Recycling of Radioactive Materials – a Must Requirement for Fusion

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Outline

If we ask members of general public:

What concerns them the most about nuclear energy?

Answers:

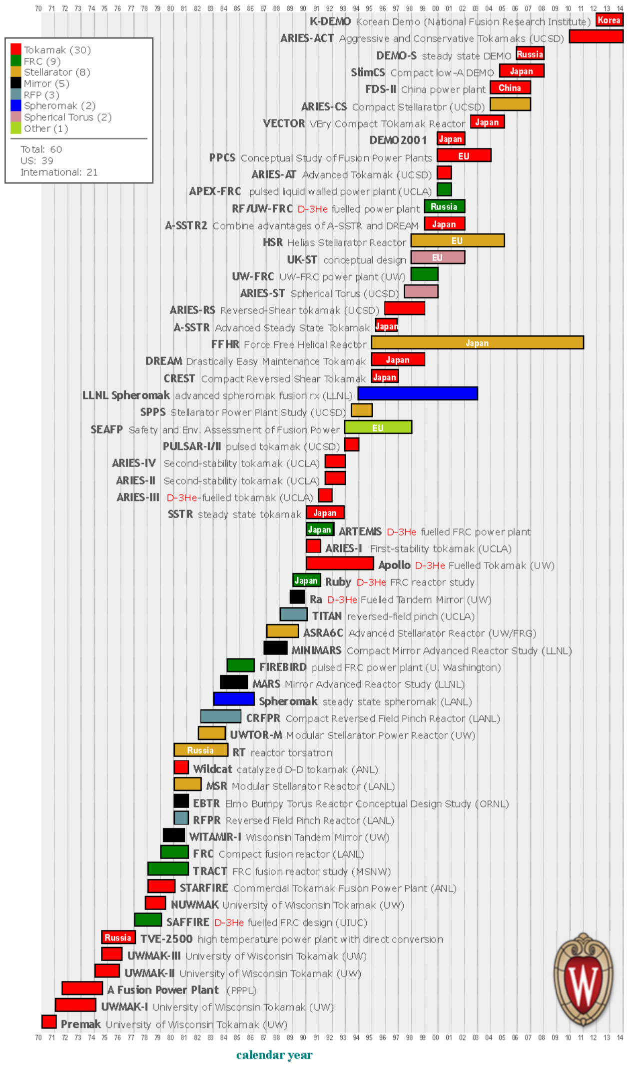
1- Safety

2- Radioactive Waste (what to do with it?)

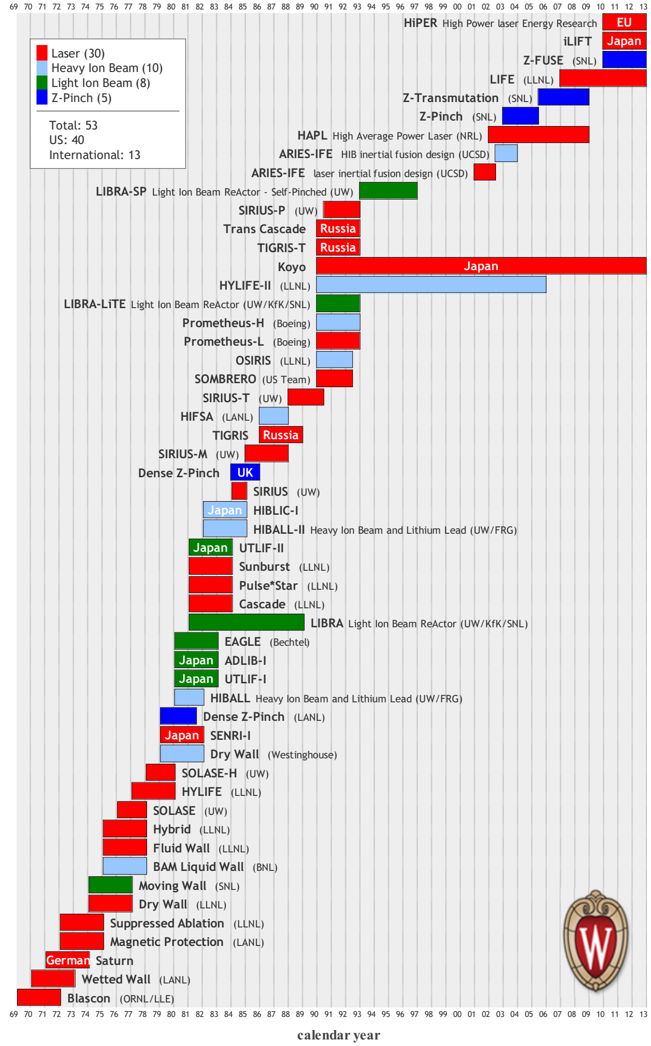
Also big issues: Cost and Proliferation.

