Making Sense of Fusion Radwaste: Recycling and Clearance, Avoiding Disposal

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(Based on presentation given at VLT 4/18/07 Conference Call)

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, <u>if technically and economically feasible.</u>

- **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.

Quotes

ARIES Top-Level Requirements (STARLITE Study* – 1997)	Generate **no radwaste greater than Class C**
Laila (ARIES Project Meeting – 4/06)	Avoid geological burial, promote **recycling/clearance**, and minimize volume of active materials.
A. Opdenaker (E-mails – 06/07)	Sounds good. Your idea is the way we should be going, even if we do not know every detail of how to implement it right now!
D. Petti (IAEA Safety Meeting – 7/06)	Fusion radwaste can be **recycled**.
Farrokh (FPA Meeting – 9/06)	Generated waste can be returned to environment or **recycled** in less than a few hundred years (i.e., not geological time-scale).
S. Dean (quoting Farrokh) (FPA Meeting Minutes – 10/06)	Waste can be **recycled** in less than a few hundred years.
Siegfried (ARIES Memo – 2/07) **and Rene** (ARIES Project Meeting – 4/07)	Potential blanket waste treatment methods: **re-use, re-cycling**, shallow land burial.

* General public and government agencies ask for an energy source which is safer, generates little or no waste, does not deplete limited natural resources.

U.S. Repositories

- **High-level waste (HLW) repositories:**
  - **Hanford** facility in WA:
    - 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)
    - Max capacity 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 SC:
    - 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 WA:
    - 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, but 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 asked DOE to remove LLW stored at INL and ship it out of state.
- Utah 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**:
  - 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.

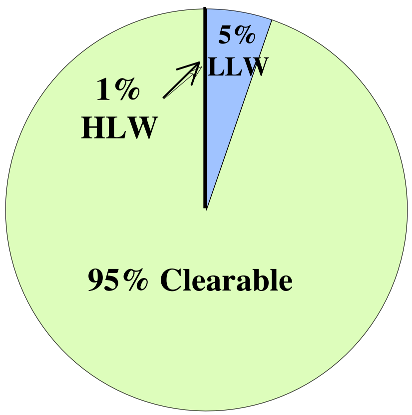
U.S. Needs National Solution for LLW Problem (Cont.)

- **Government Accountability Office** (GAO) **report** issued June 2004:
  - Annual LLW volume increased by 200% between 1999 and 2003, primarily due to LLW shipped to commercial disposal by DOE.
  - There is no expected shortfalls for Class A waste.
  - At current Class B & C LLW volumes, disposal availability appears adequate until at least mid-2008.
  - If disposal conditions do not change, however, most states will not have a place to dispose of their Class B & C wastes after 2008.
  - Generators can minimize, process, and safely store waste (onsite).
  - However, as LLW storage volume and duration increase in absence of reliable and cost-effective disposal options, so might the safety and security risks.
  - LLW disposal availability adequate in the short-term, but oversight needed to identify any future shortfalls.

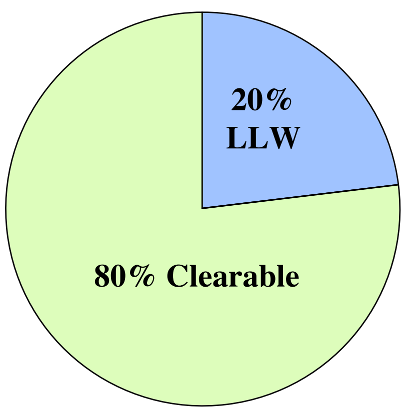
Fusion Generates Large Amount of LLW that Fills Repositories Rapidly

