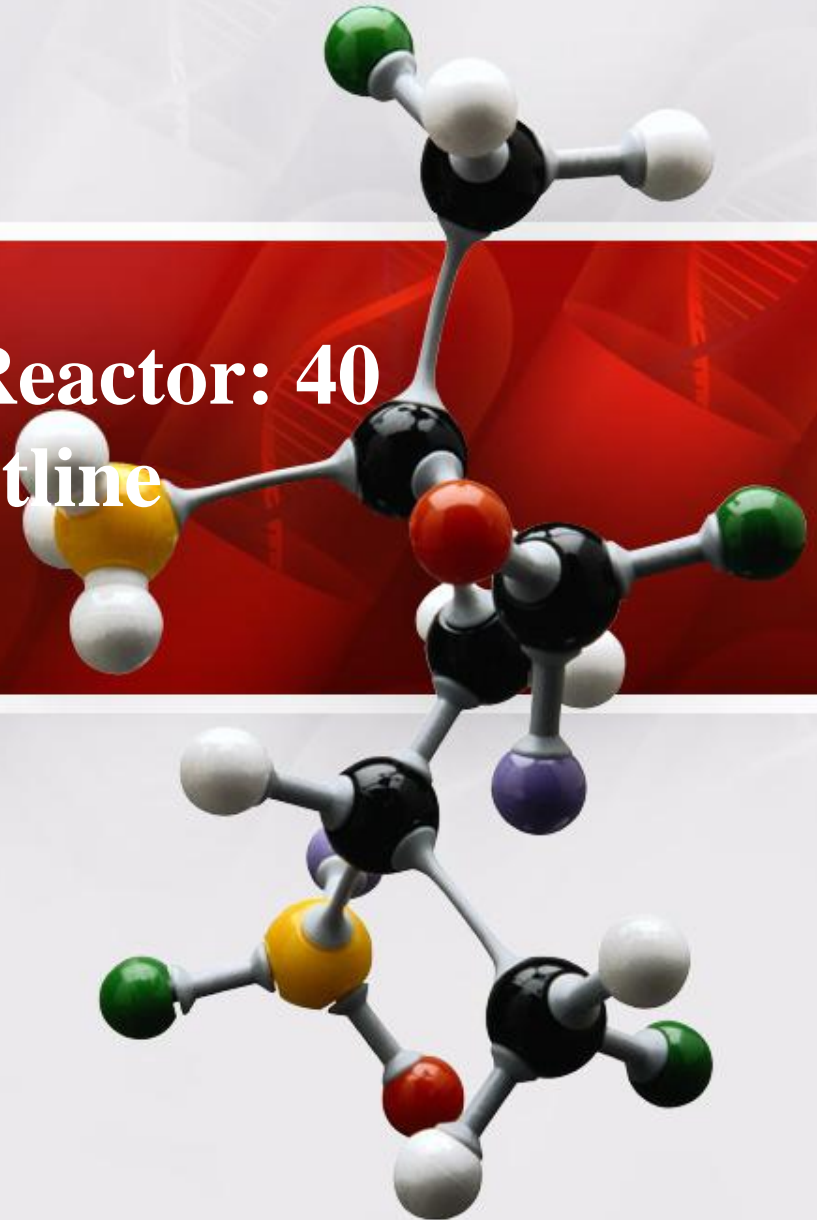


# Liquid Fueled Thorium Reactor: 40 Megawatt Pilot Plant Outline

*Charles S. Holden, Thorenco LLC*





# Defining Differences: Liquid Fuel Thorium Reactor

- *Neutrons convert Fertile Thorium-232 to fissile Uranium-233*
- *No Plutonium Produced*
- *No melt downs*
- *No fuel rods*
- *No cooling ponds*
- *No 10,000+ year spent fuel storage*



# Coolant Salt: Sodium Beryllium Fluoride

- NaFBeF<sub>2</sub> Eutectic (57%: 43%)
- Operates at Atmospheric Pressure
- Melting Point 340° C
- Boiling point over 1500° C
- Natural Convection at 40 Megawatts in pool type reactor
- Forced circulation optional at low power

