Liquid Fueled Thorium Reactor: 40 Megawatt Pilot Plant Outline

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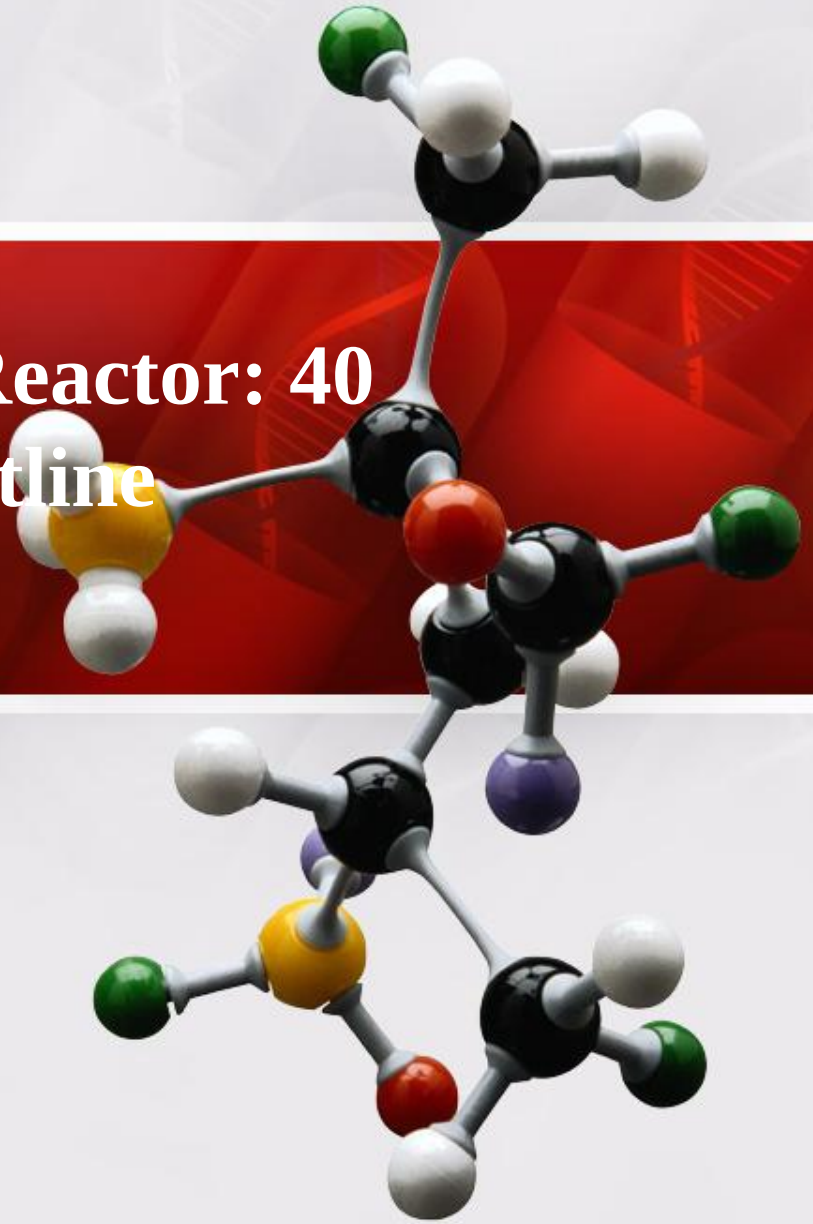
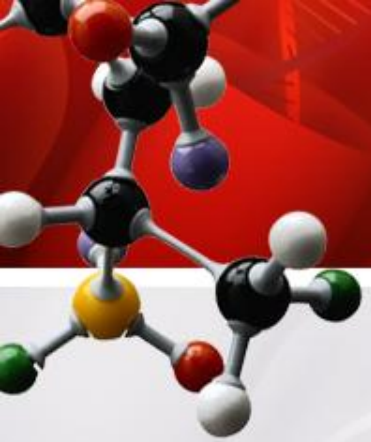