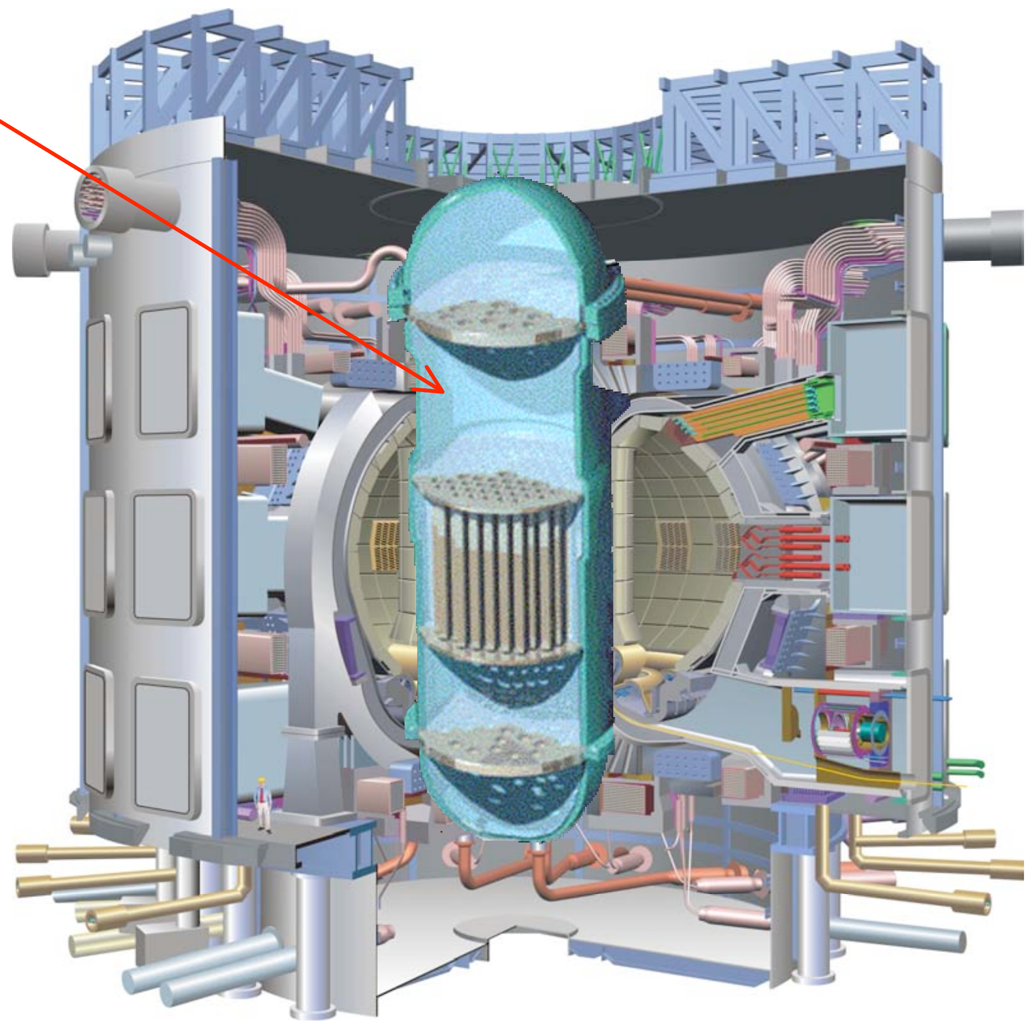
Economic Simplified Boiling Water Reactor (ESBWR) - Gen-III⁺
Reactor Vessel: 6.4 m ID, 21 m H

Fission



Fusion





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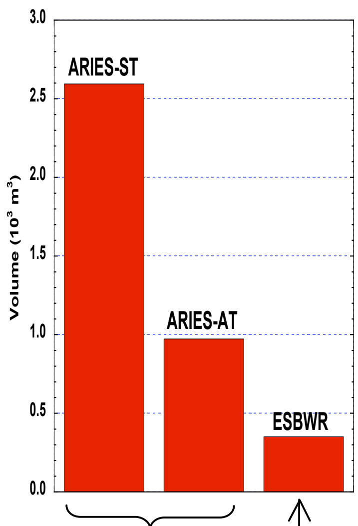
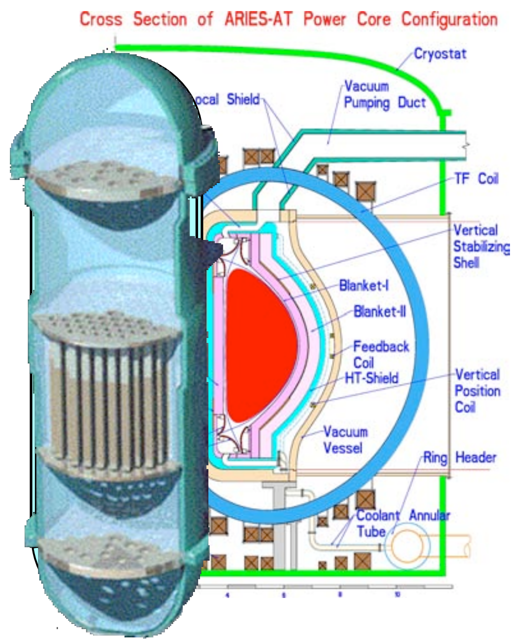
Fusion Generates Large Amount of LLW that Fills Repositories Rapidly (Cont.)

