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GE team is focused on cladding material, no fuel development at this time
Approach to Study and Rank the Steels

1. Environmental Degradation Under Normal Operation Conditions
2. Environmental Degradation Under Accident Scenarios
3. Fabrication Capabilities
4. Regulatory Analysis, Fuel Economy
## Materials Selected to Study

<table>
<thead>
<tr>
<th></th>
<th>Alloy</th>
<th>Nominal Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Zirc-2 UNS R60802</td>
<td>Zr + 1.2-1.7 Sn + 0.07-0.2 Fe + 0.05-0.15 Cr + 0.03-0.08 Ni</td>
</tr>
<tr>
<td>B</td>
<td>Ferritic steel T91 K90901</td>
<td>Fe + 9 Cr + 1 Mo + 0.2 V</td>
</tr>
<tr>
<td>C</td>
<td>Ferritic steel HT9 S42100</td>
<td>Fe + 12 Cr + 1 Mo + 0.5 Ni + 0.5 W + 0.3 V</td>
</tr>
<tr>
<td>D</td>
<td>Nano ferritic alloys - NFA</td>
<td>e.g. 14YWT; Fe + 14 Cr + 0.4 Ti + 3 W + 0.25 Y2O3</td>
</tr>
<tr>
<td>E</td>
<td>MA956 or UNS S67956</td>
<td>Fe + 18.5-21.5 Cr + 3.75-5.75 Al + 0.2-0.6 Ti + 0.3-0.7 Y2O3</td>
</tr>
<tr>
<td>G</td>
<td>APMT</td>
<td>Fe + 22 Cr + 5 Al + 3 Mo</td>
</tr>
<tr>
<td>H</td>
<td>High Cr Ebrite S44627</td>
<td>Fe + 25-27.5 Cr + 1 Mo + 0.17 (Ni + Cu)</td>
</tr>
<tr>
<td>J</td>
<td>Alloy 33 – UNS R20033</td>
<td>33 Cr + 32 Fe + 31 Ni + 1.6 Mo + 0.6Cu + 0.4 N</td>
</tr>
</tbody>
</table>
Advanced Steel Cladding Benefits & Focus Areas

Ferritic stainless steel containing chromium & aluminum (Fe-Cr-Al)

1) High probability of near term solution.
2) Several hundred times more resistant to steam oxidation than current Zr alloys
3) Resistant to general corrosion & stress corrosion cracking under normal operation high temperature water
4) Less susceptible than Zr alloys to galvanic corrosion with other reactor materials under irradiation.
5) Resistant to neutron damage
6) Can be welded

Main Areas of Focus 2015-2016
- Continued evaluations related to performance metrics including fretting resistance
- Fabrication capabilities into long small diameter thin walled tubing
- Cost of neutron economy (reduced wall thickness to 16 mils or 400 µm)
Compact Tension Specimen of 23% cold worked APMT tested in 288°C Water + 2 ppm O$_2$ up to a stress intensity of 40 ksi$\sqrt{\text{in}}$.

In chromium ferritic alloys a crack may propagate under cyclic loading (fatigue) but it stops growing as the load cycling frequency is decreased.
Compact Tension Specimen of HT9 neutron irradiated to 36.9 dpa and tested in 288°C Water + 2 ppm O₂ up to a stress intensity of 38 ksi√in
Reaction with Steam, tested at GE Research

100% Steam
800°C

- Zirc-2
- T91
- NFA
- APMT
- Alloy 33

Mass Change (mg/cm²)

Test Time (h)

Consumed

Zirc-2, 24 hours, 800°C, 100x

APMT, 24 hours, 800°C, 500x

GE, Dolley & Rebak, OECD-NEA Accident Tolerant Fuel Meeting, 24-September-2014
Summary and Conclusions

1. The proposed advanced steels are as good as zirconium alloys under normal operation conditions
   • Resistant to general corrosion and environmental cracking
   • Resistant to galvanic corrosion considering other reactor materials
   • Resistant to environmental cracking after irradiation
Summary and Conclusions

2. Advanced steels outperform the zirconium alloys under accident conditions
   • Better mechanical strength at higher temperature
   • Improved reaction kinetics with steam
   • Lower generation of hydrogen gas when reacting with steam
   • Enhanced retention of fission products