Making Sense of 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.

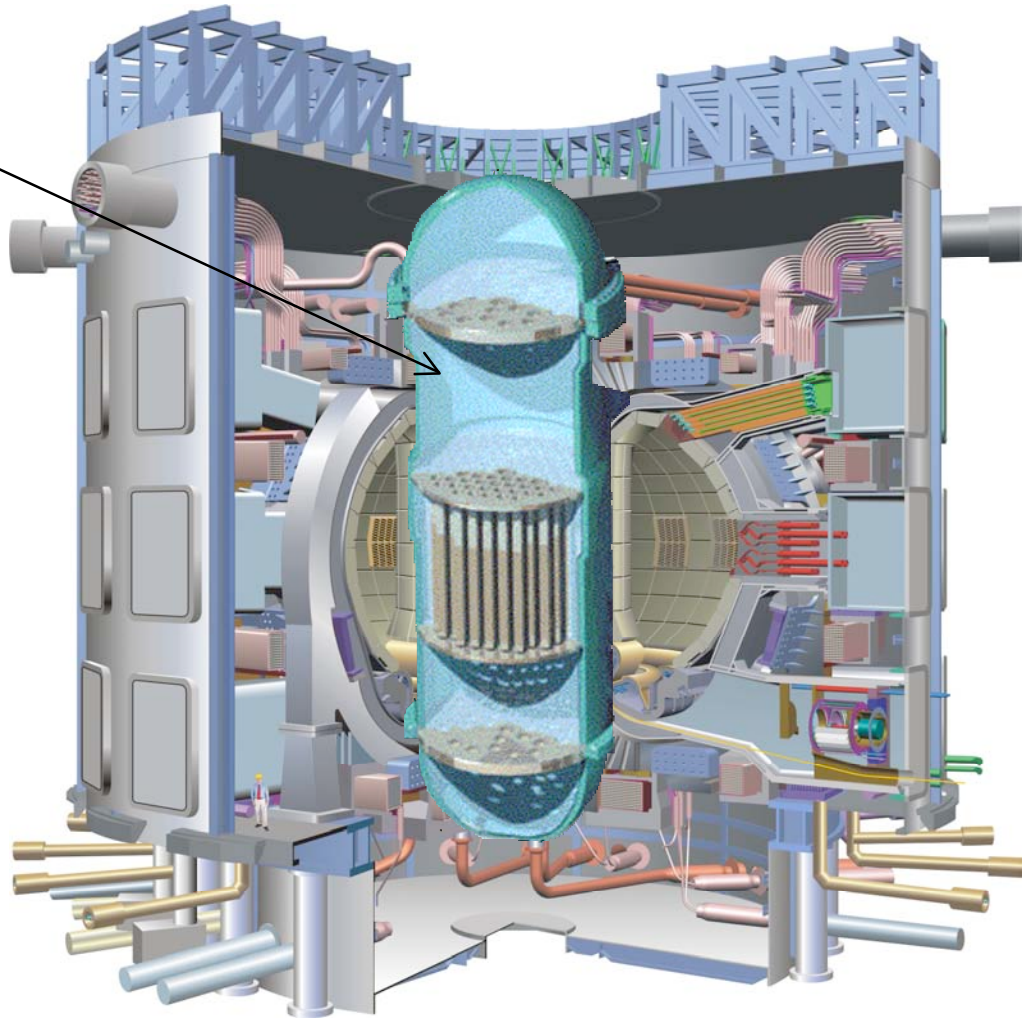
- **New Strategy**: Develop new framework for fusion: nothing should be disposed of in ground, instead recycle and/or clear all active materials, if technically and economically feasible.

- **Why?**
  - Limited capacity of existing low-level waste repositories
  - Political difficulty of building new repositories
  - Tighter environmental controls
  - No radwaste burden for future generations.

- **Impact**: Promote fusion as **waste-free** source of energy.