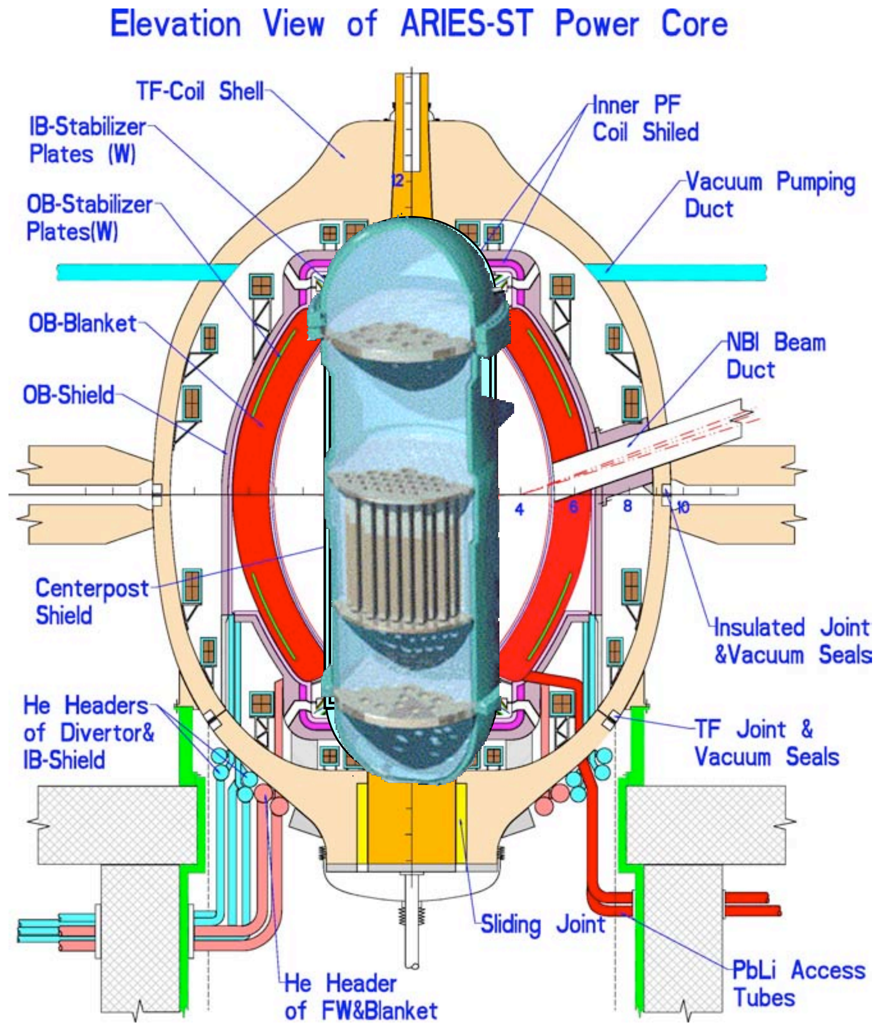


Class A & C LLW
(active for 100s y)

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



ARIES-AT
Advanced Tokamak



ARIES-ST Spherical Tokamak

What UW Suggests

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

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

  M – <u>M</u>inimize volume of active materials by design.

  R – <u>R</u>ecycle*, if economically and technologically feasible.

  C – <u>C</u>lear# slightly-irradiated materials.

  B – <u>B</u>urn active byproducts, if any, in fusion devices@.

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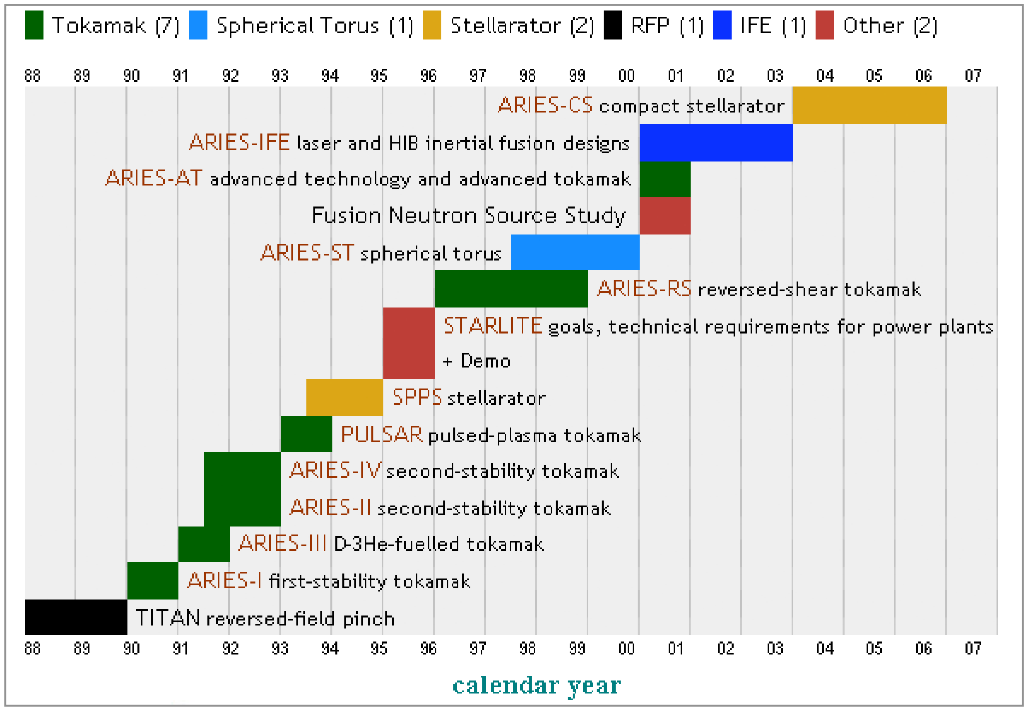
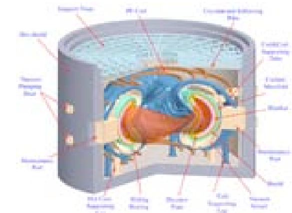
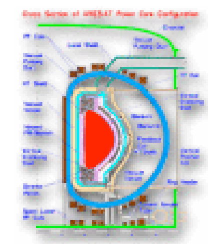
* Reuse within nuclear industry.
# Unconditional release to commercial market to fabricate as consumer products.
@ L. El-Guebaly, "Managing Fusion High Level Waste – a Strategy for Burning the Long-Lived Products in Fusion Devices," *Fusion Engineering and Design*, **81** (2006) 1321-1326.

