Ceramic HEPA Filter Program

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LLNL Ceramic HEPA Filter Program

- Potential benefits of ceramic filters in nuclear facilities
  - Short term, intermediate, long term benefits
  - Benefits of Ceramic Filter Technology

- History
  - International R&D
  - U.S. R&D

- Results
  - ATI Test Results
  - ICET Testing – forthcoming

- Current Technical Developments & Path forward
  - Testing at LLNL, ATI, and ICET
  - Filter, component, and material testing at Cal Poly’s High Temperature Test Unit (HTTU)
  - Nanofiber R&D at LLNL

- Conclusion

- Thanks
Potential Benefits of Ceramic Filters

- Ceramic HEPA filters should survive higher temperatures and fires better than existing technology

- Short term benefit for DOE, NRC, and industry
  - Cal Poly High Temperature Test Unit (HTTU) provides unique testing capability
    - Materials, components, filter testing with high temperature air flow
    - Capability for testing components to simulate a facility subjected to an earthquake followed by a fire (aka shake-n-bake test)

- Intermediate term benefit for DOE, NRC, and industry
  - Spin-off technologies applicable to other commercial industries
  - Filtration for specialty applications, e.g., explosive applications

- Long term benefit for DOE, NRC, and industry
  - Engineering solution to safety problem
    - Improvements in filter performance (e.g., heat and fire resistant) will improve facility safety and decrease dependence on associated support systems
  - Large potential life-cycle cost savings
  - Facilitates development and deployment of LLNL process innovations to allow continuous ventilation system operation during a fire
Benefits of Ceramic Filter Technology

- Overcomes problems with existing technologies in DOE facilities
  - Existing HEPA filters result in significant design, operational, and compliance costs for associated fire protection and support systems
  - Defense Nuclear Facilities Safety Board (DNFSB) correspondences and presentations by DNFSB members highlighted need for HEPA filter R&D
    - DNFSB Recommendation 2009-2 highlights this issue for a nuclear facility response to an evaluation basis earthquake followed by a fire (LANL PF-4)
    - DNFSB comments on a new facility under construction (CMRR) highlighted significance of HEPA filter issues and escalated costs (note current status of CMRR)
    - DNFSB comments continue in 2012

- Advantageous to focus on engineering safety solutions rather than primarily additional DSA analysis
  - Increase safety and performance, while significantly lowering cost
  - Reduce or eliminate safety basis costs associated with safety class and safety significant systems in nuclear facilities
    - Fire suppression, fire detection and alarm, and internal building structure
  - Provide protection for acidic fume environments in nuclear facilities
    - Formerly protected by Teflon™ pre-filters (prior to DNFSB comments)
DOE Complex Needs Analysis

- 100% of knowledgeable nuclear air cleaning professionals believe HEPA filter media strength is very, or extremely, important
- 92% of knowledgeable nuclear air cleaning professionals believe it is important to develop alternatives to current glass-fiber filters
History of Ceramic HEPA Filter Program

- LLNL has conducted research into more advanced HEPA filters for more than 30 years, e.g.,
  - Metal HEPA filters, Dr. Werner Bergman et al.

- International R&D
  - Mark Mitchell & Dr. Werner Bergman initiated the ceramic HEPA filter research, including work by Russian national institutes
    - Bochvar, Bakor, and Radium Khlopin Institute
    - Resulted in ceramic HEPA filter proof-of-concept

- Current U.S. R&D (NSR&D)
  - Goal: Develop a fire resistant filter with better performance (e.g., heat, flame, moisture, corrosion, loading)
Current Program Status

- Completed international R&D tested a wide variety of ceramic substrates, coatings, and technologies to apply coatings
  - Down selected two filter technologies
  - LLNL testing Russian filter prototypes
    - Mini-assembly (8.5”x8.5”x11.5”)
    - Full-scale assembly (2’x2’x11.5”)
- Ongoing University Collaboration (CalPoly)
  - Enhanced testing capability - High Temperature Test Unit (HTTU)
    - HTTU provides an unique capability to test binders, sealants, and frames
    - See separate presentation on HTTU
  - Tooling capability to replace individual tubes in support of R&D and manufacturing
- LLNL R&D
  - Invented new sealants to be tested at Cal Poly (HTTU)
  - Invented new filtration coatings
  - Commercial procurements of ceramic substrates
  - Innovative new coatings lab at LLNL
    - Nanofiber coating apparatus designed, fabricated, installed, and in testing
International R&D - Nonproliferation

- Intended to be a self-sustaining enterprise for the long term employment of scientists, engineers, and technicians

- Russian R&D nuclear and ceramics capabilities
  - Bochvar
    - Leading Russian institute conducting research on fuel cycle technologies & fissile materials processing
    - Founded in 1945 to solve materials science and technology problems related to the production of nuclear weapons, capabilities in ceramic technology, emphasis on applied technology at large scales
  - Radium Khlopin
    - Developed reprocessing technologies for fissile materials production
    - Conducts R&D for the nuclear industry, analytical laboratory services, environmental investigations of nuclear tests, designs accident response procedures and produces isotopes

