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

The NRC: Safety and SCALE

A NRR, NMSS, and RES Collaboration

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Office of Nuclear Regulatory Research

USNRC - Authority

- NRC's legislated authority is summarized in NUREG-0980 "Nuclear Regulatory Legislation"
  - ADAMS No: ML13274A489
- Some Key legislation
  - Atomic Energy Act of 1946:
    - How technology will be used
  - Atomic Energy Act of 1954
    - Allowed for commercial nuclear reactors
  - Energy Reorganization Act of 1974
    - Established the US-NRC

USNRC - Mission

- Mission

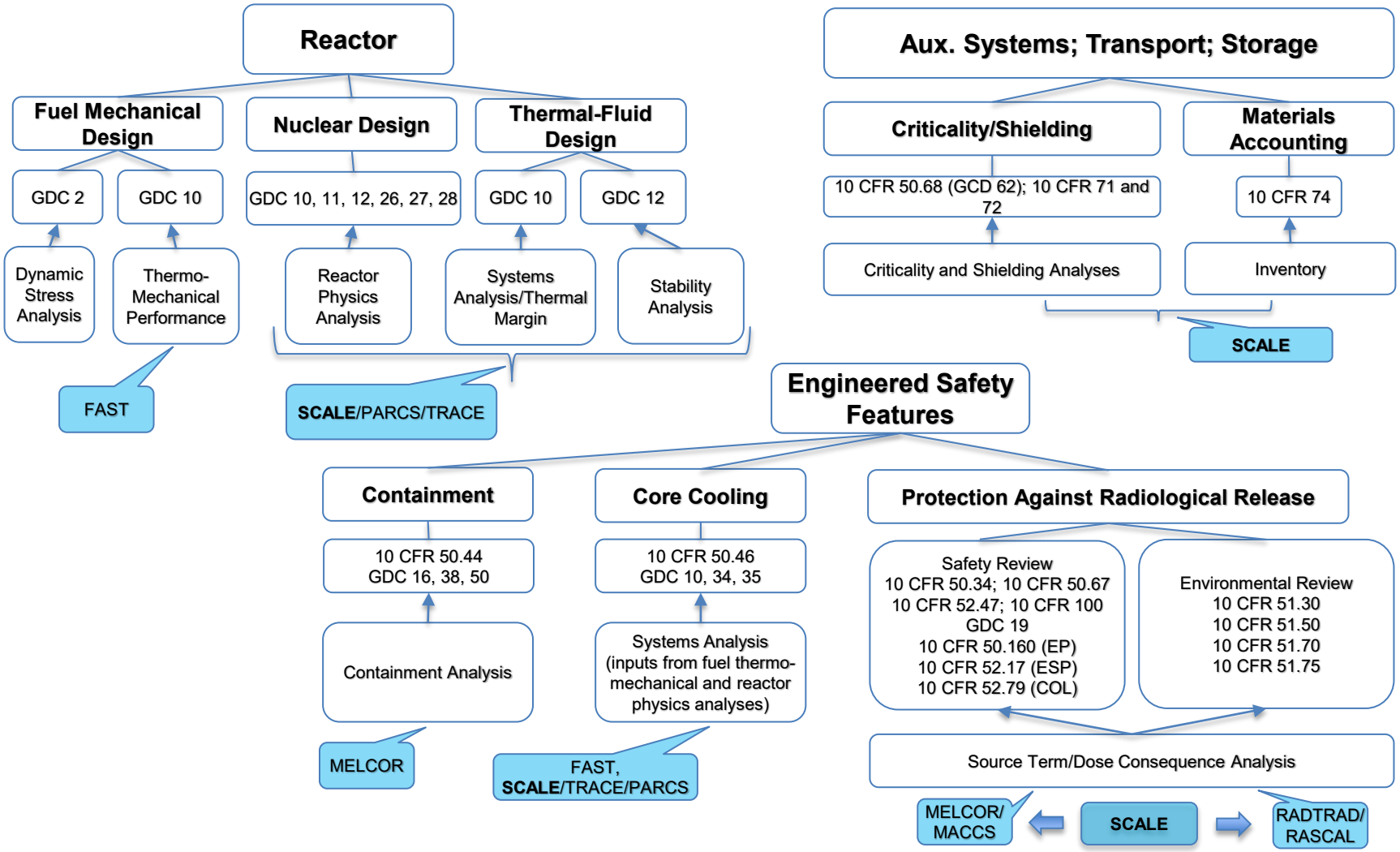
"The NRC licenses and regulates the Nation's civilian use of radioactive materials to provide reasonable assurance of adequate protection of public health and safety and to promote the common defense and security and to protect the environment"
(https://www.nrc.gov/about-nrc.html)