ARIES Designs
(1988-2007)

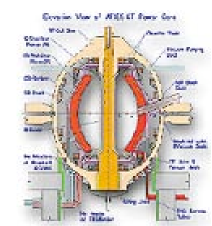




ARIES-CS



ARIES-AT



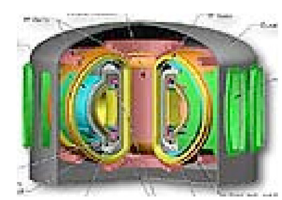
ARIES-ST

ARIES-I

ARIES-III

ARIES-IV

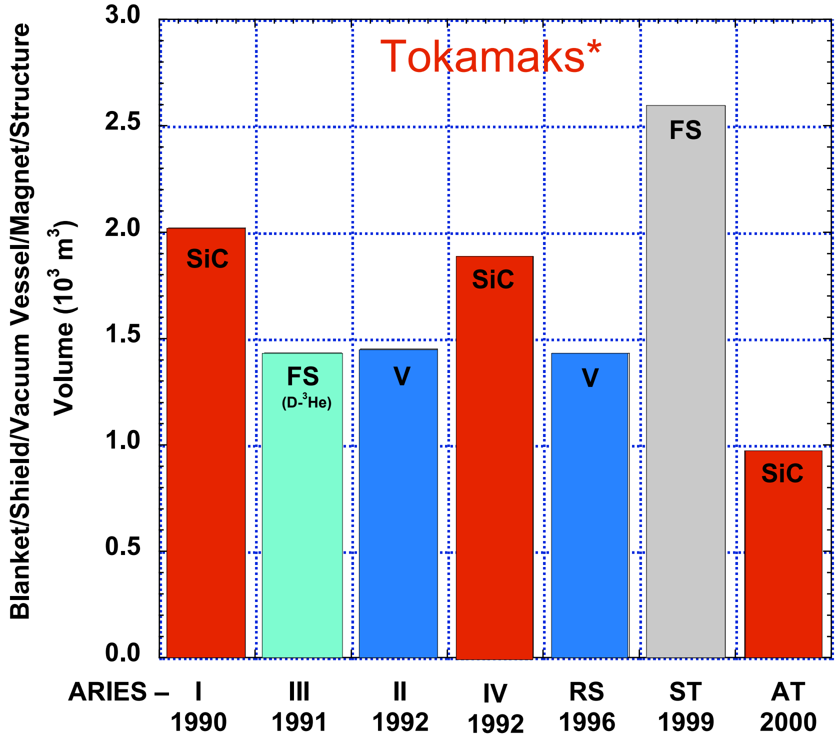
SPPS

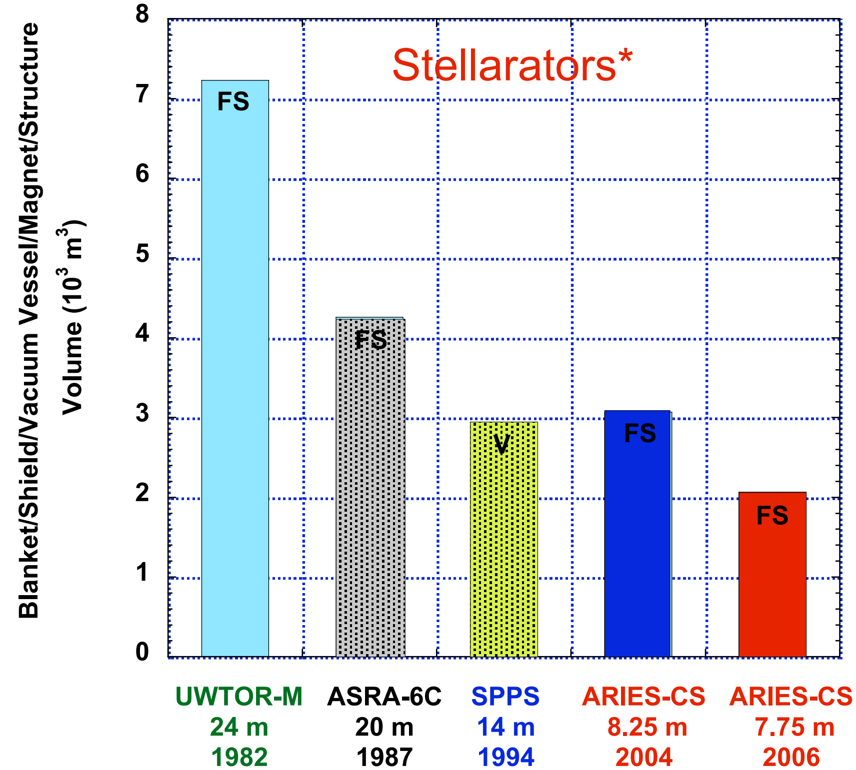


ARIES-RS

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 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***	**yes** (a must requirement)	yes	yes (as Class A)
MFE:				
ARIES-CS@	**all**	**yes**	yes / no	yes (as Class A & C)