Fusion Generates Large Amount of LLW that Fills Repositories Rapidly

Advanced Fission Reactor Vessel (ESBWR) (21 m x 6.4 m)



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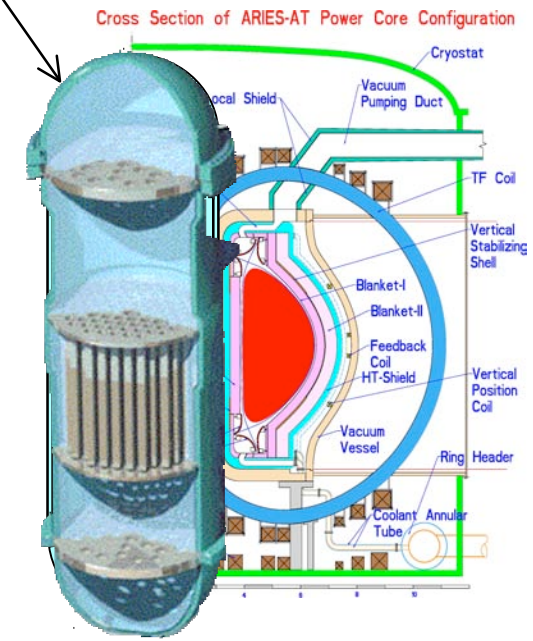
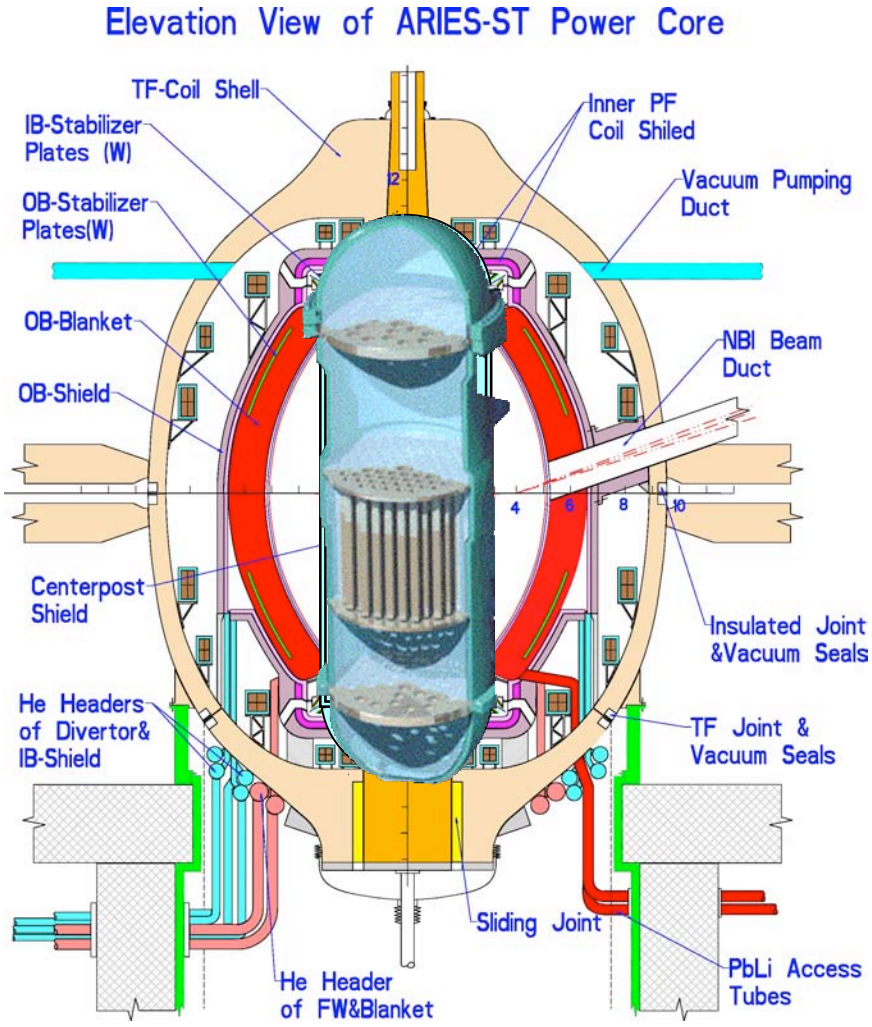
Fusion Generates Large Amount of LLW that Fills Repositories Rapidly (Cont.)

Advanced Fission Reactor Vessel (ESBWR) (21 m x 6.4 m)



ARIES-AT
Advanced Tokamak



ARIES-ST Spherical Tokamak

What UW Suggests

Fusion designs should adopt **MRCB** philosophy:

M – Minimize volume of active materials by design.

R – Recycle, if economically and technologically feasible.

