U.S. DEPARTMENT OF ENERGY

Advanced Fuels Campaign

Office of Nuclear Energy

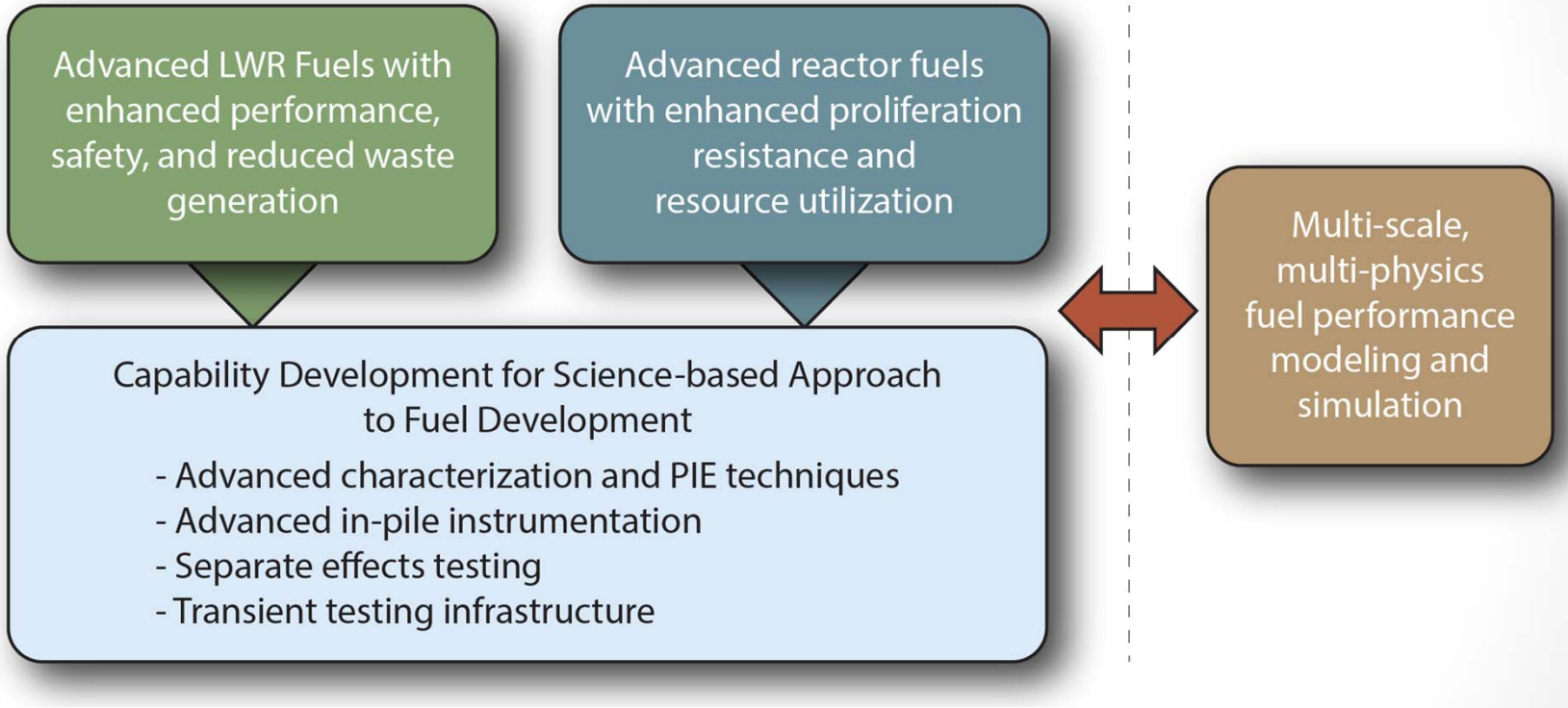
Jon Carmack

National Technical Director

Advanced Fuels Campaign

March 28, 2017

The FCRD Advanced Fuel Campaign is tasked with development of near term accident tolerant LWR fuel technology and performing research and development of long term advanced reactor fuel options.



AFC High Level Technical Objectives (5-year)

- Identify and select advanced LWR fuel concepts for development towards lead test rod testing by 2022.
- Support the near term qualification and sourcing of driver fuel for near-term test and demo reactors.
- Complete the conceptual design for the baseline advanced reactor fuel technologies with emphasis on the fundamental understanding of the fuel fabrication and performance characteristics for recycle fuels.
- Achieve state-of-the art infrastructure that can be used to perform fuel research and development from a “science-based” approach accelerating further development of selected concepts.
- Integrate with the development of the predictive, multi-scale, multi-physics fuel performance code.

