LA-UR-13-24242
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Title: Rapid Light Water Reactor modeling for MCNP and Associated Boiling Water Reactor Library

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Intended for: American Nuclear Society 2013 Annual Meeting, 2013-06-16/2013-06-20 (Atlanta, Georgia, United States)

Issued: 2013-06-11

Rapid Light Water Reactor Modeling for MCNP and Associated Boiling Water Reactor Library

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2013 ANS Annual Meeting
"Nuclear Science and Technology – Next Generation Nuclear Energy: Prospects and Challenges"
Atlanta, GA
June 16-20 2013

Outline

- **Rapid Light Water Reactor Modeling for MCNP using LWRgen**
  - Quickly generates MCNP input deck for a reactor core with fresh fuel
  - Built in templates for Pressurized and Boiling Water Reactors (PWR/BWR), and BWR with water wings
  - Core reflectivity options for reducing memory requirements and simulation time
- **Next Generation Safeguards Initiative (NGSI) Spent Fuel Library 5**

Creating LWRGen

- **Tools Flex and Bison used for scanning and parsing the generation file**
  - Steamline the reading and processing of input files
  - Flex scans the input performing lexical analysis (what was read)
  - Bison parses the input performing semantic analysis (what did it mean)
  - Industry standard programs with over 30 years of use
  - Allows for relatively easy customization of format for generation file
  - Algebraic expressions can be used so that hand calculations are not needed
- **Written in C++ using Object Oriented Programming**
  - Naming conventions can be kept, which make updating or customizing relatively easy
  - Entire core geometry is quickly built within LWRGen

Generating the Core

- **Keyword option for selecting between PWR or BWR with/without water wings**
- **Variable assembly size with options for placement of fuel rods versus guide tubes**
- **Variable core size**
- **Reflectivity options for 1/8th, 1/4th, Full Core or a single assembly with reflective boundaries**
- **Temperature specifications for fuel, cladding, and moderator**

Additional options for BWR cores

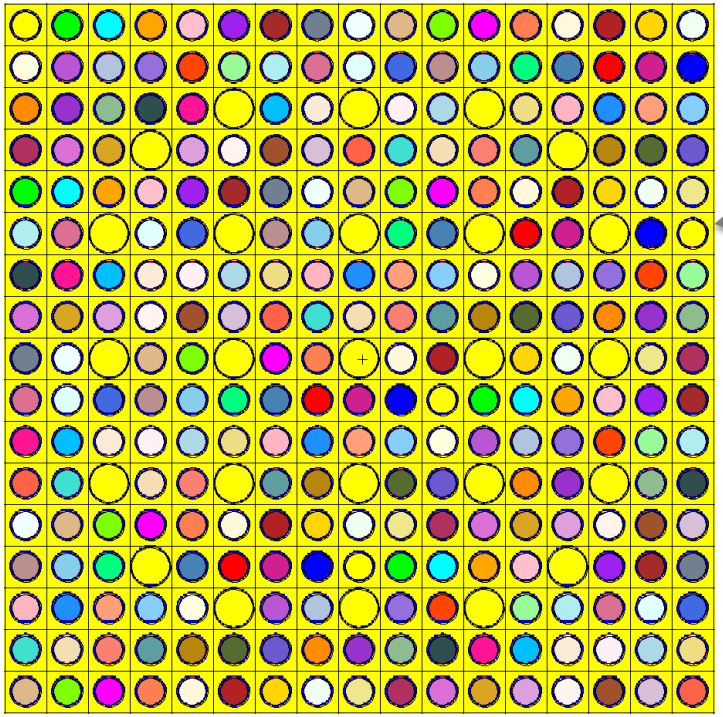
- Axial moderator zoning for changes in density with height
- Box parameters for specifying geometry of fuel channels
- Water wing parameters for specifying geometry of wings and channel
- Parameters for determining control blades details

Pin Options

- **Options for specifying density and enrichment of fresh fuel**
- **Axial and radial zoning that generate unique materials in fuel rods for higher fidelity simulations and burnup calculations**
- **Parameters for height and radius of pin, gap, and cladding as well as pin pitch**