- An aspect to this is to understand, control and predict the behavior of systems that contain radioactive material

Performance of Confirmatory or scoping studies

- Computer codes may be applied by staff to support confirmatory evaluations for such conditions as:
  - First-of-a-kind (or unique) designs, features, or operations
  - Where safety margins are small
  - To focus use of NRC resources in the review process (e.g., requests for additional information, areas to audit)
  - Gain insights on sensitivities and important areas of application

Driver: Notional Reg-Code Matrix



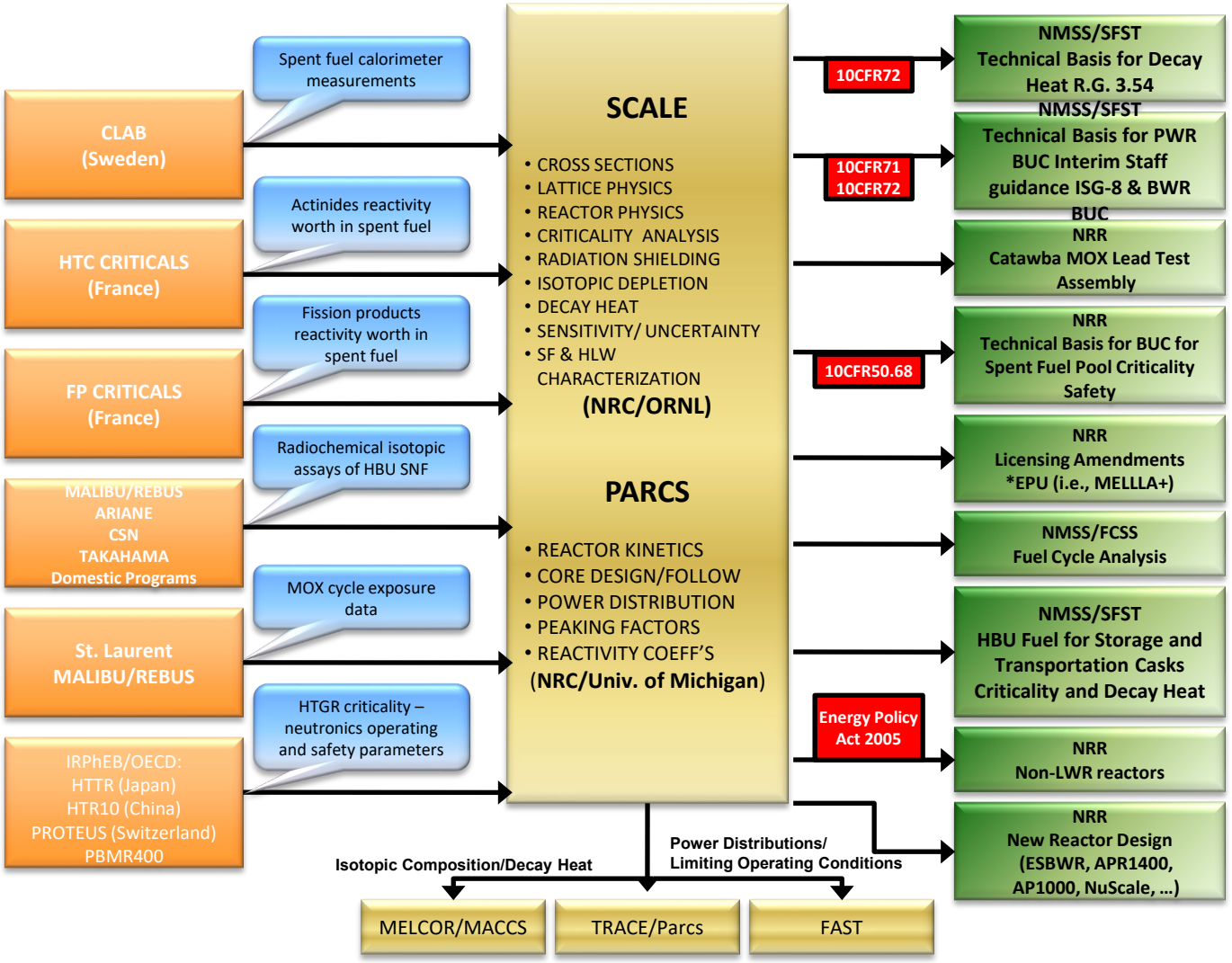
Need - NRC Neutronics Needs

- NRC mission necessarily means the following capabilities are required:
  - Fundamental nuclear data and development of nuclear application libraries
  - Criticality analyses
  - Shielding analyses
  - Develop time dependent inventory, or depletion, and decay heats
  - S/U, ability to assess the benchmarks used to support computer code validation and develop computer code bias and bias uncertainty to understand its impact to safety
  - Code development with understanding of the needs of down stream codes such as fuel performance, radionuclide transport, consequence analysis, materials, emergency response, etc

Solution: SCALE, NRC's Swiss Army Knife

- Extensive use in various regulatory applications
- Domestic and international users – over 9,600 licenses in 61 nations issued for SCALE through January 2020 (over 2,300 licenses for SCALE 6.2 since its release in April 2016); including 33 foreign regulators
- SCALE, initially developed by NMSS, now covers NRC neutronics needs:
  - Generate lattice parameters for PARCS analysis to support for example the MELLLA+ power uprate at operating reactors
  - Generate nuclides inventories and decay heat for thermal-hydraulics and severe accident/source term analysis
  - Perform confirmatory analysis (criticality, decay heat and shielding) for licensing spent fuel casks and radioactive material transportation packages.
  - Perform shielding and materials activation analysis
  - Supports other computer codes, such as PARCS, TRACE/Parcs, MELCOR, MACCS, FAST, UNF-ST&NDARDS*, and NASA/RPSDET

*DOE developed tool that NRC is also using



SCALE -> FAST

- **F**uel **A**nalysis under **S**teady-State and **T**ransients Brief used to understand steady-state and transient (AOOs) response of fuel rods in-reactor and dry-storage conditions
- Outputs: Heat conduction; clad elasticity and deformation include creep; PCMI; FGR; RIP; clad oxidation; etc