Integrating DOE and Industry Efforts

High Performance Accident Tolerant LWR Fuels

- Accident tolerant
- Ceramic and chromium coated zircaloys
- Multi-layer ceramic claddings
- High density ceramics
- High thermal performance

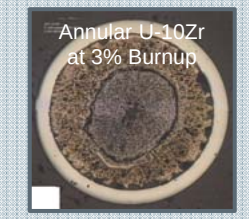
AREVA

GE imagination at work

Westinghouse

Fast Reactor Fuels

- Advanced manufacturing
- Actinide bearing
- Advanced performance



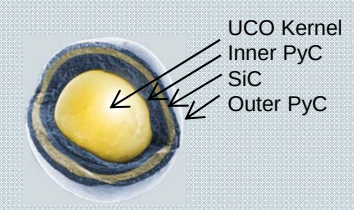
KAERI Korea Atomic Energy Research Institute

OKLO

TerraPower

High Temperature Gas Reactor Fuels

- TRISO based fuel
- High burnup – high temperature
- Multi-layer fission production retention



BWXT
BWX Technologies, Inc.

Xenergy

DOE AFC is providing the U.S. nuclear industry with fuel and technology qualification, development, and testing resources.

AFC is supported by a large part of the U.S. nuclear complex

National Laboratories

Universities

Nuclear Industry

University R&D plays an important role in advanced nuclear fuels and materials principally through the NEUP program

- Typically > 30 projects in a given year in AFC.
- Large number of lead and collaborating universities.

NEUP Nuclear Energy University Programs
U.S. Department of Energy

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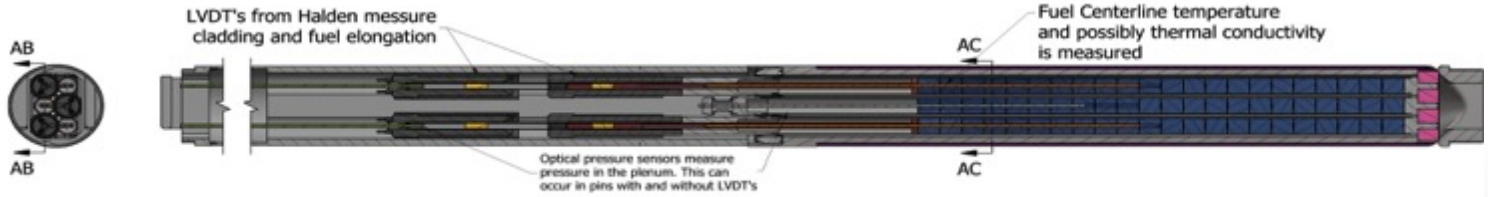
FY16 NEUP AFC Related Project Awards

NEUP Project #	Title	PI	Lead Institution
16-10668	Microstructure experiments-enabled MARMOT simulations of SiC/SiC-based accident tolerant nuclear fuel system	Jake Eapen	NCSU
16-10221	Alloying agents to stabilize lanthanides against fuel cladding chemical interaction: Tellurium and Antimony studies	Jinsuo Zhang	Ohio State University
16-10667	A coupled experimental and simulation approach to investigate the impact of grain growth, amorphization, and grain subdivision in accident tolerant U3Si2 LWR fuel	Mike Tonks	Pennsylvania State University
16-10648	Microstructure, thermal, and mechanical property relationships in U and U-Zr alloys	Maria Okuniewski	Purdue University
16-10648	Oxidation and corrosion-resistant uranium silicide fuels	Jie Lian	RPI
16-10523	A science based approach for selecting dopants in FCCI-resistant metallic fuel systems	Indrajit Charit	Univ. of Idaho
16-10204	Phase equilibria and thermochemistry of advanced fuels: modeling burnup behavior	Ted Bessmann	Univ. of South Carolina

2017 ATF Primary Activities

- Year 1 of Phase II ATF Activities
- Initiate ATF-2 loop irradiation in ATR and establish loop irradiation in Halden
- Develop necessary experimental capability for transient testing
- Establish fuel handbooks for ATF technologies
- PIE of initial ATF-1 fuel rodlets

