Safety, Activation, and Waste Disposal

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http://fti.neep.wisc.edu/FTI/ARIES/AUG2000/safety_lae.pdf

ARIES Peer Review Meeting
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UCSD

Outline

I – Safety:

- Key features
- Accident identification
- Radioactive inventory and decay heat (SiC, V, FS)
- Design integration

II – Activation and radwaste classification:

- Strict requirement for low level waste only
- Constraints on material choices
- Need for impurity control
- Waste management: Dispose, recycle, or clear

III – Waste volume minimization:

- Improvements over past 10 years
- Innovative design solutions for waste minimization

ARIES-RS, -ST, -AT Designs Meet Safety Requirements

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- No evacuation plan required even in worst case accident
  Dose at site boundary < 1 rem* for ARIES-RS,-ST,-AT designs
  Contributors to dose: Activation products
  T in breeder and structure
  W dust
  Po in LiPb
- Low activation materials for highly irradiated components
- Radioactive materials confined with multiple barriers: VV and cryostat
- No energy and pressurization threats to confinement barriers
  - Decay heat problem solved by design
    Segmented cooling system into 4 loops
    Decay heat removal system
    ⇒ Peak temp during accident < 800 ^{o}C
  - Chemical reactions avoided
    No water in Li system
    Separate LiPb and water cooled components
  - No combustible gas generated
    Avoid water in Li system
    No hydrides in shield
  - Chemical energy controlled by design
    Multiple barriers between components
    4 drain tanks for each Li or LiPb loop
    Avoid water, steam, or air interactions with hot materials
  - Overpressure protection system
  - Rapid plasma shutdown
    Highly reliable multiple systems needed
    High speed of action (< 1 s)
- Tritium inventory < 1 kg in FPC
- Low level waste (WDR < 1 for all components)
- Minimum volume of radwaste

* Early dose duration is usually 7 days exposure

Selective Accidents Assessed for Each Design*
With Most Scenarios Applied to ARIES-AT

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	ARIES Designs
• **Loss of coolant accident** (LOCA) No coolant in ALL loops Decay heat raises temperatures of solids High temperature mobilizes activation products	RS , ST , AT
• **Loss of flow accident** (LOFA) Coolants stop flowing in all or some loops Decay heat raises temperatures of solids High temperature mobilizes activation products	AT
• **Loss of vacuum accident** (LOVA) Failure in penetrations causes air ingress into VV Dust and T mobilized in VV Loops operate normally and cool down the system Buoyancy driven flow from VV to environment	RS , AT
• **By-pass events** In-vessel events (e.g., disruption-induced LOCA) Failure of penetration line Release path that by-passes confinement barriers Air ingress into VV Dust and T mobilized in VV Air exchanges between chamber and bypass room	AT
• **Ex-vessel events that require plasma shutdown** Ex-vessel events not felt by plasma (e.g., pump seizure, LOCA, etc..) Blanket heat removal capability is reduced Plasma shutdown is required	AT
• **Loss of power** Similar to LOFA	
• **Transient overpower and plasma abnormalities** ELMS, MARFE, or over-fueling cause power excursion (FW/Blanket has margin to overcome this event)	
• **External events** Seismic, airplane crash, tornado, etc…	
• **Operator's errors**	

* Due to time and resources limitations, it was not possible to assess all accidents for each design. However, the most credible accidents were considered

Strong Safety-Design Integration Helped Meet Safety Requirements

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- Safety requirements defined at beginning of study
- Safety constraints included in radial build definition, subsystem designs, and maintenance scheme
- Iteration with designers improved safety function implementation
- Confinement enhanced through:
    - Decay heat removal system
    - Chemical energy control
    - Safety grade plant shutdown
- Improved robustness of design response to off-normal events
- Detailed waste management assessment