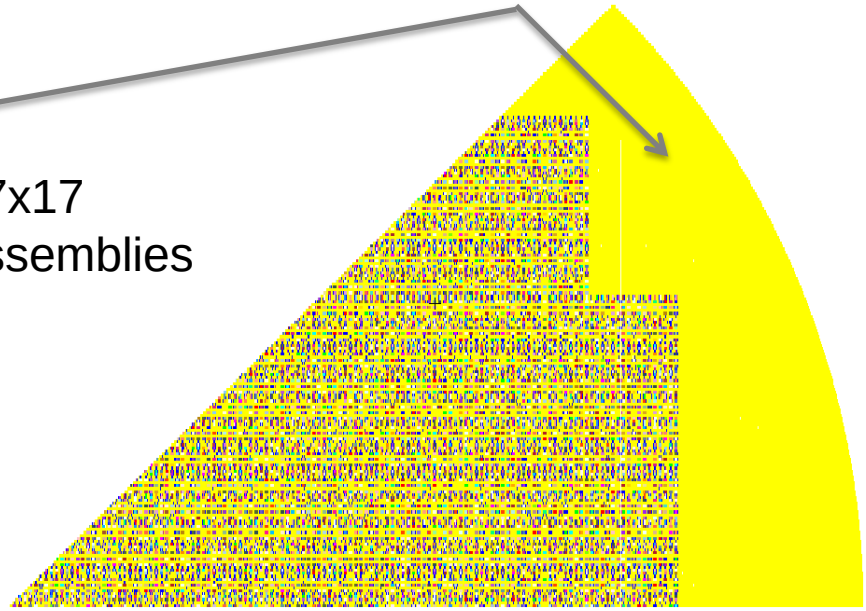
Surfaces, Materials, and Plot for 17x17 assemblies in 1/8th core

17x17 assembly showing replaced guide tubes



Water regions colored yellow

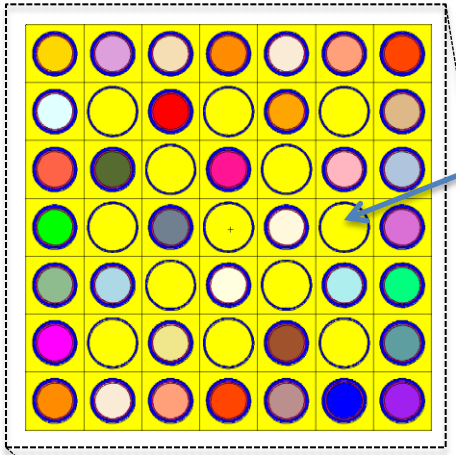
17x17 assemblies



Plots for 7x7 assemblies

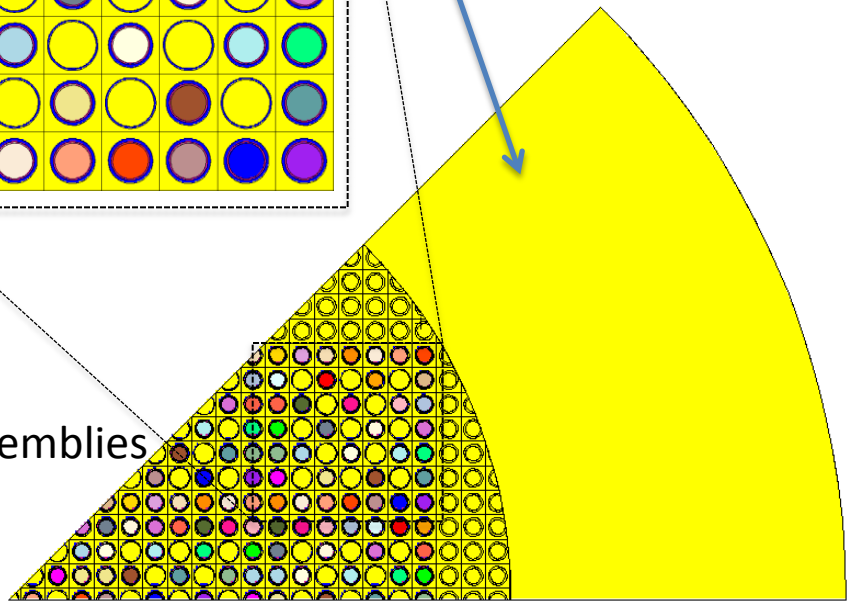
6 axial zones per pin with unique materials for each

