# Safety, Activation, and Waste Disposal

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

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

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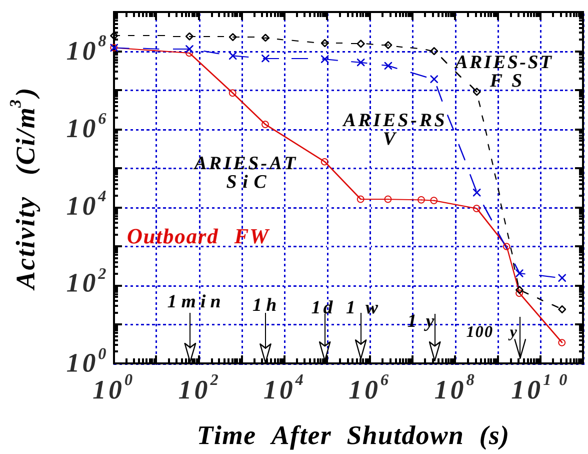


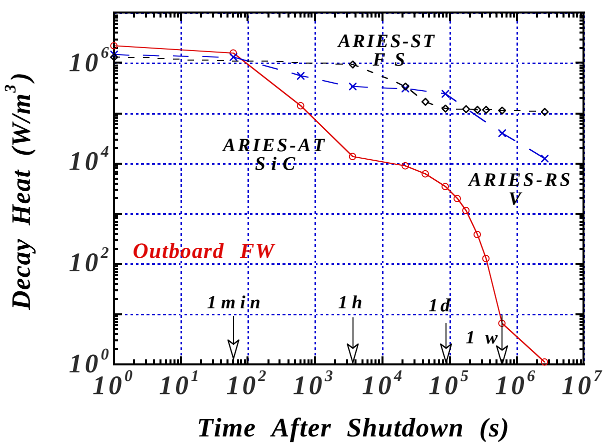


- SiC offers rapid decay of activity and decay heat at 1 min after shutdown, a major safety advantage
- ARIES-RS and ST require active means to remove decay heat
- ARIES-AT temperature during LOCA/LOFA events remained below allowable, requiring no active system for decay heat removal

  ⇒ Safer and simpler design

# Waste Management



- 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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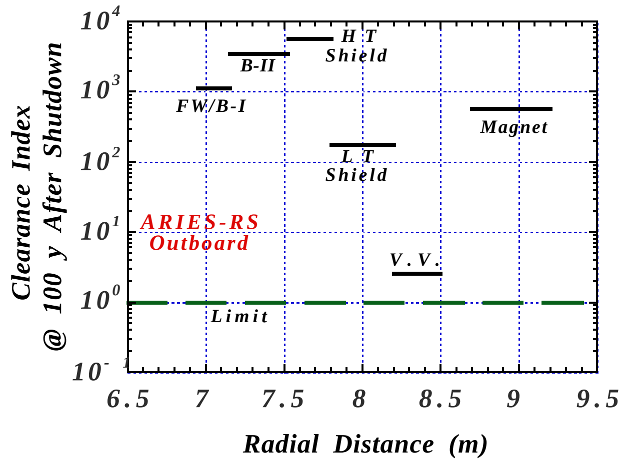


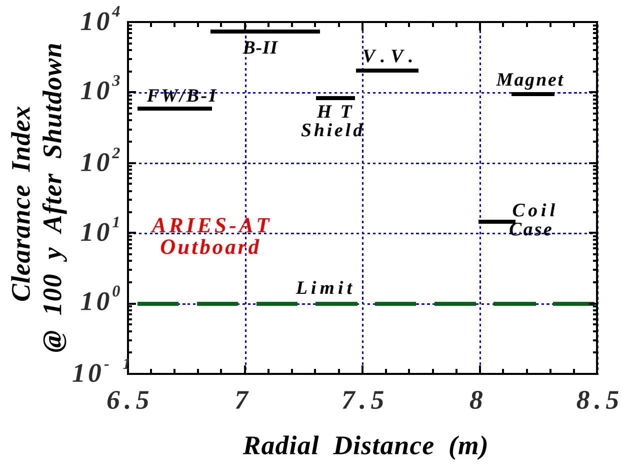


- All ARIES components have clearance index > 1 based on IAEA clearance limits
- NRC limits could be more restrictive than IAEA's (dose ~1 mrem/y)