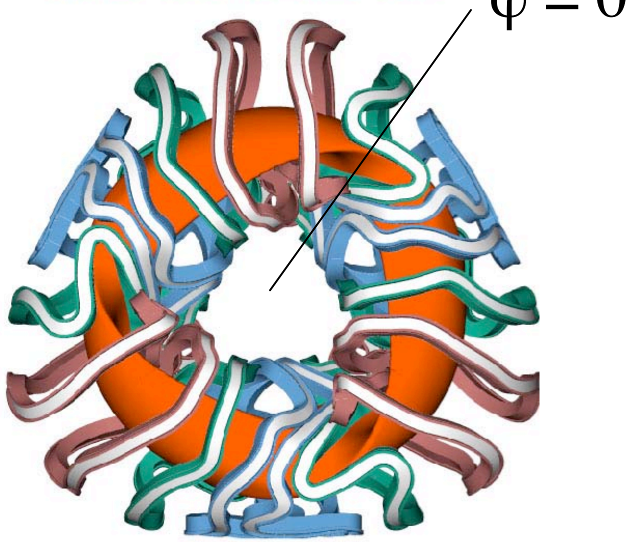
L. El-Guebaly, P. Wilson, D. Henderson, and A. Varuttamaseni, "Feasibility of Target Materials Recycling as Waste Management Alternative," *Fusion Science & Technology*, **46**, No. 3, 506-518 (2004).

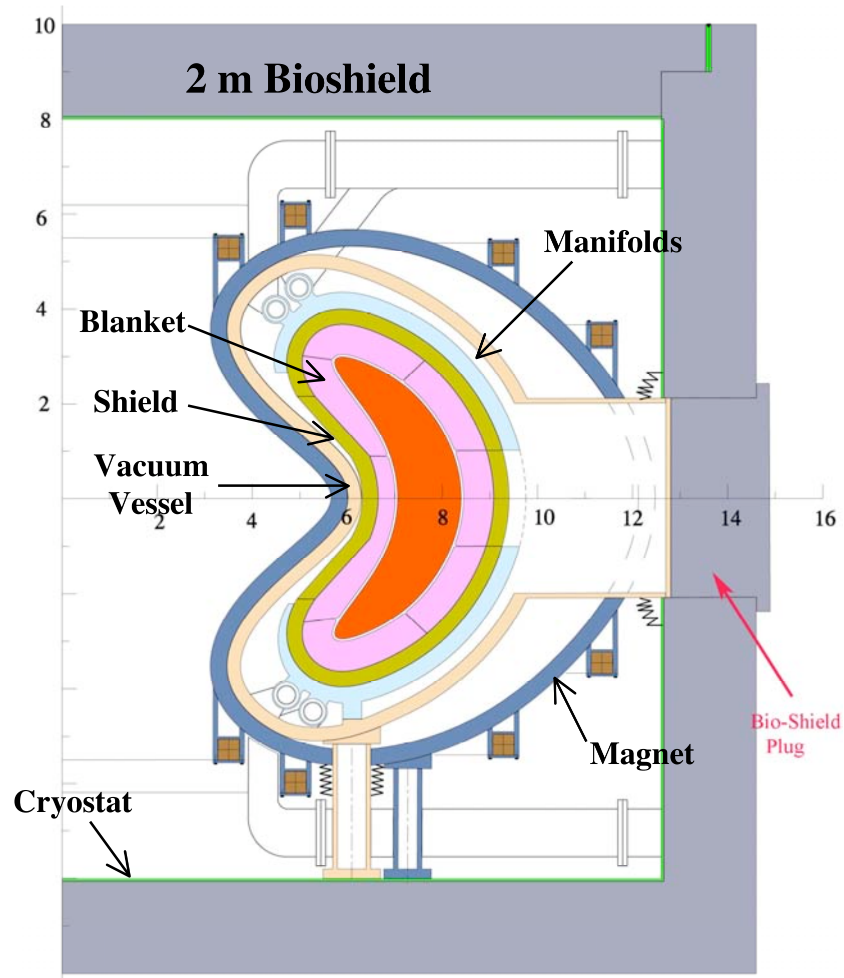
* L. El-Guebaly, P. Wilson, and M. Sawan, "Activation and Waste Stream Analysis for RTL of Z-Pinch Power Plant," To be published in *Fusion Science & Technology*.

@ 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

ARIES-CS Plasma and Coils





ARIES-CS Cross Section @ φ = 0

3 Field Periods.

LiPb/He/FS System.

7.75 m Major Radius.