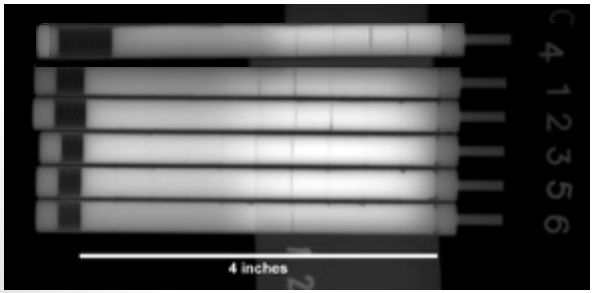
ATR ATF-2 PWR Loop Test



U.S. DOE-supported Industry Teams working to insert ATF into LWR condition loop irradiations

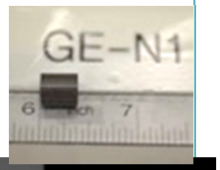
AREVA

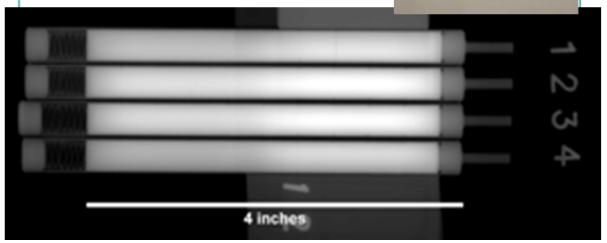
- **Cr coated Zr**
- **Increased fuel conductivity**
- Additives
  - Chromia dopant



GE

- Develop advanced **ferritic/martensitic steel alloys (e.g., Fe-Cr-Al) for fuel cladding** to improve behavior under severe accident scenarios
- Objectives:
  - Characterize candidate steels
  - Study tube fabrication methods, neutronics, fuel economy, thermo-hydraulic calculations, regulatory approval path
  - Initiate ATR testing with UO_2 and two cladding materials.

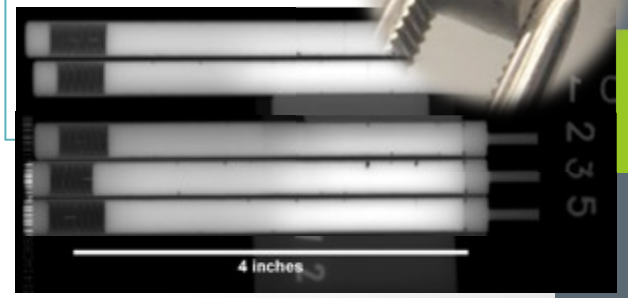




Westinghouse

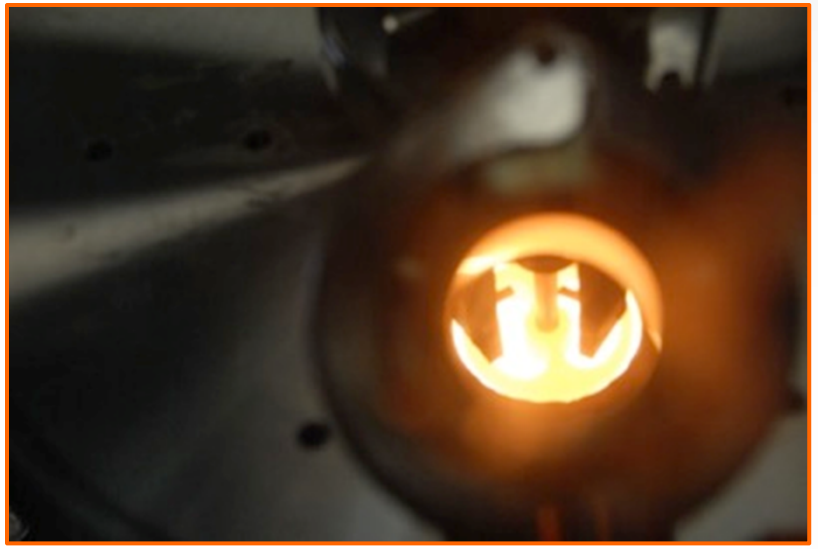
- **Cladding** concepts:
  - **SiC** and SiC ceramic matrix composites;
  - **coated Zr alloys**
- **High density/high thermal conductivity fuel pellets**
- First batch of U_3Si_2 pellets were sintered using finely ground powder
- Pellets were pressed using pressures of 6,000-10,000 psi and sintered at temperatures of 1400° C

