Waste management strategy for EU DEMO: status, challenges and perspectives

S. Rosanvallon[a,b], P. Kanth[a,c], J. Elbez-Uzan[a,b]

[a]DEMO Central Team, EUROfusion, Garching, Boltzmannstr. 2 85748 Germany
[b]IRFM, CEA, F-13108 Saint Paul lez Durance, France
[c]United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, OX14 3DB, United Kingdom

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Outline

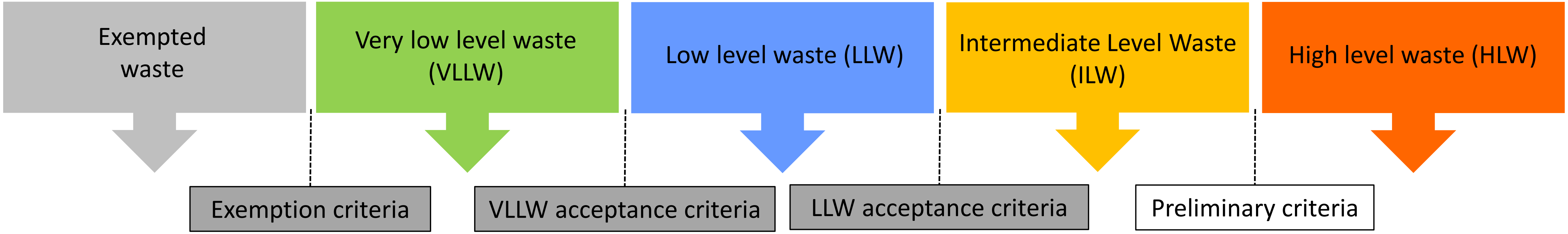
- Introduction
- Waste classification status
- Challenges
  - Reduction of the radiotoxicity
  - Reduction of the radioactive waste amounts
- Perspectives for EU DEMO
- Conclusions

Introduction

- European DEMO objectives
  - Net electricity, closed-tritium fuel cycle and plant availability
  - While demonstrating the safety and environmental advantages of fusion power compared with fission designs
- Coherent strategy for dealing with the waste needs to be part of the justification for realizing DEMO:
  - Minimization of the amount of radioactive waste produced
  - Minimization of the long-term geological disposal waste
  - Ability to detritiate efficiently
- No Host country, so no regulatory framework but shall be part of the design process

Waste classification status

Waste classification status



Focus on long-term geological waste disposal

LLWR (UK) Waste Acceptance Criteria:

- Total beta/gamma limit < 1.2×10^4 Bq/g
- Total alpha < 4×10^3 Bq/g

CSA (FR) Waste Acceptance Criteria

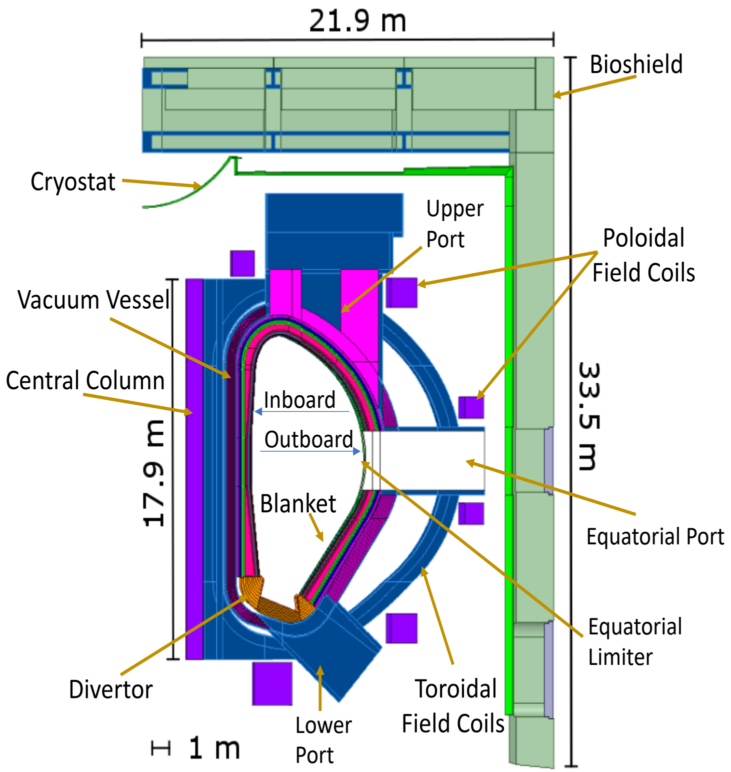
- Total alpha < 4×10^3 Bq/g
- ^{3}H < 2×10^5 Bq/g
- ^{14}C < 9.2×10^4 Bq/g
- ^{60}Co < 1.3×10^8 Bq/g
- ^{59}Ni < 1.1×10^5 Bq/g
- ^{63}Ni < 3.2×10^6 Bq/g
- ^{94}Nb < 1.2×10^2 Bq/g
- ^{93}Mo < 3.8×10^4 Bq/g

