Roadmap
GENERATION IV
nuclear energy systems
TWG-4, Non-Classical

# A Summary of Generation IV Non-Classical Nuclear Systems

## Generation IV Roadmap TW-4, Non-Classical Concepts

Generation IV Roadmap Session II
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# *People Involved in this Work*

- ***TWG-4 Non-Classical Reactor Concepts Members***
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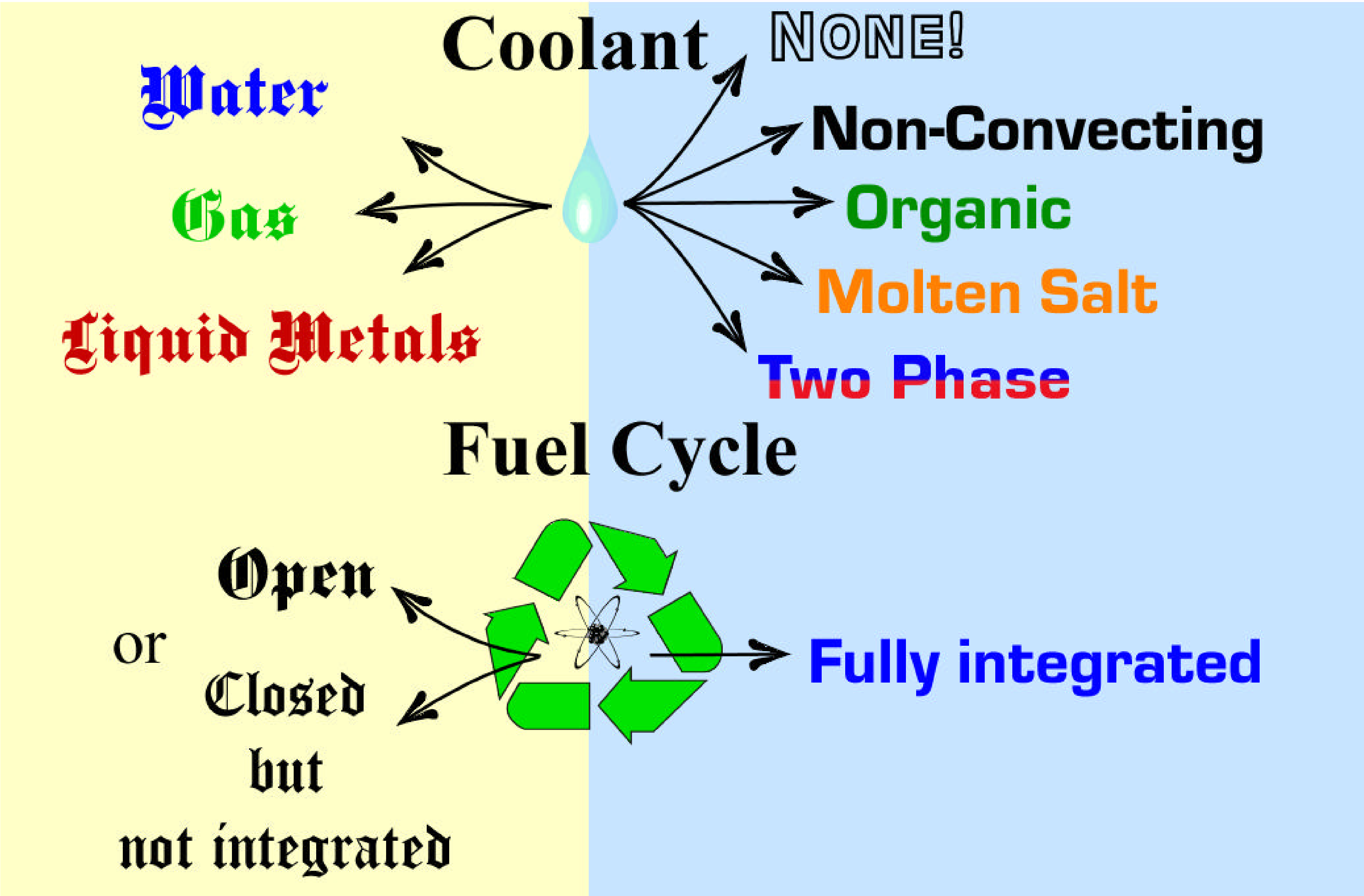
# Classical vs Non-Classical – Coolant & Fuel

