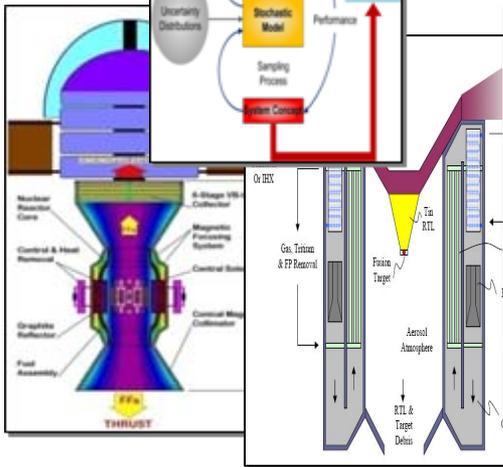
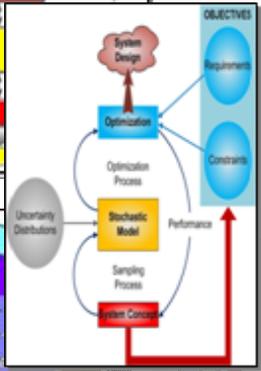
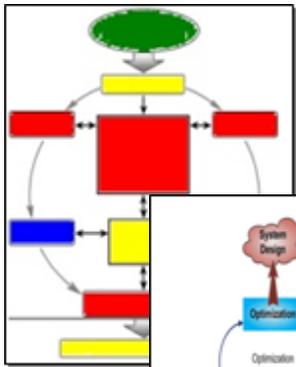
Research activities in the areas related to advanced energy technologies at Texas A&M University will be discussed. Dr. Tsvetkov is an Assistant Professor at the Department of Nuclear Engineering, Texas A&M University. His baseline research areas are the integrated analysis of nuclear systems and development of methods and tools including integrated/hybrid Monte Carlo-deterministic modeling and coupled neutronics-thermal-hydraulic analysis. Subject-specific areas of interest include: direct nuclear energy conversion, high temperature reactors, space power/propulsion, environmental and non-proliferation aspects. Dr. Tsvetkov actively participates in a number of international research and education programs sponsored by the US government, NATO and the European Community. The purpose of the seminar is to highlight current research activities and interests in order to identify potential interests for collaboration as well as outline specific research areas like VHTR with advanced actinide fuels.

# ADVANCED ENERGY TECHNOLOGIES RESEARCH

Advances in nuclear technology through pioneering research and teaching excellence

## High Fidelity System Modeling for Advanced Energy Technologies: Methods Development, Concepts, Design, and Analysis

Dr. Pavel V. Tsvetkov  
Nuclear Engineering, Texas A&M University



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## High Fidelity System Modeling for Advanced Energy Technologies: Methods Development, Concepts, Design, and Analysis

Dr. Pavel V. Tsvetkov

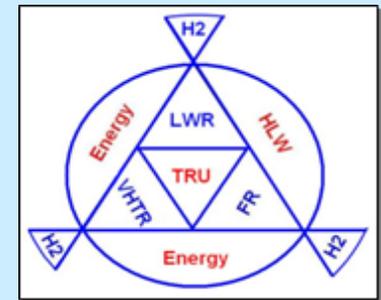
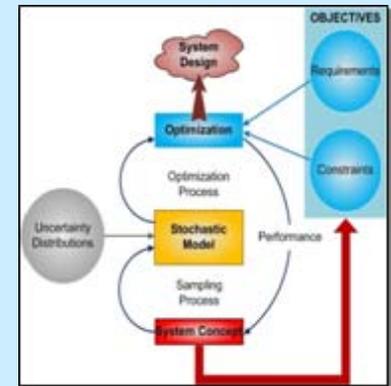
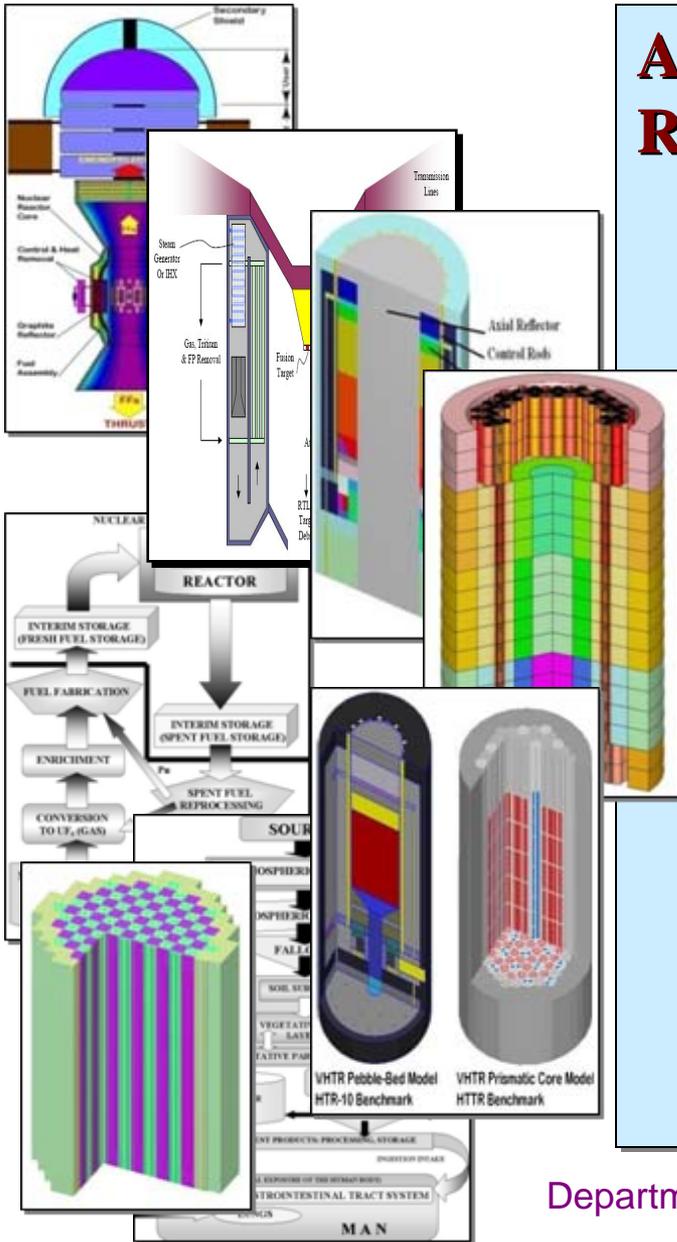
Nuclear Engineering, Texas A&M University

### DISCLAIMER

- This presentation only introduces our research in the area we like to identify as “High Fidelity System Modeling”. For details, let’s talk!
- The described efforts represent ongoing and future contributions of my students.
- Our efforts are possible because of our sponsors. Our sponsors also partially define our research directions and applications

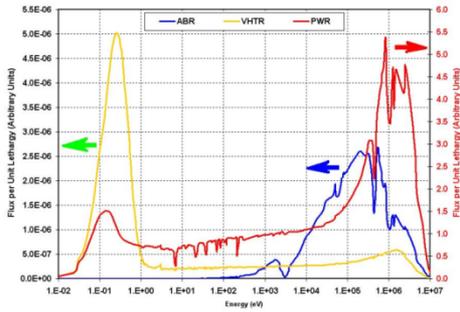
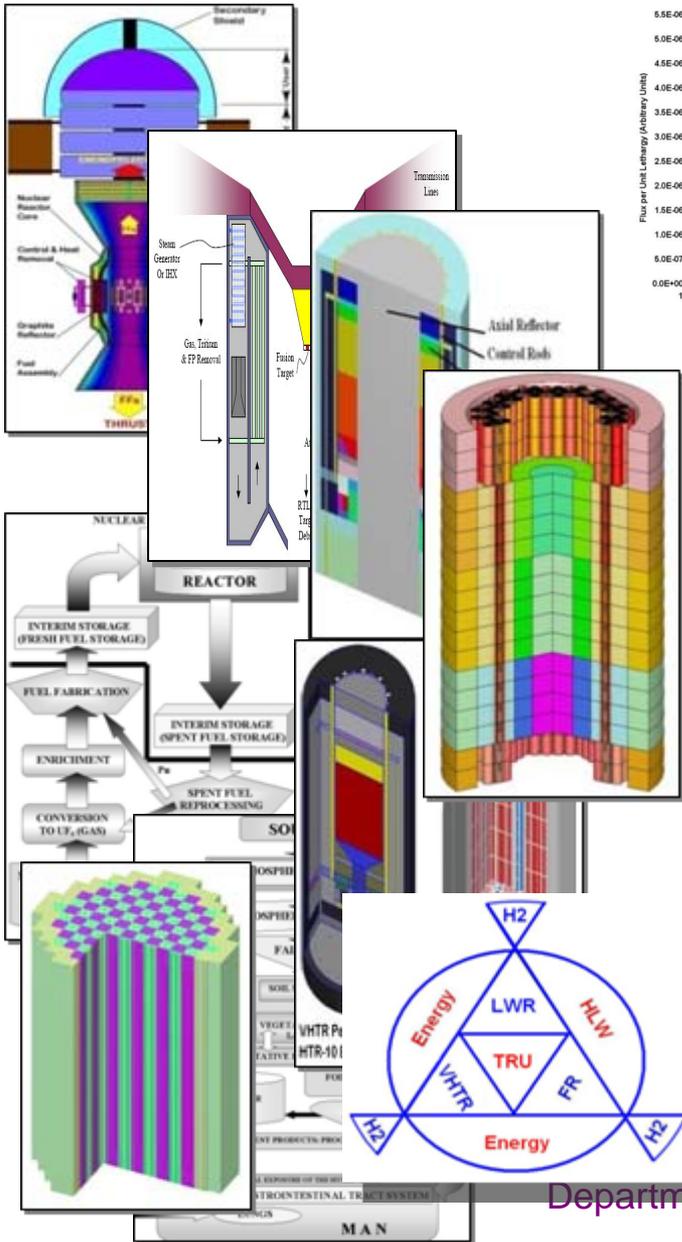
# ADVANCED ENERGY TECHNOLOGIES RESEARCH

- Self Introduction (Who am I?)
- Interests
- Capabilities
- Research Directions
- Potential Collaboration Venues
- Conclusions





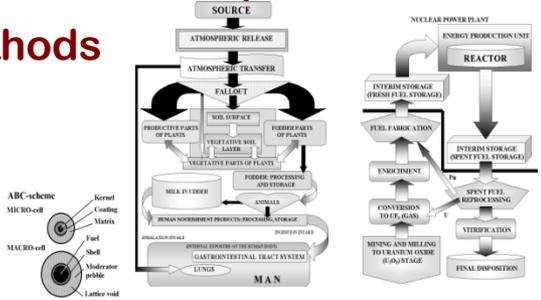
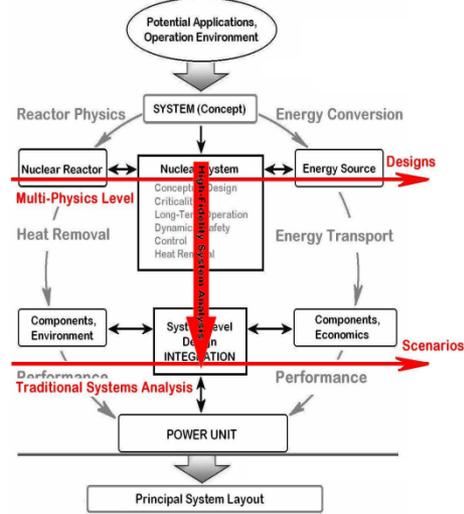




**Next Generation VVER,  
BN Family, Transition to BN1600  
GA MHR for Pu Incineration  
LEU-HTR PROTEUS Benchmark  
Direct Energy Conversion  
Advanced Waste Incinerators  
General reactor physics methods development**

- Surface pseudo-source methods
- Complex systems
- Reload optimization
- Multi-objective optimization
- Monte Carlo methods
- Benchmarking, V&V Theory

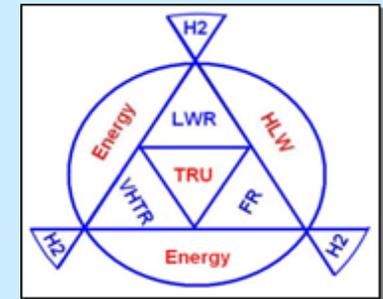
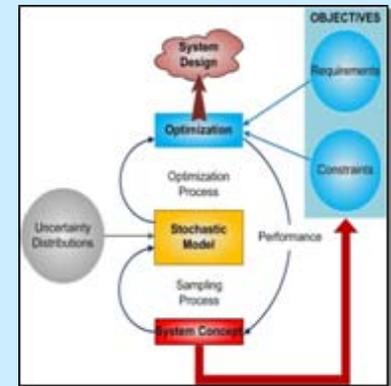
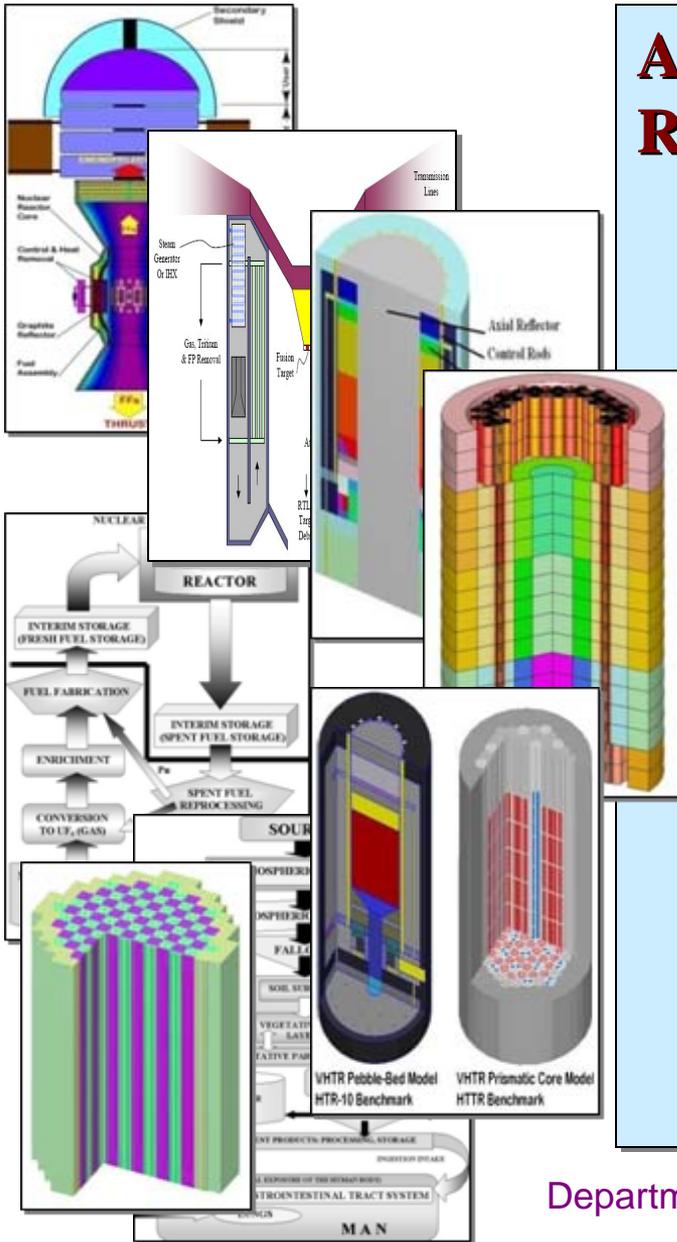
**Nuclear Engineering,  
1992 - ...**



**Who am I?**

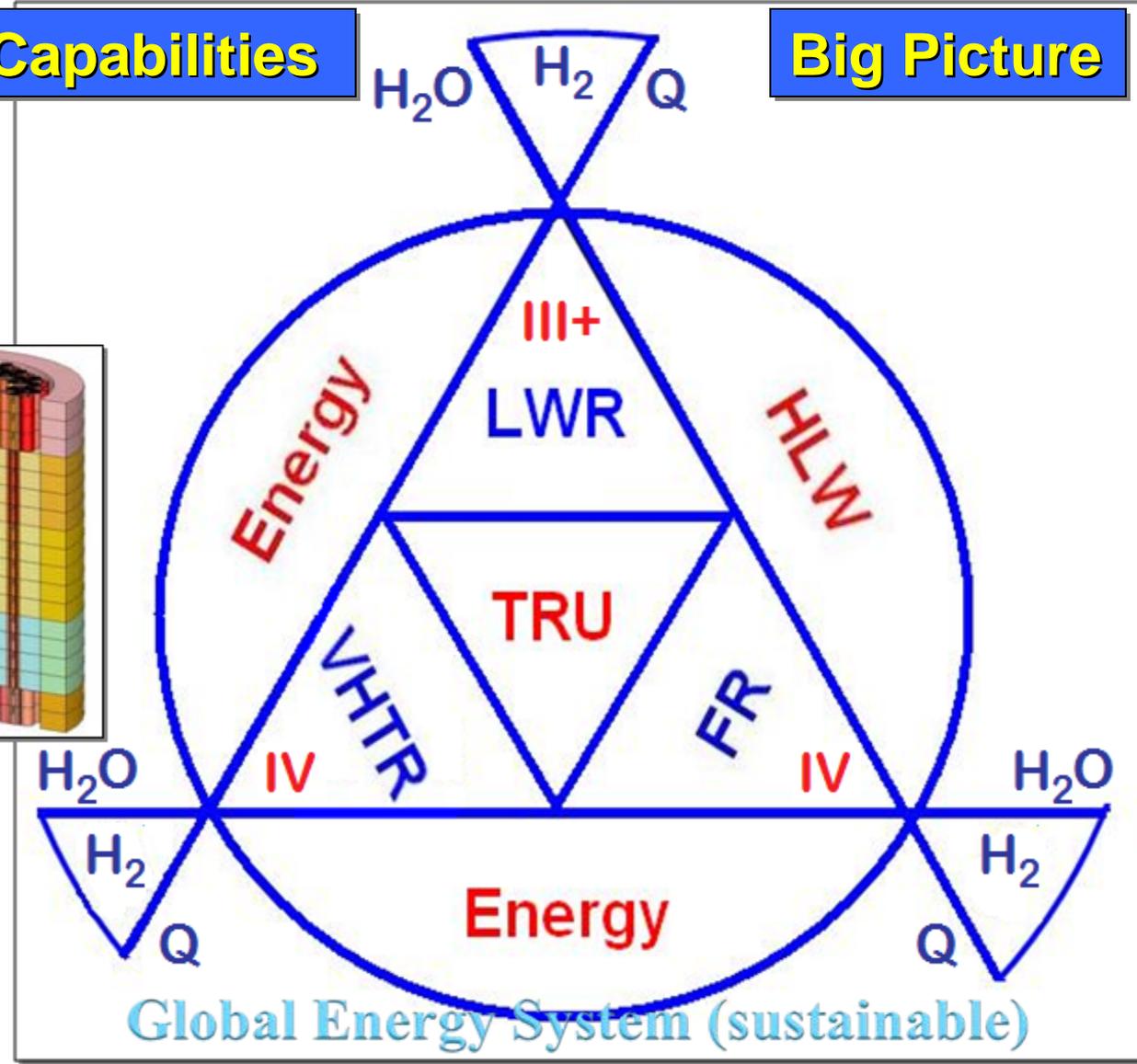
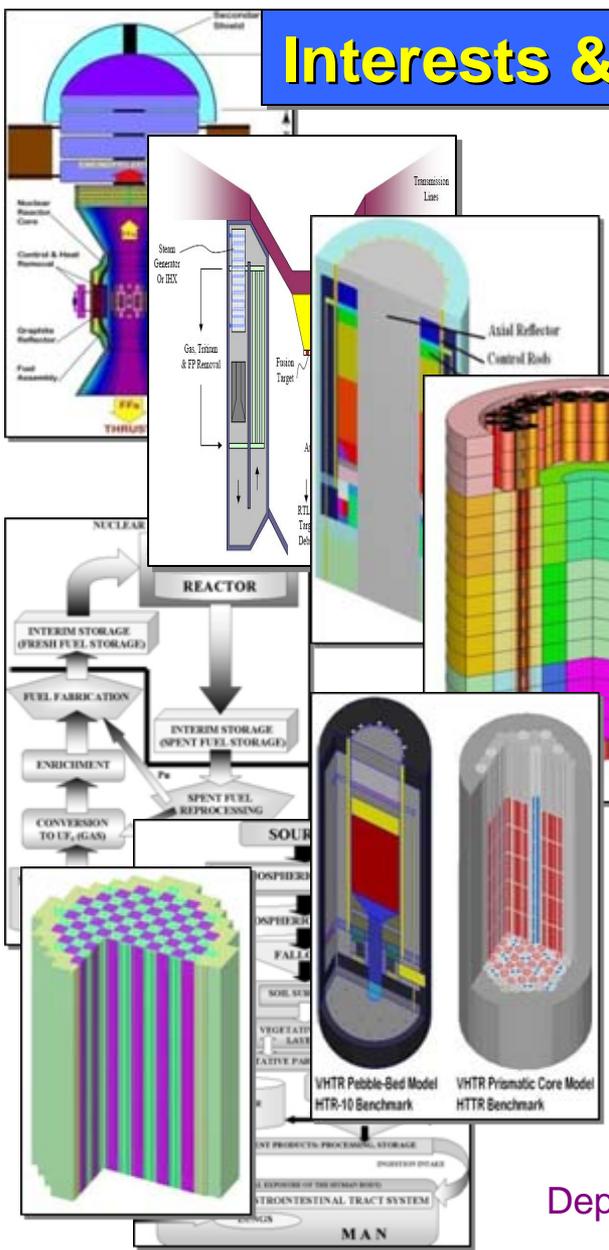
# ADVANCED ENERGY TECHNOLOGIES RESEARCH

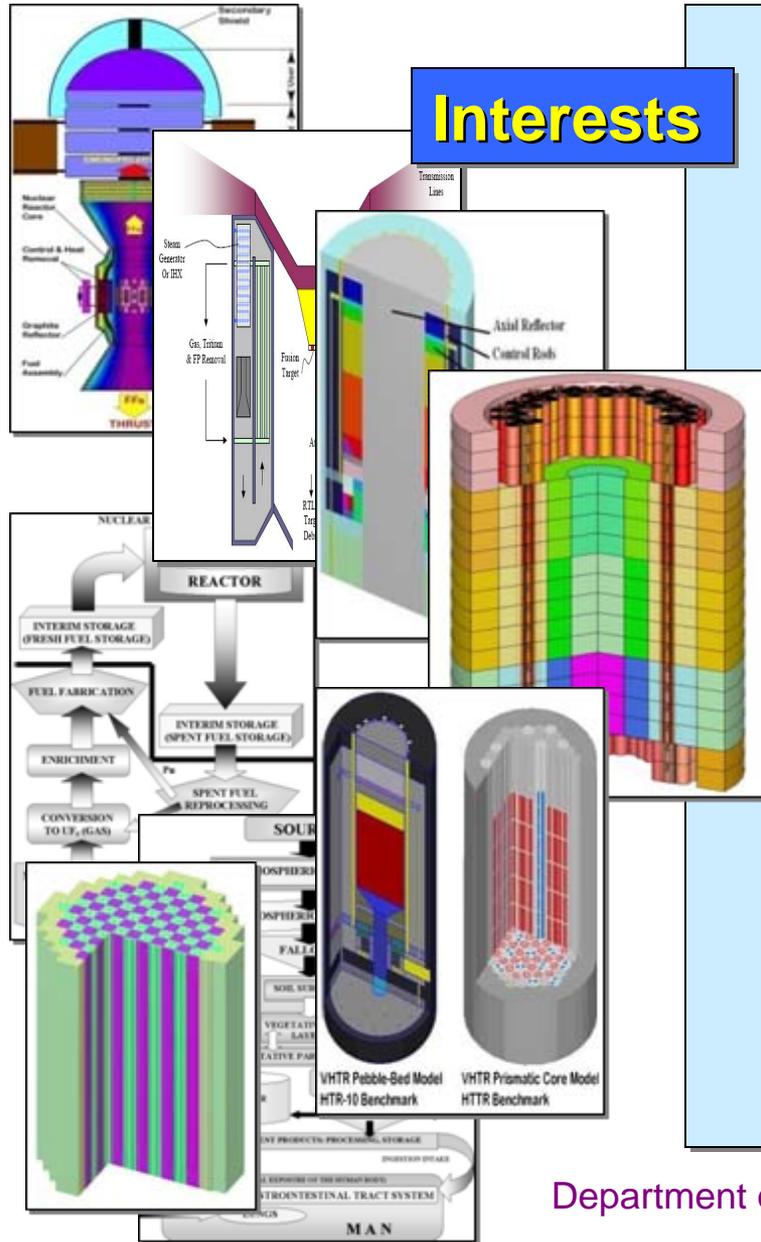
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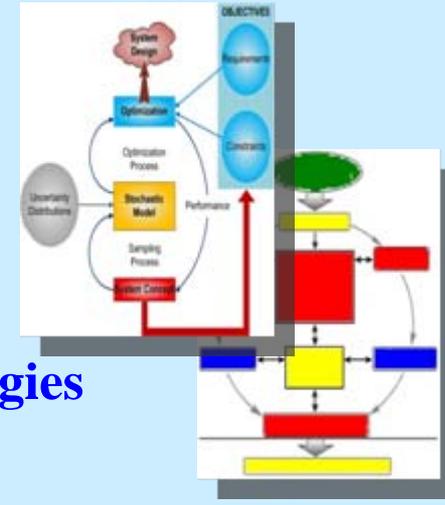
# Interests & Capabilities

# Big Picture



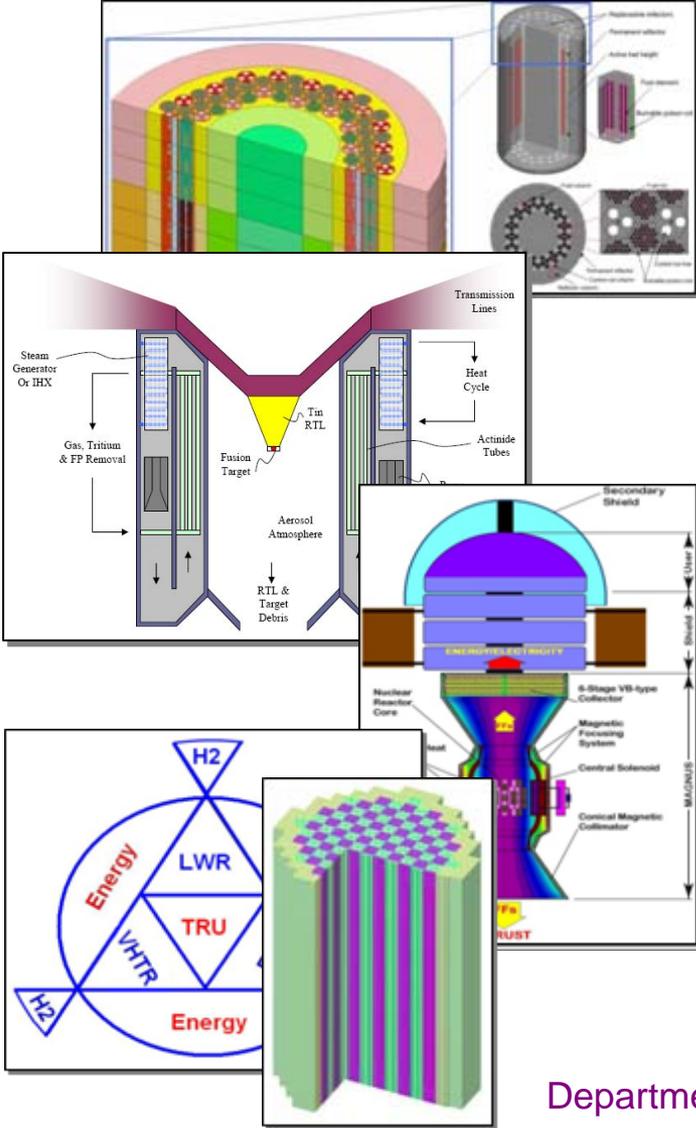


- **Advanced Energy Technologies**
- **Reactor Physics, T-H, Energy Conversion**
- **Integrated Analysis of Nuclear Systems**
- **Sensitivity/Uncertainty, Optimization**
- **Monte Carlo, Hybrid Methods, etc.**
- **HTGRs, Fast Reactors, DEC**
- **Advanced Fuel Cycles**
- **Energy Sustainability**
- **Safety Analysis**
- **Information Technologies**



**High Fidelity System Modeling for Advanced Energy Technologies**

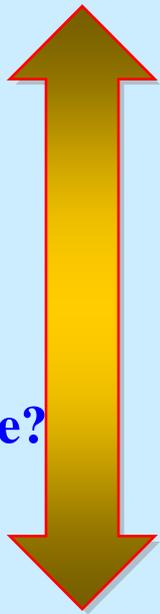
# Why? What? When? How?



