# Environmental Aspects of Recent Trend in Managing Fusion Radwaste: Recycling and Clearance, Avoiding Disposal

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# Handling Fusion Radioactive Materials is Important to Future of Fusion Energy

- **Background**: Majority of fusion power plants designed to date focused on disposal of active materials in repositories, adopting fission waste management approach preferred in 1970's.

- **New Strategy**: Develop new framework for fusion:
  - Minimal radwaste should be disposed of in ground
  - Recycle* and/or clear# all active materials, if technically and economically feasible.

- **Why?**
  - Limited capacity of existing low-level waste repositories
  - Political difficulty of building new repositories
  - Tighter environmental controls
  - Minimize radwaste burden for future generations.

- **Applications**: Any fusion concept (MFE & IFE); power plants and experimental devices.

- **Impact**: Promote fusion as nuclear source of energy with minimal environmental impact.

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* Reuse within nuclear industry.

\# Unconditional release to commercial market to fabricate as consumer products.

# U.S. Repositories

- **High-level waste (HLW) repositories:**
  - **Hanford** facility in Washington:
    - In operation since 1960.
    - 67,000 $m^3$ capacity.
  - **Yucca Mountain** repository in Nevada:
    - Planned to open in March 2017.
    - Total life cost $70B (originally estimated at $27B).
    - Capacity 70,000-120,000 tons

      (fission reactors generates 2,000 tons/y; 55,000 tons currently stored in 39 states).
    - Still needed even with fission spent fuel recycling program.
    - **Not politically acceptable**!

# U.S. Repositories (Cont.)

- **Low-level waste (LLW) repositories**:
  - **Barnwell facility** in South Carolina:
    - 1971 – 2038.
    - Class A, B, C* LLW.
    - Supports east-coast reactors and hospitals.
    - Will severely curtail amount of LLW received in July 2008.
    - 36 states will lose access to Barnwell on 7/1/08, having no place to dispose 91% of their Class B & C LLW.
  - **Richland facility** in Washington:
    - Class C LLW.
    - 125,000 $m^3$ capacity.
    - Supports 11 northwest states.
  - **Clive facility** in Utah:
    - Class A LLW only.
    - Disposes 98% of U.S. Class A waste volume

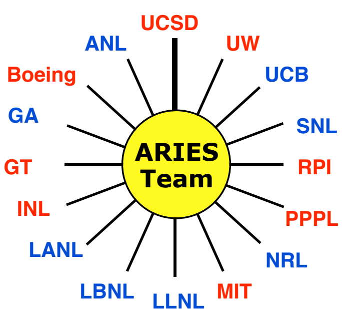
      (does not accept sealed sources or biological tissue waste – a great concern for biotech industry).

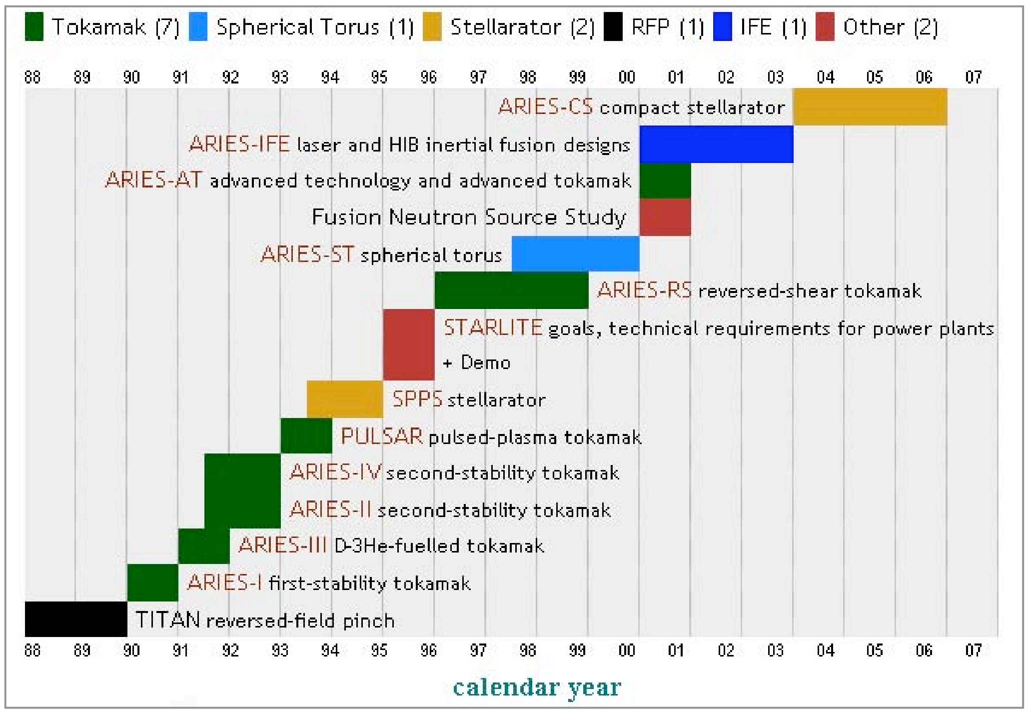
* 0.1, 2, and 7 $Ci/ft^3$ for Class A, B, and C waste, respectively.

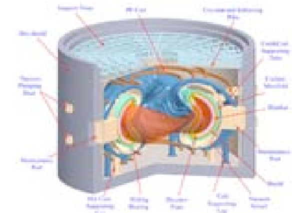
# U.S. Needs National Solution for LLW Problem

- LLW disposal is state responsibility, but no state would accept to be "nuclear dump ground" for the nation.
- Several states tried to developed disposal sites, then changed their mind because of strong opposition from public and environmentalists.
- Idaho state asked DOE to remove LLW stored at INL and ship it out of state.
- Utah state refused to open new Class C repository.
- Some utilities store LLW on site because of limited and expensive offsite disposal options.
- As near-term solution, DOE opened its disposal facilities to commercial LLW.
- **Nuclear Regulatory Commission (NRC)**:
  - Favors permanent disposal instead of indefinite, onsite storage, but there is no estimate of how long it would take to develop disposal facility.
  - Future availability of disposal capacity and disposal cost under current system remain highly uncertain.