U_3Si_2 Pellet



2017 Advanced Reactor Fuels Activities

- Am distillation
- Np feedstock
- Remote fuel casting
- Advanced fuel fabrication
- Thermal/Fast comparison



KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

TerraPower™

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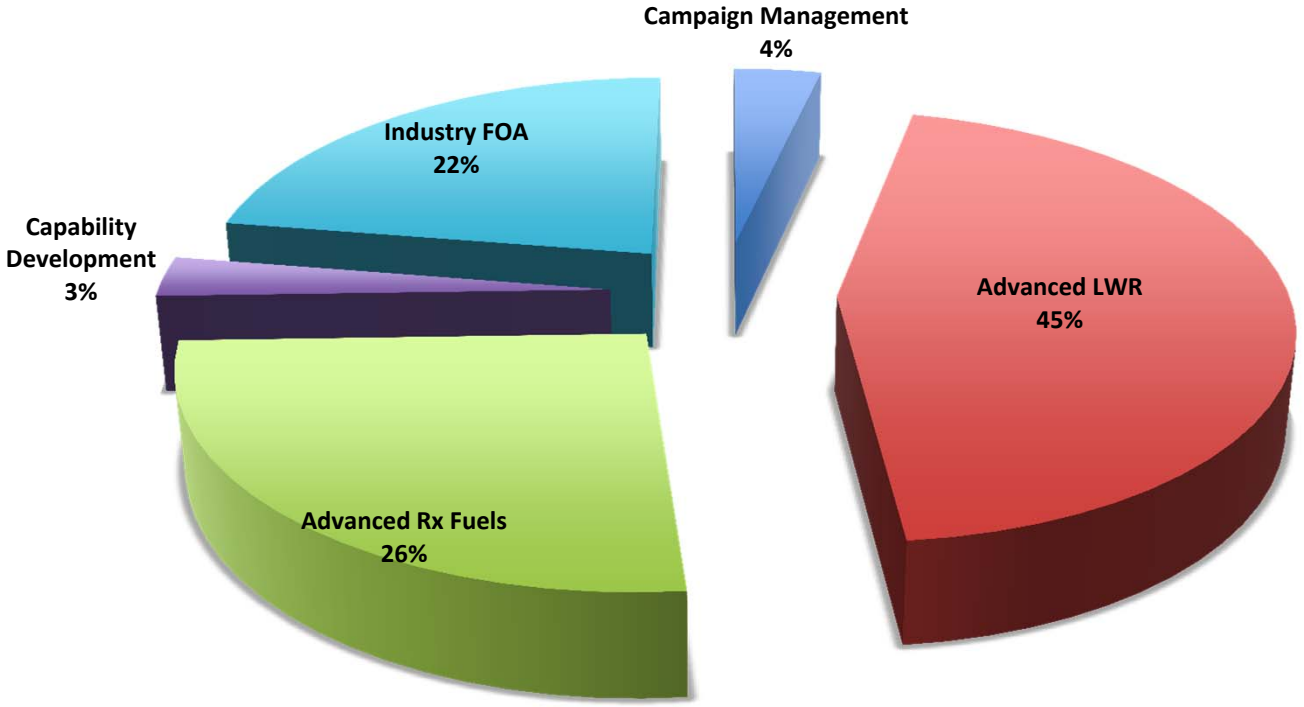
FY17 Budget



Total FY17 Operating ($56.9M) including FY16 CO

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Bilateral International Collaboration Includes Significant ATF Development

France
- *Advanced core materials*
- *Joint support of Halden collaborative irradiations*
- *Transient Testing*

European Union
- *Three general INERIs currently underway with JRC-ITU*

Japan
- *Definition of attributes and metrics*
- *Coordination of technology research and development*
- *Coordination of facilities used for R&D*

Russian Federation (currently on hold)
- ***Advanced LWR fuels and ATF***
- *Exchange of attributes and metrics*

China
- *Attributes and metrics*
- *Information exchange on R&D facilities*
- *Assessment of ATF Performance*
- *Collaborative testing opportunities*

UK
- *Active partners in ATF FOAs and IRPs*
- *Joint participation in ATF OECD/NEA*
- *Basic material properties of high density fuels*