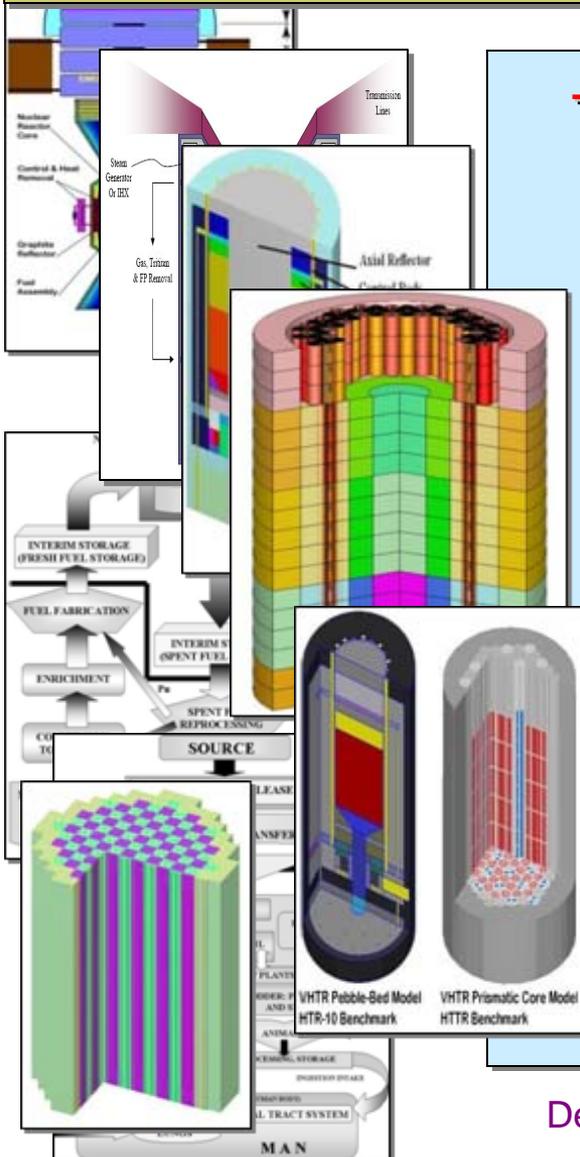
**Interests**

**Observations**

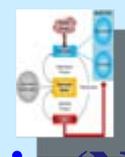
- The need for Big Picture representation?
- Analysis purpose and level?
- Capturing the System Concept?
- Capturing the System Physics?
- Capturing the System Performance?
- Analysis Benchmark options?



# High Fidelity System Modeling for Advanced Energy Technologies



## TOOLS & METHODS



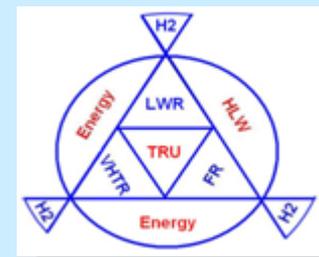
## Interests

- Coupled Analysis (Neutronics-T-H)
- Advanced High-Fidelity System Modeling
- Monte Carlo, Hybrid Methods, etc.

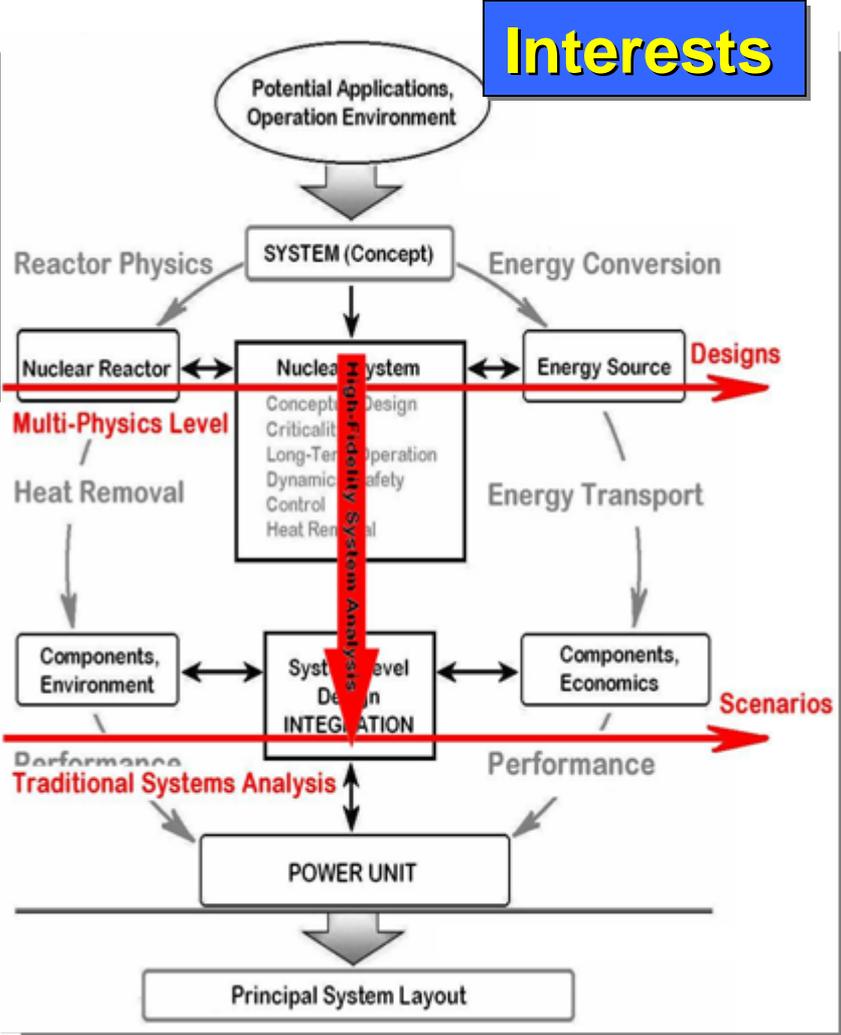
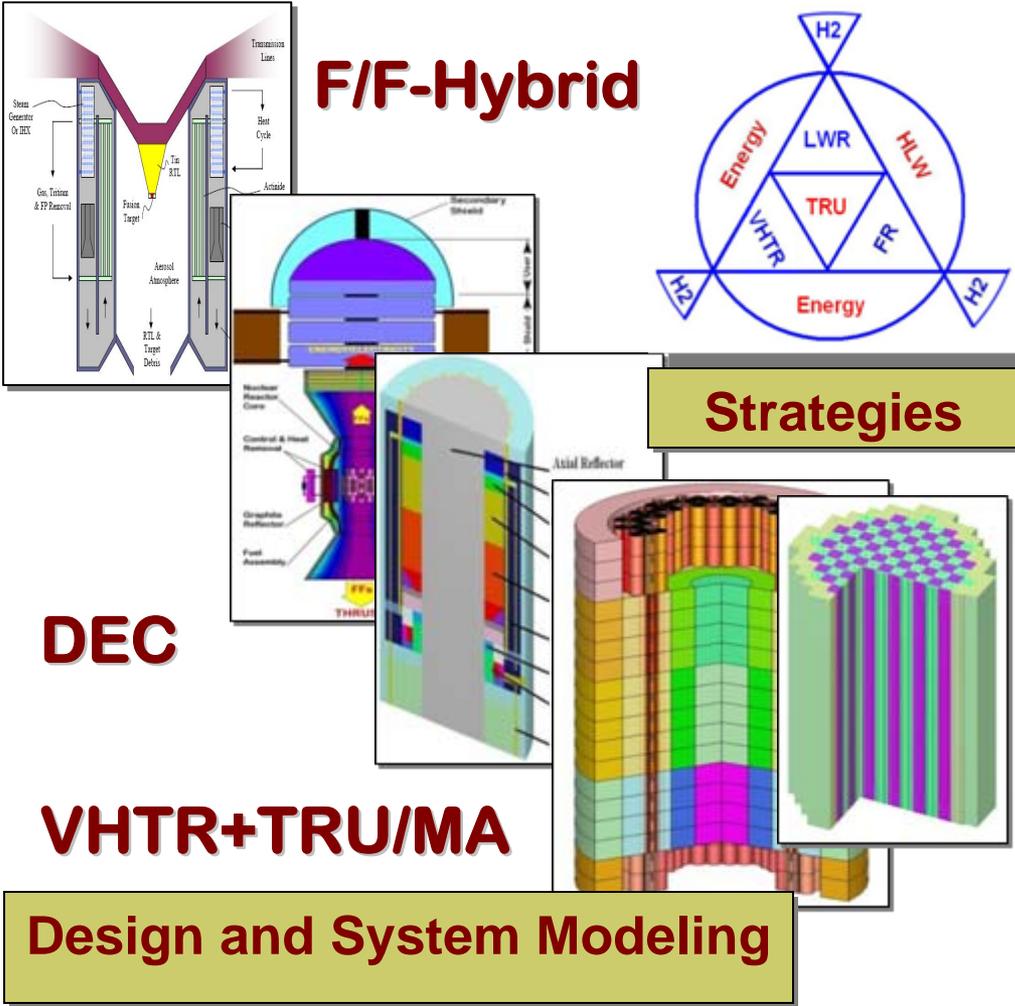
## SYSTEMS & TECHNOLOGIES



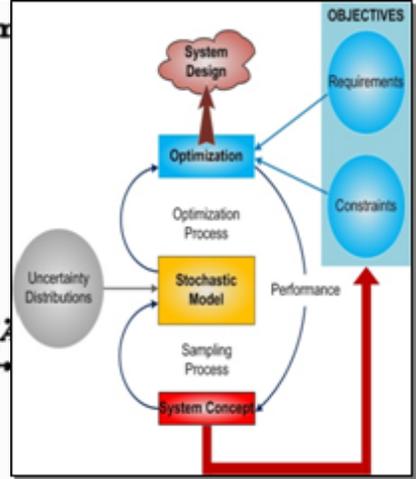
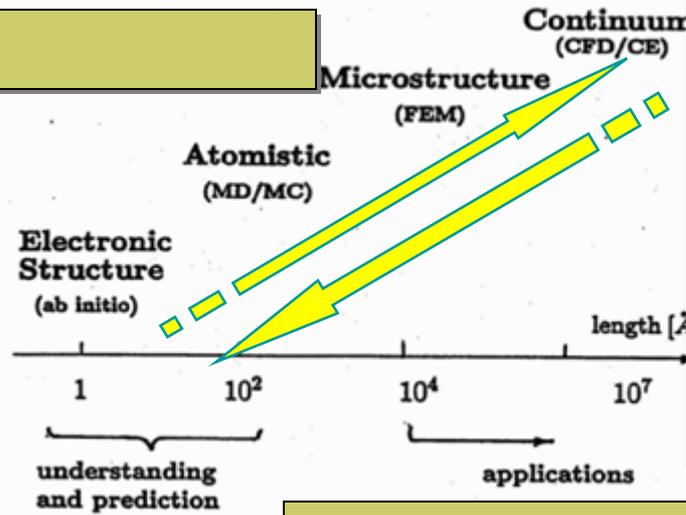
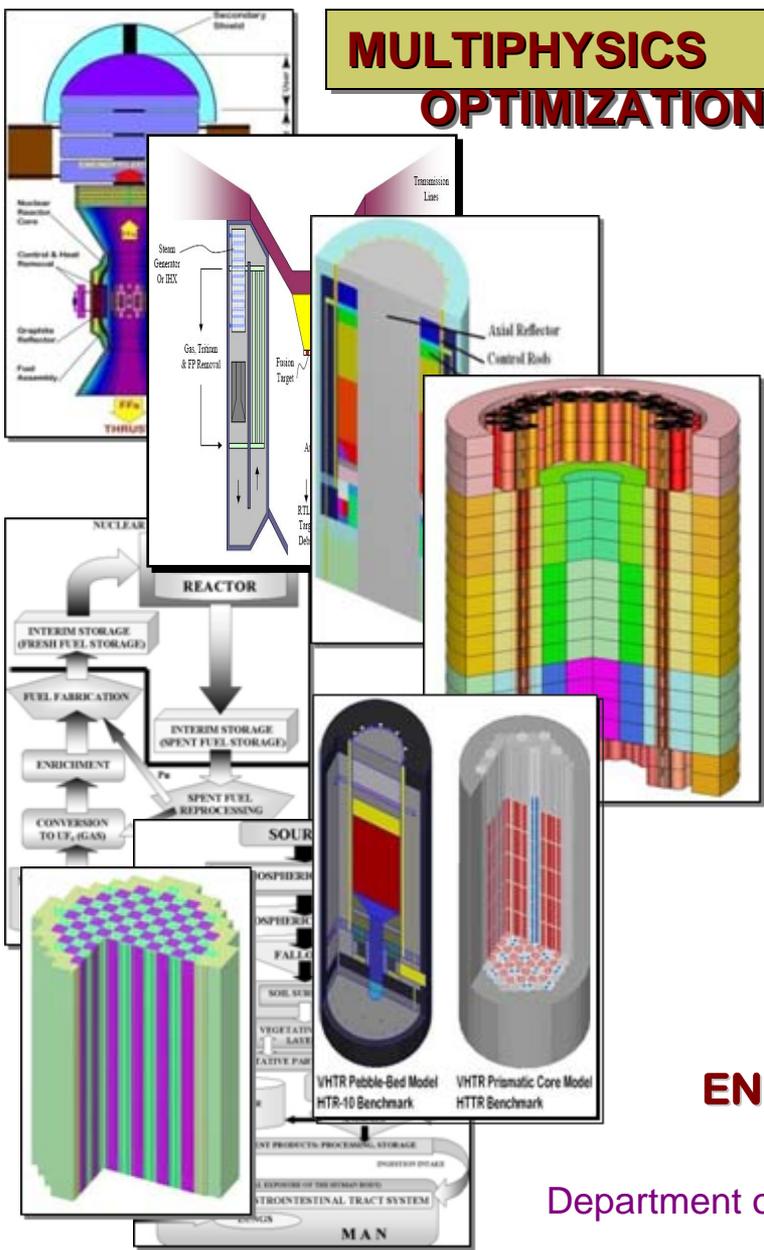
- HTGRs, Fast Reactors, New Systems
- Advanced Fuel Cycles
- Safety Analysis



# High Fidelity System Modeling for Advanced Energy Technologies



# MULTIPHYSICS OPTIMIZATION



## Complex Systems

- Computational time
- Basic physics knowledge
- Amount of data to process and pass
- Integration/Optimization

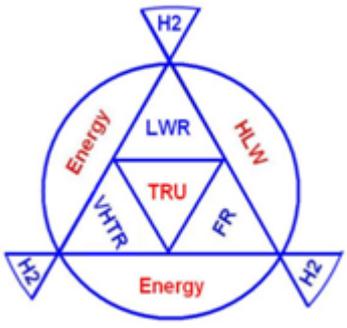
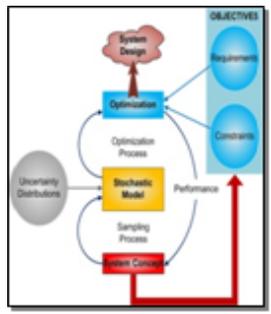
**ENERGY SYSTEM = NUCLEAR SYSTEM + FUEL CYCLE**

# High Fidelity System Modeling for Advanced Energy Technologies

The top diagram shows a nuclear power plant cycle: **NUCLEAR POWER PLANT** (containing **ENERGY PRODUCTION UNIT** and **REACTOR**) feeds into **INTERIM STORAGE (FRESH FUEL STORAGE)**, which leads to **FUEL FABRICATION** and **ENRICHMENT**. This then feeds into **INTERIM STORAGE (SPENT FUEL STORAGE)**, which leads to **SPENT FUEL REPROCESSING**, **VERIFICATION**, and **FINAL DISPOSITION**. A globe is positioned between the two diagrams.

The bottom diagram is a food chain diagram showing the flow from **SOURCE** through **ATMOSPHERE**, **FALLS**, **SOIL SURFACE**, **PRODUCTIVE PARTS OF PLANTS**, **VEGETATIVE PARTS OF PLANTS**, **VEGETATIVE MILK LAYER**, **FODDER, PROCESSING AND STORAGE**, **MILK IN UDDER**, **ANIMALS**, **HUMAN NUTRIMENT PRODUCTS, PROCESSING, STORAGE**, **INTERNAL RESERVE OF THE HUMAN BODY**, **GASTROINTESTINAL TRACT SYSTEM**, **LUNGS**, and **MAN**.

**Complex Systems**



**Sustainable Energy System**

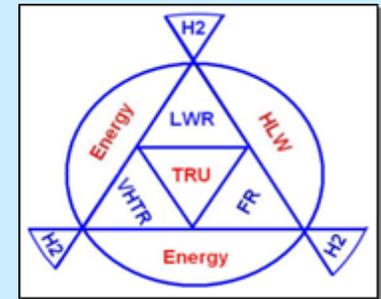
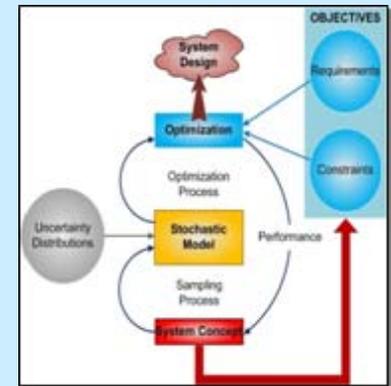
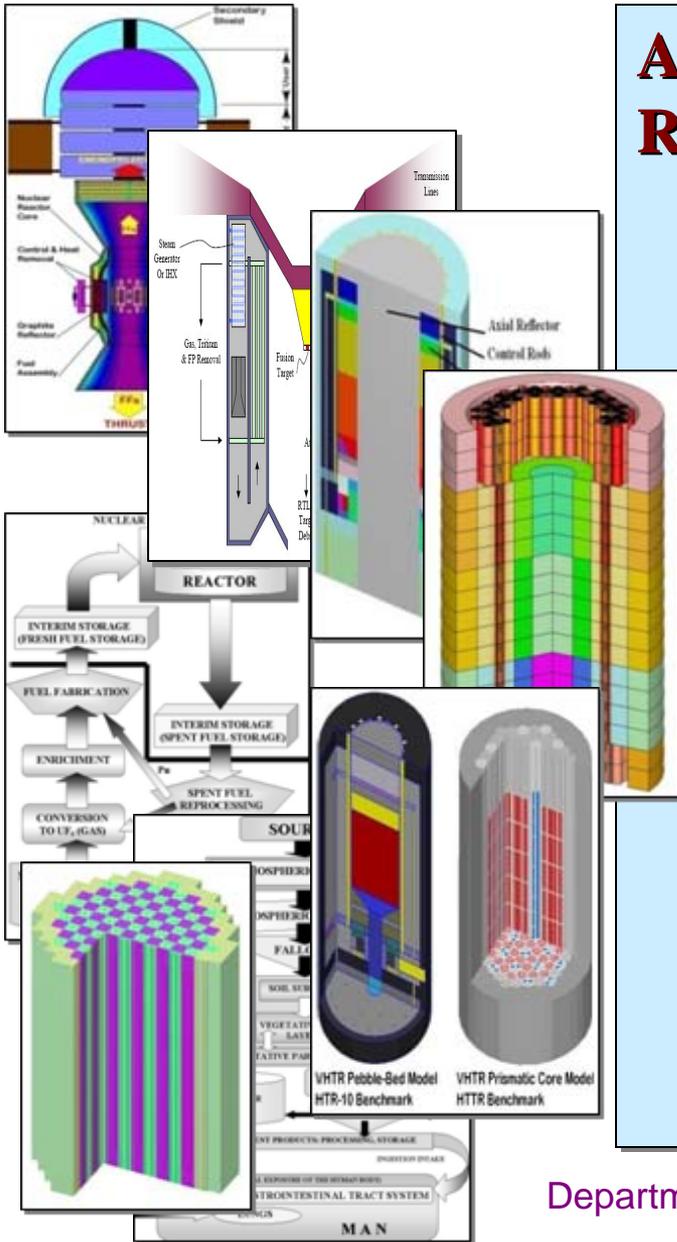
This block contains several detailed diagrams of nuclear reactor components. On the right, a vertical cross-section of a reactor core is shown with labels: **Axial Reflector**, **Control Rods**, **Cold Gas Plenum**, **Core Cavity**, **Pebble Bed**, **Radial Reflector**, **Discharge System**, and **Hot Gas Plenum**. Other diagrams show a **Steam Generator Or HEX**, **Gas Inlet and FP Removal**, **Tracer**, **Tracer Target**, **Control & Heat Removal**, **Graphite Reflector**, **Fuel Assembly**, **VHTR Pebble-Bed Model HTR-10 Benchmark**, and **VHTR Prismatic Core Model HTR Benchmark**.

**Complicated Systems**

**Interests**

# ADVANCED ENERGY TECHNOLOGIES RESEARCH

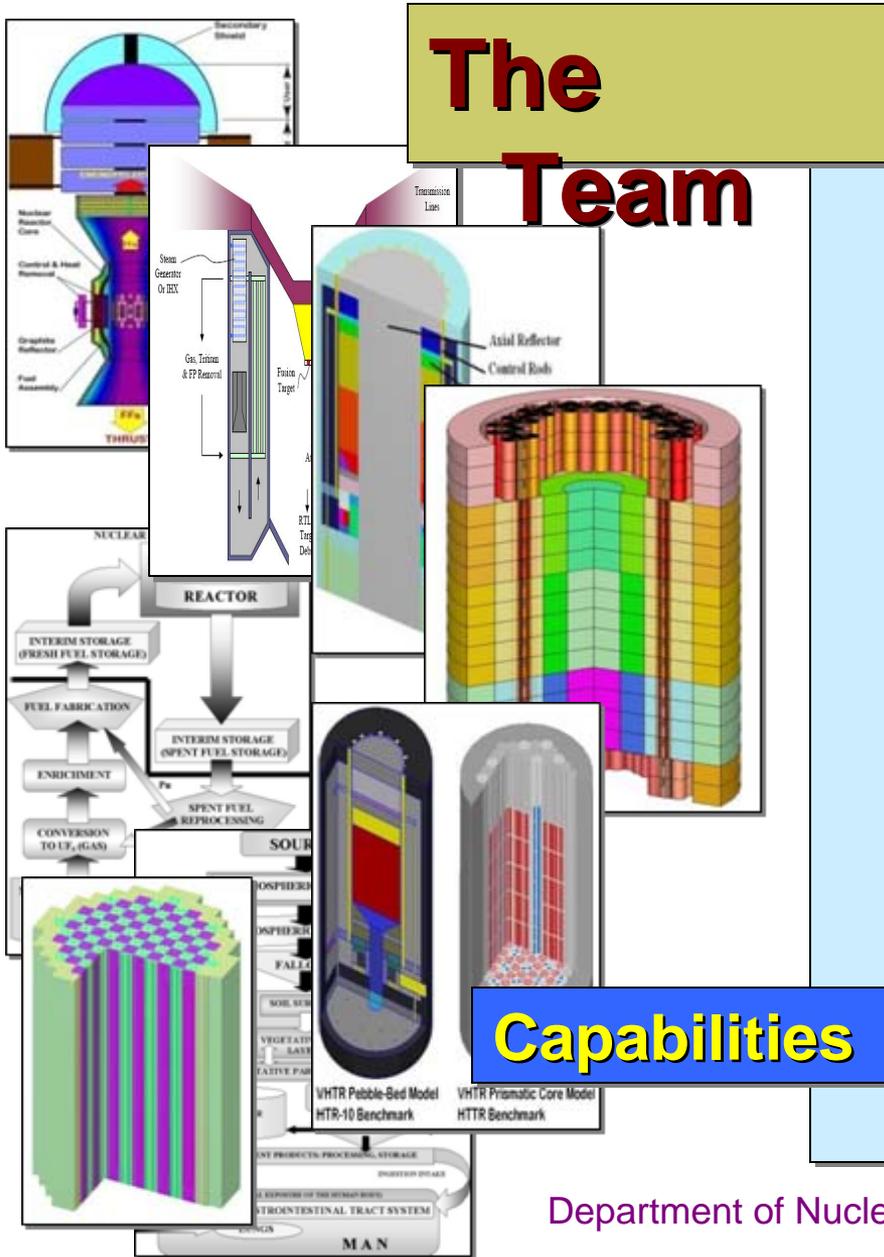
- Self Introduction (Who am I?)
- Interests
- Capabilities
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- Conclusions



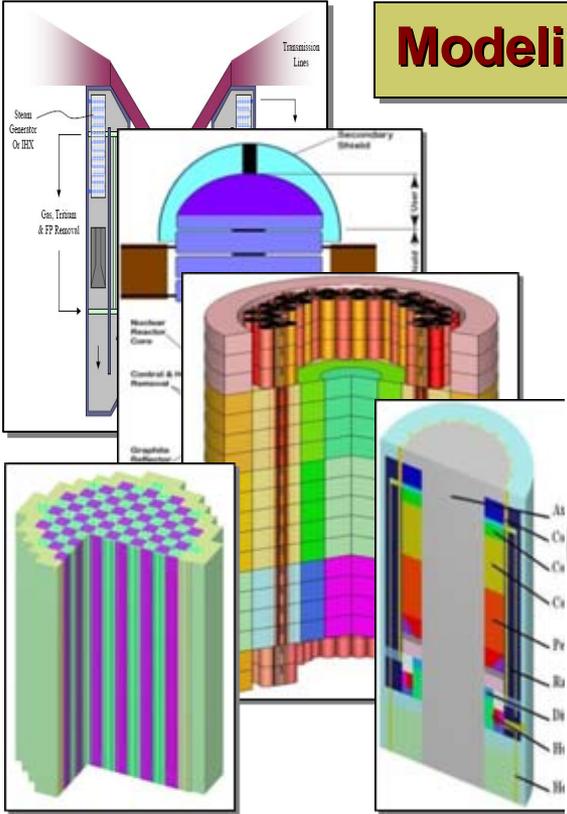
# The Team

1. Celestino Abrego (Ph.D.)
2. Ayodeji Alajo (M.S., Ph.D.)
3. David Ames (M.S., Ph.D.)
4. Avery Guild-Bingham (Ph.D.)
5. Tom Lewis (M.S., Ph.D.)
6. Brian Massingill (undergraduates)
7. Megan Pritchard (M.S., Ph.D.)
8. Tim Rogers (undergraduate)
9. Ni Zhen (undergraduate)
10. Michael Naramore (undergraduate)
11. Chris Van der Hoeven (undergraduate)
12. Tuan Huang (undergraduate)