7x7 assembly showing replaced guide tubes

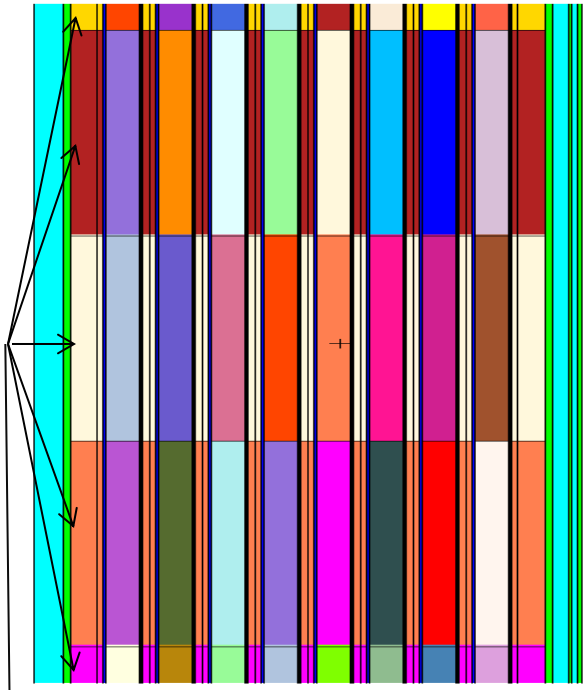


Water regions colored yellow

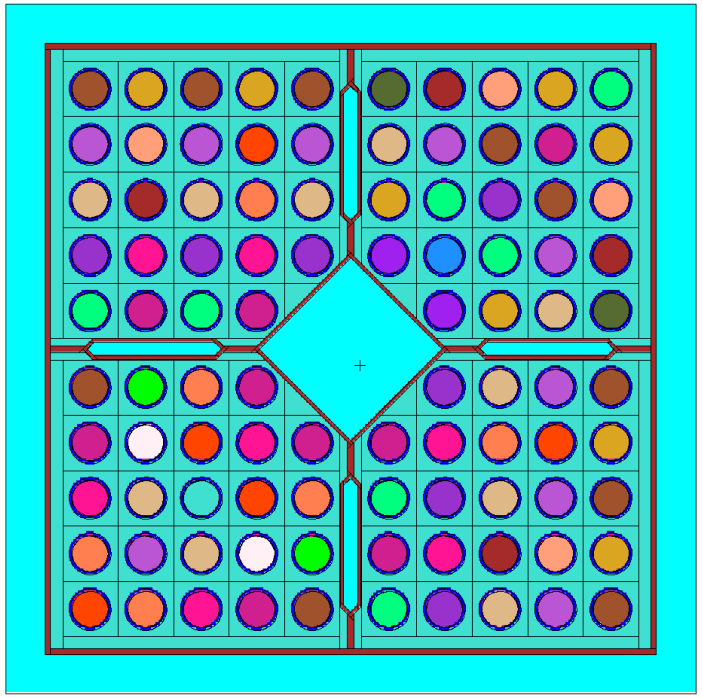
7x7 assemblies



Added BWR Features



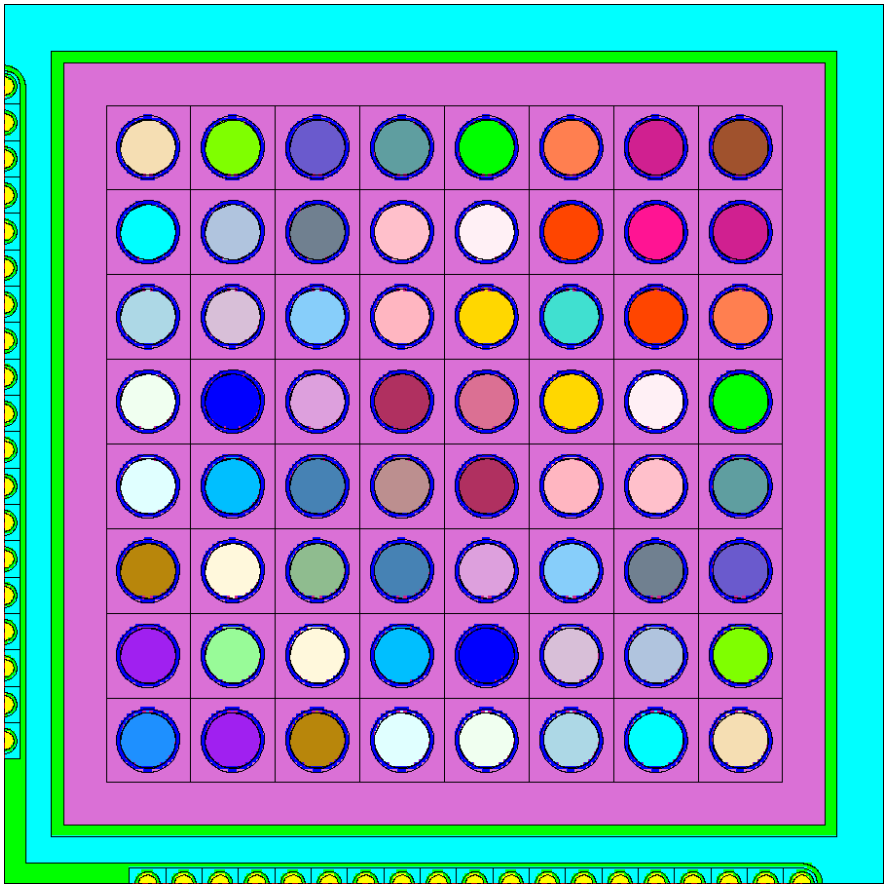
Axially Zoned moderator densities



Water wings and water channel added with option for replacing removed pins with moderator (used in Spent Fuel Library 5)

