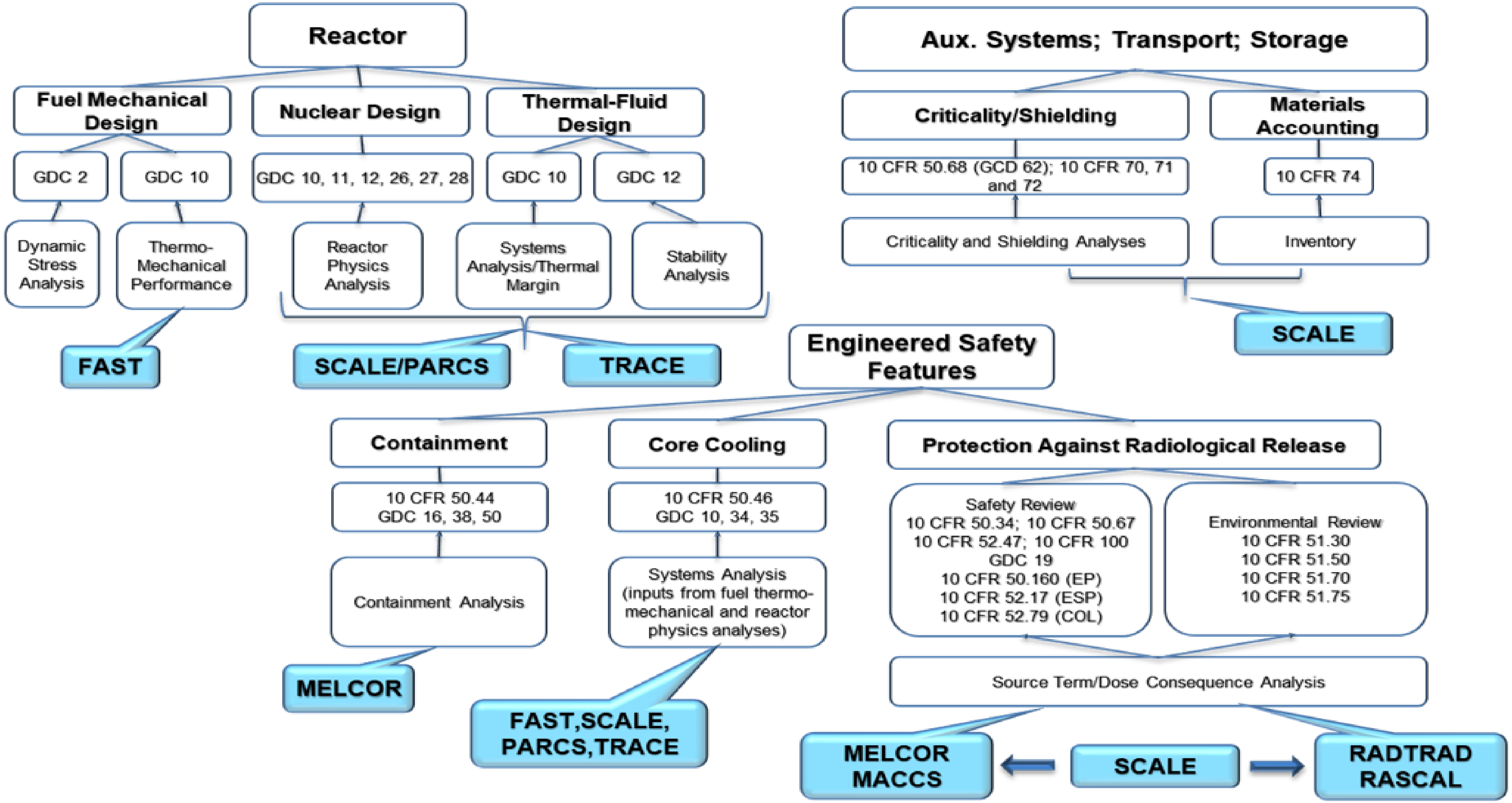
NRC Regulatory Applications with SCALE

2024 SCALE's Users Group
June 5th 2024

Lucas Kyriazidis
Office of Nuclear Regulatory Research
Division of Systems Analysis
Fuels & Source Term Code Development