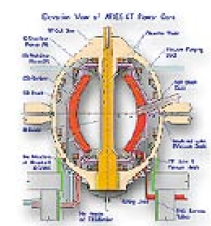
# ARIES Designs
(1988-2007)

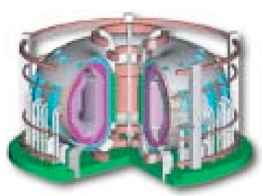




ARIES-CS


ARIES-AT *

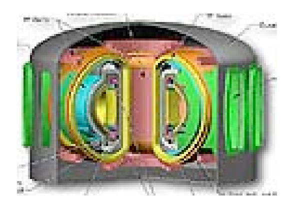

ARIES-ST *


ARIES-I


ARIES-III


ARIES-IV

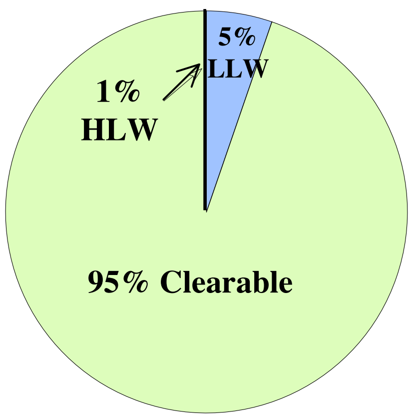

SPPS


ARIES-RS

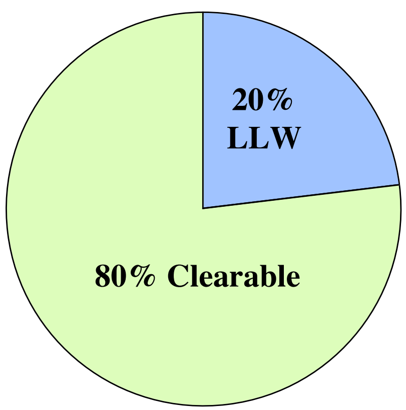
# Fusion Generates Large Amount of LLW that Fills Repositories Rapidly

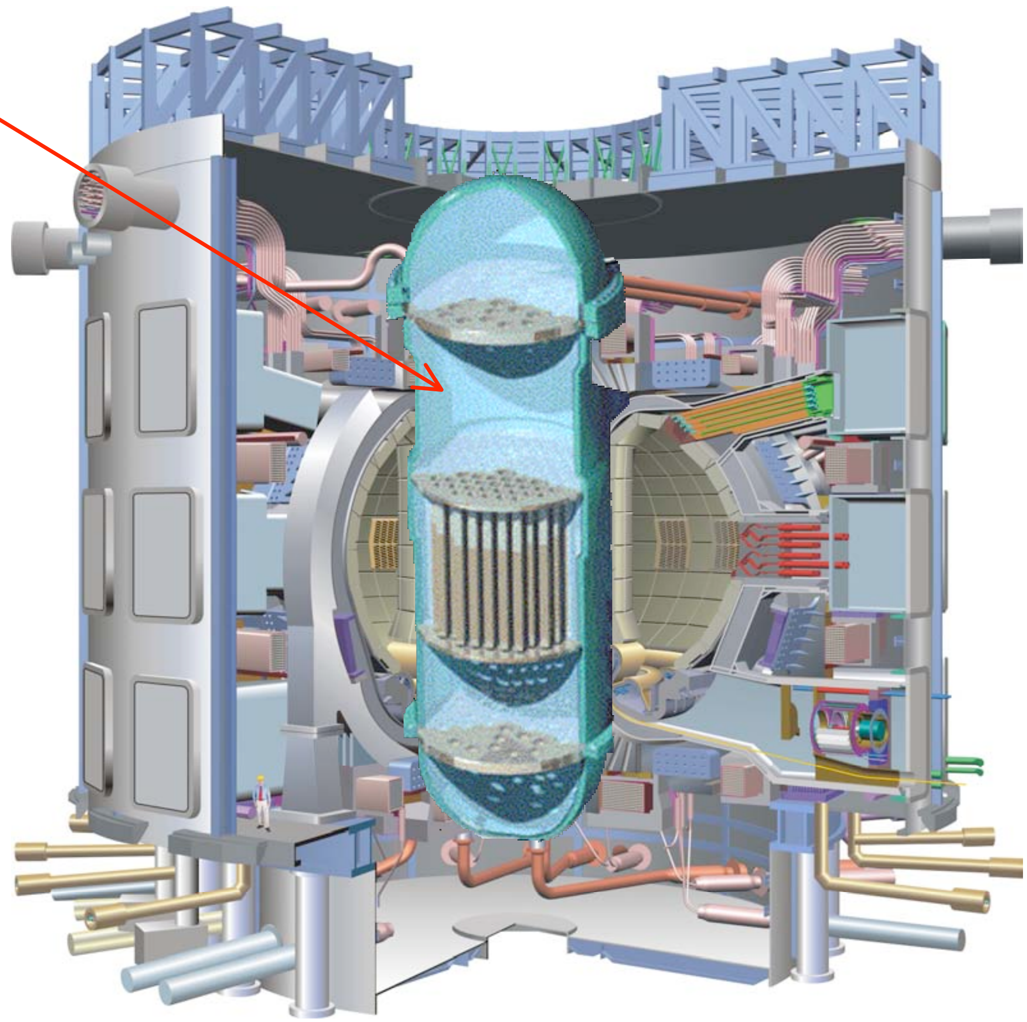
**Economic Simplified Boiling Water Reactor (ESBWR) - Gen-III$^{+}$**
**Reactor Vessel: 6.4 m ID, 21 m H**