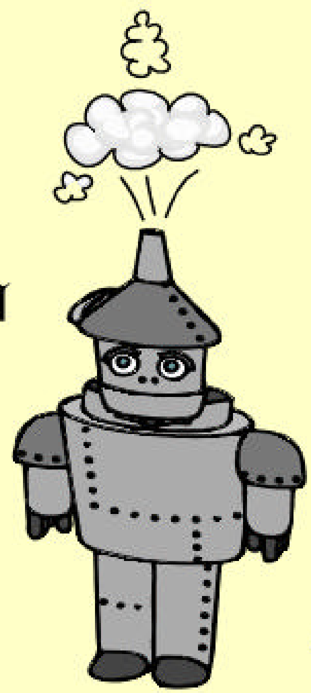


# *Classical vs Non-Classical – Fuel Design*

Classical vs Non-Classical

**Fuel Design**

Solid Clad



No Clad

Liquid

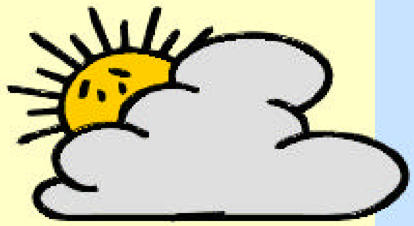
Gas or Vapor

Thin Film

# ***Classical vs Non-Classical – Power***

## Carnot ΔT

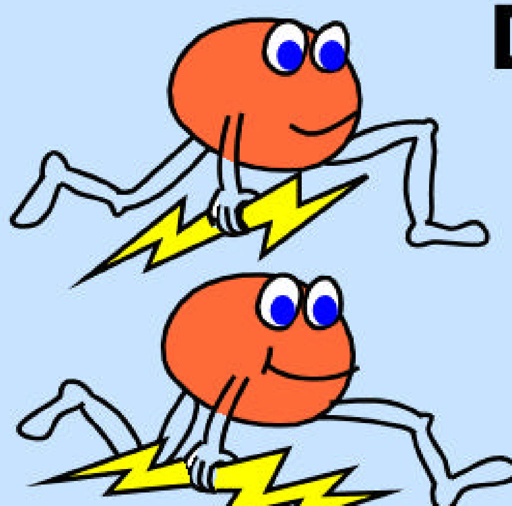
300-1000 K



300-3000 K

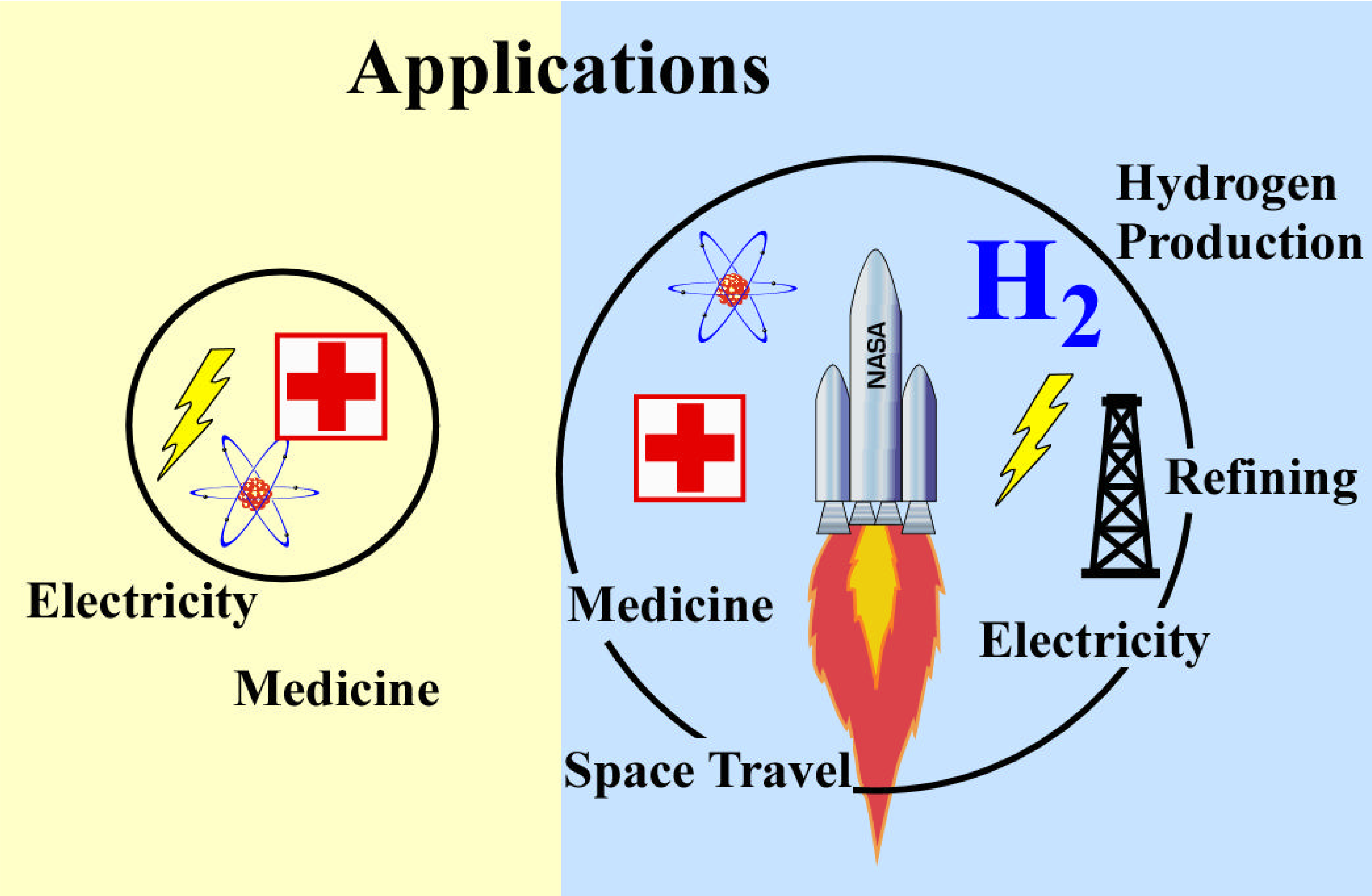
## Power Cycle

Steam
Rankine
or
Brayton



Direct
- MHD
- Thermionic
- AMTEC
- Combined

# Classical vs Non-Classical – Applications



# *Non-Classical* Reactor *Concepts*

- **A total of 32 concepts gathered, among them 28 meet the Generation IV requirement of fission based self sustained criticality.**
- **Based on the primary design features , six "Concept Sets" are defined as:**