Activation and Waste: Requirements and Impacts

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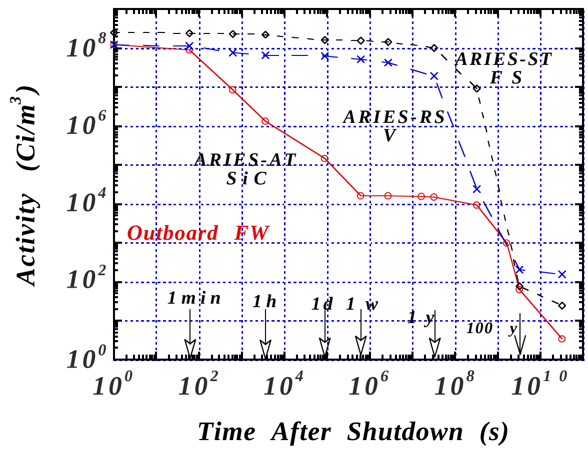
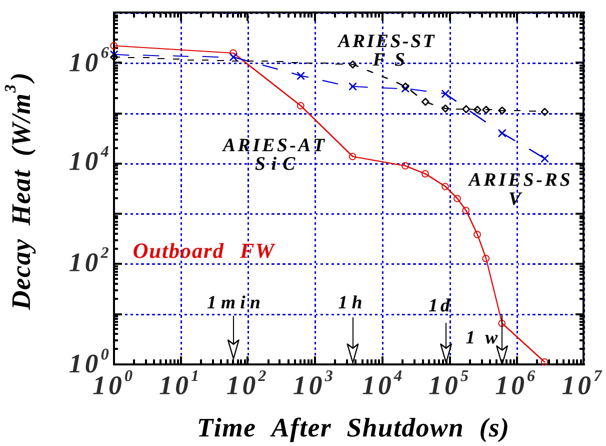
Requirements	Design Impacts
Low level waste	Use low activation materials (SiC, V, FS)
	Control impurities
	Limit components lifetime, if needed
Reduce volume of waste*	Compact radial build
	Optimize shield
	Segment blanket#
	Prolong components' lifetimes
	Recycle waste
	Clear ex-vessel components

* to increase repository capacity
# not applicable to toroidally helium-cooled options

Most Recent ARIES-AT Design is Safer and Simpler Compared to ARIES-RS and -ST





- SiC offers rapid decay of activity and decay heat at 1 min after shutdown, a major safety advantage
- ARIES-RS and ST require active means to remove decay heat
- ARIES-AT temperature during LOCA/LOFA events remained below allowable, requiring no active system for decay heat removal

  ⇒ Safer and simpler design

Waste Management

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- Three Options:
  - Clear or "free release" of materials to industrial facilities if

    Clearance Index < 1
  - Dispose near surface as Class A or Class C low level waste (LLW)
  - Recycle waste and reuse in nuclear facilities

- Clearance and disposal options addressed in details in ARIES studies

- Waste could be recycled at unknown cost:
  - INEEL 1994 study on V recycling
  - Various studies on FS recycling
  - No study available on SiC recycling

Because of Compactness, ARIES Components Cannot be Cleared*

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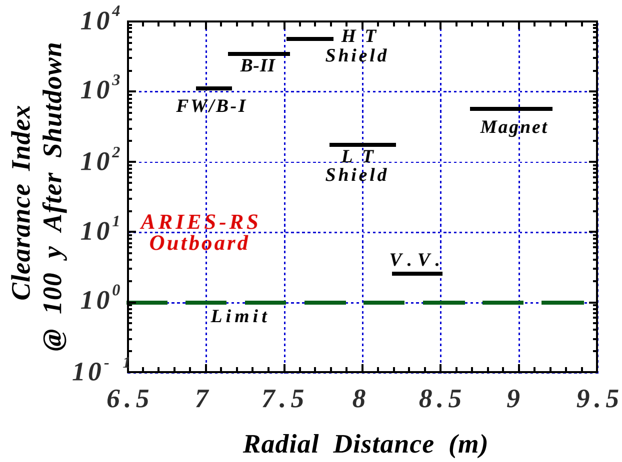

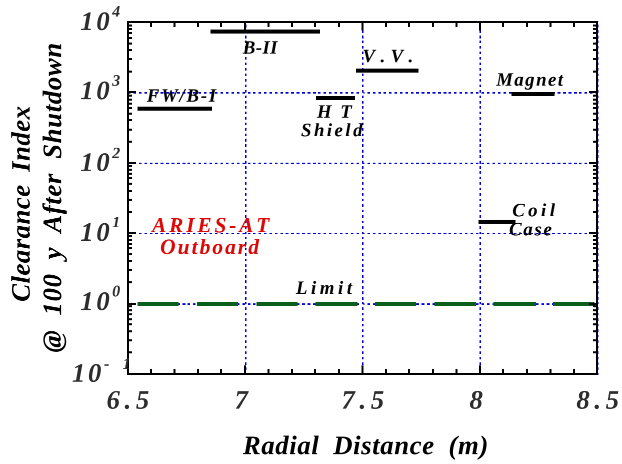

- All ARIES components have clearance index > 1 based on IAEA clearance limits
- NRC limits could be more restrictive than IAEA's (dose ~1 mrem/y)

ARIES waste will be disposed of as LLW or could be recycled

* Defined as unrestricted release of items and materials from radiologically controlled areas