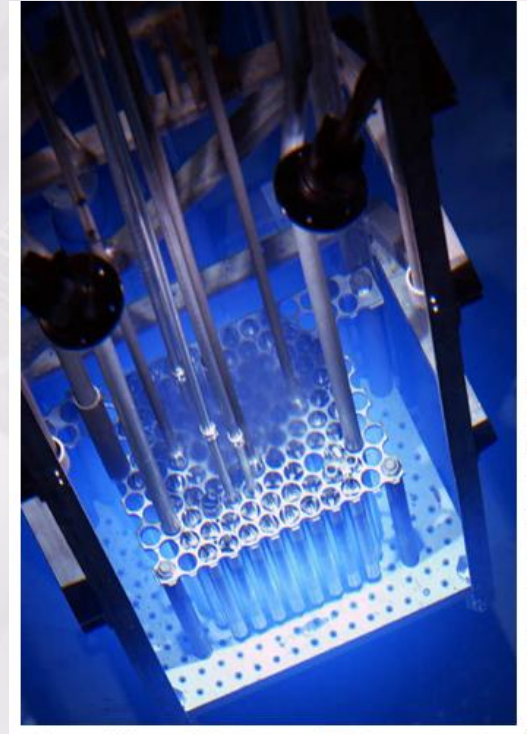


# Thorium-Uranium-Sodium- Beryllium-Fluoride Fuel Salt

- Molecular Percentage of Fluoride Compounds
  - Fissile  $^{235}\text{UF}_4$  circa **6.5%**
  - Fertile  $^{232}\text{ThF}_4$  circa
  - **6.5% Case 1**
  - **13% Case 2**
  - **45% Case 6**
  - Sodium Fluoride NaF **53.5% Case 1**
  - Beryllium Fluoride  $\text{BeF}_2$  **33.5% Case 1**

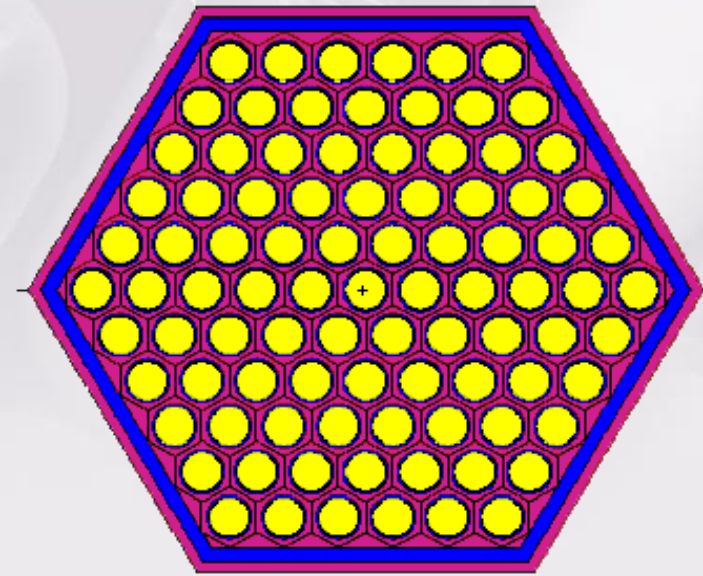
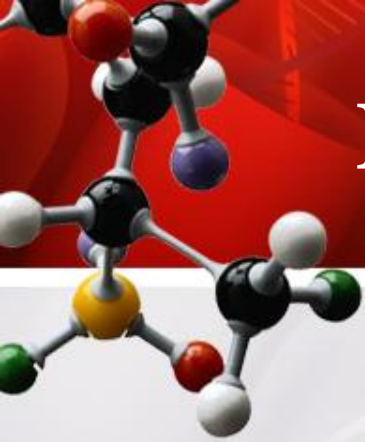
# Liquid Fuel Characteristics

- Fuel Melting Point
  - (400° C +/-25° C est.)
- Chemically Compatible with both
  - Sodium Beryllium Fluoride Coolant
  - Hastelloy-Nickel Cladding
- Beryllium is Moderator in fuel and coolant as salt BeF<sub>2</sub>