## Capabilities

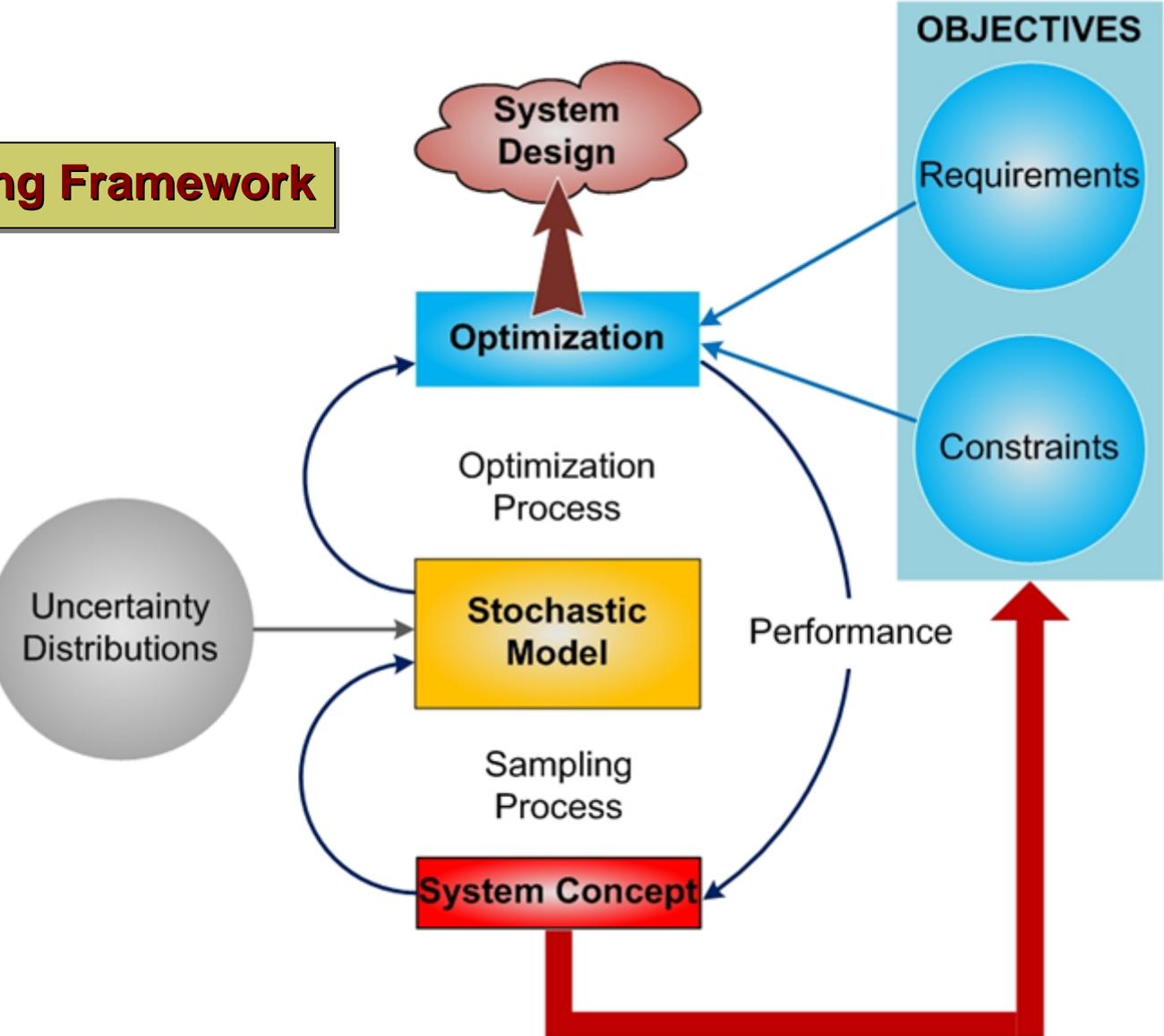


# Capabilities



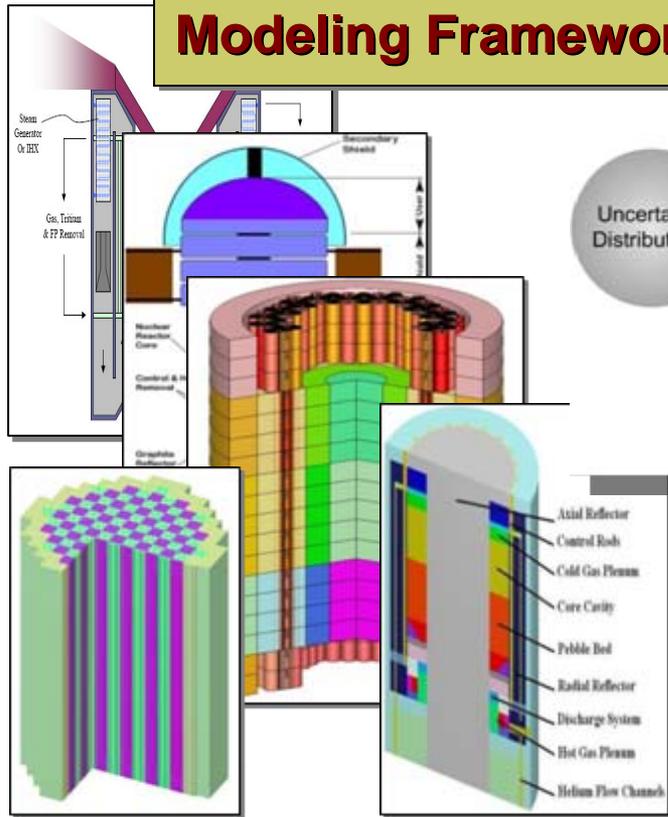
# Modeling Framework

# System Design

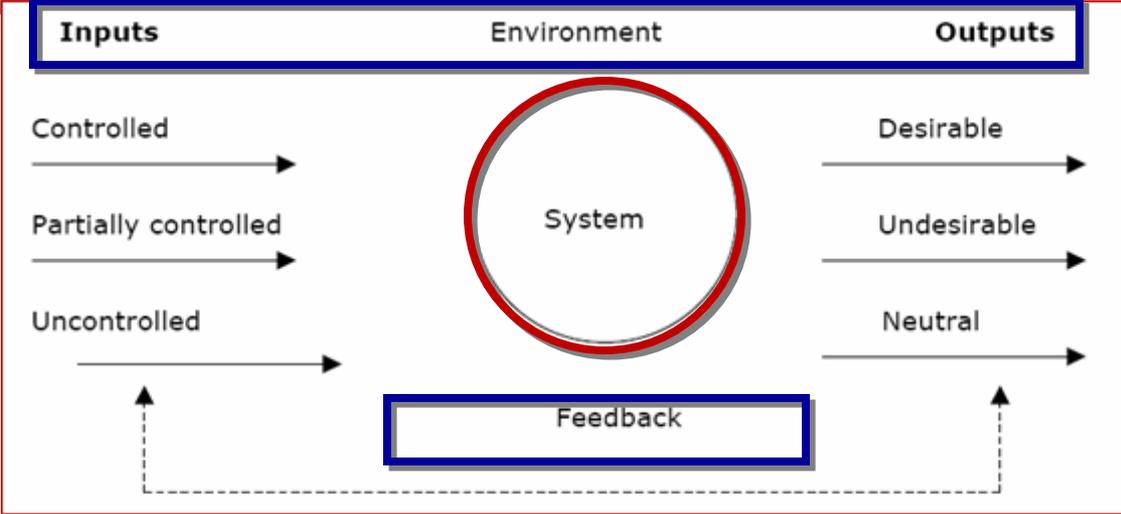
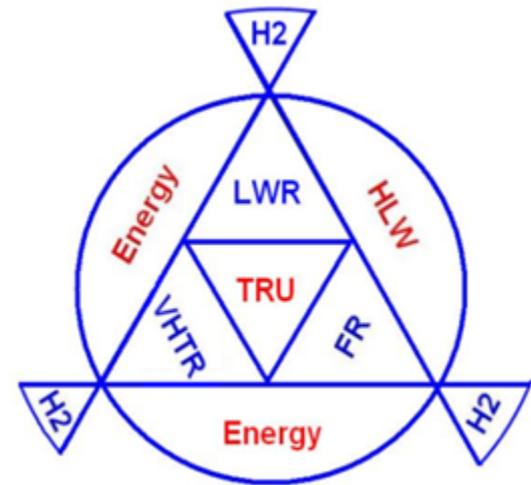
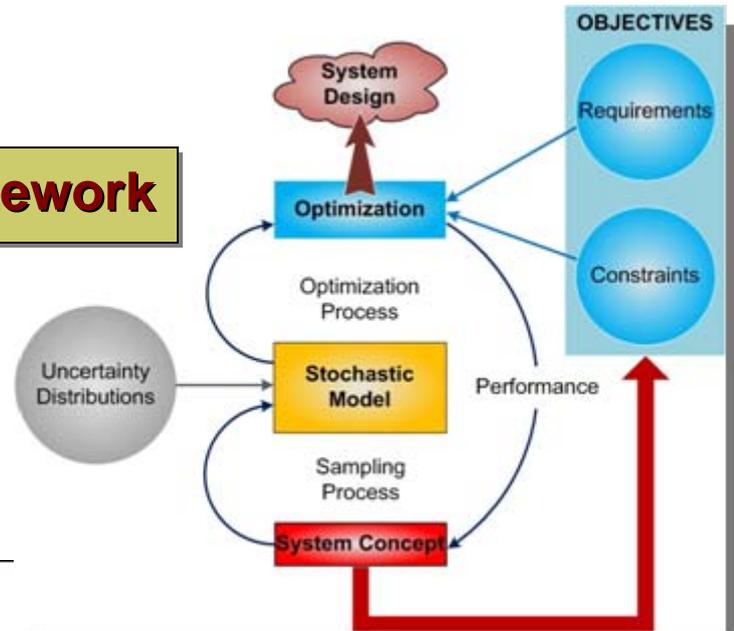


# Capabilities

## Modeling Framework

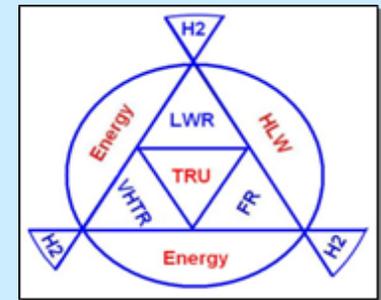
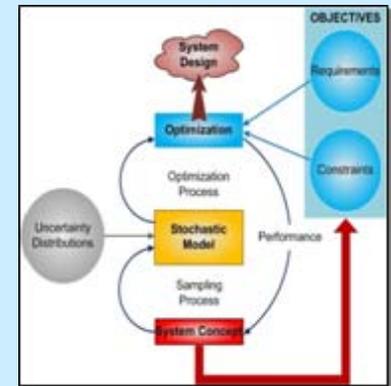
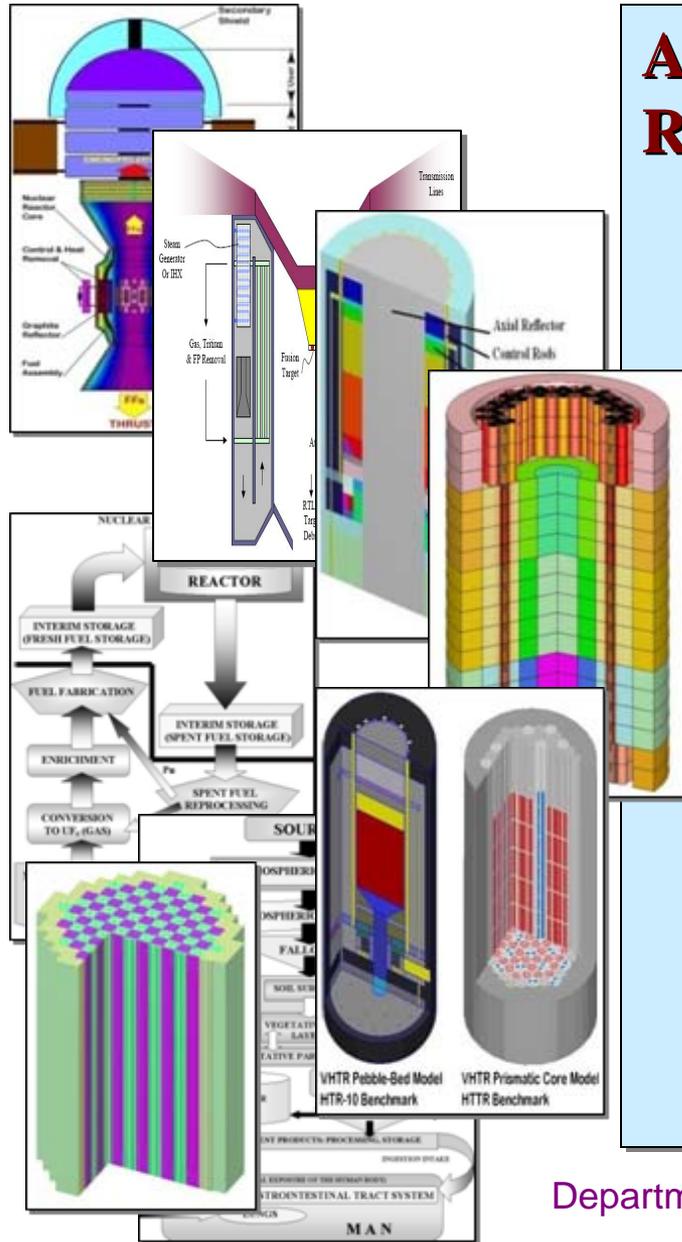


## System Design



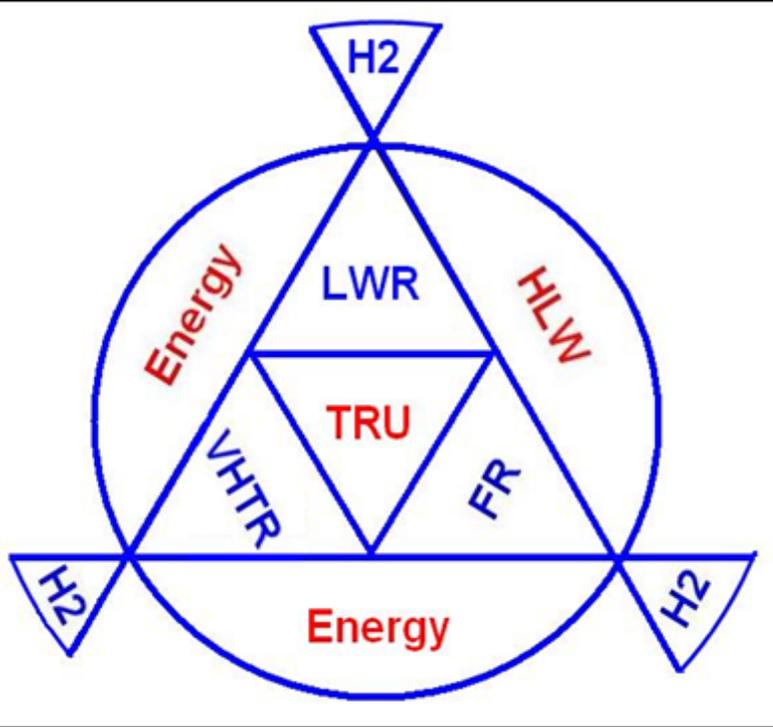
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**Advanced High-Fidelity System Analysis and Methods Development**



**Advanced High-Fidelity System Modeling**

***Basic Data:  
material properties,  
nuclear data,  
uncertainties***

**Nuclear Data for Higher Actinides**

# Basic Nuclear Data

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)

- **Decay Data**
- **Cross Sections**
- **Neutron Yields**
- **Fission Spectra**
- **Delayed Neutron Data**
- **Covariance Matrices**

ENDFB 6.8							
	$\sigma_f$	$\sigma_y$	$\nu$	$\nu_d$	$\eta$	$\alpha$	$\beta$
Np237	✓	✓	✓	✓	✓	✓	✓
U234	✓	✓	✓	✓	✓	✓	✓
U235	✓	✓	✓	✓	✓	✓	✓
U238	✓	✓	✓	✓	✓	✓	✓
Pu238	✓	✓	✓	✓	✓	✓	✓
Pu239	✓	✓	✓	✓	✓	✓	✓
Pu240	✓	✓	✓	✓	✓	✓	✓
Pu241	✓	✓	✓	✓	✓	✓	✓
Pu242	✓	✓	✓	✓	✓	✓	✓
Am241	✓	✓	✓	✓	✓	✓	✓
Am242m	✓	✓	✓	✓	✓	✓	✓
Am243	✓	✓	✓	✓	✓	✓	✓
Cm241	✓	✓	✓	✓	✓	✓	✓
Cm242	✓	✓	✓	✓	✓	✓	✓
Cm243	✓	✓	✓	✓	✓	✓	✓
Cm244	✓	✓	✓	✓	✓	✓	✓
Cm245	✓	✓	✓	✓	✓	✓	✓
Cm246	✓	✓	✓	✓	✓	✓	✓
Cm247	✓	✓	✓	✓	✓	✓	✓
Cm248	✓	✓	✓	✓	✓	✓	✓
Bk249	✓	✓	✓	✓	✓	✓	✓
Cf249	✓	✓	✓	✓	✓	✓	✓
Cf250	✓	✓	✓	✓	✓	✓	✓
Cf251	✓	✓	✓	✓	✓	✓	✓
Cf252	✓	✓	✓	✓	✓	✓	✓
Cf253	✓	✓	✓	✓	✓	✓	✓

- **ENDF/B-6.8**
- **JEF-2.2**
- **JENDL-3.3**

- **Sensitivity/Uncertainty**
- **Modeling Reliability**

Nuclear Data for Higher Actinides

# Observations:

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)

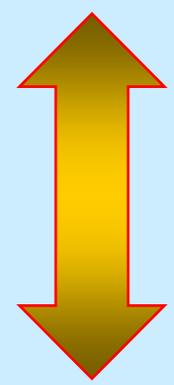


- **Inconsistent data sets**
- **Incomplete information**
- **Limited number of experiments**

**BUT**

- **Sufficient for conceptual studies**

- **ENDF/B-6.8**
- **JEF-2.2**
- **JENDL-3.3**



- **Sensitivity/Uncertainty**
- **Modeling Reliability**

**Advanced High-Fidelity System Analysis and Methods Development**

**NUCLEAR DATA FOR ADVANCED ENERGY SYSTEMS**

- **Decay Data**
- **Cross Sections**
- **Neutron Yields**
- **Fission Spectra**
- **Delayed Neutron Data**
- **Covariance Matrices**
  - **Sensitivity/Uncertainty**
  - **Modeling Reliability**

ENDFB 6.8						
	$\sigma_f$	$\sigma_a$	$\nu$	$\nu_d$	$\eta$	$\beta$
Np237	✓	✓	✓	✓	✓	✓
U234	✓	✓	✓	✓	✓	✓
U235	✓	✓	✓	✓	✓	✓
U238	✓	✓	✓	✓	✓	✓
Pu238	✓	✓	✓	✓	✓	✓
Pu239	✓	✓	✓	✓	✓	✓
Pu240	✓	✓	✓	✓	✓	✓
Pu241	✓	✓	✓	✓	✓	✓
Pu242	✓	✓	✓	✓	✓	✓
Am241						
Am242m						
Am243						
Cm241						
Cm242						
Cm243						
Cm244						
Cm245						
Cm246						
Cm247						
Cm248						
Bk249						
Cf249						
Cf250						
Cf251						
Cf252						
Cf253						

90	91	92	94	95	96	97	98	99	100	101	102	103	
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)

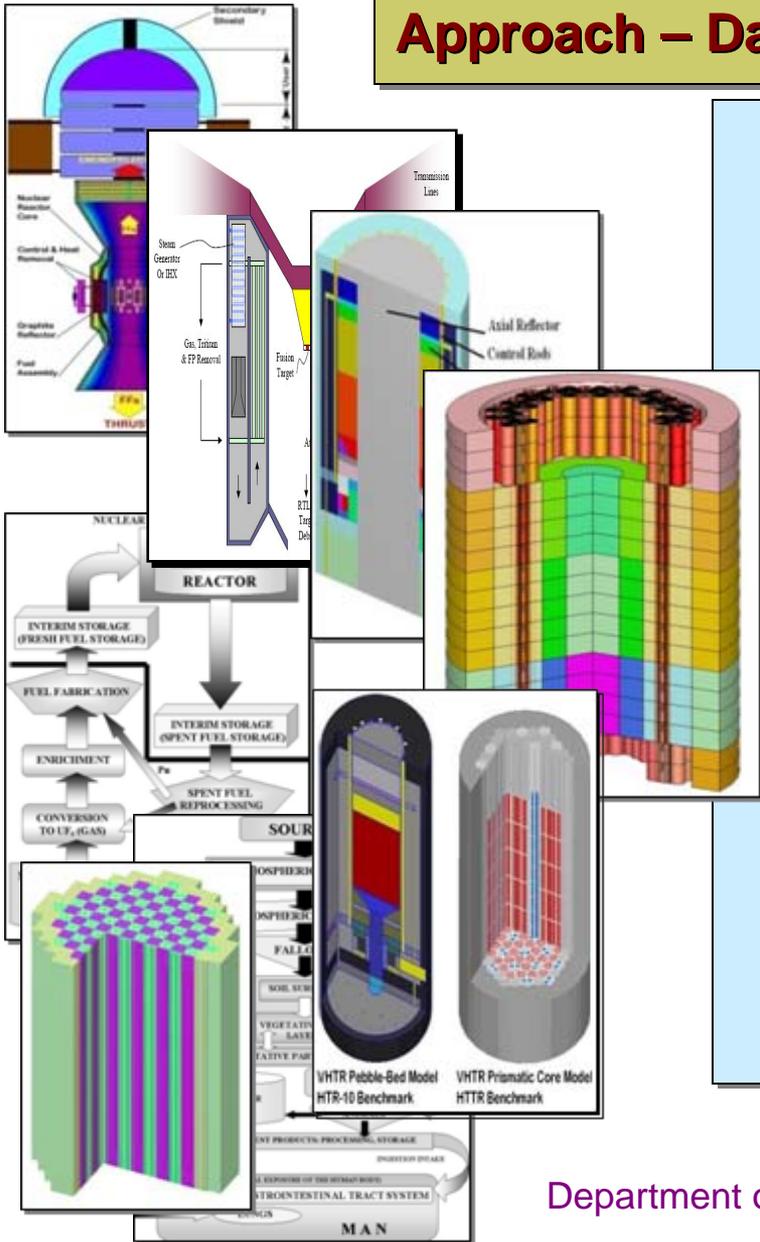
**Challenges:**

- **New Evaluations for MAs**
- **New Experimental Benchmark Problems (Criticality, Burnup)**

**Method/Code/Model V&V**

- **Experiment-to-Code**
- **Code-to-Code**

**Approach – Data S/U**



- **MatWeb (42,000 existing materials)**
- **NIST (Ceramic Materials)**
- **Ceramic Industry Database**
- **AMPTIAC (Advanced Materials Data)**
- **MATPRO Library**
- **INSC Database**
- **Transmutation Fuels Data (IAEA, ...)**
- **Benchmark Problem Specifications**

- **Sensitivity/Uncertainty**
- **Modeling Reliability**

## Capturing System Details

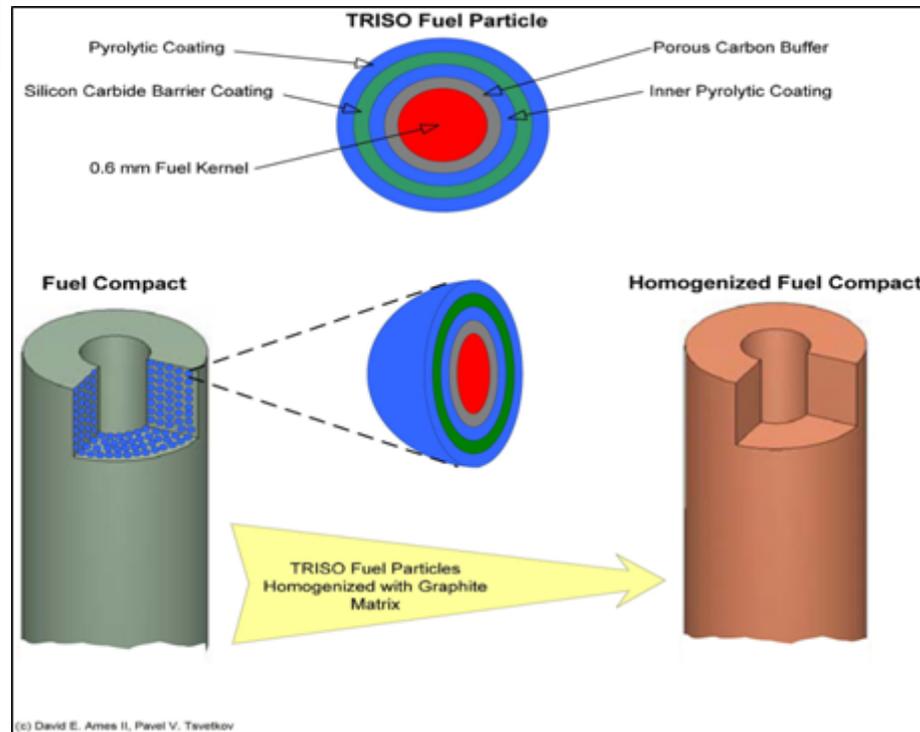
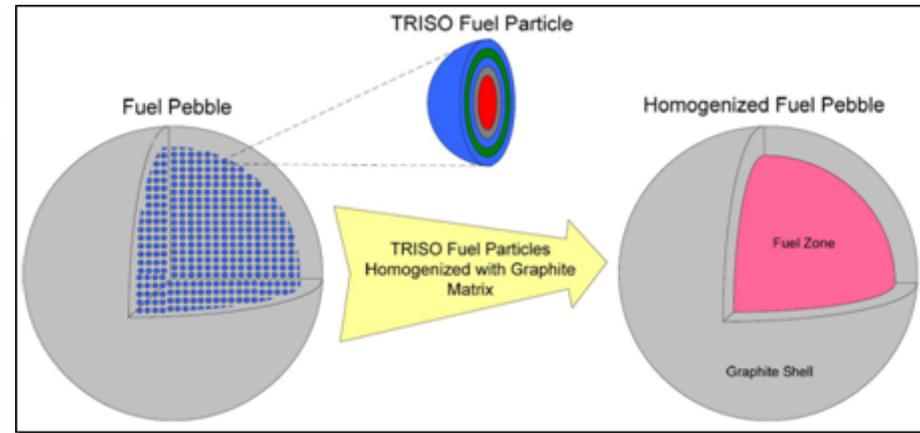
- **Micro-particle fuel**
- **Pebble/Compact**
- **Pebble Bed/Block Stack**
- **Core+Channels+Reflectors**

### Accounting for Double-Heterogeneity

(LEU-HTR PROTEUS Cores 1 - 6, Cumulative Analysis)

Reaction Rate Ratio	Relative Effect (%)*
Epithermal-to-Thermal $^{238}\text{U}$ Capture	-(30-50)
Epithermal-to-Thermal $^{235}\text{U}$ Fission	-(9-11)
$^{238}\text{U}$ Capture-to- $^{235}\text{U}$ Fission	-(30-42)

\*Effects of the exact modeling are computed relative to the simplified single-level macro-heterogeneity modeling.



