**High Temperature Steels**

**Sheet 1: Fusion Energy Steels**

Here are the compositions of several prominent reduced activation ferritic/martensitic (RAFM) steels used in fusion energy research. These compositions are typically tailored to optimize performance under the extreme conditions of a fusion reactor, including resistance to neutron irradiation, high temperatures, and mechanical stress.

**### 1. CLAM (China Low Activation Martensitic) Steel:**

- \*\*Chromium (Cr):\*\* 8.5-9.5%

- \*\*Tungsten (W):\*\* 1.0-1.4%

- \*\*Vanadium (V):\*\* 0.15-0.25%

- \*\*Carbon (C):\*\* 0.08-0.12%

- \*\*Manganese (Mn):\*\* 0.4-0.8%

- \*\*Silicon (Si):\*\* 0.1-0.5%

- \*\*Niobium (Nb):\*\* 0.05-0.10%

- \*\*Nitrogen (N):\*\* 0.03-0.07%

- \*\*Ta (Tantalum):\*\* ~0.05%

- \*\*Iron (Fe):\*\* Balance

**### 2. F82H:**

- \*\*Chromium (Cr):\*\* 7.8-8.2%

- \*\*Molybdenum (Mo):\*\* 0.9-1.1%

- \*\*Wolfram (W):\*\* 1.8-2.2%

- \*\*Vanadium (V):\*\* 0.18-0.24%

- \*\*Carbon (C):\*\* 0.08-0.12%

- \*\*Manganese (Mn):\*\* 0.4-0.7%

- \*\*Silicon (Si):\*\* 0.15-0.35%

- \*\*Tantalum (Ta):\*\* 0.06-0.12%

- \*\*Iron (Fe):\*\* Balance

**### 3. EUROFER:**

- \*\*Chromium (Cr):\*\* 8.0-9.0%

- \*\*Tungsten (W):\*\* 1.0-1.2%

- \*\*Vanadium (V):\*\* 0.10-0.20%

- \*\*Carbon (C):\*\* 0.10-0.14%

- \*\*Manganese (Mn):\*\* 0.4-0.8%

- \*\*Silicon (Si):\*\* Max 0.25%

- \*\*Ta (Tantalum):\*\* ~0.05%

- \*\*Iron (Fe):\*\* Balance

**### 4. Korean Reduced Activation Ferritic/Martensitic (K-RAFM) Steel:**

- \*\*Chromium (Cr):\*\* ~9%

- \*\*Tungsten (W):\*\* ~1%

- \*\*Carbon (C):\*\* ~0.1%

- \*\*Manganese (Mn):\*\* ~0.6%

- \*\*Vanadium (V):\*\* ~0.2%

- \*\*Silicon (Si):\*\* ~0.25%

- \*\*Niobium (Nb):\*\* ~0.1%

- \*\*Iron (Fe):\*\* Balance

**### 5. OPTIFER:**

- The OPTIFER series includes several variants with slightly different compositions, primarily adjusting Chromium, Tungsten, and Vanadium levels to optimize specific properties.

**### 6. JLF-1 (Japan Low-activation Ferritic) Steel:**

- \*\*Chromium (Cr):\*\* 8-9%

- \*\*Molybdenum (Mo):\*\* ~1%

- \*\*Vanadium (V):\*\* 0.2%

- \*\*Carbon (C):\*\* 0.1-0.12%

- \*\*Manganese (Mn):\*\* ~0.6%

- \*\*Silicon (Si):\*\* ~0.25%

- \*\*Niobium (Nb):\*\* ~0.1%

- \*\*Iron (Fe):\*\* Balance

**### 7. INRAFM Steel (Indian Reduced Activation Ferritic/Martensitic Steel):**

- \*\*Chromium (Cr):\*\* ~9%

- \*\*Tungsten (W):\*\* ~1%

- \*\*Carbon (C):\*\* ~0.1%

- \*\*Manganese (Mn):\*\* ~0.6%

- \*\*Vanadium (V):\*\* ~0.2%

- \*\*Silicon (Si):\*\* ~0.3%

- \*\*Niobium (Nb):\*\* ~0.1%

- \*\*Iron (Fe):\*\* Balance

**### 8. V4Cr4Ti:**

- \*\*Chromium (Cr):\*\* ~4%

- \*\*Titanium (Ti):\*\* ~4%

- \*\*Vanadium (V):\*\* Trace amounts

- \*\*Carbon (C):\*\* Low

- \*\*Manganese (Mn):\*\* Low

- \*\*Silicon (Si):\*\* Low

- \*\*Iron (Fe):\*\* Balance

Each of these materials has been developed to meet specific criteria for use in nuclear fusion reactors,

**Sheet2: Low-Activation ODS Steels**

The compositions of some prominent low-activation oxide dispersion strengthened (ODS) steels, specifically designed for use in nuclear applications such as fusion reactors, are detailed below. These steels are engineered for high-temperature strength, radiation resistance, and low activation characteristics.

