NEI INTERNATIONAL URANIUM FUEL SEMINAR

# Ceramic Cladding for High Burn Up, Zero Defect, Nuclear Fuel; An Update

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NEI

# Topics

1. October 2008 Denver Uranium Seminar
2. Where we are today – the technology
3. Political
4. Economics and Cost Considerations
5. Future Prospects

# Why Ceramic Cladding

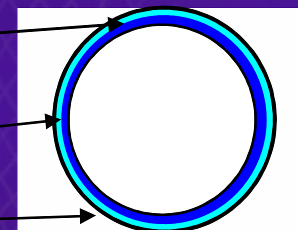
- October 2008 -Towards Zero Defects, Lower Fuel Costs, and High Burn-up; A New Approach – NEI Uranium Seminar in Denver
- Some reasons for considering new SiC ceramic cladding to replace zircaloy in future water reactors
  - Very hard – reduced failure rates from fretting, wear, etc.
  - Central layer is a composite of fibers and matrix – not brittle like other ceramics
  - Radiation resistant – very long lifetime – allows higher burnup
  - Retains strength to 1500C and higher – may allow power uprates – 10 to 25% beyond what is possible with advanced zirconium alloys
  - DNB proof, dry-out proof – during operational transients.
  - Does not balloon, or react exothermically during LOCA – reducing the already low probability and consequences of DBA LOCA . Passively safe fuel.
  - Passively safe fuel may offset some containment and component degradation, and thereby facilitate relicensing beyond 60 years.

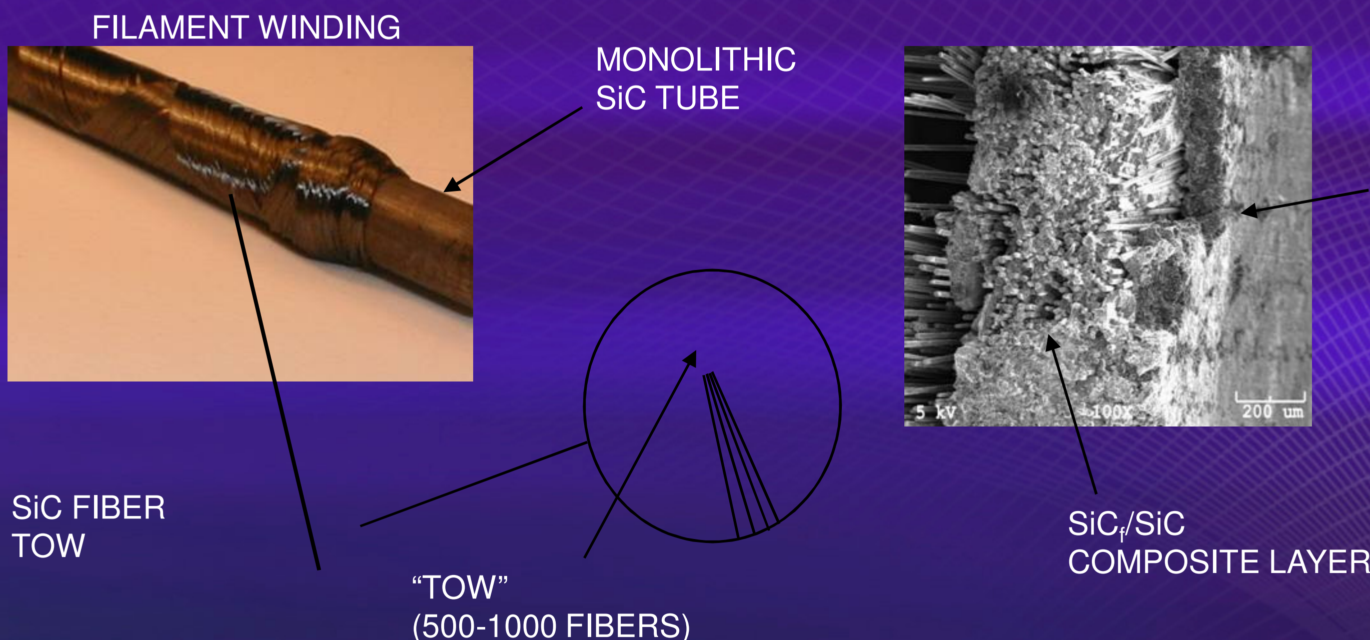
# What Is It ?

Dense leak tight SiC inner layer (12 – 15  mils)

Robust composite intermediate layer (12 – 15 mils)

Outer Corrosion barrier layer (4-5 mils)





# Fundamentally Different Behavior

- The inner dense monolith holds fission gases up to 5000 psi and does not creep down on the pellet
- In the event of an accident – e.g. Reactivity Insertion or Loss of Coolant, the inside tube leaks and releases gas, but central composite layer retains its shape and the fuel out to strains of >8% .
- No ballooning or exothermic metal water reaction or $H_2$
- Mechanical behavior verified by tests on un-irradiated tubes and on clad tubes irradiated in the MIT research reactor.

