D-^{3}He Fueled Fusion Devices as Step Towards Total Fusion Safety

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History & Background Info

- In late 1980s, fusion safety stimulated worldwide research for fuel cycles other than D-T.
- Advanced cycles (such as D-D, **D-^{3}He**, p-^{11}B, and ^{3}He-^{3}He) do not require breeding large amount of T (~56 kg/y for 1 GW of D-T fusion power).
- Some advanced cycles (e.g., D-^{3}He) are not completely aneutronic due to side D-D reactions.
- However, neutron wall loading can be kept low (by orders of magnitude) compared to D-T fueled plants with same output power.
- **Attractive features for D-^{3}He fuel cycle include:**
  - No T breeding blanket.
  - All components are permanent, meaning no need to replace FW/shield during entire plant lifetime (~ 50 y).
  - Potential for direct energy conversion.
  - **Low activity, decay heat, and radwaste levels.**
  - Low releasable radioactive inventory from credible accidents.
- **Concerns for D-^{3}He fuel cycle :**
  - ^{3}He availability.
  - Higher plasma ion temp (50-100 keV) compared to D-T (10-20 keV).

Objectives

- Apply most recent radwaste management schemes to D-^{3}He fueled devices: **<u>ARIES-III</u>** <u>power plant</u> and **<u>Candor</u>** <u>experiment</u>*.

- Compare radiological aspect of D-^{3}He and D-T fuel cycles and highlight differences.

* L. El-Guebaly and M. Zucchetti, "Recent Developments in Environmental Aspects of D-^{3}He Fuelled Fusion Devices," Fusion Engineering and Design, vol. 82, # 4 (2007) 351-361.

Handling Fusion Radwaste is Important to Future of Fusion Energy

- 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 amount 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
  - No long-lived radwaste burden for future generations.

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

Fusion Designs Should Adopt **MRCB** Philosophy

M – Minimize volume of active materials by design
or by employing advanced fuel cycle.

R – Recycle, if economically and technologically feasible.

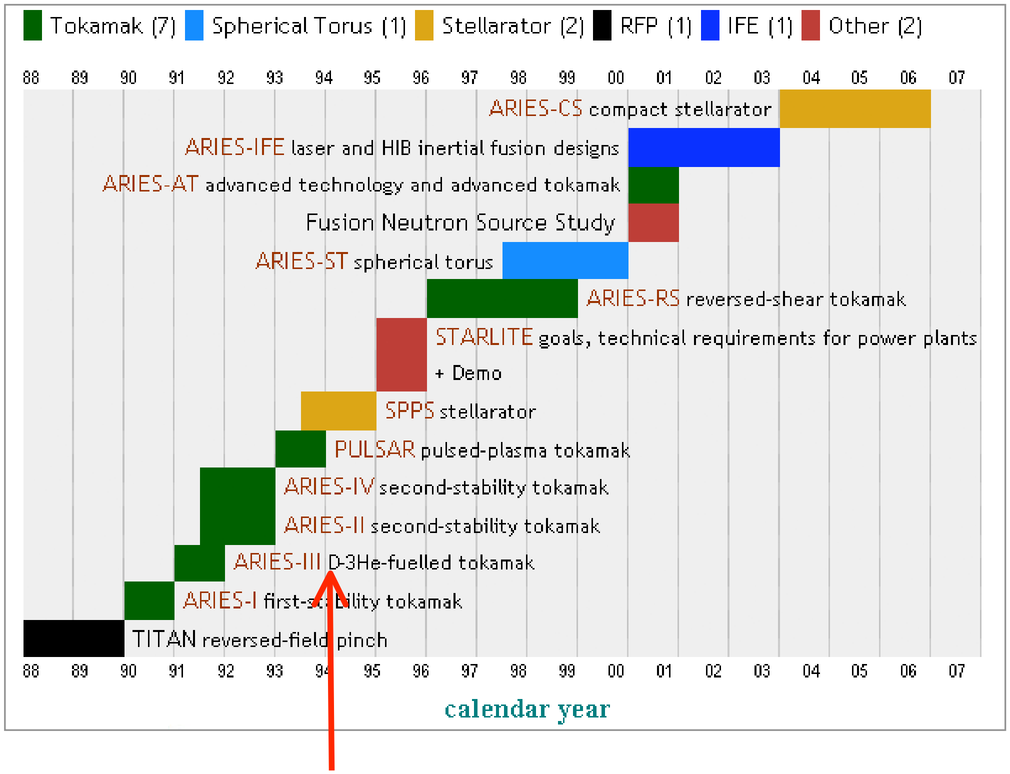
C – Clear slightly-irradiated materials.

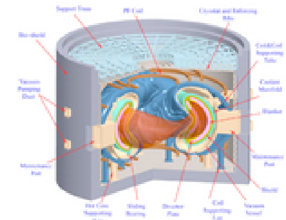
B – Burn active byproducts, if any, in fusion devices*.