Defining Differences: Liquid Fuel Thorium Reactor

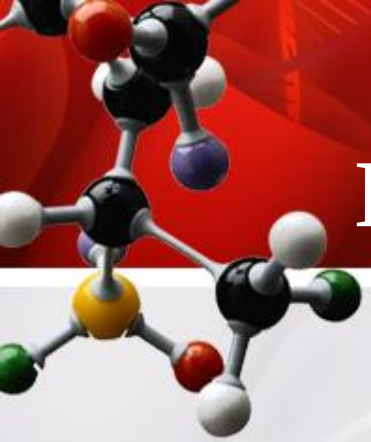


- ***Neutrons convert Fertile Thorium-232 to fissile Uranium-233***
- ***No Plutonium Produced***
- ***No melt downs***
- ***No fuel rods***
- ***No cooling ponds***
- ***No 10,000+ year spent fuel storage***

Coolant Salt: Sodium Beryllium Fluoride

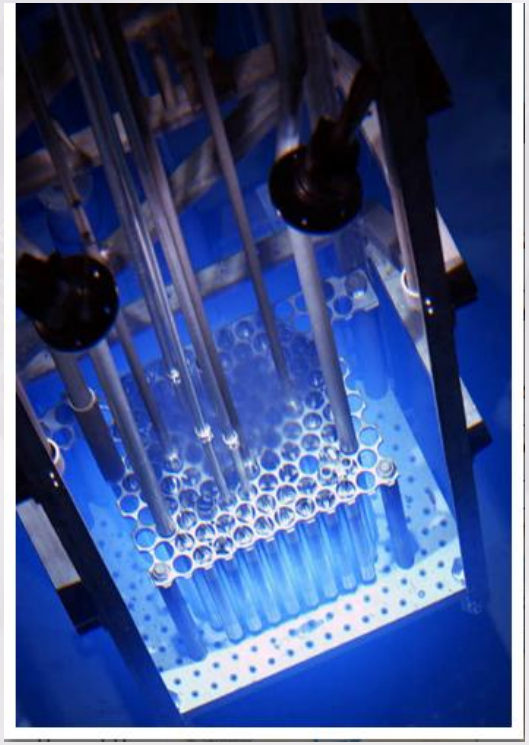
- $NaFBeF_2$ Eutectic (57%: 43%)
- Operates at Atmospheric Pressure
- Melting Point 340° C
- Boiling point over 1500° C
- Natural Convection at 40 Megawatts in pool type reactor
- Forced circulation optional at low power

Thorium-Uranium-Sodium-Beryllium-Fluoride Fuel Salt



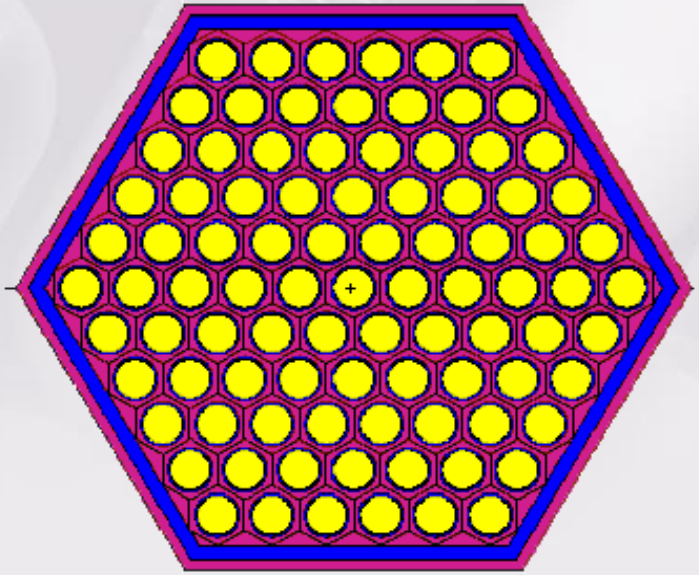
- Molecular Percentage of Fluoride Compounds
  - **Fissile $^{235}UF_4$ circa 6.5%**
  - **Fertile $^{232}ThF_4$ circa**
  - **6.5% Case 1**
  - **13% Case 2**
  - **45% Case 6**
  - **Sodium Fluoride NaF 53.5% Case 1**
  - **Beryllium Fluoride BeF_2 33.5% Case 1**

Liquid Fuel Characteristics



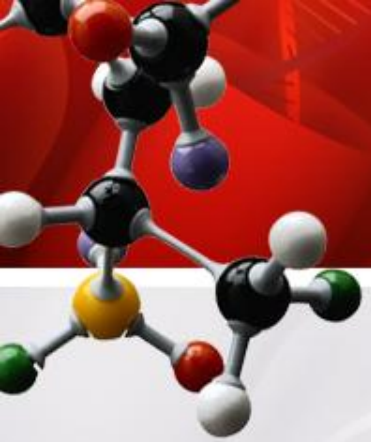
- Fuel Melting Point
  - (400° C +/-25° C est.)
- Chemically Compatible with both
  - Sodium Beryllium Fluoride Coolant
  - Hastelloy-Nickel Cladding
- Beryllium is Moderator in fuel and coolant as salt BeF2