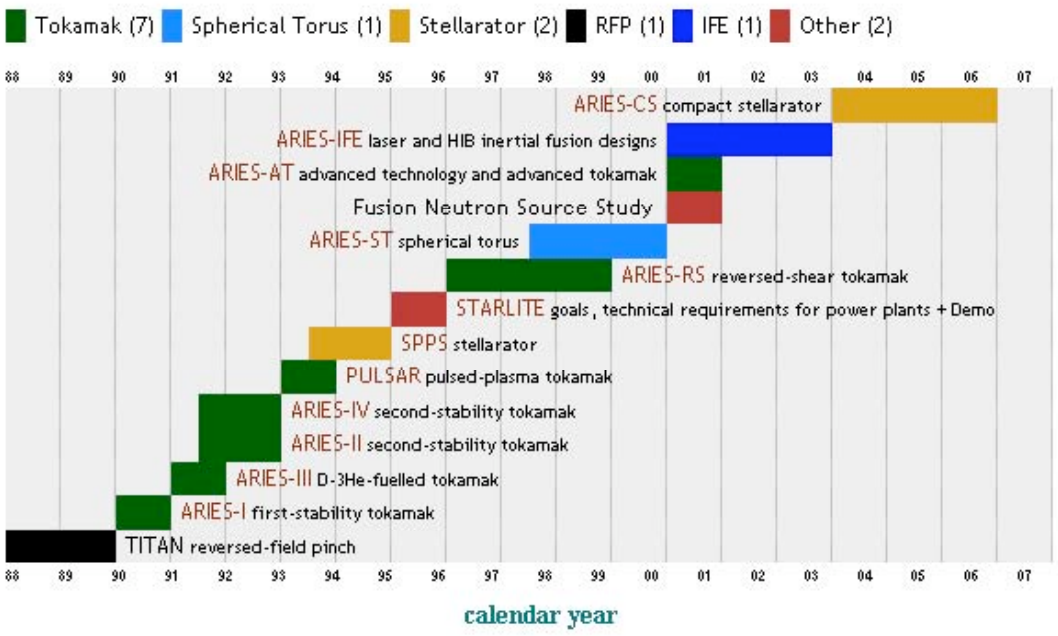
C – Clear slightly-irradiated materials.

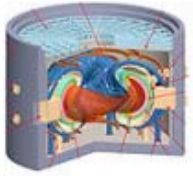
B – Burn active byproducts, if any, in fusion devices*.

* 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.

ARIES Designs
(1988-2007)

