# *Advanced Gas Reactor Fuels Program Review*

# *Overview of the Advanced Gas Reactor Fuel Development and Qualification Program*

**David Petti**

Director, VHTR Technology Development Office

**July 15-16, 2015**

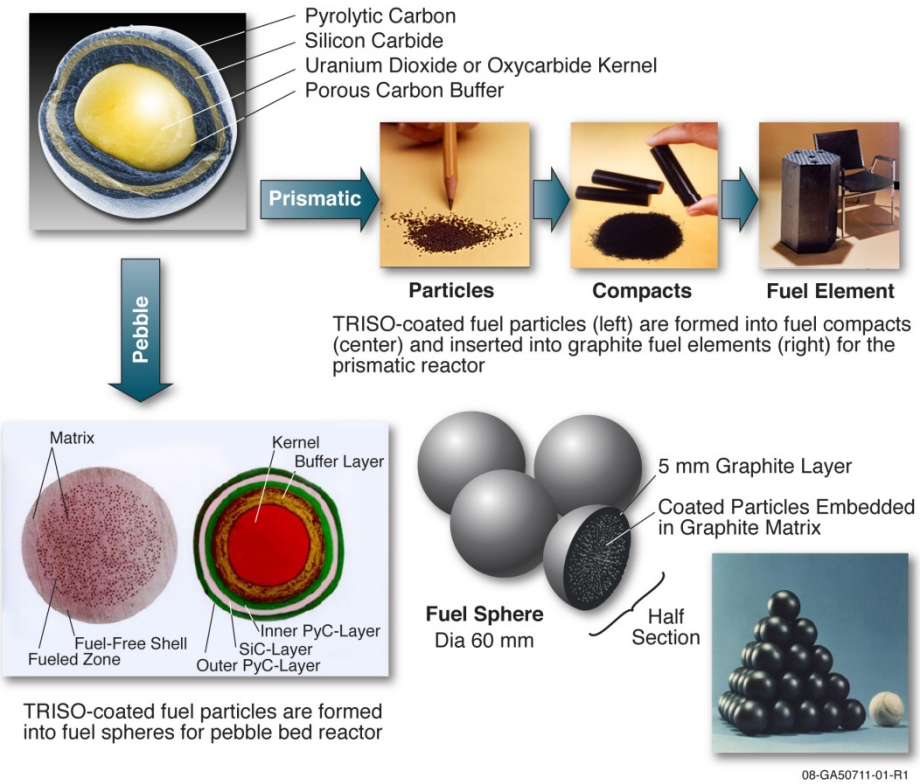
www.inl.gov

Idaho National Laboratory

# *TRISO-Coated Particle Fuel is at the Heart of the High Temperature Gas Reactor Concept*
## *(provides technical basis for co-location with industrial facilities)*

*Key aspects of TRISO Fuel:*

- *German industrial experience demonstrated TRISO -coated particle fuel can be fabricated to achieve high-quality levels with very low defects*
- *Fuel is very robust with no failures anticipated during irradiation and under accident conditions*
- *Fuel form retains fission products resulting in a high degree of safety*



# *HTGRs have Multiple Barriers to Radionuclide Release that Comprise the "Functional Containment"*

- Functional Containment is the collection of design selections that, taken together, ensure that:
  - Radionuclides are retained within multiple barriers, with emphasis on retention at their source in the fuel
  - Regulatory requirements and plant design goals for release of radionuclides are met at the Exclusion Area Boundary

- Fuel Kernel
- Fuel Particle Coatings
- Matrix/Graphite

} Fuel Element

- Helium Pressure Boundary
- Reactor Building

# *TRISO Fuel is at the heart of the safety case for modular HTGRs*

- Fabrication of high-quality low-defect fuel is achievable at industrial scale
  - Defect fractions on the order of $10^{-5}$
  - Process produces narrow distributions of fuel attributes (standard deviation of thicknesses and densities are small)
  - Process is stable and repeatable at industrial scale (batch to batch variation is very small)

→ Results in low activity of fission products in helium coolant

For the small level of defective particles, significant retention in fuel kernel, fuel matrix and graphite

- Robust irradiation performance inside design service envelope
  - Designer assumes incremental failure fraction of $2 \times 10^{-4}$
  - Performance is better than designer assumption

→ Results in low incremental release of fission products to the helium coolants

Significant retention of metallic fission products in graphite and fuel matrix

- Robust accident performance inside design service envelope
  - Designer assumes incremental failure fraction of $6 \times 10^{-4}$
  - Performance is better than designer assumption

→ Results in low incremental release of fission products under accident conditions

**Low Source Term**

# Objectives

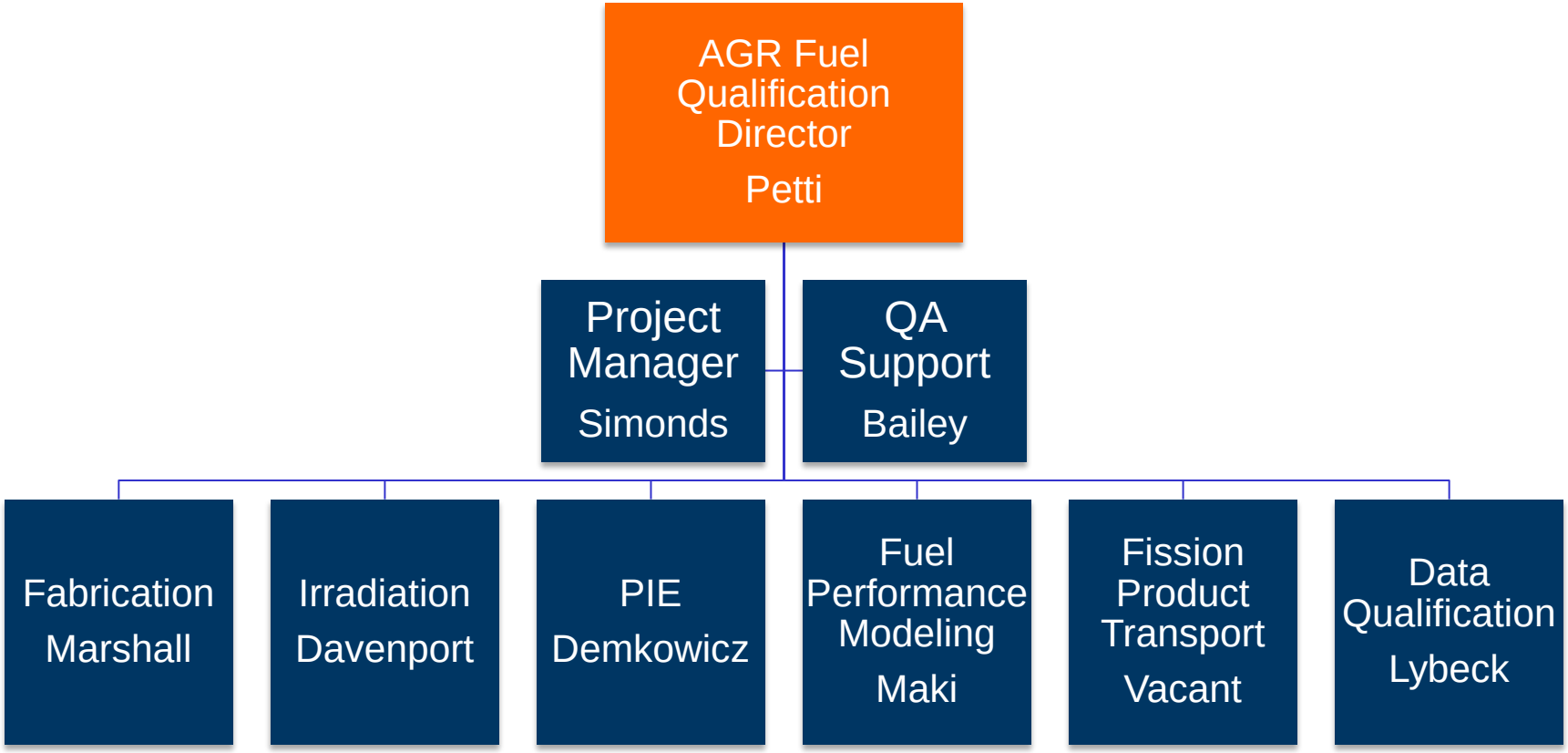
- Provide a fuel qualification data set in support of the licensing and operation of an HTGR
  - HTGR fuel performance demonstration and qualification comprise the longest duration research and development (R&D) task required for design and licensing
  - The fuel form is to be demonstrated and qualified for service conditions enveloping normal operation and potential accident scenarios
- Support deployment of the HTGR for hydrogen, process heat, and energy production in the United States by reducing market entry risks posed by technical uncertainties associated with fuel production and qualification
- Extend the value of DOE resources by using international collaboration mechanisms

# Program Plan

- Developed at start of the program
- Complete listing of activities necessary to qualify UCO TRISO fuel for use in modular HTGRs
- Full life-cycle cost and schedule used to guide program's financial needs and establish key milestones
- Updated annually to account for any new scope or changes based on R&D done to date

# Approach

- WBS established to coincide with key technical activities in the program not with each “campaign”

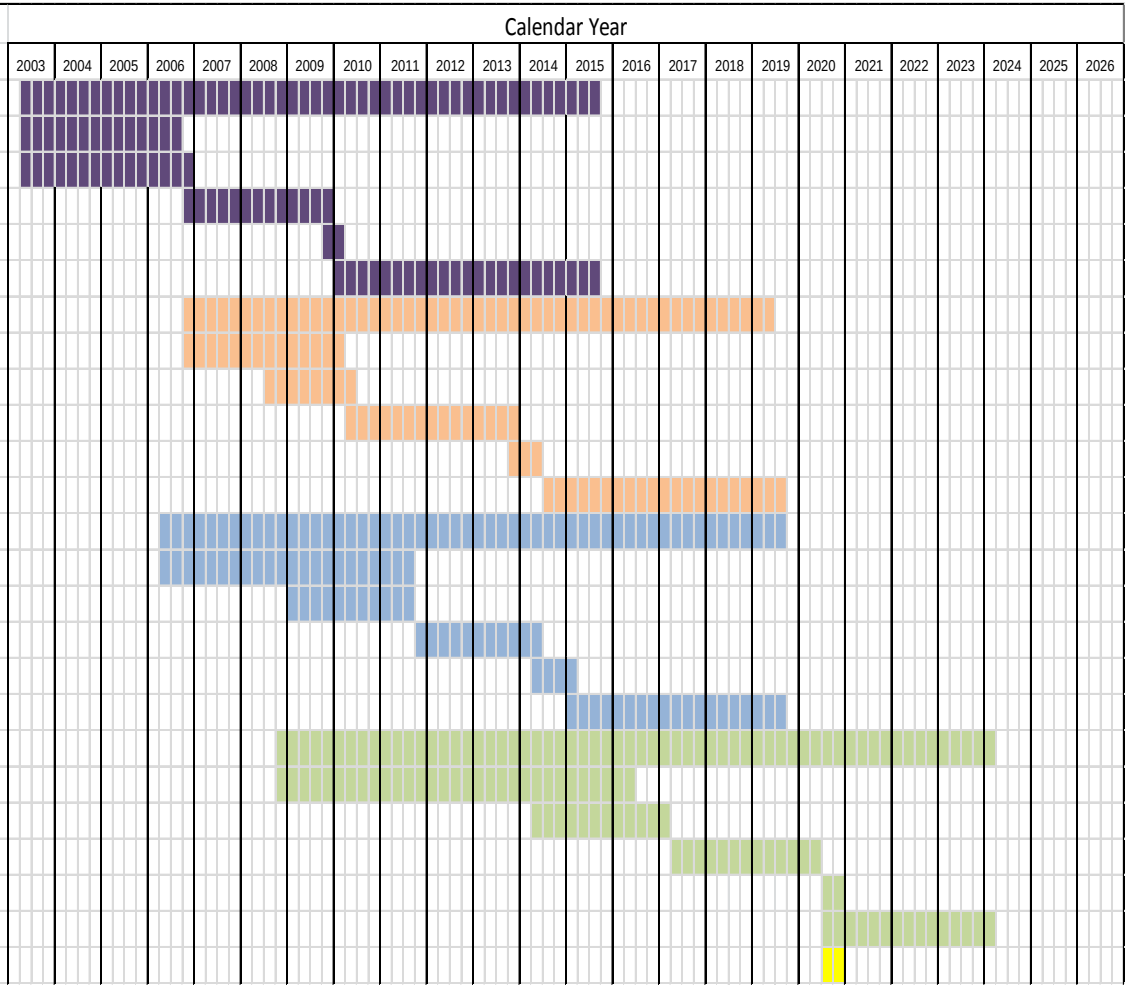


# History

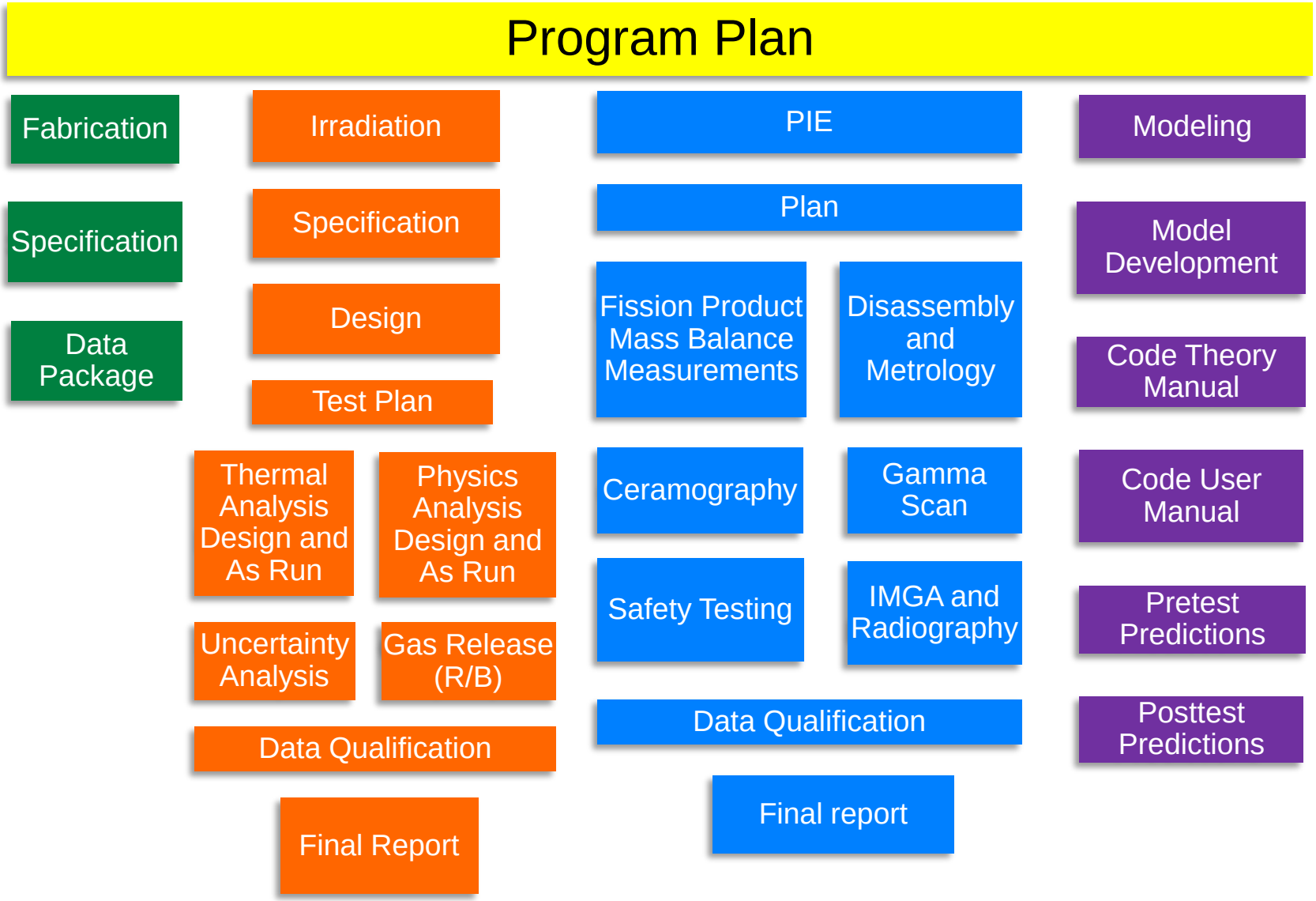
- Started in Summer 2002
- Initial plan developed in 2003
- Early days (2003-2006)
  - Re-establish fabrication capability
  - Fabrication studies
  - AGR-1 capsule design, assembly and insertion
- Recent past (2006-2009)
  - AGR-1 irradiation
  - Scale up coating
  - AGR-2 coated particle fuel fabrication
  - Fuel acquisition strategy for NGNP project
- Past four years 2010-2014
  - AGR-1 PIE
  - AGR-2 Irradiation
  - AGR-3/4 fuel fabrication (designed-to-fail fuel)
  - AGR-3/4 Irradiation
  - Compacting scaleup
  - Preparations for AGR-2 and AGR-3/4 PIE
  - Fuel fabrication for qualification fuel (AGR-5/6/7)
  - Pre-conceptual design of AGR-5/6/7 capsule

# Schedule

| Fuel Development and Qualification | | |
|---|---|---|
| **Activity** | **Start** | **Finish** |
| **AGR-1 - Shakedown Small Coater Fuel** | **5/1/2003** | **9/12/2015** |
| AGR-1 Fuel Fabrication | 5/1/2003 | 9/29/2006 |
| AGR-1 Design and Assembly | 5/1/2003 | 12/22/2006 |
| AGR-1 Irradiation (Large B) | 12/25/2006 | 11/6/2009 |
| AGR-1 Test Train Cooldown | 11/7/2009 | 2/28/2010 |
| AGR-1 PIE and Safety Testing | 3/1/2010 | 9/12/2015 |
| **AGR-2 Production Scale Coater Development** | **12/2/2006** | **7/20/2019** |
| AGR-2 Fuel Fabrication | 10/2/2006 | 4/9/2010 |
| AGR-2 Design and Assembly | 5/5/2008 | 6/11/2010 |
| AGR-2 Irradiation (Large B) | 6/23/2010 | 10/16/2013 |
| AGR-2 Train Cooldown | 10/17/2013 | 7/10/2014 |
| AGR-2 PIE and Safety Testing | 7/14/2014 | 7/27/2019 |
| **AGR-3/4 Fission Product Transport Data** | **5/8/2006** | **8/20/2019** |
| AGR-3/4 Fuel Fabrication | 5/3/2006 | 9/28/2011 |
| AGR-3/4 Design and Assembly | 3/2/2009 | 9/30/2011 |
| AGR-3/4 Irradiation (NEFT) | 12/14/2011 | 4/7/2014 |
| AGR-3/4 Train Cooldown | 4/7/2014 | 3/18/2015 |
| AGR-3/4 PIE and Safety Testing | 3/18/2015 | 8/20/2019 |
| **AGR-5/6/7 Fuel Qualification** | **10/1/2008** | **3/26/2024** |
| AGR-5/6/7 Fuel Fabrication | 10/1/2008 | 6/30/2016 |
| AGR-5/6/7 Design and Assembly | 5/1/2014 | 4/15/2017 |
| AGR-5/6/7 Irradiation (NEFT) | 6/27/2017 | 7/1/2020 |
| AGR-5/6/7 Test Train Cooldown | 7/18/2020 | 10/31/2020 |
| AGR-5/6/7 PIE and Safety Testing | 11/1/2023 | 3/26/2024 |
| **ATR Core Internals Changeout (no irradiation)** | **7/2/2020** | **12/31/2020** |



# Documentation Tree



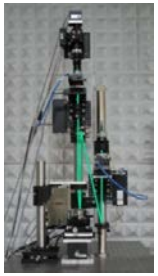
# *Scientific Publications*

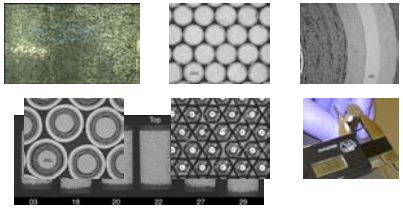
- Significant number of publications in archival literature
  - Approximately 100 conference papers, journal articles and book chapters
- Strong support of bi-annual HTR conference (fuel session is always largest and strong presence from US)
- Have a presence at other conferences (ICAPP, ANS NF&SM, TMS, PHYSOR)

# International Collaborations

- Currently focused through Gen-IV Fuel and Fuel Cycle Project Management Board
  - Share information in all areas but fuel fabrication
  - Current work focused on QC round-robin, fuel performance code benchmark, sharing know-how on furnace design and operation, and sharing results of irradiation, PIE and safety testing
  - Previous collaborations included broad QC round robin, extensive fuel performance code benchmarking, and sharing know-how on irradiation testing and PIE techniques
  - Host an international SiC workshop every two years for detailed information exchange. Meeting in Korea this past September
- Have had I-NERIs in the past with France and Japan. In future may have one with Dutch through EU if they can get funding but looks unlikely now

# NGNP/AGR TRISO Fuel Qualification Program





## Fuel Fabrication

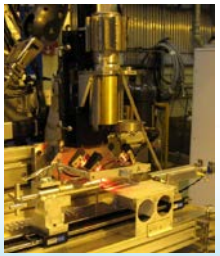
Individual capsule assembly with fuel compacts

Completed test train

## Irradiations

Insertion into INL ATR

FPMS system

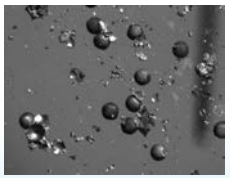


AGR-1 Disassembly

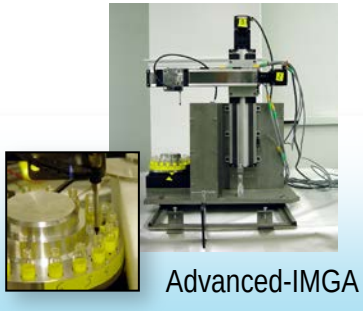
ORNL Furnace

INL Furnace

## Post-irradiation Examination and Safety Testing

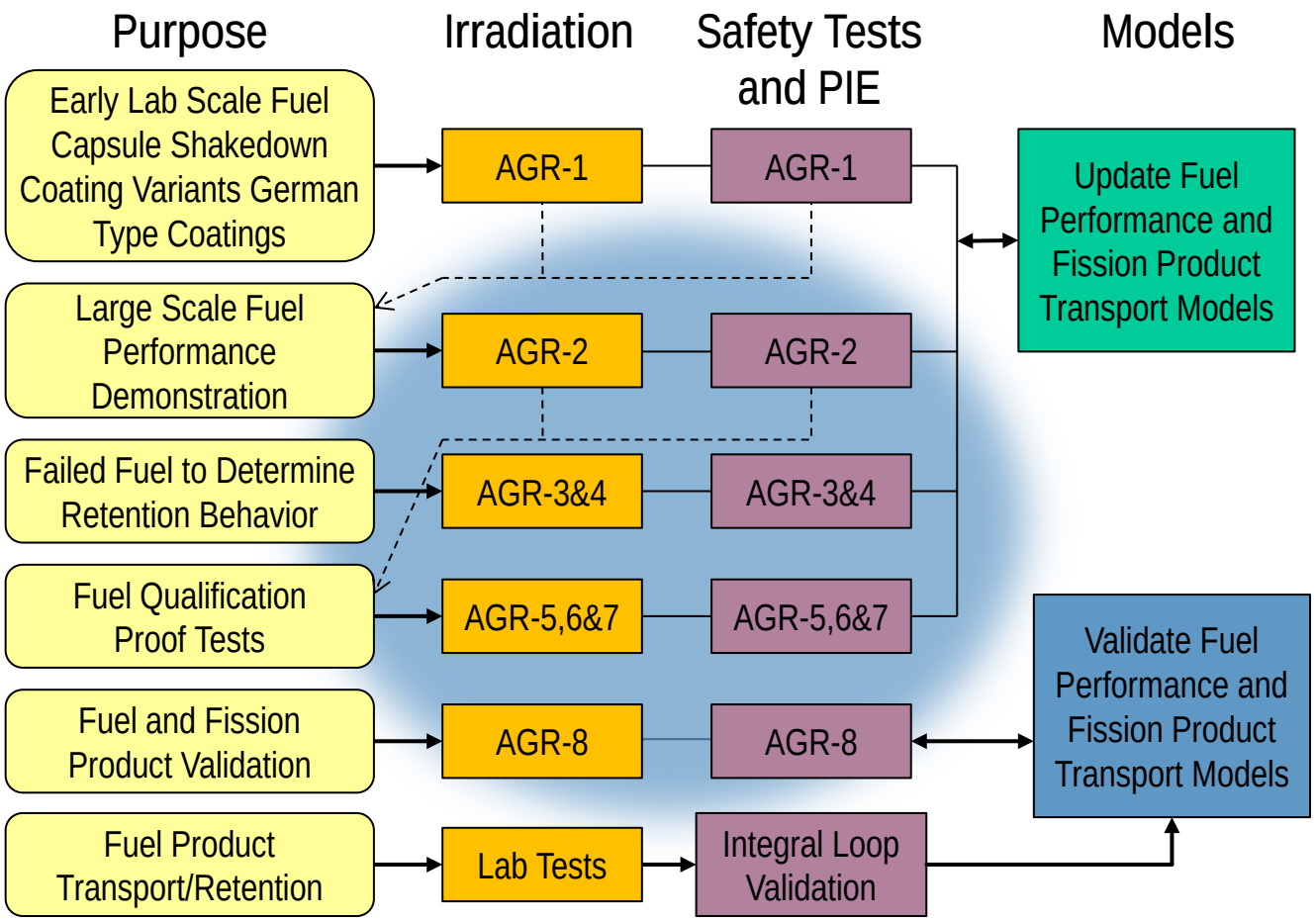


Deconsolidated AGR-1 particles



Advanced-IMGA

# Overview of AGR Program Activities




Moisture and air ingress effects are part of AGR-5/6 PIE

# Fuel Fabrication Campaigns

| | AGR-1 | AGR-2 | AGR-5/6 |
|---|---|---|---|
| Kernels | Engineering scale | Engineering scale | Engineering scale |
| Coatings | Lab scale | Engineering scale | Engineering scale |
| Compacting | Lab scale | Lab scale | Engineering scale |

# *What you will hear today...*

- AGR-1
  - PIE wrap up
  - AGR-1 advanced microscopy
- AGR-2
  - Quick overview of experiment
  - Irradiation summary
  - Uncertainty analysis
  - PARFUME safety test predictions
  - Status of PIE
    - Disassembly and Metrology
    - Gamma scanning
    - Heating test results
    - Path forward
- AGR-3/4
  - Quick overview of experiment
  - Irradiation summary
  - Status of disassembly
  - Graphite matrix ring plans
  - Plans for future
- AGR-5/6/7
  - Fuel fabrication status
  - Test Train Design status

# *Fuel Future Activities (next 4 years)*

- Complete PIE and safety testing of AGR-2 industrially produced TRISO particles
- Complete PIE and safety testing of AGR-3/4
  - This fuel contains designed to fail particles and provides crucial information about fission product release from failed/defective UCO TRISO fuel which is needed to support VHTR source term analysis
- Complete fabrication of final qualification fuel at B&W for AGR-5/6/7 campaign
- Complete design of AGR-5/6/7 irradiation test train and initiate irradiation of qualification fuel
- Beyond 2018, complete AGR-5/6/7 irradiation, complete PIE and safety testing including moisture and air ingress effects