Others
- *Canada bilateral under development*
- *OECD/NEA Expert Groups*
- *IAEA Expert Group on ATF*
- *Enlarged Halden Reactor Group*

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International Collaboration Includes Significant Advanced Reactor Fuels Development

France
- *FUTURIX-FTA, MI Irradiation and PIE*
- *Fuel Performance Code Comparison*
- *Joint AmBB irradiations in ATR*
- *Cladding materials*
- *Trilateral transient testing*

European Union
- *Three general INERIs currently underway with JRC-ITU*

South Korea (KAERI)
- *Metal fuel fabrication technology and irradiation performance through the JFCS*

Russian Federation (currently on hold)
- *Materials and fuels irradiation in BOR60*
- *Characterization and PIE methods*
- *In-pile instrumentation and testing*
- *Nitrides*

Japan
- *Metallic fuel*
- *Oxidation kinetics*

China
- *Materials and fuels irradiation in CFTR*
- *Metal fuel fundamental properties*

UK – (under development)
- *PIE technique development*
- *Characterization technique development*
- *Fuel performance modeling and simulation*

Others
- *OECD/NEA, IAEA, GIF-GENIV projects*

WJC1

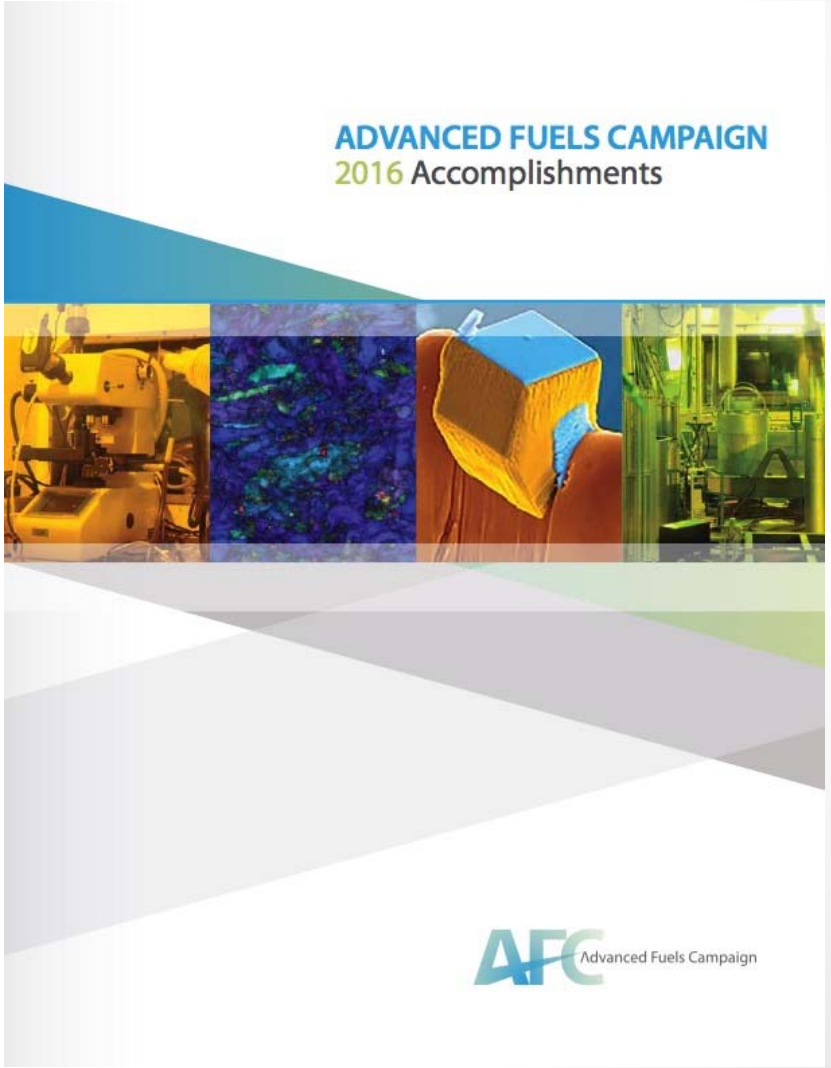
Summary

- Full 2016 Accomplishments Report at:

  https://nuclearfuel.inl.gov/

- Major Efforts for FY2017
  - Initiating ATF-2 Loop Irradiation
  - Rev 0 of Thermal/Fast Comparison
  - Establish handbooks with revision and update process

