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Fusion-Fission Hybrid Systems

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Fusion-Fission Hybrid Systems

Hybrid Presentation Outline

- Functions
- Options and features
- Examples
- Future steps

Fusion-Fission Hybrid Systems

Functions:

- Burner (Transmuter) and Energy Production
  - Fission transuranics and produce energy, or
  - Fission transuranics without Plutonium and produce energy
  - Transmute long lived fission products
- Fissile Breeding
  - Breed Pu from U-238 or U-233 from Th
- Energy Production
  - Produce energy from natural or depleted uranium, or thorium
- Tritium Breeding
  - Breed tritium for the fusion driver operation

The hybrid systems of this presentation perform simultaneously the highlighted functions

Fusion-Fission Hybrid Systems

Performance Adventages Relative to Other Nuclear Systems:

- Complete utilization of the tranuranics
- Transmute simultaneously the long lived fission products as much as possible
- Eliminate or reduce significantly the need for a long-term geological storage
- Utilize existing developed technologies and operational procedures as much as possible
- Eliminate the need for additional fuel processing steps
- Minimize the required fusion power
- Avoid structure damage issues
- Maintain constant peak performance during operation

Technical Issues of Hybrid Fuel Forms

- Solid Form
  - Development and qualification are needed
  - Burnup limit and the D-T neutron damage impact the performance
  - Clad irradiation damage from the D-T neutrons limit the utilization
  - Processing steps for material recovery are required
  - Storage is needed for the unutilized materials
- Fluid Form (salt or liquid metal carriers)
  - Salt or liquid metal can be used
  - Transuranics can be dissolved or suspended (TRISO type particles) in the carrier
  - Solubility limits for actinides and fission products are adequate
  - Material compatibility with the structure material limits the choices
  - MHD issue of liquid metal requires a separate coolant for heat removal
  - Fluid chemistry control is required

Tritium Breeding and Heat Removal

Tritium Breeding

- The hybrid system has to produce its tritium fuel
- Separate tritium breeding modules can be used
  - *Breeding modules between or behind the fission modules*
  - *Breeding materials and tritium recovery methods have been developed for fusion power blankets*
- Integrated tritium breeding function with the fission modules (Example: FLIBE salt and lithium lead eutectic)

Coolant Design Option

- Self-cooled or separate coolant option for the salt carrier
- Separate coolant option for the liquid metal carrier (MHD issue)

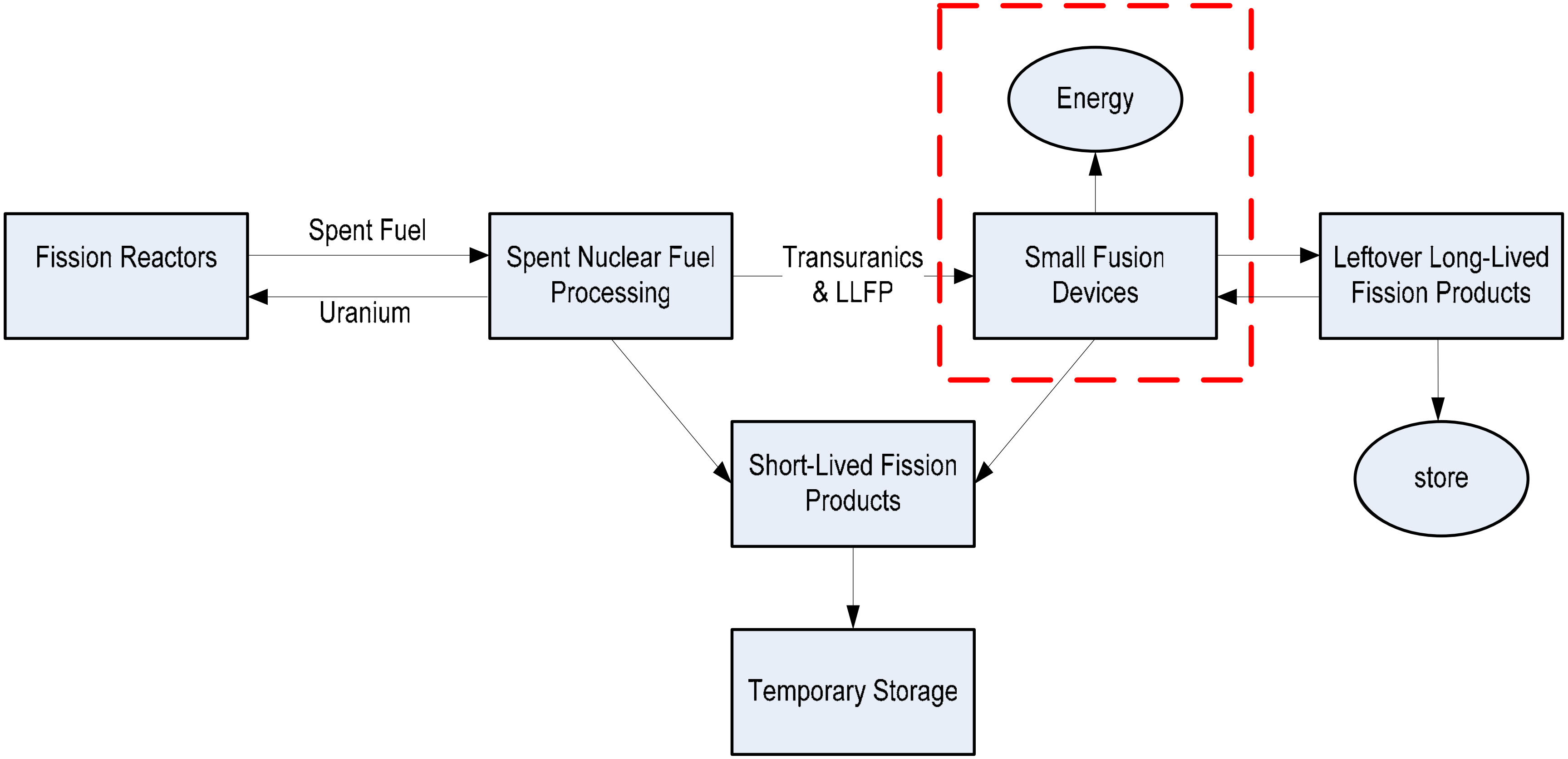
US Commercial Spent Nuclear Fuel Inventory