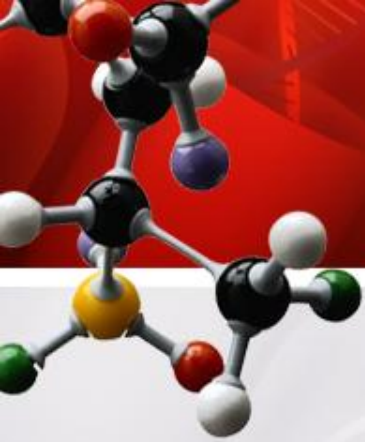


# Honeycomb Geometry



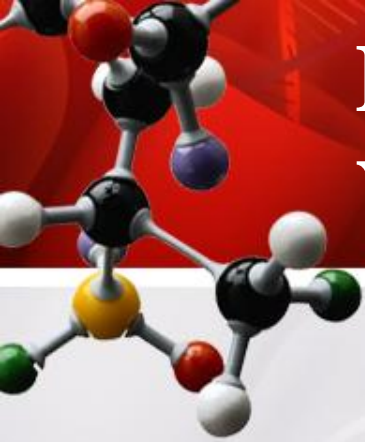
- Liquid Fuel in Hastelloy Lattice (Red)
- NaF BeF<sub>2</sub> Coolant (Yellow)
- Thorium Reflector (Blue)
- BeF<sub>2</sub> moderator is in coolant and in fuel

# Honey Comb Geometry



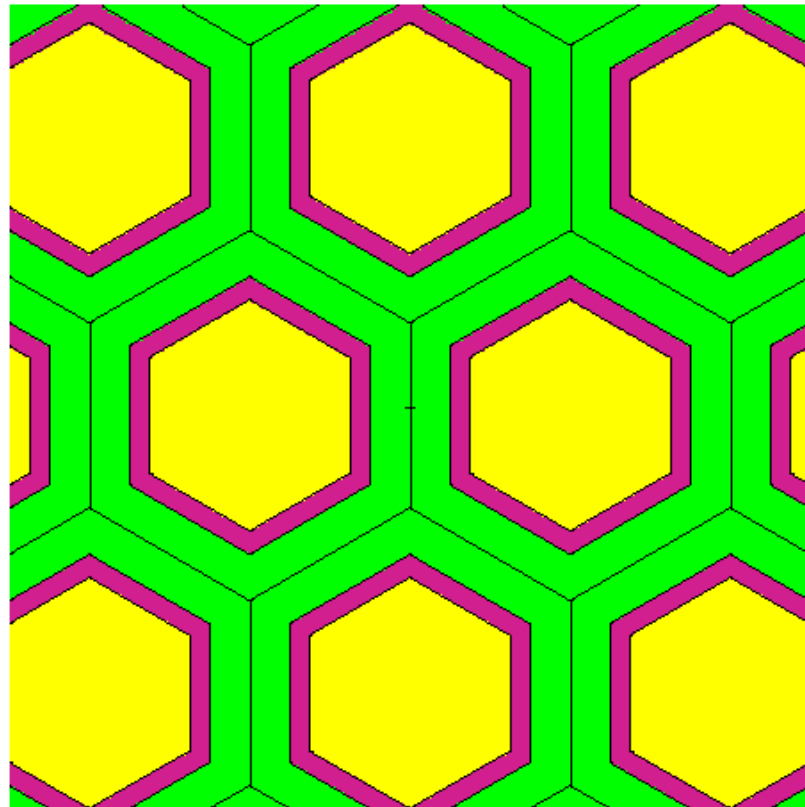
- Fuel, Fission gasses and Fission Products kept inside Hastelloy Hex Cell Lattice.
- Fuel is pumped through & out Lattice
- Fission gasses trapped outside of the core

