Preliminary Safety Assessment of the ARIES-ST Divertor

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Objectives

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- Calculate the waste disposal ratings of the different divertor components
- Calculate the divertor activity to estimate the potential effects of radioactive inventory mobilization in the event of an accident
- Calculate decay heat generated in the divertor to examine the thermal response of the divertor structure following a LOCA
- Calculate off-site doses at the site boundary during a LOCA or following disruptions

Basic Assumptions

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- Average neutron wall loading of 0.5 MW/m^2
- The divertor plate and manifold have a lifetime of 2.86 FPY
- The divertor shield has a lifetime of 40 FPY
- Activation product mobilization are considered for the following pathways:
  - Oxidation-driven mobilization during a LOCA
  - Mobilization during a disruption by direct vaporization
  - Mobilization of tokamak dust following a disruption
- For all pathways, the Sv/TBq values are calculated using the MACCS2 code assuming a ground release, atmospheric stability class F, 2 km site boundary and 1 m/s wind speed

Material Composition

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Zone	Thickness (cm)	Composition
Divertor Plate		
W Brush	0.3	100% W
Coolant Channel	2	50% W and 50% He
Back plate	3	100% Ferritic steel
Manifold	34	67% Ferritic steel and 37% He
Shield		
HT shield	25	15% Ferritic steel, 80% WC and 5% He
LT shield	36	15% Ferritic steel, 70% WC and 15% H_2O

Waste Disposal Ratings

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- WDR for Class C waste are calculated using the 10CFR61 and Fetter waste disposal limits
- The tungsten composition used in the analysis is also used in the latest ITER safety analysis
- Waste disposal ratings are given after 1 year following shutdown
- Waste disposal ratings are given for compacted wastes

Waste Disposal Ratings Using 10CFR61 Limits

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Zone	FPY	WDR	Dominant Nuclides
W Brush	2.86	0.96	^{94}Nb
W Brush + Cooling Channel	2.86	1.04	^{94}Nb
Divertor Plate	2.86	0.33	^{94}Nb
Manifold	2.86	0.03	^{94}Nb
Shield	40	7.4e-3	^{94}Nb, ^{14}C

Waste Disposal Ratings Using Fetter Limits

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Zone	FPY	WDR	Dominant Nuclides
W Brush	2.86	2.01	^{108m}Ag, ^{94}Nb
W Brush + Cooling Channel	2.86	1.96	^{94}Nb, ^{108m}Ag
Divertor Plate	2.86	0.68	^{94}Nb, ^{108m}Ag
Manifold	2.86	0.1	^{192m}Ir, ^{94}Nb
Shield	40	0.012	^{192m}Ir, ^{94}Nb

Oxidation-Driven Mobilization Analysis

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- Off-site dose caused by the oxidation-driven mobilization of tungsten is calculated using the temperature profile obtained from the LOCA analysis
- The LOCA is assumed to last for 24 hours during which the tungsten brush reaches an average temperature of 600 °C (conservative assumption)
- The release rates used are based on INEL's oxidation-driven volatility data
- A leak rate of 1% per day through the vacuum boundary and a containment factor of 99% for the containment boundary are considered
- Taking credit for confinement, limits the off-site dose caused by oxidation-driven volatility to only 0.3 μSv

Direct Vaporization Analysis

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- Assumptions used for the energy dissipated in the divertor during a disruption are similar to assumptions used in the ITER safety analysis
- Following a disruption, off-site doses could be produced by direct vaporization of the divertor surface layer
- Total Energy dissipated during the energy quench phase is 1.45GJ and consists of:
  - Energy dissipated (80% of the plasma energy content) during thermal quench phase (1 ms) is 1.14GJ
  - Energy dissipated during current quench phase (50 ms) is 0.31GJ
- During a disruption, very small particles (0.1 μm) are mobilized by direct vaporization
- Assuming a divertor surface area of 150 m^2, the total amount of tungsten vaporized during a disruption is 8.69 kg
- A leak rate of 1% per day through the vacuum boundary and a containment factor of 99% for the containment boundary are considered
- Taking credit for confinement, limits the off-site dose caused by direct vaporization to only 7.94 μSv per disruption

Tokamak Dust Analysis

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- Calculation are based on assumptions used in ITER safety analysis
- Tokamak dust is produced by the vaporization of divertor surface material and accumulated during previous plasma disruptions
- Sputtering of dust occurs during normal operation following disruptions
- The dust could be mobilized during an accident or during in-vessel maintenance
- Tokamak dust is assumed to only include 10% of material eroded via disruption and sputtering and does not re-deposit on the divertor surface
- Tokamak dust is defined as particles smaller than 100 μm in diameter
- A total of 6 kg of tungsten dust are produced by disruption and sputtering per full-power disruption
- Tests at FZK showed that between 2% - 20% of the dust could be mobilized during an air ingress into vacuum
- Assuming a containment factor of 99% for the containment boundary, limits the off-site dose caused by dust mobilization to 10.96 - 109.6 μSv per disruption

Early Dose from Divertor Plate (by Pathway)

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Pathway	Inventory (mSv)	Dose Released (mSv)	Dominant Nuclides
Oxidation-driven volatility	7.78e4	0.3	^{187}W, ^{181}W, ^{185}W
Direct vaporization*	79.4	7.94	^{187}W, ^{181}W, ^{185}W
Tokamak dust*	54.8	10.96 - 109.6	^{187}W, ^{181}W, ^{185}W

* Dose per disruption

Conclusions

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- After 2.86 FPY, the divertor plate and manifold will qualify for disposal as Class C low level waste
- After 40 FPY, the shield would also qualify for disposal as Class C LLW
- The off-site dose calculations indicate that off-site dose caused by oxidation-driven volatility is negligible if the vacuum and containment barriers stay intact
- A total of 8.89 kg of tungsten are vaporized during each disruption resulting in a low off-site dose if the vacuum and containment barriers stay intact
- A total of 6 kg of tungsten dust are produced by disruption and sputtering resulting in a low off-site dose following a vacuum breach and air ingress into the vacuum vessel if the containment barrier stays intact