**Fission**



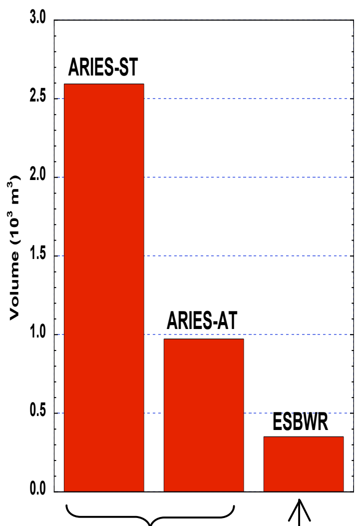

**Fusion**



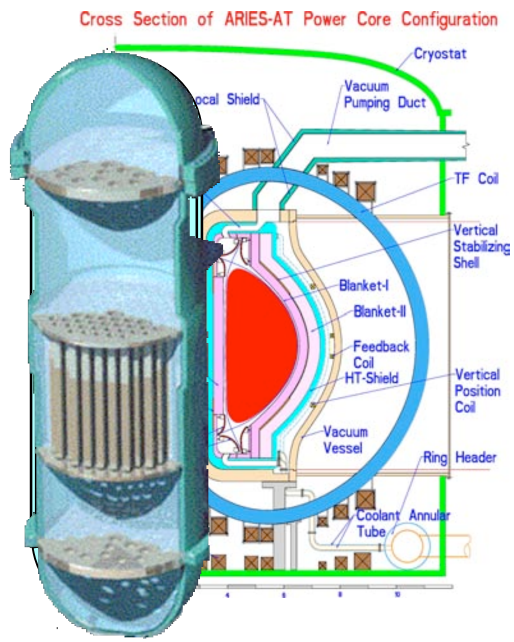
**ITER**

# Fusion Generates Large Amount of LLW that Fills Repositories Rapidly (Cont.)

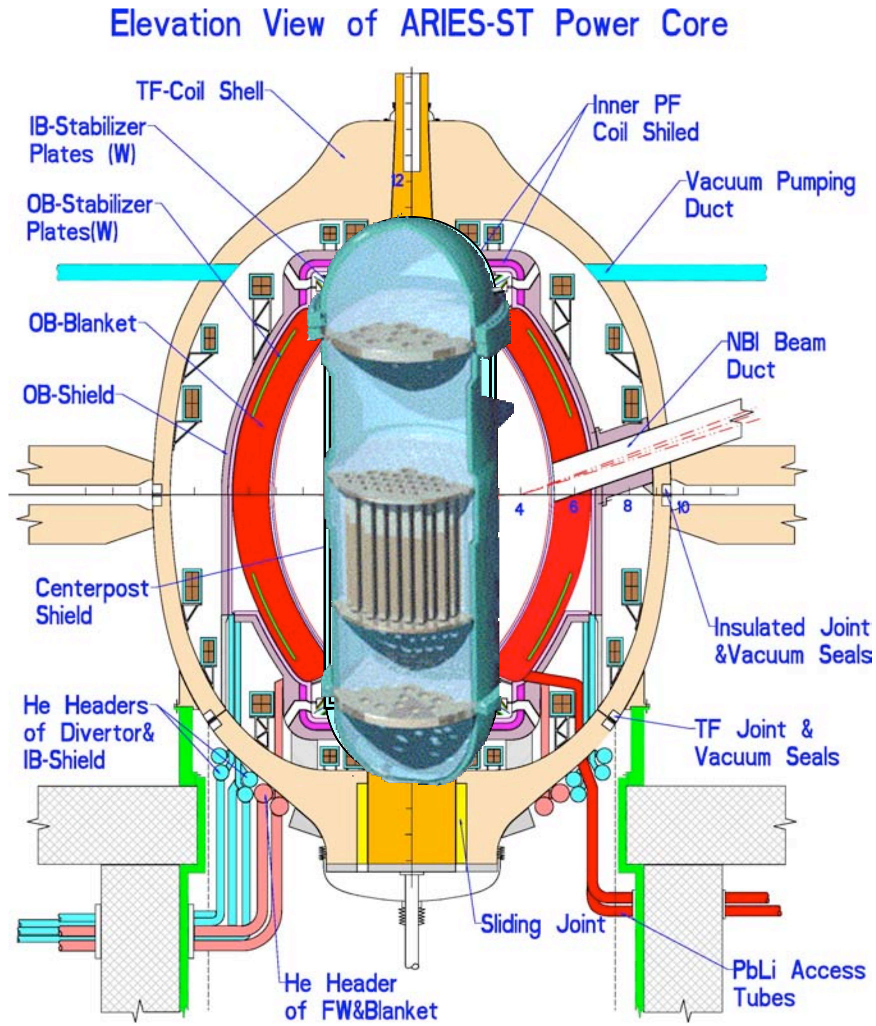



**Class A & C LLW**
(active for 100s y)

**HLW** w/ TRU (active for 10,000 y)
**& Class C LLW**




**ARIES-AT**
**Advanced Tokamak**




**ARIES-ST Spherical Tokamak**

# What We Suggest

- **Business as usual is not environmentally attractive option. Something should be done.**

- Fusion designs should adopt **MRCB** philosophy:

  **M** – Minimize volume of active materials by design.

  **R** – Recycle*, if economically and technologically feasible.

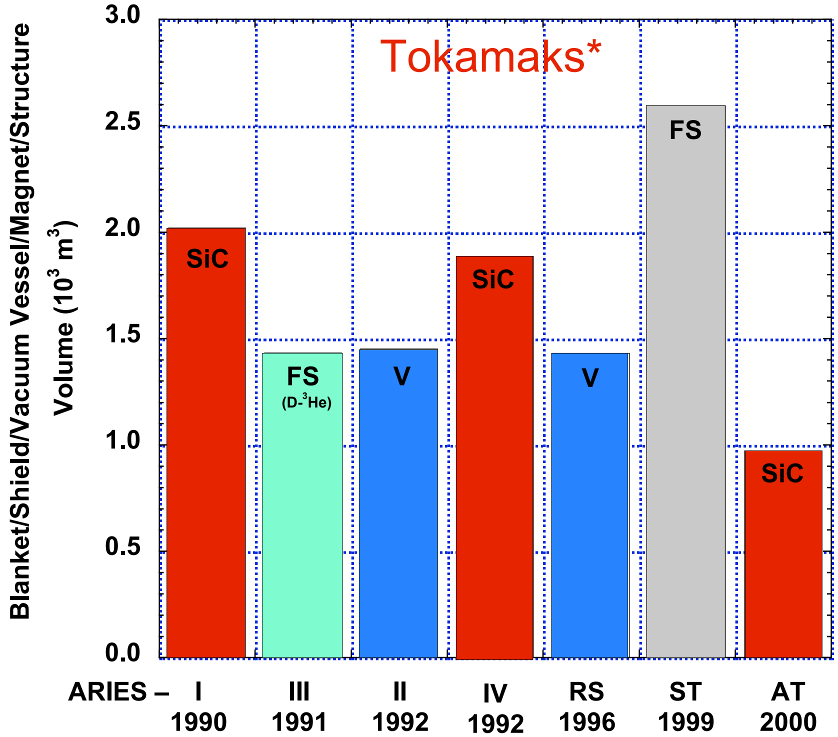
  **C** – Clear# slightly-irradiated materials.

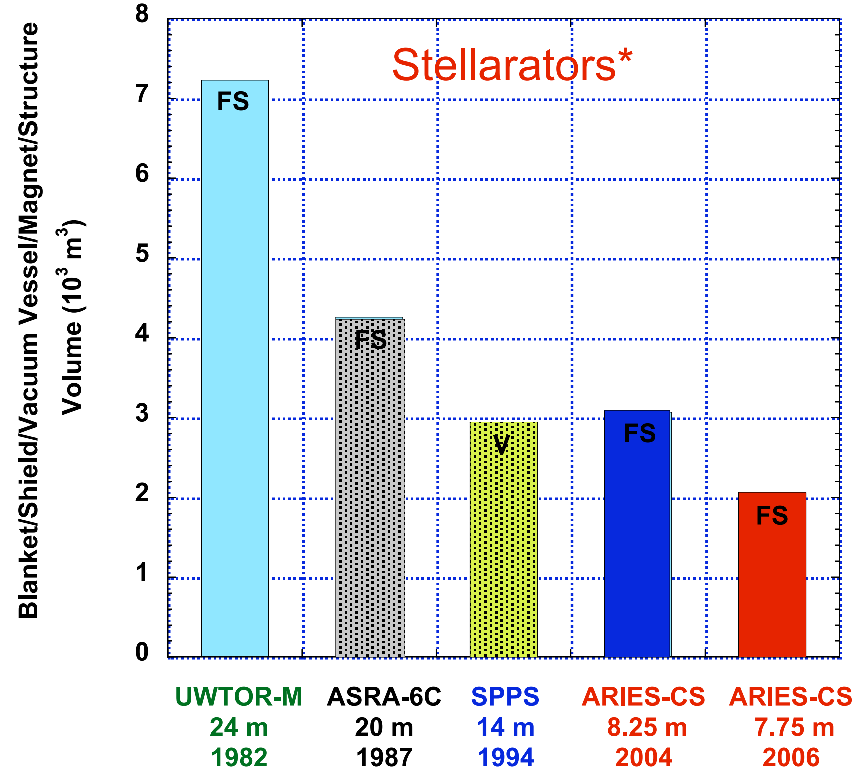
  **B** – Burn active byproducts, if any, in fusion devices@.