**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<br>Ir ≤ 0.02 wppm for Tenelon and MHT-9<br>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<br>10% Class C | Nb ≤ 1 wppm for ORNL-FS<br>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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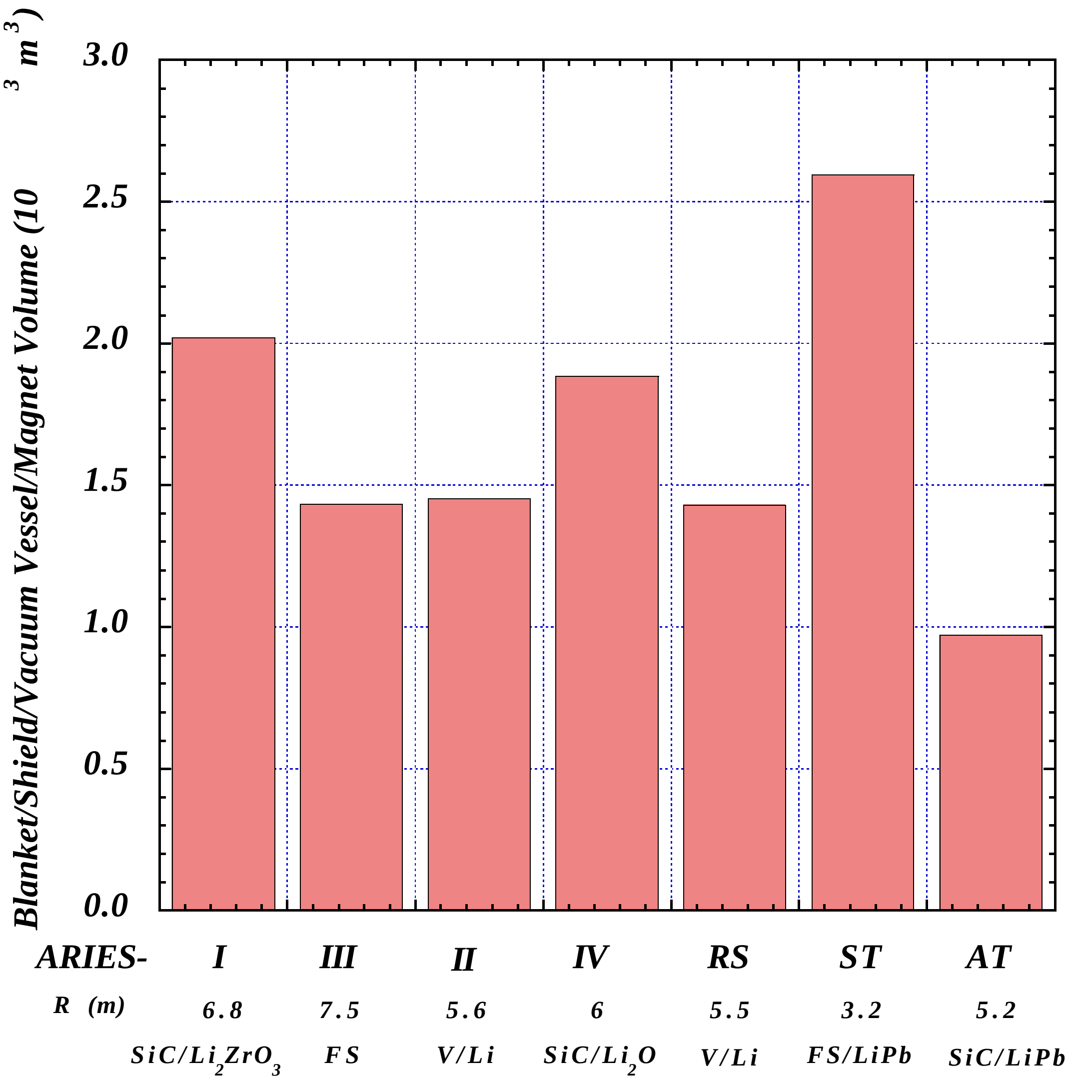


* Reported volumes are not compacted

# Breakdown of ARIES-AT Waste

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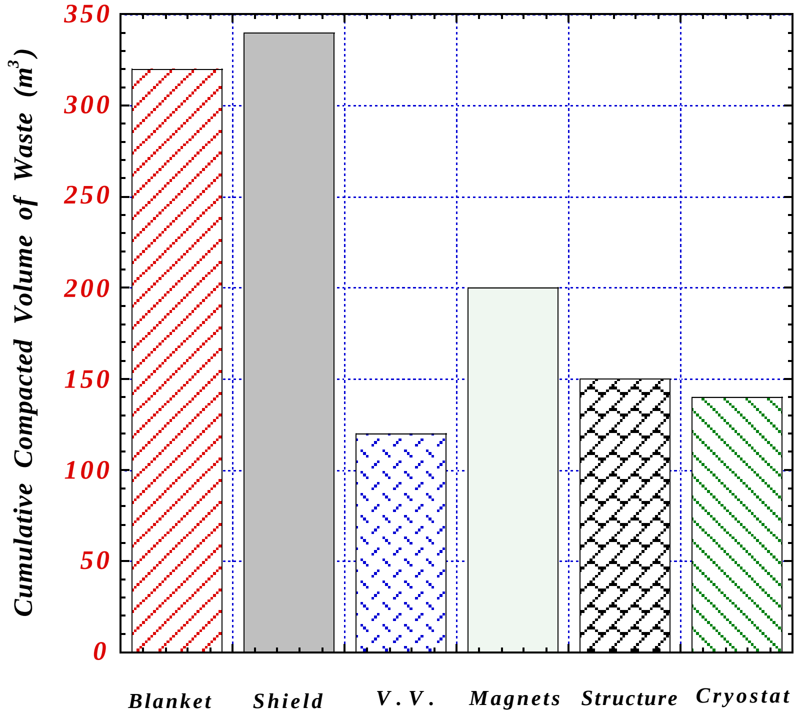
| | Cumulative Compacted Waste Volume ($m^3$) | |
|---|---|---|
| IB & OB Blanket-I | 287 | (22%) |
| OB Blanket-II* | 33 | ( 3%) |
| Shield* | 340 | (27%) |
| V.V. | 120 | ( 9%) |
| Magnets | 200 | (16%) |
| Structure | 150 | (12%) |
| Cryostat | 140 | (11%) |




- 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

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- 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