Expert Group on Accident Tolerant Fuels for Light Water Reactors

Second Meeting, Paris, France

Accident Tolerant Advanced Steels Cladding for Commercial Light Water Reactors

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24-September-2014

This material is based upon work supported by the Dept. of Energy [National Nuclear Security Administration] under Award Number DE-NE0000568. This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

GE team is focused on cladding material, no fuel development at this time

GE Global Research

SANDVIK

Michigan Engineering

Los Alamos NATIONAL LABORATORY

GNF Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi

Oak Ridge National Laboratory

INL Idaho National Laboratory

BROOKHAVEN NATIONAL LABORATORY

Approach to Study and Rank the Steels

Environmental Degradation Under Normal Operation Conditions

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Environmental Degradation Under Accident Scenarios

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Fabrication Capabilities

↓

Regulatory Analysis, Fuel Economy

Materials Selected to Study

	Alloy	Nominal Composition
A	Zirc-2 UNS R60802	Zr + 1.2-1.7 Sn + 0.07-0.2 Fe + 0.05-0.15 Cr + 0.03-0.08 Ni
B	Ferritic steel T91 K90901	Fe + 9 Cr + 1 Mo + 0.2 V
C	Ferritic steel HT9 S42100	Fe + 12 Cr + 1 Mo + 0.5 Ni + 0.5 W + 0.3 V
D	Nano ferritic alloys - NFA	e.g. 14YWT; Fe + 14 Cr + 0.4 Ti + 3 W + 0.25 Y_2O_3
E	MA956 or UNS S67956	Fe + 18.5-21.5 Cr + 3.75-5.75 Al + 0.2-0.6 Ti + 0.3-0.7 Y_2O_3
G	APMT	Fe + 22 Cr + 5 Al + 3 Mo
H	High Cr Ebrite S44627	Fe + 25-27.5 Cr + 1 Mo + 0.17 (Ni + Cu)
J	Alloy 33 – UNS R20033	33 Cr + 32 Fe + 31 Ni + 1.6 Mo + 0.6Cu + 0.4 N

Advanced Steel Cladding Benefits & Focus Areas

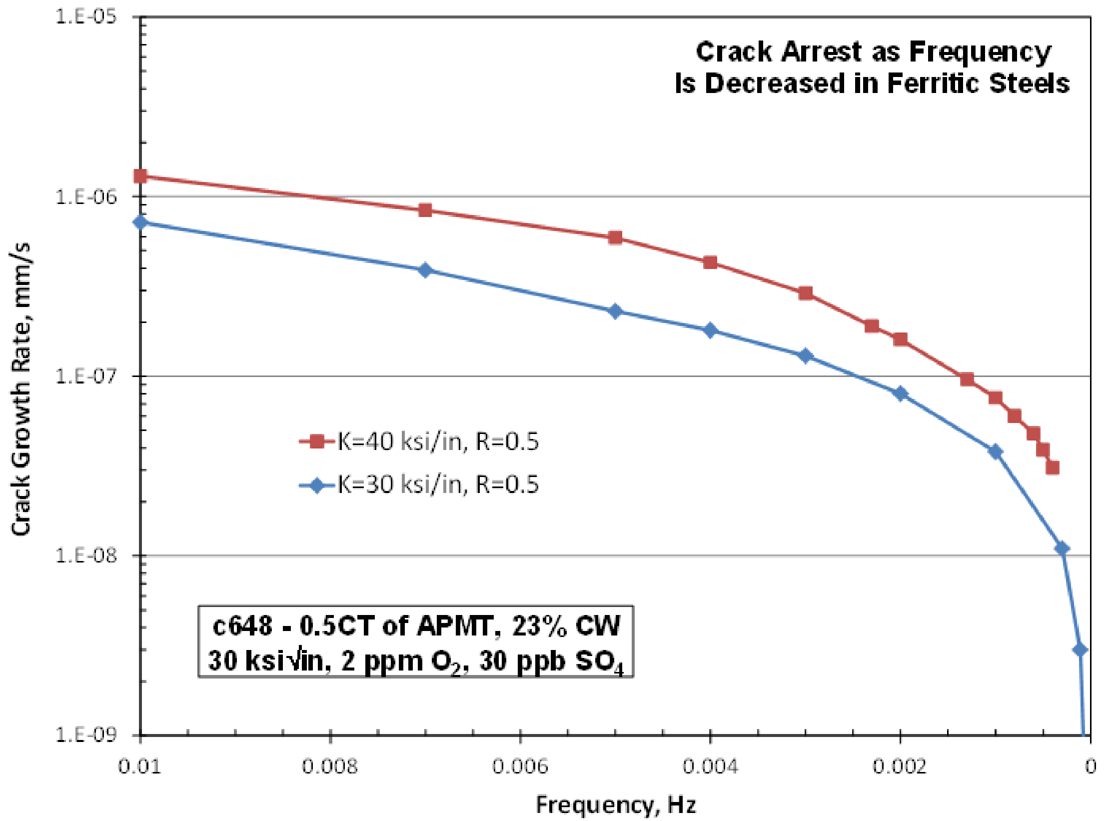
Ferritic stainless steel containing chromium & aluminum (Fe-Cr-Al)