(c) David E. Ames II, Pavel V. Tsvetkov

## Capturing System Details

- **Micro-particle fuel**
- **Pebble/Compact**
- **Pebble Bed/Block Stack**
- **Core+Channels+Reflectors**

Accounting for Double-Heterogeneity

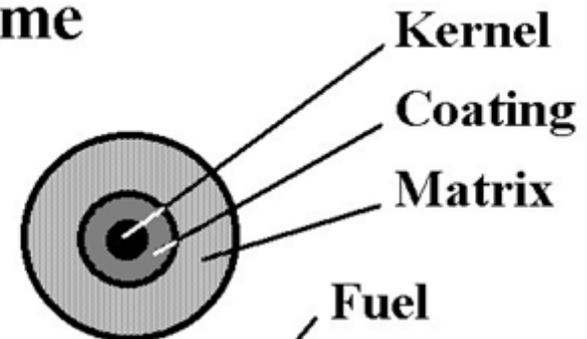
(LEU-HTR PROTEUS Cores 1 - 6, Cumulative Analysis)

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Epithermal-to-Thermal $^{238}\text{U}$ Capture	-(30-50)
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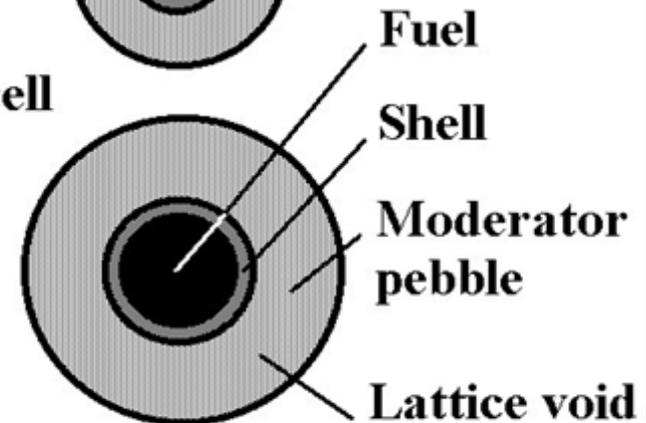
\*Effects of the exact modeling are computed relative to the simplified single-level macro-heterogeneity modeling.

### ABC-scheme

MICRO-cell

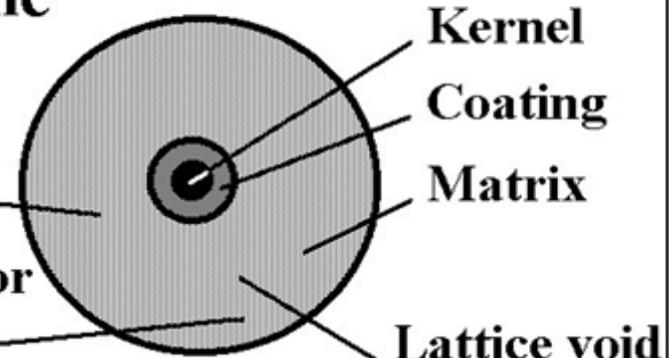


MACRO-cell



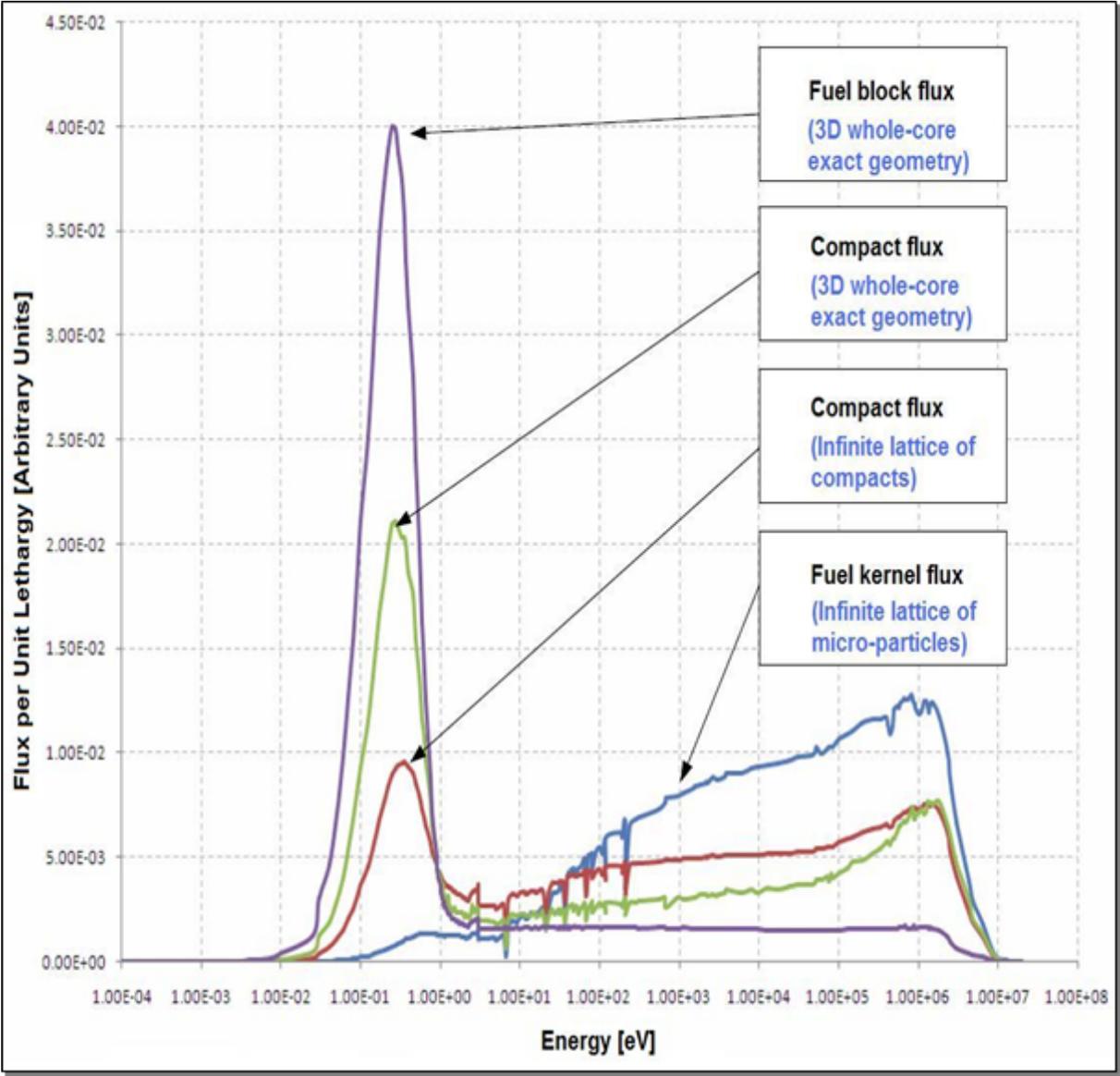
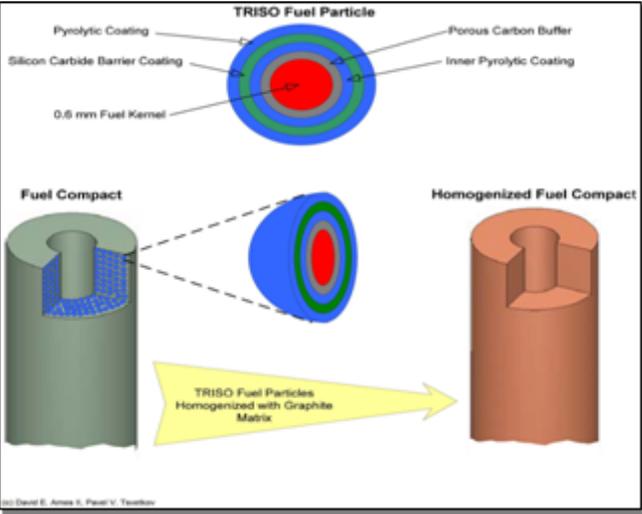
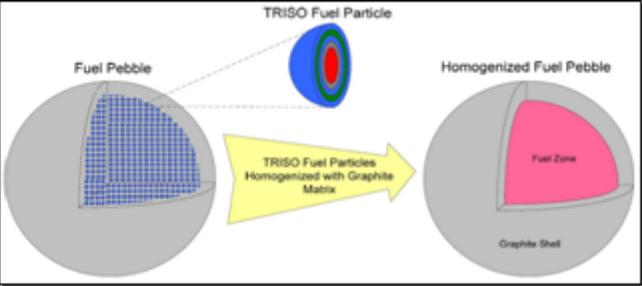
### C-scheme

Shell  
Moderator pebble



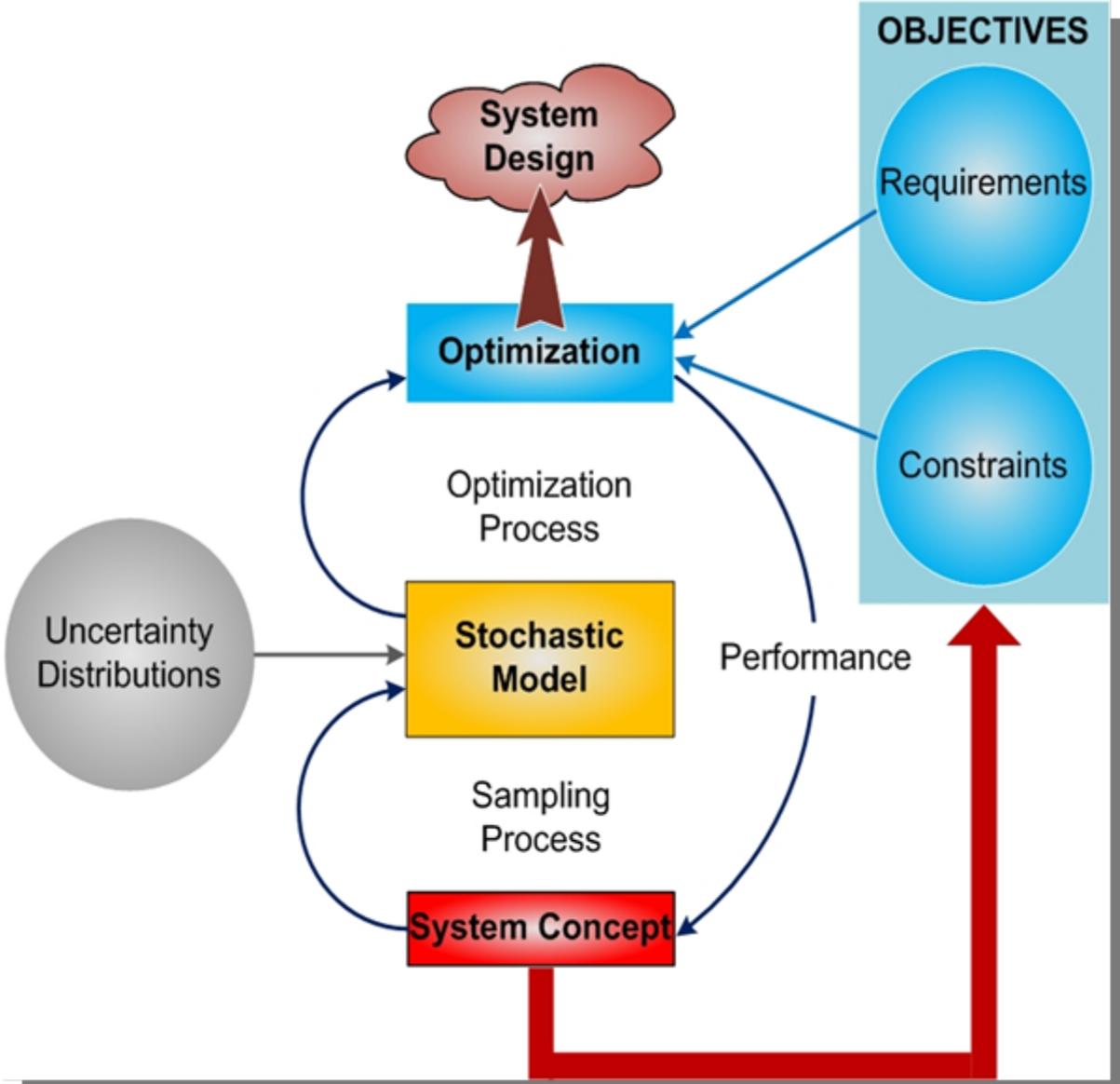
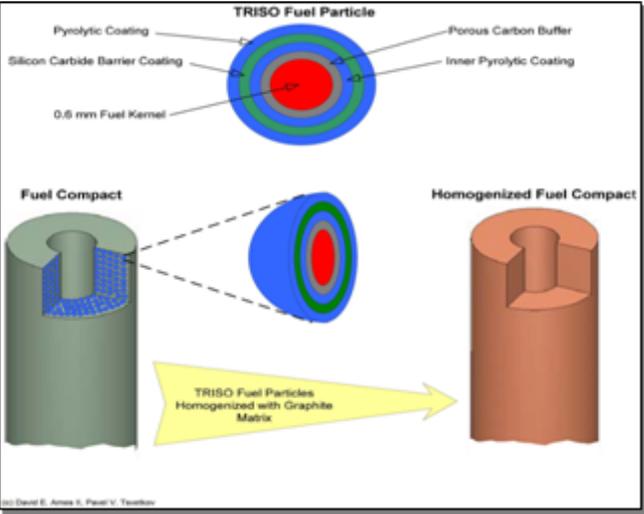
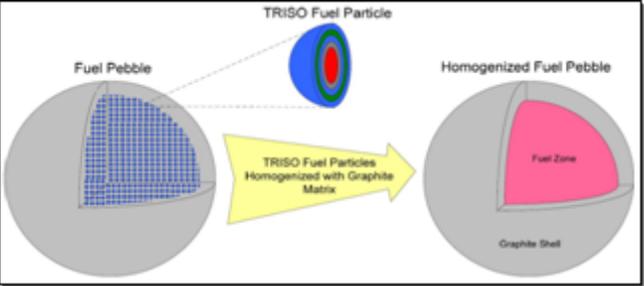
**Approach – Modeling Details**

- **Micro-particle fuel**
- **Pebble/Compact**
- **Pebble Bed/Block Stack**
- **Core+Channels+Reflectors**



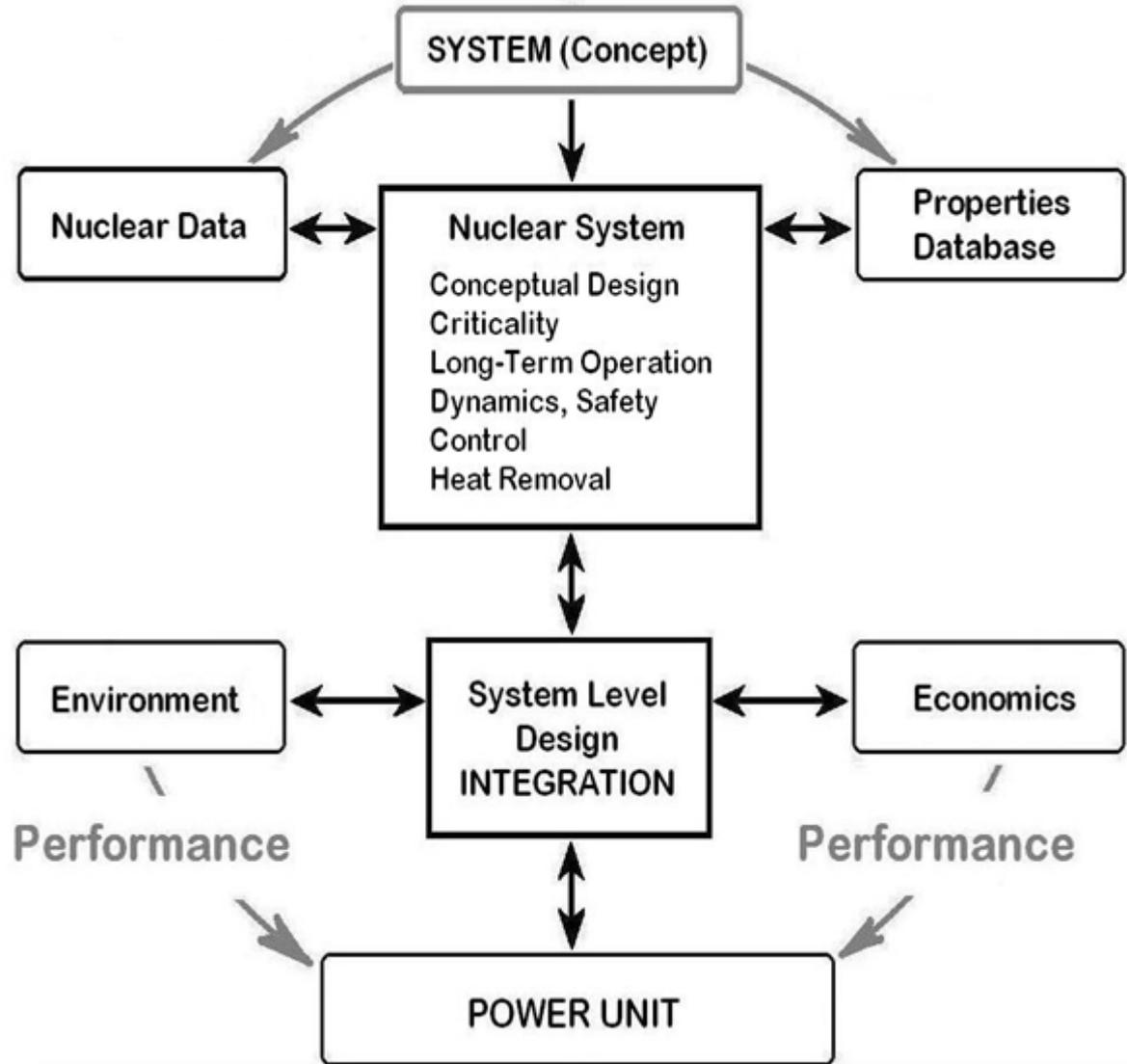
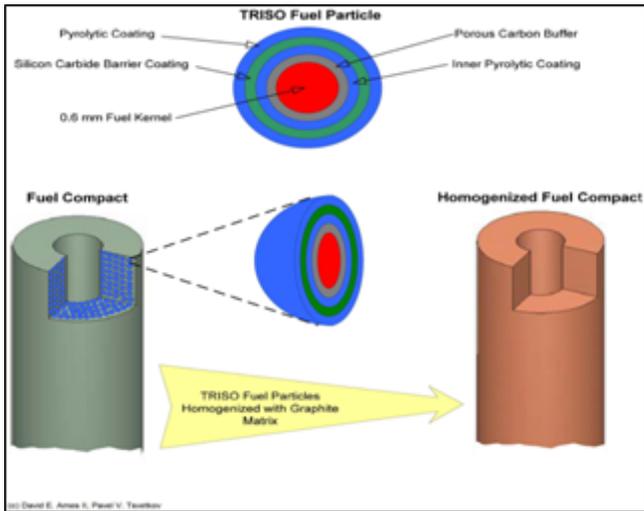
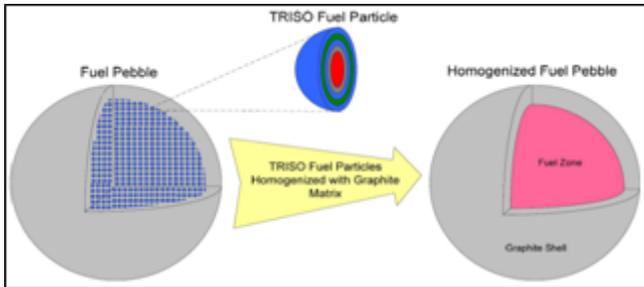
**Approach – Modeling Details**

- **Micro-particle fuel**
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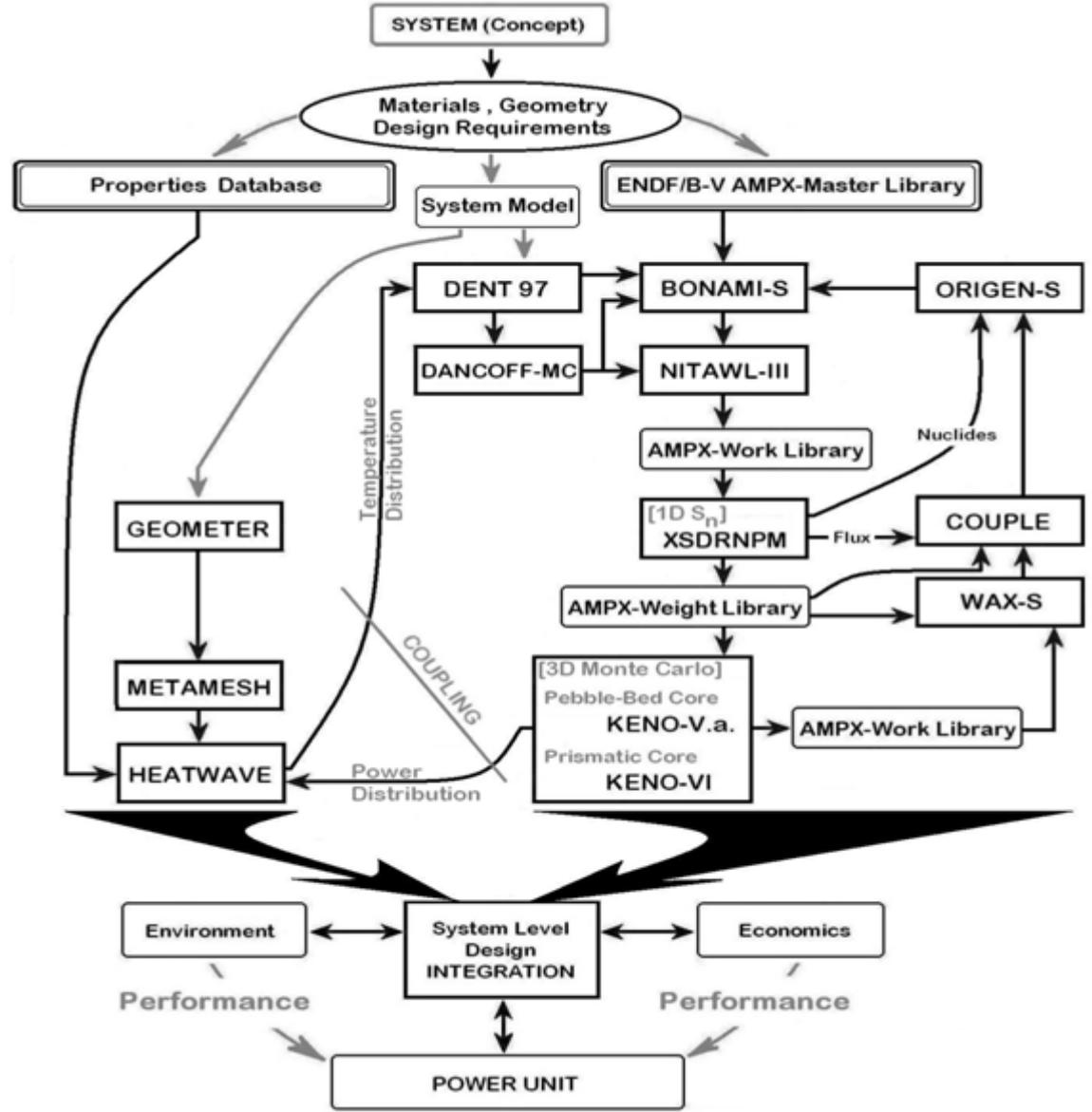
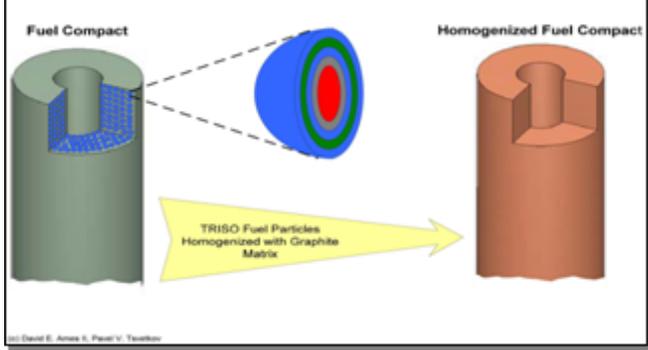
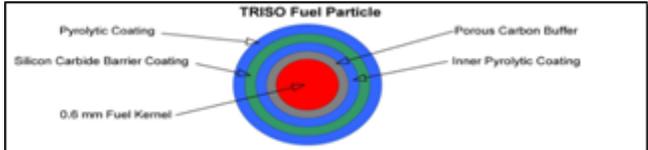
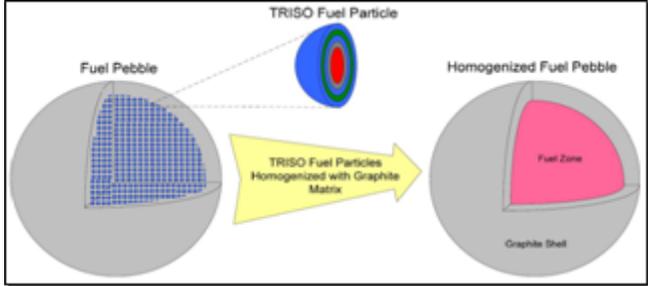
**Approach – Modeling Details**

- **Micro-particle fuel**
- **Pebble/Compact**
- **Pebble Bed/Block Stack**
- **Core+Channels+Reflectors**