Since 1970, Over 100 Fusion Studies Demonstrated Adequate Performance in Several Safety and Environmental Areas

MFE Studies

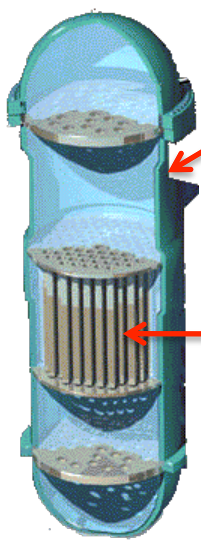


IFE Studies



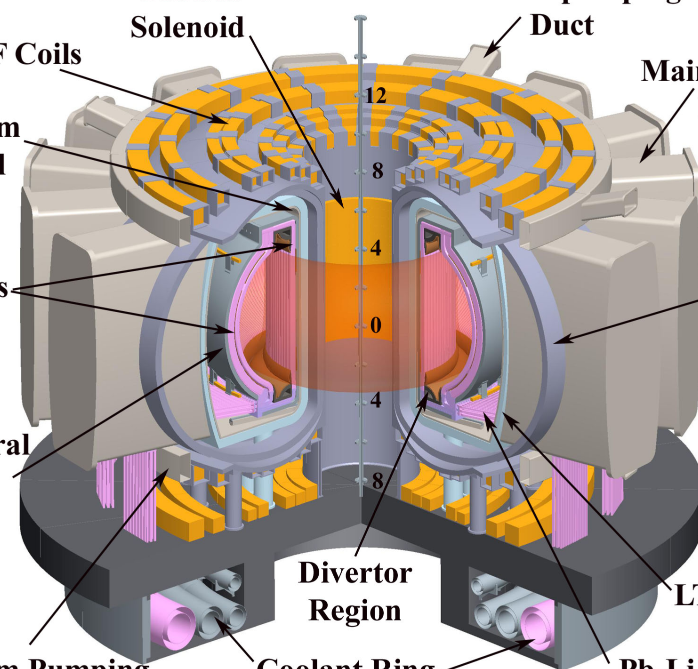
Fusion Does Not Produce High-Level Waste, but Generates Large Amount of Low-Level Waste

Power core of advanced **fission** reactor



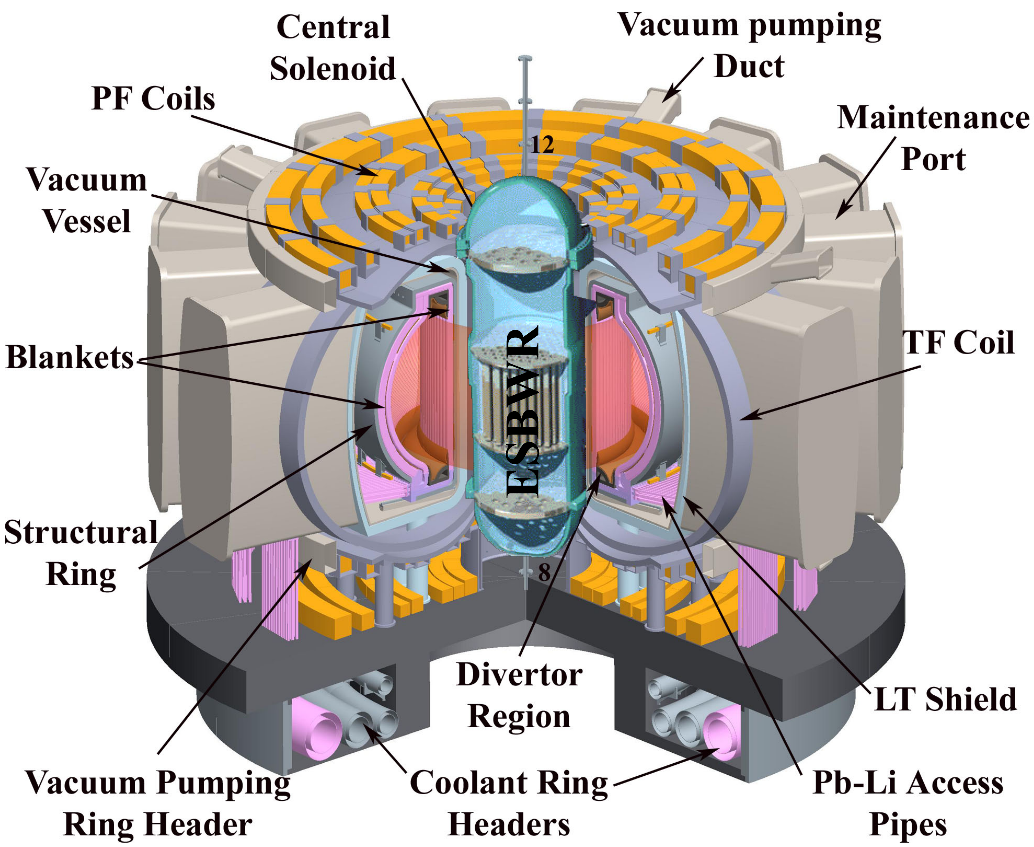
Advanced Fission Reactor Vessel (ESBWR) (21 m x 6.4 m)