- **In 2015, the estimated U.S. inventory of spent nuclear fuel is 70,000 tons, which compose of:**

Uranium	66872 tons
Short-lived fission products	2279 tons
Transuranics	689 tons
Long-lived fission products	160 tons

- **The spent nuclear is processed to remove the uranium isotopes and short-lived fission products.**
- **The transuranics, long-lived fission products, and 3.3 tons of uranium (Separation efficiency of 99.995 w%) can be used in fusion drivers.**

Spent Nuclear Fuel Disposal Flow Chart Using Fusion Drivers



Hybrid Example

A fusion driver using lead carrier with continuous feed of transuranics and long lived fission products with constant fusion power has the following performance:

Transuranic utilization, Kg/MW.y of fusion neutron power	**68.0**
Long-lived fission products transmutation, Kg/MW.y	**8.50**
Number of fission reactions per D-T neutron	**10.65**
Fusion neutron power for utilizing the actinides of 70000 tons of spent nuclear fuel over 40 full power years, MW	**253**
Fusion neutron power per hybrid transmuter assuming 15 drivers each generating 1 GW_e per driver, MW	**16.9**
Total transuranic utilization, tons	**689**
Total long-lived fission products transmutation, tons	**86**

Tritium breeding need to be added

Neutronic Performance of Lithium-lead Eutectic Carrier Normalized to D-T Source Neutrons (60-cm Blanket with graphite Reflector)

K_{eff}	0.979	0.944
k_s	0.991	0.974
^{6}Li enrichment (%)	0.19	1.0
$\Sigma_f\varphi$	36.9	12.3
$\nu\Sigma_f\varphi$	108	36.0
Multiplication	2.01	1.7
$\Sigma_a\varphi$	64.5	22.7
TBR	1.16	1.74
Leakage	8.65	2.87

The neutron multiplication is much more than $1/(1-K_{eff})$

Fusion Transmutation Example (continued)

- Lead-bismuth fuel carrier has better performance than lead. It has been used as fission reactor coolant and spallation target for generating neutrons for accelerator driven systems. At present, It is under development around the world for accelerator driven systems.
- The 70000 tons of spent fuel can be disposed of with the use of fifteen small fusion drivers. Each has a fusion neutron power of 16.9 MW operating for 40 full power years. The neutron wall loading of such hybrid driver is less than $\underline{0.1\ \mathrm{MW/m^2}}$, which simplifies the design and avoid the first wall replacement requirements.
- Each driver will generate about 1 GW_e. The generated power represents a 15% increase in the US nuclear power generation without adding CO_2 or spent nuclear fuel to the environment.

Future steps

- Define goals and minimum requirements for the hybrid system
- Define key parameters and a geometrical configuration of the hybrid system for initial studies
- Define two fusion blanket configurations (inside and outside the TF coils) for the initial studies
- Select two fuel carrier (liquid metal and salt) for performing comparison study and define related issues and future analyses
- Perform initial set of analyses to define the performance parameters of the selected hybrid systems
- Utilize the obtained results for system studies and initial comparison
- Based on the obtained results re-examine the hybrid parameters and blanket configurations for detailed design analyses

Hybrid Coolants

- **Gas, liquid metal, or salt can be considered.**
- **Gas has low (ρ Cp), which has adverse effect on the hybrid design.**
- **Liquid metal has the most favorable design characteristics, however, the main issue is the MHD problem. A separate coolant is required.**
- **In general, salts have higher melting point, limit the structural material selection, and produce softer neutron spectrum relative to liquid metals.**
- **The salt carrier requires chemistry control to avoid corrosion and remove short term fission products.**
- **FLIBE salt and lithium-lead eutectic have a good data base and it is under consideration for fusion blankets as a tritium breeder and coolant.**
- **Pb-Bi has been used to cool fission reactors and tested for accelerator driven systems as a target material and coolant.**
- **Other salts and liquid metals have been proposed for such applications and deserve considerations.**