Low Level Waste Achieved
With Impurity Control

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Design	WDR[*]	LLW Classification	Impurity limit
ARIES-RS	< 1	Class C	Nb ≤ 0.5 wppm for V Ir ≤ 0.02 wppm for Tenelon and MHT-9 Ag ≤ 0.1 wppm for Tenelon and MHT-9
ARIES-ST	< 1	Class C	Nb ≤ 0.5 wppm for ORNL-FS
ARIES-AT	<< 1	90% Class A 10% Class C	Nb ≤ 1 wppm for ORNL-FS Mo ≤ 20 wppm for ORNL-FS

Feedback to Fusion community:

- Material developers should control Nb, Ag, and Ir impurities in low activation materials below ppm level. Higher level allowed for Mo
- NRC should develop Class A and Class C waste disposal limits for materials of interest to fusion
- NRC should develop Clearance limits for all radioactive isotopes

[*] < 1 means low level waste

Recent ARIES Designs Generate Less Waste*

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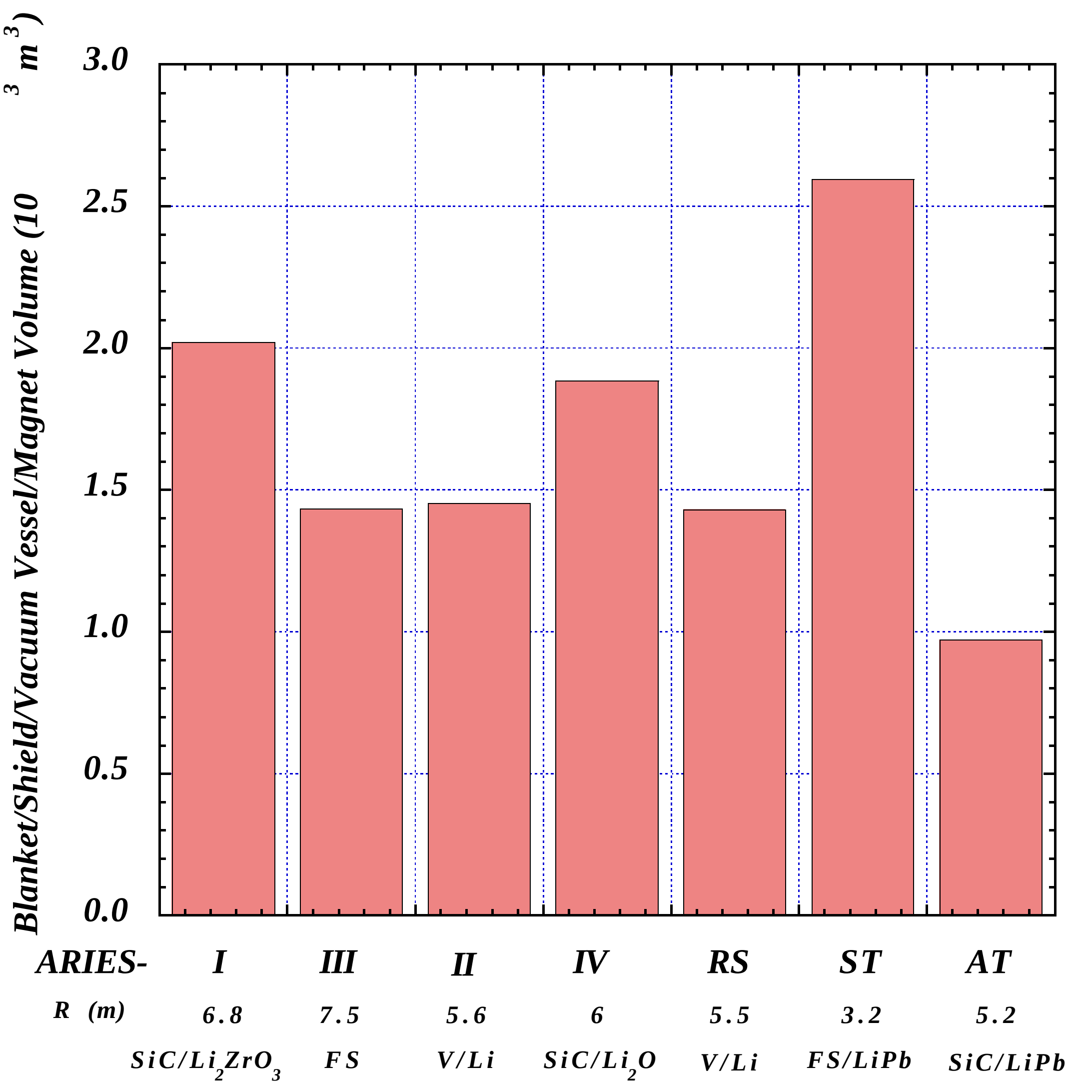