  - ***1. Liquid Core Reactors***
  - ***2. Gas Core Reactors***
  - ***3. Non-Conventional Coolant Reactors***
  - ***4. Non-Convection Cooled Reactors***
  - ***5. Direct Energy Conversion Reactors***
  - ***6. Modular Deployable Reactors***
- **Non-Classical reactor concepts feature higher potential to meet or exceed Gen IV performance goals at somewhat lower technology readiness level.**

# ***A Summary of Liquid Core Reactor Concepts***

## Innovative Approaches

***Examples***

### *1. Molten Salt Core*

**HERACLITUS - Circulating fuel, natural thorium molten salt.**

**MSBR - Molten Salt Breeder, liquid uranium and thorium fluorides.**

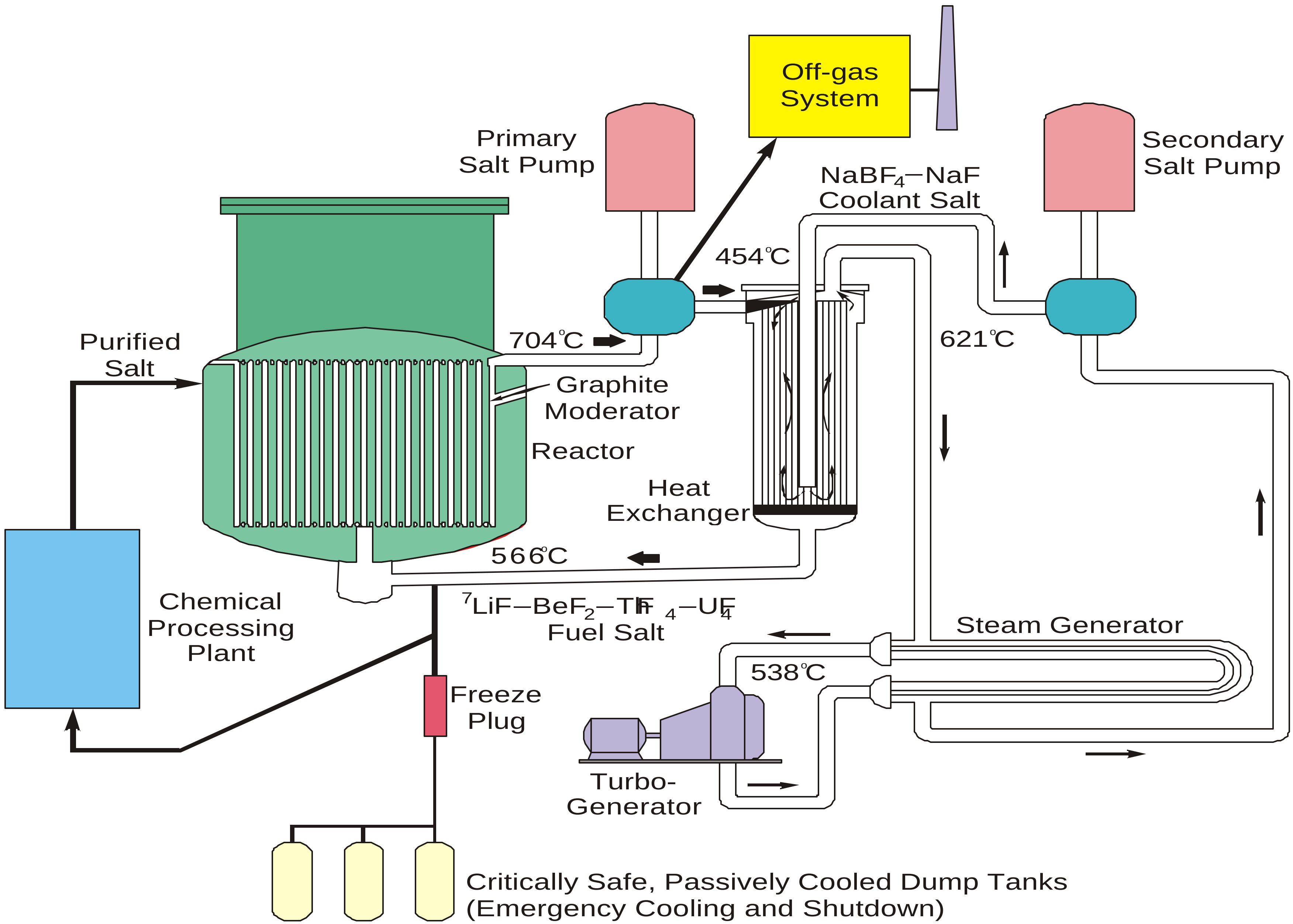
**AMSTER - Actinides Molten Salt Transmuter**