- SCALE provides radial and axial power and inventory
- Collaboration between NRC and PNNL (POC: Michelle Bales/James Corson)

SCALE ->TRACE-PARCS/PARCS

- **P**urdue **A**dvanced **R**eactor **C**ore **S**imulator and (used stand alone or coupled mode) and **T**RAC/**R**ELAP **A**dvanced **C**omputational **E**ngine.
- PARCS is a 3D core reactor simulator and TRACE is a component based transient analysis code
- Outputs: PARCS (Eigen-value; depletion with T/H feedback; pin-powers; etc)
- Outputs: TRACE (DBA system response tool)
- SCALE provides nodal data to PARCS
- Collaboration between NRC, UM, PSU, and ISL (POC: Nate Hudson and Chris Murray)

SCALE – MELCOR

- MELCOR is not an acronym
- MELCOR is a fully integrated, engineering-level computer code modeling severe accident progression
  - Core degradation, radionuclide release and transport, combustion events, etc.
  - Provides estimation of the source term to the environment accounting for natural aerosol depletion processes (plate out, retention in other fluid volumes, etc.)
- SCALE provides
  - Fuel radionuclide inventories
  - Decay heats
  - Kinetics parameters, etc.
- Collaboration between NRC and SNL (POC: Hossein Esmaili/Don Algama)

SCALE -> MACCS

- **M**ELCOR **A**ccident **C**onsequence **C**ode **S**ystem, simulates the impact of severe accidents on the surrounding environment.
- Takes source terms from MELCOR to estimate health consequences.
- SCALE provides inventory data.
- Collaboration between NRC and SNL (POC: Jon Barr)

SCALE -> RASCAL

- Developed by NRC for ~30yrs
  - Used to assess plume phase of radiological events
  - Estimates dose and consequences for Protective Action Recommendations (PAR)
- Uses real time meteorological data (downloads).
- Uses pre-estimated, accident-specific source terms from MELCOR to calculate dose consequences.
- SCALE provides core inventory data.
- Collaboration between NRC, SNL, PNNL & Athey Consulting (POC: Stephanie Bush-Goddard).

SCALE -> RADTRAD

- The **RAD**ionuclide, **T**ransport, **R**emoval, **A**nd **D**ose estimation code is an NPP licensing and siting code
- Used to demonstrate compliance with nuclear plant siting criteria (10 CFR 100) under design basis accidents (DBAs) for
  - Exclusion Area Boundary (EAB)
  - Low Population Zone (LPZ)
  - Control room (CR)
- Uses the Symbolic Nuclear Analysis Package (SNAP) Model Editor and X/Q values from PAVAN and ARCON.
- SCALE provides PWR and BWR core inventory data.
- Collaboration between NRC and Information Systems Laboratory (ISL), Inc. (POC: Kerstun Norman).