* Reuse within nuclear industry.
\# Unconditional release to commercial market to fabricate as consumer products.
@ L. El-Guebaly, "Managing Fusion High Level Waste – a Strategy for Burning the Long-Lived Products in Fusion Devices," *Fusion Engineering and Design*, **81** (2006) 1321-1326.

# Radwaste Minimization

# ARIES Project Committed to Radwaste Minimization




Tokamak waste volume halved over 10 y study period

Stellarator waste volume dropped by 3-fold over 25 y study period

* Actual volumes of components (not compacted, no replacements).

# Disposal, Recycling, and Clearance

# Disposal, Recycling, Clearance Approaches Applied to Recent Fusion Studies
## (**red** indicates preference)

| | Components | Recycle? | Clear? | Dispose of @ EOL? |
|---|---|---|---|---|
| **IFE**: | | | | |
| **ARIES-IFE** | **Targets**[#] | no (for economic reasons) | yes / no | **yes** (as Class A) |
| **Z-Pinch-IFE** | **RTL**[*] (carbon steel) | **yes** (a *must* requirement) | yes | yes (as Class A) |
| **MFE**: | | | | |
| **ARIES-CS**[@] | **all** | **yes** | yes / no | yes (as Class A & C) |

# L. El-Guebaly, P. Wilson, D. Henderson, and A. Varuttamaseni, "Feasibility of Target Materials Recycling as Waste Management Alternative," *Fusion Science & Technology*, **46**, No. 3, 506-518 (2004).

* L. El-Guebaly, P. Wilson, and M. Sawan, "Activation and Waste Stream Analysis for RTL of Z-Pinch Power Plant," To be published in *Fusion Science & Technology*.

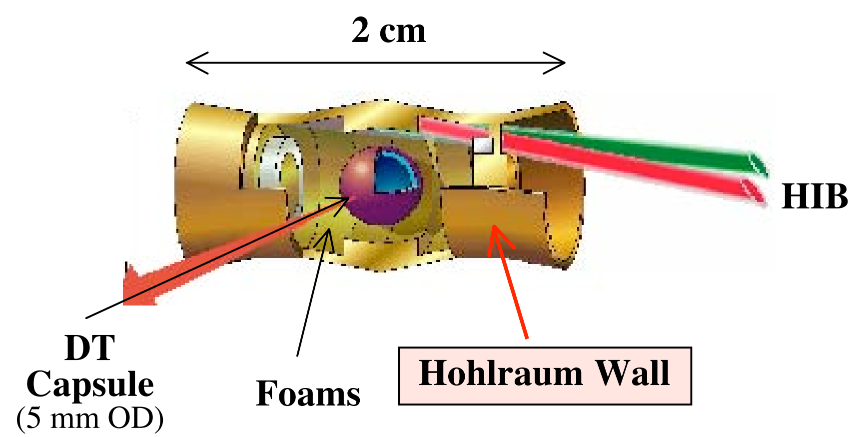
@ L. El-Guebaly et al., "Designing ARIES-CS Compact Radial Build and Nuclear System: Neutronics, Shielding, and Activation," To be published in *Fusion Science and Technology*.

# Economics Prevent Recycling of ARIES-IFE-HIB Hohlraum Wall

| | One-Shot Use Scenario | Recycling Scenario |
|---|---|---|
| **Cost per Target** | **$ 0.4** | **$ 3.15** |
| **Incremental Change to COE** | ~ 10 mills/kWh | ~ 70 mills/kWh |
| **Cost of Electricity (COE)** | **~ 70 mills/kWh** | **~ 130 mills/kWh** |

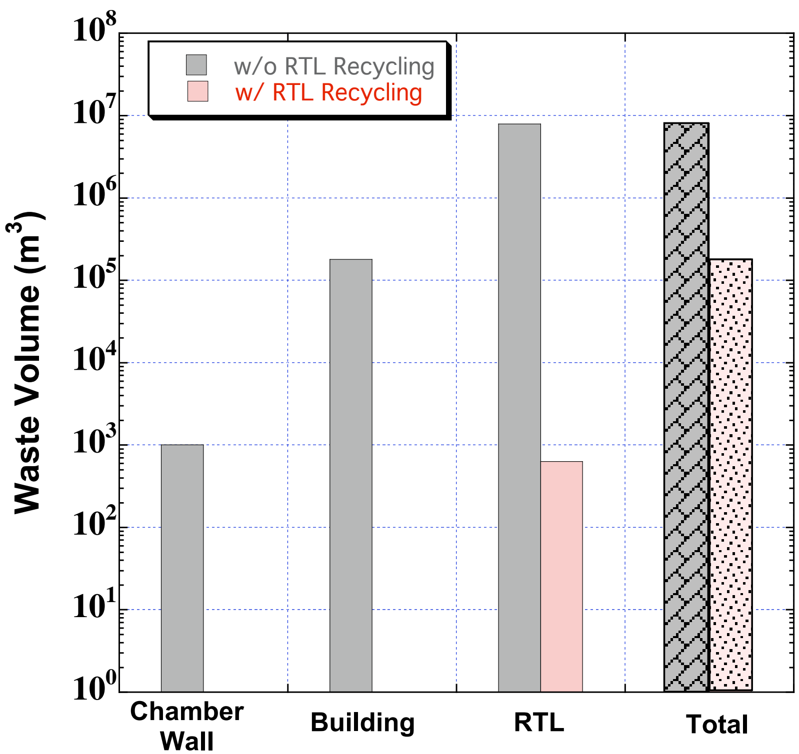
**Preferred Option** (points to One-Shot Use Scenario)

- **Recycling** of hohlraum walls **doubles COE.**
- Hohlraum walls represent **< 1% of waste stream.**
- Once-through use generates **Class A** LLW.
- **Few materials** (Au, Hg, Ta) have **CI < 1**.
- **Target factory designers prefer dealing with non-radioactive hohlraum wall materials.**