Power core of advanced **fusion** power plant

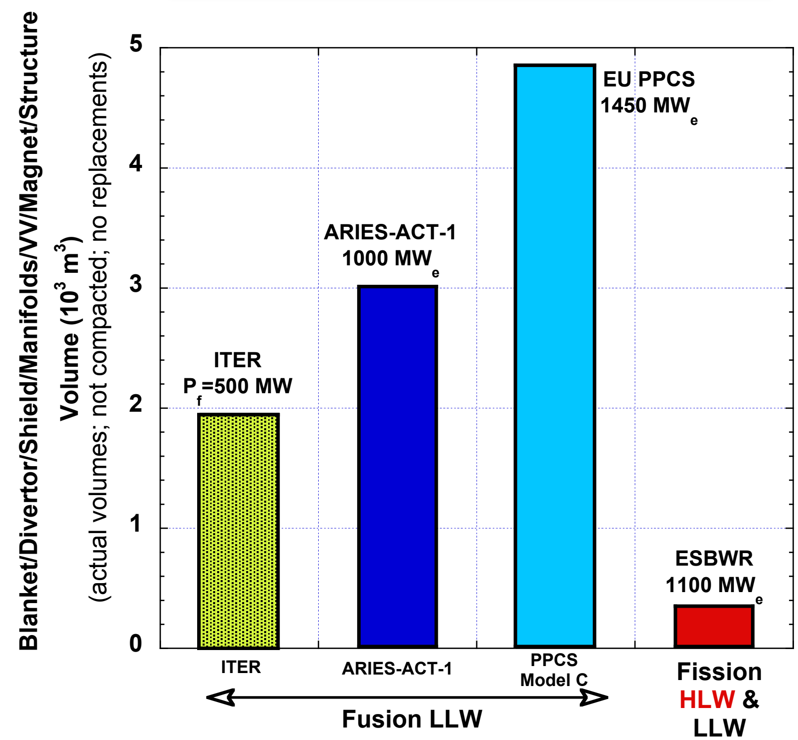


ARIES-ACT-1 Power Plant
(R= 6.25 m)

Fusion Does Not Produce High-Level Waste, but Generates Large Amount of Low-Level Waste (Cont.)



FPC Volume
(Cryostat and bioshield not included)



Fission power core fits inside inboard of fusion power core

Pressing Question

- What should we do with **fusion** activated materials generated during operation and after decommissioning?

- Geological disposal is NOT environmentally attractive option.

- Need to develop integrated management strategy for radioactive materials to minimize radwaste burden for future generations.

Options for Radwaste Management

- **Disposal in space**.
- **Ice-sheet disposal** @ north/south pole.
- **Seabed disposal**.

Faced strong opposition from federal government, nuclear industry, and environmental groups

- **Transmutation of long-lived radionuclides**
(⇒ proliferation concerns for fission, not for fusion).
- **Geological disposal** (preferred US option during past 50 years. Before 1980, Nuclear Regulatory Commission (NRC) did not look at back-end of fuel cycle when considering environmental impact statement for reactor applications)

  ⇒ Fusion should avoid fission mistakes

  Develop strategy for handling radioactive materials before applying for licensing.

- new **Recycling** / reprocessing (reuse within nuclear industry).
- new **Clearance** (release to commercial market if materials are slightly radioactive, containing 10 μSv/y (< 1% of background radiation)).