Decay heat limit within the disposal box:

- UK limits: 60 W for 2 m box or 2 W/t of waste,
- FR limits: 10 W/package or 2.5 W/t (considering a packing factor of 5t per 5 m^3 package for massive components)

Waste classification status

- Classification of WCLL and HCPB concepts
- End-of-life for ex-vessel component (70 dpa), 20 dpa irradiation damage in BB First Wall, 0.5 dpa in target Cu of divertor



Water-cooled lithium lead (WCLL)	
Structural material	EUROFER97
First wall	W
Tritium breeder	Pb-15.7%Li
Neutron multiplier	Pb-15.7%Li
Helium-cooled pebble bed (HCPB)	
Structural material	EUROFER97
First wall	W
Tritium breeder	Advanced ceramic breeder pebbles (Li_4SiO_4 + 35%mol Li_2TiO_3) KALOS ((KArlsruhe Lithium OrthoSilicate)
Neutron multiplier	$Be_{12}Ti$ hexagonal prismatic blocks

Identify the nuclides responsible for the classification
Determine if changes in the design could improve the waste performance

Waste classification status – HLW assessment

WCLL Components		Dominant nuclides: Above 2 W/t of waste – at 1 year	Dominant nuclides: Above 2 W/t of waste – at 50 years
Blanket (detritiation 99%)	Inboard	^{54}Mn (53%), ^{55}Fe (6%), ^{60}Co (11%), ^{182}Ta (25%), ^{181}W (1%), ^{185}W (2%)	
	Outboard	^{54}Mn (59%), ^{55}Fe (7%), ^{60}Co (9%), ^{182}Ta (21%), ^{181}W (1%), ^{185}W (2%)	
Limiter		^{54}Mn (19%), ^{60}Co (30%), ^{182}Ta (30%), ^{181}W (8%), ^{185}W (9%)	
Divertor		^{54}Mn (31%), ^{55}Fe (4%), ^{60}Co (33%), ^{182}Ta (25%), ^{185}W (3%)	

- Detritiation of the breeder considered: 99 %
- After 1 year of radioactive decay, few nuclides leading to more than 2W/t
- After 50 years, no HLW issue linked to decay heat anymore

Detritiation of the breeder required to limit radioactive decay needs

Waste classification status – ILW assessment

WCLL Components		Dominant nuclides			
		Above UK LLW β+γ limit		Above French LLW limit	
		at 20 years	at 50 years	at 20 years	at 50 years
Blanket (detritiation 99%)	Inboard	^{3}H (65%), ^{55}Fe (34%), ^{60}Co (1%)	^{3}H (99%)	^{3}H, ^{94}Nb	^{3}H, ^{94}Nb
	Outboard	^{3}H (63%), ^{55}Fe (36%), ^{60}Co (1%)			
Limiter		^{55}Fe (69%), ^{60}Co (17%), ^{63}Ni (13%)	^{60}Co (3%), ^{63}Ni (94%)	^{94}Nb	^{94}Nb
Divertor		^{55}Fe (81%), ^{60}Co (14%), ^{63}Ni (5%)	^{3}H (1%), ^{14}C (2%), ^{55}Fe (1%), ^{60}Co (6%), ^{63}Ni (89%)	^{94}Nb	^{94}Nb