**ARIES-IFE Target**

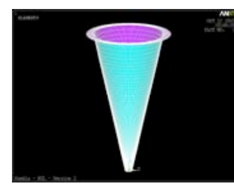
# Recycling is a "Must" Requirement for RTL of Z-Pinch to Minimize Radwaste Stream and Enhance Economics

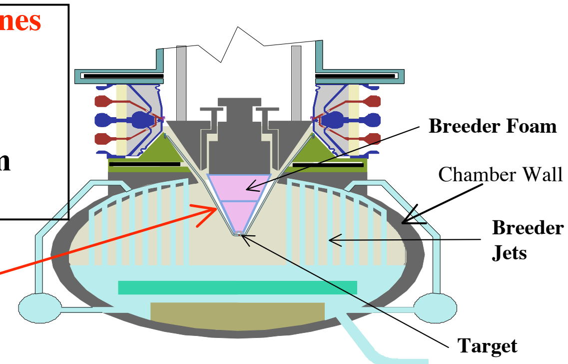



No recycling during 40 FPY
Total RTL volume = 7 M m$^3$

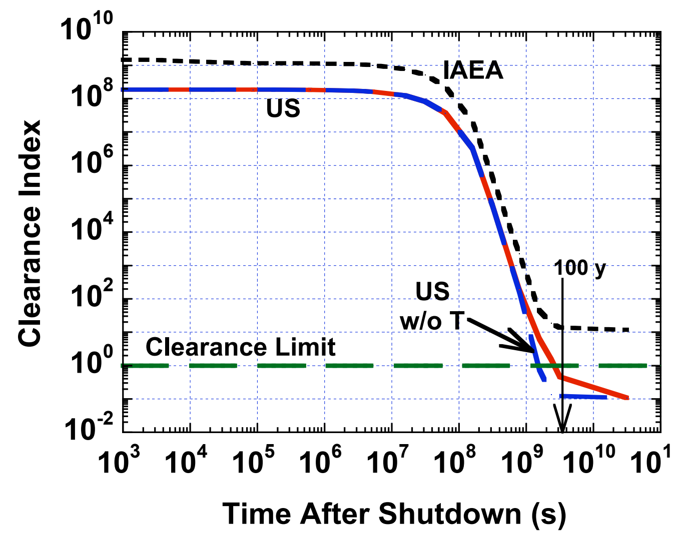
With recycling
1.1 day RTL inventory
Total RTL volume = 0.0005 M m$^3$

**Recyclable Transmission Lines**
**Top diameter = 1 m**
**Bottom diameter = 0.1 m**
**Length = 2 m**
**Total thickness = 0.142 cm**
**50 kg / RTL**





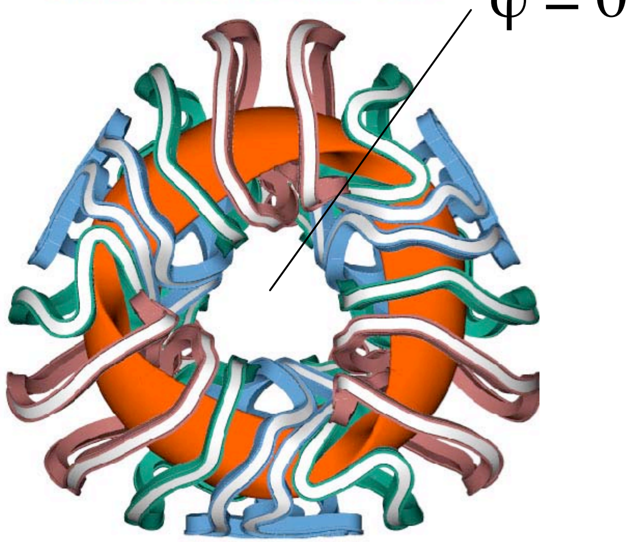

**Z-Pinch Chamber**



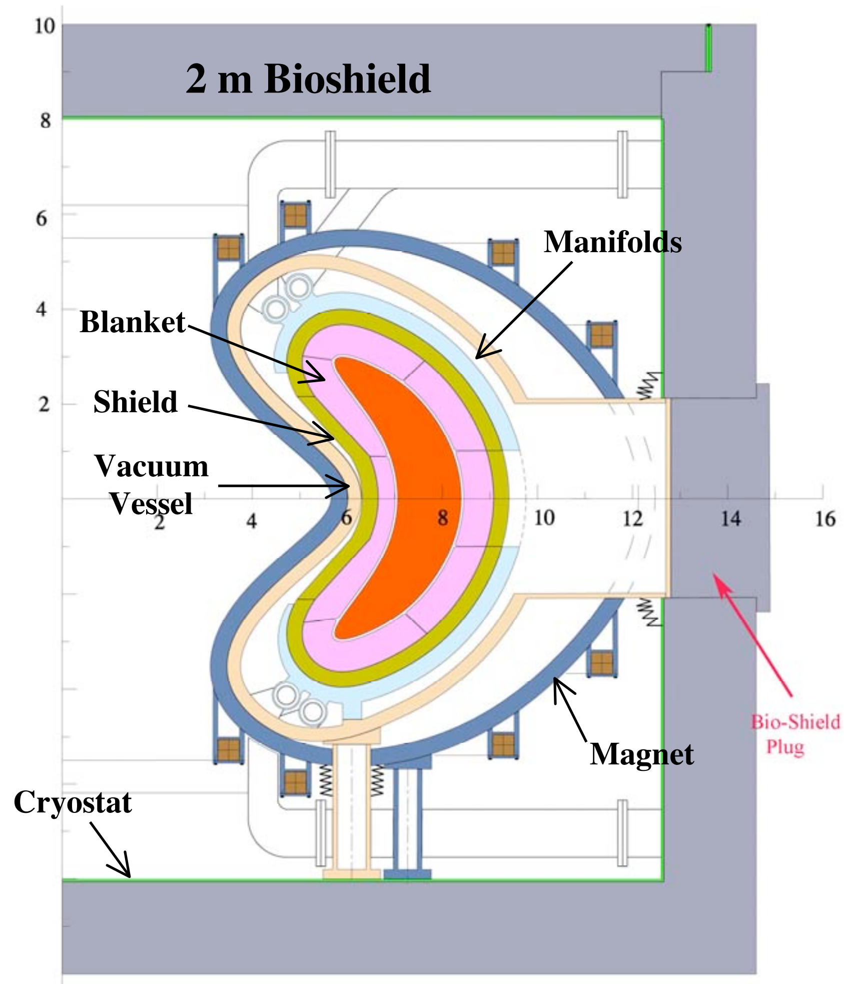

According to U.S. guidelines, RTL waste could be stored for 50 y after plant decommissioning, then reused within nuclear industry or released to commercial market