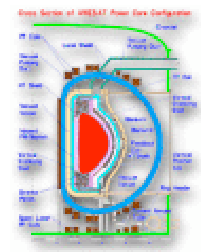
* L. El-Guebaly, "Managing Fusion High Level Waste – a Strategy for Burning the Long-Lived Products in Fusion Devices," *Fusion Engineering and Design*, **81** (2006) 1321-1326.

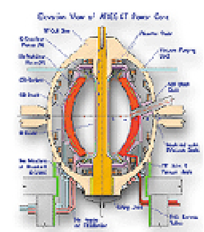
ARIES-III Power Plant Selected for Radwaste Assessment

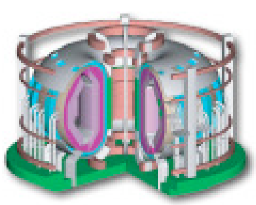
ARIES Project Timeline




ARIES-CS


ARIES-AT

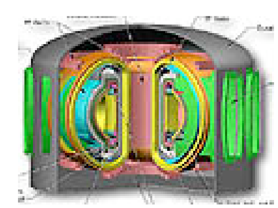

ARIES-ST


ARIES-I

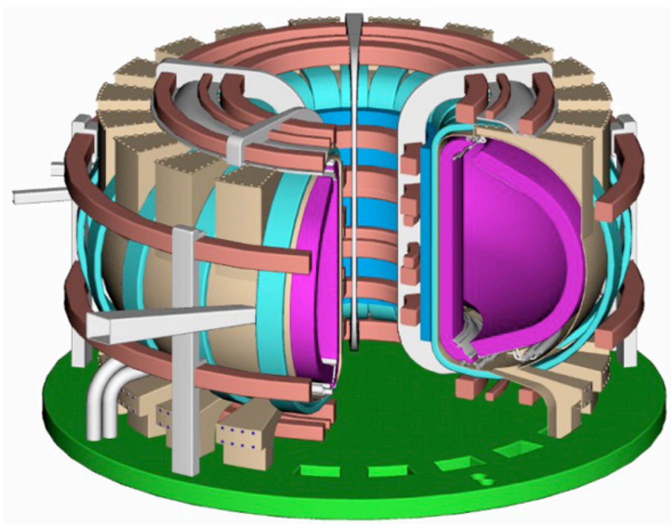

ARIES-III


ARIES-IV


SPPS

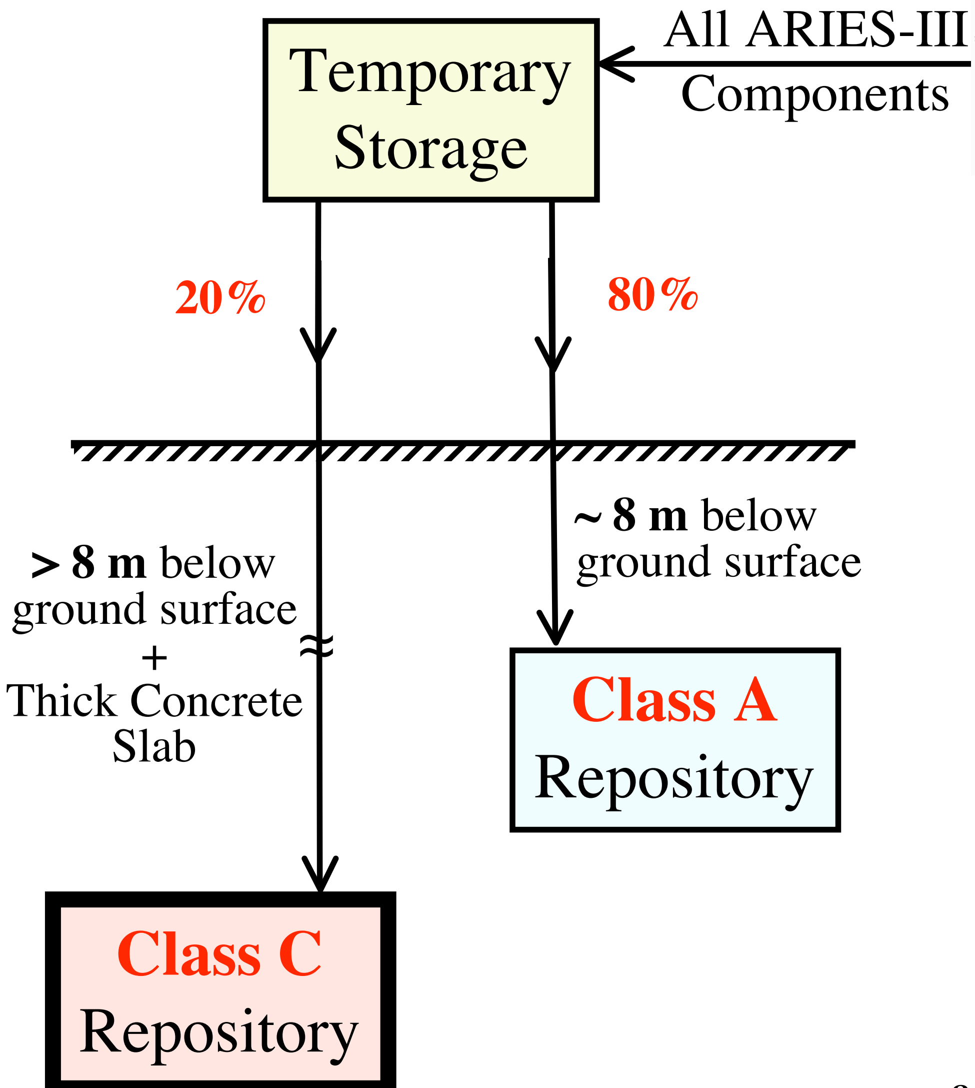

ARIES-RS

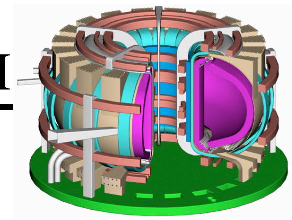
ARIES-III Power Plant



1000 MW_e Output Power
7.5 m Major Radius
D-^{3}He Neutron Source:
70% 2.45 MeV n's
30% 14.1 MeV n's
0.1 MW/m^2 Average NWL
Ferritic Steel Structure
Organic Coolant with 44% η_{th}
40 FPY Permanent Components
85% Availability