NRC SCALE Activities - Nuclear Data

- Basic Research
  - Assessing performance of ENDF/B-VII.1 vs. ENDF/B-VIII.0 (including uncertainty data) for diverse applications
  - Updating independent FP yields (ENDF/B-VIII.0) to be consistent with decay data/cumulative yields
  - Introducing data correlations to reduce integral uncertainties (more consistent with observed biases)
  - New LWR MG (252grp), Non-LWR LWR (1,400) available in SCALE 6.3
- Standard Light Water Reactor (LWR)
  - Extending nuclear data in SCALE with uncertainty (kinetics)
  - Improving SAMPLER (SCALE's arbitrary uncertainty propagation engine), e.g. additional sensitivity indices, correlation calculations
- LWR/Accident Tolerant Fuel (ATF), High Burnup (HBU), High Assay Low-Enriched Uranium (HALEU)
  - Assessing isotopics/reactivity for ATF, HBU and HALEU systems related to standard LWR
  - Performing similarity assessments to understand criticality validation basis
  - Developing new methods for isotopics validation basis
- Non-LWR
  - Assessing important nuclear data for non-LWR systems--anything new/different compared to LWRs
  - Affect on safety-related parameters (power peaking factors, reactivity coefficients, delayed neutron fraction)
  - Affect on severe accident analysis (isotopics, reactivity coefficients)