NRC's Simulation Codes in the Regulatory Framework

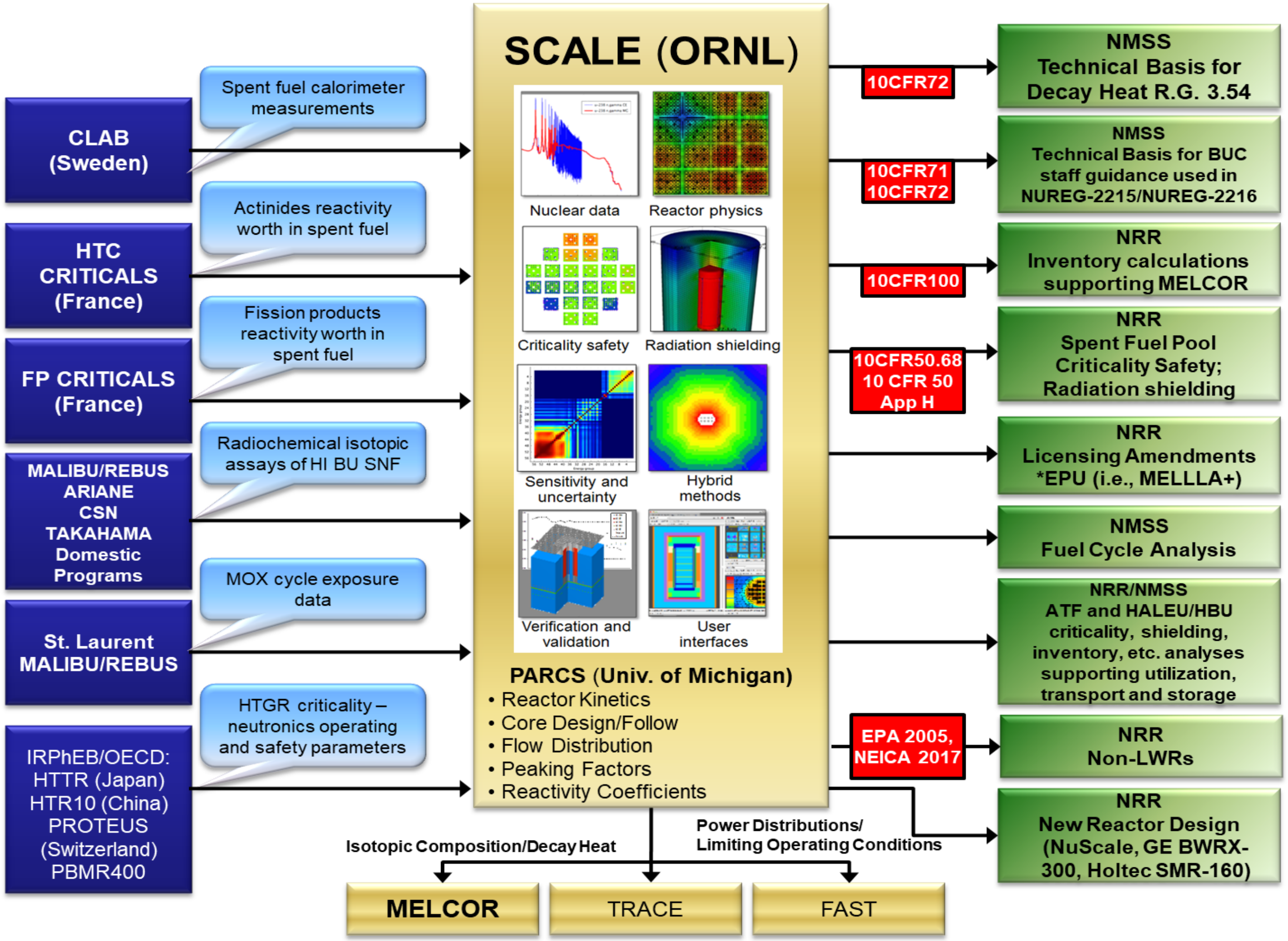


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SCALE Development & Validation

- SCALE supports licensing activities in both the Offices of Nuclear Regulatory Regulation (NRR) & Nuclear Materials Safety and Safeguards (NMSS)
  - Spent fuel pool criticality
  - Generating nuclear physics and decay heat parameters for design basis accident analysis
  - Review of consolidated interim storage facilities
  - Burnup credit analyses

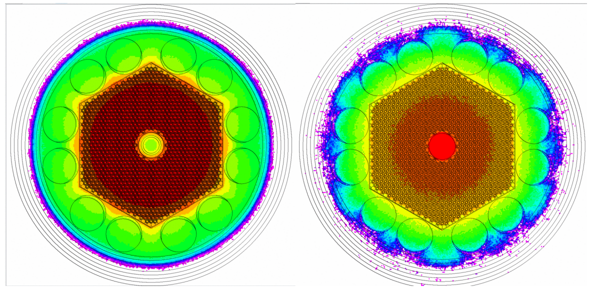
NRC participates in multi-lateral experimental programs to validate and assess our computer codes. Recently, NRC has joined Studsvik's LAGER program aimed at producing radiochemical isotopic assay data of gadolinia doped fuel rods.