# Detail of Honeycomb Green Fuel; Yellow Coolant ; Red Hastelloy



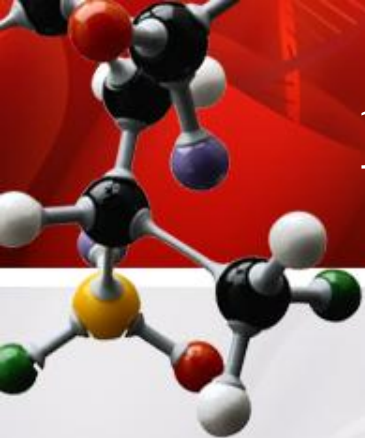
04/19/11 10:57:09  
Standard ACRR Model with MSR

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( 0.000000, 1.000000, 0.000000)  
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( -2.00, 0.11, 0.00)  
extent - ( 5.00, 5.00)



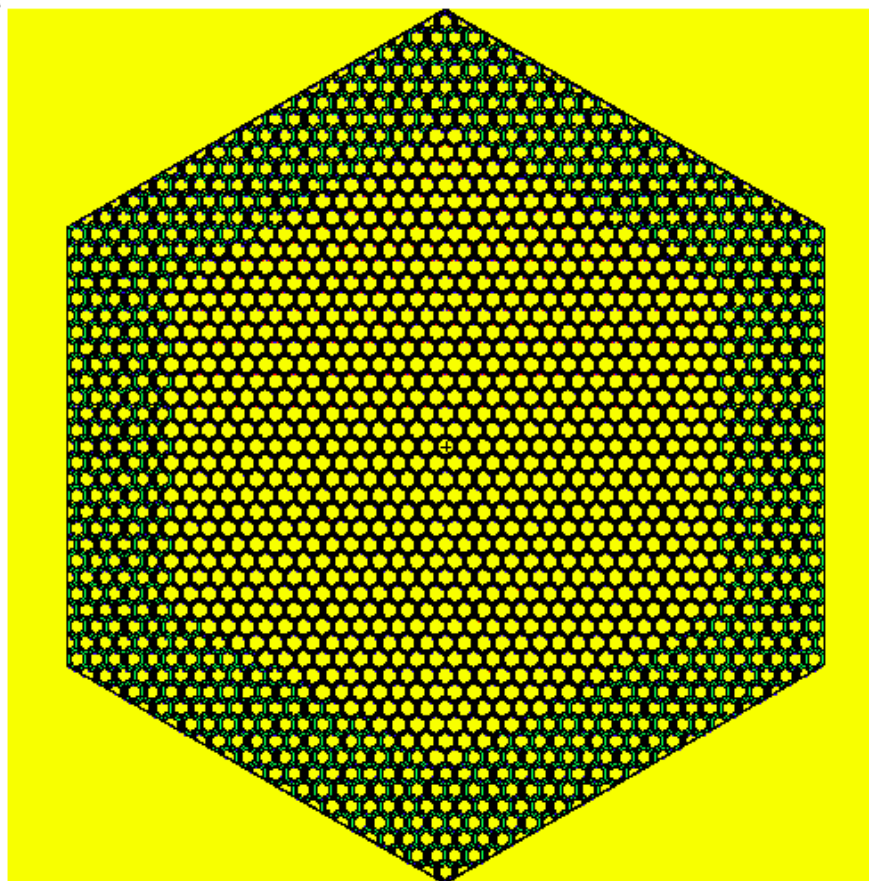


# 160 Cm. Honeycomb Array

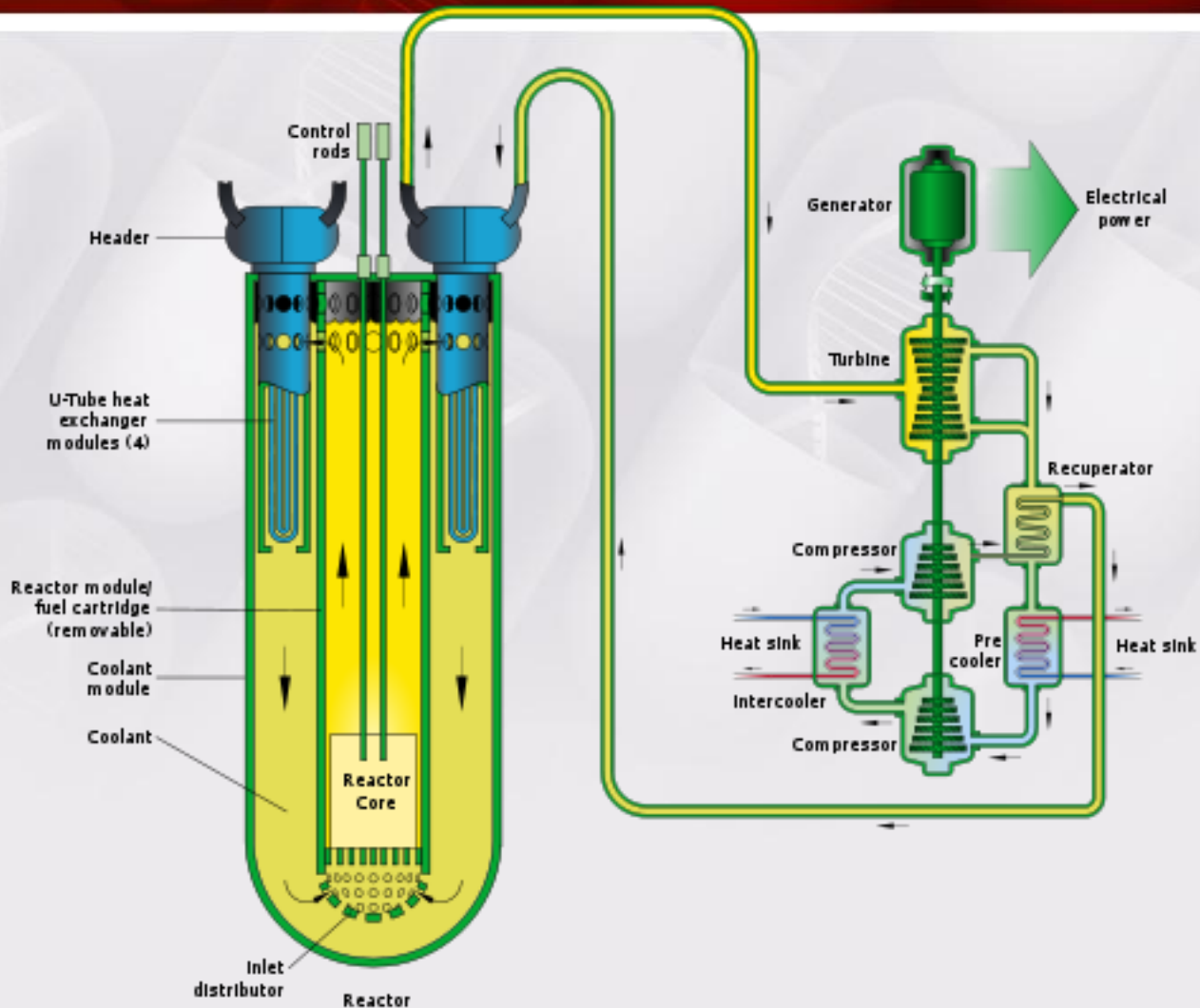


01/14/11 15:43:44  
Standard ACRR Model with FREC-II

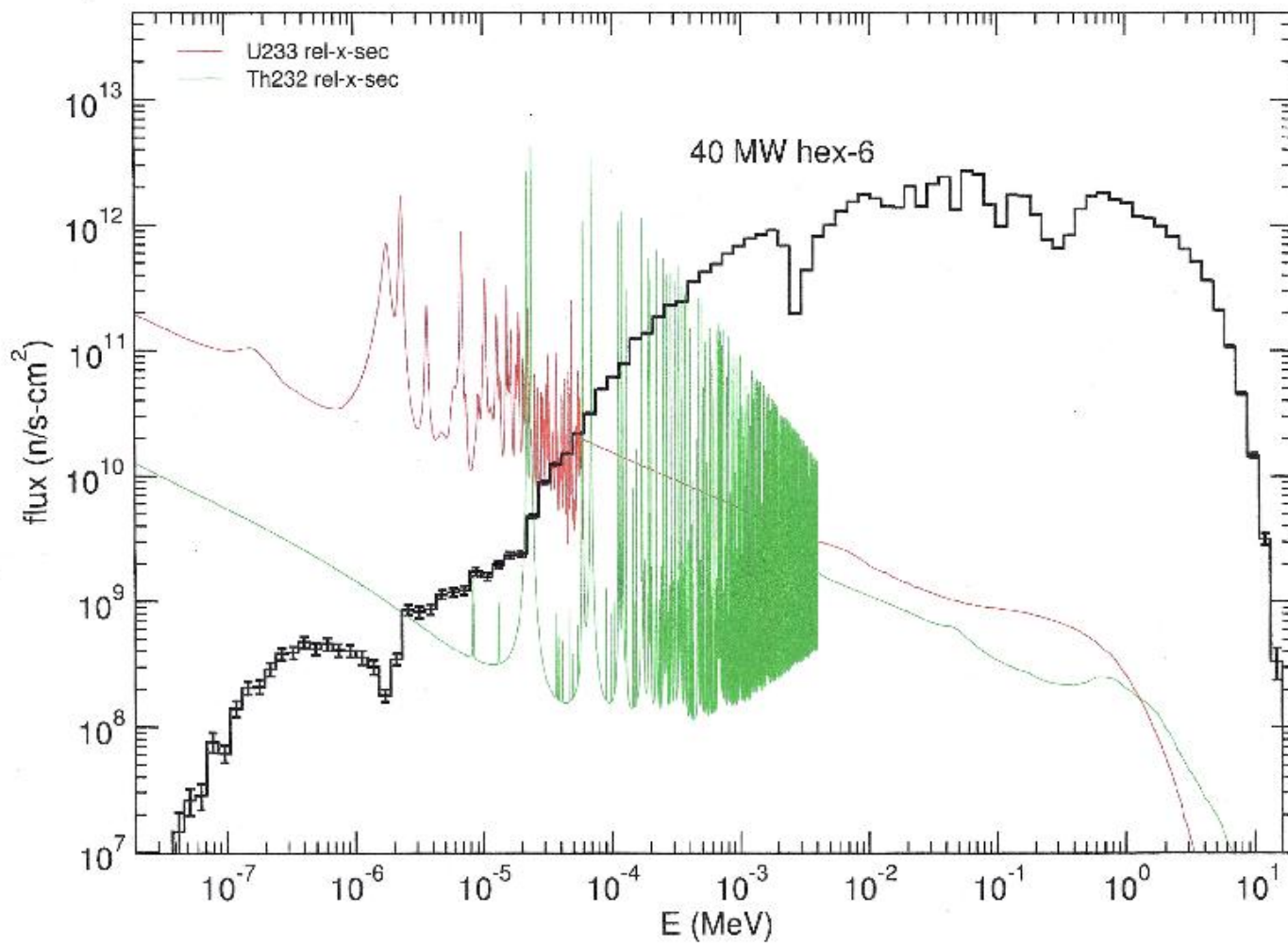