### *2. Liquid Metal Core*

**LM-FR - Liquid Metal Equilibrium Fast Reactor, Mg-Pu Eutectic.**

**MSBR - Molten Salt Breeder, liquid uranium and thorium fluorides.**

# Molten Salt Reactor



# A Summary of Gas Core Nuclear Systems

## Innovative Approaches

*Examples*

### *1. GCR/VCR-MHD*

**$UF_4$ with either KF vapor Rankine cycle or He Brayton cycle.**

**Efficient MHD energy conversion with fission enhanced ionization.**

### *2. GCR-Graphite Wall*

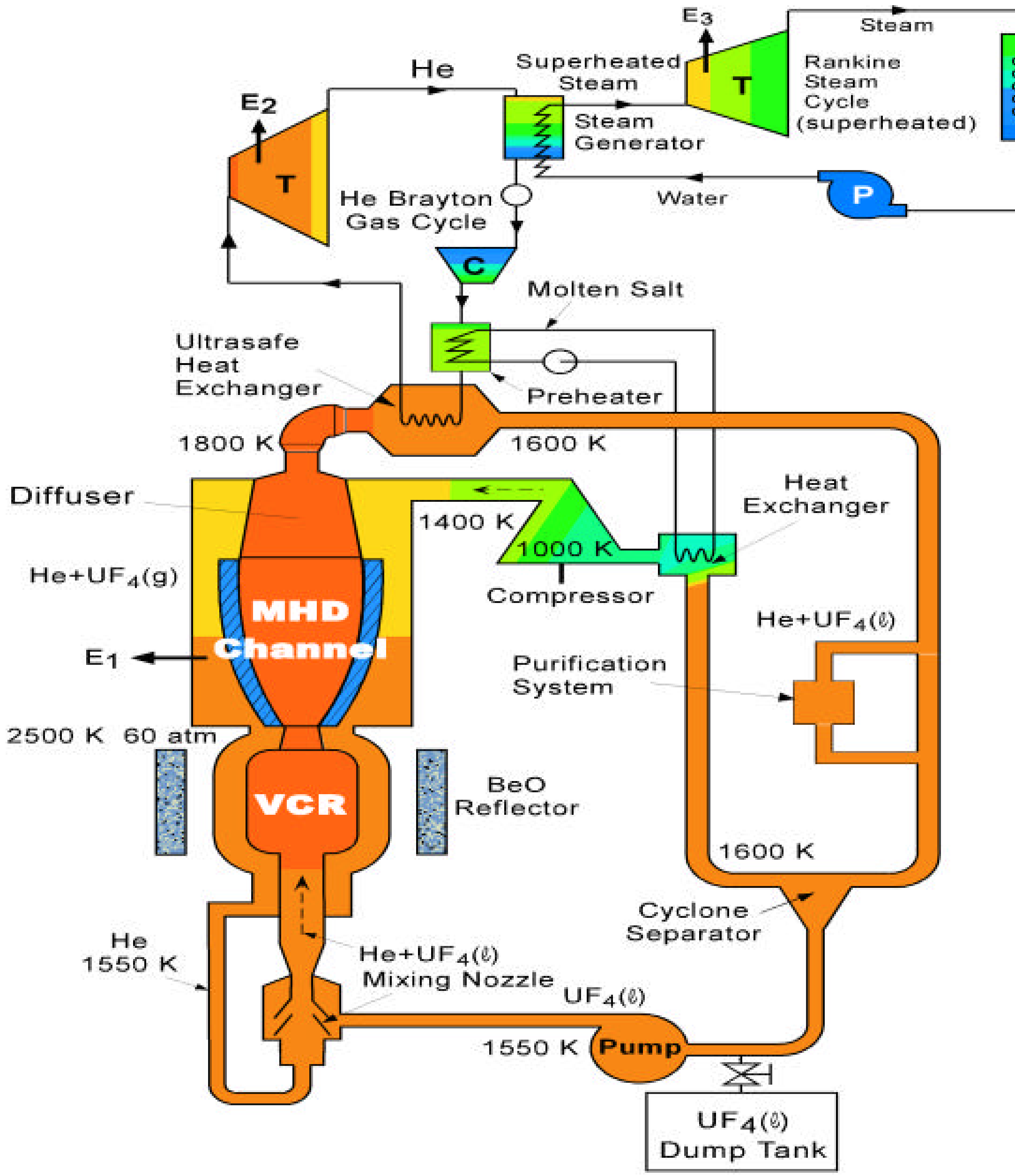
**Neutralizes high temperature wall corrosion.**