**### 1. \*\*ODS Eurofer:\*\***

- \*\*Iron (Fe):\*\* Balance

- \*\*Chromium (Cr):\*\* 8.0-9.0%

- \*\*Tungsten (W):\*\* 1.0-1.2%

- \*\*Carbon (C):\*\* 0.1%

- \*\*Manganese (Mn):\*\* 0.4-0.6%

- \*\*Silicon (Si):\*\* Max 0.25%

- \*\*Vanadium (V):\*\* 0.10-0.12%

- \*\*Yttrium Oxide (Y2O3):\*\* 0.3% (volume fraction)

- \*\*Titanium (Ti):\*\* Small amounts for grain refinement

- \*\*Tantalum (Ta):\*\* ~0.05% to enhance creep strength

**### 2. \*\*14YWT (14Cr-1W-0.4Ti + Y2O3):\*\***

- \*\*Iron (Fe):\*\* Balance

- \*\*Chromium (Cr):\*\* Approximately 14%

- \*\*Tungsten (W):\*\* Approximately 1%

- \*\*Titanium (Ti):\*\* Approximately 0.4%

- \*\*Yttrium Oxide (Y2O3):\*\* Typically around 0.3% to 0.5% (volume fraction)

- \*\*Carbon (C):\*\* 0.05-0.15%

- \*\*Manganese (Mn):\*\* 0.3-0.6%

- \*\*Silicon (Si):\*\* Up to 0.3%

- \*\*Vanadium (V):\*\* Minor contributions for grain refinement

**### 3. \*\*MA957:\*\***

- \*\*Iron (Fe):\*\* Balance

- \*\*Chromium (Cr):\*\* About 14%

- \*\*Titanium (Ti):\*\* 0.3-0.4%

- \*\*Aluminum (Al):\*\* 4-5%

- \*\*Yttrium Oxide (Y2O3):\*\* Around 0.5% (volume fraction)

- \*\*Molybdenum (Mo):\*\* 0.5-1%

- \*\*Silicon (Si):\*\* Less than 0.5%

- \*\*Carbon (C):\*\* Approximately 0.05%

- \*\*Manganese (Mn):\*\* Up to 0.5%

1. \*\*MA956 (FeCrAlY)\*\* - Iron-chromium-aluminum-yttrium alloy known for its high-temperature oxidation resistance and strength.

 **Iron (Fe):** Balance

 **Chromium (Cr):** Approximately 20%

 **Aluminum (Al):** Approximately 4.5%

 **Titanium (Ti):** Approximately 1%

 **Yttrium oxide (Y2O3):** Approximately 0.5% (dispersed phase)

**Sheet 3: ### Austenitic Stainless Steels:**

1. \*\*310 (UNS S31000)\*\* - High-chromium nickel alloy with good oxidation resistance up to 1100°C.

 **Chromium (Cr)**: 24-26%

 **Nickel (Ni)**: 19-22%

 **Manganese (Mn)**: ≤2%

 **Silicon (Si)**: ≤1.5%

 **Carbon (C)**: ≤0.25%

 **Phosphorus (P)**: ≤0.045%

1.  **Sulfur (S)**: ≤0.03%
2. \*\*316H (UNS S31609)\*\* - High-carbon version of 316 stainless steel, offering enhanced high-temperature strength.
3.  **Chromium (Cr)**: 16-18%
4.  **Nickel (Ni)**: 10-14%
5.  **Molybdenum (Mo)**: 2-3%
6.  **Manganese (Mn)**: ≤2%
7.  **Silicon (Si)**: ≤1%
8.  **Carbon (C)**: ≤0.08%
9.  **Phosphorus (P)**: ≤0.045%
10.  **Sulfur (S)**: ≤0.03%

3. 304 stainless steel, also known as UNS S30400, is a popular austenitic stainless steel grade. Its composition typically includes the following elements:

* **Chromium (Cr)**: 18-20%
* **Nickel (Ni)**: 8-10.5%
* **Manganese (Mn)**: ≤2%
* **Silicon (Si)**: ≤1%
* **Carbon (C)**: ≤0.08%
* **Phosphorus (P)**: ≤0.045%
* **Sulfur (S)**: ≤0.03%

**Sheet 4: ### Ferritic Stainless Steels:**

* 1. \*\*Alloy 800 (UNS N08800)\*\* - Iron-nickel-chromium alloy with good strength and oxidation resistance up to 1100°C.
*  **Nickel (Ni):** 30.0 to 35.0%
*  **Chromium (Cr):** 19.0 to 23.0%
*  **Iron (Fe):** Balance (typically 39.5% or more)
*  **Manganese (Mn):** up to 1.5%
*  **Carbon (C):** 0.1% maximum
*  **Silicon (Si):** up to 1.0%
*  **Aluminum (Al):** 0.15 to 0.60%
*  **Titanium (Ti):** 0.15 to 0.60%
*  **Sulfur (S):** 0.015% maximum
*  **Copper (Cu):** 0.75% maximum

2. \*\*Alloy 800H (UNS N08810)\*\* - High-carbon version of Alloy 800 with improved high-temperature properties.