In-vessel components, above the LLW after 50yrs:

- In UK
  - ^{3}H for the blankets, ^{63}Ni for the limiters and the divertor
- In France
  - ^{94}Nb

Waste classification status – ILW assessment

WCLL Components	Dominant nuclides			
	Above UK LLW β+γ limit		Above French LLW limit	
	at 20 years	at 50 years	at 20 years	at 50 years
Upper and equatorial port	^{60}Co (19%), ^{63}Ni (71%)	^{63}Ni (98%)		
Lower Port	^{55}Fe (13%), ^{60}Co (18%), ^{63}Ni (67%)	^{63}Ni (97%)		
Vacuum vessel (inboard)	^{55}Fe (49%), ^{60}Co (22%), ^{63}Ni (27%)	^{63}Ni (93%)		
Vacuum vessel (shell)	^{55}Fe (15%), ^{60}Co (27%), ^{63}Ni (55%)	^{63}Ni (95%)		
Vacuum vessel (outboard)	^{55}Fe (54%), ^{60}Co (21%), ^{63}Ni (23%)	^{63}Ni (93%)		

Ports and VV

- Above the LLW threshold in UK after 50 yrs because of ^{63}Ni
- Below the LLW threshold in France

Bioshield, cryostat, intercoils shield and coils:

- Below the LLW threshold both in UK and France few hours after shutdown

Waste classification status

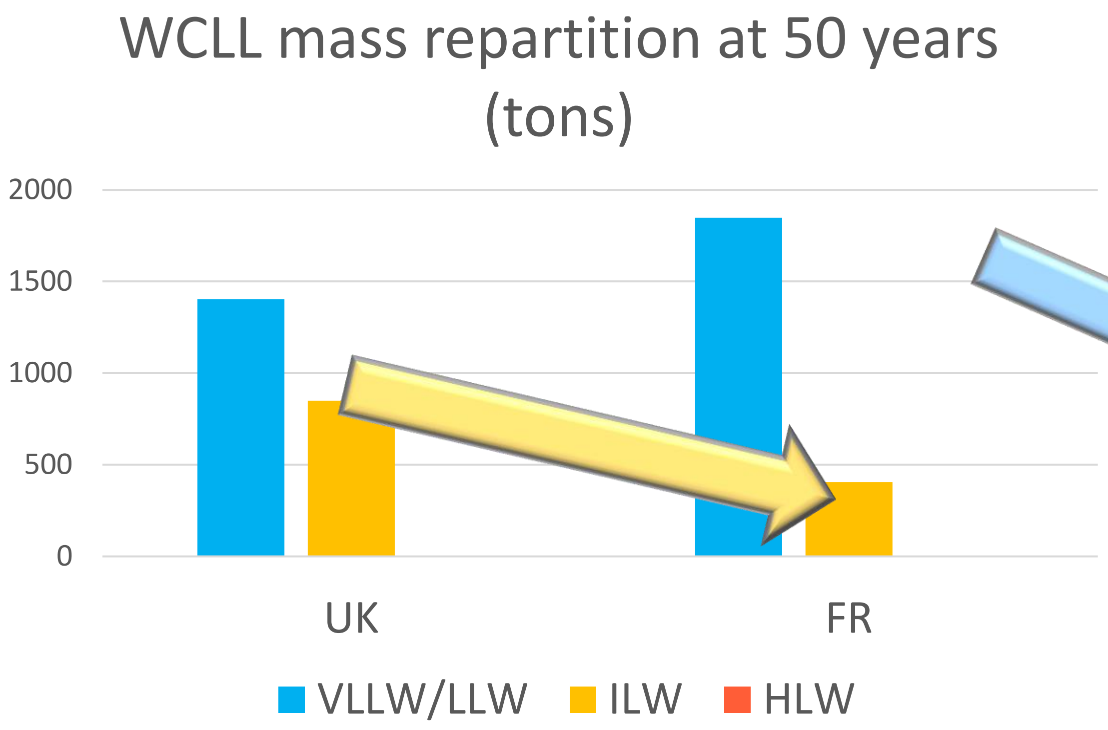
HCPB vs WCLL, main differences:

- VV inboard and shell: LLW → ILW after 50 yrs in France because of ^{94}Nb
- The ILW blanket classification also due to limits on α emitters
  - ^{239}Pu (for 32%) and ^{241}Am (for 49%) because of U impurity in $Be_{12}Ti$.

50 dpa vs 20 dpa, main differences:

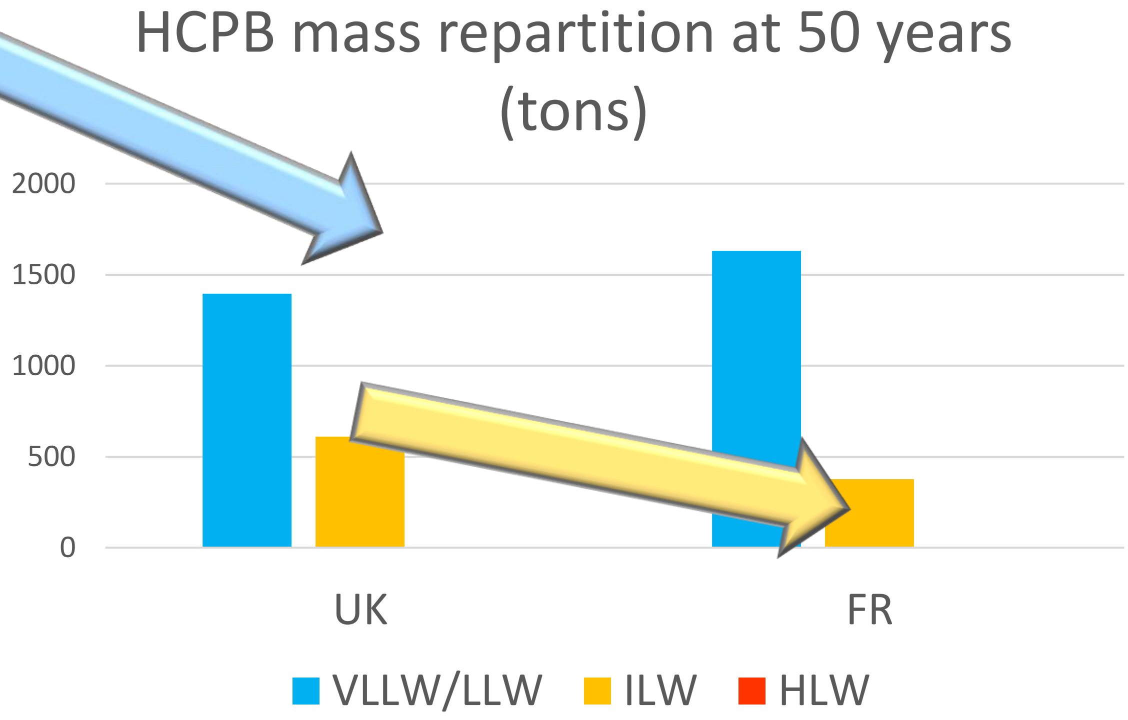
- Some additional nuclides become responsible for the BB ILW classification:
  - UK: ^{14}C from KALOS, $Be_{12}Ti$ and EUROFER
  - France: ^{108m}Ag from W and $Be_{12}Ti$