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SCALE Code Development Activities & Priorities

- NRC actively supports development of SCALE & PARCS, focused around several key areas
  1) Expanding current code capabilities
  2) Assessing current and new LWR & non-LWR concepts
  3) Expanding SCALE's validation & assessment suite
  4) Training & improving the users' experience



Heat Pipe Reactor SCALE Model from NRC's Source Term Demonstration Project

FY24 & FY25 Priorities & Highlights

SCALE

- Assessing SCALE with new experimental data from multi-lateral programs (e.g., REGAL, LAGER, EPRI/SKB, etc.)
- Improving simulation capabilities of Polaris / PARCS for BWRs
- Generating new experimental data for expanding the RCA validation basis for HBU & ATF Designs
- Continued capability & assessment of ATF/HBU/EE, HALEU, non-LWRs
  - Longer-term ATF concepts
  - Higher enrichments, 19.75 wt.% U235
  - MSRs, SFRs, HTGRs, FHRs, HPRs

PARCS

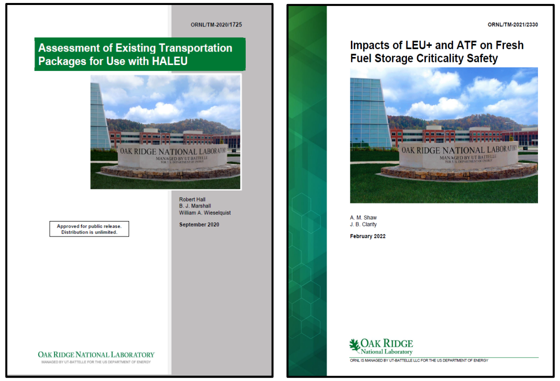
- Additional assessment of Polaris / PARCS for modern BWR cores
- Continued capability & assessment for ATF/HBU/EE, HALEU, and non-LWR analysis
  - SFR thermal expansion (radial/axial)
- Improve and test hybrid depletion (macro/micro)
- Implement new cross-section interpolation scheme for better accuracy at cold conditions
- PATHS bypass and water rod flow model – for later cross section co-branching on bypass/water rod properties
- 2X2 PWR depletion sub-node mesh to support ATF; consolidate nodal methods onto 2G-MG CMFD for improved stability

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

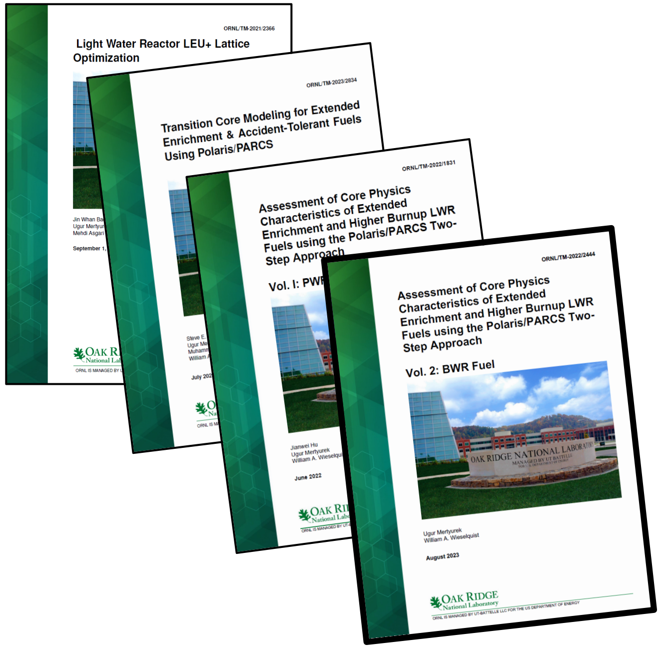
Use of SCALE for LWR Regulatory Decision-making

Accident Tolerant, High Burnup, and Extended Enrichment Fuels

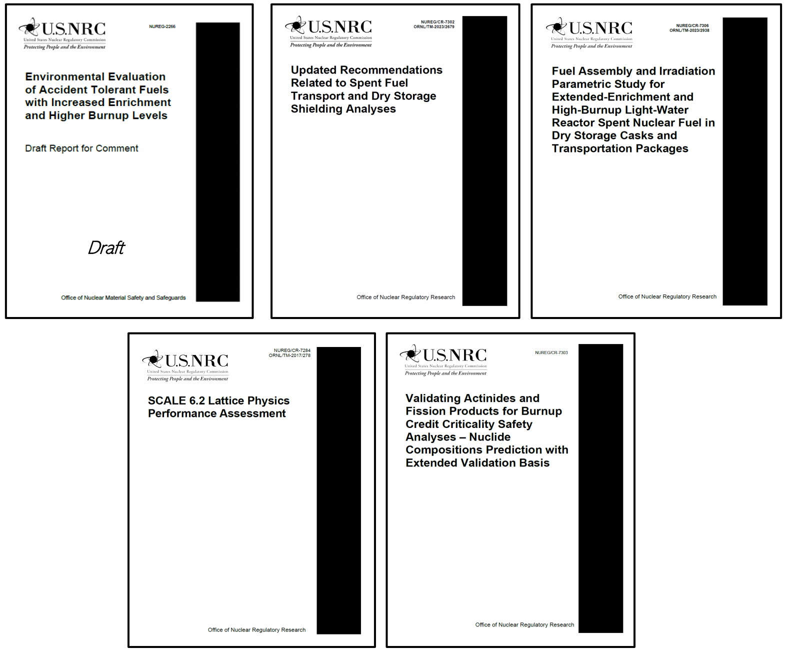
Front-End (Criticality Safety)