Need Solution for Disposal Problems

- **New strategy** should be developed, calling for major rethinking, education, and research to make this new strategy a reality:
  - Avoid geological disposal
  - Minimize volume of radwaste by:
    - Clever designs
    - Promoting new concepts:

      Recycling – Reuse within nuclear industry, if technically and economically feasible

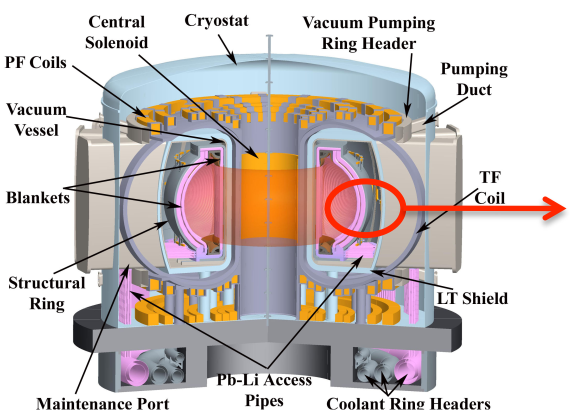
      Clearance – Unconditional release to commercial market to fabricate as consumer products (or dispose of in non-nuclear landfill). This is currently performed on case-by-case basis for US nuclear facilities. Clearable materials are safe, containing 10 μSv/y (< 1% of background radiation).
- **Why**?
  - Limited capacity of existing LLW repositories. (Three commercial repositories will be closed by mid-century before building 1^{st} fusion power plant)
  - Political difficulty of building new repositories
  - Stricter regulations and tighter environmental controls
  - Uncertain geological conditions over long time
  - Promote nuclear as energy source with minimal environmental impact
  - Minimize radwaste burden for future generations
  - Handling of radioactive materials is important to future of fusion energy.

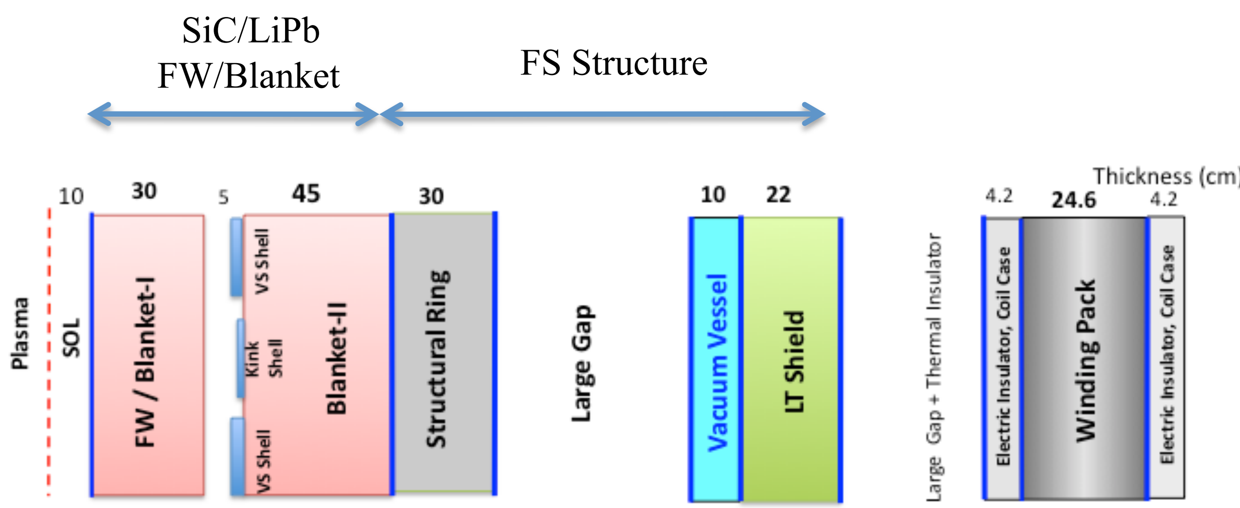
Recycling and Clearance

The solution…

(Relatively easy to apply from science perspectives, but
real challenge in US from policy, regulatory, and public acceptance perspectives)

Applying Recycling and Clearance to Outboard of ARIES-ACT-1

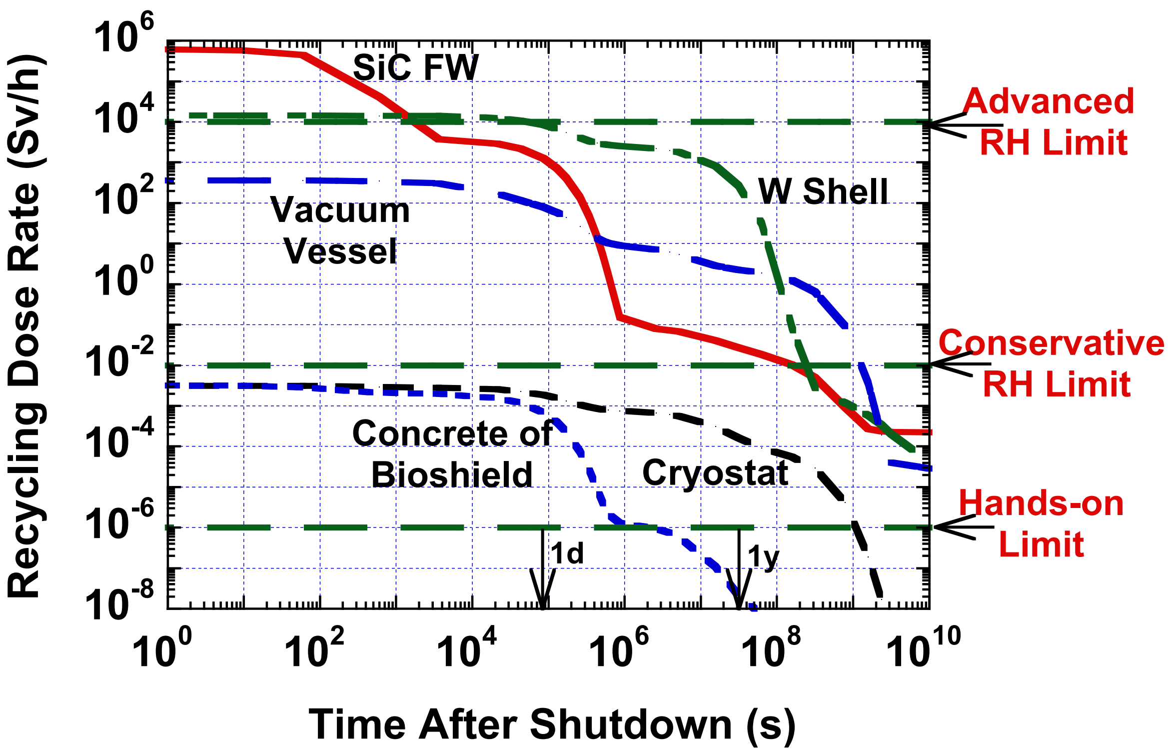


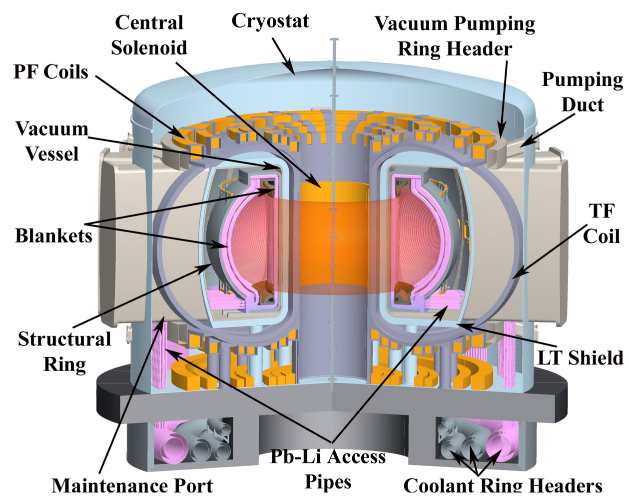


Outboard Radial Build

All In-vessel Components can