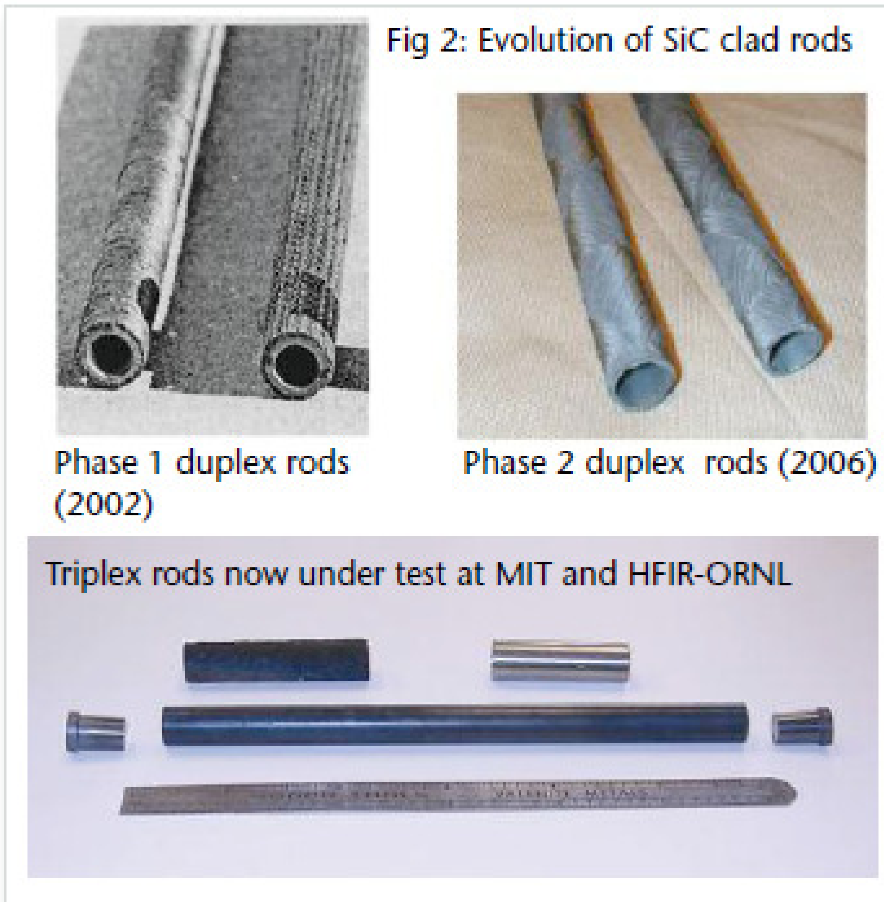
# 2. Progress Since Denver

- Continued exposure in LWR coolant loop of MIT reactor - 20 EFPMs
- Very slow recision – round 6 tubes - extrapolates to ~ 10 years
- HFIR capsules – standard $UO_2$ fuel 17 x 17 size – just starting
- New round 7 made with special coating for HFIR capsules
- Coated tubes had de-lamination after MITR-2 exposure
- Don't need coating for Halden-ATR test or commercial application
- HFIR – demonstrate acceptable pellet clad interaction. Ongoing

Potential Obstacles Remaining

end joint – tried some bond agents – not good – will try others
very long tubes – know how to do it, but requires new funding.
higher fuel temperatures – no clad creep – gap remains - annulus
what about the fuel cycle economics – EPRI sponsored MIT study

# Evolution of CTP's SiC Triplex Clad



# Fuel Assembly Distortion – Channel Box Bowing

- May be  just as limiting to extending burnup as the fuel rod burnup limit and zirc cladding
- Both PWRs and BWRs
- Stiffness of the assembly is dominated by the array of rods inside the assembly, rather than the PWR CRGT and BWR channel box structures.
- Analyses indicate that an array of very stiff rods, such as SiC clad rods, will dominate the bowing effect and restrict bowing at high burnup, even with weak CRGT structure or weak channel boxes.
- We are proposing a small business project to DOE this winter to study this effect.

# 3. The politics
# A national program is needed

- As noted in Denver – too  high risk to expect program success with just industry investment
- Major national advantages – less spent fuel, power up-ratings, greater safety margins
- Starting to get some DOE investment – DOE is funding the test at HFIR, the ongoing test at MIT, and has started a small research program at INL.
- EPRI has provided support - $300 K in 2 years
- Demonstration and commercialization is different than scientific research.  This administration has ambitious "science" oriented nuclear research program including materials research
- What's missing is commercial demonstration – couple product development and demonstration, including manufacturing technology, with the "materials properties" developed in the labs.

# FY 11 Senate Approved DOE Appropriations Language

- *Fuel Cycle Research and Development.-The* Committee recommends $191,000,000 for Fuel Cycle Research and Development. The Committee recommends $40,000,000 for the Advanced Fuels program, including $7,000,000 for the Department to issue a competitive solicitation requesting industry teams (fuel suppliers, utilities and advanced ceramic developers) for cost shared proposals to develop and test advanced LWR fuel with ceramic cladding, with the capability of very high burn up and with the objective of achieving readiness for Lead Test Rod operation in commercial reactors within 5 years. This should be awarded on a 50-50 cost-share basis.

