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)
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-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*.

ARIES Designs
(1988-2007)

ARIES Project Timeline

- ARIES-I: first stability tokamak
- ARIES-II: second-stability tokamak
- ARIES-III: deuterium-fueled tokamak
- ARIES-IV: second-stability tokamak
- STARLITE: initial technical requirements for power plants
- ARIES-CS: compact stellarator
- ARIES-ST: spherical torus
- ARIES-AT: advanced technology and advanced tokamak design
- PULSAR: pulsed plasma tokamak
- SPPS: stellarator
- TITAN: reversed-field pinch
- ARIES-CS: compact stellarator
- ARIES-AT: advanced technology and advanced tokamak design
- Fusion Neutron Source Study
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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)

<table>
<thead>
<tr>
<th>Components</th>
<th>Recycle?</th>
<th>Clear?</th>
<th>Dispose of @ EOL?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IFE:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARIES-IFE</td>
<td>no</td>
<td>yes / no</td>
<td>yes (for economic reasons)</td>
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<td><strong>Z-Pinch-IFE</strong></td>
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<td><strong>MFE:</strong></td>
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<tr>
<td>ARIES-CS@</td>
<td>all</td>
<td>yes</td>
<td>yes / no</td>
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</table>


@ 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/m² Average NWL.
3 FPY Replaceable FW/Blanket.
40 FPY Permanent Components.
~78 mills/kWh COE ($2004).
ARIES-CS LLW Classification for Geological Disposal

Temporary Storage

All ARIES-CS Components (~8,000 m³)

Class C Repository

(~1,400 m³) (18%)

> 8 m below ground surface + Thick Concrete Slab

(~6,600 m³) (82%)

~ 8 m below ground surface

Class A Repository

Least hazardous type of waste

<table>
<thead>
<tr>
<th></th>
<th>Class C LLW</th>
<th>Class A LLW</th>
<th>Could be Cleared?</th>
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<tbody>
<tr>
<td>FW/Blkt/BW</td>
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<td>Shield/Manifolds</td>
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<tr>
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<tr>
<td>Nb₂Sn</td>
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<tr>
<td>Cu Stabilizer</td>
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<td>✓</td>
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<tr>
<td>Bioshield</td>
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</table>
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

Original Components
2 Sets of Replaceable Components

Final Inspection and Testing

Blanket & Divertor Fabrication and Assembly

Recycling Facility

Temporary Storage

Materials Segregation

Commercial Market (or Nuclear Industry)

Permanent Components @ EOL

Replaceable Components (@ 3 FPY)

Fresh Supply (if needed)

Nuclear Industry

Ore Mines & Mills

CI > 1
(Slightly Radioactive Materials)

CI < 1

During Operation

After Decommission
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 m³ 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 ($\geq 10,000$ 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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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.