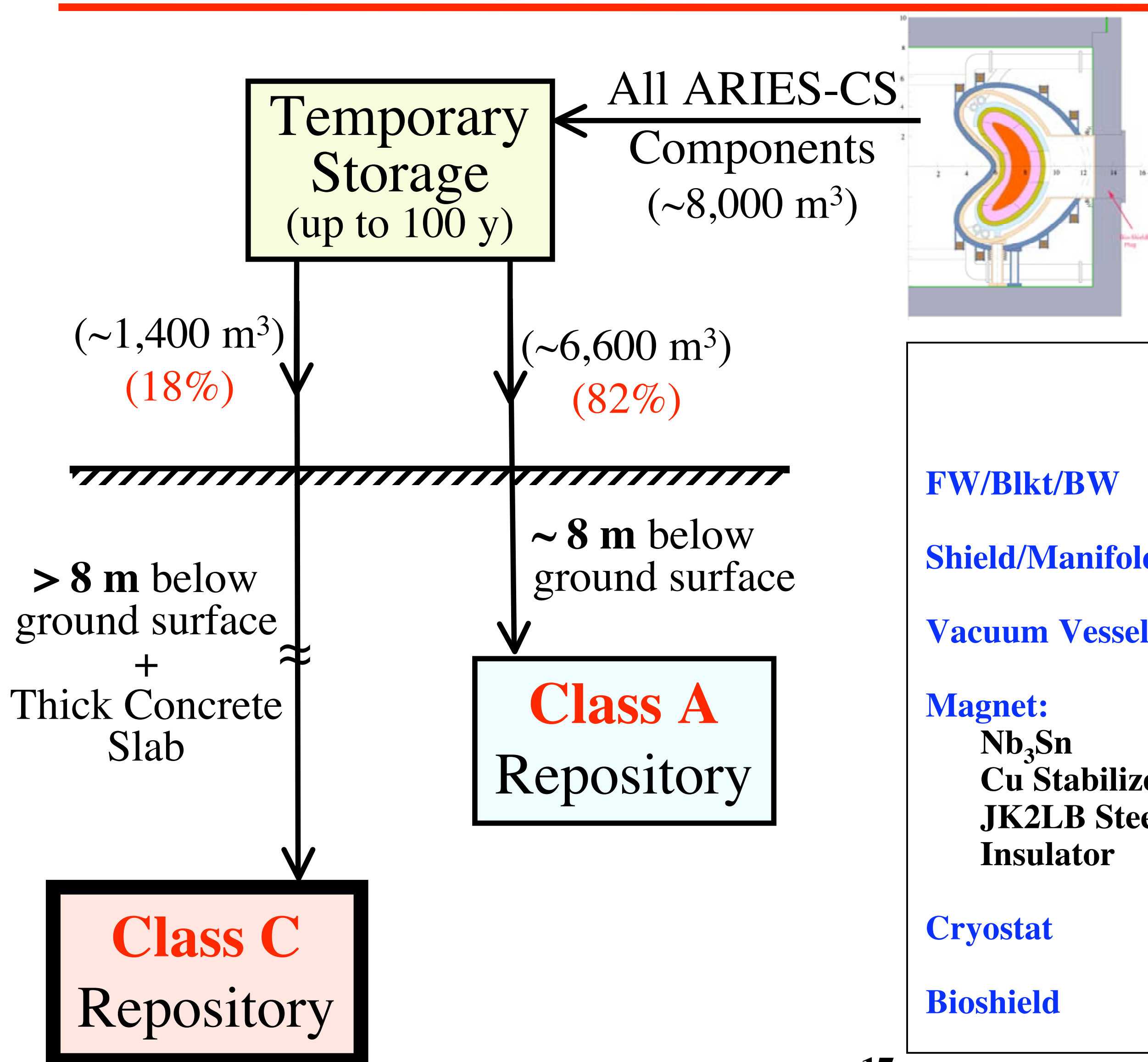
2.6 MW/m^2 Average NWL.

3 FPY Replaceable FW/Blanket.

40 FPY Permanent Components.

~78 mills/kWh COE ($2004).

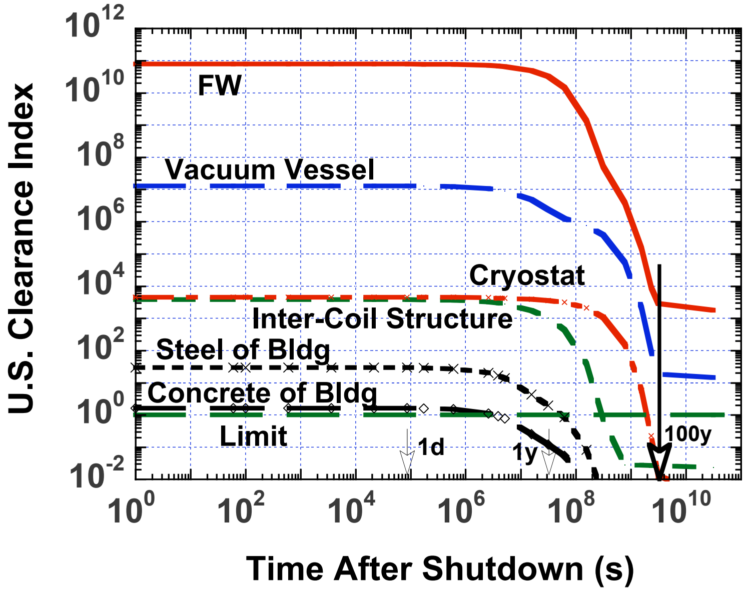
ARIES-CS LLW Classification for Geological Disposal

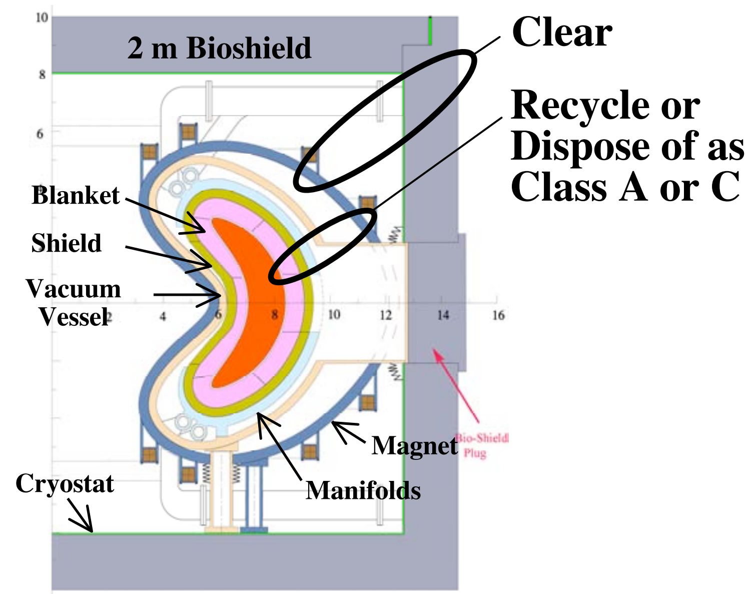


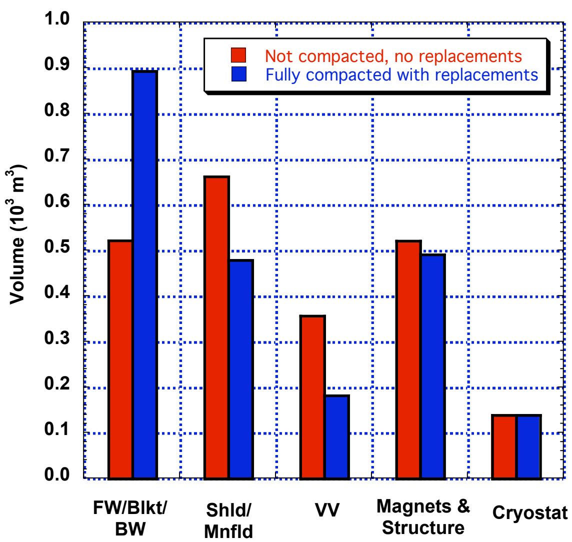
Least hazardous type of waste

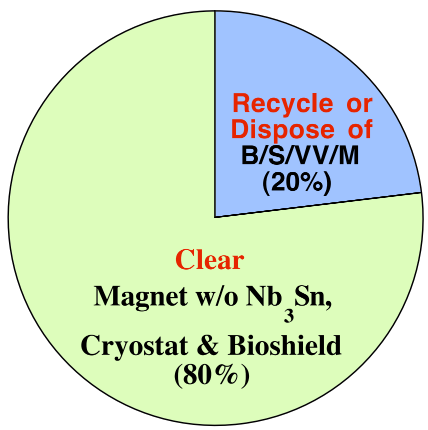
	Class C LLW	Class A LLW	Could be Cleared?
FW/Blkt/BW	√		no
Shield/Manifolds	√		no
Vacuum Vessel		√	no
Magnet:			
Nb_3Sn	√		no
Cu Stabilizer		√	√
JK2LB Steel		√	√
Insulator		√	√
Cryostat		√	√
Bioshield		√	√