# 4. Fuel Cycle Economics

- At Denver – Frank Rives – so what sort of fuel management scheme would go with SiC clad and what are the economics ???
- EPRI sponsored study at MIT – almost finished.

  includes 0, 10% and 20% power uprates
- Also includes increase PWR cycle length to 24 month cycles
- Preliminary results just reviewed at EPRI meeting 9-30
- Not yet vetted or published and not converted to economic analysis
- Still some value in examining preliminary results

# EPRI Sponsored MIT study
# Cycle Specifics

| | Nomina l (Zr) | Nominal (SiC) | 10% Uprate (SiC) | 20% Uprate (SiC) |
|---|---|---|---|---|
| Power ($MW_{th}$) | 3587 | 3587 | 3946 | 4304 |
| Core Volume (L) | 32641 | 32641 | 32641 | 32641 |
| Power Density (kW/L) | 110 | 110 | 121 | 132 |
| Avg. Fuel Temp. (K) | 878 | 905 | 920 | 940 |
| Avg. Moderator Temp. (K) | 585 | 585 | 583 | 581 |
| 18-Month Cycle Burnup (GWd/MTU) | 19.52 | 21.62 | 23.78 | 25.94 |
| 24-Month Cycle Burnup (GWd/MTU) | - | 29.20 | - | - |
| Capacity Factor: 95% | | | | |
| Refueling Days: 28 Days | | | | |
| EFPDs: 493 (18 months) , 666 (24 months) | | | | |

# EPRI Sponsored MIT Study - 2

| Reload # | Uprate | w/o | Cycle B. | Disch. B. | EFPD | Boron | $F_{\Delta H}$ | $F_q$ | MTC | Max Pin Burnup |
|---|---|---|---|---|---|---|---|---|---|---|
| A. 84 | - | 4.35 | 19.4 | 44.6 | 490 | 1371 | 1.549 | 1.79 | < 0 | 72.4 |
| B. 52 | - | 6.74 | 21.4 | 79.4 | 487 | 1776 | 1.595 | 1.91 | < 0 | 107.9 |
| C. 64 | - | 6.10 | 21.9 | 66.0 | 500 | 1696 | 1.634 | 1.91 | < 0 | 114.6 |
| D. 84 | - | 4.64 | 21.8 | 50.1 | 498 | 1514 | 1.572 | 1.89 | < 0 | 82.6 |
| E. 84 | 10% | 5.09 | 23.9 | 54.9 | 497 | 1825 | 1.607 | 1.93 | < 0 | 86.6 |
| F. 84 | 20% | 5.54 | 25.7 | 59.0 | 489 | 1675 | 1.589 | 1.95 | < 0 | 92.8 |
| G. 112 | - | 5.24 | 29.3 | 50.5 | 668 | 1694 | 1.577 | 2.01 | < 0 | 72.6 |

# Selected Conclusions - MIT Study

- Case B – no power uprate; 6.7% enrichment; 18 month cycle; reload batch reduced from 84 to 52; average burnup at 80 gwd/t; spent fuel volume reduced by 78%
- Case F – 20% power uprate; 5.5% enrichment; 18 month cycle; reload batch stays at 84; average burnup at 59 gwd/t; spent fuel volume reduced by 32%
- Case G – no power uprate; 5.24% enrichment; 24 month cycle; reload batch increased to 112; average burnup 50.5 gwd/t; spent fuel volume reduced by 13%; eliminate one refueling every 6 years.

# 5. Future Prospects

- CTP is a small company – we have agility, but small resources
- Ceramic clad could be of major benefit to future LWR operations.
- Have had support of a fuel supplier
- DOE has just awarded CTP a new SBIR – to prove superior performance of SiC in LOCA – results March 2011
- SBIR also includes study of Thoria-Plutonia fuel with SiC cladding
- The Thoria (instead of DU) allows burn down of most of the Pu and actinides in one additional pass, and also eliminates need for annular fuel to reduce fuel temperature. But reprocessing infra-structure and a MOX-like plant to fabricate the fuel – decades away.
- We look at it as a second generation of ceramic clad application – standard $UO_2$ first. That is our current focus.
- The prospects for an industry led, DOE – industry cost shared program aimed at lead test rods, and then if successful, lead test assemblies, has emerged as the best past forward.

# Next Steps

- CTP will continue to promote an industry led, cost shared, Federal program – thanks to USACA we are half way there.
- Cannot succeed without some owner- operator "Expressions of Interest" – willingness to join a team proposal leading to small number of lead test rods - to encourage Fed Investment
- Also, need continued support of EPRI efforts as we develop solutions to technical problems and evolve improved fuel management schemes to take advantage of SiC clad
- NRC has encouraged us because they like passively safe fuel – A paraphrase - "keeping the test rods below 30 will facilitate NRC review and approval".
- New NRC LOCA rule – allows non metallic cladding
- Halden tests beginning in 2013
- Ready for lead test rods in 2016 and lead test assemblies in 2020

# Questions ?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