Waste classification status



No HLW due to decay heat

Less waste with HCPB



Less ILW with French classification

Waste classification status

Nuclides of interest

- Tritium → detritiation
- ^{14}C (from ^{14}N) → decarburization
- ^{63}Ni (from ^{62}Ni)
- ^{94}Nb (from ^{93}Nb)

} → Optimization of Ni and Nb contents

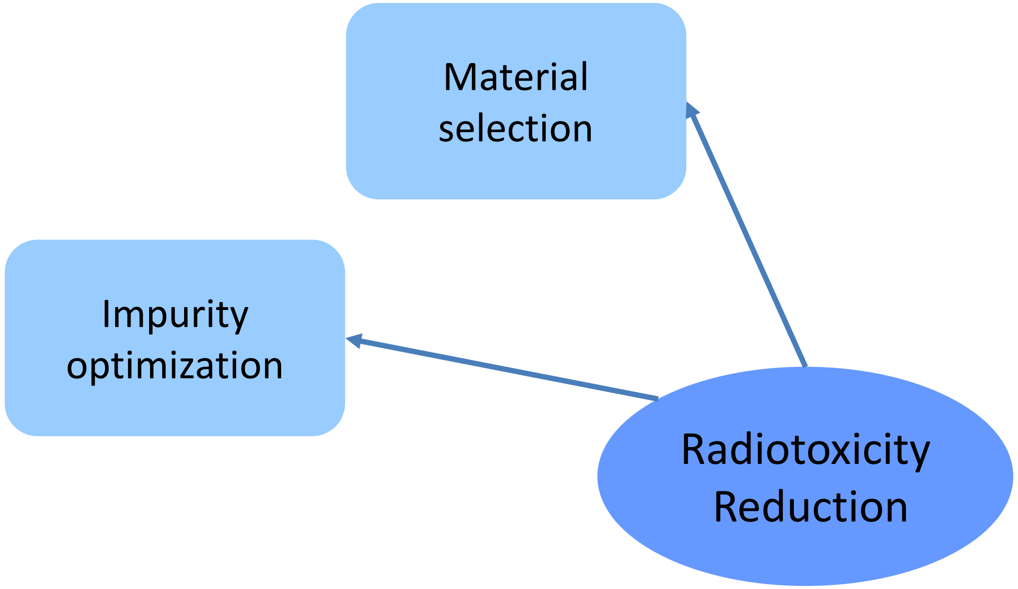
Challenges

Challenges

Radiotoxicity Reduction