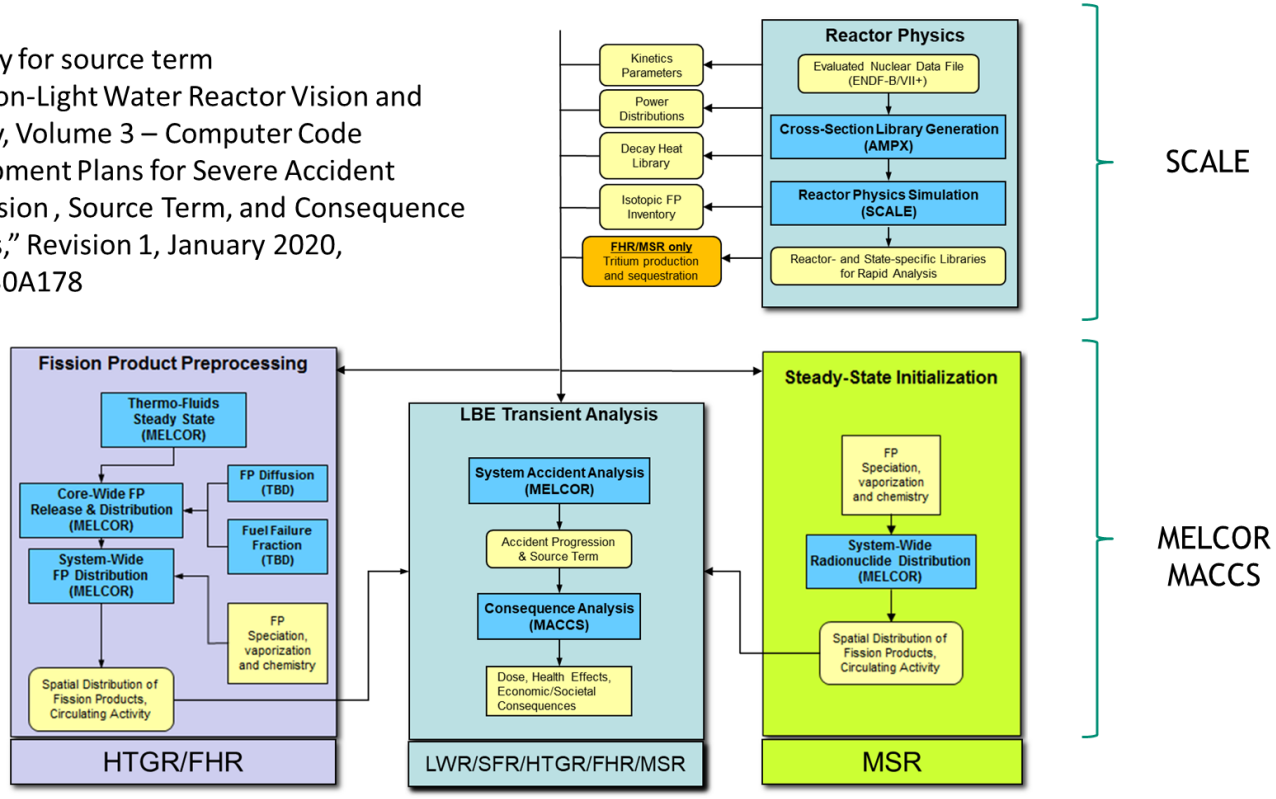
NRC SCALE Activities - Applications

- SCALE 6.3 release for the end of the year
  - ENDF/B-VIII data
  - Shift Monte Carlo code integrated into CSAS, TRITON, MAVRIC
  - Improvements to Polaris for ATF
  - Improvements to XSProc for HTGR, FAST coupling
  - Improvements to Sampler for sensitivity indices and delayed neutron uncertainty
- Transport, Storage and Fuel Cycle:
  - Development of criticality and shielding guidance
  - Development of Volume 5 to the Non-LWR IAPs. We will investigate the impacts of Non-LWRs to the existing fuel cycle using SCALE and MELCOR capabilities
  - Being applied to the review of current cask and storage applications
- Standard Light Water Reactor (LWR)
  - Polaris additions for gamma detector, BWR box "cutout"
  - Comprehensive 4-volume SCALE Validation Report based on 6.2.4 (ORIGEN, Polaris, TRITON, CSAS, MAVRIC, ORIGAMI)
- LWR/Accident Tolerant Fuel (ATF), High Burnup (HBU), High Assay Low-Enriched Uranium (HALEU)
  - Assessing the SCALE neutronics suite capabilities throughout the fuel cycle
  - HBU up to 80GWd/MTU (~ Aug '20)
  - HALEU up to 8wt% (~Oct '20)
  - ATF Designs (~Jan '21)
    - PWR/BWR like with Cr cladding
    - PWR/BWR like with Cr doped
- Non-LWR
  - We are taking existing SCALE, and SCALE-MELCOR approaches and apply to fuel cycle and Severe Accident applications.
  - Reference plant data are being developed for publicly available:
    - HPR: MEGAPOWER
    - HTGR: PBMR-400
    - FHR: University of Berkley

NRC SCALE Activities - Applications

Evaluation Model and Suite of Codes

Code strategy for source term
"NRC Non-Light Water Reactor Vision and Strategy, Volume 3 – Computer Code Development Plans for Severe Accident Progression , Source Term, and Consequence Analysis," Revision 1, January 2020, ML20030A178



Summary

- Staff recognizes the importance of high-quality nuclear data as the foundation for reliable and robust nuclear systems analysis
- Staff recognizes the need for understandable and appropriately V&V application codes
- Staff actively drive the development of SCALE, and coordinate development with other teams such as FAST, PARCS, MELCOR/MACCS, RASCAL/RADTRAD, to support confirmatory and scoping analyses for LWR (including ATF, HBU and HALEU related activities) and Non-LWR
- Nuclear data collection (e.g. measurements), evaluation (e.g. ENDF/B), processing for use in software (e.g. SCALE/AMPX), and application (e.g. SCALE/Polaris-TRITON-SHIFT-TSUNAMI-etc) must strive for
  - transparency and reproducibility,
  - robust handling of uncertainty (including correlations), and
  - rigorous validation which leads to understanding of bias+bias uncertainty (nuclear data and otherwise) for real analysis scenarios.
- Will Wieselquist, SCALE Director, will be providing further discussion on SCALE development and applications, and Andy Bielen (NRC) will be providing a discussion on how SCALE was used in a recent licensing activity.

Thank you

BACK UP

Transportation and storage licensing at NRC

analysis end-points

ENDF/B
Physics data
Thermal scattering law, resonance data, energy distributions, fission yields, decay constants, etc.