Honeycomb Geometry



- Liquid Fuel in Hastelloy Lattice (Red)
- NaF BeF_2 Coolant (Yellow)
- Thorium Reflector (Blue)
- BeF_2 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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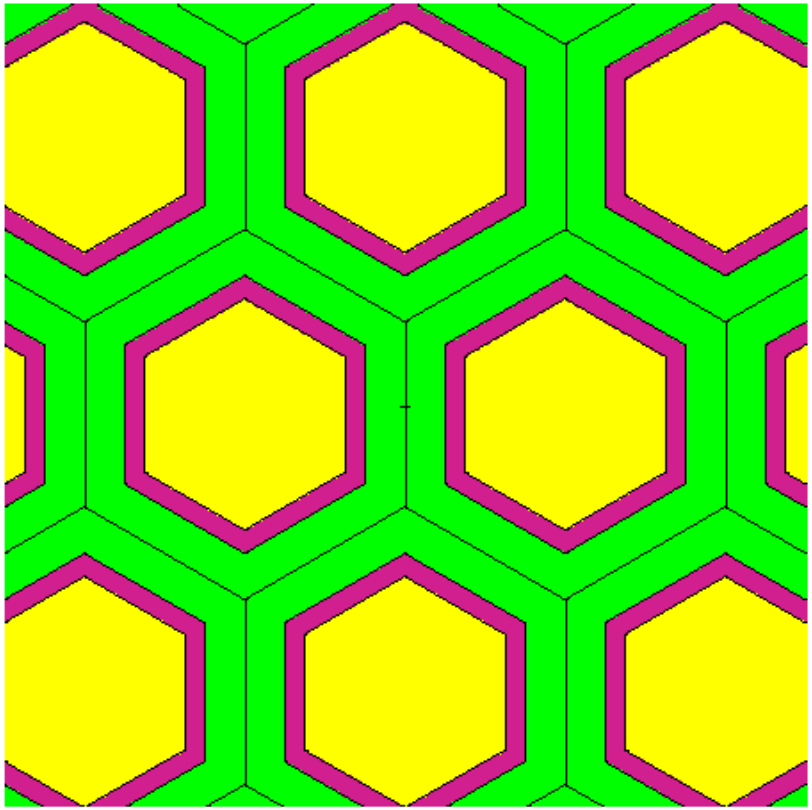

160 Cm. Honeycomb Array

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Standard ACRR Model with FREC-II