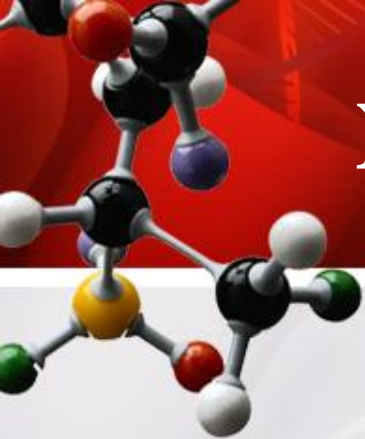
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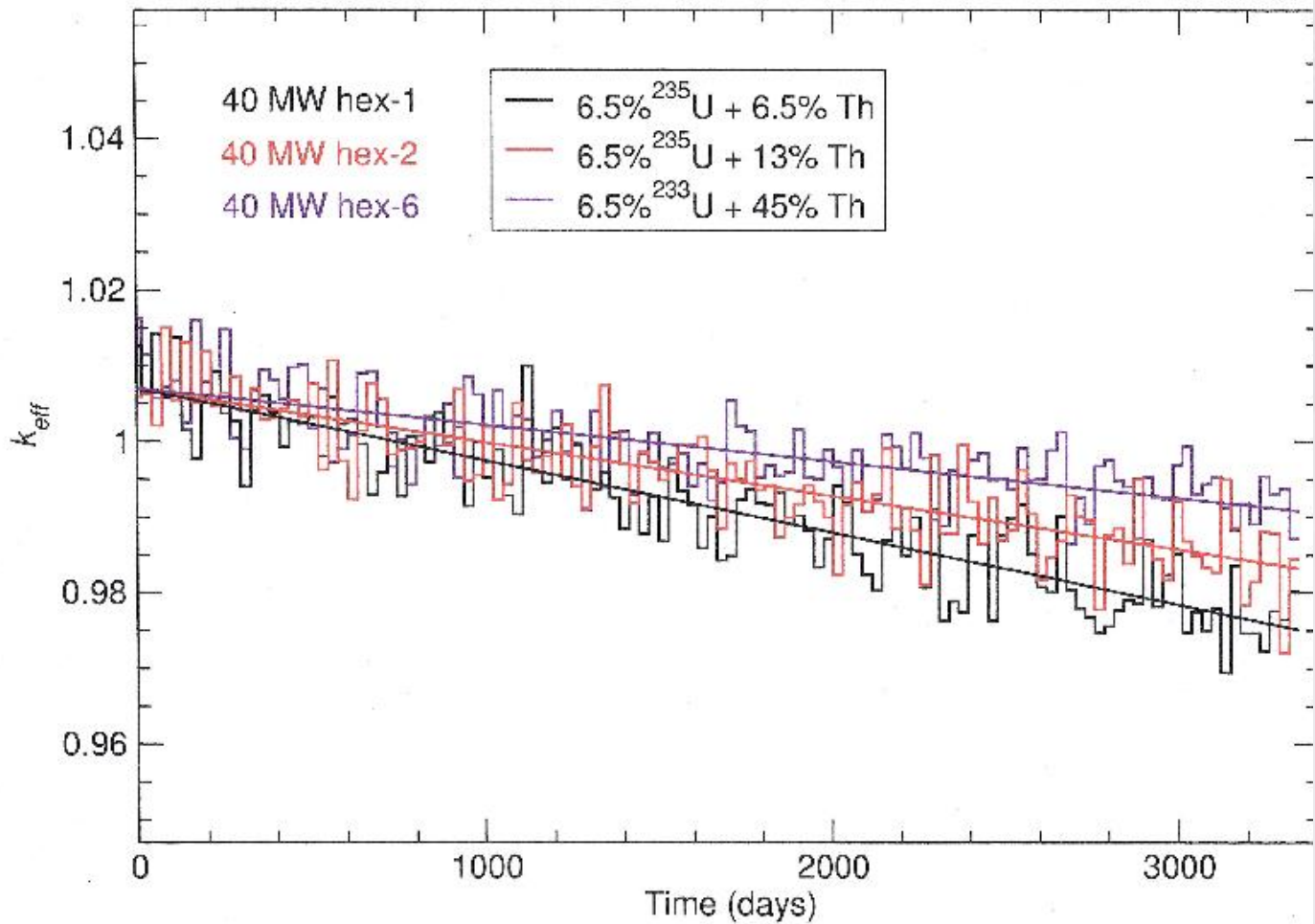
# Deep Salt Pool Design