### *3. Plasma/Vortex Flow*

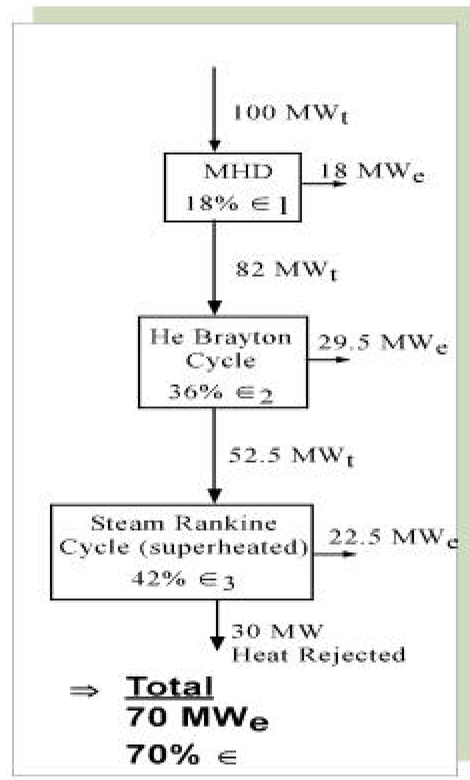
**Varieties of vortex flow GCR's, high T, diverse uses.**

**$UF_6$ or U vapor with He or Argon.**

# Gas Core Reactor Power System




***V**apor **C**ore **R**eactor with Combined Direct/Indirect **E**nergy **C**onversion (VCR-DEC)*




**Thermodynamic Efficiencies and Power Ouputs**

# Liquid and Gas/Vapor Core Reactor Properties

1. Significant advances can be made in conversion efficiency, diversification of energy products, resource utilization and waste minimization.

1. Excellent non-proliferation characteristics due to one to two orders of magnitude lower fuel inventory and plutonium buildup.

3. Minimized source term due to online separation and removal of fission products and ultralow equilibrium concentration of minor actinides.

4. Gas/vapor core reactors could potentially eliminate the need for Offsite Emergency Planning, which is a key safety goal for the Gen IV reactors.

5. Many technology challenges; high temperature materials, energy conversion, dynamics and control, remote operation, fuel chemistry and fuel handling, fission product separation, and safety.