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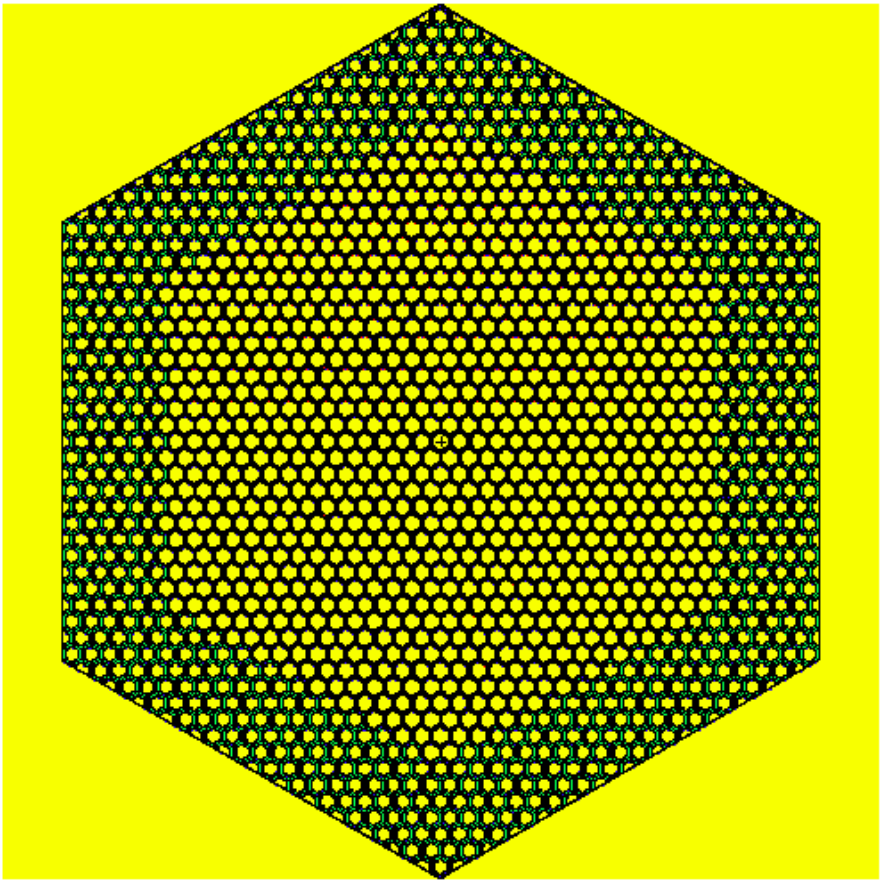