- Evolve



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Slide 14

WJC1 Update with new coversheet
Jon Carmack, 10/12/2015

Most documents coming available on OSTI

OSTI Document Links of Interest:

Overview of Accident Tolerant Fuel Program
http://www.osti.gov/scitech/servlets/purl/1130553

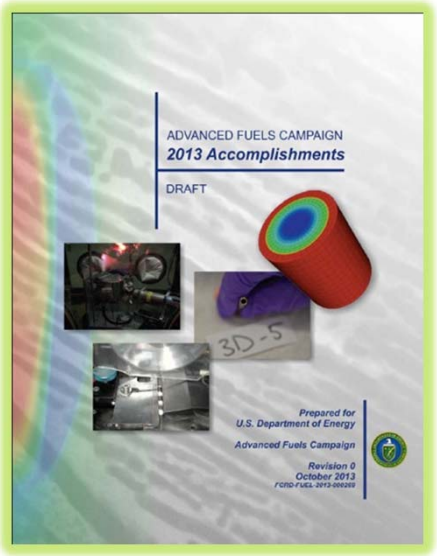
Accident Tolerant Fuel Performance Metrics
http://www.osti.gov/scitech/servlets/purl/1129113

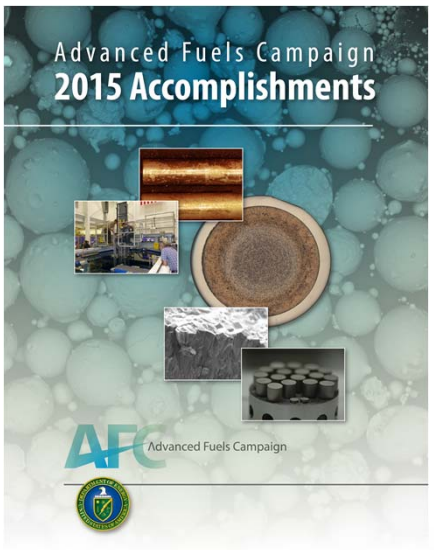
2013 Accomplishments Report
http://www.osti.gov/scitech/servlets/purl/1120800

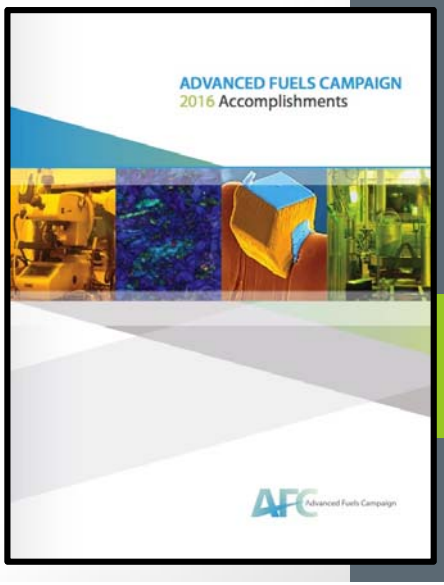
2014 Accomplishments Report
http://www.osti.gov/scitech/biblio/1169217

2015 Accomplishments Report
http://www.osti.gov/scitech/servlets/purl/1236849

2016 Accomplishments Report
Link in Dec 2016







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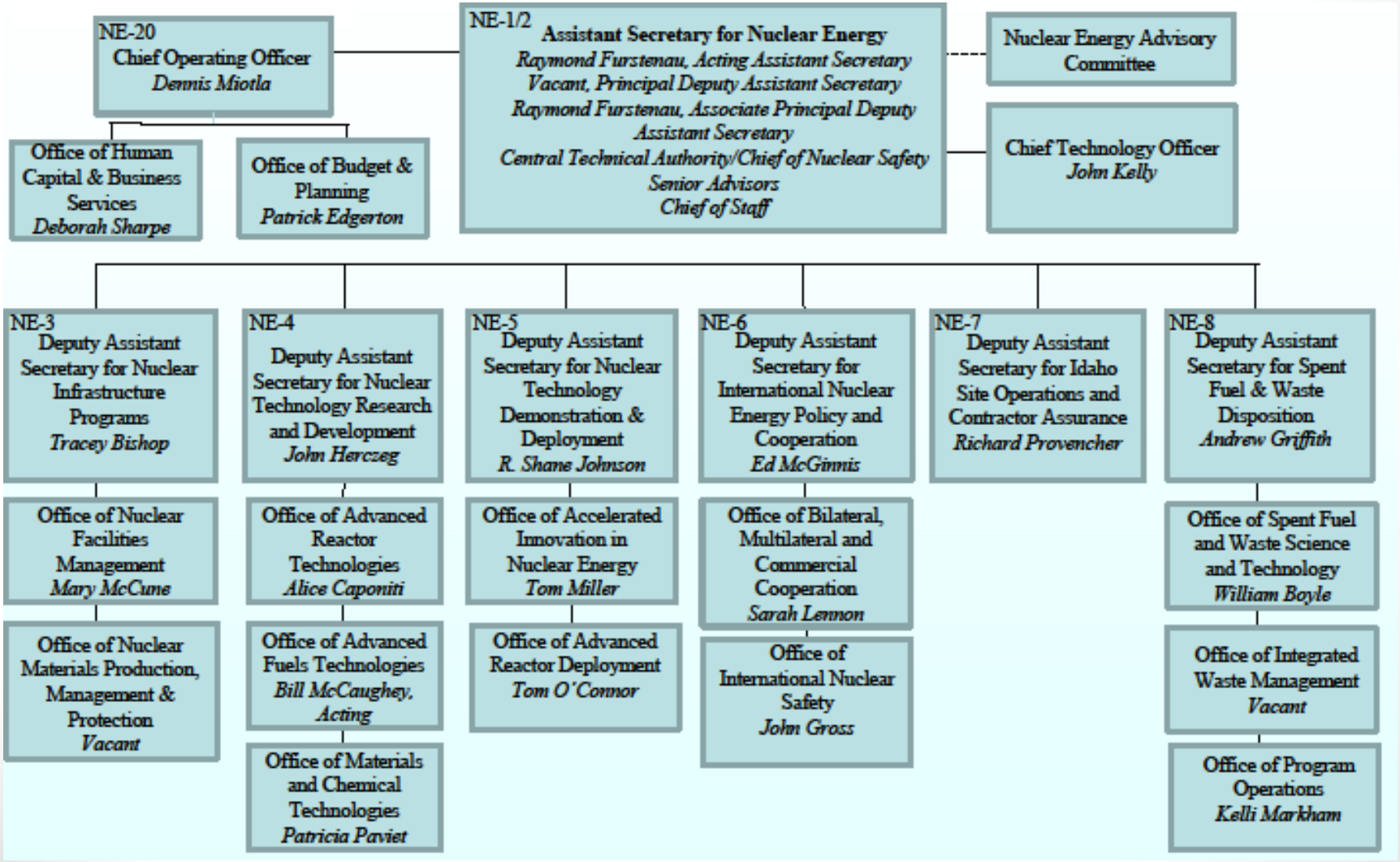
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Raymond Furstenau, Acting Assistant Secretary
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Central Technical Authority/Chief of Nuclear Safety
Senior Advisors
Chief of Staff
Nuclear Energy Advisory Committee
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R. Shane Johnson
Office of Accelerated Innovation in Nuclear Energy
Tom Miller
Office of Advanced Reactor Deployment
Tom O'Connor
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Ed McGinnis
Office of Bilateral, Multilateral and Commercial Cooperation
Sarah Lennon
Office of International Nuclear Safety
John Gross
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Richard Provencher
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Andrew Griffith
Office of Spent Fuel and Waste Science and Technology
William Boyle
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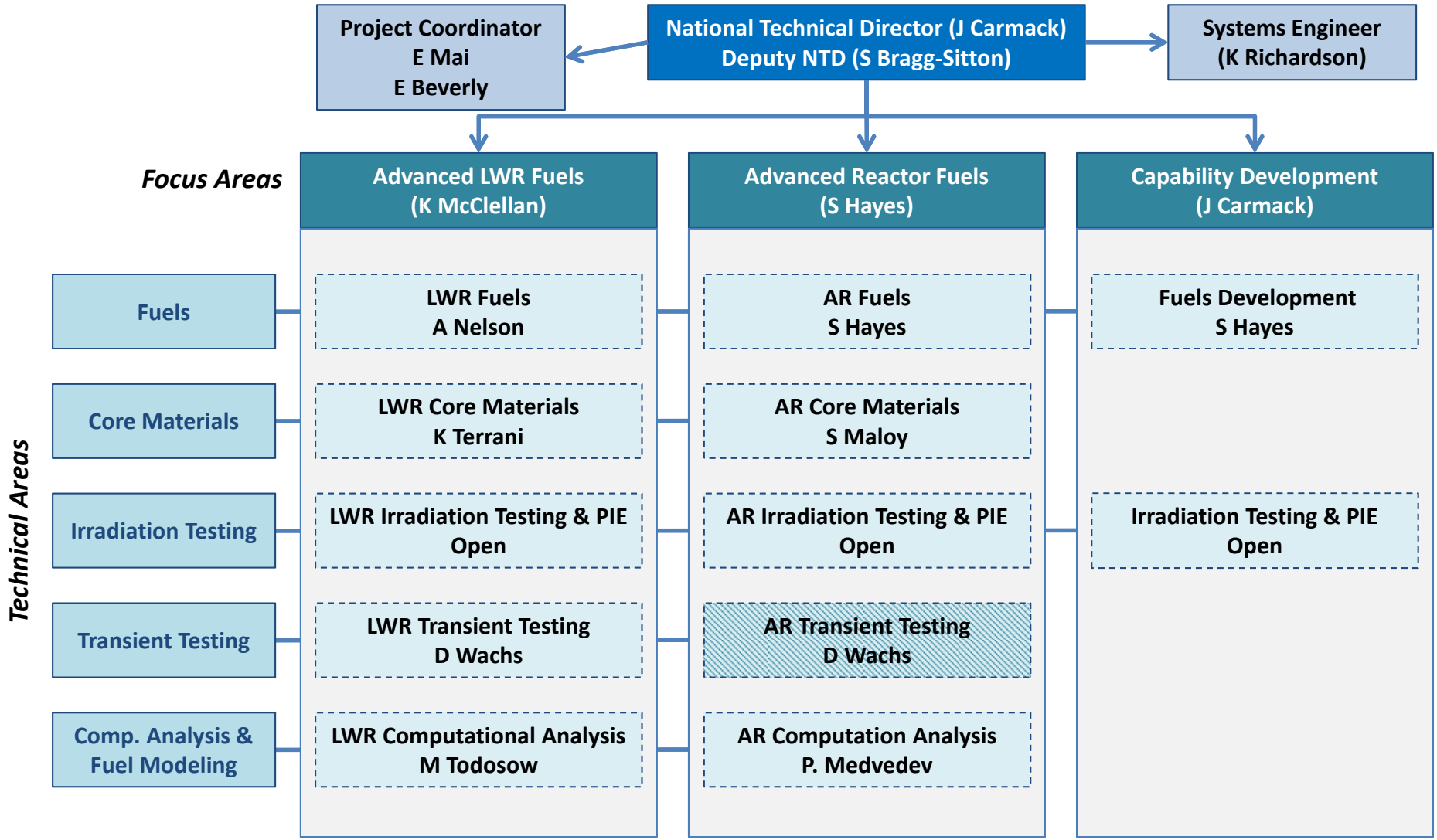