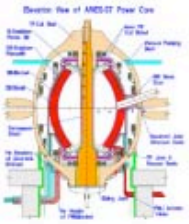
ARIES Project Timeline



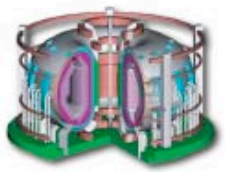


ARIES-CS

ARIES-AT

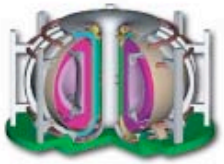


ARIES-ST



ARIES-I

ARIES-III



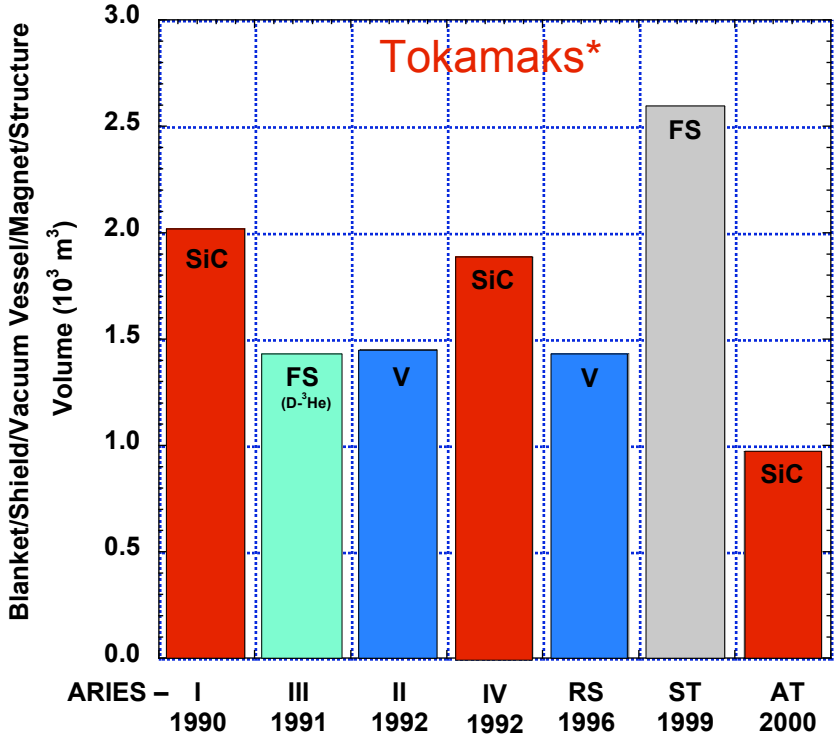
ARIES-IV

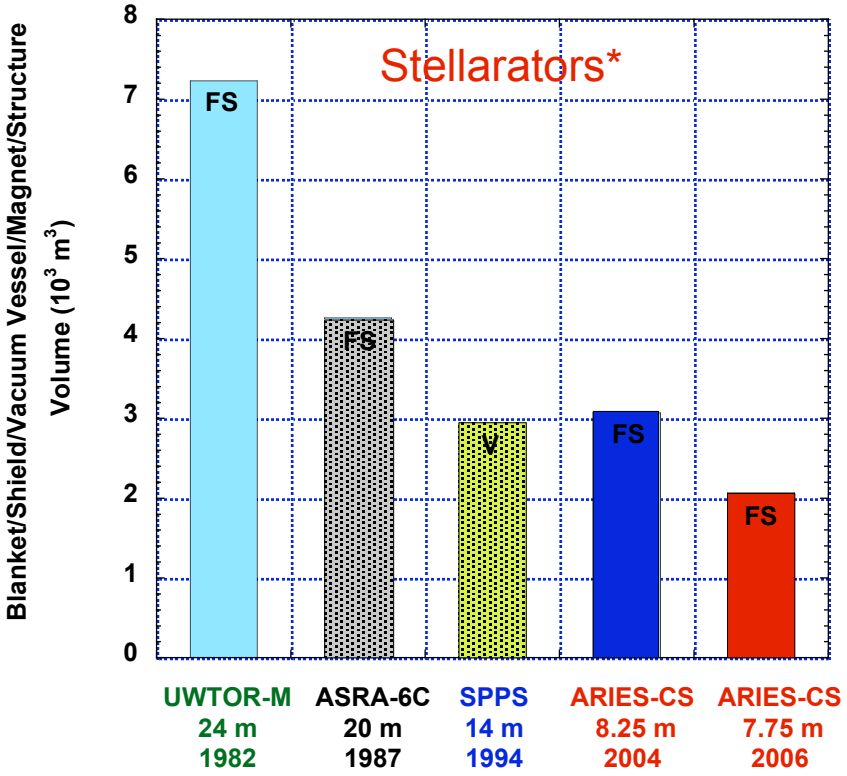
SPPS

ARIES-RS

Radwaste Minimization

ARIES Project Committed to Waste Minimization





Tokamak waste volume halved over 10 y study period

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

* Actual volumes (not compacted, no replacements).

Disposal, Recycling, and Clearance

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

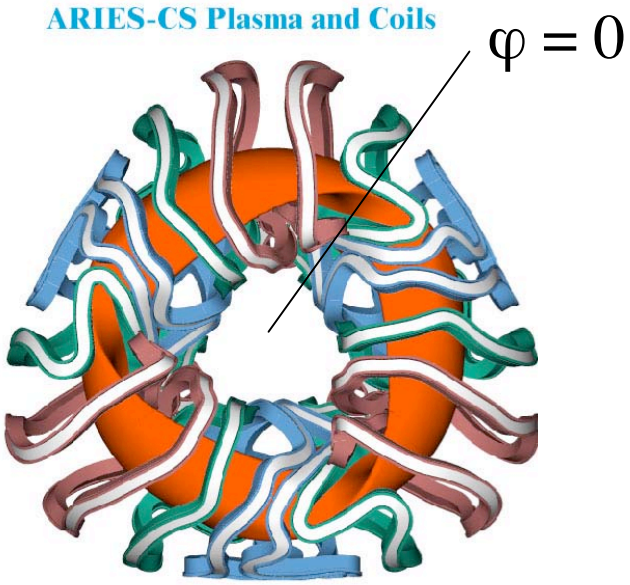
	Components	Recycle?	Clear?	Dispose of @ EOL?
IFE:				
ARIES-IFE	**Targets**[#]	no (for economic reasons)	yes / no	**yes** (as Class A)
Z-Pinch-IFE	**RTL**[*]	**yes** (a must requirement)	yes	yes (as Class A)
MFE:				
ARIES-CS[@]	**all**	**yes**	yes / no	yes (as Class A & C)

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).