* Reported volumes are not compacted

Breakdown of ARIES-AT Waste

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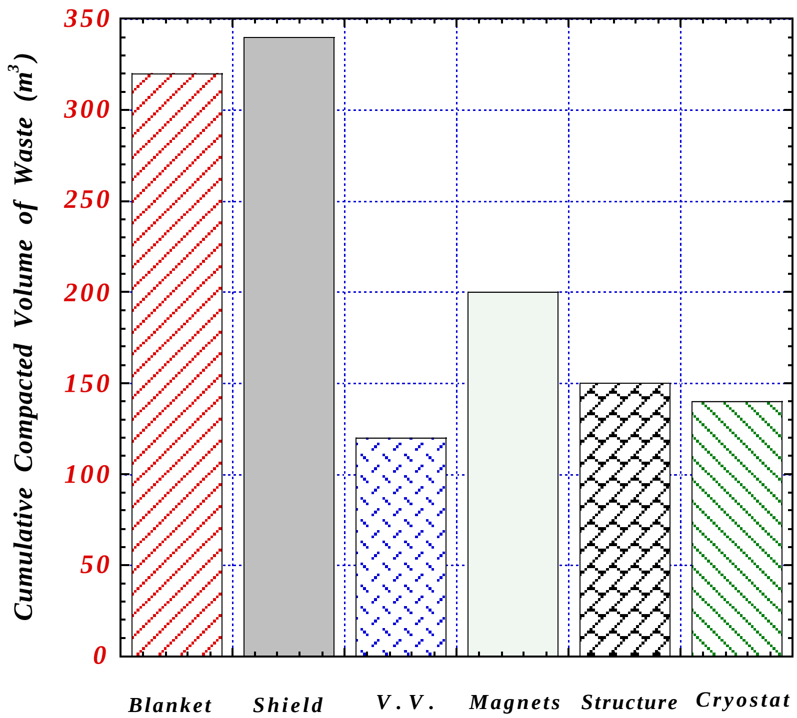
	Cumulative Compacted Waste Volume (m^3)	
IB & OB Blanket-I	287	(22%)
OB Blanket-II*	33	(3%)
Shield*	340	(27%)
V.V.	120	(9%)
Magnets	200	(16%)
Structure	150	(12%)
Cryostat	140	(11%)



- Successful effort made to lower blanket and shield contribution to 50% range by:
  - segmenting the blankets
  - optimizing the shield

* Assuming no spare components

ARIES-RS and –AT Blanket Segmented to Reduce Waste Volume

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- Segmentation lowered cumulative blanket waste by factor of 2

- Back blanket segment could either be lifetime component or replaced less frequently than front segment

- Radiation damage determines service lifetime of individual components

Design	Structure	limit	B-I Lifetime	B-II Lifetime	Shield Lifetime
ARIES-RS	V	200 dpa	2.5	7.5	40
ARIES-ST	FS	200 dpa	3	---	40
ARIES-AT	SiC	3% burnup	4	40	40

- Massive shields are lifetime components. Radiation protection provided by blanket

Well Optimized Shield Helps Reduce Radial Standoff, Machine Size, and thus Waste Volume

- Machines made entirely out of V and SiC structures are large and expensive (COE > 100 mills/kWh)

- Better shielding materials (WC, B_4C, FS, H_2O) incorporated to reduce machine size

- Safety, economics, and breeding constraints limit the use of those materials, e.g.,

Li breeder	⇒	No water
Low COE	⇒	WC and B_4C for IB only
Limited breeding in ST	⇒	No WC and H_2O in IB shield

- Shielding design guidelines to reduce waste volume and cost:
  - Limit V and SiC structures to high temperature components
  - Use FS filler with SiC & V structures
  - Use less expensive FS structure for back low-temperature components
  - Employ highly efficient WC and B_4C fillers for IB side only (monitor WC decay heat)
  - Cool low-temperature components with water, if compatible with breeder

State-of-the-Art Codes and Latest Data Currently Used for Nuclear and Safety Analyses

- **Safety analysis**:
  - **MELCOR** code for accident progression
  - **ANSYS** finite element 1-, 2-, 3-D code for LOCA/LOFA

- **Activation analysis**:
  - **ALARA** 1-, 2-, 3-D code
    - Newly developed at UW
    - Can handle pulsed operation

- **Neutron and gamma transport analysis**:
  - **DANTSYS** discrete ordinate 1-, 2-, 3-D code system
  - **MCNP** 3-D Monte Carlo code

- **Nuclear data**:
  - **FENDL-2** IAEA most recent cross section library