ARIES-III LLW Classification for Geological Disposal

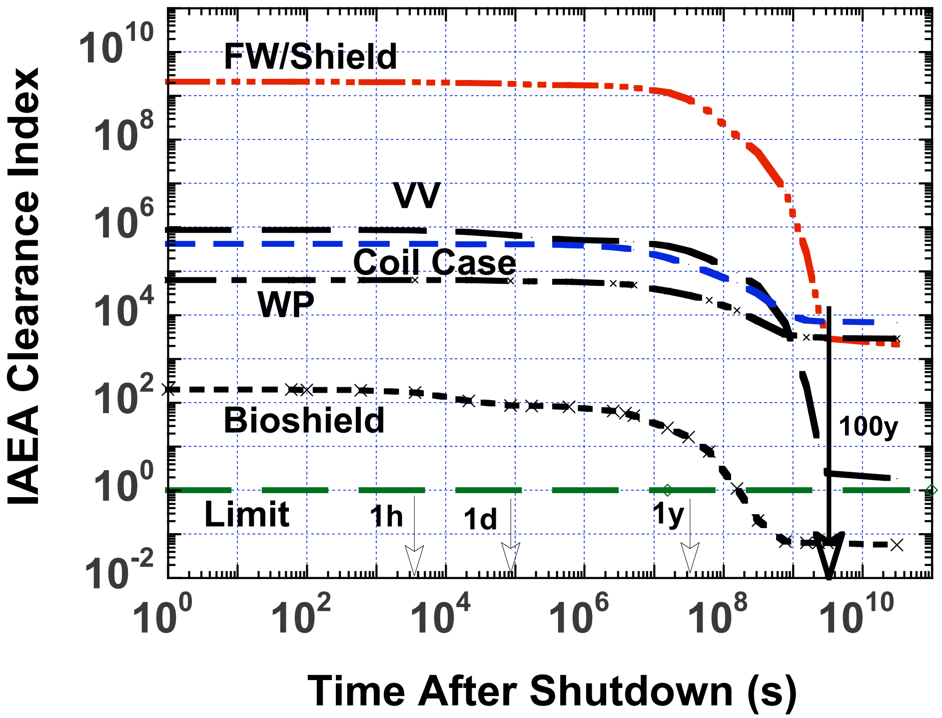


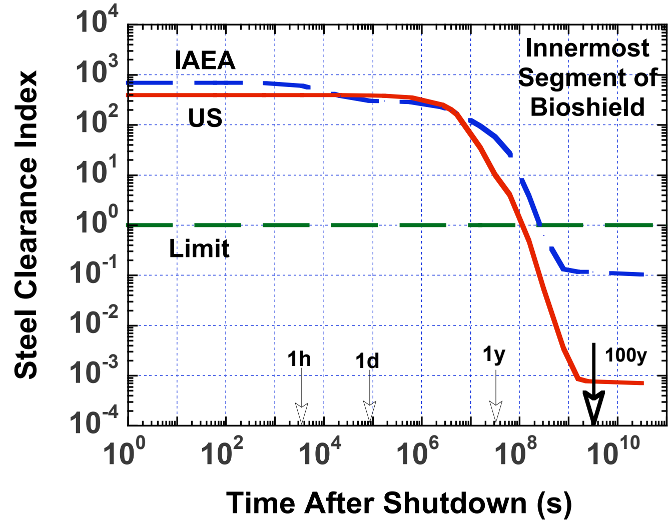


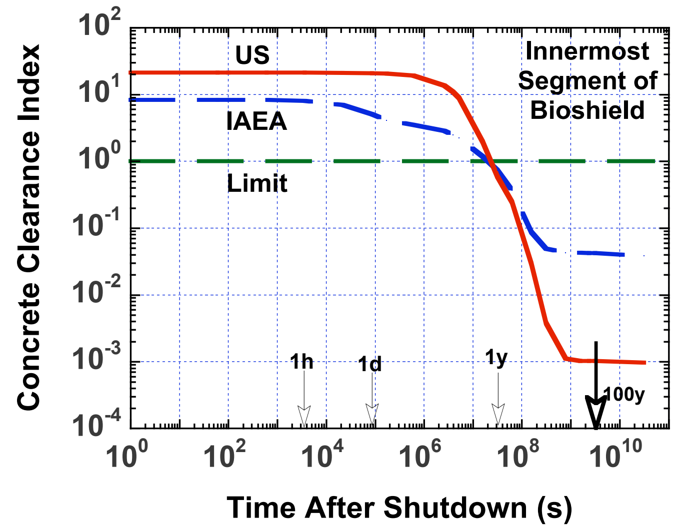
Least hazardous type of waste

	Class C LLW	Class A LLW	Could be Cleared?