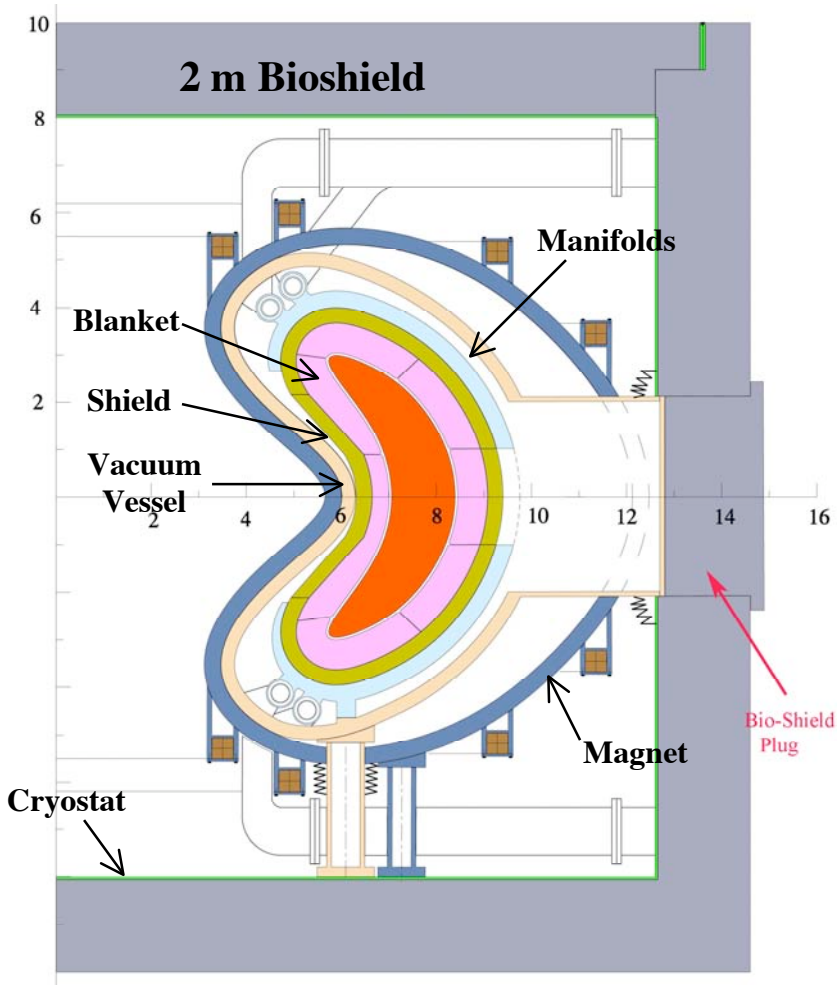
* L. El-Guebaly, P. Wilson, and M. Sawan, "Activation and Waste Stream Analysis for RTL of Z-Pinch Power Plant," To be published in *Fusion Science & Technology*.

@ 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*.

ARIES Compact Stellarator

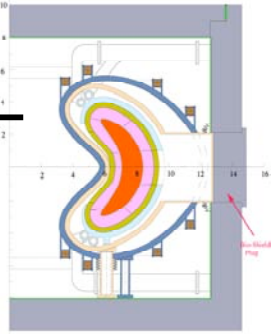


- 3 Field Periods.
- LiPb/He/FS System.
- 7.75 m Major Radius.
- 2.6 MW/m^2 Average NWL.
- 3 FPY Replaceable FW/Blanket.
- 40 FPY Permanent Components.
- ~78 mills/kWh COE ($2004).



ARIES-CS Cross Section @ φ = 0

ARIES-CS LLW Classification for Geological Disposal



All ARIES-CS Components (~8,000 m³)

Temporary Storage

(~1,400 m³) (18%)

(~6,600 m³) (82%)