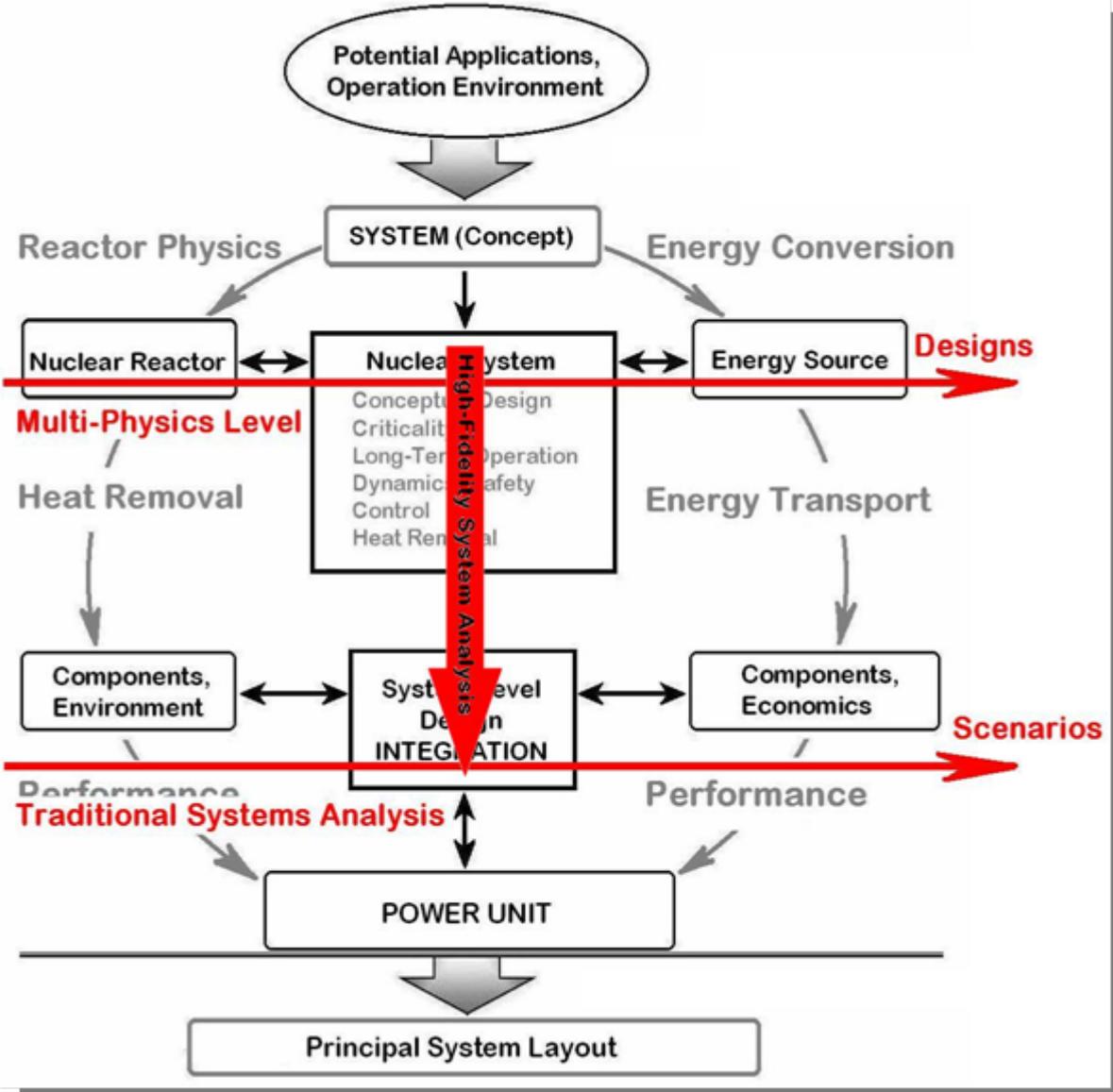
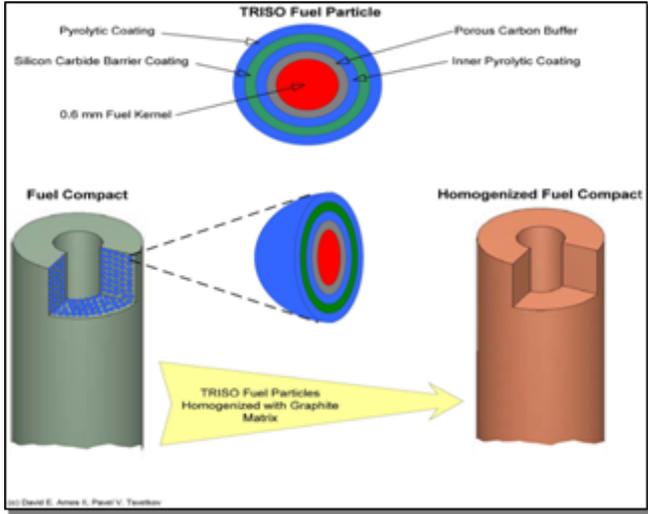
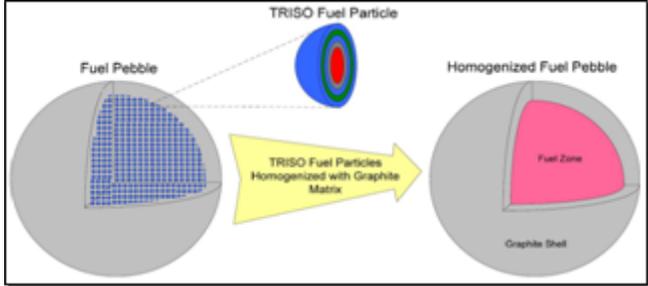
**Approach – Modeling Details**

- Micro-particle fuel
- Pebble/Compact
- Pebble Bed/Block Stack
- Core+Channels+Reflectors



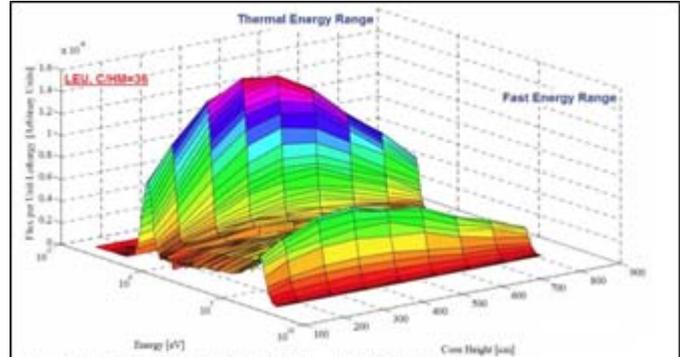
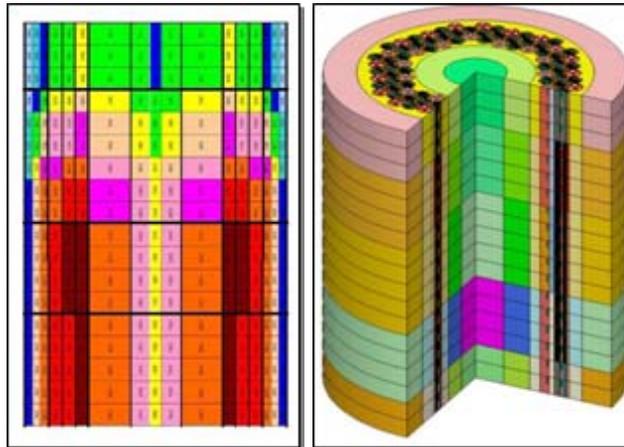
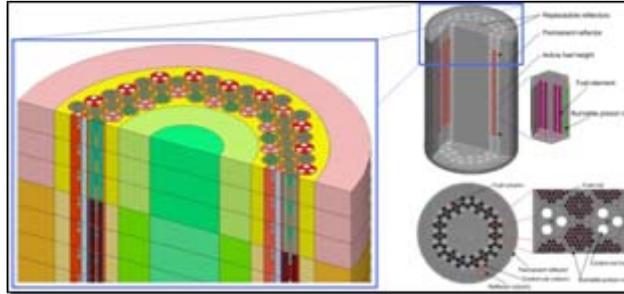
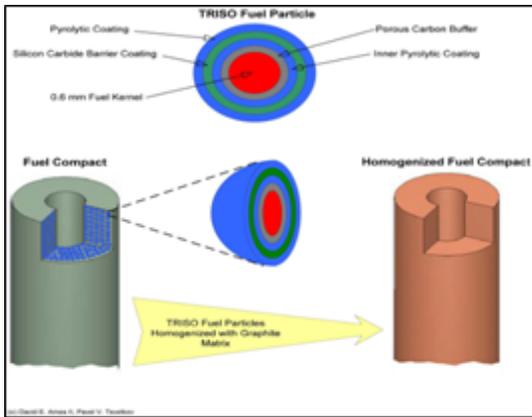
**Approach – Modeling Details**

- **Micro-particle fuel**
- **Pebble/Compact**
- **Pebble Bed/Block Stack**
- **Core+Channels+Reflectors**

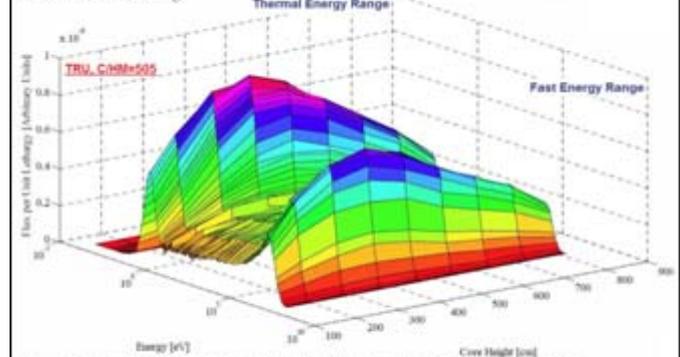


## Modeling Details

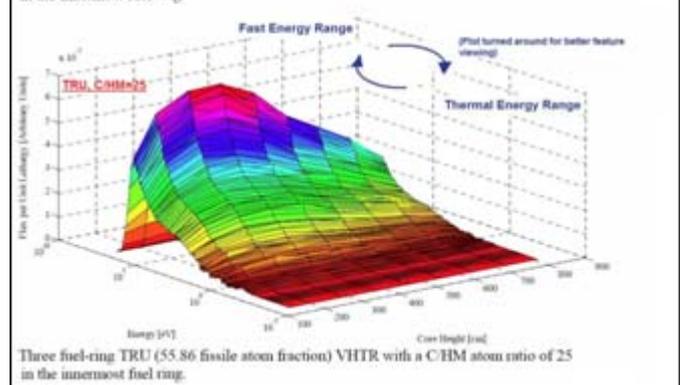
- Micro-particle fuel
- Compact
- Block Stack
- Core Internals



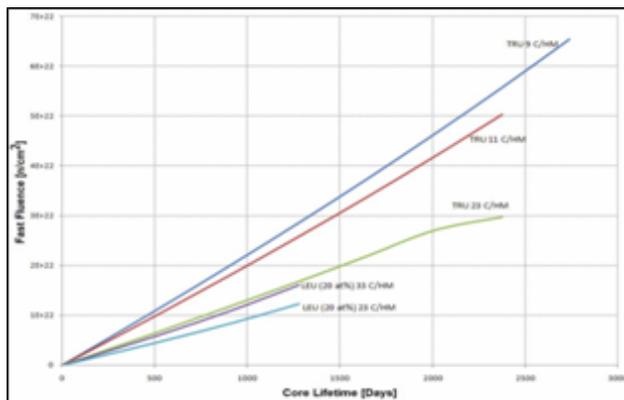
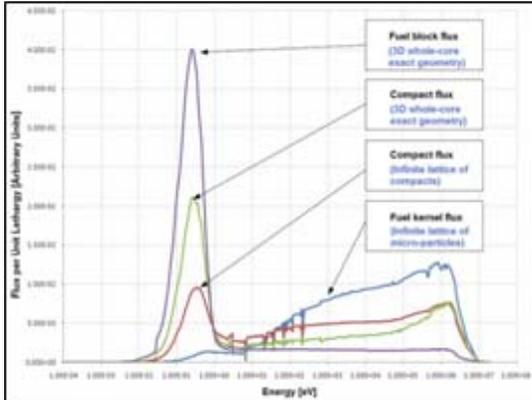
Three fuel-ring LEU (7.92 at %) fueled VHTR with a C/HM atom ratio of 36 in the innermost fuel ring.



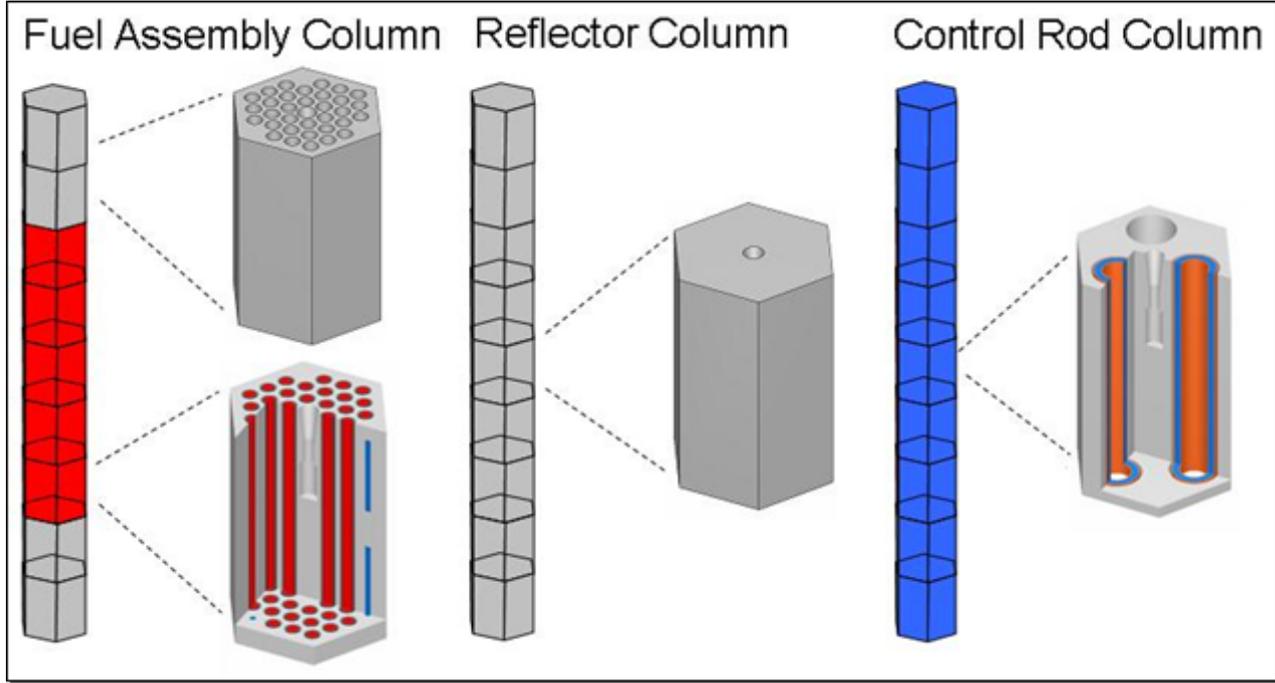
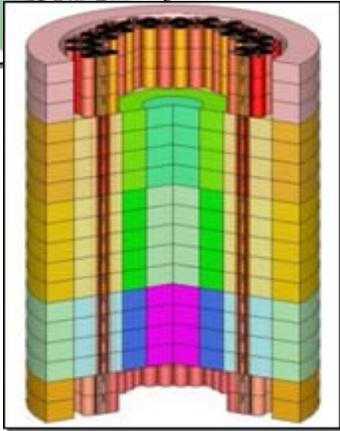
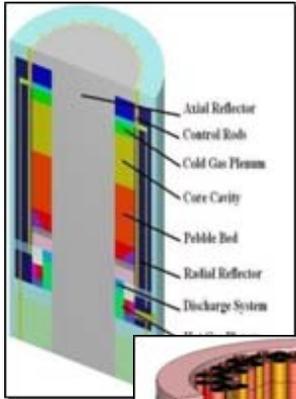
Three fuel-ring TRU (55.86 fissile atom fraction) VHTR with a C/HM atom ratio of 505 in the innermost fuel ring.



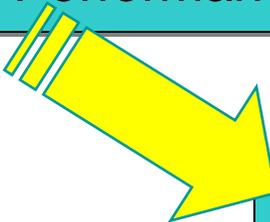
Three fuel-ring TRU (55.86 fissile atom fraction) VHTR with a C/HM atom ratio of 25 in the innermost fuel ring.



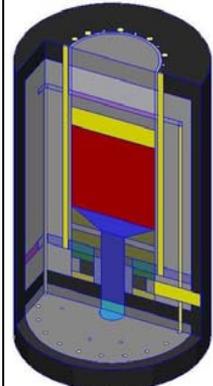
# Benchmarks, Modeling Details



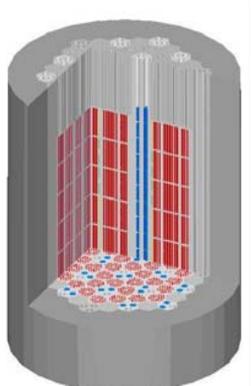
Preliminary Performance Analysis



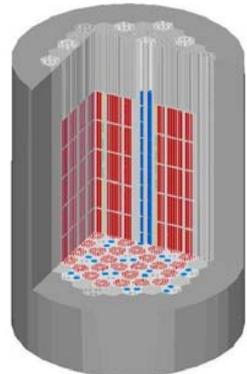
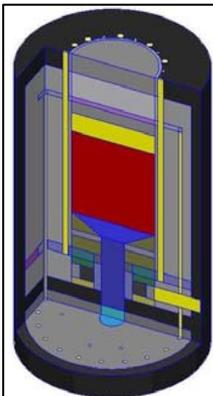
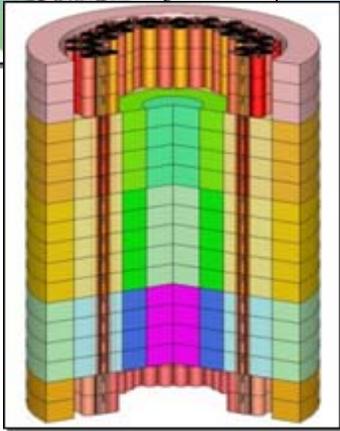
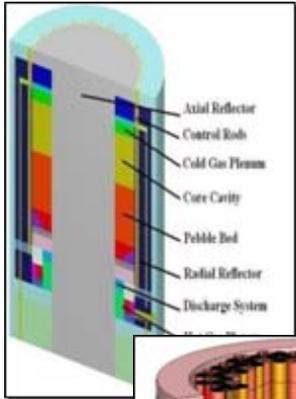
Performance Analysis



VHTR Pebble-Bed Model  
HTR-10 Benchmark



VHTR Prismatic Core Model  
HTR Benchmark



VHTR Pebble-Bed Model  
HTR-10 Benchmark

VHTR Prismatic Core Model  
HTRR Benchmark

## Benchmarks

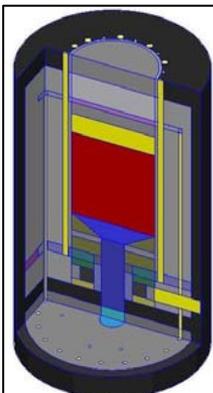
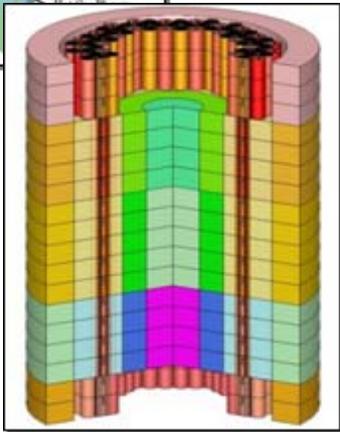
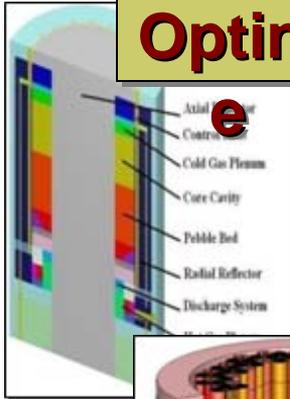
- **LEU-HTR PROTEUS**
- **HTRR Program**
- **HTR-10 Program**
- **FSV Data**
- **Other (History Data)**

## Validation and Verification

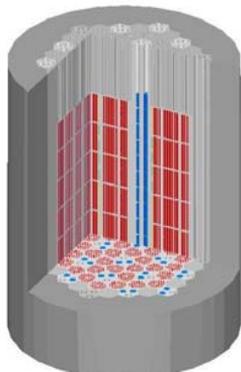
- **Experiment-to-Code**
- **Code-to-Code**

- **Sensitivity/Uncertainty**
- **Modeling Reliability**

# Optimization/S/U/Performanc

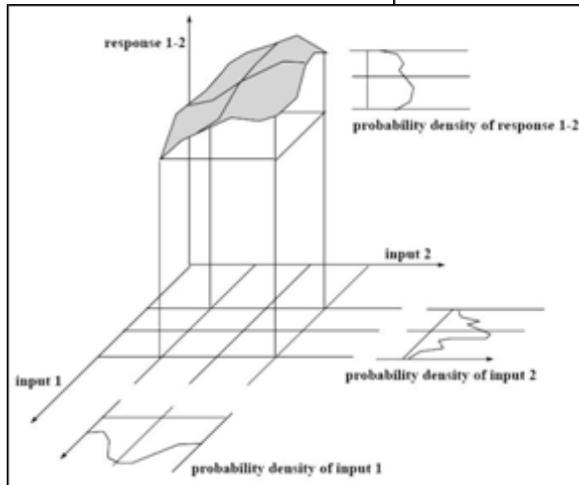
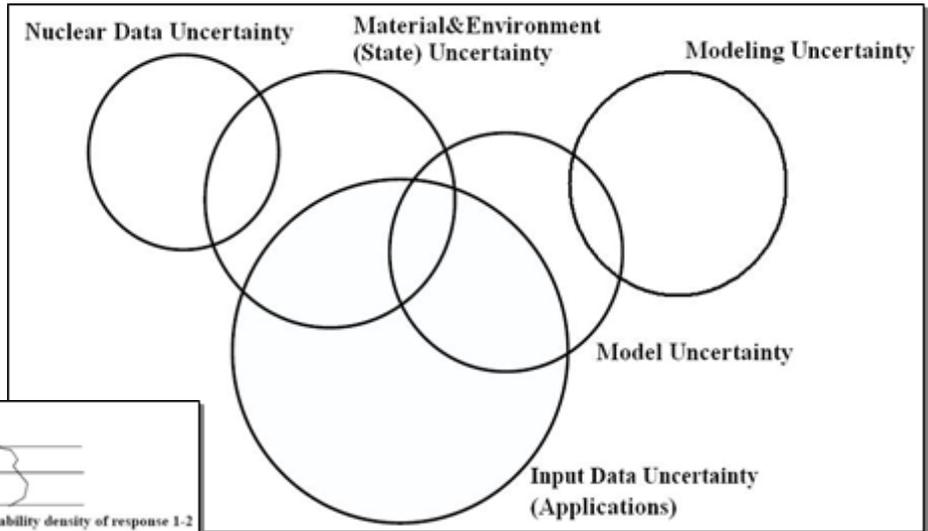


VHTR Pebble-Bed Model  
HTR-10 Benchmark

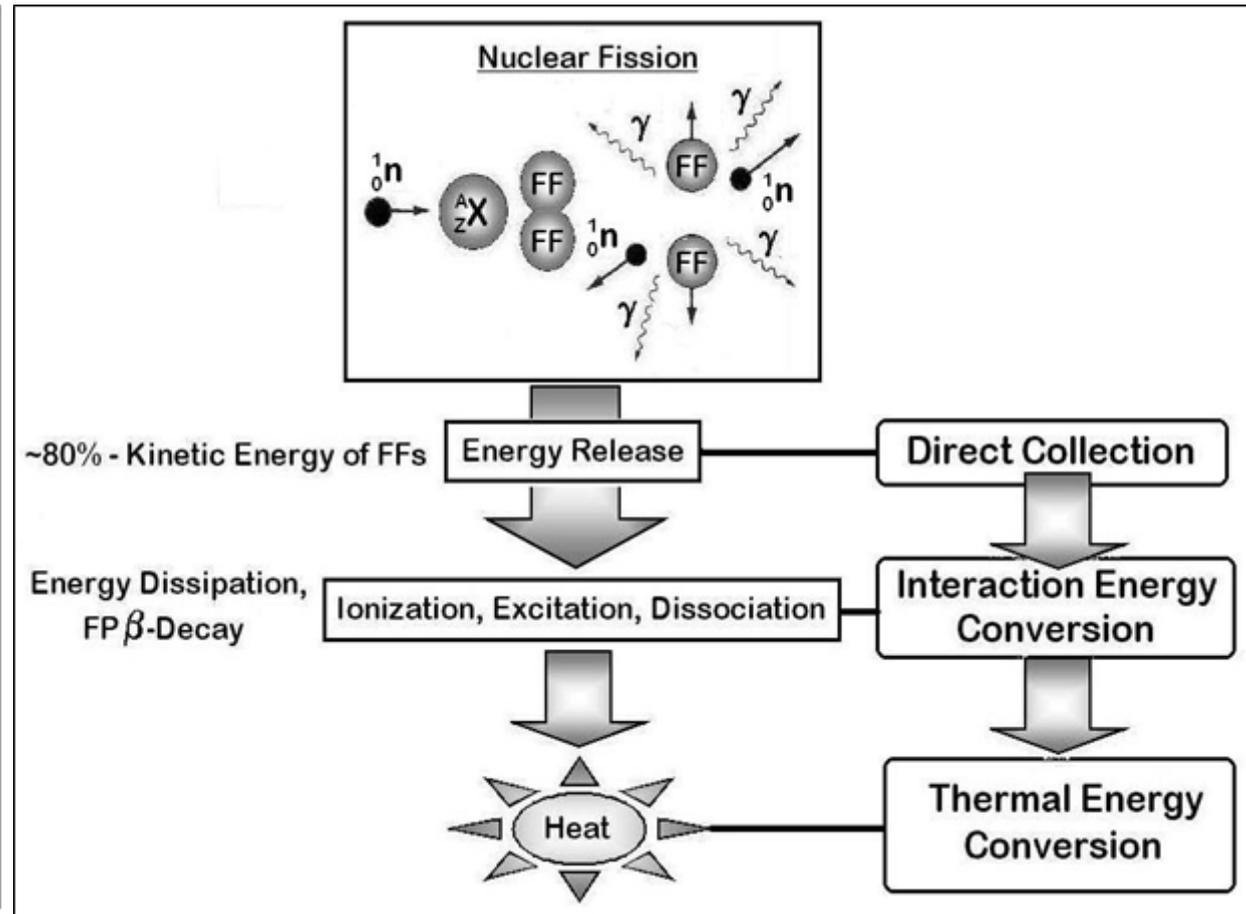
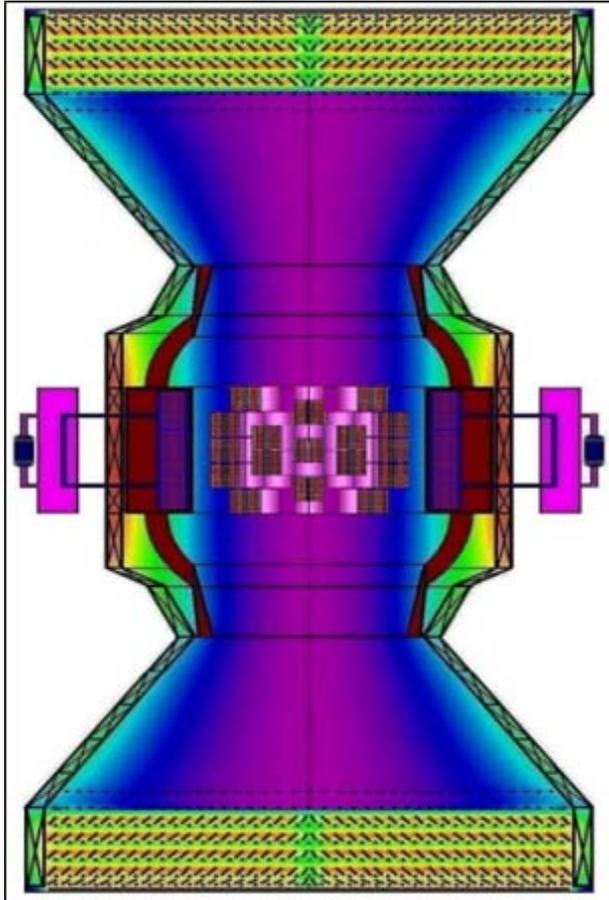