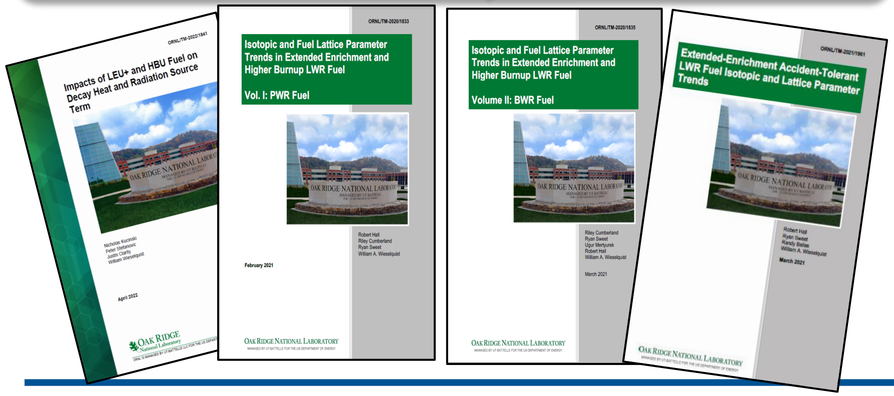
In-Reactor & Power Production



NRC Staff Guidance & Tools



Shielding, Dose, Inventory Generation, and Decay Heat

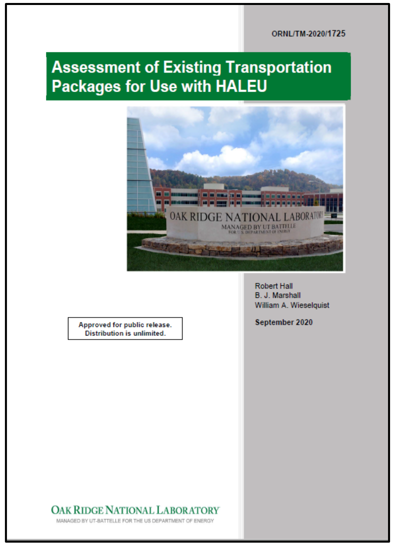


Numerous publicly-available, technical assessments and reports, using SCALE, for key regulatory areas.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Use of SCALE for LWR Regulatory Decision-making

Technical assessments supported NMSS' review of several increased enrichment transportation package licensing submittals (e.g., DN30-X, RAJ-II, Traveller, etc.)


ORNL/TM-2020/1725

Assessment of Existing Transportation Packages for Use with HALEU

Robert Hall
B. J. Marshall
William A. Wieselquist

September 2020

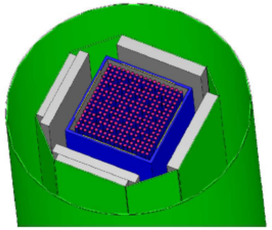
Approved for public release. Distribution is unlimited.