be Recycled in 1 day with Advanced RH Equipment

OB Components



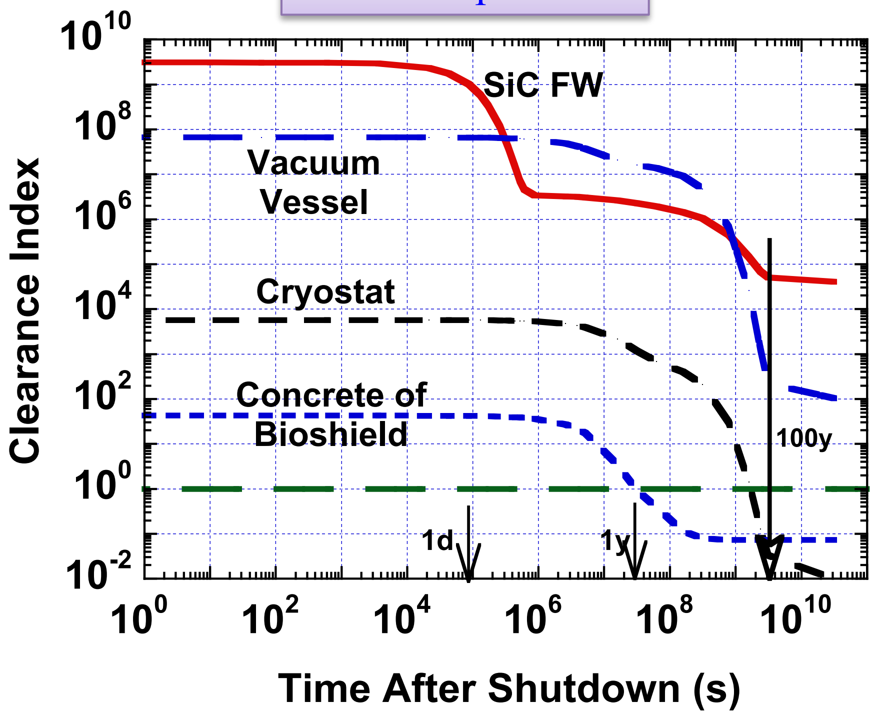


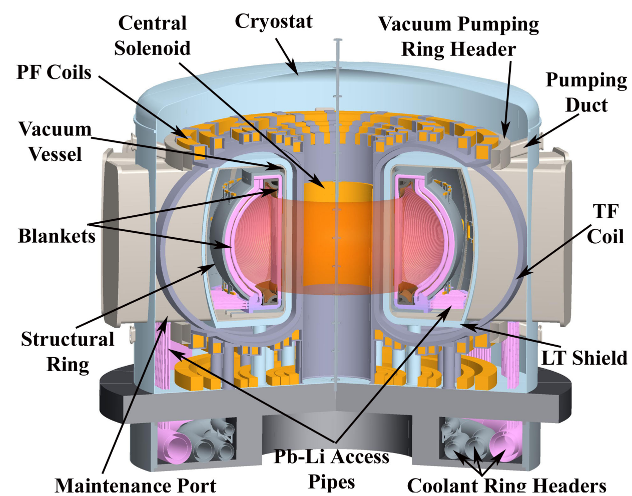
3 m thick bioshield (not shown) surrounds cryostat