VHTR Prismatic Core Model  
HTR Benchmark

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)

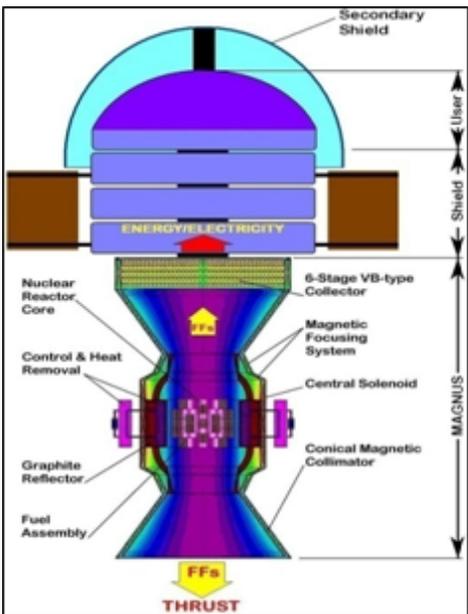
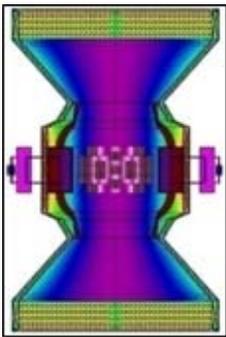


# Ultra Advanced Systems - Conceptual Studies



# Capturing System Concept – Direct Energy Conversion

# Capturing System Concept

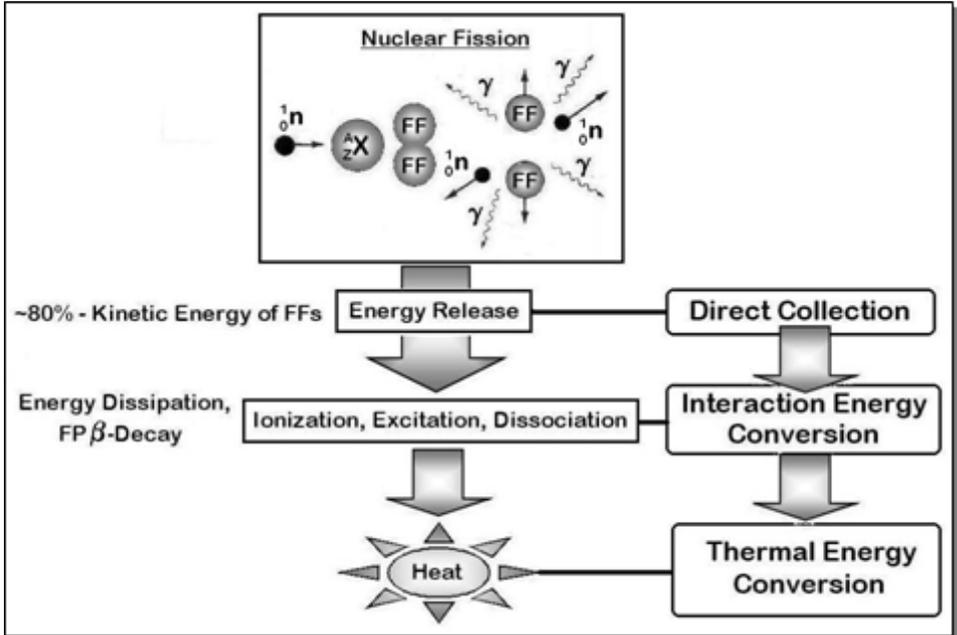
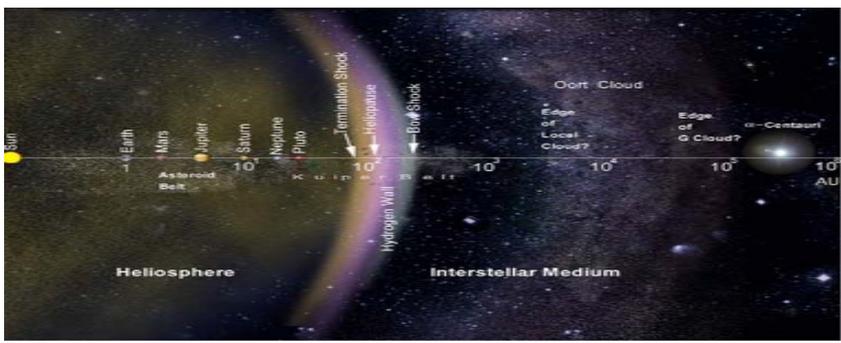
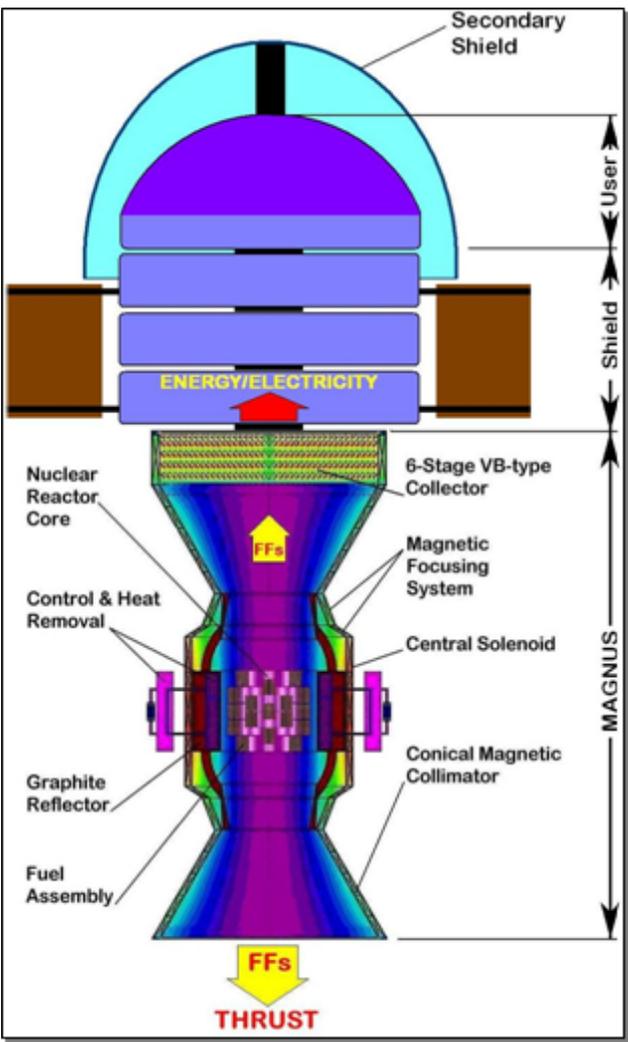
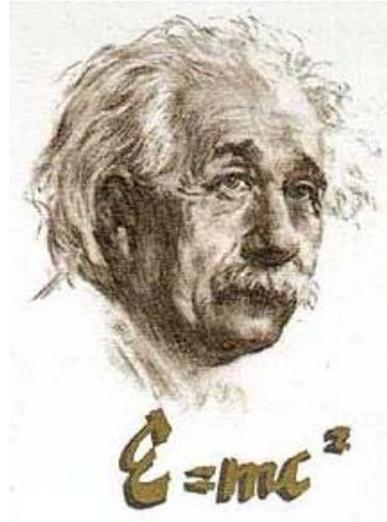


- 2005** - **MAG**netic **NU**clear **S**ystem (FFMC, FEC)
- 2002** - U.S. DOE NERI DEC Proof-of-Principle Project
- 1999** - U.S. DOE NERI DEC Power Production Program  
**Fission Fragment Magnetic Collimator (TAMU)**  
**Spherical Fission Electric Cell (SNL)**

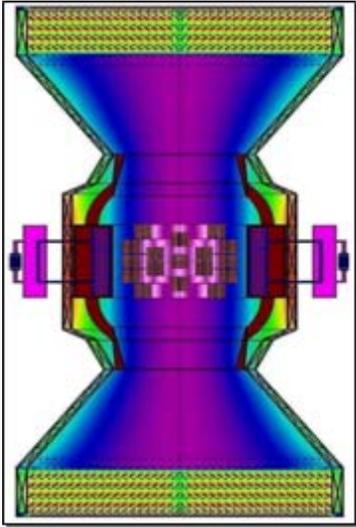
- 1988** - Fission Fragment Rocket
- 1967** - Large Gas-cooled Reactor for Space
- 1965** - JPL Experiments for Fission Cells
- 1963** - Converter for Space
- 1957** - First Detailed Theoretical Study
- 1944** - Electricity from Kinetic Energy of Fission Fragments
- 1913** - Electricity from Kinetic Energy of Charged Particles

**Direct Energy Conversion – 92 years**

# Direct Energy Conversion Systems



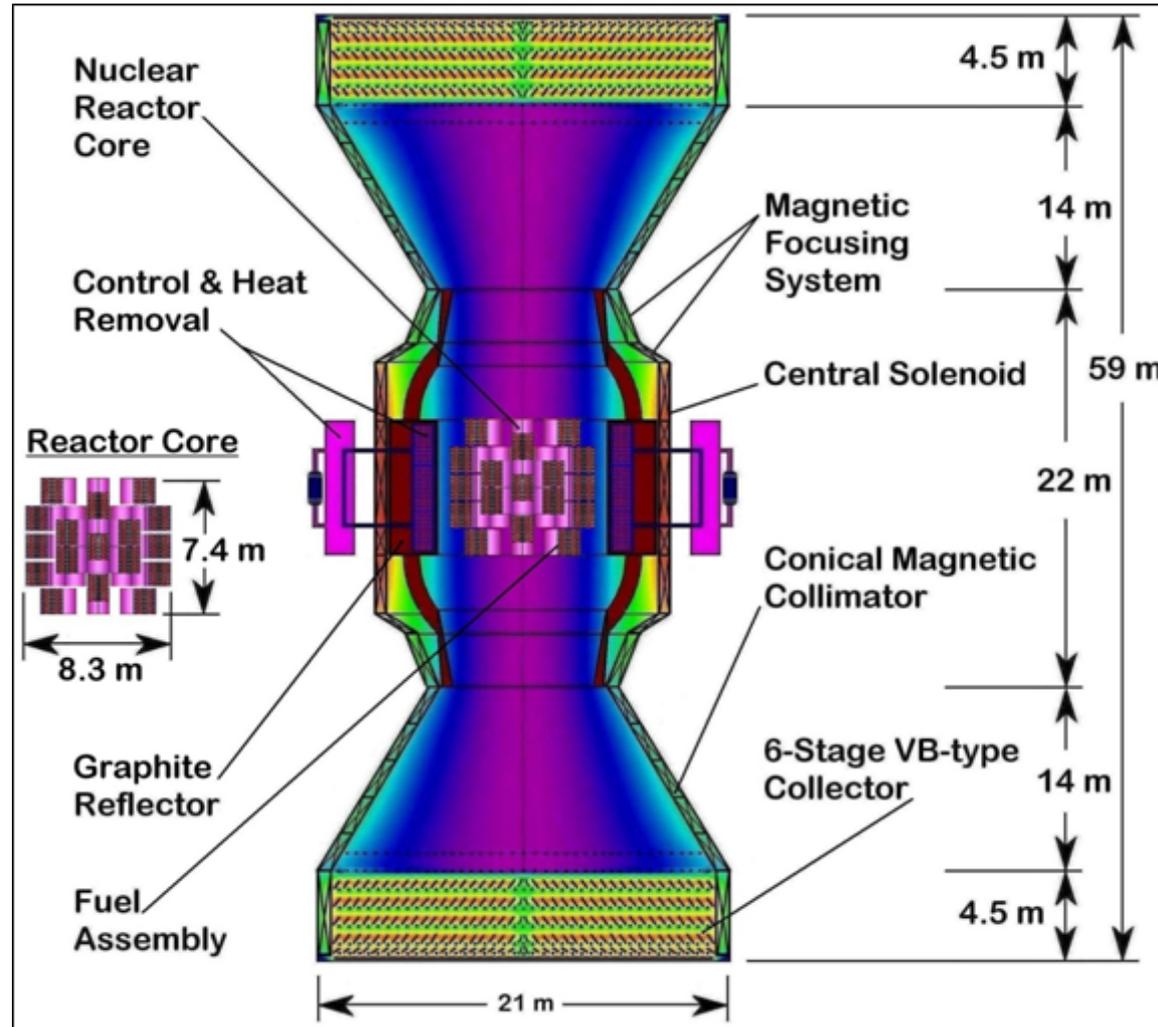
## Direct Energy Conversion Systems



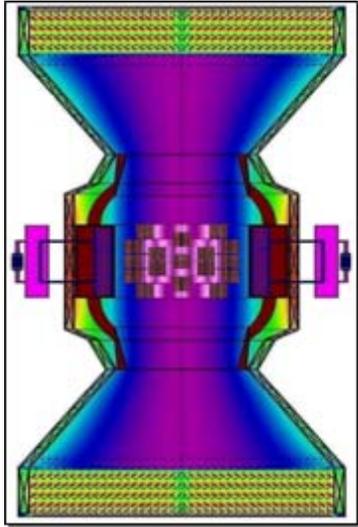
### Technical Challenges

- **Elements with Ultra-Thin Fuel Layers**
- **Secondary Electron Suppression**
- **Criticality and Long-Term Operation**
- **Stability of High-Voltage Differentials in Radiation Environment**
- **Insulators for Radiation Environment**

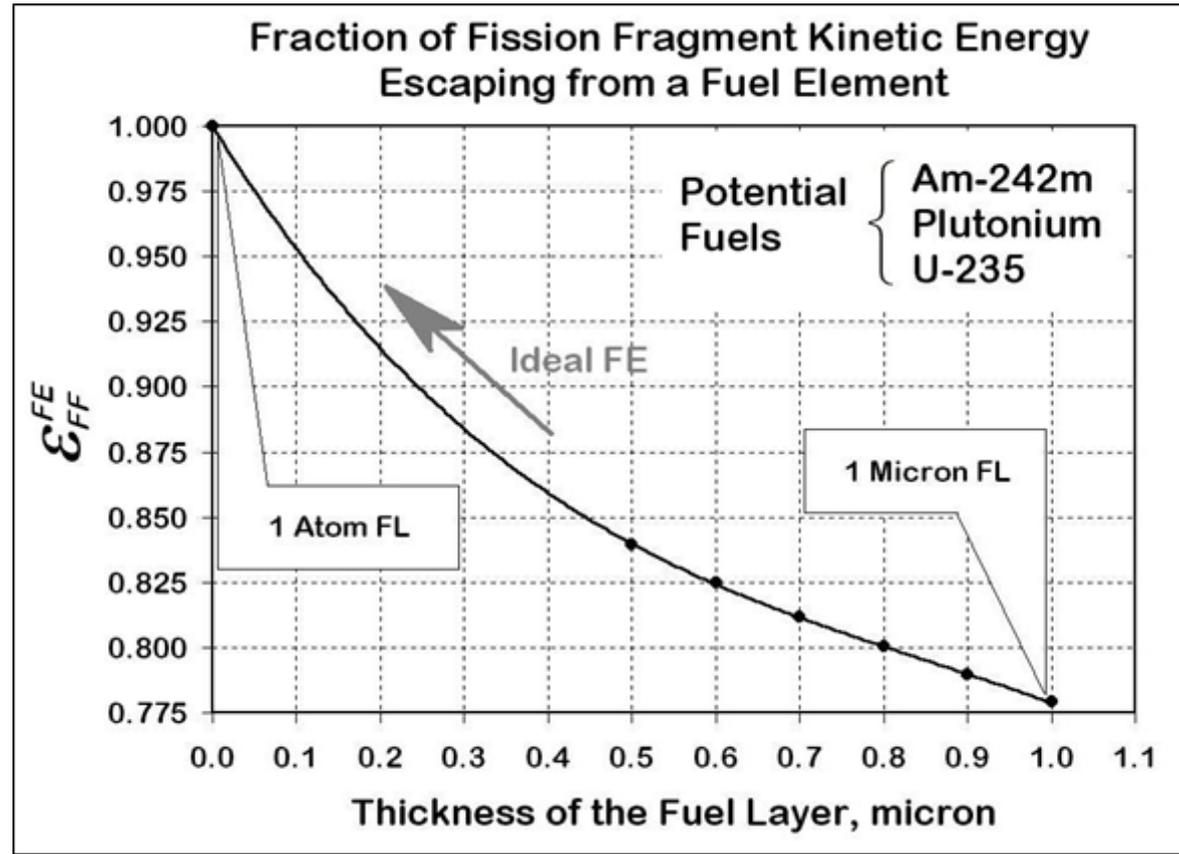
# Direct Energy Conversion Systems



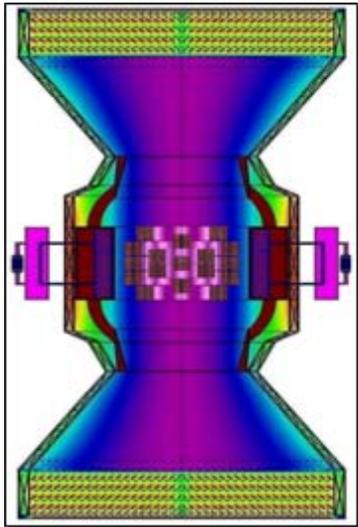
# Direct Energy Conversion Systems



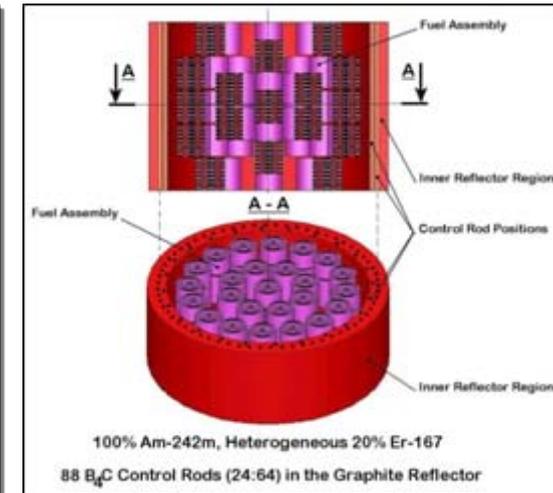
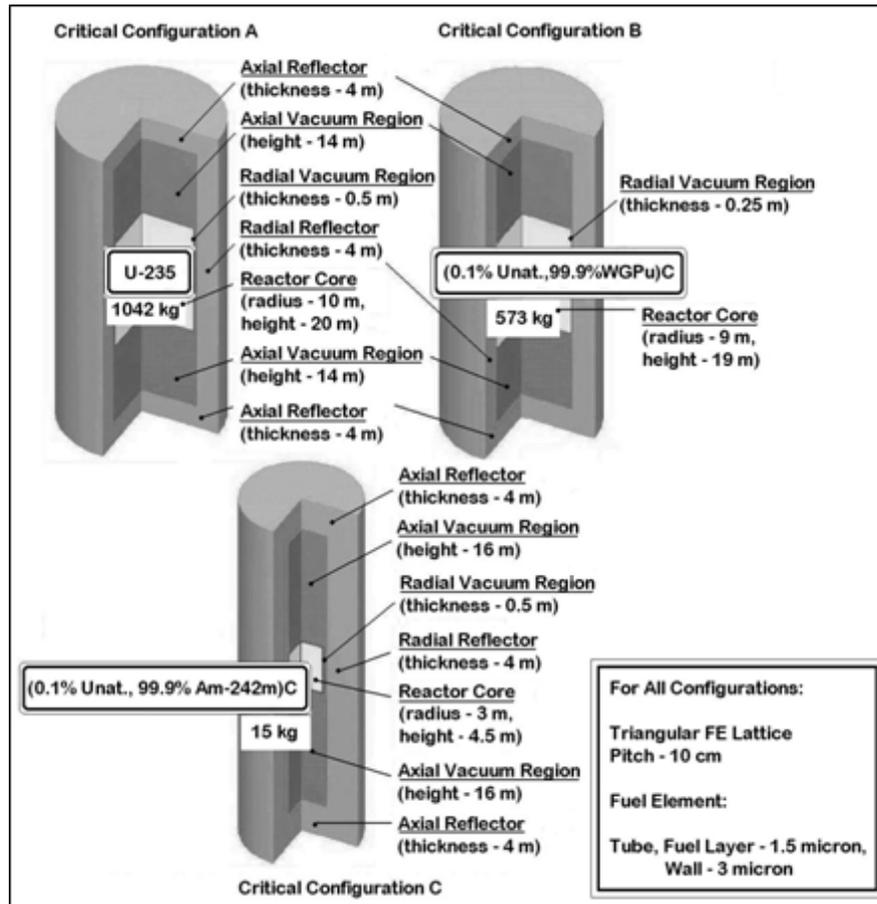
## Fuel Element - Graphite Fiber with Ultra-Thin Fuel Layer



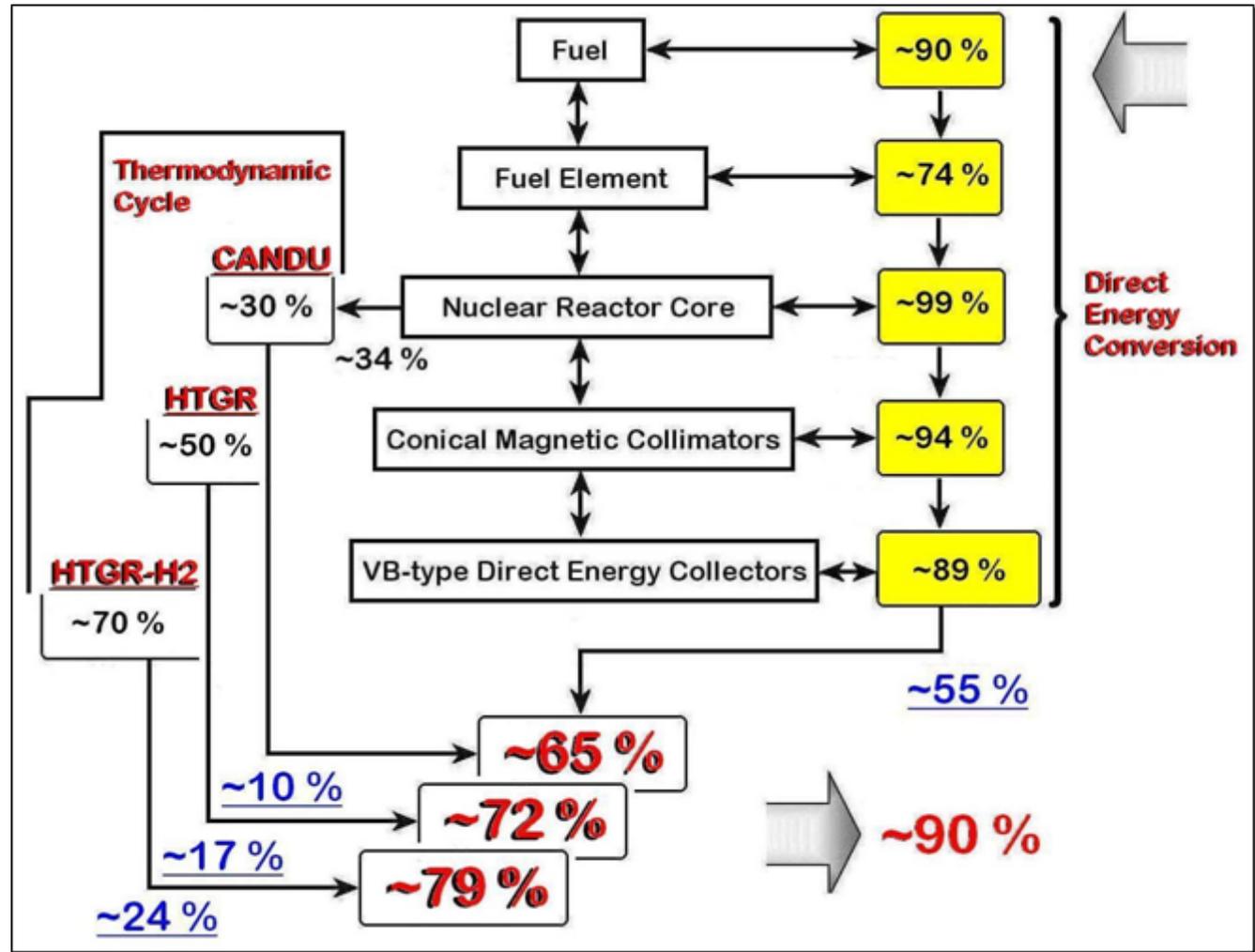
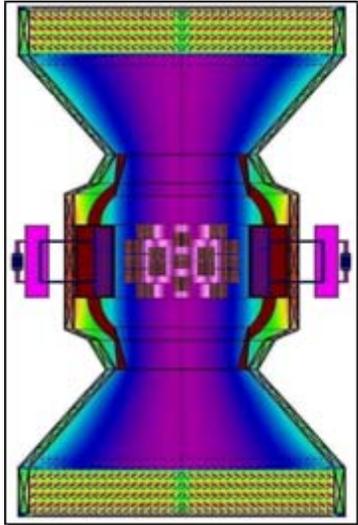
# Direct Energy Conversion Systems