Integrating Industry and DOE Programs: Major Accomplishments and Impact

- Metallic Fuel
  - Established remote casting fabrication capability for KAERI CRADA.
  - Established new TerraPower proprietary fabrication line.
  - Irradiating and performing PIE on several TerraPower fuel experiments in ATR accelerating fuel qualification.
- Accident Tolerant Fuels
  - Currently irradiating LWR ATF fuel technologies for GE, Westinghouse, and AREVA in ATR.
  - Will initiate (late 2017) the first PWR condition loop irradiation in ATR for ATF vendor fuel technologies.
  - Currently working towards initiating transient testing in TREAT in FY18 to support all technology vendors.
  - Executing PIE on several ATF fuel specimen from ATR ATF-1.
  - Rapidly moving ATF towards 2022 LFA/LFR insertion.
- TRISO Fuel
  - Formal fuel qualification underway:
    - AGR-5/6/7 fuel particles and compacts have been fabricated.
    - Majority of AGR-5/6/7 test train components have been fabricated; awaiting fuel compacts to complete fab and load test train.
    - AGR-5/6/7 irradiation scheduled to start at the end of FY17 (194 UCO fuel compacts).
  - PIE on AGR-2 UCO and UO_2 fuel is approximately half complete. Confirms excellent performance of UCO fuel and demonstrates increased tendency for SiC degradation in UO_2 fuel at elevated temperatures.