Bioshield could be recycled with hands-on shortly after shutdown

Clearance

OB Components

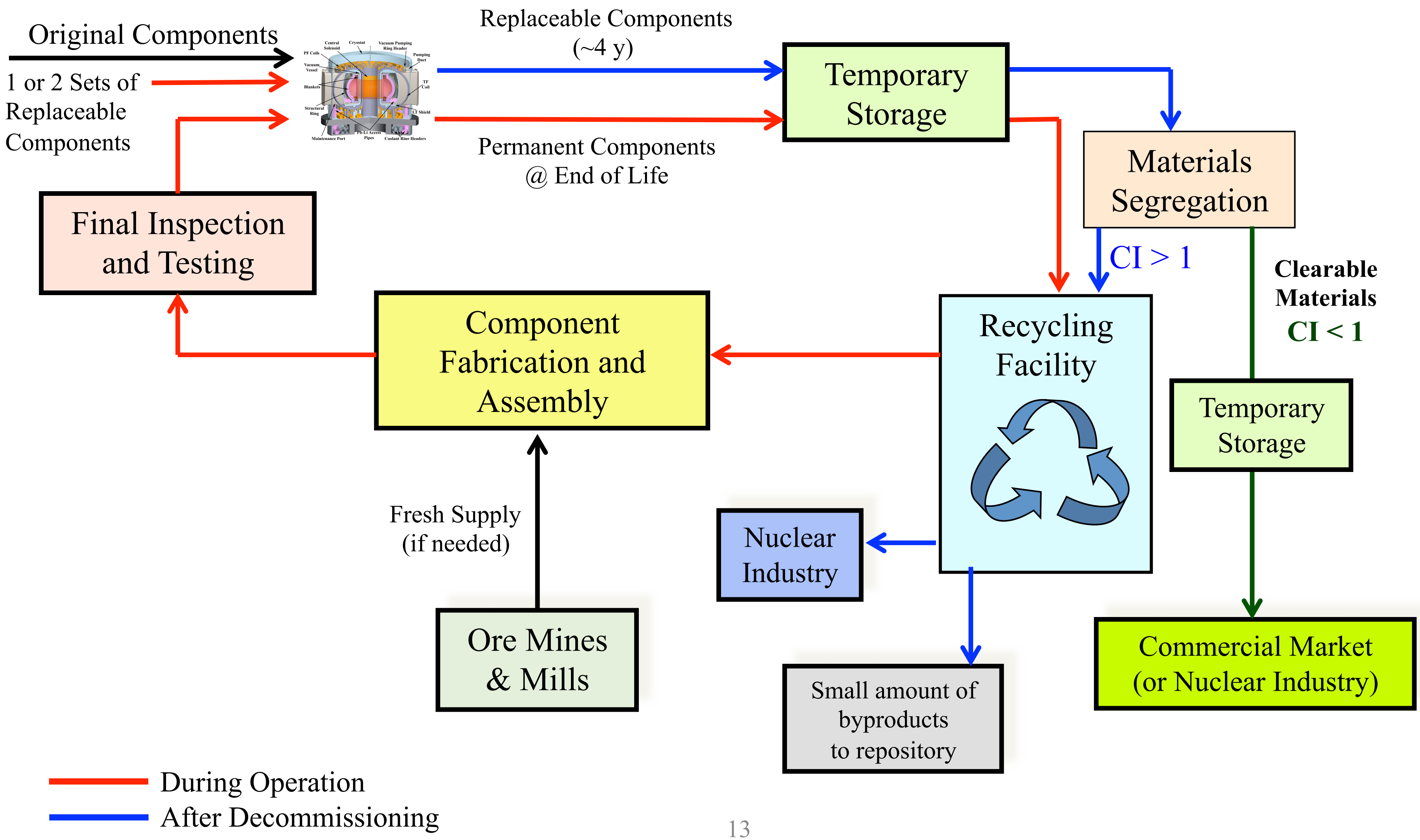




3 m thick bioshield (not shown) surrounds cryostat

- In-vessel components are not clearable (CI >> 1) even after extended cooling period of 100 y.
- Cryostat and bioshield can be cleared in < 100 y after decommissioning.

Recycling & Clearance Flow Diagram



General Observations

- Most fusion studies indicated recycling and clearance are technically feasible, providing effective means to minimize radwaste volume. (Only radioactive materials assign for geologic disposal are labeled radwaste).

- Recycling and clearance should be pursued despite lack of details at present.

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

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* L. El-Guebaly, V. Massaut, K. Tobita, and L. Cadwallader, "Goals, Challenges, and Successes of Managing Fusion Active Materials," Fusion Engineering and Design 83, Issues 7-9 (2008) 928-935.
L.A. El-Guebaly, " Future Trend Toward the Ultimate Goal of Radwaste-Free Fusion: Feasibility of Recycling/Clearance, Avoiding Geological Disposal." J. Plasma and Fusion Research, 8, 3404041-1-6 (May 2013).

Key Issues and Needs for Disposal

Issues:

- High disposal cost (for preparation, characterization, packaging, interim storage, transportation, licensing, and disposal)
- No HLW repositories
- Limited capacity of existing LLW repositories
- Political difficulty of building new repositories
- Prediction of repository's conditions for long time into future
- Radwaste burden for future generations.

Needs:

- Revised activity limits for HLW and LLW issued by legal authority (NRC)
- Repositories designed for T-containing materials
- Reversible disposal process and retrievable waste (to gain public acceptance and ease licensing).

Key Issues and Needs for Recycling

Issues:

- Separation of various activated materials from complex components
- Radiochemical or isotopic separation processes for some materials, if needed
- Treatment and remote re-fabrication of radioactive materials
- Radiotoxicity and radioisotope buildup and release by subsequent reuse
- Properties of recycled materials? Any structural role? Reuse as filler?
- Handling of T containing materials during recycling
- Management of secondary waste. Any materials for disposal? Volume? Radwaste level?
- Energy demand for recycling process
- Cost of recycled materials
- Recycling plant capacity and support ratio

Needs:

- R&D program to address recycling issues
- Radiation-resistant remote handling equipment
- Reversible assembling process of components and constituents (to ease separation of materials after use)
- Efficient detritiation system
- Large and low-cost interim storage facility with decay heat removal capacity
- Nuclear industry should accept recycled materials
- Recycling infrastructure.

Key Issues and Needs for Clearance

Issues:

- Discrepancies between proposed US-NRC & IAEA clearance standards#
- Impact on clearance index prediction of missing radioisotopes
- Radioisotope buildup and release by subsequent reuse.