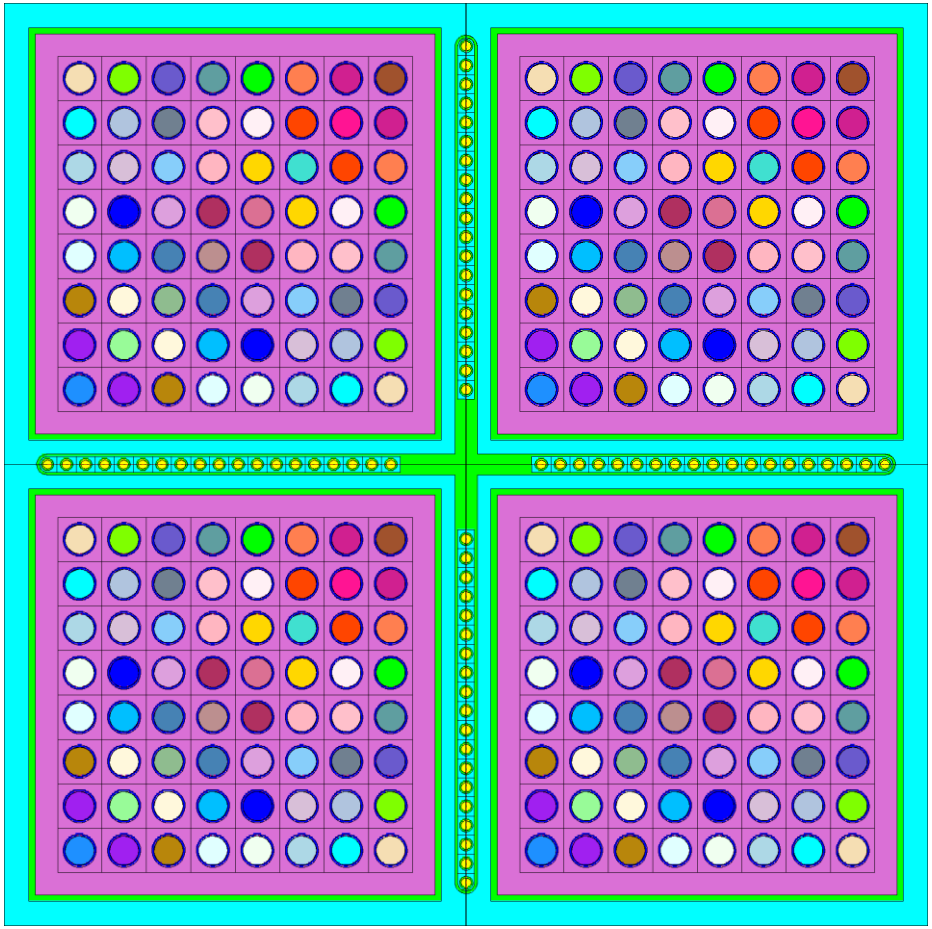
Added BWR Features: Control Blades

- **Sizing Parameters**
  - Custom heights
  - Variable number of pins within blade
  - Size and Pitch of pin
  - Offset for determining extent of blade



BWR: Complete blade

- 4 Quadrants form a complete blade
- Allows for non-symmetric and reflective bounds modeling



More to come!