~ 8 m below ground surface

> 8 m below ground surface + Thick Concrete Slab ≈

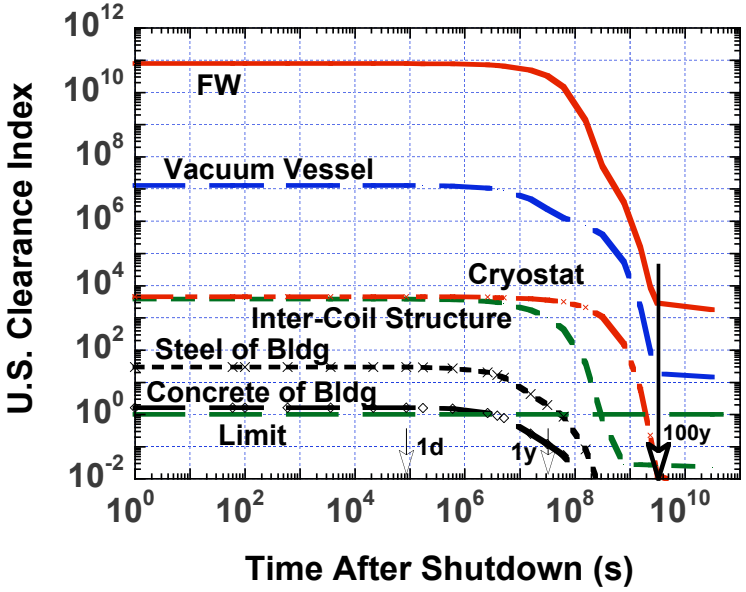
Class A Repository

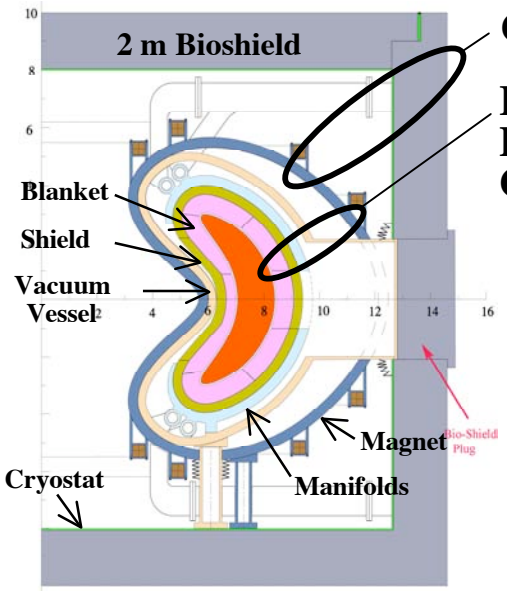
Class C Repository

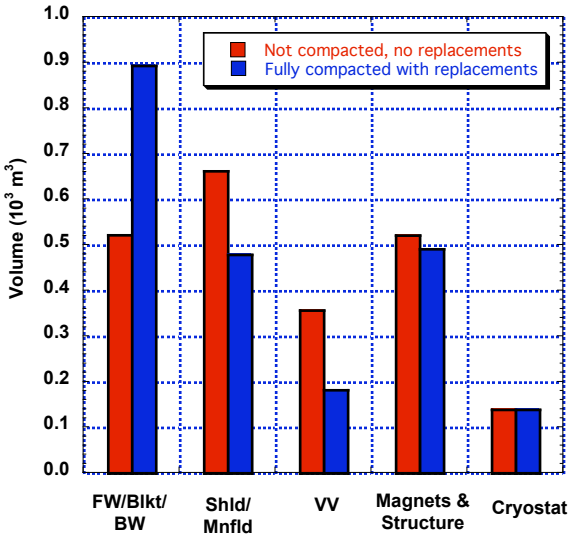
Least hazardous type of waste

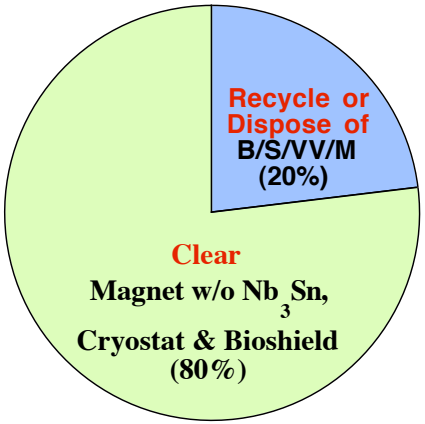
	Class C LLW	Class A LLW	Could be Cleared?
FW/Blkt/BW	√		**no**
Shield/Manifolds	√		**no**
Vacuum Vessel		√	**no**
Magnet:			
Nb_3Sn	√		**no**
Cu Stabilizer		√	√
JK2LB Steel		√	√
Insulator		√	√
Cryostat		√	√
Bioshield		√	√