Needs:

- Official clearance limits issued by legal authorities
- Accurate measurements and reduction of impurities that deter clearance of in-vessel components
- Reversible assembling process of components and constituents
- Large and low-cost interim storage facility
- Clearance infrastructure
- Clearance market (Some experience exists in several EU countries: Sweden, Germany, Spain, and Belgium. At present, US industry does not support unconditional clearance claiming it could erode public confidence in US products and damage US 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).

US Industrial Experience Demonstrated Economical and Technical Feasibility of Recycling (L. Cadwallader – INL)

- **In 1960s**, ANL-West Hot Fuel Examination Facility developed radiation resistant tools to handle fission fuel rods for Experimental Breeder Reactor (EBR-II). RH equipment operated successfully at 10,000 Sv/h.

- INL and industrial firm recycled activated Pb bricks for nuclear industry. Cost of Pb LLW disposal was ~$5/pound while cost of recycling was ~$4.3/pound including fabrication into brick shapes.

  Savings:
  - Recycling versus disposal cost
  - Disposal volume over entire lifecycle
  - Not requiring purchase of new Pb bricks.

- INL and industrial company fabricated shielding casks out of recycled stainless steel:
  - Casks were designed, built, and tested for strength and impact
  - Slag from melting tends to collect some radionuclides
  - Composition adjustments after slag removal produced metal alloys with properties very similar to those of fresh alloys
  - Prototype casks functioned well and are still in use since 1996.

More Recent Developments

- **In US:**
  - US recycled tons of metals and concrete from fission plant for reuse within nuclear industry.
  - In 2003, NRC issued clearance guidelines for 4 materials (containing 115 elements): steel, Cu, and Al scraps, and concrete rubbles.
  - MOX* fuel fabrication facility in South Carolina is ~60% complete and will start operation in 2016.
  - In 2010, DOE required decontamination of 15,300 tons of radioactive nickel and recycling into products that will be used in radiologically-controlled applications.

- **Internationally**:
  - Advanced MOX* fuel recycling technology exists in many European countries (France, Belgium, UK, etc.).
  - In 2004, IAEA issued clearance guidelines for 257 elements.
  - Other regulatory agencies (in Europe and Russia) issued guidelines for clearance.

- Such developments at the national and international levels will be of great importance to fusion, but adaptation is necessary to the fusion needs (radiation level, component size, weight, etc.).

* Mix of Pu and U Oxides.

Maturation of Recycling and Clearance Approaches

It's just matter of time to develop recycling/clearance technologies and standards.

Designers should:

- Minimize radwaste volume by clever designs
- Promote environmentally attractive scenarios such as recycling and clearance, avoiding geological disposal
- Continue addressing critical issues for all three options
- Address technical and economical aspects before selecting the most suitable radwaste management approach for any fusion component.

Nuclear industry and regulatory organizations should:

- Continue developing advanced radiation-resistant remote handling equipment capable of handling > 10,000 Sv/h
- Issue official guidelines for unconditional release of fusion clearable materials
- Accept recycled materials from dismantled nuclear facilities
- Continue national and international efforts to convince industrial and environmental groups that clearance can be conducted safely with no risk to public health.

Growing International Effort in Support of New Trend to Manage Fusion Radioactive Materials

- IEA implementing agreement forms basis for international collaboration.

- IEA Cooperative program on "Environmental, Safety, and Economic Aspects of Fusion Power" – <u>Task 6: Radioactive Waste Study</u>
  - USA: L. El-Guebaly
  - EU: M. Zucchetti (Coordinator)
  - Japan: K. Tobita
  - RF: V. Kapyshev
  - China: Z. Chang
  - S. Korea: J-H. Han.

- Recent publications:
  - M. Zucchetti, L. Di Pace, L. El-Guebaly, B.N. Kolbasov, V. Massaut, R. Pampin, and P. Wilson, "The Back End of the Fusion Materials Cycle," Fusion Science and Technology 52, No. 2 (2009) 109-139.
  - M. Zucchetti, L. Di Pace, L. El-Guebaly, J-H. Han, B.N. Kolbasov, V. Massaut, and Y. Someya, "Recent Advances in Fusion Radioactive Material Studies," Fusion Engineering and Design, in press.
  - B. Kolbasov, L. El-Guebaly, V. Khripunov et al., "<u>Some Technological Problems of Fusion Materials Management</u>," to be presented at 11th ISFNT, Barcelona, Spain, September 16-20, 2013. To be published in Fusion Engineering and Design.

To Be Addressed

- Critical issues identified for recycling/clearance.
- Impact of recycling/clearance on the development of low-activation ferritic steel.