FW/Shield		√	**no**
Vacuum Vessel		√	**no**
Magnet:	√		
Nb_3Sn (6%)			**no**
Incalloy (57%)			**no**
Cu (29%)			√
Insulator (4%)			√
Bioshield		√	√

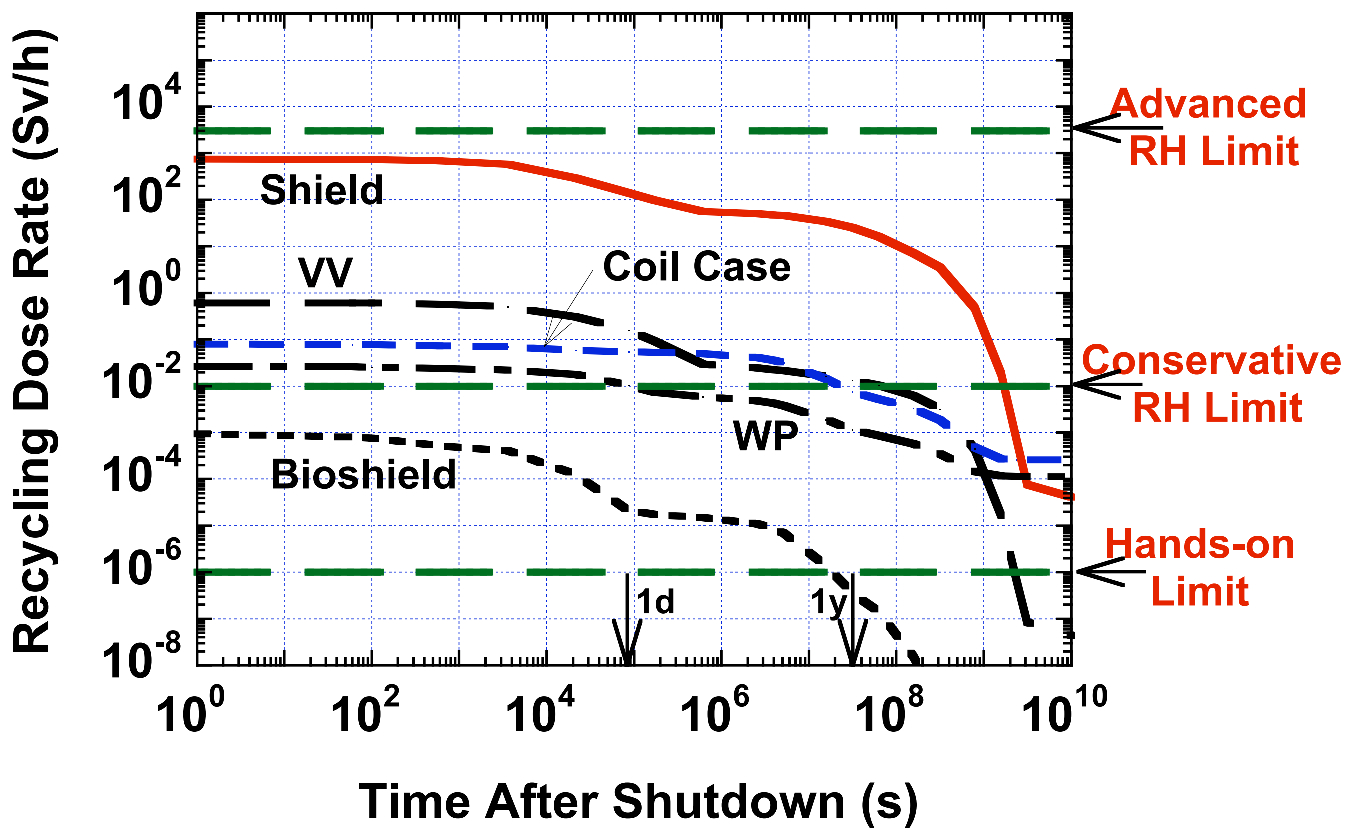
85% of ARIES-III Radwaste can be Cleared in < 10 y after Decommissioning