OAK RIDGE NATIONAL LABORATORY

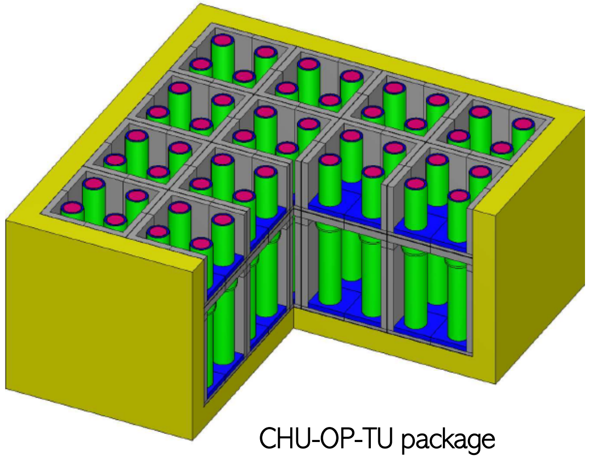
Package	Fuel form	Enrichment (wt.% ^{235}U)	HAC array size	Notes
Traveller	PWR FA[1]	5	Varies	Current limit.
Traveller	PWR FA[1]	~6	Small	Enrichment increases ~0.5% with array size halved. Additional margin is available for some fuel designs and package versions.
Traveller	PWR FA[1]	~7	1	Approximate limit for a single package without additional margin credit.
Traveller	PWR FA[1]	8	Large	Same array size as for the current limit with credit for 52 IFBA per fuel assembly.
Traveller	PWR/BWR fuel pins	>10	Infinite	Additional margin is available to support higher enrichment.
CHT-OP-TU	UO_2 powder	5	50	Current limit, 8 in. pipe.
CHT-OP-TU	UO_2 powder	8	18	7.5 in. pipe.
CHT-OP-TU	UO_2 powder	18	48	6 in. pipe.
CHT-OP-TU	UO_2 pellets	5	50	Current limit, 7.5 in. pipe.
CHT-OP-TU	UO_2 pellets	6.9	18	7.5 in. pipe.
CHT-OP-TU	UO_2 pellets	16.5	48	6 in. pipe.
Versa-Pac	Multiple	10	100	55 gal drum, 5 in. pipe, 1,605 g ^{235}U.
Versa-Pac	Multiple	20	100	55 gal drum, 5 in. pipe, 1,215 g ^{235}U.
TN-B1	BWR FA[2]	5	100	Current limit, 13 Gd rods/assembly.
TN-B1	BWR FA[2]	6	49	13 Gd rods/assembly.
TN-B1	BWR FA[2]	7.8	25	13 Gd rods/assembly.
TN-B1	BWR FA[2]	9.8	16	13 Gd rods/assembly.
TN-B1	BWR FA[2]	8	100	24 Gd rods/assembly.
DN-30	UF_6	5	Infinite	Current limit. Few benchmark candidates.
DN-30	UF_6	6.7	6	HUR sphere governs.
DN-30	UF_6	12.5	1	HUR sphere governs. Few benchmark candidates.

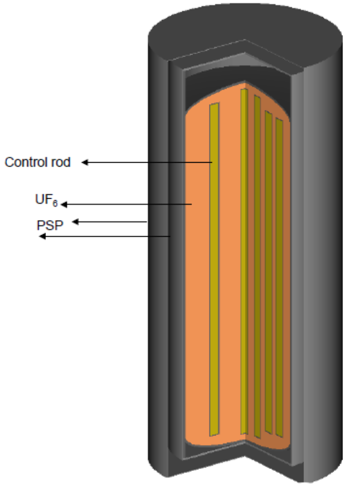
[1]PWR FA = PWR fuel assembly, one per package, assembly average enrichment
[2]BWR FA = BWR fuel assemblies, two per package, assembly average enrichment

- Commercial LWR fuel vendors are pursuing changes to current enrichment limits of 5 wt. %.
- Technical assessment performed to study how increased enrichment impacts currently licensed transportation packages. (SCALE/KENO-VI)
- Key quantities of interest were looked at, related to criticality safety.


Traveller with 17x17 PWR fuel assemblies.


VersaPac with TRISO pebbles


CHU-OP-TU package with powdered UO_2.



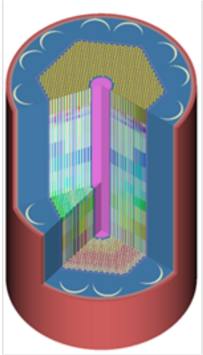
DN30-X with increased U-235 enrichment

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

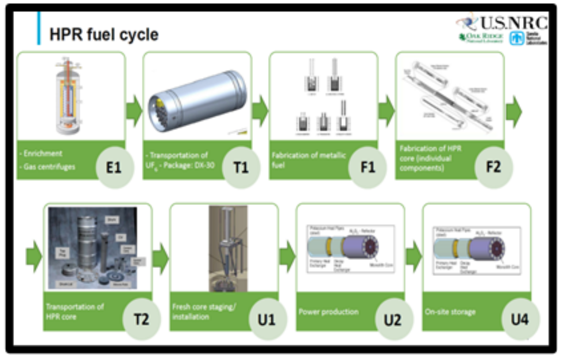
Use of SCALE for Non-LWR Regulatory Decision-making

NRC's Demonstration Projects Highlighting Non-LWR Simulation Capabilities

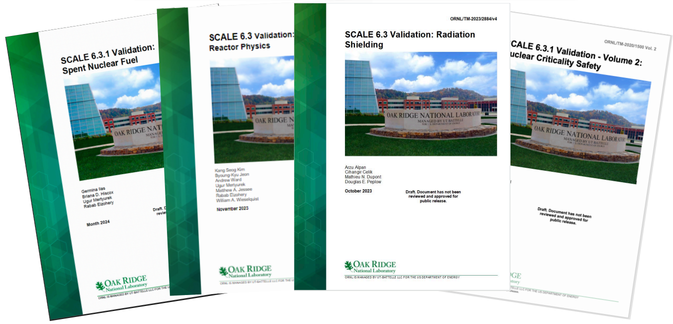
- **Volume 3** – SCALE/MELCOR Source Term Demonstration Project & **Volume 5** – SCALE/MELCOR Fuel Cycle Demonstration Project