- Goal
  - Develop ceramic HEPA filter technology
  - Establish working relationship between U. S. industrial partner and Russian nuclear laboratories
  - Long term employment of Russian WMD scientists, engineers, and technicians to fabricate ceramic HEPA filters for U. S., Russian, foreign markets, and conduct ongoing R&D services
Monitoring Russian Research
Russian R&D Explored and Down Selected Ceramics and Designs for Membranes and Substrates

Filter Element with Aluminum-Oxide Membrane Made by Gas-Plasma Spraying Method

Fiber-Structured Filtering Element Samples

Various ceramic samples

Research included:
• Variety of Alumina Electrocorundums
• Disthene-Sillimanite
• SiC (numerous approaches) substrate
• Aluminum oxide substrate
• Preparation techniques such as slurry molding, casting, plasma deposition, proprietary vacuum deposition
Early Russian Filter Development

- Porous SiC substrate considered for increased strength
- Balance filtration efficiency and pressure drop utilizing the characteristics of the substrate and the coating
  - Sintered powder substrate has low efficiency and high pressure drop, but high strength
  - Fibrous substrates have moderate efficiency and low pressure drop, but low strength

Early SiC cylinder

Photomicrograph of early fiber research
SEM of final substrate and coating – Russian proof-of-concept

- Substrate has large, well bonded grains
  - Strength
  - Large porosity

- Filter media is composed of fine fibers
  - Nominally many are sub-micron
  - Smaller fibers should increase efficiency and lower dP
Russian filter proof-of-concept

- Ceramic HEPA filter in metal housing
- Weight
  - Mini-assembly
    - 14.3 lbs / 4.5 kg
  - Full scale (Class 5)
    - 110 lbs / 50 kg
Russian filter proof-of-concept
Testing at ATI

- Successful proof-of-concept
- Independent verification of HEPA filtration (> 99.97% filtration efficiency) at
  - 30 cfm (dP 2.8”)
  - 71 cfm (dP 6.1”)
- Unsatisfactory dP
  - R&D of filter media coatings at LLNL to reach final goal
Russian filter proof of concept-Testing at ICET forthcoming

- Plan to utilize the currently developed test stand used to qualify metal HEPA filters for AG-1 Section FI to also qualify ceramic HEPA filters.
Current Technical Developments

- Developing ceramic HEPA filter technology meeting specifications of existing nuclear grade HEPA systems
  - Three Main Projects
    - Ceramic HEPA Filter Testing at LLNL, ATI, and ICET
    - University Collaboration (Cal Poly) student projects to develop improved testing capabilities (HTTU provides an unique capability to test binders, sealants, and frames)
    - Filter media research at LLNL to reduce dP and maintain filtration efficiency
  - Intellectual Property
    - Portfolio of over a dozen inventions and patents
Current Technical Developments - Testing

- Prototype Ceramic HEPA Testing at LLNL, ATI, and ICET
  - ASME 510 leak test at LLNL industrial hygiene laboratory
    - Scanning individual components and assembled HEPA filter
  - Certification testing at ATI complete
    - Future filters will likewise be sent to ATI for testing
  - Next step: ICET qualification testing of Russian proof-of-concept filters
    - Future filters will likewise be to ICET
  - Pave the way for revised regulations

  New ASME AG-1 Section for Ceramic Filters and DOE-STD-3020 revision
Current Technical Developments – Cal Poly

- Tooling Project – Complete
- High Temperature Testing Unit (HTTU) to study HEPA filter behavior as effected by fire conditions
  - HTTU provides an unique capability to test binders, sealants, and frames
  - Primarily targeted for ceramic filters, but can support studies of non-ceramic filters if desired
- Status
  - Design HTTU and Control System – Complete
  - Fabrication, test and demonstrate HTTU – In progress
  - Install and test controls & instrumentation for HTTU – In progress
- Conduct experiments on various HEPA filter materials and designs
  - Better sealants, binders, and other components (e.g., frames)
  - Question: Any interest in integral welded frame with a flat sealing surface instead of bolted frame?
  - Question: Any interest in shake-n-bake test capability?
Current Technical Developments – Nanofibers

- Nanofiber coatings research
  - Reduce pressure drop while maintaining filtration efficiency
  - Develop and test improved filtration materials for ceramic filters using LLNL/DOE developed innovations
    - Research contract fabrication opportunities - Complete
      - Procured R&D quantity of substrate elements (tubes)
    - Proof test (compressive strength) tubes - Complete
    - Measure dP of tubes at flow rates required by 3020
      - Complete for substrates
    - Developed deposition system for coating tubes
      - Coating R&D - In progress
Conclusions

- Research has short, intermediate, and long term benefits to DOE Complex, NRC, and industry
- Completed Russian R&D and successful proof-of-concept
- Ceramic HEPA Filter Program is developing unique capabilities to answer complex questions
- Path forward
  - Testing of binders, sealants, and frames (see Cal Poly presentation)
  - Development of filter media to reduce dP and maintain filtration efficiency
  - Portfolio of over 12 inventions with provisional patents already filed
- We will continue to pursue NSR&D funding for this program
- We welcome suggestions for future research ideas to best fit your needs
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