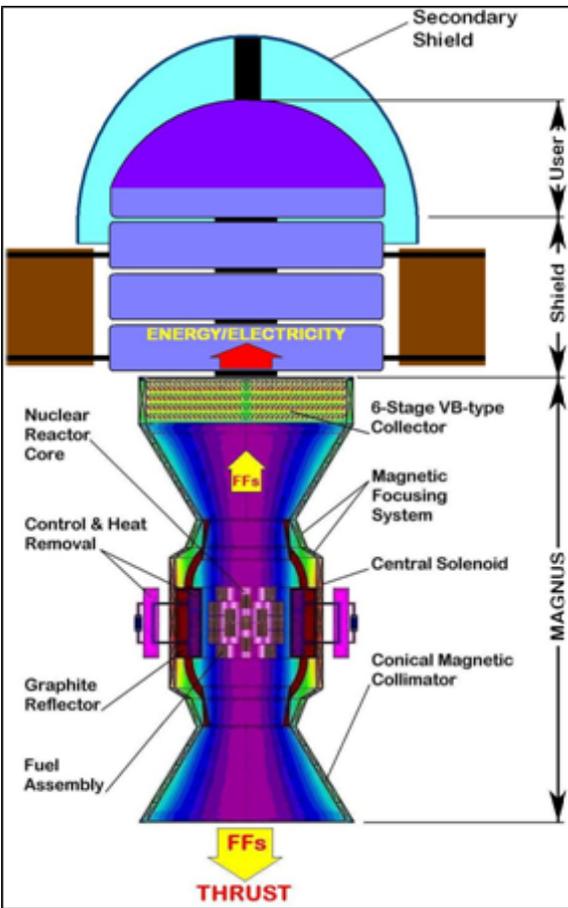


## Fuel Element - Graphite Fiber with Ultra-Thin Fuel Layer



# Direct Energy Conversion Systems

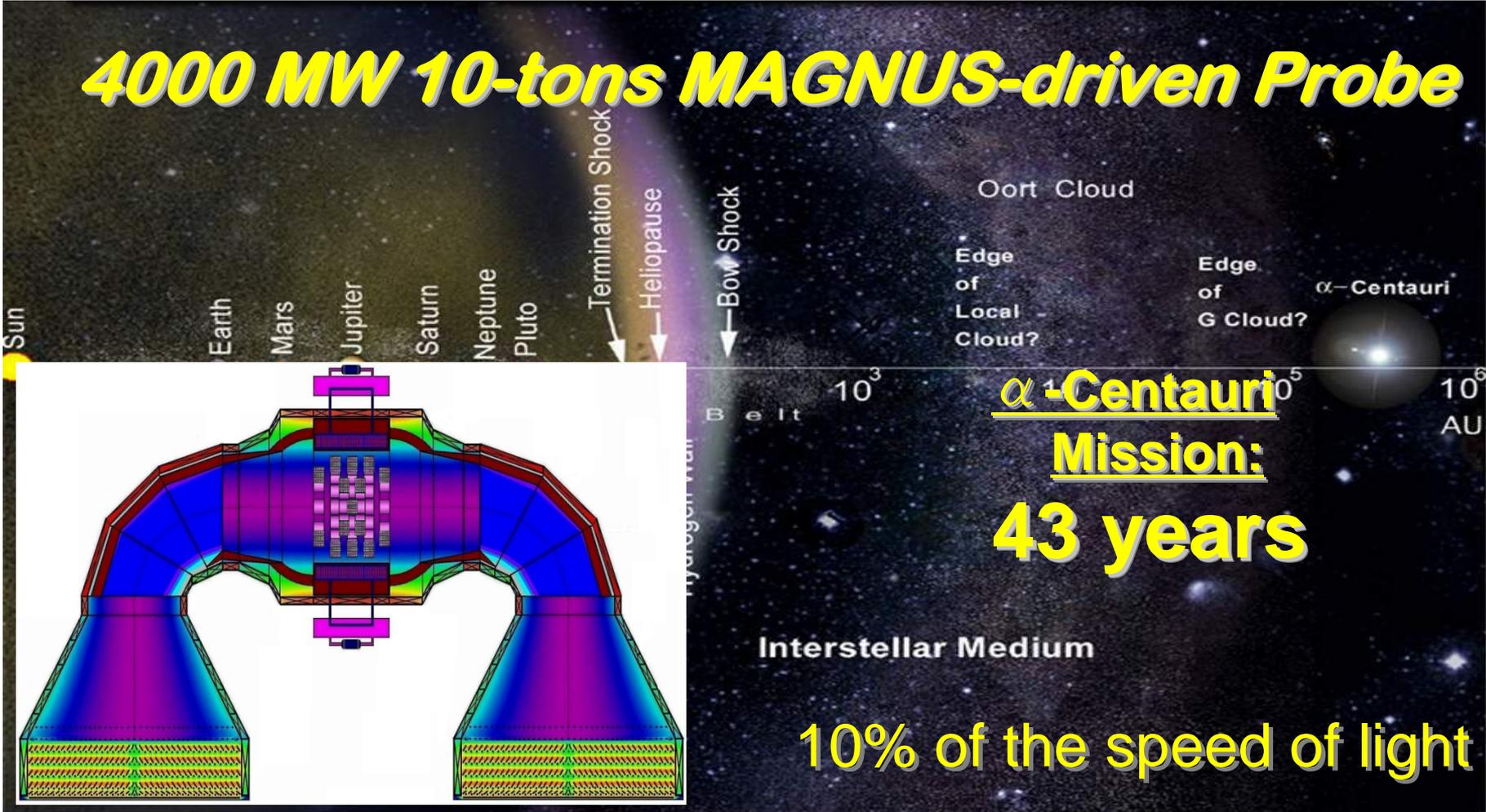




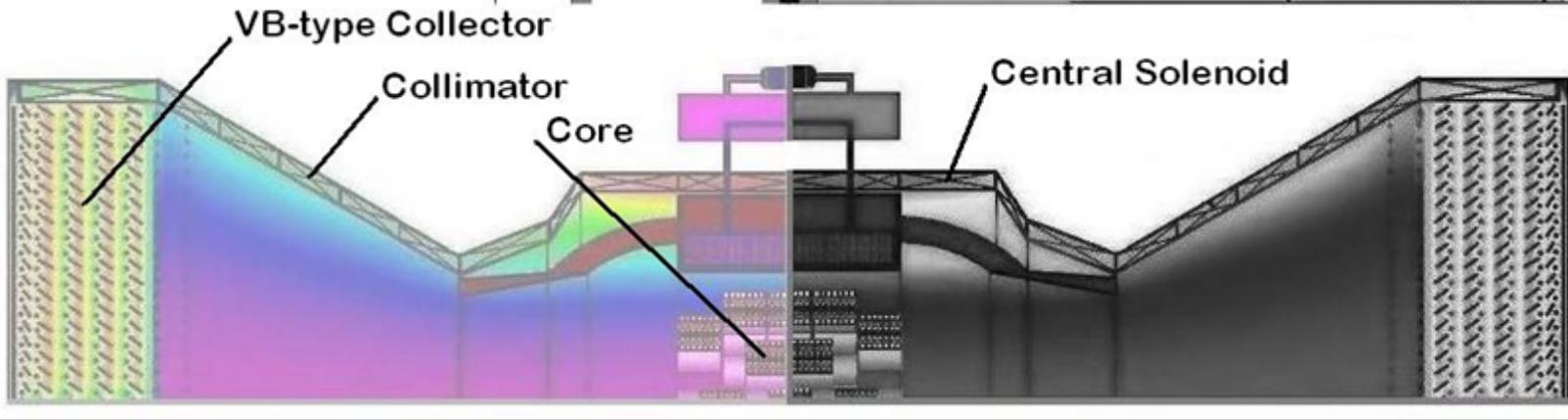
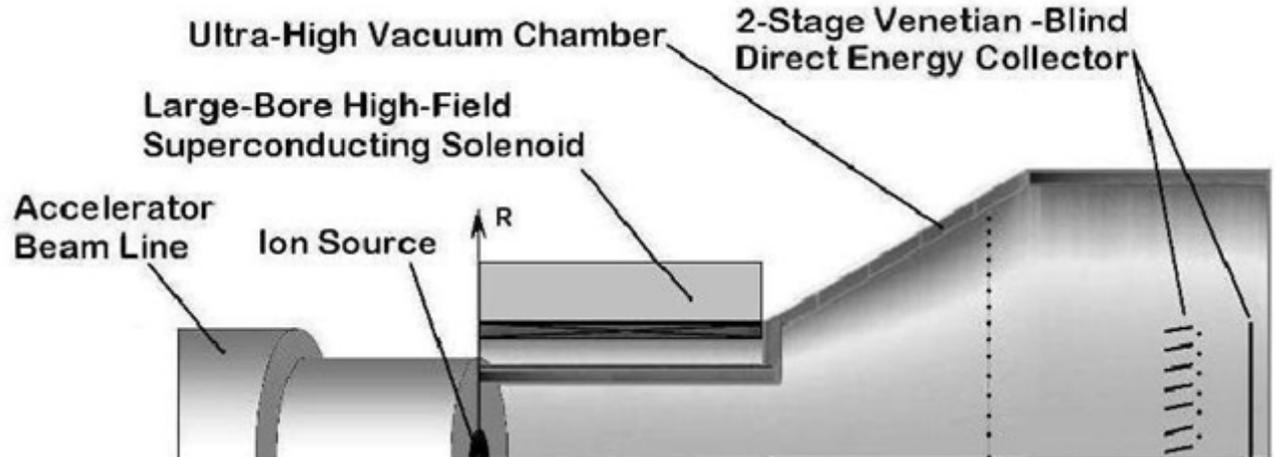
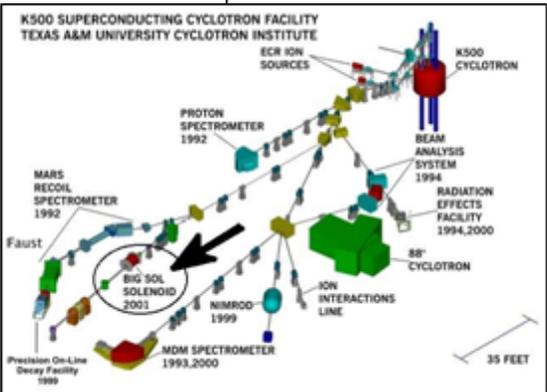
## MAGNUS – Space Power and Propulsion

- High-efficiency DEC
- High specific impulse
- Long-term operation
- Absence of chemical propellant
- Absence of thermal energy conversion
- Absence of moving components

# Direct Energy Conversion Systems

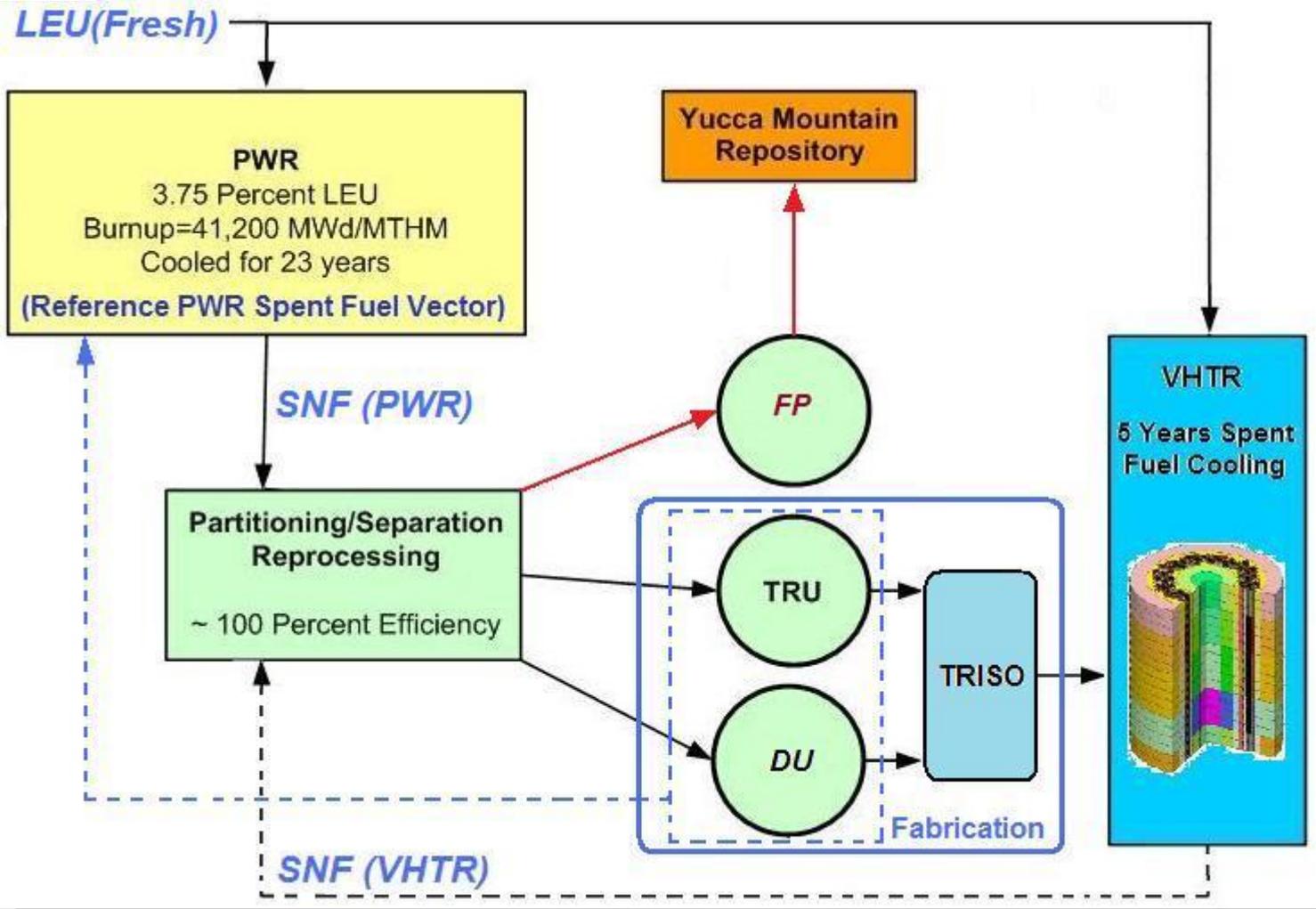
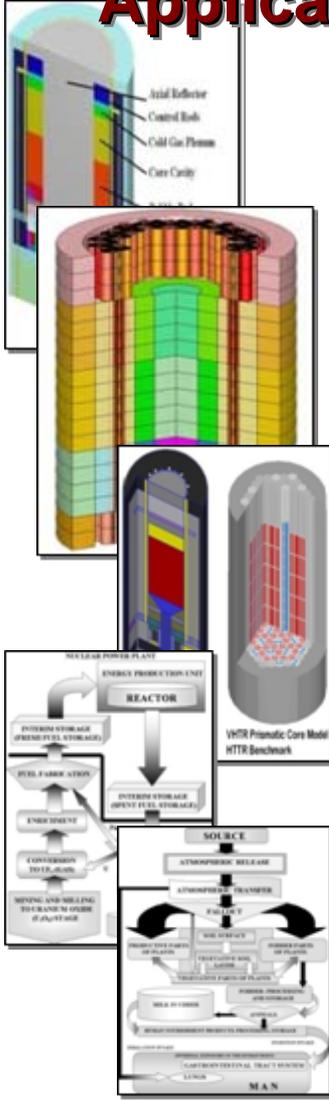


# Direct Energy Conversion Systems

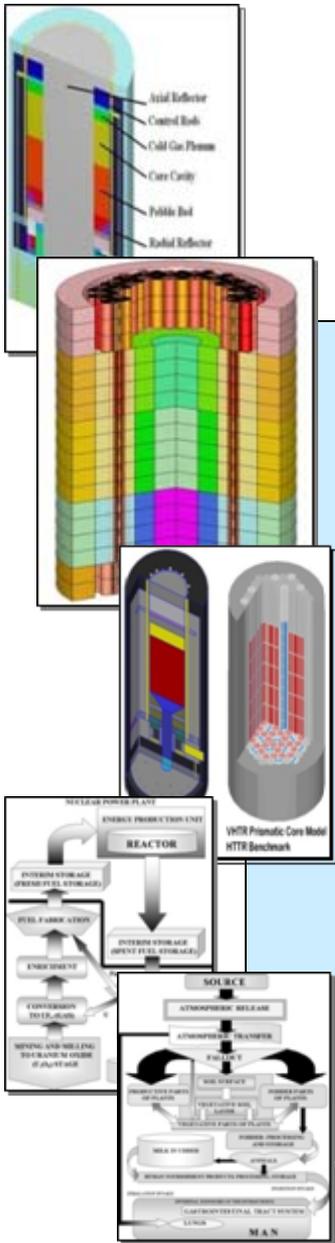


## FFMC Prototype Concept

# Very High Temperature Reactors for Advanced Applications

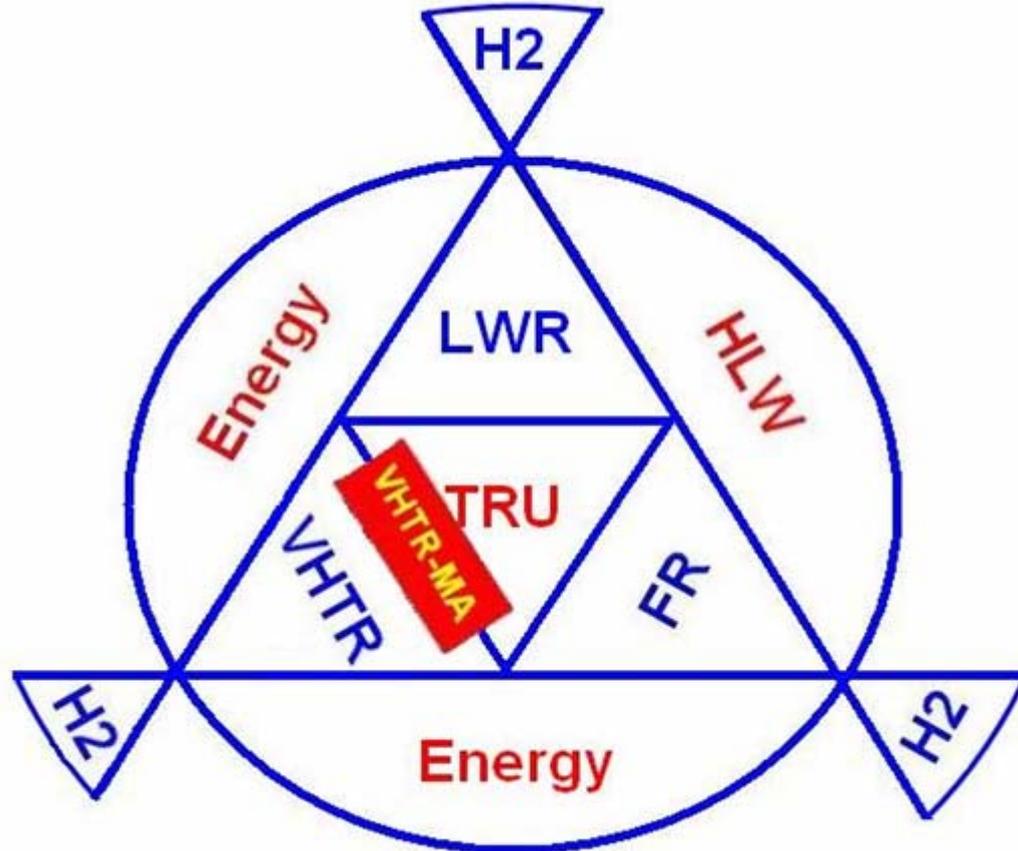
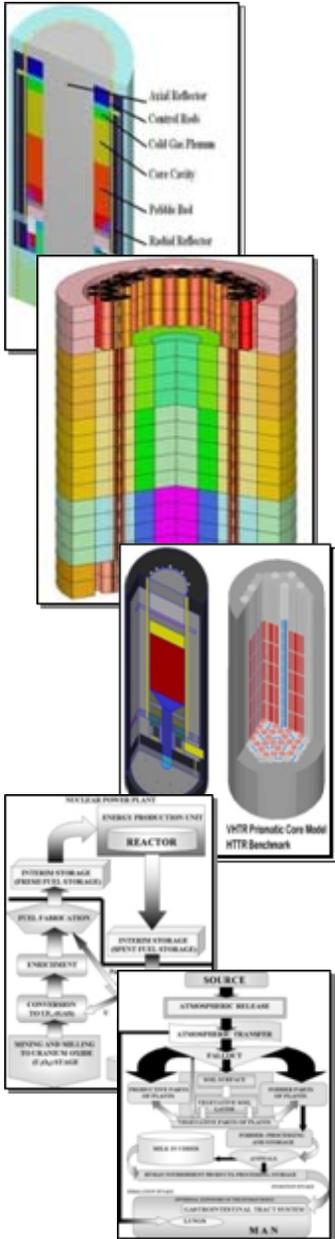


# Utilization of Minor Actinides as a Fuel Component for Ultra-Long Life VHTR Configurations: Designs, Advantages, and Limitations

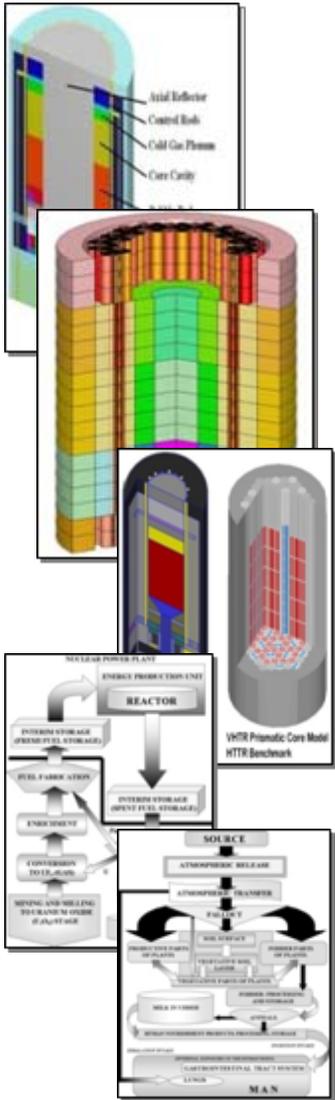
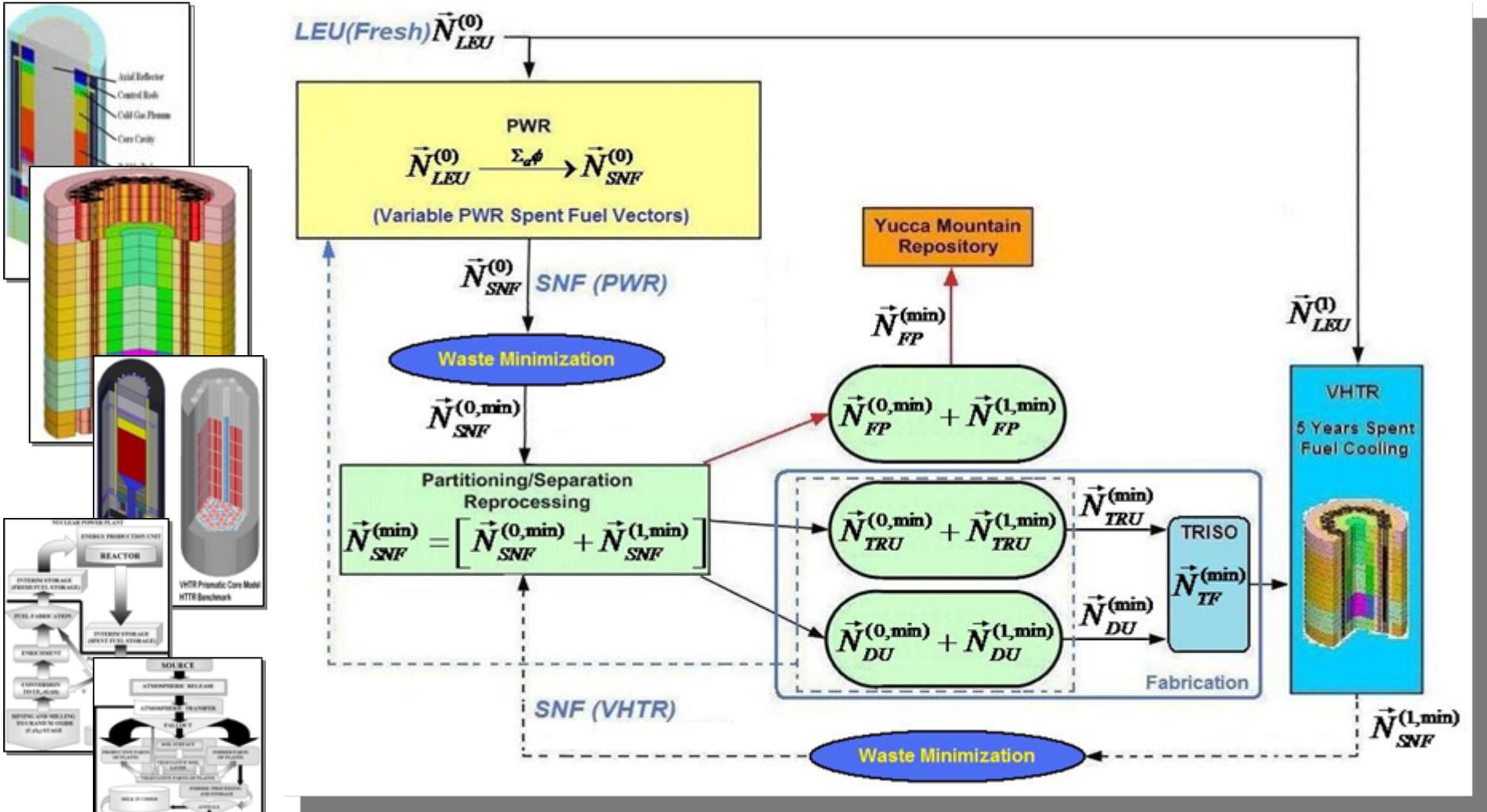


- **3D Core/System Model**
- **Benchmark Suite (Experiment/Code)**
- **V&V of VHTR Models**
- **Uncertainty/Performance**
- **Optimization ( $OTTO$ ,  $T_{max}$ ,  $N_{min}$ ,  $B_{max}$ ,  $\Delta\rho_{min}$ )**
- **Dynamics, Safety, Non-Proliferation**