- **Axial enrichment mapping**
  - Simple customization for placing guide tubes, burnable poison rods, and varying enrichment of pins
  - Create multiple assemblies for cores with different assemblies configurations
  - Combine enrichment maps for creating assemblies that vary in height:
    - Pins with enrichment that changes with height
    - Partial length pins
    - Pins with burnable poison sections
- **Control blade mapping**
  - Multiple control blade heights
  - Custom placement of control blades within the core

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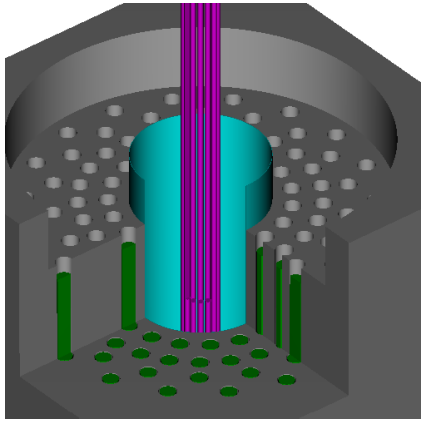
  - Quickly generates MCNP input deck for a reactor core with fresh fuel
  - Built in templates for Pressurized and Boiling Water Reactors (PWR/BWR), and BWR with water wings
  - Core reflectivity options for reducing memory requirements and simulation time
- **Next Generation Safeguards Initiative (NGSI) Spent Fuel Library 5**
  - Used LWRGen to quickly generate assembly models
  - Predict mass and detect division of Plutonium from spent fuel
  - 192 Assembly variations based on SVEA-96 BWR assemblies

Next Generation of Safeguards Initiative Spent Fuel Project



- **Goals are to quantify capability of NDA techniques to:**
  - Measure Pu mass
  - Detect partial defects/diversion (“completeness”)
  - Determine “correctness” of declaration (initial enrichment, burnup, cooling time)
- **Many Non-Destructive Assay (NDA) techniques exist**
  - No single NDA technique can, in isolation, provide everything
  - Passive gamma and neutron are existing technologies
  - Several new instruments are additionally being built and tested
- **Instrumentation is designed using MCNP simulations of representative fuel assemblies**
  - Several Spent Fuel Libraries (SFLs) 1-4 were created in the past for PWRs
  - LWRGen was used to create libraries for a BWR (SFL5)

Spent Fuel Library 5 assembly features

- **Initial Enrichments of 2.0%, 2.5%, and 3.0% averaged over assemblies**
  - Model based on SVEA-96 assemblies, allowing for further verification and validation of safeguards initiatives
- **Burnup values of 12, 24, 36, and 48 GWd/tU**
  - 30 day power down periods between cycles with slow startups for Xenon buildup
  - Average assembly power of 4.5 MW
- **Cooling Times of 0d, 14d, 1y, 5y, 20y, 40y, 50y, and 80y**
  - Predicts isotopic concentrations at time of fuel removal and up to 80 years afterwards
- **Burned with and without Control Blades for bounding conditions**
- **3 IE * 4 BU * 8 CT * 2 Blade Settings = 192 BWR Assembly variations**