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

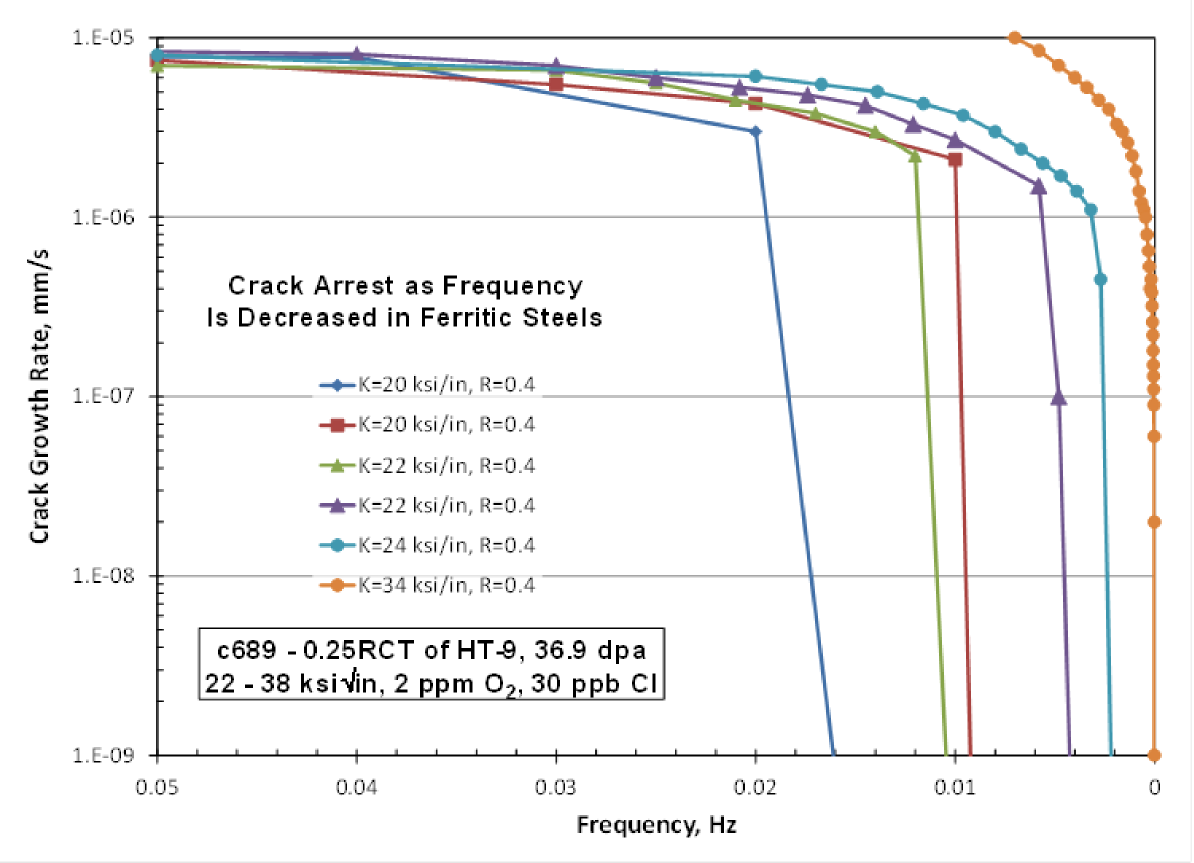
- Continued evaluations related to performance metrics including fretting resistance
- Fabrication capabilities into long small diameter thin walled tubing
- Cost of neutron economy (reduced wall thickness to 16 mils or 400 μm)