# ARIES Compact Stellarator

ARIES-CS Plasma and Coils

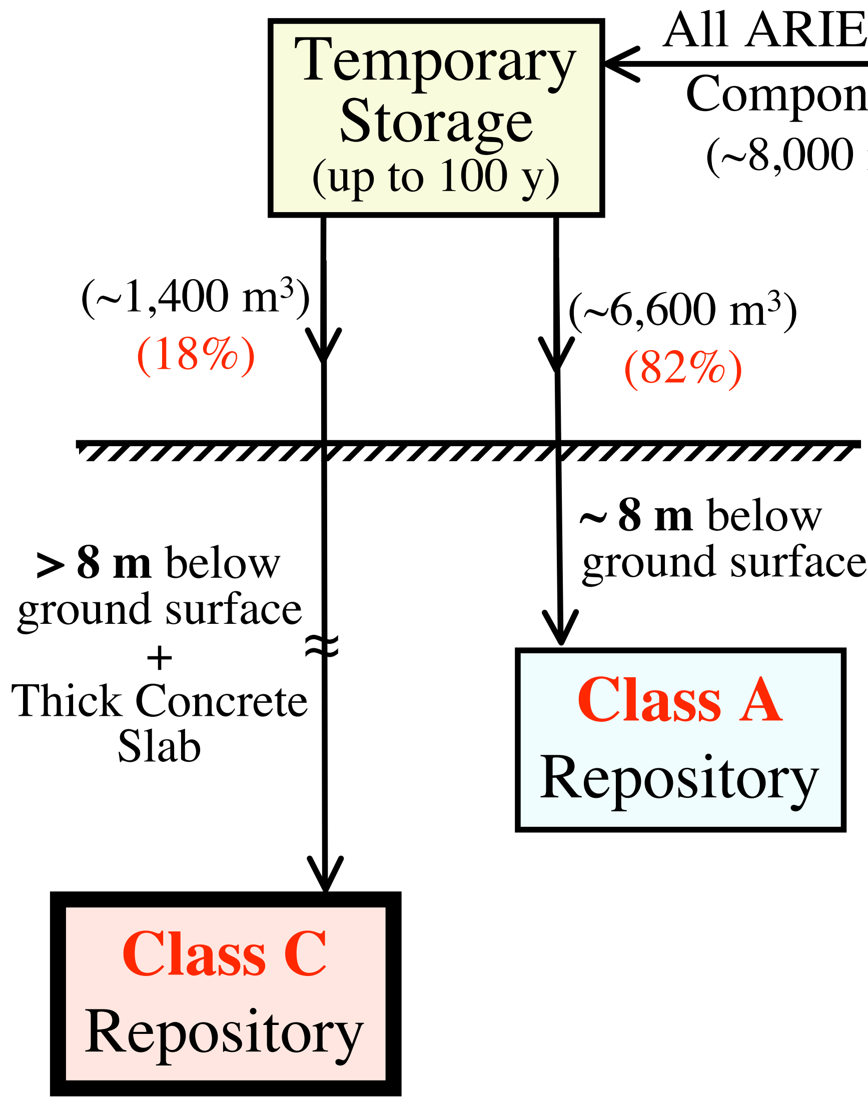


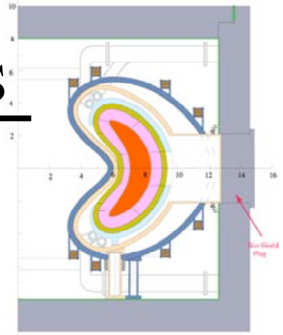

| |
|---|
| 3 Field Periods. |
| LiPb/He/FS System. |
| 7.75 m Major Radius. |
| 2.6 MW/m$^2$ Average NWL. |
| 3 FPY Replaceable FW/Blanket. |
| 40 FPY Permanent Components. |
| ~78 mills/kWh COE ($2004). |




**ARIES-CS Cross Section @ $\varphi = 0$**

# ARIES-CS LLW Classification for Geological Disposal



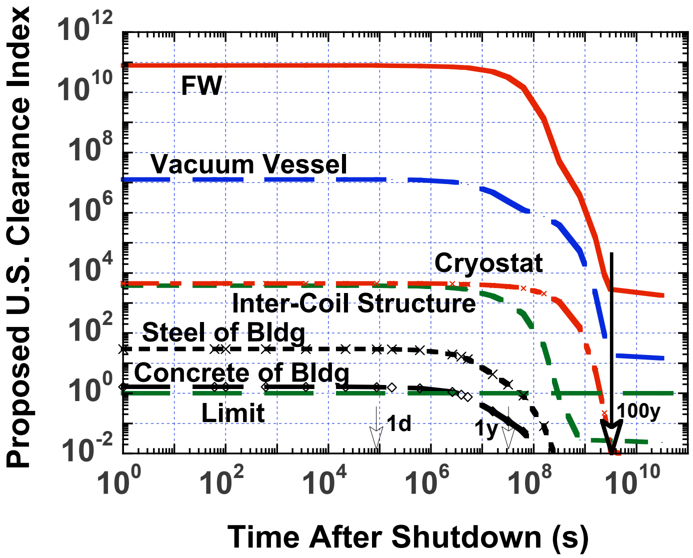



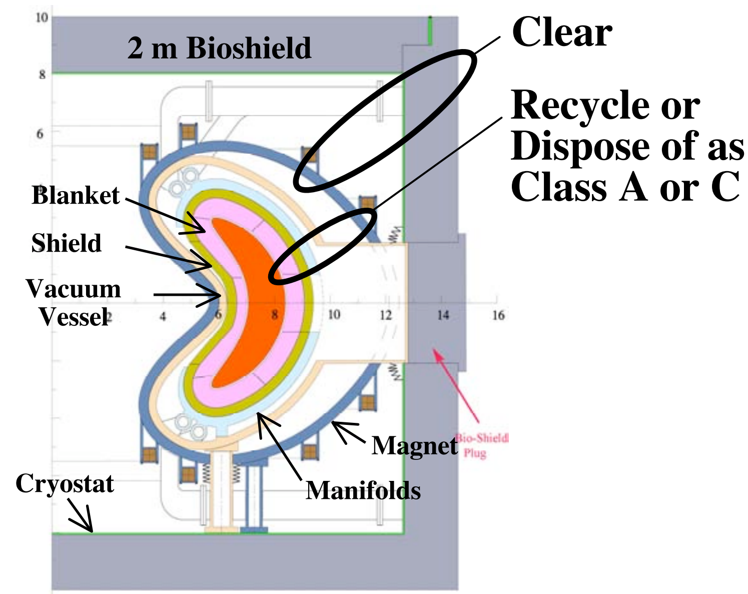
Least hazardous type of waste

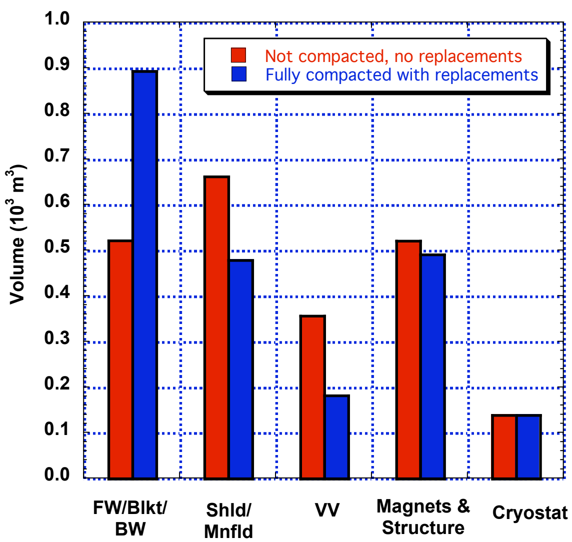
| | Class C LLW | Class A LLW | Could be Cleared? |
|---|---|---|---|
| FW/Blkt/BW | √ | | no |
| Shield/Manifolds | √ | | no |
| Vacuum Vessel | | √ | no |
| Magnet: | | | |
| $Nb_3Sn$ | √ | | no |
| Cu Stabilizer | | √ | √ |
| JK2LB Steel* | | √ | √ |
| Insulator | | √ | √ |
| Cryostat | | √ | √ |
| Bioshield | | √ | √ |

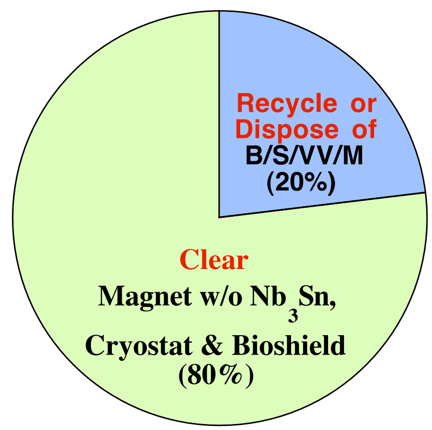
* Preferred over Incoloy-908 for clearance considerations.