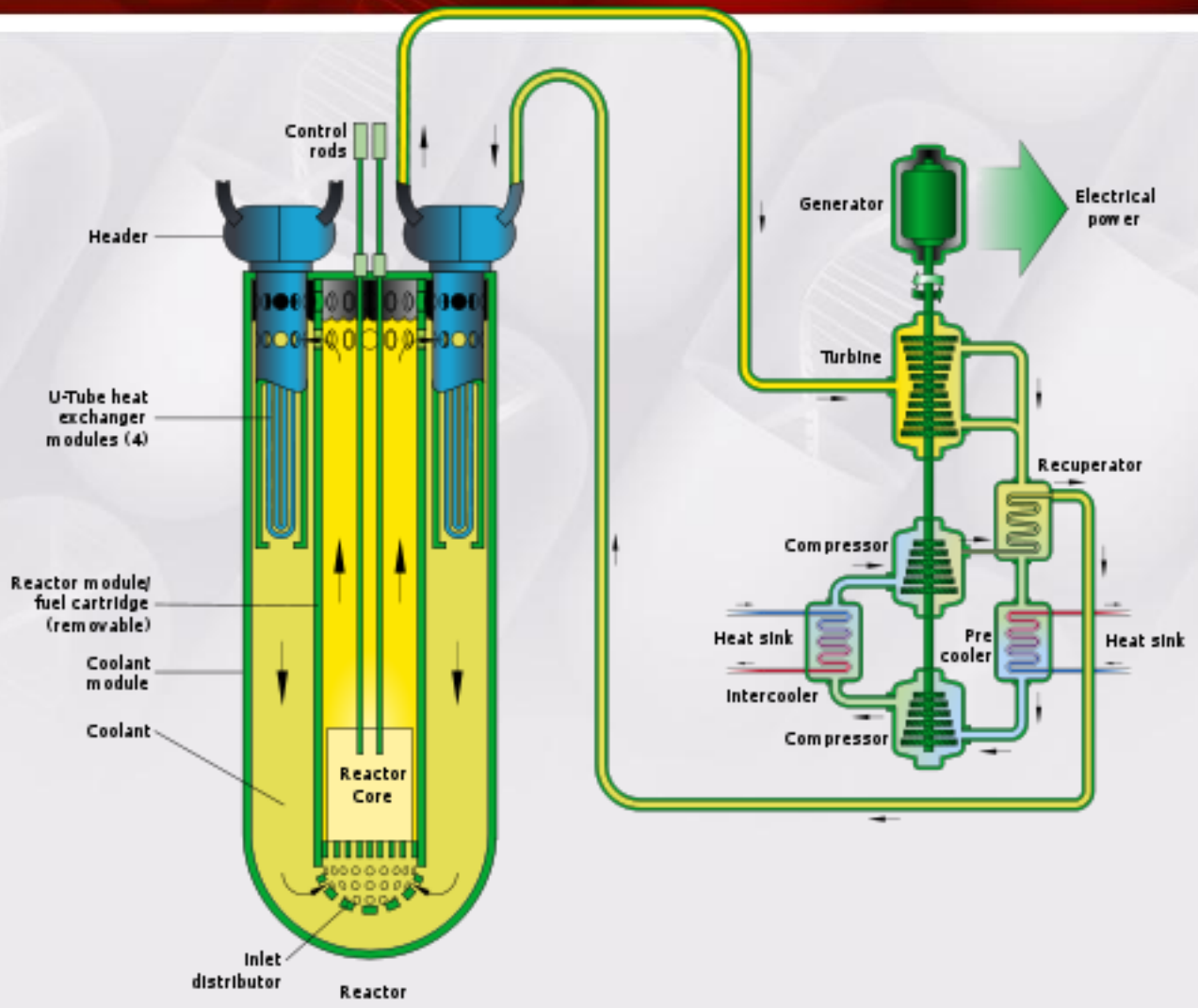
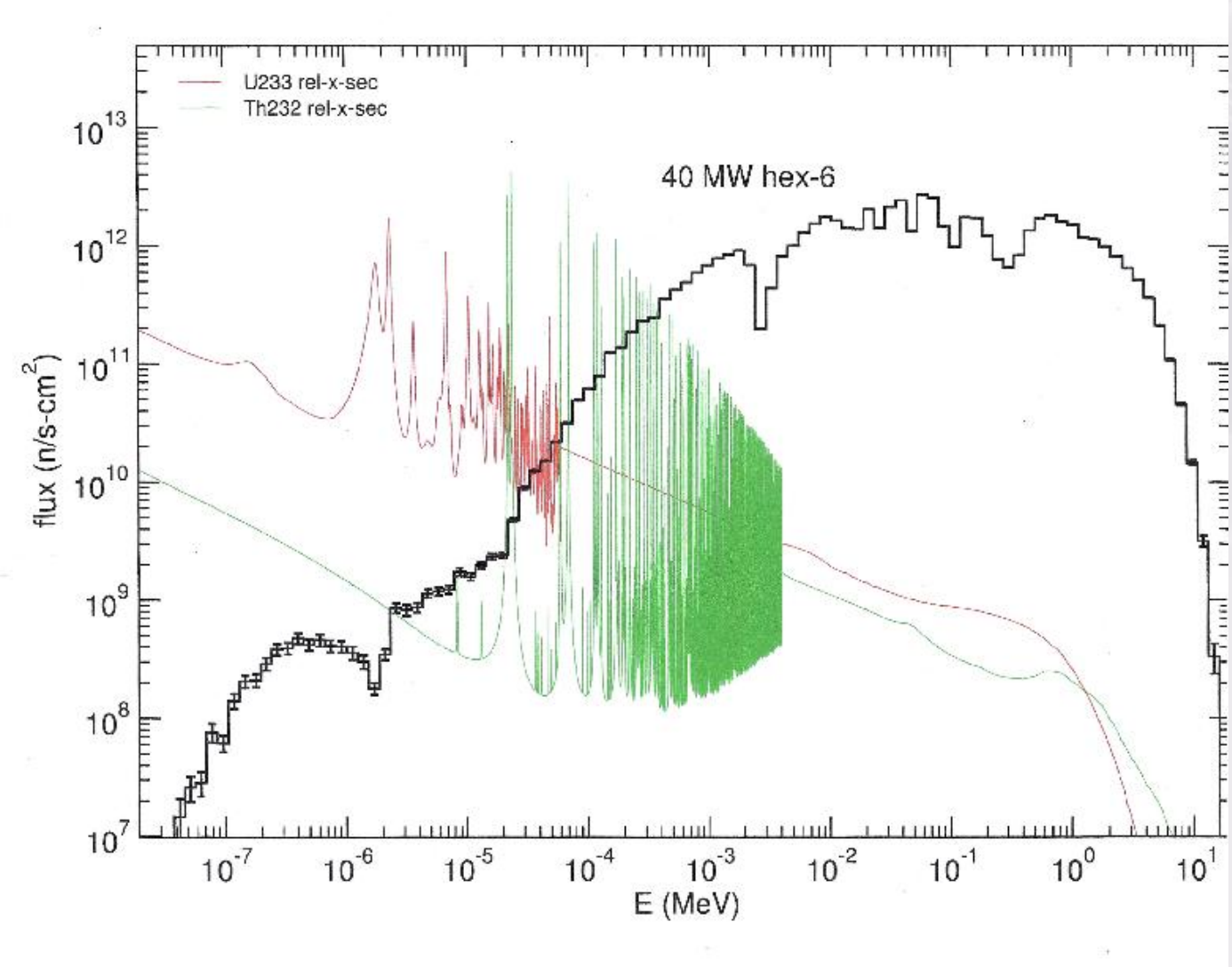