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√in

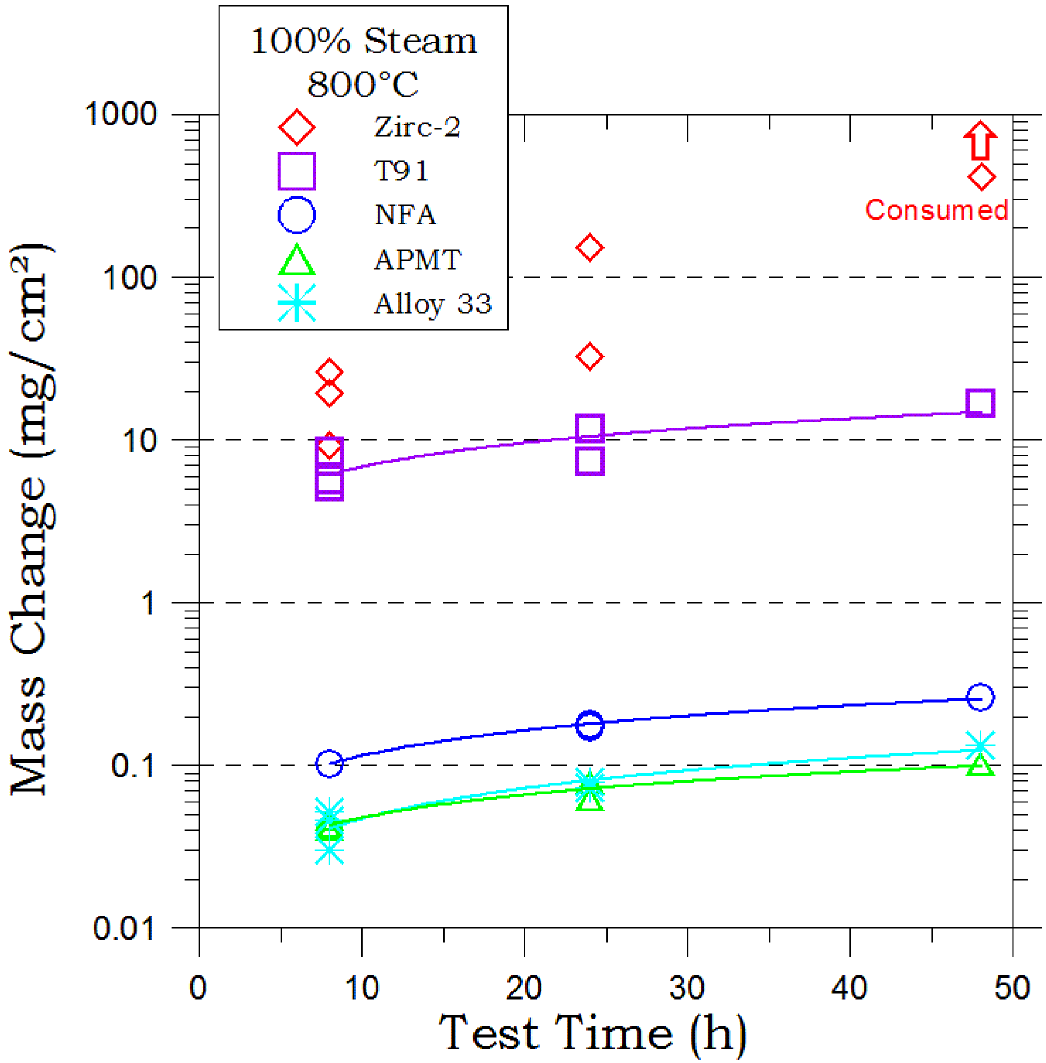


In chromium ferritic alloys a crack may propagate under cyclic loading (fatigue) but it stops growing as the load cycling frequency is decreased.

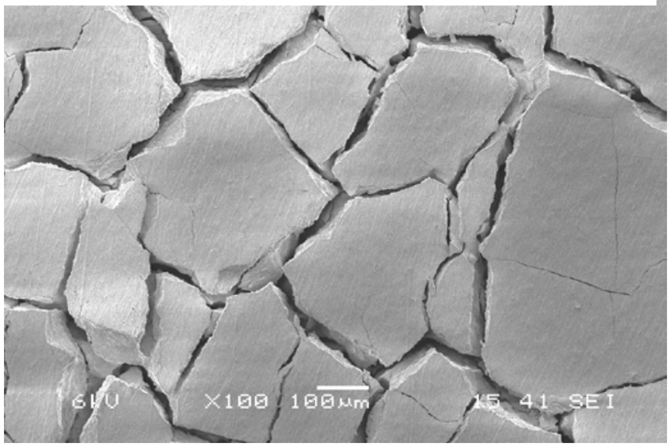
Compact Tension Specimen of HT9 neutron irradiated to 36.9 dpa and tested in 288°C Water + 2 ppm O_2 up to a stress intensity of 38 ksi√in



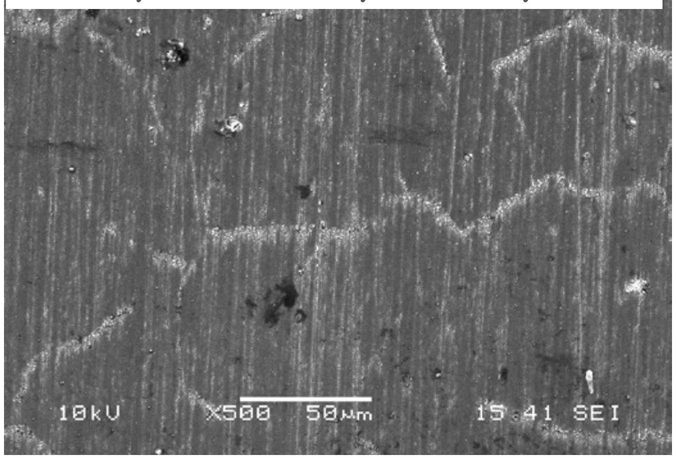
Reaction with Steam, tested at GE Research



Zirc-2, 24 hours, 800°C, 100x



APMT, 24 hours, 800°C, 500x



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