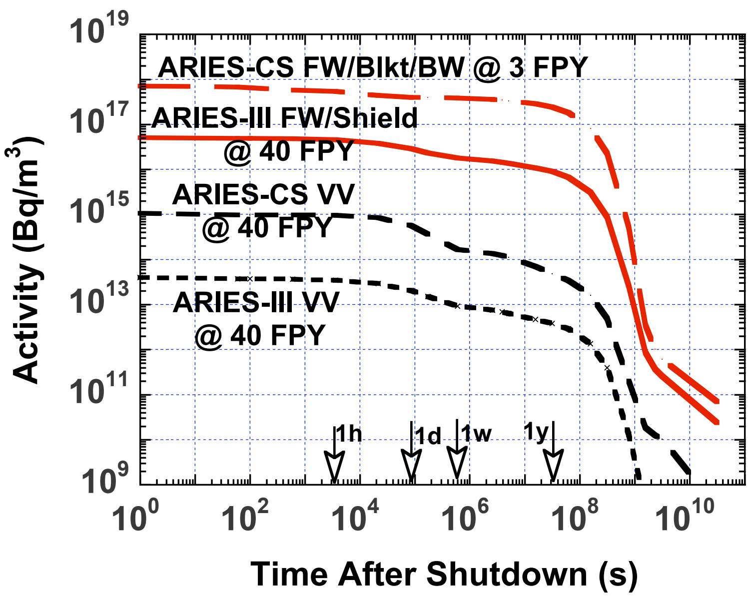


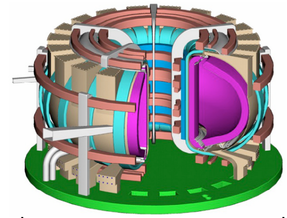


All ARIES-III Components can be Recycled in < 1 y Using Advanced and Conventional RH Equipment