Waste amount Reduction

Challenges

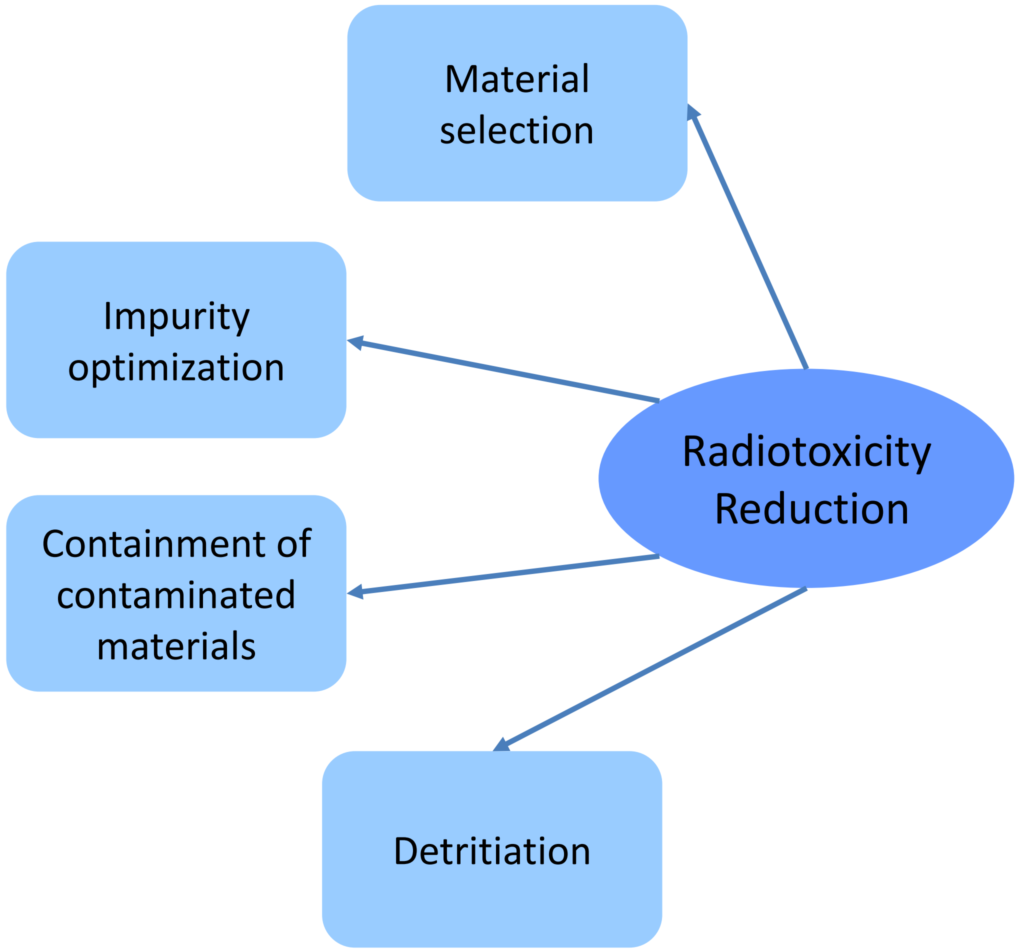


- Reduced Activation Ferritic-Martensitic steel EUROFER97
  - Reduced concentration on detrimental impurities: Mo, Ni, Al, Nb, Co and Cu vs SS316LN
  - Further reduction with EUROFER batch 3:
    - 90% for Nb, 5% for N and 15% for Ni

HCPB blanket		Time to LLW (yrs)
Inboard	EUROFER	> 100 (^{94}Nb)
	EUROFER B3	1
Outboard	EUROFER	> 100 (^{94}Nb)
	EUROFER B3	5