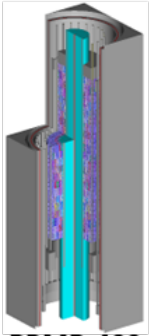


INL Design A (Heat pipe reactor)

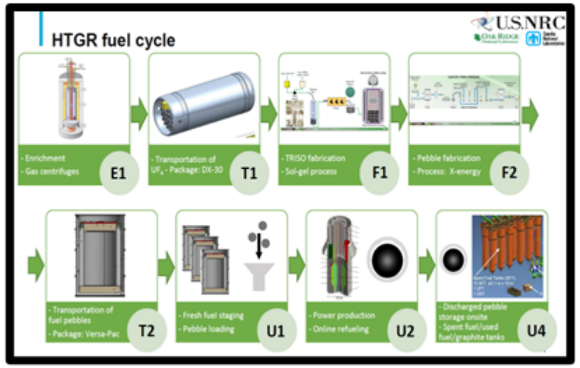


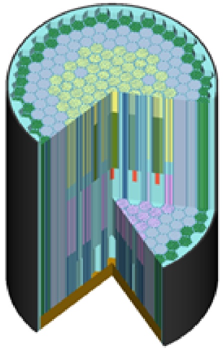
Validation & Assessment



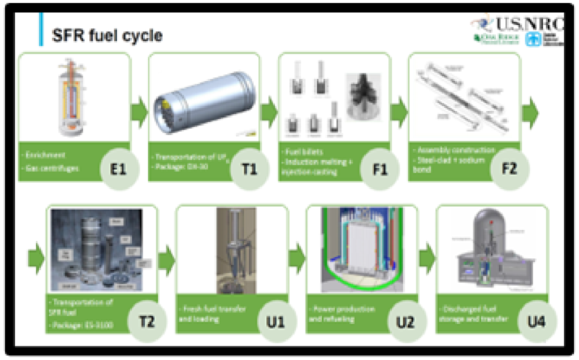


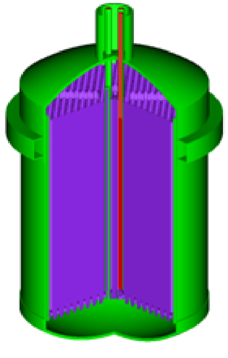
PBMR-400 (High temperature gas-cooled reactor)



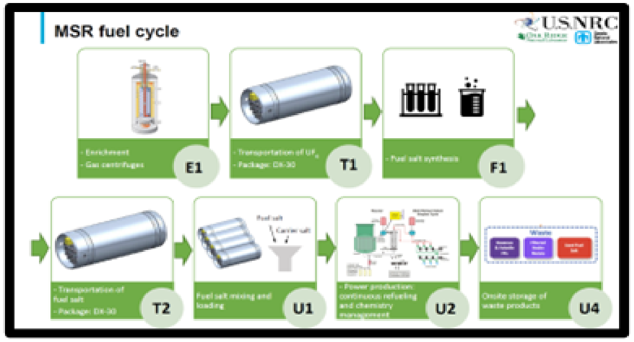


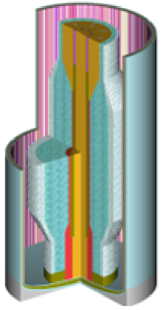
ABTR (Sodium-cooled fast reactor)



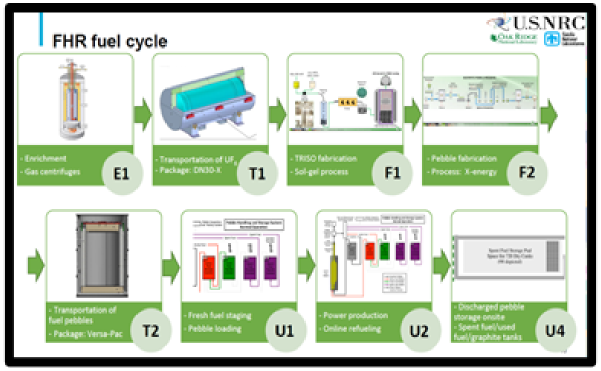


MSRE (Molten salt reactor)





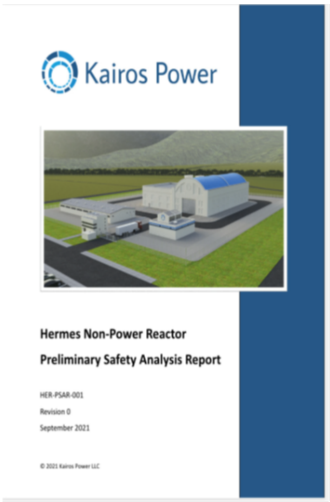
UCB Mark 1 (Fluoride salt-cooled high temperature reactor)



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Use of SCALE for Non-LWR Regulatory Decision-making