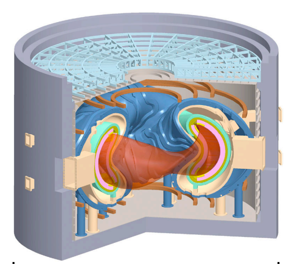


Comparison of D-^{3}He and D-T Fueled Power Plants of Comparable Major Radii

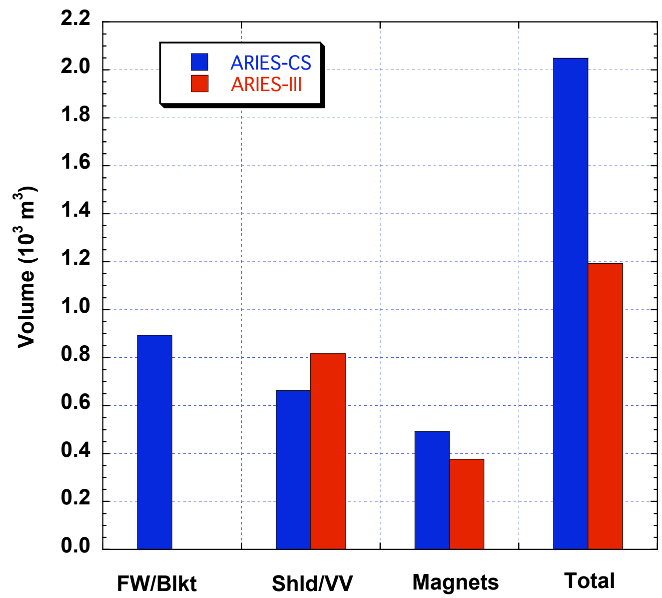




ARIES-III
D-^{3}He Fuel
R= 7.5 m



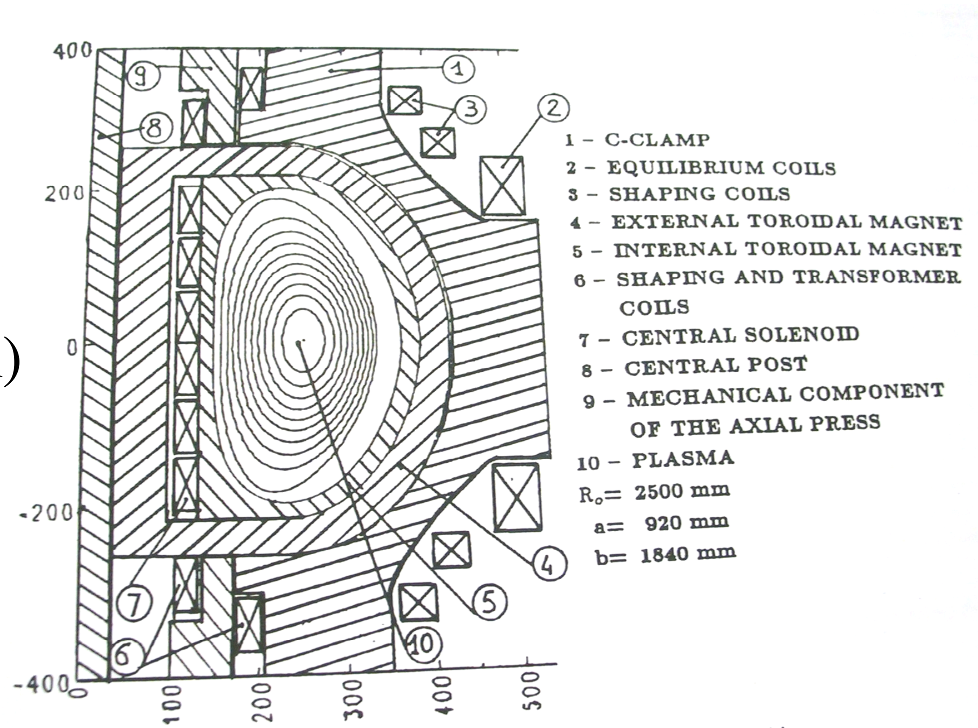
ARIES-CS
D-T Fuel
R= 7.75 m



ARIES-III radwaste inventory is ~50% of ARIES-CS'

Candor Experiment

Z (cm)



R (cm)

2.5 m Major Radius

Cu Magnet

D-T Trigger to Reach Ignition

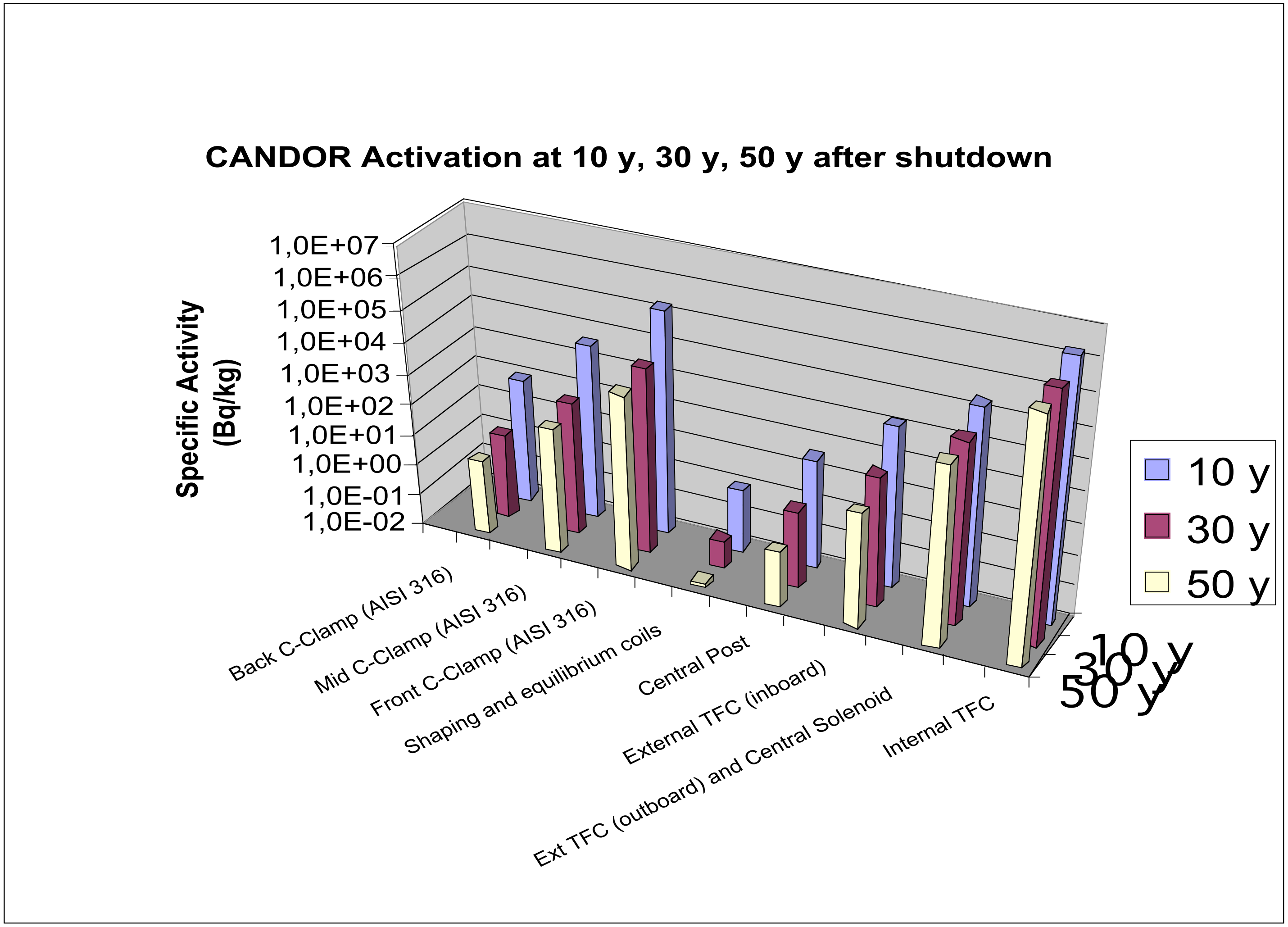
D-^{3}He Neutron Source:

74% 2.45 MeV n's

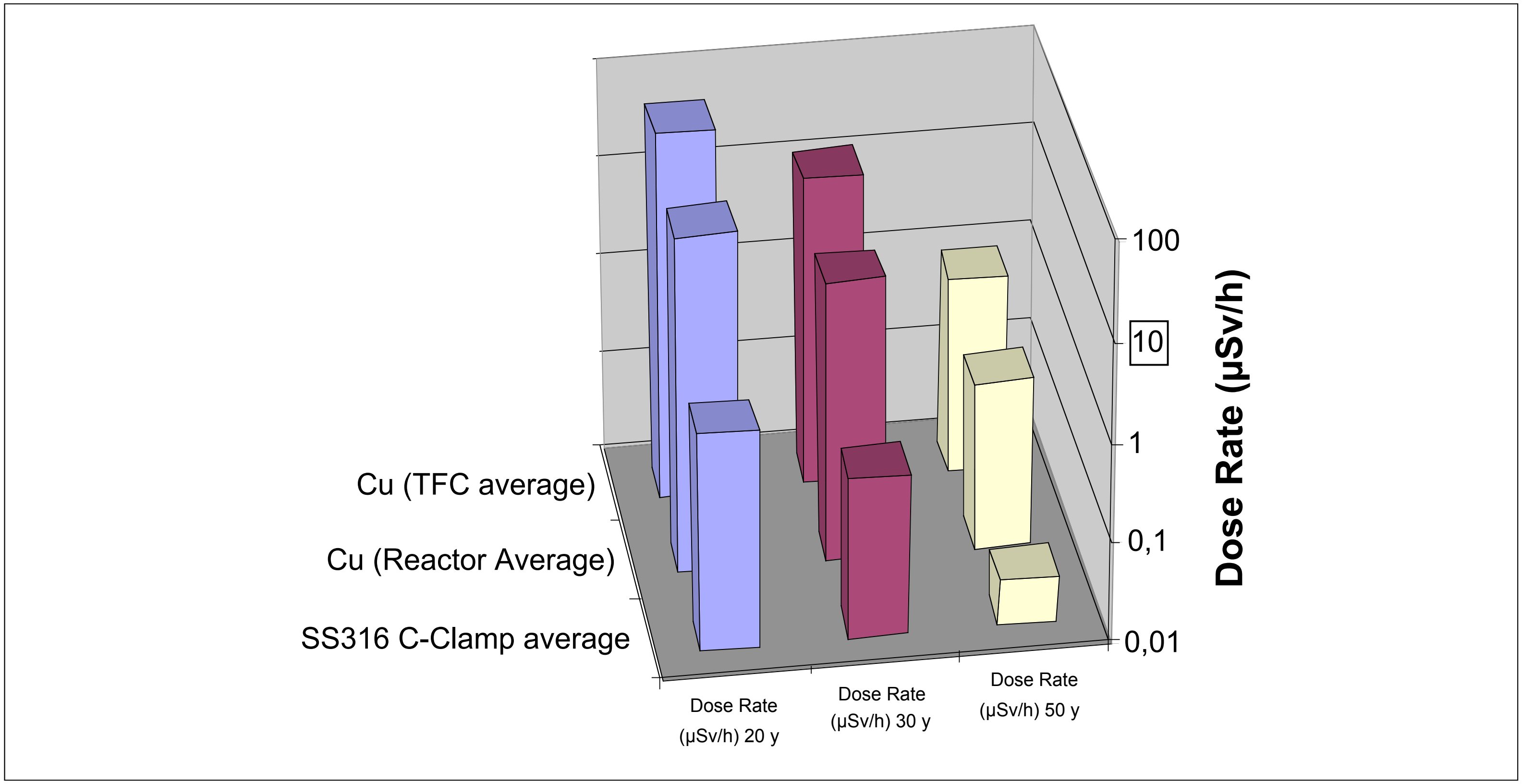
26% 14.1 MeV n's

1.2 MW/m^2 Average NWL

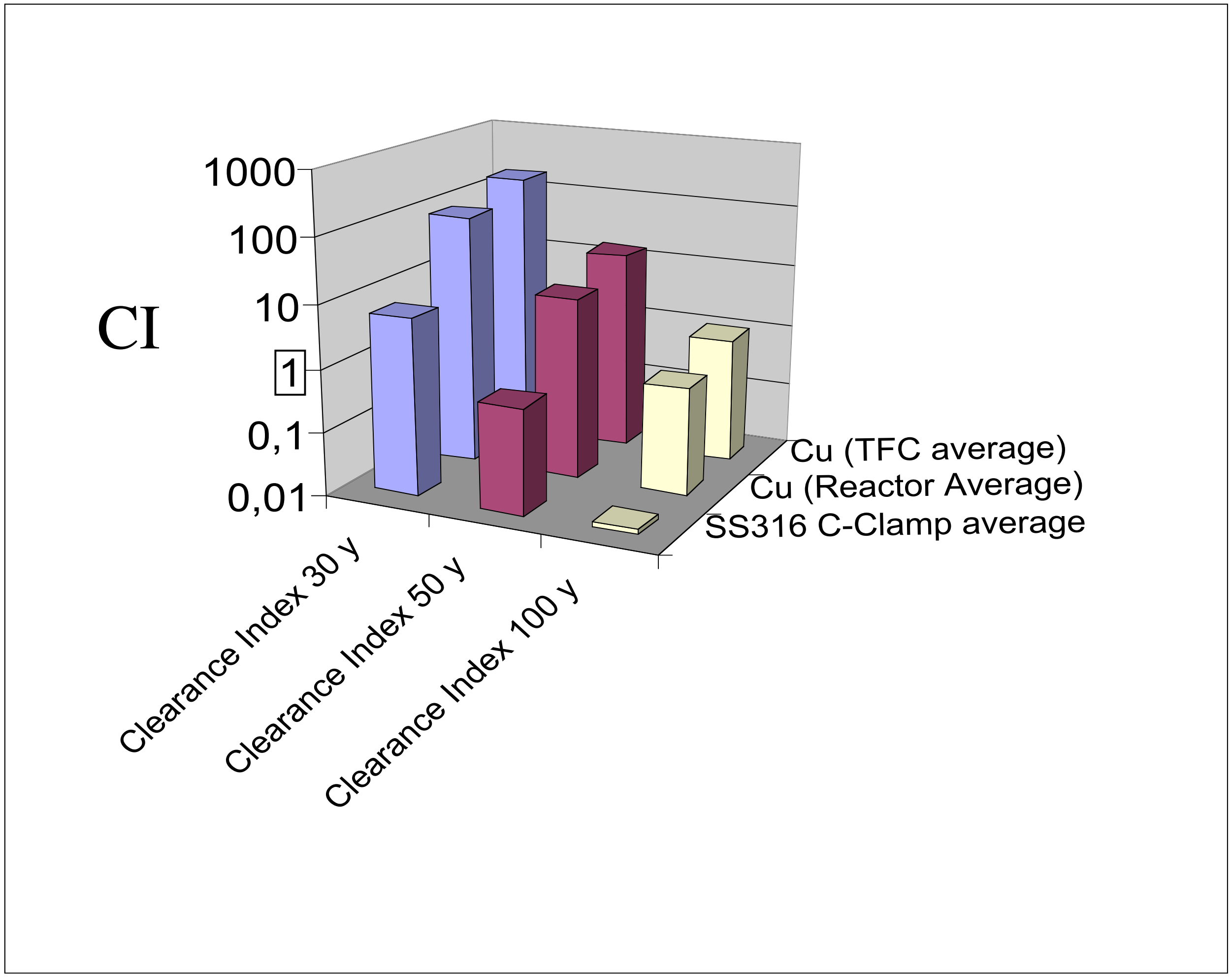
Candor Specific Activity



Hands-on Recycling of Candor Components is Feasible within 10-30 y



All Candor Components can be Cleared in 50-100 y



Conclusions

- Recycling and clearance of all components should be essential goal of fusion studies to minimize radwaste stream.
- Advanced D-^{3}He fuelled designs offer further step toward intrinsic safety and environmental goals.
- For D-^{3}He fuelled ARIES-III power plant:
  - All in-vessel components qualify as Class A waste, the least hazardous type based on U.S. guidelines.
  - All components can be recycled using conventional and advanced remote handling equipment.
  - Bioshield contains traces of radioactivity and can be cleared from regulatory control after relatively short period of time (~10 y).
- D-^{3}He fuelled Candor experiment reaches zero-waste option as all wastes can be cleared within 100 y.
- Low neutron production of D-^{3}He fuel helps overcome some of engineering and material hurdles to fusion development.
- Advanced fuel cycle development should be carried out in parallel with current mainstream fusion pathway that primarily focuses on D-T tokamaks.