 **Nickel (Ni):** 30.0 to 35.0%

 **Chromium (Cr):** 19.0 to 23.0%

 **Iron (Fe):** Balance

 **Manganese (Mn):** up to 1.5%

 **Carbon (C):** 0.05 to 0.10% (higher than in Alloy 800)

 **Silicon (Si):** up to 1.0%

 **Aluminum (Al):** 0.15 to 0.60%

 **Titanium (Ti):** 0.15 to 0.60%

 **Sulfur (S):** 0.015% maximum

 **Copper (Cu):** 0.75% maximum

**Sheet 5: ### Martensitic Stainless Steels:**

9Cr-1Mo (ASTM A387 Grade 9 Class 1)\*\* - Chromium-molybdenum alloy steel used in elevated temperature applications such as pressure vessels and boilers.

 **Chromium (Cr):** 8.0 to 10.0%

 **Molybdenum (Mo):** 0.90 to 1.10%

 **Carbon (C):** 0.15% maximum

 **Manganese (Mn):** 0.30 to 0.60%

 **Silicon (Si):** 0.50% maximum

 **Phosphorus (P):** 0.030% maximum

 **Sulfur (S):** 0.030% maximum

 **Iron (Fe):** Balance

410S (UNS S41008)\*\* - Low-carbon martensitic stainless steel with improved high-temperature oxidation resistance compared to standard 410 stainless steel.

 **Chromium (Cr):** 11.5 to 13.5%

 **Nickel (Ni):** 0.6% maximum

 **Carbon (C):** 0.08% maximum

 **Manganese (Mn):** 1.0% maximum

 **Silicon (Si):** 1.0% maximum

 **Phosphorus (P):** 0.04% maximum

 **Sulfur (S):** 0.03% maximum

 **Iron (Fe):** Balance

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 **Chromium (Cr):** 12.0% - 12.5%

 **Molybdenum (Mo):** 0.8% - 1.0%

 **Carbon (C):** 0.2% - 0.25%

 **Vanadium (V):** 0.25% - 0.35%

 **Manganese (Mn):** 0.3% - 0.6%

 **Silicon (Si):** 0.2% - 0.5%

 **Nickel (Ni):** 0.3% maximum

 **Phosphorus (P):** 0.02% maximum

 **Sulfur (S):** 0.01% maximum

*  **Iron (Fe):** Balance

ASTM A335 Grade P91\*\* - Chromium-molybdenum alloy steel suitable for high-temperature service up to 600°C.

 **Chromium (Cr):** 8.0 to 9.5%

 **Molybdenum (Mo):** 0.85 to 1.05%

 **Carbon (C):** 0.08 to 0.12%

 **Manganese (Mn):** 0.30 to 0.60%

 **Silicon (Si):** 0.20 to 0.50%

 **Vanadium (V):** 0.18 to 0.25%

 **Niobium (Nb):** 0.06 to 0.10%

 **Nitrogen (N):** 0.030 to 0.070%

 **Aluminum (Al):** 0.02 maximum

 **Copper (Cu):** 0.40 maximum

*  **Nickel (Ni):** 0.40 maximum

ASTM A387 Grade 91 Class 2\*\* - Chromium-molybdenum alloy steel with enhanced high-temperature properties for pressure vessel applications.

1.  **Chromium (Cr):** 8.0% to 9.5%
2.  **Molybdenum (Mo):** 0.85% to 1.05%
3.  **Carbon (C):** 0.08% to 0.12%
4.  **Manganese (Mn):** 0.30% to 0.60%
5.  **Silicon (Si):** 0.20% to 0.50%
6.  **Vanadium (V):** 0.18% to 0.25%
7.  **Nickel (Ni):** 0.40% maximum
8.  **Niobium (Nb):** 0.06% to 0.10%
9.  **Nitrogen (N):** 0.030% to 0.070%
10.  **Aluminum (Al):** 0.02% maximum
11.  **Copper (Cu):** 0.20% maximum
12.  **Phosphorus (P):** 0.020% maximum
13.  **Sulfur (S):** 0.010% maximum
14.  **Boron (B):** 0.001% to 0.006%
15.  **Titanium (Ti):** 0.01% maximum
16.  **Zirconium (Zr):** 0.01% maximum
17.  **Iron (Fe):** Balance