→ BB moving faster from ILW to LLW in France

Challenges

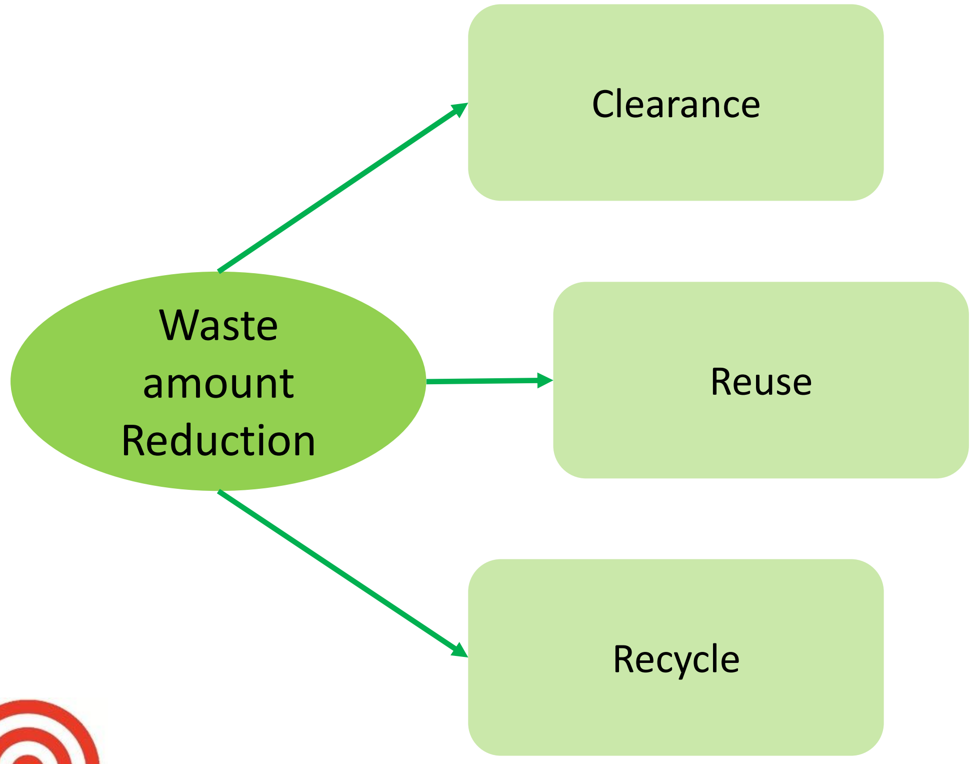


- Anti-permeation and corrosion barrier coatings for WCLL
  - Less T permeation and less Activated Corrosion products
  - Al based coatings
- Detritiation
  - Thermal desorption under atmospheric air w/wo gaseous hydrogen, melting under vacuum, static hydrogen atmosphere or argon flow

This Thursday
P5D1: Mark Gilbert
Fusion waste requirements for tritium control: perspectives and current research

Challenges

- Clearance to reduce the amount of radioactive materials that will have to be considered as nuclear waste
- Recycling & reuse will also become essential
  - Segregation of mixed activated materials,
  - Processes to remove detrimental isotopes (removal of "slag" from melts)
  - Management of secondary waste,
  - Expected properties of recycled materials,
  - Manufacturing of component using radioactive materials as raw materials,
  - Radioactive build up in materials…



Continue R&D to optimize waste management processes

Perspectives for EU DEMO

Perspectives for EU DEMO

EUROfusion R&D programmes to fulfil the high level plant requirements on waste and decommissioning.

- Establishment of inventories for solid, liquid and gaseous waste stream
- Treatments to be developed inside and outside the plant to facilitate their management in final disposal
  - Materials Detritiation Facility (MDF) at UKAEA
    - Tritium levels after processing below 100 Bq/g.
    - Work is on-going by assessing impact of temperature (between 600 and 1000°C), flow rates (between 250 and 1000 l/min), ramp rate (between 2.5 and 10°C/min) and holding time (between 0 and 24h)
    - Reproducibility impacted by current limitations of the process (flow and tritium monitoring, memory effect between detritiation batches…) → optimization

Perspectives for EU DEMO

- Dust detritiation → sintering at ENEA/RINA
  - Distributed pores, open porosity and large metal surface for efficient detritiation (removal of 50 to 70 % of the absorbed hydrogen simulating tritium)
  - Transform dust into a massive product facilitating handling and final disposal by avoiding any radioactive dust dispersion

Next plans

- Test technologies for activated steel treatment including optimization the waste recycling process
- Reduce the constraints on the management of waste such as mercury contained within the pumping systems, PbLi (including secondary waste from PbLi decontamination), pebbles or getter beds…
- Outline a first decommissioning plan

This Thursday
P5D2: Oliver Gastaldi
Overview of French R&D studies for the development of tritium confining packages

As a conclusion

- Waste evaluation
  - Evaluations of the waste classification are regularly performed to assess impact of design choices
  - Last evaluation has shown that no waste will require HLW disposal if efficient detritiation is performed
  - ILW can’t be avoided with current design and analysed disposal and effort should continue to reduce amounts of Nb and Ni in EUROFER
- EUROfusion R&D programme developed to limit waste burden on the next generations
- The ultimate goal at conceptual phase → identify any showstopper and identify the needs for the Active Maintenance Facility and Waste Treatment Facility.

Thanks for your attention

- Sandrine Rosanvallon

DEMO Central Team, EUROfusion, Garching,
Boltzmannstr. 2 85748 Germany
IRFM, CEA, F-13108 Saint-Paul-lez-Durance, France

- sandrine.rosanvallon@cea.fr