Neutronics Issues for Advanced Ferritic Steel

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Ferritic Alloys Considered

- Neutronics features compared for three representative ferritic alloys
  - Conventional ferritic/martensitic steel
    - Commercial alloy F82H
  - ODS ferritic steel
    - Commercial alloy MA957
  - Nano-composited ferritic steel (NCF)
    - 12YWT alloy

Composition of Alloys Used in Assessment (wt%)

Constituent Element	F82H	MA957	12YWT
Cr	8	13.87	12.58
Si	0.1	0.04	0.1
Ni	0.05	0.13	0.27
Ti	0.005	1.05	0.35
Mn	0.1	0.06	0.05
W	2	-	2.44
Mo	0.002	0.3	0.02
C	0.1	0.014	0.052
O	0.005	0.22	0.16
Al	0.01	0.1	-
Ta	0.04	-	-
V	0.2	-	-
Y_2O_3	-	0.25	0.25
Fe	Balance	Balance	Balance

- Impurities needed for activation and safety assessment
- Impurities not available for MA957 and 12YWT and are not included in assessment

Model Used for Neutronics Comparison

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- Typical blanket with molten salt Flibe as breeder and coolant
- 0.5 cm first wall
- 5 cm multiplier zone (60% Be, 35% Flibe, 5% structure)
- 60 cm blanket zone (95% Flibe, 5% structure)
- Lithium enrichment varied
- Nuclear parameters compared for F82H, MA957, 12YWT, V4Cr4Ti, SiC/SiC

Local Tritium Breeding Ratio

	Natural Li	40% ^{6}Li	90% ^{6}Li
F82H	1.366	1.423	1.386
MA957	1.422	1.430	1.386
12YWT	1.357	1.421	1.385
V4Cr4Ti	1.444	1.460	1.417
SiC/SiC	1.412	1.385	1.331

- TBR peaks at ~40% ^{6}Li with vanadium and ferritic alloys
- TBR is highest with V alloy and lowest with SiC/SiC
- TBR slightly higher with MA957 that does not include tungsten compared to that with F82H and 12YWT

Local Energy Multiplication (M)

	Natural Li	40% ^{6}Li	90% ^{6}Li
F82H	1.267	1.257	1.254
MA957	1.264	1.257	1.254
12YWT	1.284	1.268	1.262
V4Cr4Ti	1.270	1.256	1.251
SiC/SiC	1.239	1.238	1.237

- M is highest with ferritic alloys and lowest with SiC/SiC
- M slightly higher with 12YWT compared to that with F82H and MA957

Damage Parameters at FW for 1 $MW.y/m^2$

	dpa	He appm	H appm
F82H (40% ^{6}Li)	11.70	146.5	582.0
MA957 (40% ^{6}Li)	11.62	142.3	568.9
12YWT (40% ^{6}Li)	11.65	144.6	572.2
V4Cr4Ti (40% ^{6}Li)	12.47	47.8	436
SiC/SiC (nat. Li)	11.38	1327	929

- Peak damage parameters comparable for three ferritic alloys with MA957 having slightly lower damage parameters

Damage Attenuation in Blanket

	Attenutation Factor for dpa
F82H (40% ^{6}Li)	679
MA957 (40% ^{6}Li)	684
12YWT (40% ^{6}Li)	679
V4Cr4Ti (40% ^{6}Li)	514
SiC/SiC (nat. Li)	401

- Using ferritic alloys in blanket results in better shielding characteristics compared to blankts with V alloy or SiC/SiC structure
- Blanket shielding characteristics are comparable for the three ferritic alloys with MA957 having a slight edge

Activation Considerations

- Neutronics features (TBR, M, dpa, He,…) are comparable for the three ferritic steel alloys with only very small differences yielding negligible impact on performance
- Impact of difference in elemental composition and impurity levels on safety and waste disposal expected to be more pronounced
- Although composition is dominated by Fe and Cr which do not pose serious safety and waste disposal problems, small amounts of other alloying elements or impurities could be a concern

Decay Heat Considerations

- Cr and Fe are among elements producing the least amount of decay heat
- Mn, W, and Ta are among elements that produce large decay heat. However, their small wt.% in the ferritic steel alloys is not expected to significantly influence the total decay heat generated
- Regarding the dose resulting from accidental release of activated material the elements Ta, Mo, Mn, and W are of concern. Large W content in F82H and 12YWT could be a safety concern. Mo and Mn can be reduced in 12YWT without degrading properties
- See Safety presentation by Brad Merrill for detailed discussion

Waste Disposal Considerations

- Alloying elements and impurities that produce long-lived radionuclides should be eliminated or reduced to allow for shallow-land burial of radwaste
- Among major constituent elements in the three ferritic steel alloys Mo, Ni, and Al could pose waste disposal problems
  - Mo -> ^{94}Nb (2x10^4 yr), ^{93}Mo (3000 yr), ^{99}Tc (2.1x10^5 yr)
  - Ni -> ^{59}Ni (8x10^4 yr)
  - Al -> ^{26}Al (7.2x10^5 yr)
- Y produces very small amount of two long lived isotopes (^{90}Sr, ^{87}Rb) through multiple reactions and long decay chains and is not expected to be a waste disposal issue

Waste Disposal Considerations

- Limits on element concentration for shallow-land burial of FW exposed to 20 MWy/m^2 were determined [R. Kluch, E. Cheng, M. Grossbeck, E. Bloom, "Impurity effects on reduced activation ferritic steels developed for fusion applications," J. Nucl. Materials, 280 (2000) 353-359]
- Restrictions on content of major constituent elements are Mo (31 wppm), Al (660 wppm), Ni (15%)
- Concentration of Mo (200 wppm) in NCF alloy 12YWT exceeds waste disposal limit and needs to be reduced
- Concentrations of Mo (3000 wppm) and Al (1000 wppm) in MA957 exceed waste disposal limits and need significant reduction
- See waste disposal presentation by Ed Cheng for details

Waste Disposal Considerations

An attempt should be made to eliminate or limit concentrations of impurities to the following levels [R. Kluch, E. Cheng, M. Grossbeck, E. Bloom, “Impurity effects on reduced activation ferritic steels developed for fusion applications,” J. Nucl. Materials, 280 (2000) 353-359]

Element	wppm
Ag	1.2
Bi	22
Cd	1400
Ir	22
Nb	2.4
Os	560
Pd	110
Dy	4.6
Er	28
Ho	0.7
Tb	1.9
Eu	1.3

Conclusions

- Neutronics features compared for conventional F/M steel alloy F82H, ODS alloy MA957 and NCF alloy 12YWT
- Neutronics features (TBR, M, dpa, He,…) are comparable for the different ferritic steel alloys with only very small differences yielding negligible impact on performance
- Impact of difference in elemental composition and impurity levels on safety and waste disposal is more pronounced
- Large W content in F82H and 12YWT could be a safety concern
- Mo need to be reduced in 12YWT and Mo and Al should be reduced in MA957 for shallow-land burial
- Reduction of impurity levels below specified limits is required to allow for shallow-land burial