# A Summary of Non-Conventional Cooled Reactor Concepts

## Innovative Approaches

*Examples*

### *1. AHTR - Advanced High T Reactor*

**Graphite Matrix - Molten Salt Cooled.**

**High temperature diverse uses.**

### *2. OCR - Organic Coolant Reactors*

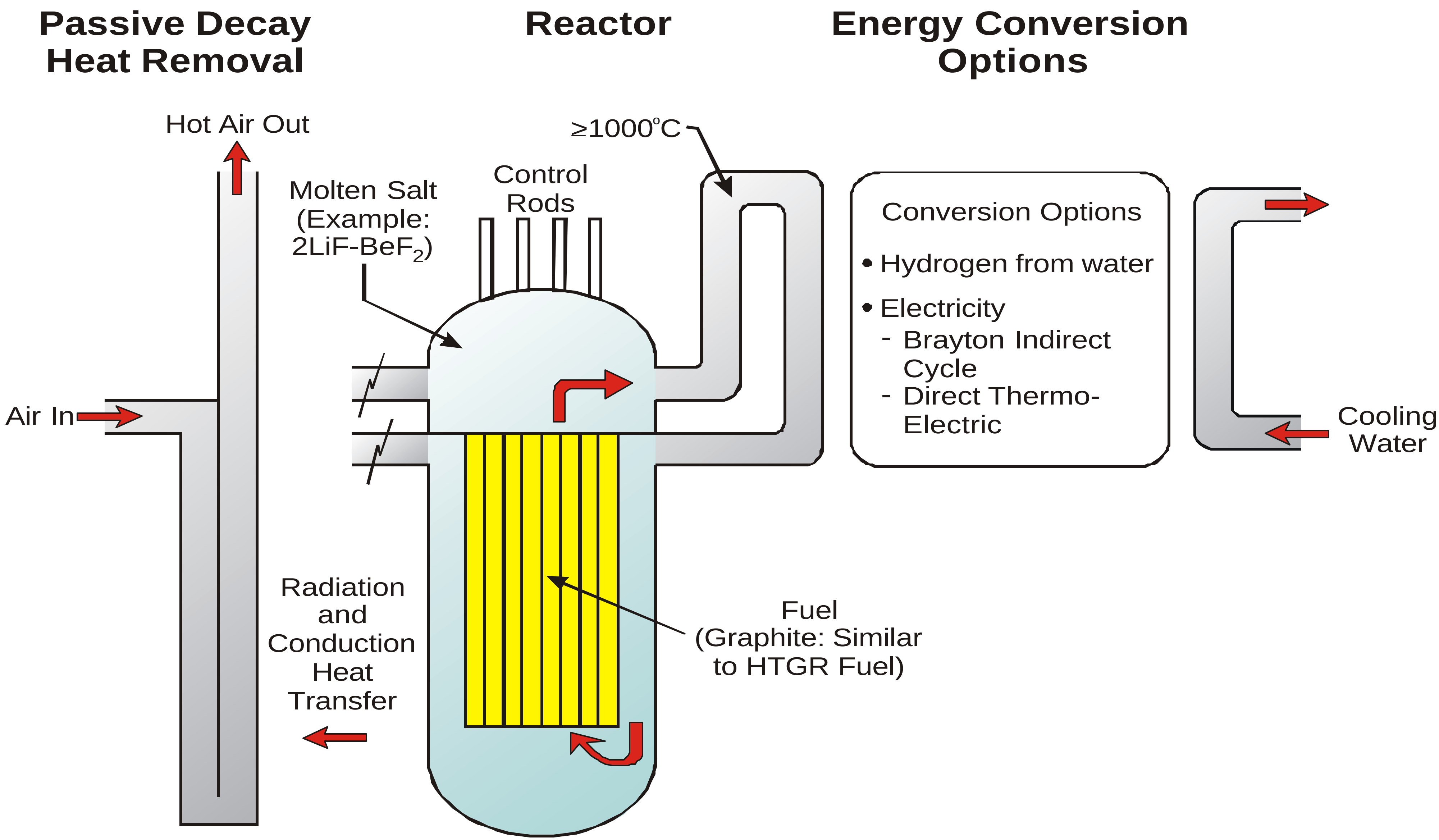
**Cheaper efficient cooling, reduced costs.**

### *3. FSEGT - Sodium Evaporation*

**Fast reactors, sodium evaporation cooling.**

**Unique sodium vapor gas turbines.**

# AHTR, Molten Salt Cooled Reactor



# Non-Conventional Cooled Reactor Properties

## 1. Molten Salt Cooled Reactors

Significant advances can be made in conversion efficiency, and diversification of energy products.

High temperature operation at low pressure, low power density, high heat capacity.

High temperature materials, fuel design, molten salt to water heat exchanger, mixed nuclear/hydrogen safety issues.

## 2. Organic Cooled Reactors

High conversion ratio, superior coolant properties, low pressure operation, lower cost coolant (compared to CANDU).

Fuel (UC) reaction with water and air, coolant flammability, coolant fouling, coolant radiolysis, reactivity coefficients.

# ***A Summary of Non-Convection Cooled Concepts***

## Innovative Approaches

***Examples***

1. ***Solid State-Heat Pipe Cooled***

## Non-Convection Cooled Reactor Properties

**Low fuel inventory, static energy conversion, small scale power applications, remote site applications.**

**High temperature fuels and materials, lifetime of energy conversion unit, dynamics and control, fuel cycle.**

# A Summary of Direct Energy Conversion Reactor Concepts

## Innovative Approaches

*Examples*

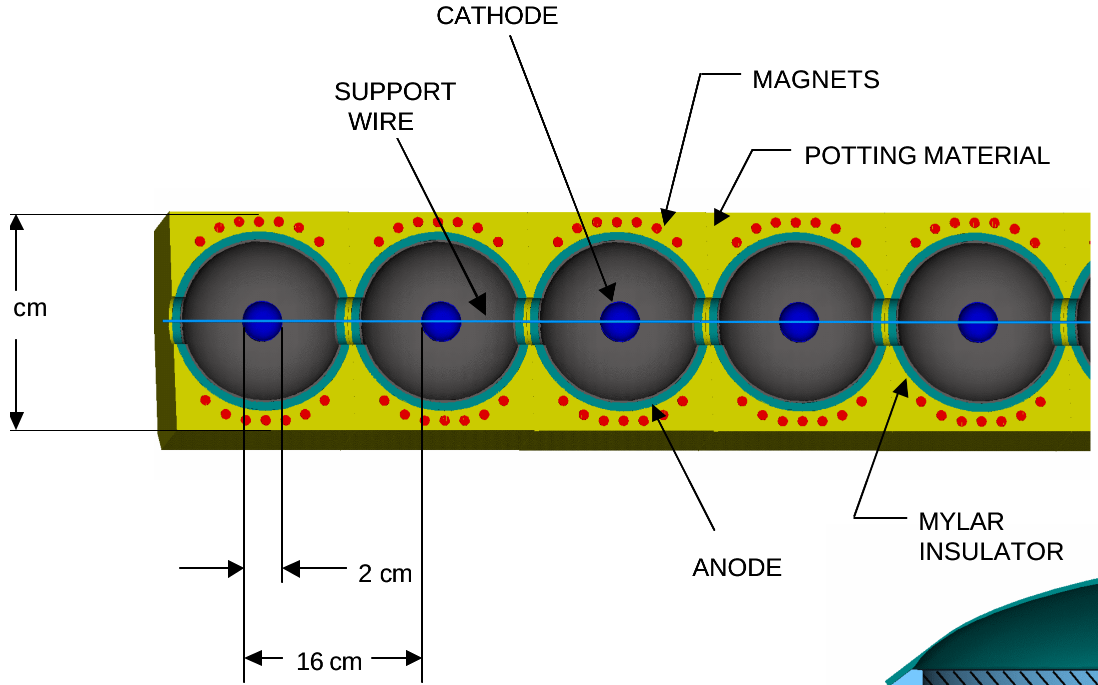
### *1. QSMC - Quasi-Spherical Fission Magnetic Cell*

