REVIEW OF CRITICALITY SAFETY ANALYSES FOR FISSILE MATERIAL TRANSPORTATION PACKAGES

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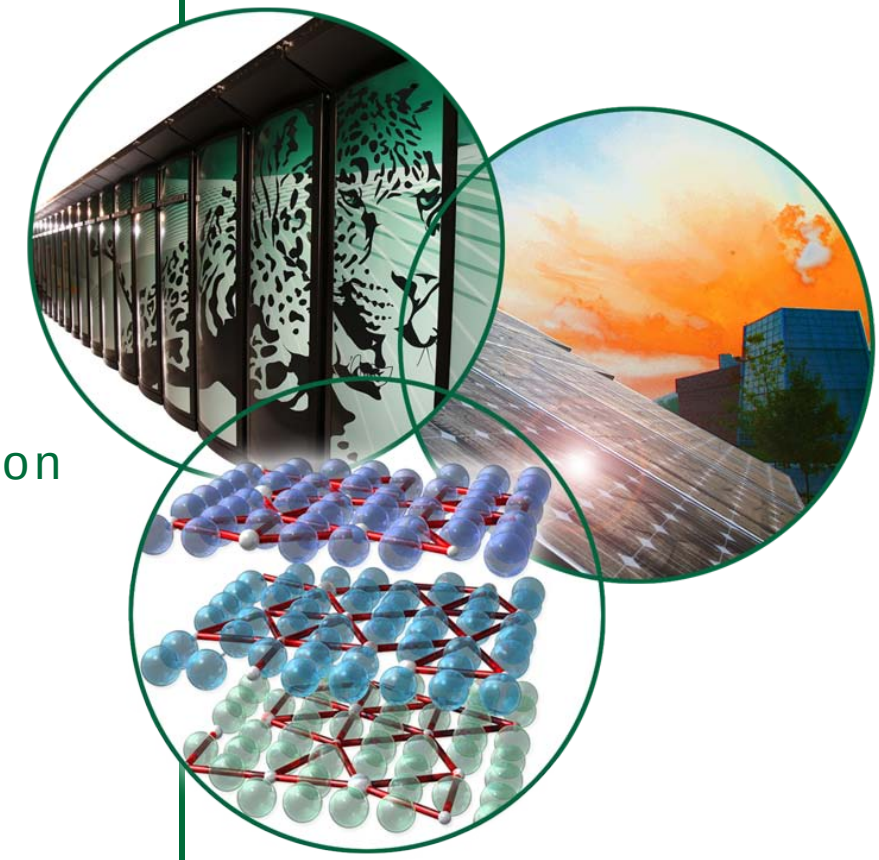

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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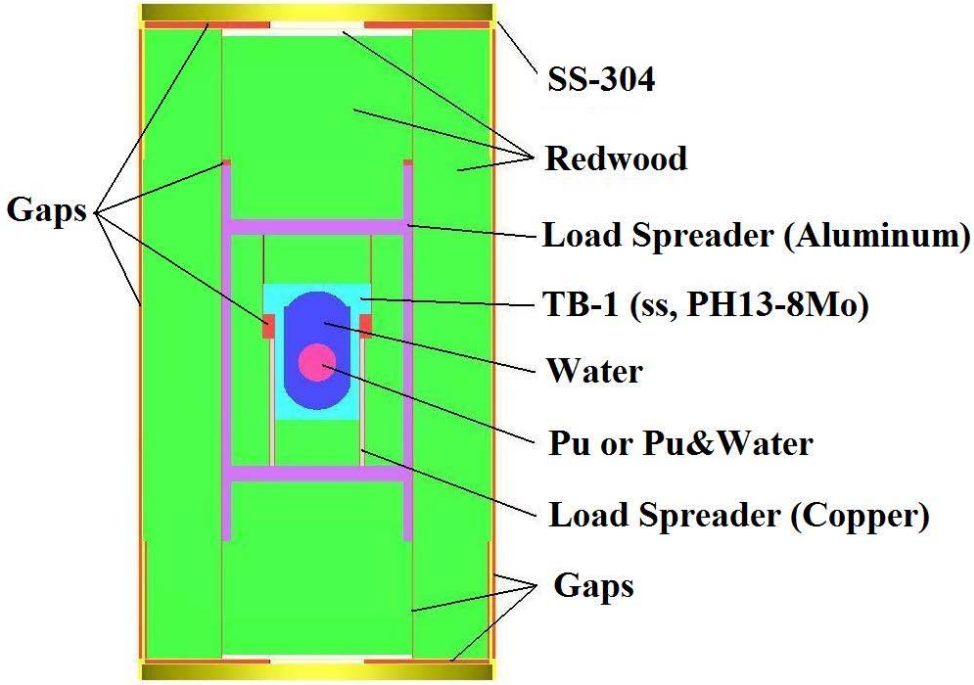
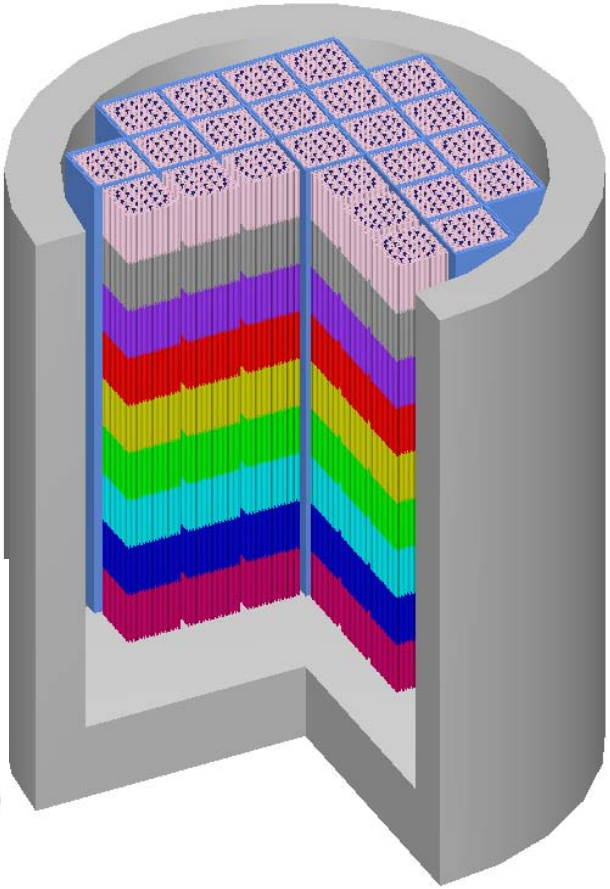
Introduction

- Setting expectations
- Resources
- Regulatory responsibility
- Regulatory review





Setting Expectations

- Communication!
  - It is very important to communicate regulatory expectations to staff preparing the criticality analysis and to the reviewers
    - regulatory requirements
    - submittal format, content and schedule
  - U.S. NRC does this by making “regulatory guides,” “standard review plans” and “interim staff guidance” available
  - U.S. NRC also publishes NUREG reports addressing analysis and licensing issues
  - NUREG/CR-5661, “Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages,” contains guidance for preparing criticality safety evaluations

Setting Expectations

- Quality Assurance!
  - QA program, 10 CFR Part 71, Subpart H
    - 10CFR71, Packaging and transportation of radioactive material
    - Subpart H covers QA associated with design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of components of packaging that are important to safety
  - QA program, 10 CFR Part 72, Subpart G

    10CFR72 includes coverage of independent storage of spent nuclear fuel
  - Level of review should include consideration of QA Program maturity and strength

Regulatory Requirements & Review

- U.S. NRC Requirements from 10 CFR Part 71

- Useful references for review:
  - NUREG-1609, SRP for Transportation Packages for Radioactive Material
  - NUREG-1617, SRP for Transportation Packages for Spent Nuclear Fuel
  - NUREG-1536R1, SRP for Dry Cask Storage Systems
  - NUREG-1567, SRP for Spent Fuel Dry Storage Facilities
  - Various Interim Staff Guidance documents
  - NUREG/CR-5661, Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages

Performing a Review

- U.S. NRC regulatory reviews typically provide a "reasonable assurance of safety"
- Lower quality or incomplete submittals either rejected or receive additional scrutiny
- Criticality review effort varies with
  - complexity of package design,
  - complexity of supporting analyses, and
  - margin to limits

Regulatory Review

- Ensure regulatory requirements are identified and met
  - Submittal should identify relevant regulatory requirements and describe how the requirements are met
  - Reviewer should confirm and agree

Regulatory Review

- Acceptable methods and data used
  - Methods used could be computational, but could also include other defensible data sources
  - Analysis methods and data used should be described
  - Some older nuclear data sets should not be used (HR 16-Group)
  - Multi-group data collapsed using appropriate neutron spectra
  - Reviewer should confirm that acceptable methods and data were used

Regulatory Review

- In U.S.
  - MCNP and SCALE-KENO frequently used for k_{eff} calculations
  - CASMO, SCALE SAS & TRITON (both ORIGEN-S based), TGBLA, Phoenix, PARAGON have been used for spent fuel composition calculations

MCNP

scale

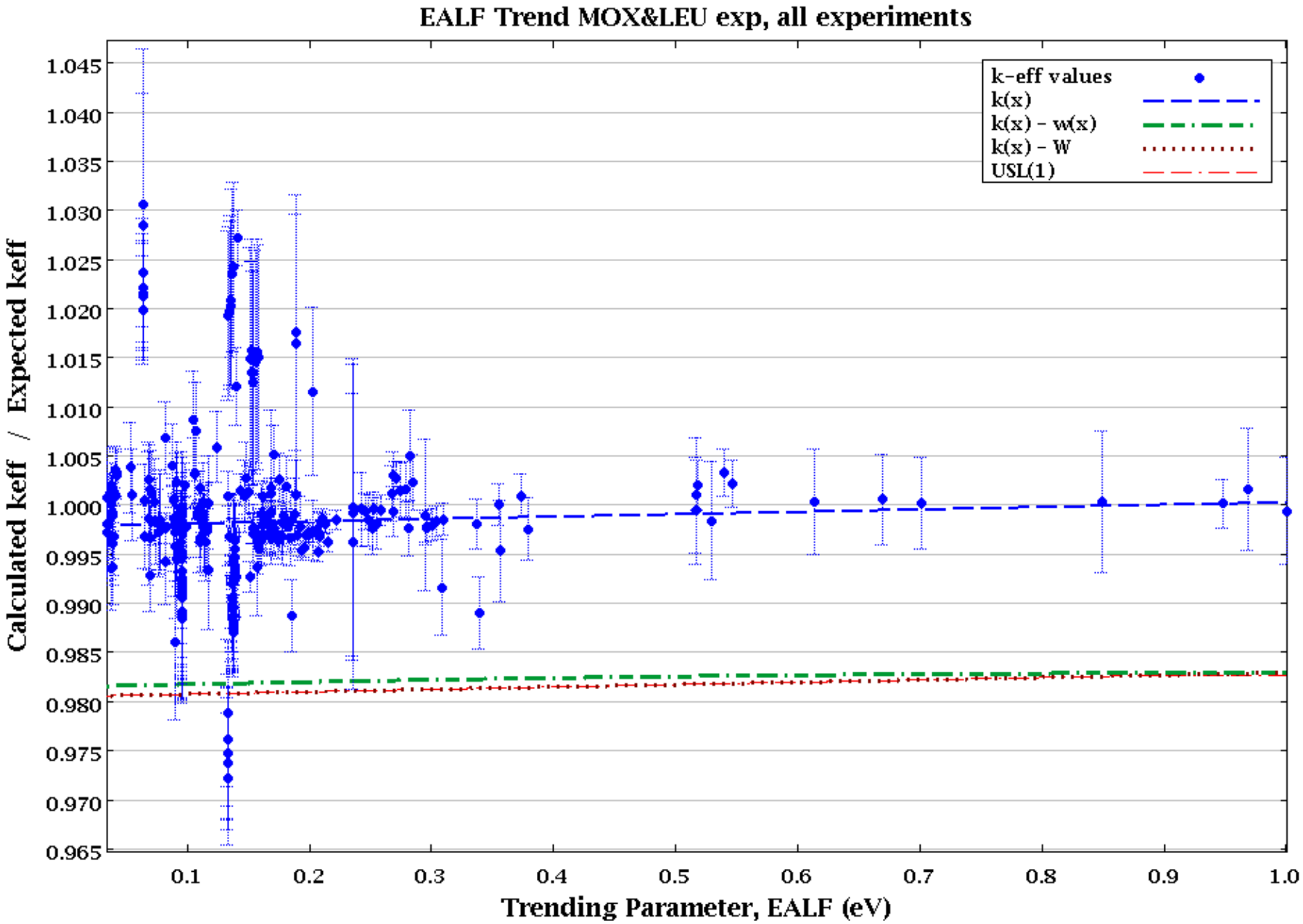
Nuclear Systems Modeling & Simulation

Regulatory Review

- Computational method validation – K_{eff} calculations
  - Validated by simulation of critical experiments that are similar to safety analysis models
  - Simulation results used to quantify bias and uncertainty associated with computational method and data
  - In U.S., uncertainty is the margin to the k_{eff} limit required to ensure that the actual k_{eff} value is below the limit

    Safety analysis k_{eff} value + bias + uncertainty < limit

  - With 95% probability with a 95% confidence level

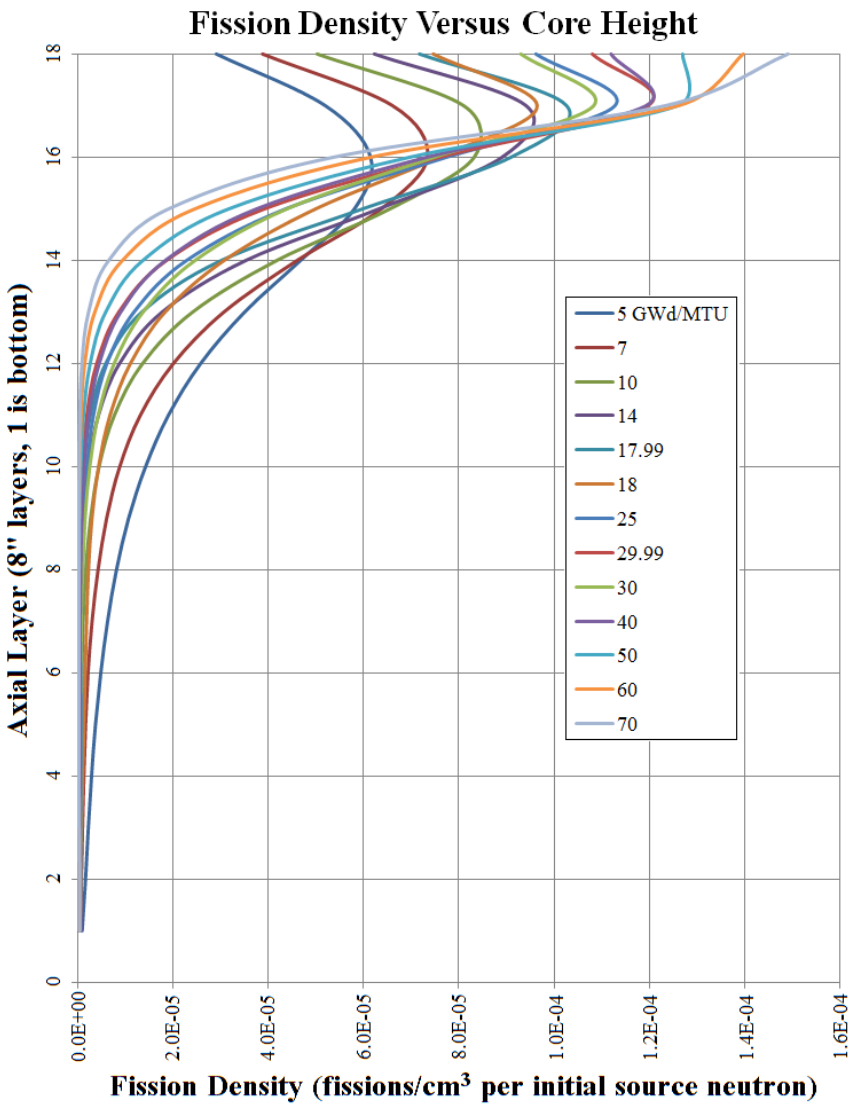

EALF Trend MOX&LEU exp, all experiments
k-eff values
k(x)
k(x) - w(x)
k(x) - W
USL(1)
Calculated keff / Expected keff
1.045
1.040
1.035
1.030
1.025
1.020
1.015
1.010
1.005
1.000
0.995
0.990
0.985
0.980
0.975
0.970
0.965
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Trending Parameter, EALF (eV)

Regulatory Review

- Computational method validation – K_{eff} calculations
  - Gaps & weaknesses in validation identified and addressed
  - Statistical methods and related-base assumptions (e.g. normality) should be described and defended
- Discussion on validation?

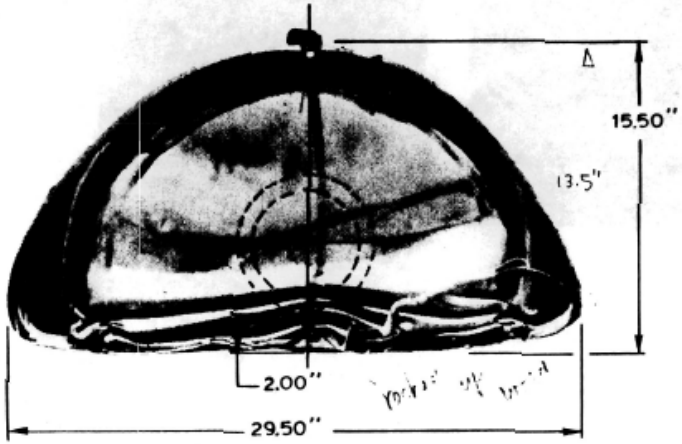
Regulatory Review

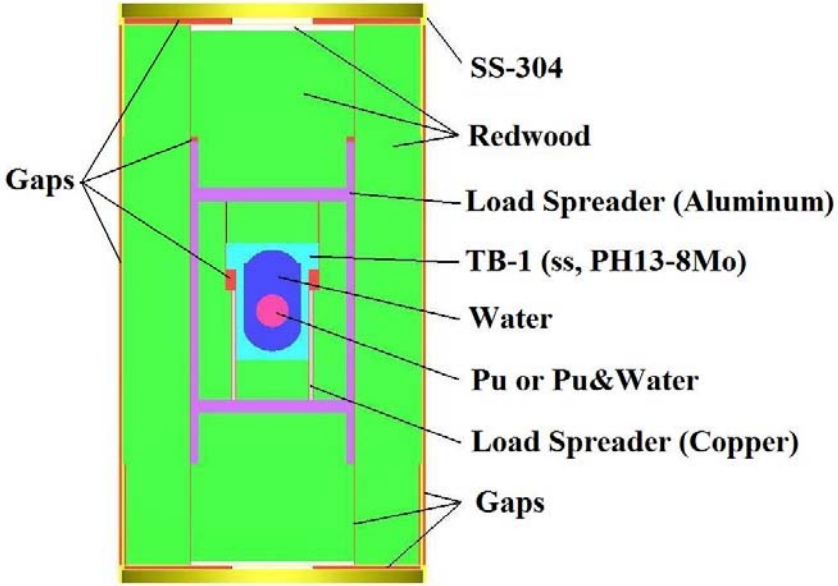
- Analysis is thorough and complete
  - Package contents (examine full range of contents)
    - Bounding contents model may vary (dry vs flooded, single package vs array, NCT vs HAC)
    - When flooded, something less than maximum allowed FM may be limiting
    - For SNF BUC, conservative burnup credit analysis approach used
    - Assumptions, simplifications, approximations identified and defended
    - Consider other intermixed materials and content-specific packaging
    - Consider any special "moderating materials" that may be present



Regulatory Review

- Analysis is thorough and complete
  - Package models (normal and damaged)
    - Tolerances and uncertainties handled conservatively
    - Credit for neutron absorbers (limit to 75% of minimum?)
    - Damaged package models reflect actual post-testing configurations or more conservative bounding configurations
    - Assumptions, simplifications, approximations identified and defended





Regulatory Review

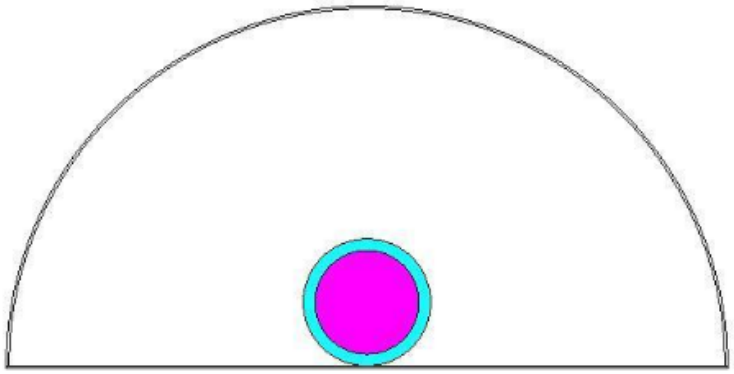
- Evaluation of single packages includes
  - Most reactive credible configuration, consistent with the chemical an physical form of contents (solid piece vs water soluble powder)
  - Close full density water reflection of the containment system
  - Look at various reflector materials, present in the packaging, that may provide better neutron reflection than water
  - Explore various combinations of optimum moderation inside undamaged and damaged packages
  - Look at variations in which some “zones” are not flooded with optimum moderation

Regulatory Review

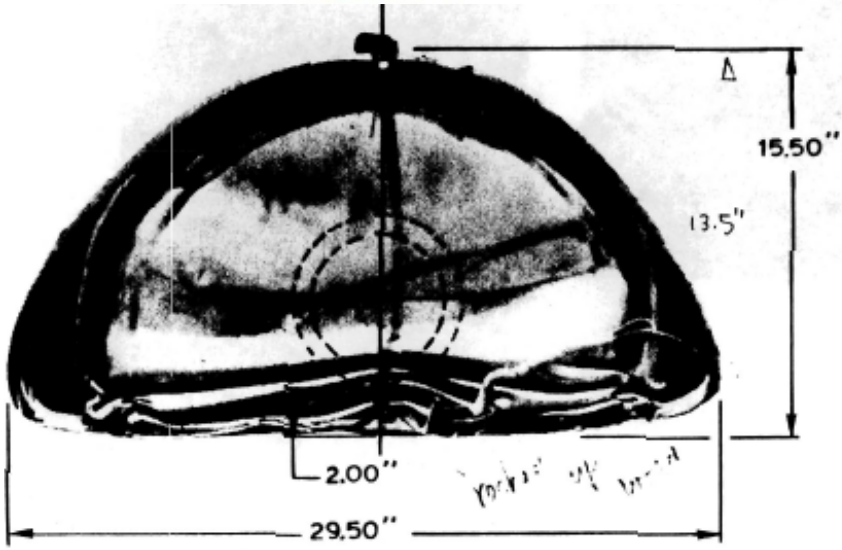
- N = maximum number of packages per shipment for nonexclusive use shipment
- 2N = maximum number of packages per shipment for exclusive use shipment
  - 5N undamaged packages subcritical in <u>any</u> arrangement with nothing between packages – finite arrays water-reflected
  - 2N damaged packages subcritical in <u>any</u> arrangement with optimum interspersed moderation – finite arrays water-reflected
    - Carefully explore various combinations of optimum moderation between and inside damaged packages
    - Look at variations in which some "zones" are not flooded with optimum moderation
- $TI_{criticality} = 50 \div N$, rounded up to nearest 0.1

Regulatory Review

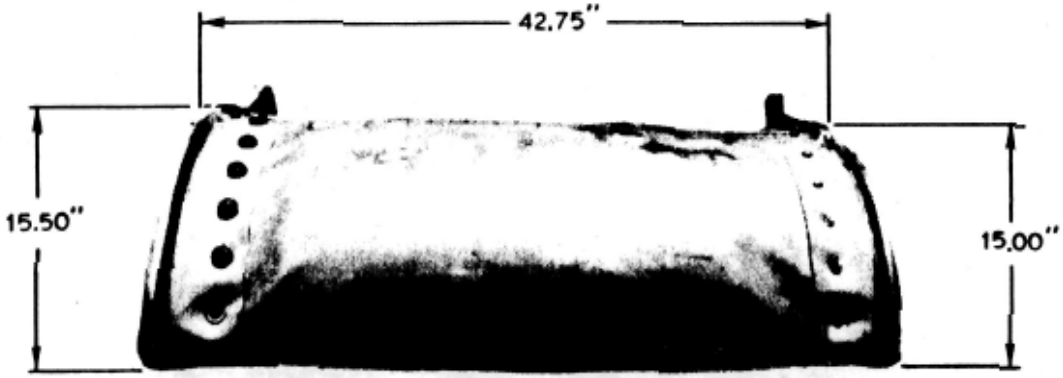
- Hypothetical accident conditions (single package & arrays)
  - Use post-test container descriptions to generate HAC models
  - Or use bounding models



End View

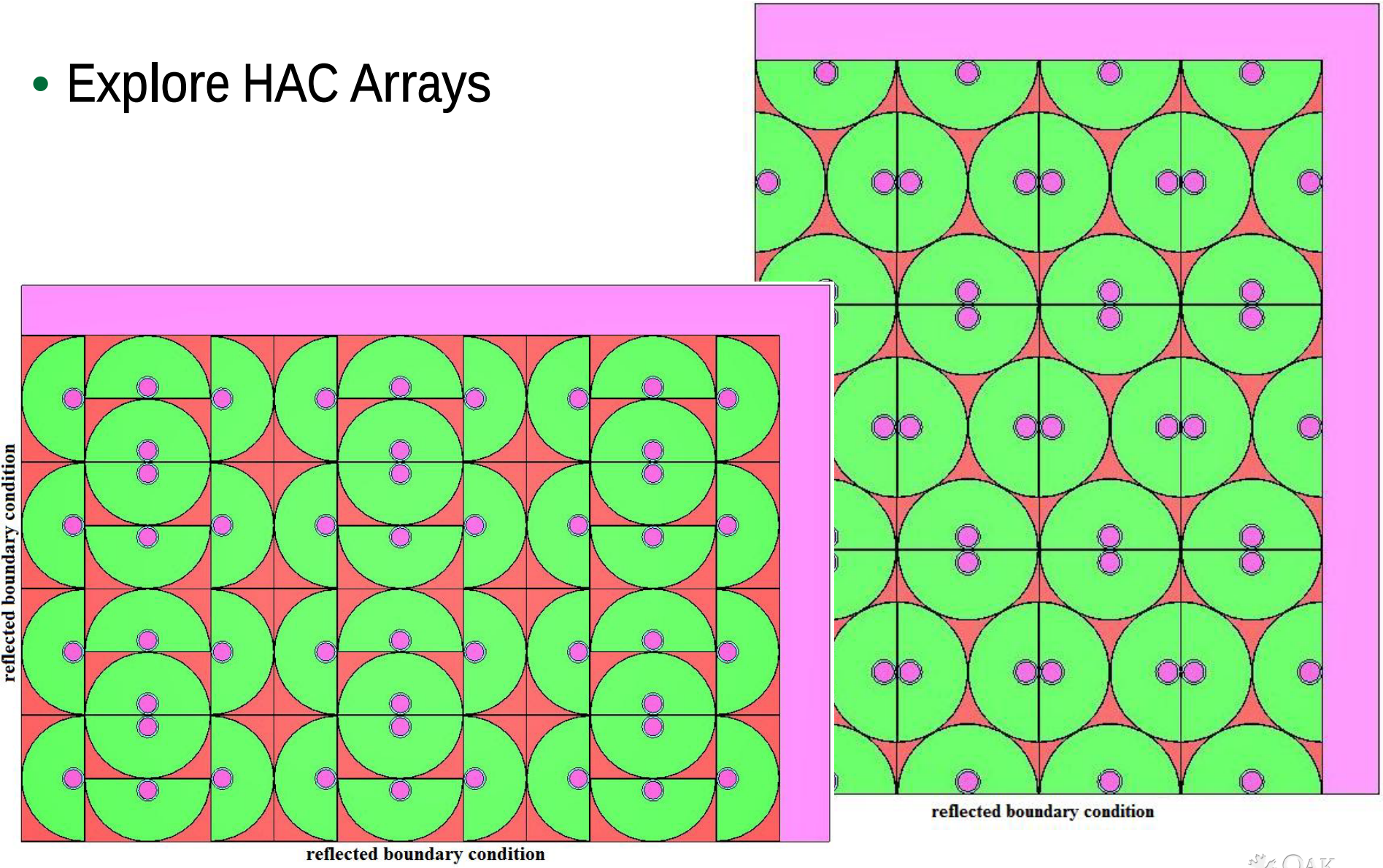


Bottom View



Regulatory Review

- Explore HAC Arrays

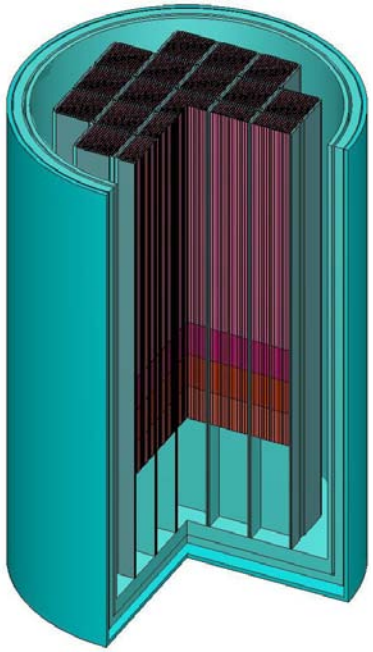


Regulatory Review

- Perform confirmatory calculations, if needed
  - Reviewer may do as many as needed to develop a “reasonable assurance of safety”
  - May also compare results from previously approved packages to results for new package
  - May do calculations to check some assertions, simplifications, approximations, assumptions
  - For burnup credit, reviewer might
    - pick a few points on a loading curve and calculate k_{eff} to confirm loading curve
    - perform fuel depletion calculations to confirm that conservative depletion parameters were used
    - try various axial burnup shapes to confirm conservative axial burnup shape used
  - Confirmatory calculations are not required, but may add confidence

Regulatory Review

- Submittal should contain everything the reviewer needs to confirm compliance with regulations and to have a reasonable assurance of safety
- Reviewer should not fill in gaps in analysis
- Confirm that criticality section is consistent with the rest of the application
  - Inconsistent but conservative is ok, should be justified



Regulatory Review

- In U.S., transportation requirements are found in package certificate-of-compliance (COC)
- Confirm that transportation requirements are not ambiguous and are consistent with analysis
  - Allowable contents
  - Allowable extra packaging, such as spacers and plastic bags
  - Packaging requirements
  - Burnup credit loading limits
- Clear, exact and comprehensive description of requirements avoids misinterpretation of the license

Questions & Discussion?

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- Thank you for your attention!

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