SCALE Analyses to Support Kairos' Hermes I Construction Permit Review


Kairos Power

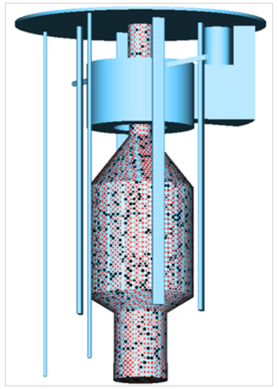
Hermes Non-Power Reactor

Preliminary Safety Analysis Report

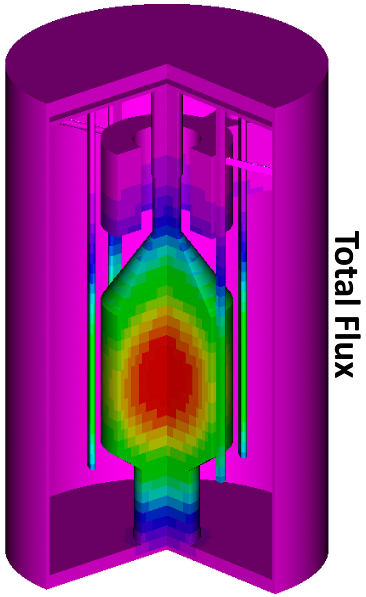
HER-PSAR-001

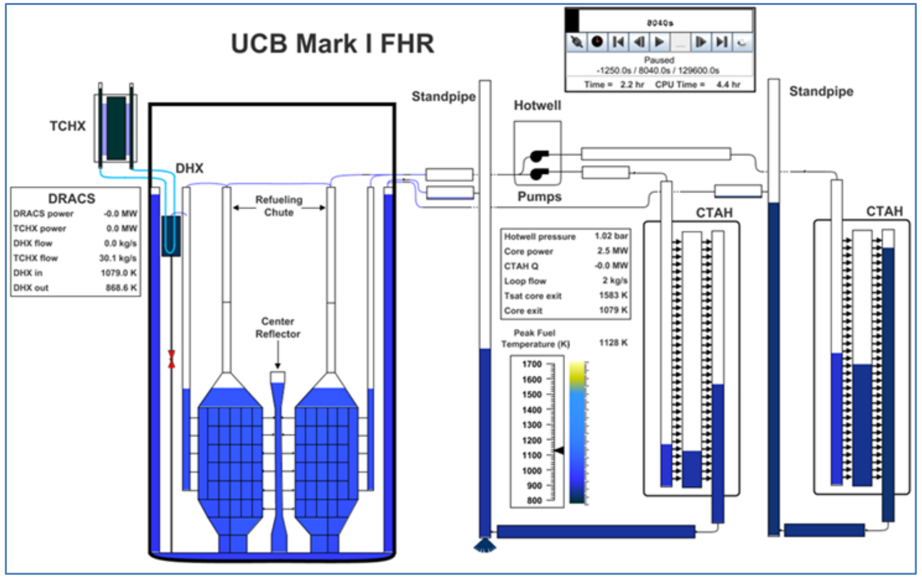
Revision 0

September 2021



Blue: FLiBe
Red: Fuel Pebble
Black: Moderator Pebble





Fluoride Salt Cooled Pebble Bed Reactor MELCOR Model

- Leveraged the existing SCALE/MELCOR UCB Mark 1 Reference plant model from Volume 3 to build the SCALE Hermes I model
- Shutdown control elements not modelled due to SCALE limitations.
- Reactor kinetics, power distributions, decay heat, and isotopic fission product inventories calculated in SCALE for use in MELCOR.
- SCALE outputs used within MELCOR to model several accidents (insertion of excess reactivity & loss of forced circulation)

Parameter	Kairos PSAR	SCALE*
Fuel Doppler (pcm/K)†	-4.1	-4.30 ± 0.27
Moderator (pcm/K)†	-0.4	-0.47 ± 0.13
Coolant (pcm/K)†	-1.6	-1.62 ± 0.02
Void (pcm/% void, @3% void)	-53	-46.6 ± 4.0
Reflector (pcm/K)†	+2.0	+1.92 ± 0.23
β_{eff} (pcm)	605	576 ± 10

Future FY24 SCALE Capability Underway

- **In-Pebble Bed Control Element Modeling in SCALE/TRITON**

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Ongoing SCALE/PARCS Development & Research

- Significant efforts underway expanding & assessing SCALE/PARCS capabilities for LWR & non-LWR
  - Upcoming SCALE/MELCOR MSR Fuel Cycle Workshop – July 11th 2024
    - Workshop will highlight generating MSR inventories in TRITON, performing 3D shielding analyses, and the coupling of ORIGEN to MELCOR for transient analysis (Agenda & Scheduler)
  - Efforts underway to perform additional detailed assessments of Polaris/PARCS for BWRs
  - Possibly expand and add new data to the existing RCA validation basis for HBU & ATF designs
    - Builds upon recently completed efforts (North Anna PWR samples) documented in '*Analytical Report for NRC HBU Fuel Specimens*'
  - Continued capability & assessment of ATF/HBU/EE, HALEU, non-LWRs
    - Expanding SCALE / PARCS capabilities for SFRs (e.g., modeling thermal expansion)