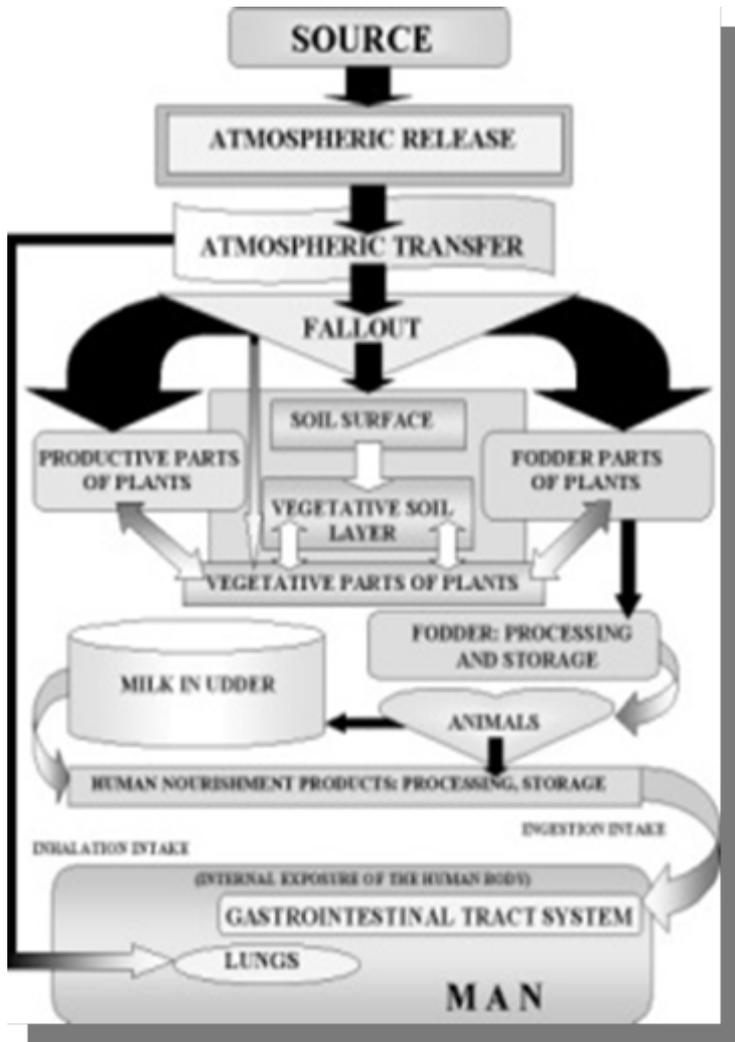
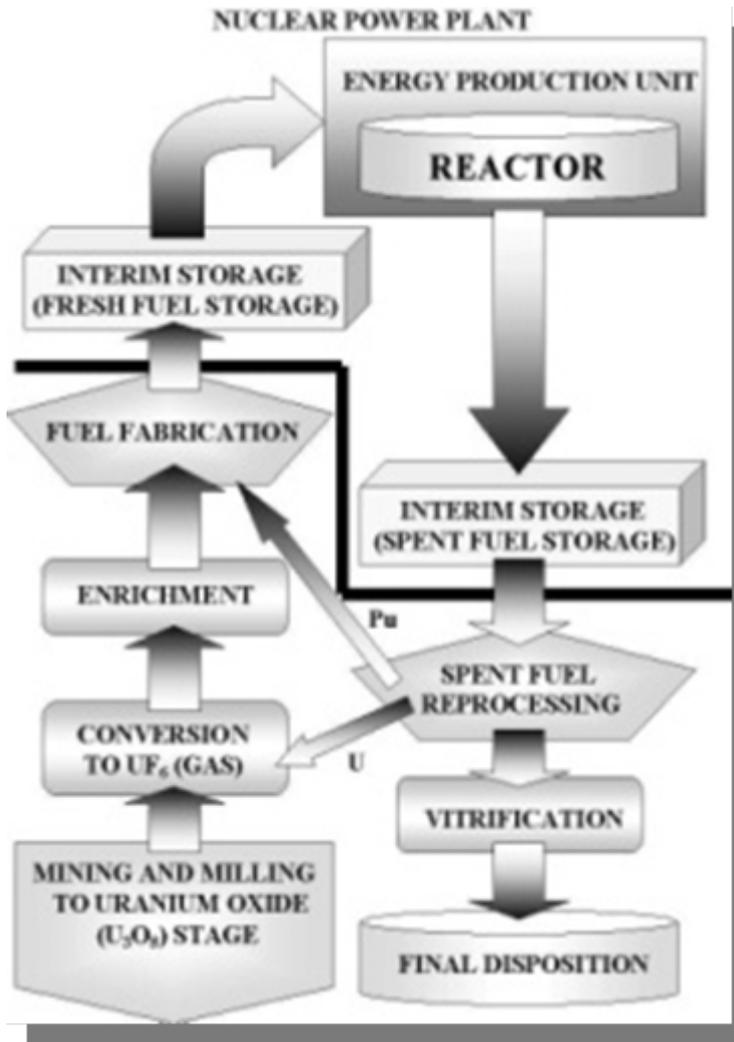
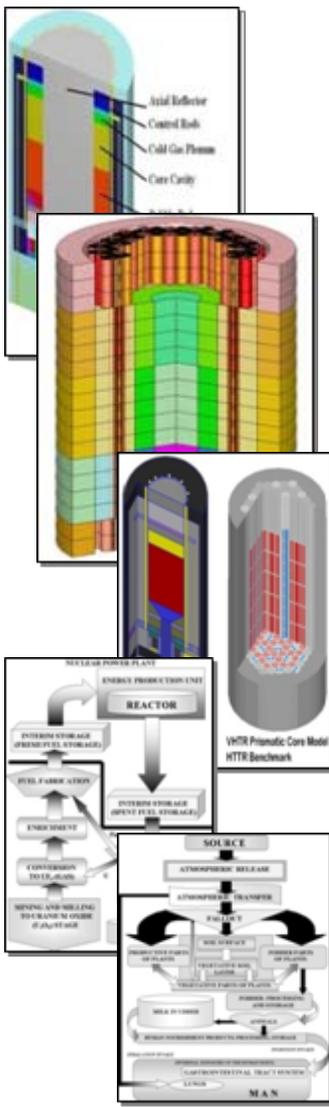
# Utilization of Minor Actinides as a Fuel Component for Ultra-Long Life VHTR Configurations: Designs, Advantages, and Limitations



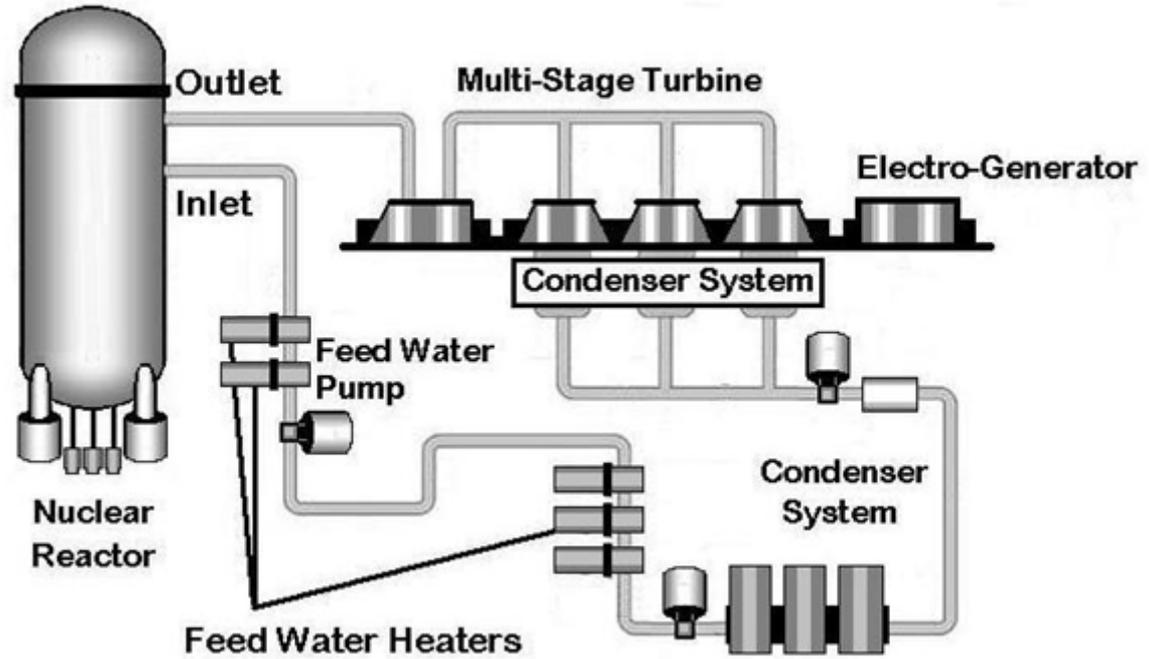
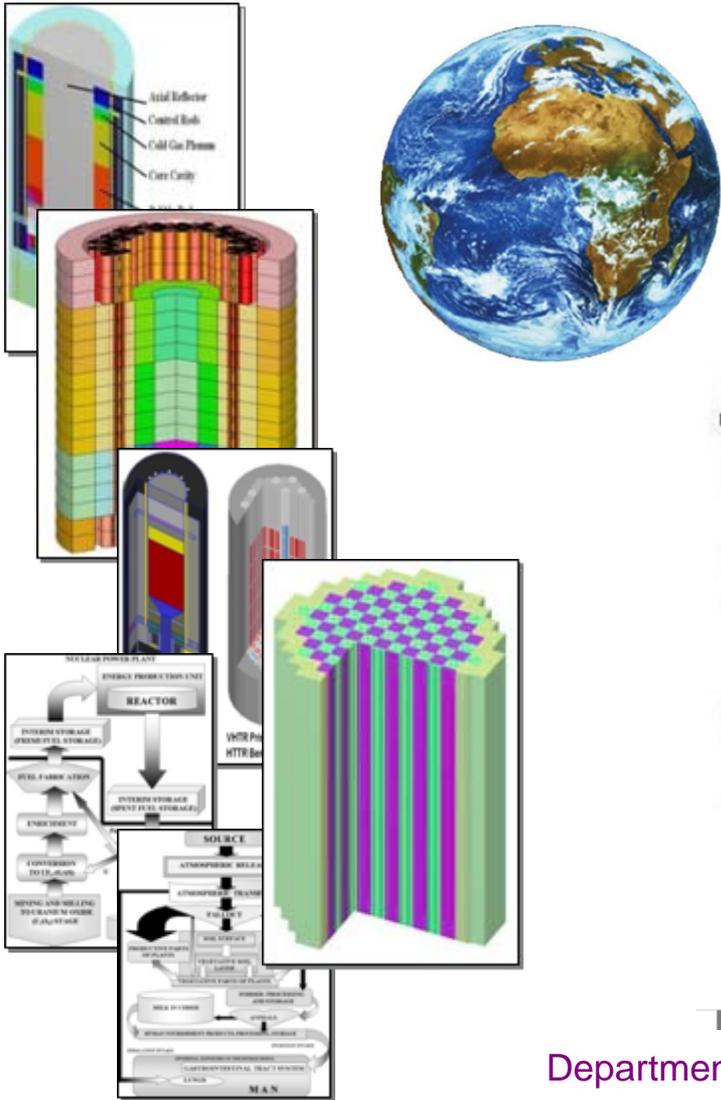
# Environmentally Benign Sustainable Fuel Cycles



# Environmentally Benign Sustainable Energy Systems

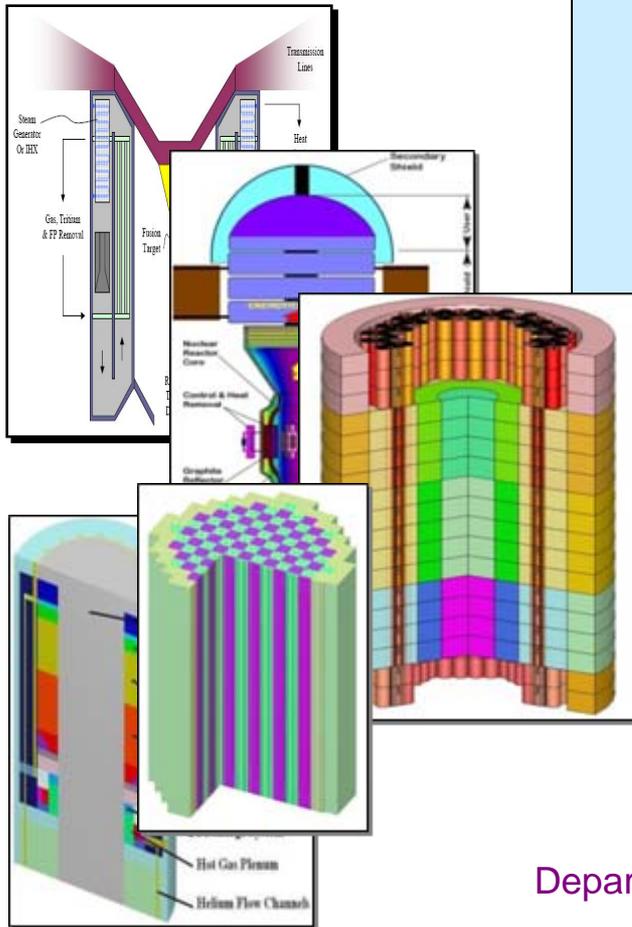


# Earth Climate Fluctuations and Nuclear Energy Systems

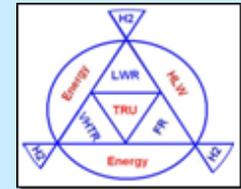
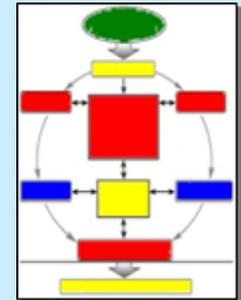




# Modeling-Based Design Development



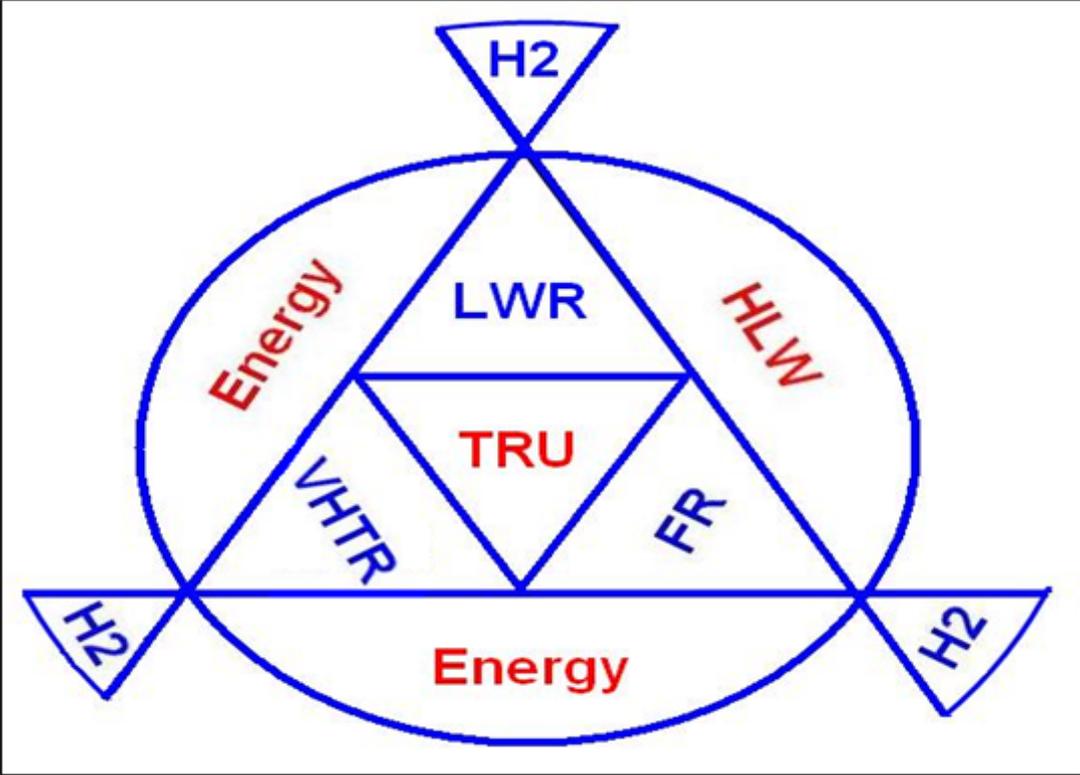
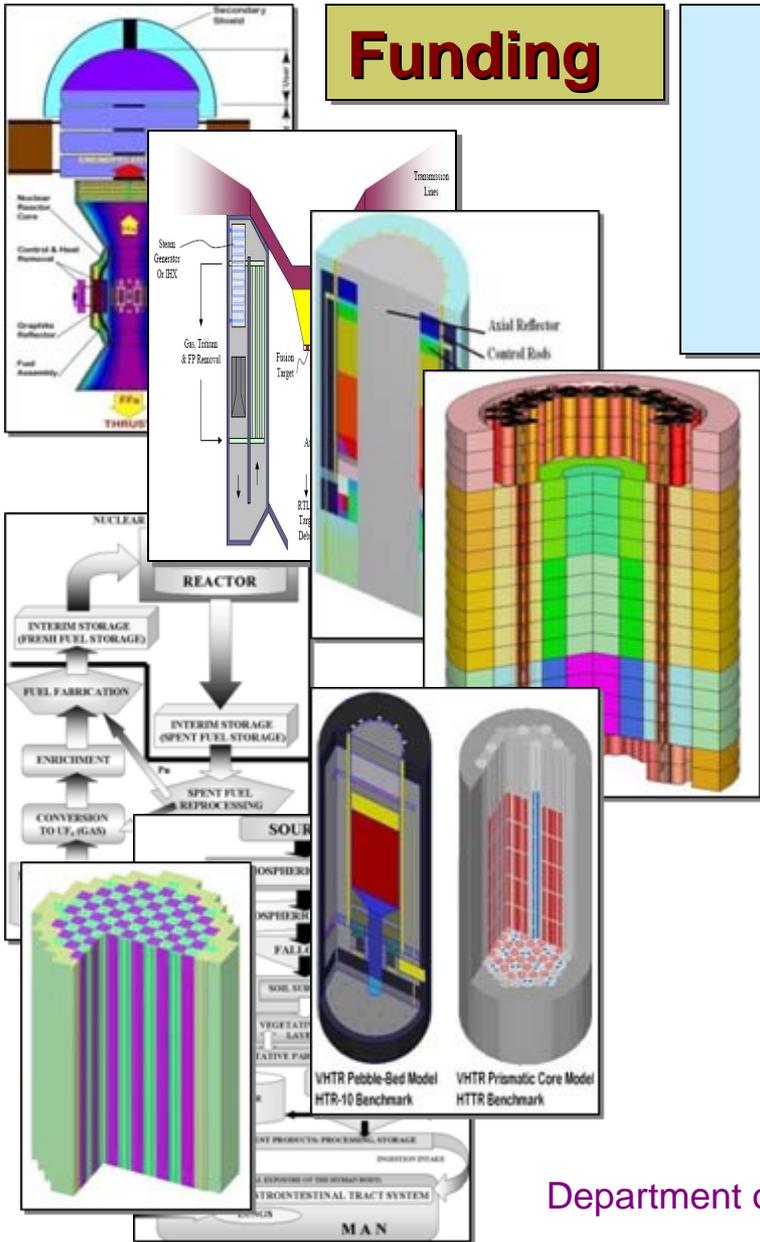
- Coupled 3D modeling
- Performance optimization
- 3D model geometry flexibility
- System life-cycle simulation
- Safety analysis
- Confirmation of inherent safety
- Economics model
- Environment interactions model
- Concurrent engineering



## Advanced High-Fidelity System Modeling

# Funding

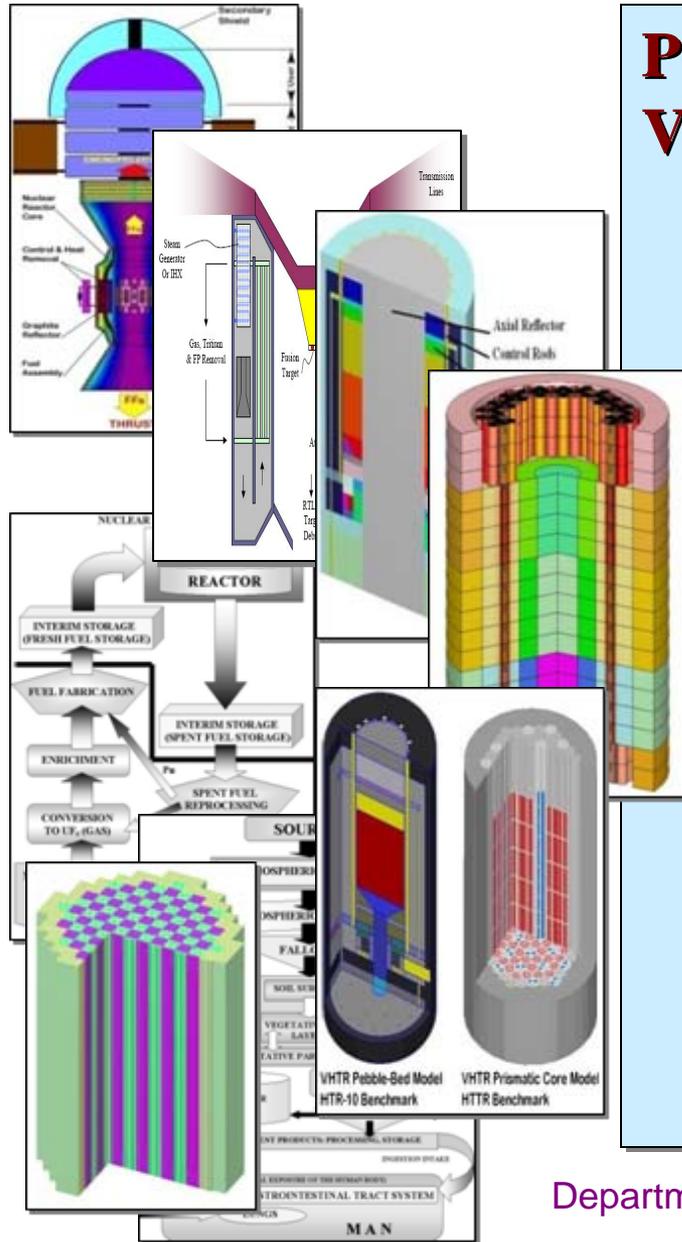
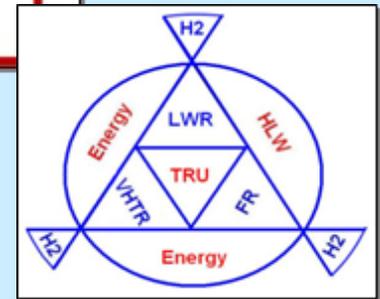
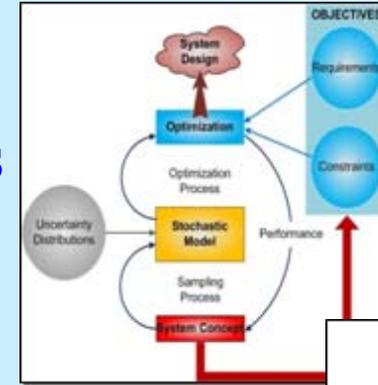
- Federal Programs
- Laboratory-Directed R&D
- Industry Collaboration

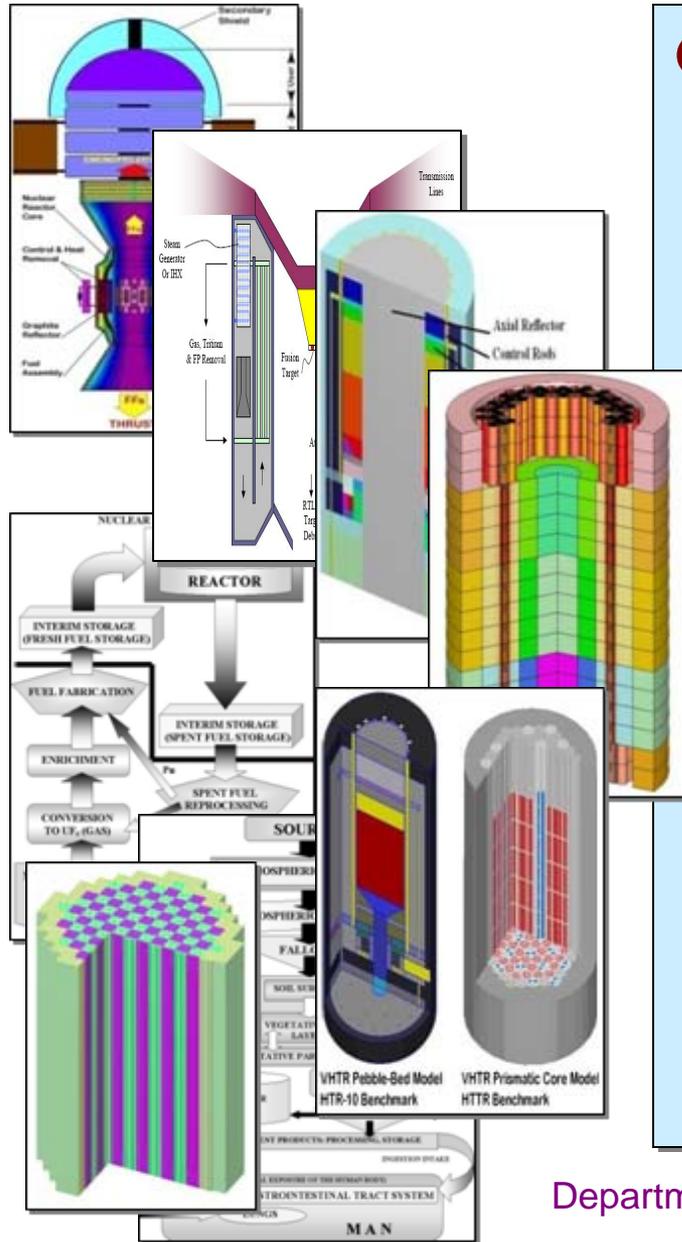




# POTENTIAL COLLABORATION VENUES

- Joint efforts
- Projects
- Proposals
- Student internships  
(leading to M.S. and Ph.D. or for development only)
- Multi-year efforts
- Undergraduate student participation





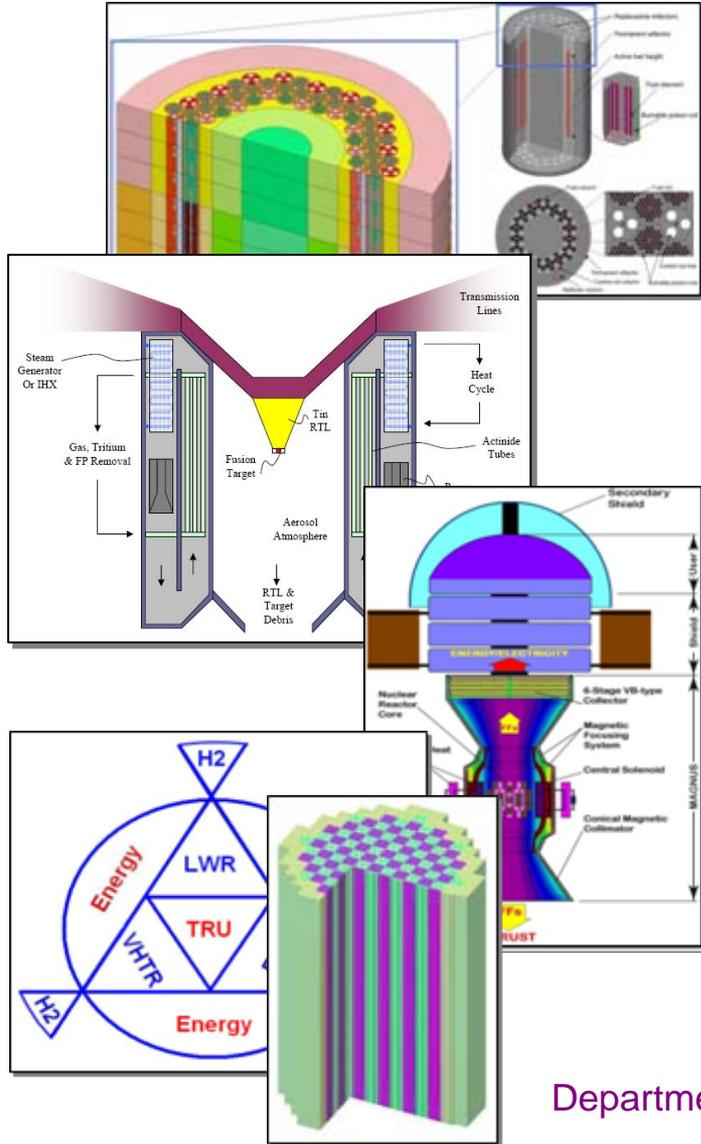
# CONCLUSIONS

- Expertise and capabilities
- Areas of common interest
- Workforce development
- Academics efforts

# THANK YOU

**High Fidelity System Modeling for Advanced Energy Technologies**

*Why? What? When? How?*



**QUESTIONS?**