# Neutron Spectrum Case 6



# K Effective Cases 1,2,6





A ball-and-stick molecular model of a complex organic or inorganic molecule, featuring various colored spheres (black, white, red, blue, yellow, green) representing different atoms, connected by grey rods representing bonds. The model is positioned in the top-left corner of the slide.

# Fuel Performance Case 6

- 10 years at 40 megawatts
- 141 Kg. U-233 “burned” during decade
- More than 100 Kg. of fissile produced
- 1600 kilograms of U-233 fissile load
- 9000 kilograms of Th-232 fertile load
- 23 Grams U-232 produced in fuel over the decade of operations





# Transuranic Production Case 6

- Neptunium-237      9.4E-07
- Plutonium-238      1.27E-04
- Plutonium-239      7.05E-07
- Plutonium-240      2.9 E-09
- Insignificant production of transuranics (less than a milligram)
- Cleaner burning fuel
- No long-lived transuranics produced



# Passive Features: Prompt Shut Down

- Vertical pipes connect hex-cell lattice to used fuel drum array underneath core.
- Hot Fuel flows by gravity when scram signal is given
- U-238 tetrafluoride (Denaturant) provides proliferation control



# Passive Features: Prompt Shut Down

- Cadmium fluoride absorbs thermal neutrons
- Shielded drums supplied with fluorides: neutron absorber, dilutant and U-238 denaturant
- Fluorides melt & mix in hot fuel, neutralizing it, containing it, and allowing passive air cooling

A 3D ball-and-stick model of a complex organic molecule, possibly a protein or enzyme, is positioned in the top-left corner. The atoms are represented by spheres of various colors: black, white, red, blue, yellow, and green, connected by grey rods representing bonds. The background of the slide is a gradient from red at the top to white at the bottom, with faint, repeating DNA double helix patterns.

# 40 Megawatt Reactor Data

- Hexagonal Prism 160 Cm. Width and Height
- Fuel Volume 2330 Liters
- Fuel 11.65 Metric Tonnes; 1-2 Metric Tonnes Fissile in Fuel
- Coolant 93,200 Liters; 450 Tonnes
- Reflector Volume 1420 Liters 16.65 Metric Tonnes

A 3D ball-and-stick model of a complex organic molecule, possibly a fuel component, is positioned in the top-left corner. The atoms are represented by spheres of various colors: black, white, red, purple, yellow, and green, connected by grey bonds. The background is a vibrant red with faint, overlapping DNA double helix patterns.

# Remote Fuel Handling

- Fresh fuel heated to liquid and pumped into the Hastelloy Lattice
- During normal operations captured fission gasses are removed
- During emergencies fuel flows by gravity to special shielded drums
- Each Used Fuel drum contains:
  - **fuel dilutant+**
  - **fuel denaturant+**
  - **neutron absorbing materials and gamma shielding.**





# Proliferation Hardening

- U-232 decays to Thallium-208
- Protactinium-233 and fission product in fuel provide a radiation shield protecting fuel from illicit diversion
- Emergency mixing uranium-238 tetra fluoride with fuel so that fissile uranium-233 is not weaponized

A ball-and-stick molecular model of a complex organic or inorganic molecule, featuring various colored spheres (black, white, red, blue, yellow, green) representing different atoms, connected by grey rods representing chemical bonds. The model is positioned in the top-left corner of the slide.

# Active Control Features

- Control rods and Safety rods can be inserted
  - Into coolant spaces in the honeycomb array
  - To reduce  $k_{\text{eff}}$  for power control or to scram the reactor
  - Fuel quality is managed during operations; fissile can be added as needed or removed by fluorination of liquid fuel
  - Fission Products can be separated by on-line distillation and fission gasses can be removed from the fuel



# MCNPX Computations

- Thank you to Dr. Richard Wittman of Pacific Northwest National Laboratory for performing modeling and optimization calculations for the 40 Megawatt Pilot Reactor Study
- Thank you to Dr. Larry A Burchfield of Radiochemistry Society for review
- Thank you to DOE and PNNL for the Technical Assistance Program that supported this work
- Thank you Thorium Energy Alliance for hosting today's event

A ball-and-stick molecular model is positioned in the top-left corner of the slide. It features a central yellow sphere (likely sulfur) bonded to several other atoms, including black (carbon), white (hydrogen), red (oxygen), and green (chlorine) spheres. The model is rendered with semi-transparent spheres and connecting rods, giving it a three-dimensional appearance.

# 10 C.F.R. 810 et. Seq.

- Restricted Nuclear Technology
- Export Controls
- Regulated Activities
- Thorium Developers consult lawyers become familiar with 10 CFR 810 et. Seq.!
- Harsh Penalties for Circumventing Export and Proliferation Controls on technology involving production of uranium-233.
- Depending on circumstances, Atomic Energy Act Violations are punishable by fines and imprisonment: 10 years to Life



# Thank you

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