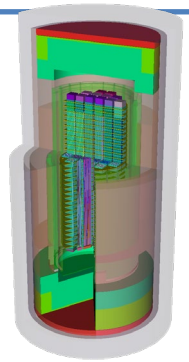
JEFF Activation
Isomeric cross sections, activation reactions

Sources4C
neutron emission data (alpha,n)

ICRP
dose conversion factors, radiotoxicity

NIST
natural abundance, atomic mass

scale
Nuclear Systems Modeling & Simulation



AMPX
Validated cross section libraries in multigroup (O(100g)) or continuous-energy (O(100,000g); depletion and decay data

MAVRIC
3D shielding and dose rate analysis

ORIGEN
General depletion, decay, source term

CSAS
3D criticality safety analysis

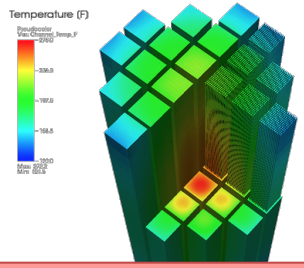
TRITON
General reactor fuel neutron transport + depletion

ORIGAMI
Reactor-specific radioactive isotopics/source term characterization

Structural analysis

ANSYS / LS-DYNA
Commercial finite element analysis

Thermal analysis



STAR-CCM+ / FLUENT
Commercial computational fluid dynamics codes

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Reactor physics confirmatory analysis at NRC

analysis end-points

ENDF/B
Physics data
Thermal scattering law, resonance data, energy distributions, fission yields, decay constants, decay energy

JEFF Activation
Isomeric cross sections, activation reactions

Kinetics Data
nuclide-specific beta-effective, neutron precursor data

Energy Release Data
nuclide-specific energy per capture/fission

NIST
natural abundance, atomic mass

scale
Nuclear Systems Modeling & Simulation

AMPX
Validated cross section libraries in multigroup (O(100g)) or continuous-energy (O(100,000g); depletion and decay data

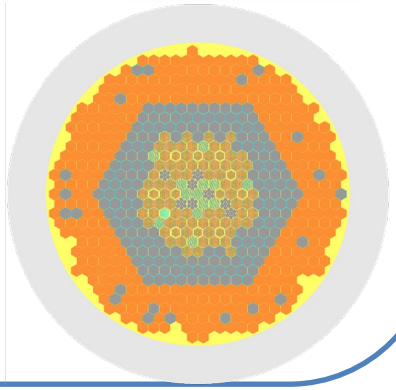
Polaris
Fast LWR lattice physics

TRITON
General 3D reactor fuel neutron transport + depletion

PARCS
Advanced core simulator
Neutron flux solver and depletion

TRACE
System level temperature distributions and feedback

FAST
Fuel performance



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Severe accident & consequence analysis at NRC

analysis end-points

ENDF/B
Physics data
Thermal scattering law, resonance data, energy distributions, fission yields, decay constants, etc.

JEFF Activation
Isomeric cross sections, activation reactions

Sources4C
neutron emission data (alpha,n)

Kinetics Data
nuclide-specific beta-effective, precursor data

NIST
natural abundance, atomic mass

scale
Nuclear Systems Modeling & Simulation

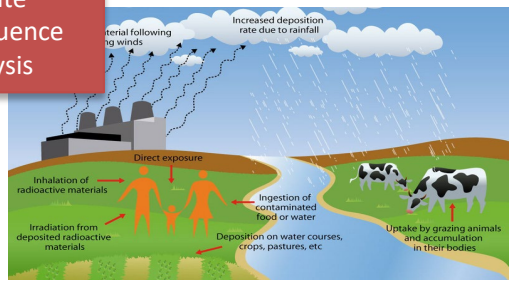
AMPX
Validated cross section libraries in multigroup (O(100g)) or continuous-energy (O(100,000g); depletion and decay data

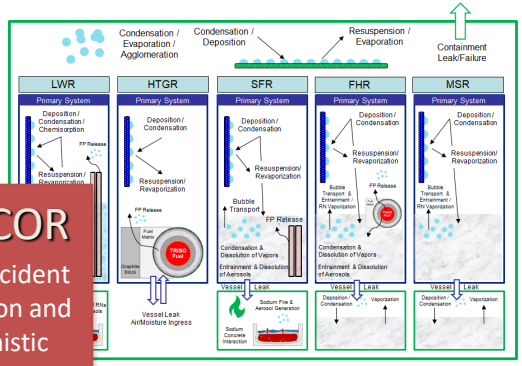
ORIGEN
General depletion, decay, source term

TRITON
General reactor fuel neutron transport + depletion

ORIGAMI
Reactor-specific radioactive isotopics/source term characterization

MACCS
Offsite consequence analysis





MELCOR
Severe accident progression and mechanistic source terms

"NRC Non-Light Water Reactor Vision and Strategy, Volume 3 – Computer Code Development Plans for Severe Accident Progression , Source Term, and Consequence Analysis," Revision 1, January 2020, ML20030A178

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