Spent Fuel Library 5 pin features

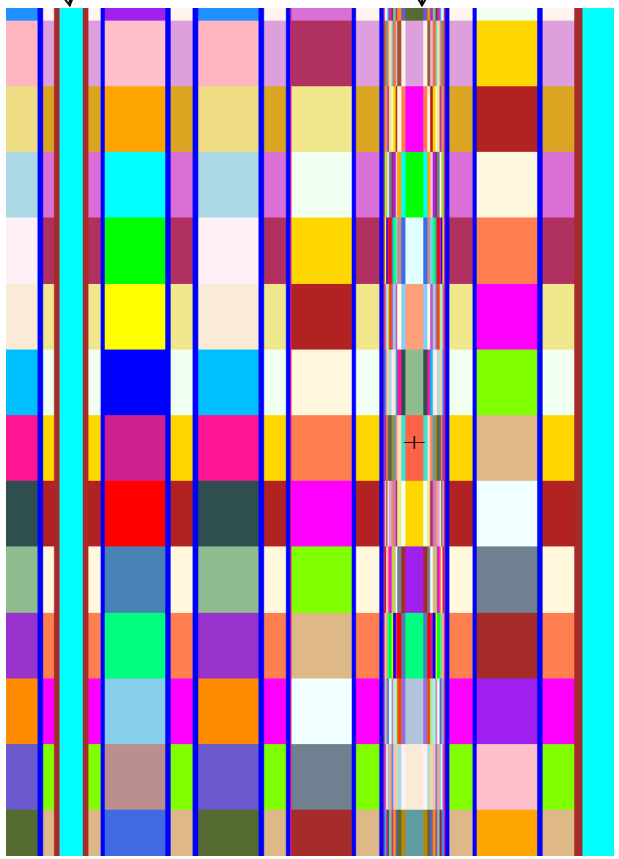
- **Fuel pins burned with 25 axial regions for high fidelity**
  - 25 axial moderator regions to simulate changes in moderator density with height
  - Burnable Poison Gadolinium pins burned with 10 equivolume radial zones
  - 2155 unique fuel materials used in burnup calculations
  - Monte Carlo burnup code *Monteburns* used to link MCNP and isotope generation and depletion code CINDER90

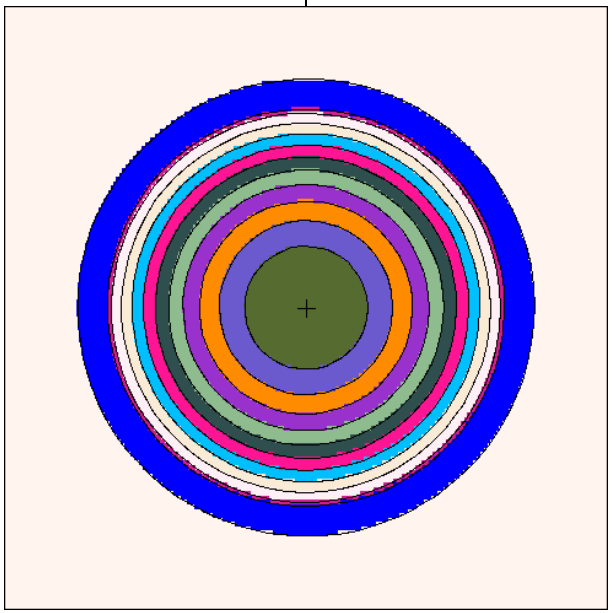
Spent Fuel Library 5 available variations

- **Library available in 4 flavors of MCNP input files:**
  - Full assembly models including 10 radially segmented BP regions
  - Full assembly models with smeared BP regions to reduce the number of fuel materials to 1325
  - Partial assembly models with smeared BP regions and 5 axial zones centered in the middle of the central zone for simulating instruments sensitive to < 75cm height (265 materials)
  - Partial assembly models with smeared BP regions and 2 axial zones centered between the two for simulating instruments sensitive to < 30cm height (106 materials)

Spent Fuel Library 5 Plots

Water wing





Vertical slice of water wing assembly with BP regions

10 equivolume regions of Gd fuel pin surrounded by gap

Conclusion

- **LWRGen allows for rapid modeling of single assembly and full core models of both Pressurized and Boiling Water Reactors**
  - Generation input file can be created in a matter of minutes and the model generated immediately vs. days creating the model by hand
  - Variations can be created with very little effort
  - For more complex geometries a base file can quickly be created and then modified to add in additional features
  - Flex/Bison and C/C++ allow for relatively simple modifications and customizations
  - Code and Documentation ready by Fall 2013 (available for distribution soon after)

Conclusion

- **Spent Fuel Library 5 expands NGSI Libraries to include BWRs**
  - High Fidelity burnup simulations accurately model radial and axial variations in fuel pins
  - 192 different assemblies allow for interpolation between data points and classifying assemblies that have been sitting in spent fuel pools
  - Can be used to verify operator history and detect diversion of SNM

Acknowledgements

The authors would like to acknowledge the support of the Swedish Nuclear Fuel and Waste Management Company (SKB), Professor Jasmina Vujic and the Berkeley Nuclear Research Center (BNRC), Next Generation Safeguards Initiative (NGSI), Office of Nonproliferation and International Security (NIS), and the National Nuclear Security Administration (NNSA).