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

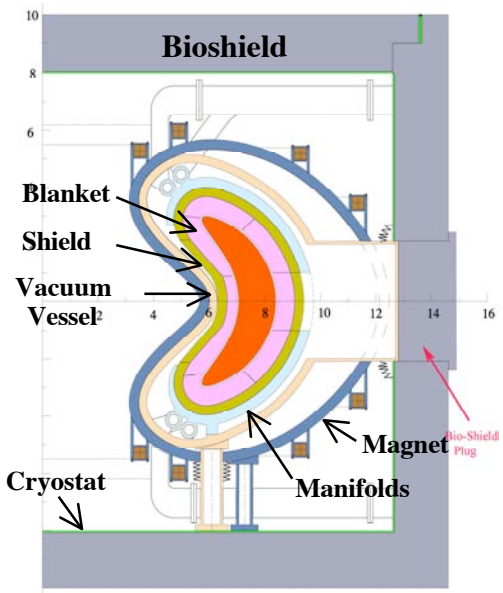


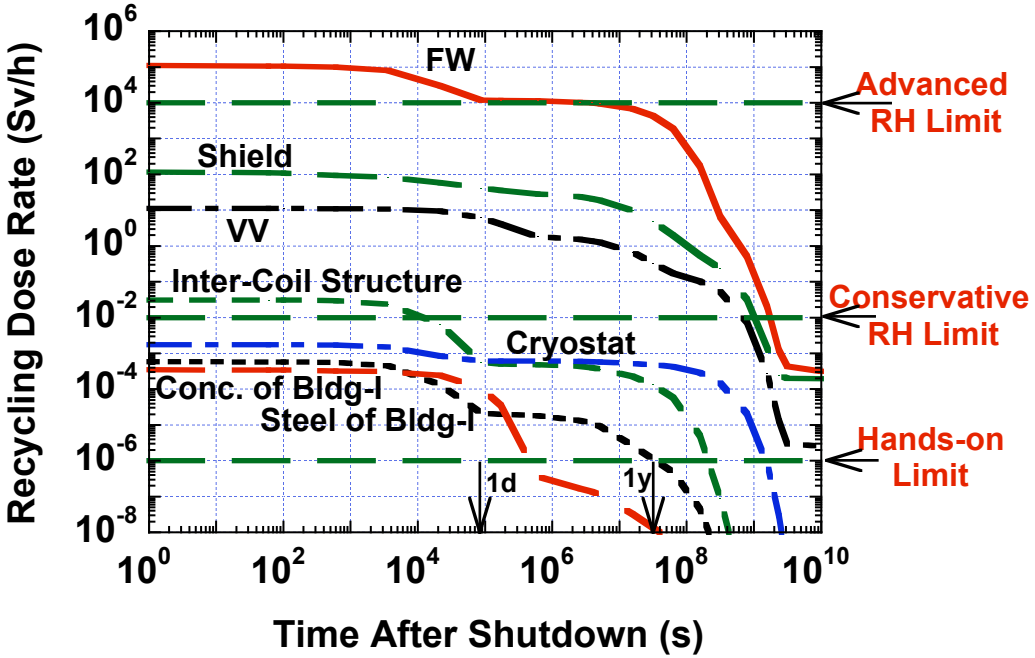




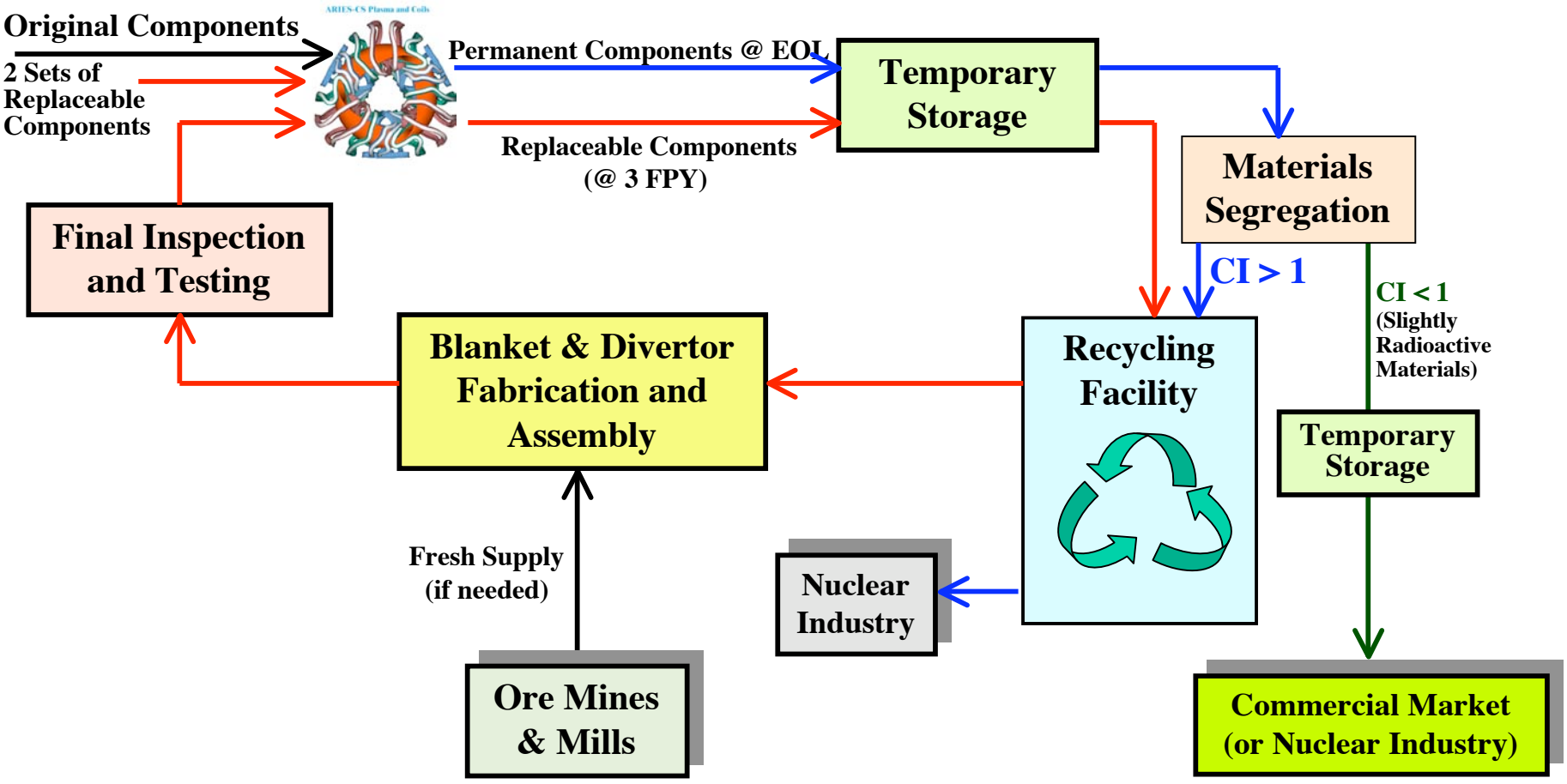


All ARIES-CS Components can be Recycled in < 1 y Using Advanced and Conventional RH Equipment





Recycling & Clearance Flow Diagram



General Observations

- **Recycling and clearance** options look promising and offer significant advantage for waste 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.
- To support our position, we identified several critical issues that 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?
- Recycling plant capacity and support ratio.
- Acceptability of nuclear industry to recycled materials.
- Recycling/clearance infrastructure.

Clearance Issues

- Discrepancies between clearance standards*.
- Lack of consideration for numerous fusion radioisotopes*.
- Impact of missing radioisotopes on CI prediction.
- Need for fusion-specific clearance limits*.
- Clearance market (none anywhere in the world, **except** in Germany and Spain. U.S. industries do not support unconditional clearance claiming it could erode public confidence in their products and damage their markets).

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* 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).

Recommendations

Fusion designs:

- Promote environmentally attractive scenarios such as recycling and clearance, avoid geological burial, and minimize waste volume by design.
- Technical and economic aspects ***must*** be addressed before selecting most suitable waste 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.

International Activities

- Growing international effort in support of this new trend in fusion radwaste management.
- UW recent activity drew attention of European colleagues asking El-Guebaly to co-author papers on fusion radwaste management.
- El-Guebaly is now U.S. Task Leader for IEA-ESEFP Task 6 on "**Fusion Radioactive Waste Studies**."
- El-Guebaly and D. Petti presented UW preliminary findings at 8th IAEA TM on **Fusion Power Plant Safety** (July 06 – Vienna, Austria).
- El-Guebaly **invited** to give oral talk at upcoming ISFNT-8 conference (Oct. 07, Germany): **Goals, Challenges, and Successes of Managing Fusion Activated Materials**.
- El-Guebaly will present UW work at upcoming 2nd IAEA TM on **1st Generation of Fusion Power Plants** (June 2007 – Vienna, Austria): **Environmental Aspects of Recent Trend in Managing Fusion Radwaste: Recycling and Clearance, Avoiding Disposal.**
- UW will continue collaborative effort with Europeans through IEA activities.