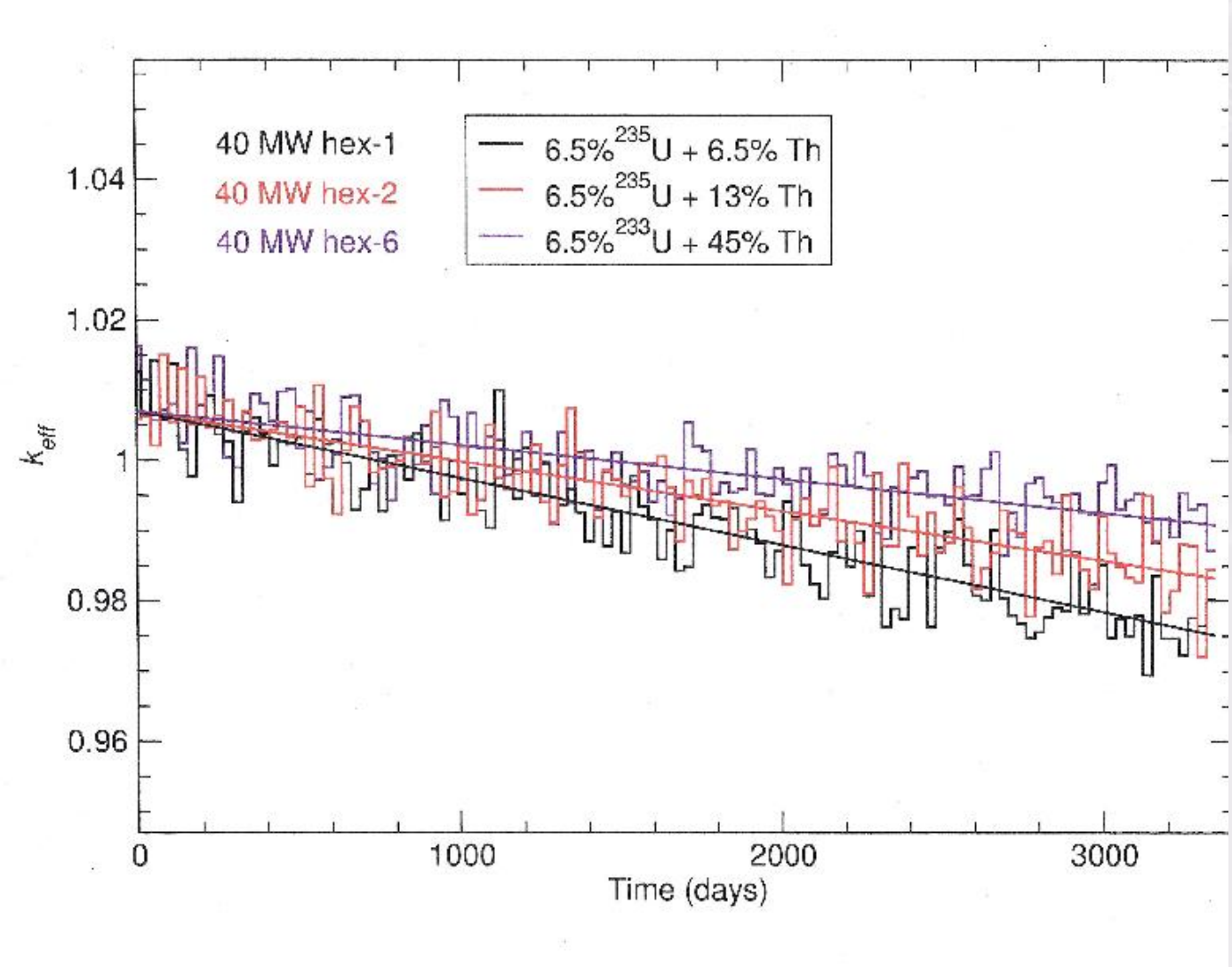
Deep Salt Pool Design



Neutron Spectrum Case 6



K Effective Cases 1,2,6



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

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

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

Active Control Features

- Control rods and Safety rods can be inserted
  - **Into coolant spaces in the honeycomb array**
  - **To reduce k_{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

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

- Restricted Nuclear Technology
- Export Controls
- Regulated Activities
- Thorium Developers consult lawyers become familiar with10 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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