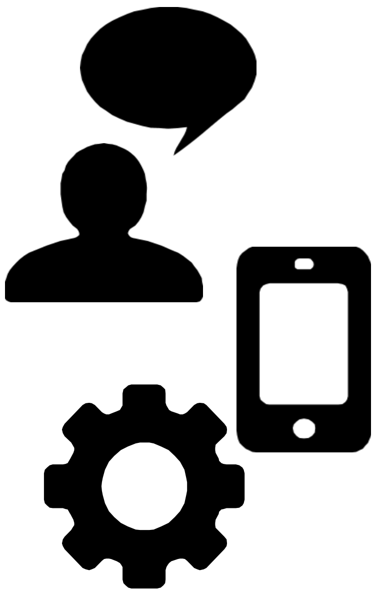
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

For More Information

Fuels – Neutronics – Severe Accidents

FUEL AND SOURCE TERM CODE DEVELOPMENT BRANCH

For questions or comments about material in this presentation, please contact Lucas Kyriazidis & Dr. Andrew Bielen in the NRC Office of Nuclear Regulatory Research, within the Fuel and Source Term Code Development Branch at Lucas.Kyriazidis@nrc.gov & Andrew.Bielen@nrc.gov.



For selected list of publications, please visit the following websites:

Non-LWR Fuel Cycle Demonstration Project	Non-LWR Source Term Demonstration Project	NRC Documents on ATF/HBU/EE

References

Links to the reports mentioned in this presentation, tabulated below

- LWRs – ATF/HBU/EE
  - Assessment of Existing Transportation Packages (ML21040A518)
  - Isotopic and Fuel Lattice Parameter Trends in EE and HBU LWR Fuels (PWR – ML21088A336) (BWR – ML21088A354)
  - Extended-Enrichment ATF LWR Fuel Isotopic and Lattice Parameter Trends (ML21088A254)
  - Impacts of LEU+ and ATF on Fresh Fuel Storage Criticality Safety (ML22098A137)
  - Impacts of LEU+ and HBU Fuel on Decay Heat and Radiation Source Term (ML22159A191)
  - Pressurized Water Reactor Gadolinia Pin Location Optimization Study (ML24069A006)
  - Assessment of Core Physics Characteristics of EE and HBU LWR Fuels using Polaris/PARCS Two-Step Approach (PWR – ML23012A122) (BWR – ML23279A041)
  - *Draft – NUREG-2266, Environmental Evaluation of ATF with IE and Higher Burnup Levels (ML23240A756)*
  - NUREG/CR-7284 – SCALE 6.2 Lattice Physics Performance assessment (ML23076A034)
  - NUREG/CR-7302 Revision 1 – Updated Recommendations Related to Spent Fuel Transport and Dry Storage Shielding Analyses (ML24031A600)
  - NUREG/CR-7303 – Validating Actinides and Fission Products for Burnup Credit Criticality Safety Analyses - Nuclide Compositions Prediction with Extended Validation Basis (ML23254A400)
  - NUREG/CR-7306 – Fuel Assembly and Irradiation Parametric Study for Extended-Enrichment and High-Burnup Light-Water Reactor Spent Nuclear Fuel in Dry Storage Casks and Transportation Packages (ML24114A120)
  - *NUREG/CR-TBD – Validation Studies for HBU and EE Fuels in BUC Criticality Safety Analyses (Coming Later in 2024)*
  - *NUREG/CR-TBD – Sensitivity / Uncertainty Methods for Nuclear Criticality Safety Validation (Coming Later in 2024)*

- Non-LWRs – Volume 3
  - Heat Pipe Reactors (Workshop slides, SCALE Report, MELCOR Report)
  - High-temperature gas-cooled reactor (Workshop slides, SCALE Report, MELCOR Report)
  - Fluoride-salt-cooled high-temperature reactor (Workshop slides, SCALE Report, MELCOR Report)
  - Molten-salt-fueled reactor (Workshop slides, SCALE Report, MELCOR Report)
  - Sodium-cooled fast reactor (Workshop slides, SCALE Report, MELCOR Report)
  - SCALE 6.3 Modeling Strategies for Reactivity, Nuclide Inventory, and Decay Heat of Non-LWRs (ML2414A078)

- Non-LWRs – Volume 5
  - Non-LWR Fuel Cycle Scenarios for SCALE and MELCOR Modeling Capability Demonstration (ML24004A270)
  - SFRs (Workshop slides, SCALE Report)
  - HTGRs (Workshop slides)

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment