OAK RIDGE National Laboratory

Detailed SCALE Dose Rate Evaluations for a Consolidated Interim Spent Nuclear Fuel Storage Facility

SCALE Users' Group Workshop September 27–29, 2018

Georgeta Radulescu
Thomas Miller
Kaushik Banerjee
Douglas Peplow

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Outline

- Introduction
- Description of a proposed consolidated interim storage facility (CISF)
- Dose rate calculation method
- CISF model
- Dose rate calculation results

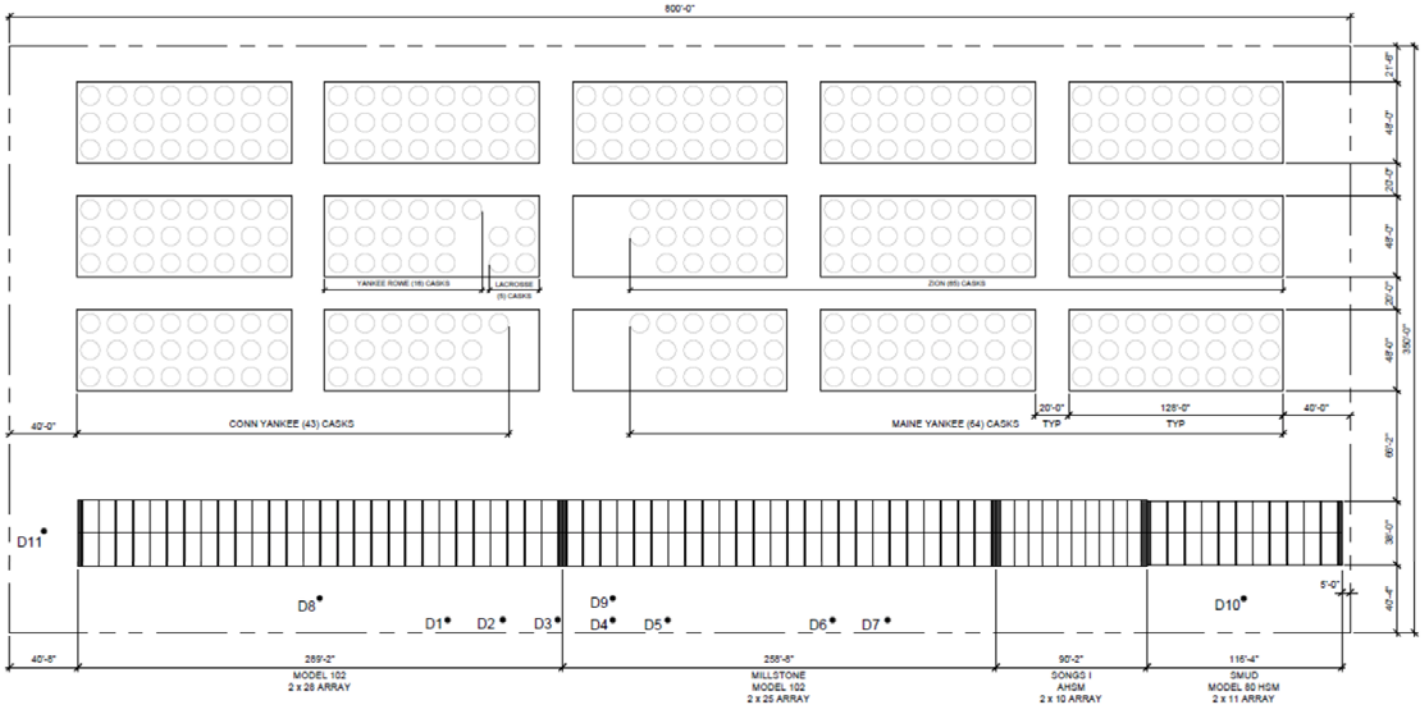
Introduction

- Purpose of calculation
  - Support US Nuclear Regulatory Commission (NRC) shielding review of the license application for a proposed CISF
- Two-step method typically used in license applications
  - Step1: Determine particle energy and angular distributions on cask external surface
  - Step 2: Use the surface source in a new radiation transport calculation
  - Method drawback: The space/energy/angle distribution of the particles coming off the cask needs to be binned, stored, and then resampled in the second step
- Detailed Monte Carlo radiation transport simulation in one step (from source to dose rate) used in this work
  - SCALE* for source term calculations and Monte Carlo radiation transport simulations
  - A series of simulations using complete site geometry (all casks present) but with only one cask containing source
  - Total dose rate calculated as the sum of uncorrelated dose rate values from separate calculations

*B. T. REARDEN and M. A. JESSEE, Eds., "*SCALE Code System*," ORNL/TM-2005/39, Version 6.2.3, Oak Ridge National Laboratory (2018). Available from Radiation Safety Information Computational Center as CCC-834.

Proposed Consolidated Interim Storage Facility (Phase 1)*

- Conceptual design of the Phase 1 CISF (467 casks)
- 319 NAC vertical storage casks
- 148 NUHOMS® horizontal storage modules
- Purpose of the calculations is to determine location of controlled area boundary based on the annual dose requirement of 0.25 mSv (25 mrem) in 10 CFR 72.104(a)†



* WCS Consolidated Interim Storage Facility Safety Analysis Report; https://www.nrc.gov/docs/ML1613/ML16133A134.pdf.

† 10 CFR Part 72, License Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater that Class C Waste.

MAVRIC* Shielding Calculation Sequence in SCALE

- Monte Carlo radiation transport code - Monaco
- Automated variance reduction – Denovo† discrete ordinates code
- Multigroup and continuous-energy cross-section data for the Monte Carlo transport
- Mesh, point detector, and region tallies
- Large number of different photon and neutron sources
- Source spectrum and strength values directly from ORIGEN binary files
  - Radiation source terms determined with ORIGAMI in the SCALE code system
- Dose rate map using a cylindrical tally mesh
- Utilities for post-processing mesh tally files

* D. E. PEPLOW, "Monte Carlo Shielding Analysis Capabilities with MAVRIC," *Nucl. Technol.* **174**(2), 289–313 (2011).
† T. M. EVANS et al., "Denovo: A New Three Dimensional Parallel Discrete Ordinates Code in SCALE," *Nucl. Technol.* **171**(2), 171–200 (2010).

Variance Reduction Method

- *Forward-weighted consistent adjoint driven importance sampling* (FW-CADIS)* method
  - Produces acceptable statistical accuracy of dose rate estimates within every geometry region outside a storage cask
  - Requires both forward and adjoint discrete ordinates calculations with Denovo
  - Generates energy- and space-dependent source biasing and particle importance parameters
- Effects
  - Particles that make important contributions to dose rate are sampled more often to increase calculation efficiency
  - Particles reaching tally regions have similar weight values, thereby reducing the statistical variance of the Monte Carlo estimate

*J. C. WAGNER, D. E. PEPLOW, and S. W. MOSHER, "FW-CADIS Method for Global and Regional Variance Reduction of Monte Carlo Radiation Transport Calculations," *Nucl. Sci. Eng.* **176**(1), 37–57 (2014).

Phase 1 CISF Model

- Seven different NAC vertical storage systems and NUHOMS® horizontal storage systems
- Seven different design basis fuel assemblies
  - Various array sizes (e.g., BWR 7x7, PWR 14x14 to 17x17)
  - Average burnup ranging from 25 GWd/MTU to 62 GWd/MTU and cooling time ranging from 3 years to 21.4 years
- The concrete pad is 243.84 m x 106.68 m x 30 cm

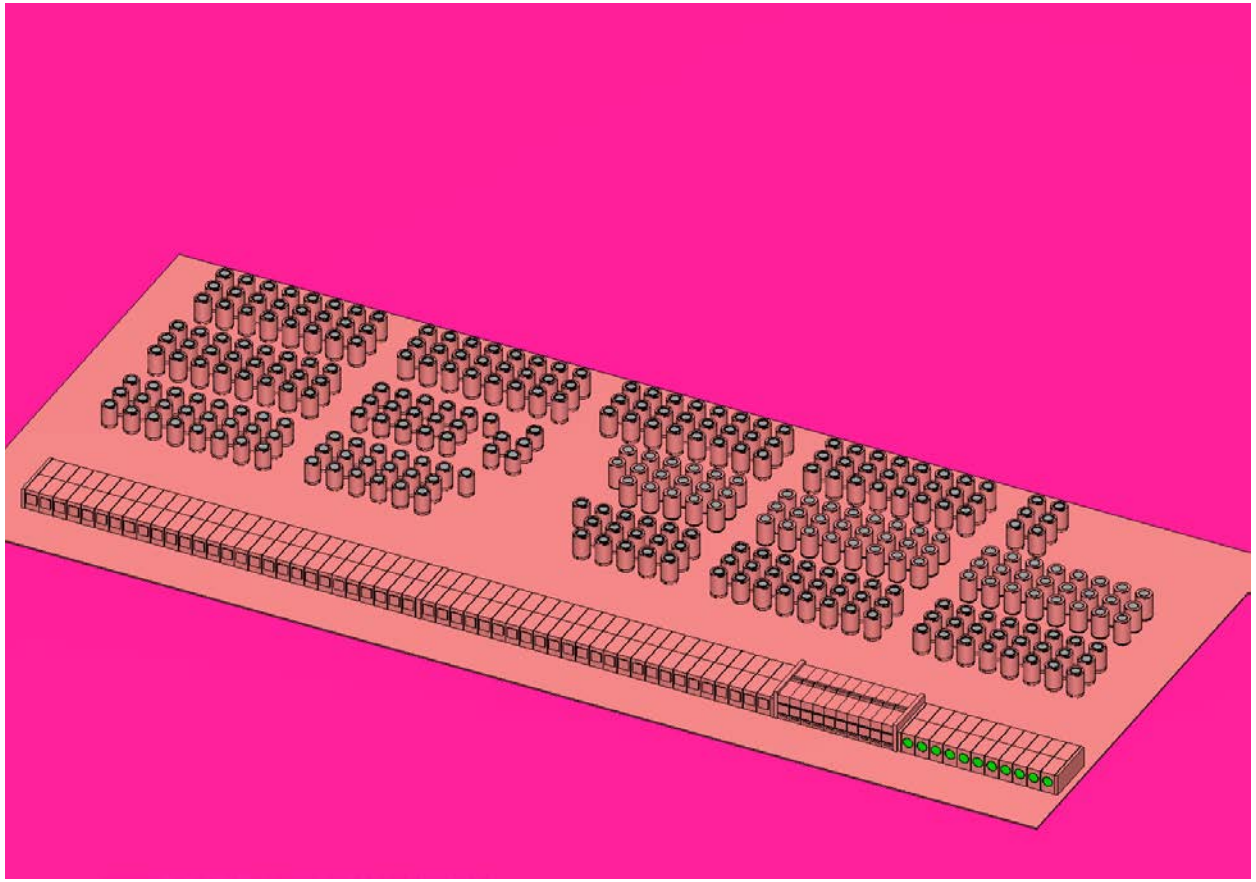
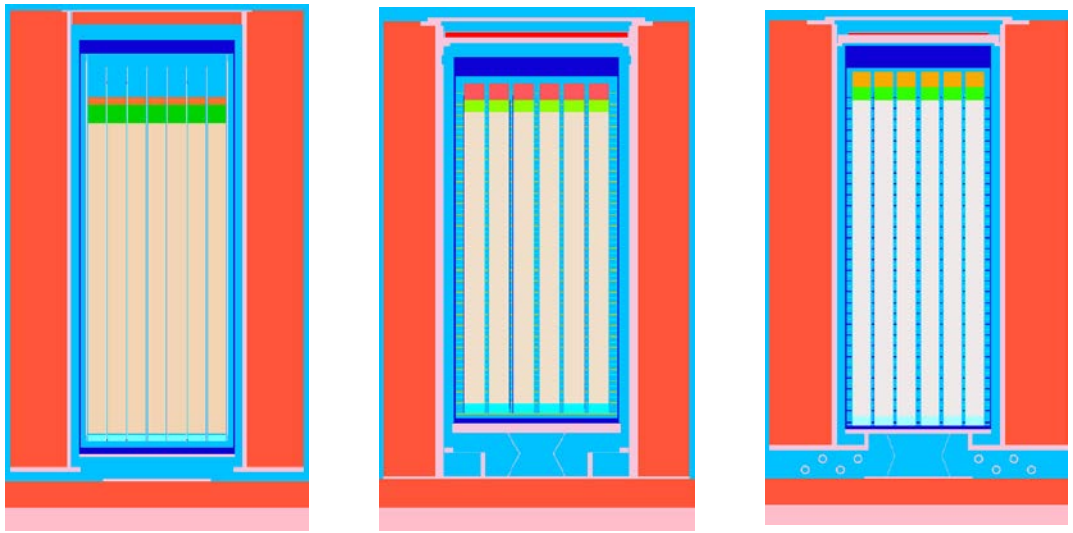
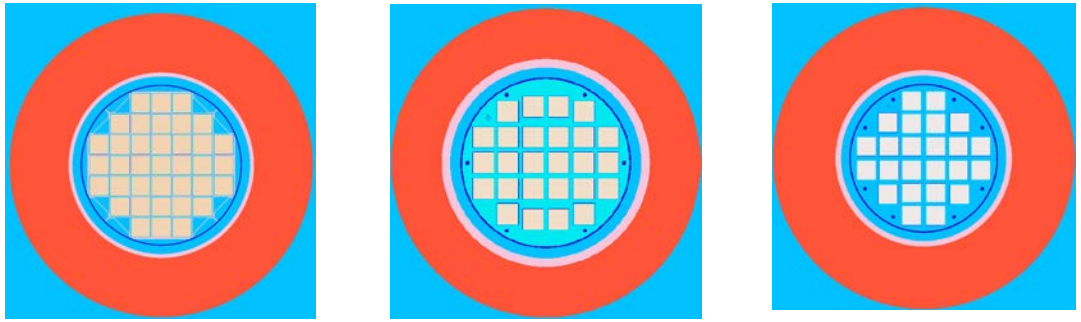


Image from KENO-3D of the Phase 1 CISF

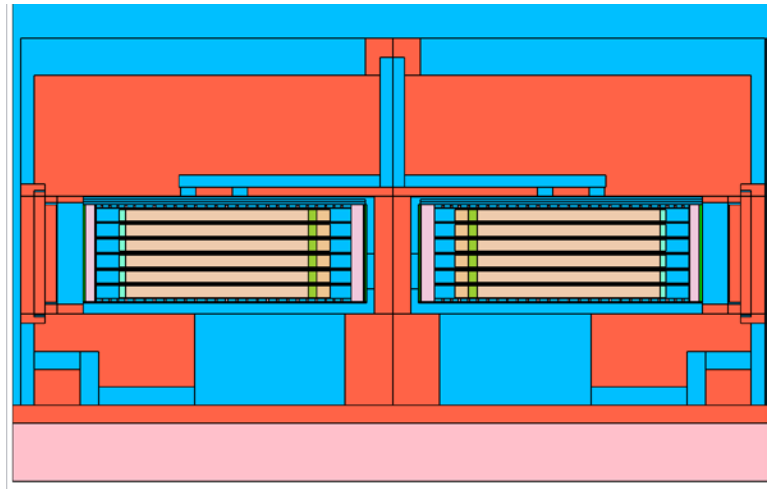
Cross-sectional Views of Individual Cask Models

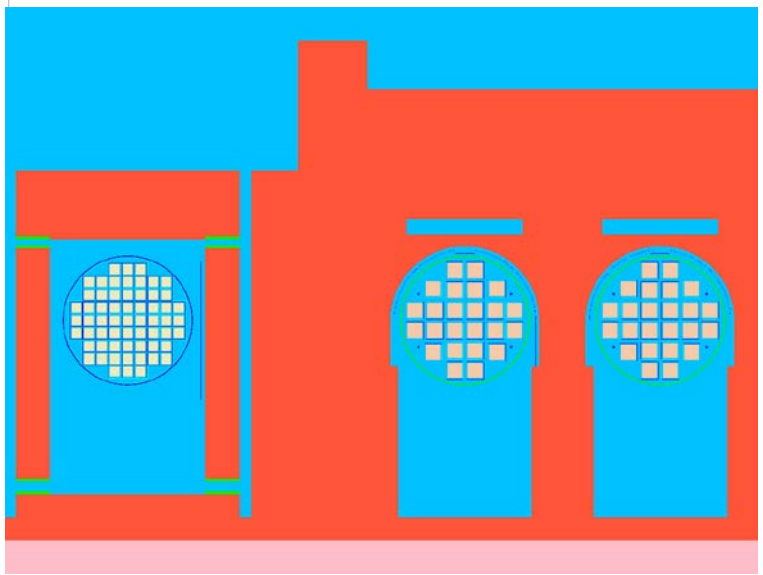
NAC Vertical Concrete Casks





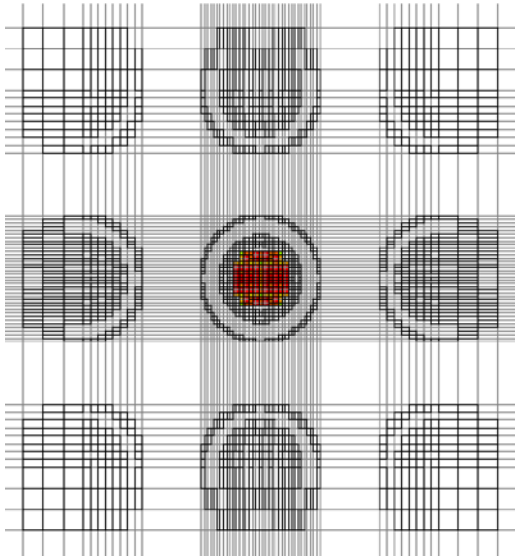
NUHOMS® Horizontal Storage Modules





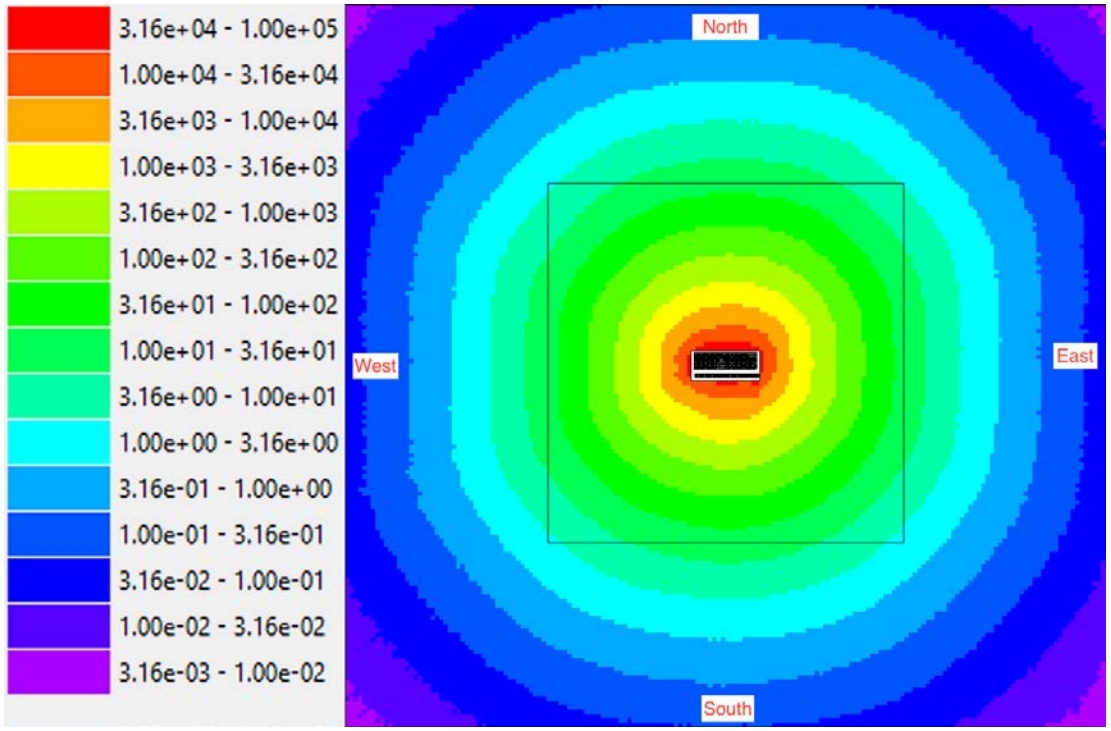
Modeling Parameter Optimization

- Volume of the surrounding air and soil
  - Soil modeled to 1 m in depth
  - Air volume gradually increased until minimal effects were noticed on the total dose rate at anticipated controlled area boundary location
  - Model geometry dimensions: 2700 m × 2600 m × 960 m
- Adjoint source region for Denovo adjoint calculations
  - Defined within the air region outside the storage pad
  - Extending from the soil top to 2 m above the soil
- Parameters describing the angular scattering in Denovo S_N calculations
  - S_4/P_3 (quadrature order =4; number of Legendre polynomials=3)
- Denovo mesh definition
  - Fine mesh for the volume of the analyzed storage cask and its adjacent casks
  - Coarse mesh elsewhere
- Tally mesh size: 15.24 m × 15.24 m × 2 m
- Computer time per case ~36 hours (MC relative statistical error per case < 20%)

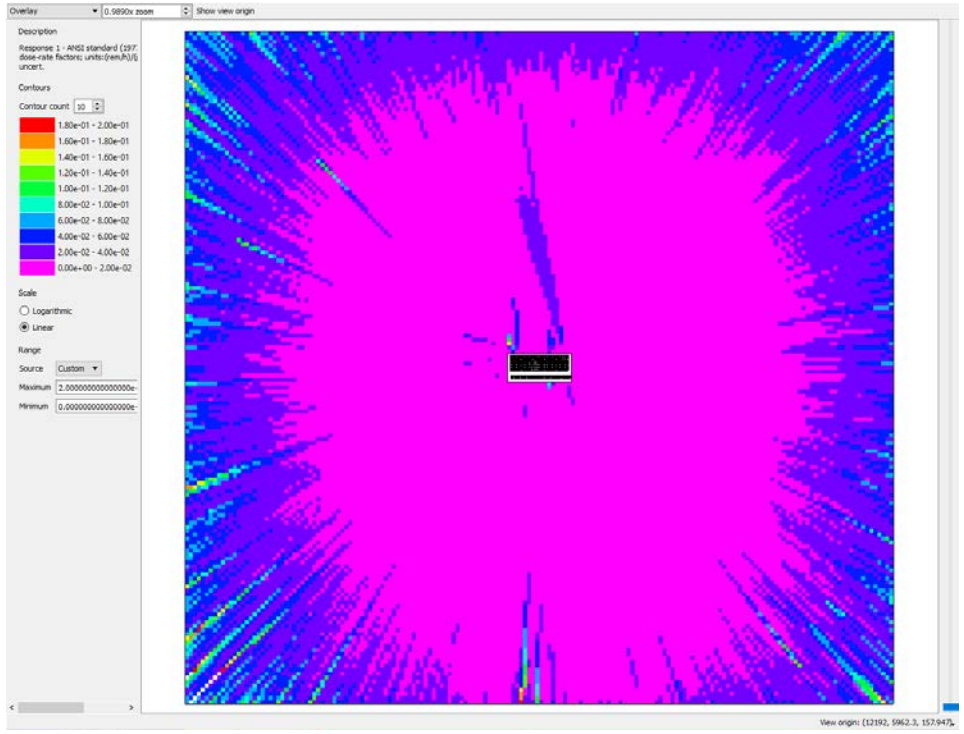


Total Dose Contours Surrounding the Phase 1 CISF

- The mesh tally only has one cell in the vertical direction, which extends from the top of the soil to 2 m above the soil
- Voxel size: 15.24m x 15.24m x 2m
- The dose response function from ANSI/ANS-1977* (recommendation in NUREG-1536 †)



Dose rate (mrem/yr) map: 2713 m x 2576 m
The black line encloses the 25 mrem/yr contour and denotes the smallest rectangle that could serve as the controlled area boundary

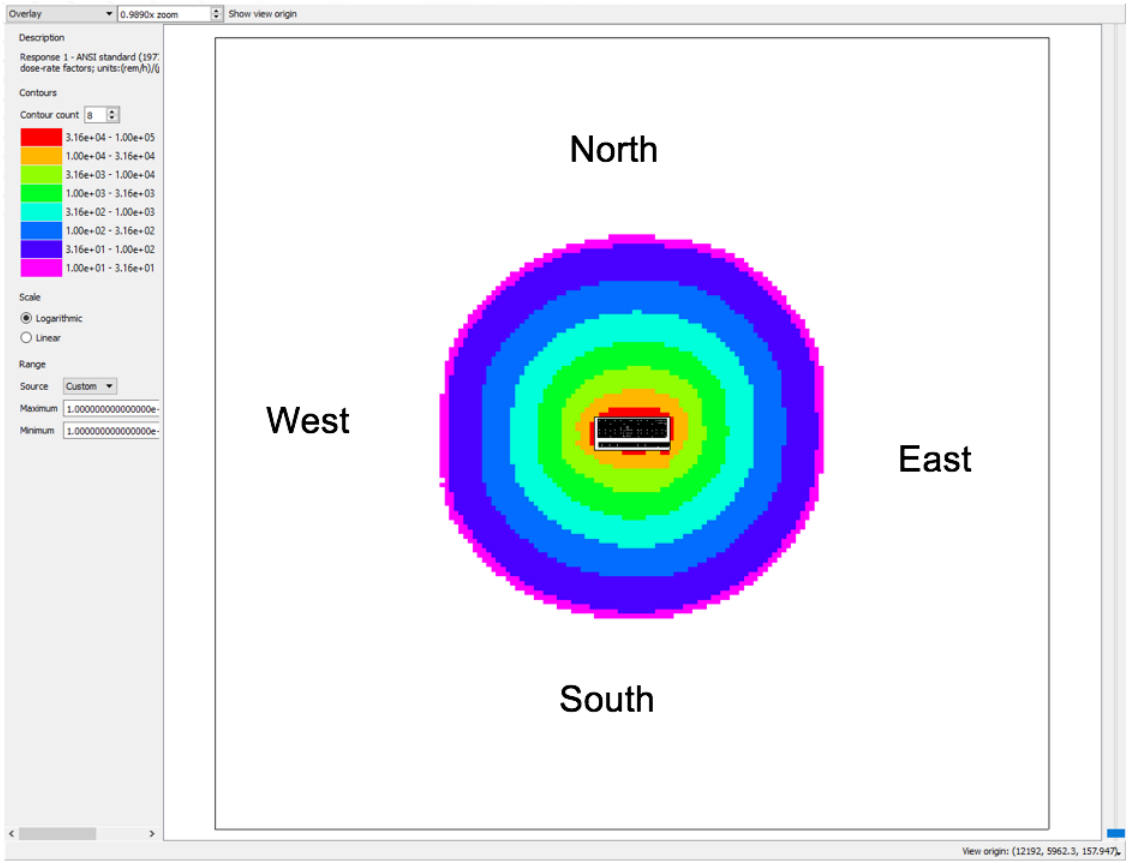


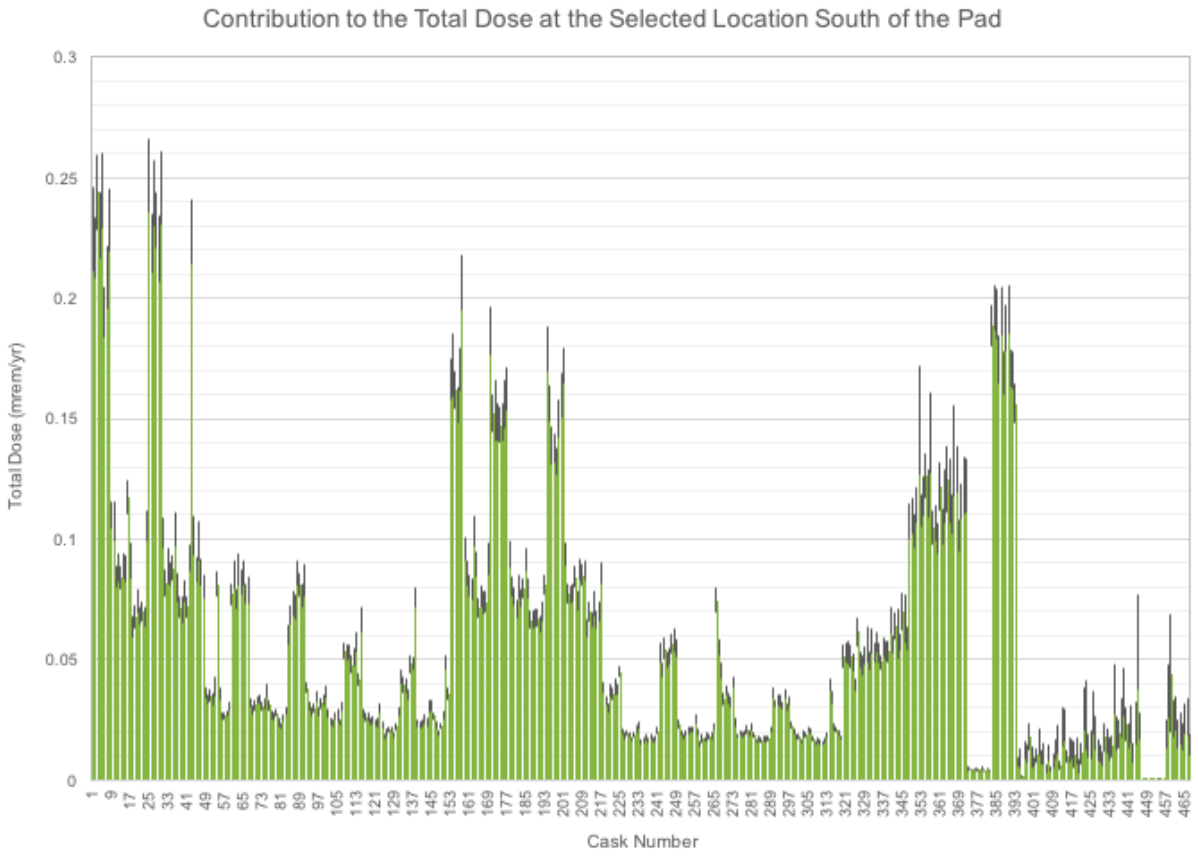
Dose rate error at the controlled area boundary < 10%

* American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors, ANSI/ANS 6.1.1-1977, American Nuclear Society (1977).
† "Standard Review Plan for Spent Fuel Dry Storage System at a General License Facility," NUREG-1536 Rev.1, US Nuclear Regulatory Commission (2010).

25 mrem/yr Dose Rate Contour

- Dose contours fit inside a box with these dimensions: 1.25 km x 1.25 km
- Individual cask contribution depends on cask shielding design, design basis radiation sources, and its relative location within the storage pad.





Conclusions

- Evaluation of controlled area boundary for a proposed consolidated interim spent fuel storage facility to support NRC review of license application
- SCALE provides capabilities for detailed shielding analyses of individual SNF casks and large spent fuel dry storage facilities
- MAVRIC – Monte Carlo shielding analysis sequence
  - Automated variance reduction to efficiently generate detailed dose rate maps
- ORNL institutional computer resources available to perform large number of calculations

Acknowledgements

- This work was supported by the US Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, Division of Spent Fuel Management

Thank you for your attention!