Direct conversion of fission fragment energy.
Cells coated with thin film of fissionable fuel.
Radiation cooling.

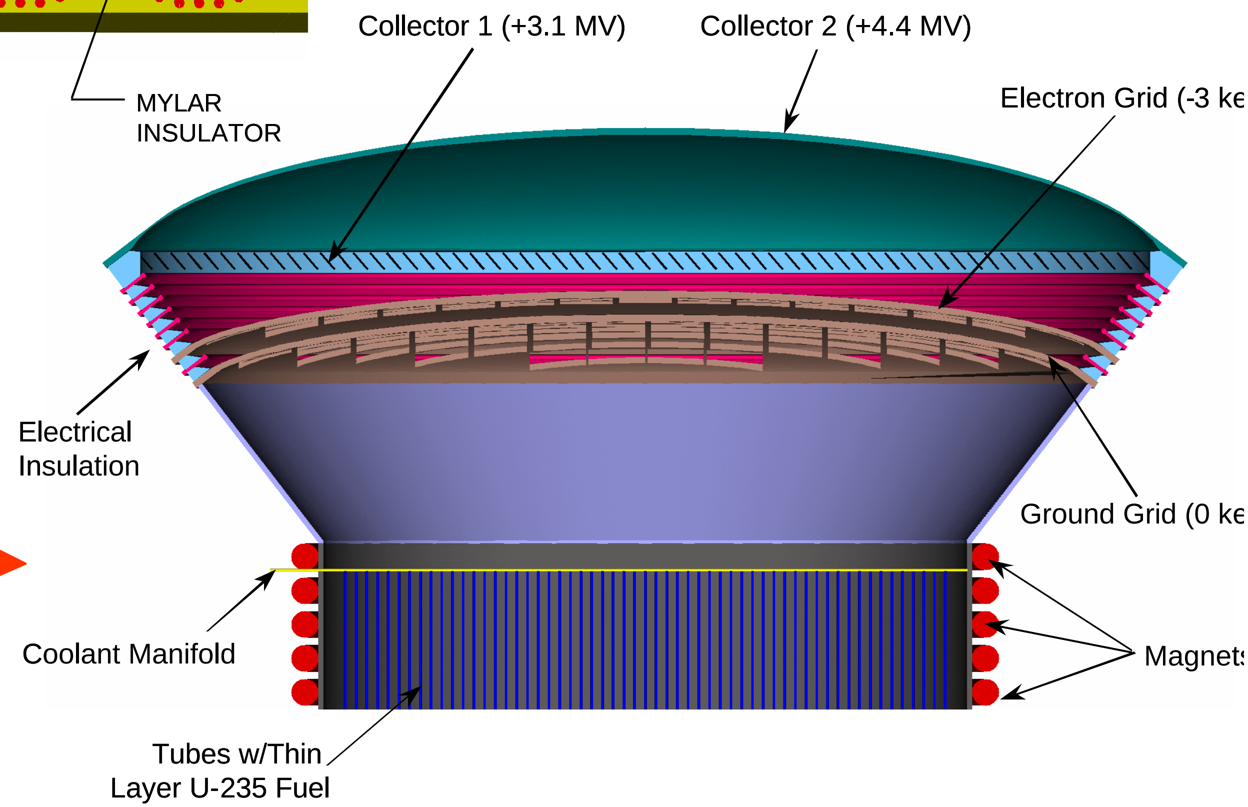
### *2. FFMC - Fission Fragment Magnetic Collimator*

Magnetically guided fission fragment trajectories.
Thin films of $UO_2$.
Heavy water coolant.

# Direct Energy Conversion Schematics




Array of fission cells




Venetian blind collector

# Direct Energy Conversion Reactor Properties

1. Low fissile inventory, proliferation resistant, no moving parts, no coolant, no flow, barely critical.

2. Hard to make critical, large systems, very low burnup, magnet design, direct energy conversion.

# ***A Summary of Modular Deployable Reactor Concepts***

## Innovative Approaches

***Examples***

***1. MMDR - Multi-Modular Deployable Reactor***

**Modular construction, factory built.**
**Transportable, easily assembled**

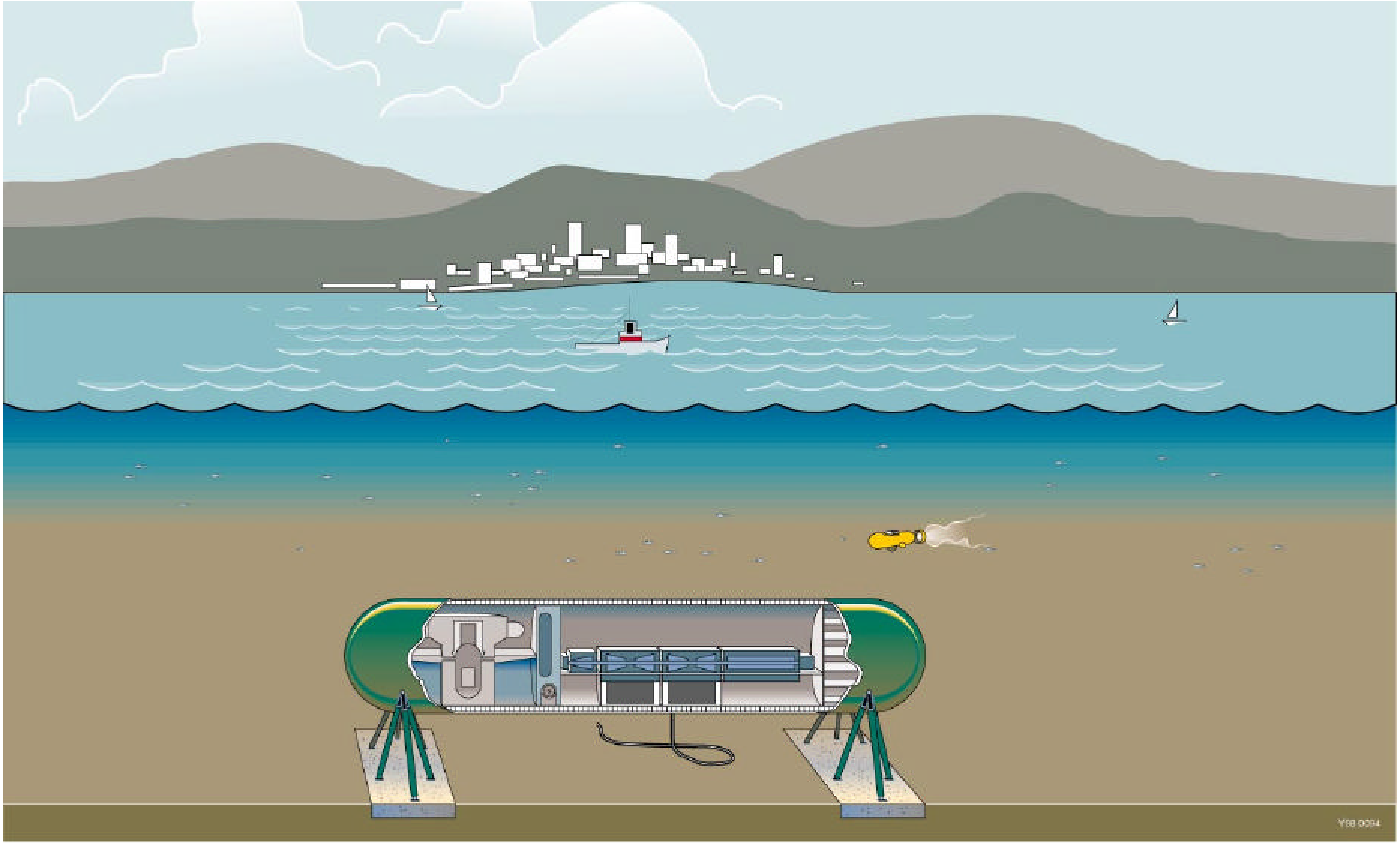
***2. SPS - Submersible Power Station***

**Transportable, modular undersea siting.**
**Coastal siting niche.**

***2. DORC - Distantly Operated Reactor Complex***

**Remotely operated.**
**Liquid metal cooled.**

# Modular Deployable Nuclear Systems



# *Summary*

1. **Despite many technology gaps and data uncertainties, there is no lack of innovation and revolutionary ideas in Non-Classical reactor concepts.**
2. **Several concepts such as gas/vapor core reactors offer promising advances toward the Gen IV goals for sustainability, safety, and economy, and have potential for making significant inroads toward achieving the optimum utilization of nuclear energy.**
3. **Gas/vapor core reactors set the upper performance potential in sustainability and safety with no insurmountable technology challenge.**
4. **Evaluations of modular deployable concepts are underway.**
5. **Direct energy conversion and non-convective cooled nuclear reactor systems are eliminated from further evaluation process.**