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

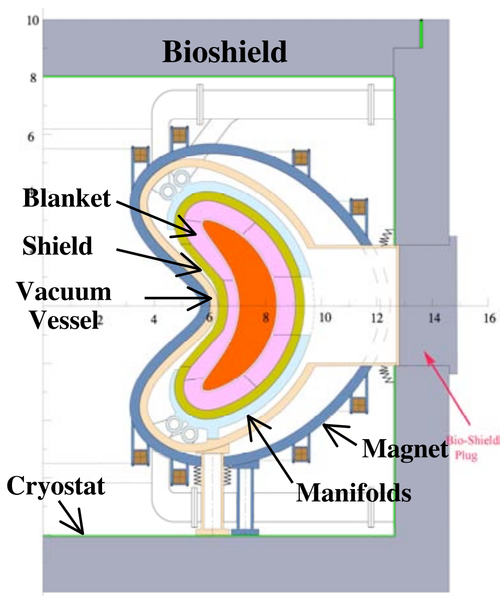


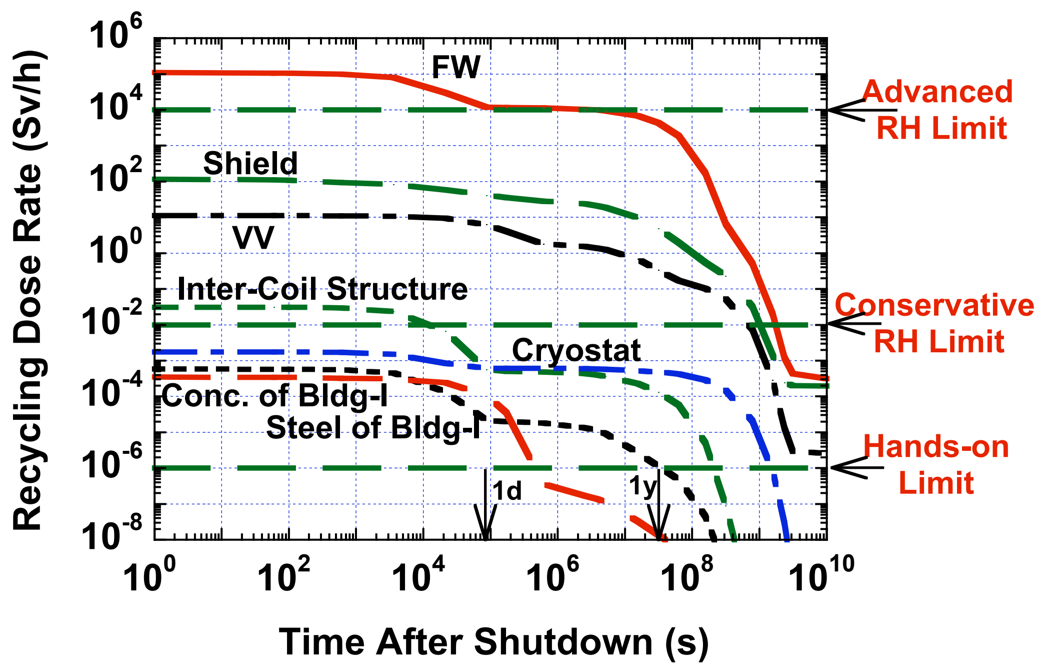






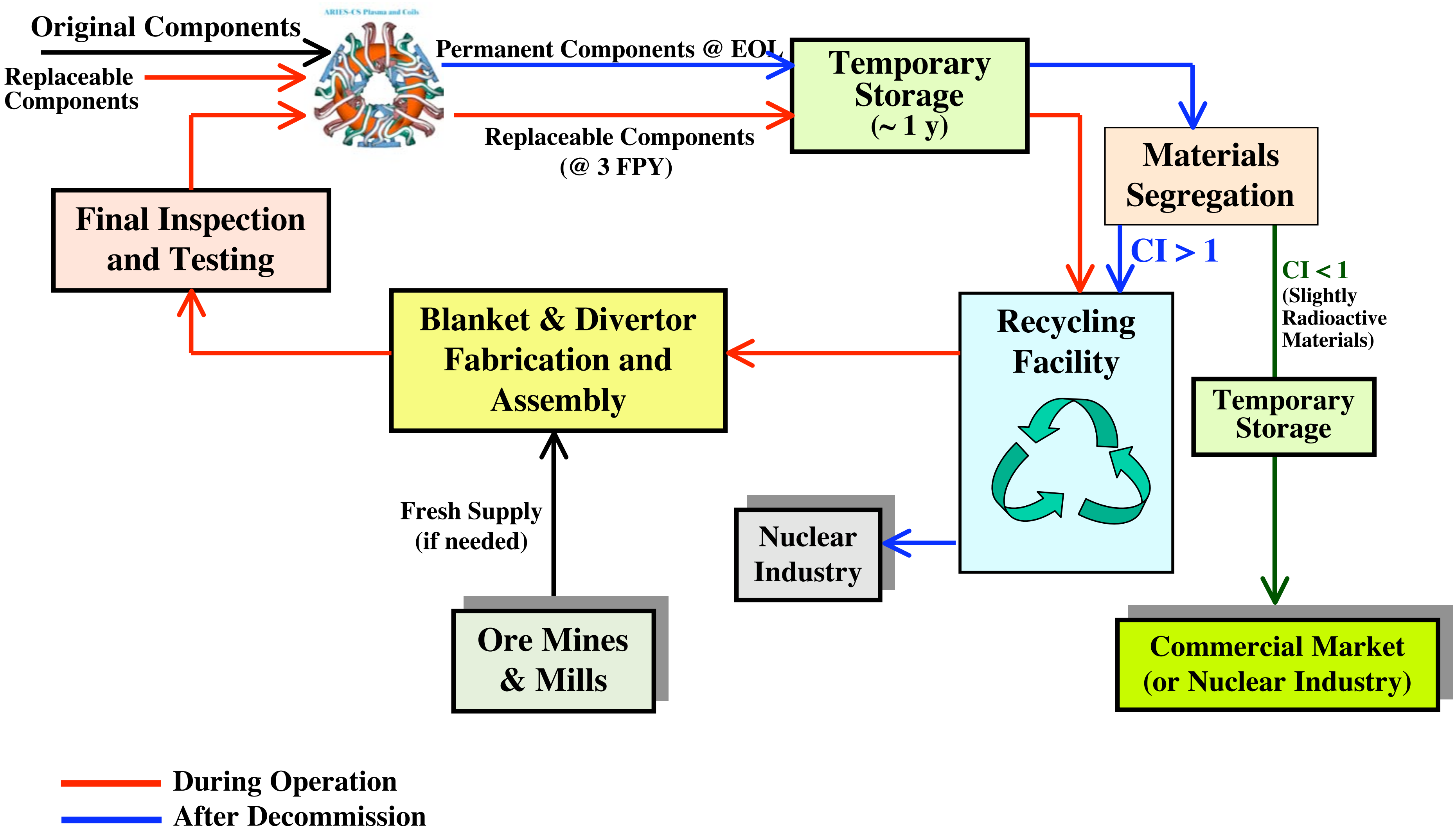
All ARIES-CS Components can be Recycled in < 1 y Using Advanced RH Equipment





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/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*.
- 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

STARLITE report:

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

- is safer
- 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 designs:

- 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 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.