# 80% of ARIES-CS Active Materials can be Cleared in < 100 y after Decommissioning

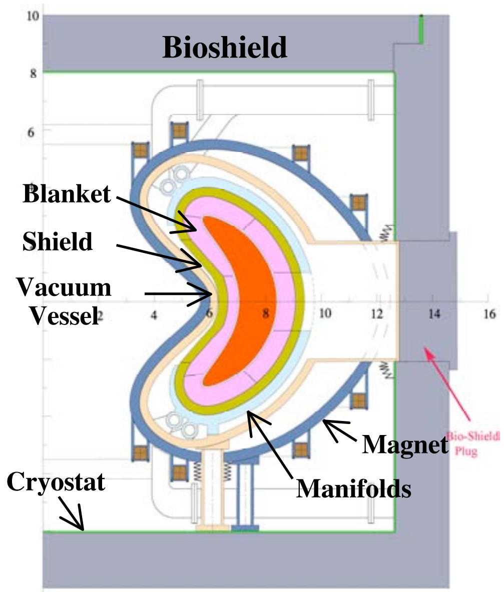


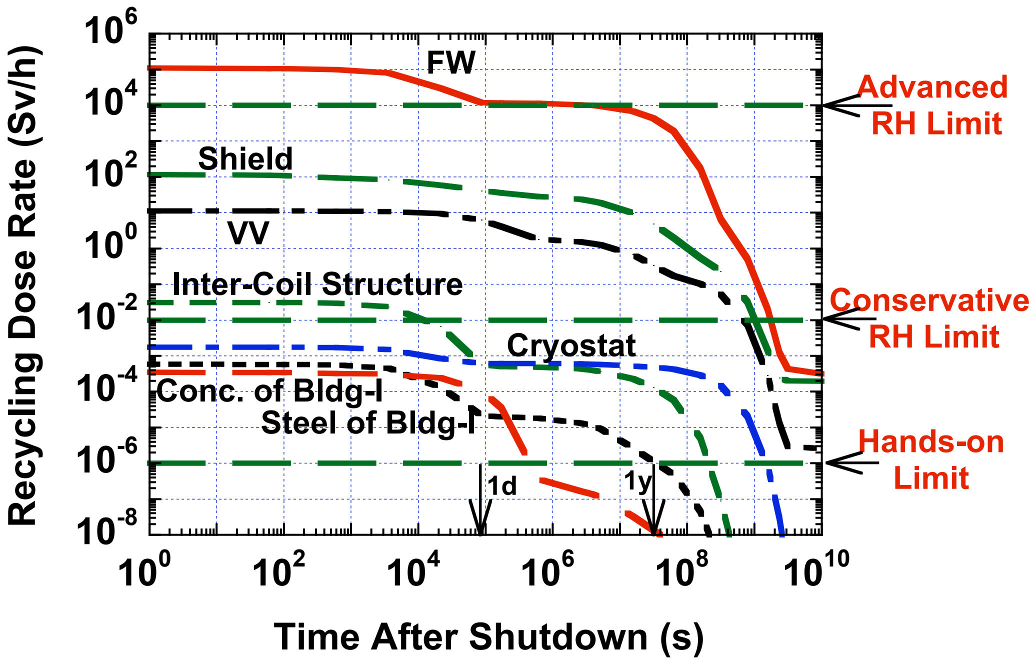



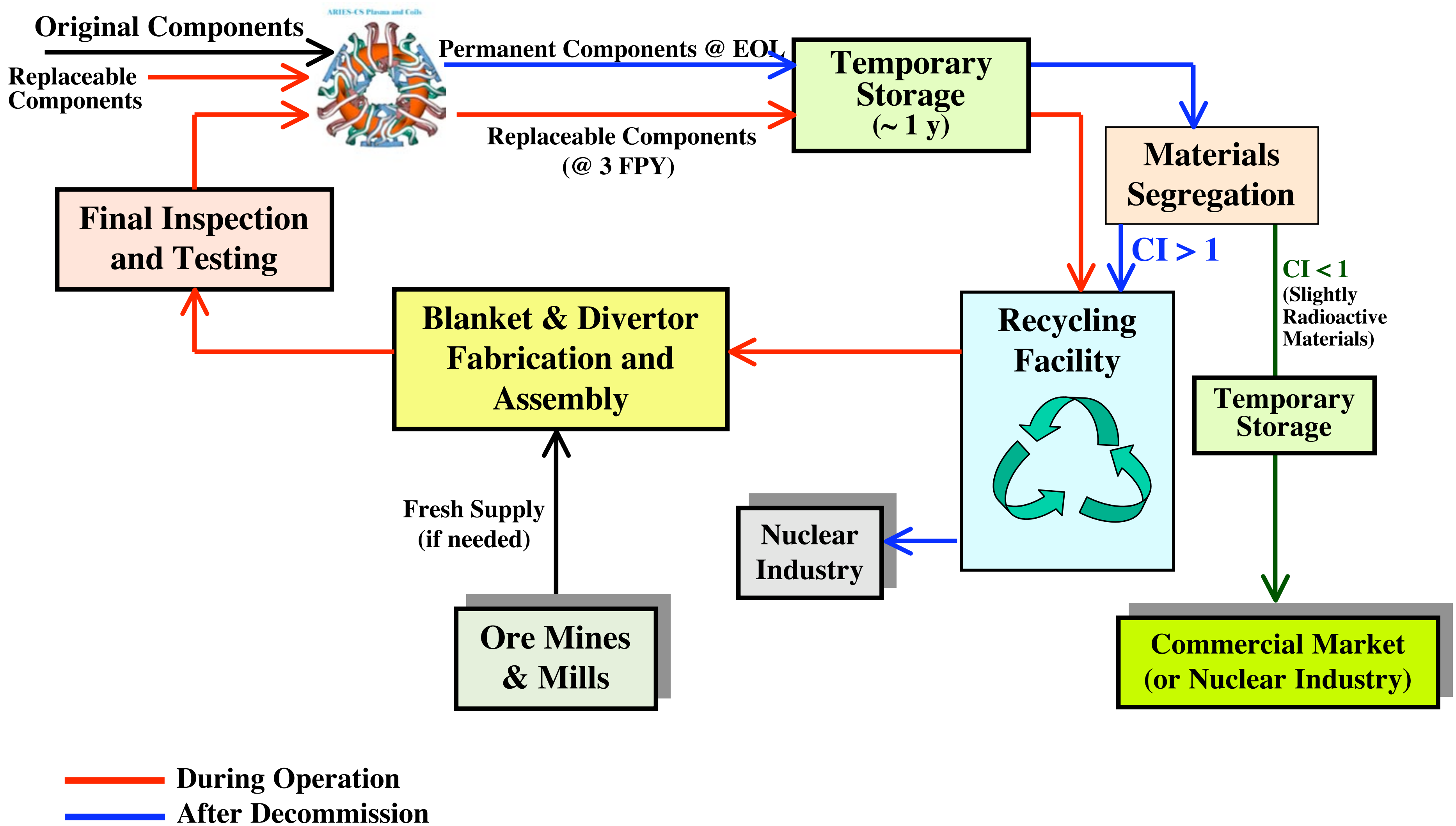
# All ARIES-CS Components can be Recycled in < 1 y Using Advanced RH Equipment




Development of more advanced RH equipment is foreseen to support fission GNEP initiative

# Recycling & Clearance Flow Diagram



# General Observations

- **Recycling and clearance** options look promising and offer significant advantage for radwaste minimization.

- They should be pursued despite lack of details at present.

- Fusion recycling technology will benefit from fission developments and accomplishments in 50-100 y.

- Several critical issues still need further investigation for all three options:
  - Disposal
  - Recycling
  - Clearance

# Disposal Issues

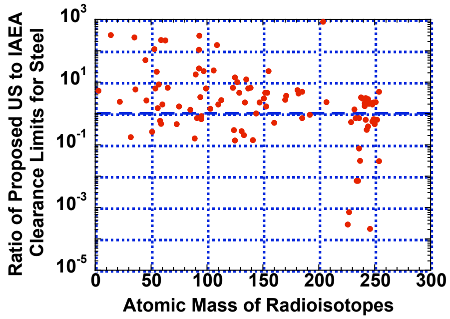
- Large volume to be disposed of (7,000 - 8,000 $m^3$ per plant, including bioshield).
- High disposal cost (for preparation, packaging, transportation, licensing, and disposal).
- Limited capacity of existing LLW repositories.
- Political difficulty of building new repositories.
- Tighter environmental controls.
- Radwaste burden for future generations.

# Recycling Issues

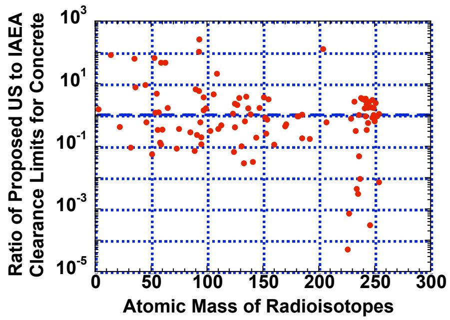
- Development of radiation-hardened RH equipment (≥ 10,000 Sv/h).
- Energy demand and cost of recycling process.
- Radiochemical or isotopic separation processes, if needed.
- Any materials for disposal? Volume? Waste level?
- Properties of recycled materials? Reuse as filler? No structural role?
- Recycling plant capacity and support ratio.
- Acceptability of nuclear industry to recycled materials.
- Recycling infrastructure.

# Clearance Issues

- Discrepancies between clearance standards*.
- Lack of consideration for numerous fusion radioisotopes*:
  ($^{10}$Be, $^{26}$Al, $^{32}$Si, $^{91,92}$Nb, $^{98}$Tc, $^{113m}$Cd, $^{121m}$Sn, $^{150}$Eu, $^{157,158}$Tb, $^{163,166m}$Ho, $^{178n}$Hf, $^{186m,187}$Re, $^{193}$Pt, $^{208,210m,212}$Bi, and $^{209}$Po).




- Impact of missing radioisotopes on CI prediction.
- Need for fusion-specific clearance limits*.
- Clearance infrastructure.




- Availability of clearance market (none anywhere in the world, **except** in Germany and Spain. Currently, U.S. industries do not support unconditional clearance claiming it could erode public confidence in their products and damage their markets).

* L. El-Guebaly, P. Wilson, and D. Paige, "Evolution of Clearance Standards and Implications for Radwaste Management of Fusion Power Plants," *Fusion Science & Technology*, **49**, 62-73 (2006).

# Q / A

General public **and** government agencies ask for energy source that:

- is safe
- generates little or no waste
- does not deplete limited natural resources.

**Question**: Which option helps earn public acceptance? Disposal or recycling/clearance?

| | **Disposal** | **Recycling/Clearance** |
|---|---|---|
| Generates little or no waste | | √ |
| Does not deplete limited natural resources | | √ |

# Recommendations

**Fusion designers:**

- Continue developing low-activation materials.
- Promote environmentally attractive scenarios such as recycling and clearance, avoid geological burial, and minimize radwaste volume by design.
- Identified critical issues should be investigated for all three options.
- Technical and economic aspects ***must*** be addressed before selecting most suitable radwaste management approach for any fusion component.

**Nuclear industry and organizations:**

- Nuclear industry ***must*** **accept recycled materials** from dismantled nuclear facilities.
- National and international organizations (NRC, IAEA, etc.) should continue their efforts to convince industrial and environmental groups that **clearance** can be conducted safely with no risk to public health.