Mechanical Degradation of Dual Purpose Canisters

Varun; A. Riahi; J. Furtney; and B. Damjanac

Itasca Consulting Group

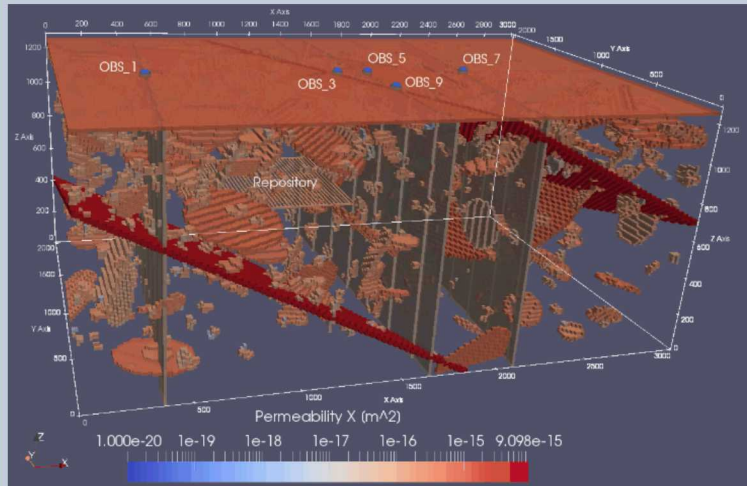
SFWD

Spent Fuel & Waste Disposition

Annual Working Group Meeting
UNLV-SEB – *Las Vegas, Nevada*
May 21-23, 2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2019-***
Approved for Unclassified, Unlimited Release



NOTICES

This is a technical presentation that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent nuclear fuel in canisters to be an acceptable waste form, absent a mutually agreed-to contract amendment. To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract provisions prevail.

Disclaimer: This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Mechanical Degradation of Dual Purpose Canisters

Varun, A. Riahi, J. Furtney and B. Damjanac

Annual Working Group Meeting UNLV-SEB – Las Vegas, Nevada

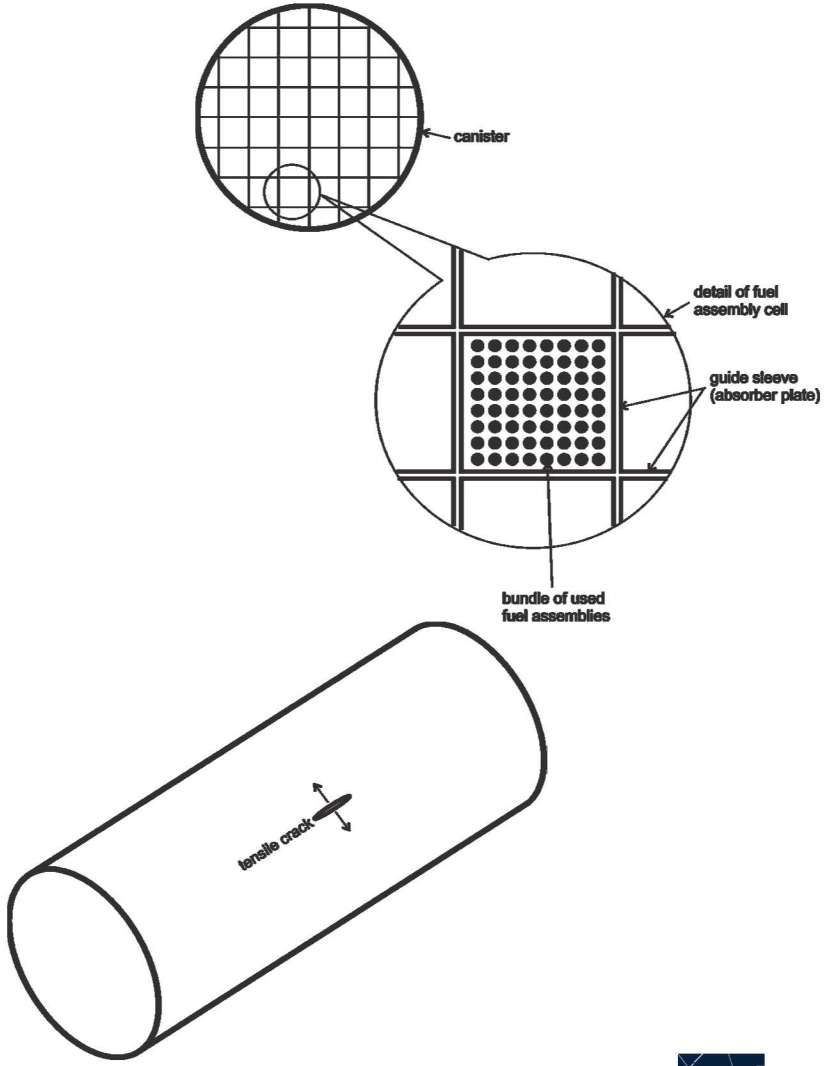
May 21-23, 2019

Introduction

- Degradation of internal structure of dual purpose canisters (DPC) will affect potential onset and evolution of nuclear criticality
- Complex problem involving interacting (coupled) chemical, nuclear, thermal, hydraulic and mechanical processes taking place on different time and length scales
- Simplifications in the initial analyses
  - Separate models focused on different scales and structures
  - Mechanical degradation due to corrosion of plates and stainless steel components under gravitational and seismic loads disregarding coupling with nuclear, thermal and hydraulic process
- Coupling of different physical processes will be included in later stages of the project
- Analyses consider egg crate canister design (Holtec MPC 32 with METAMIC basket)

Model Overview

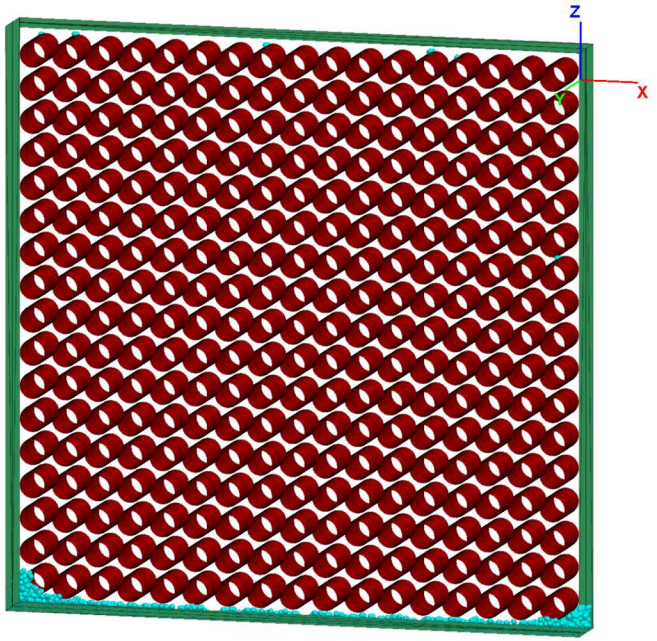
- Fuel Assembly Cell Model
  - Transport and deposition of aluminum-based plate corrosion products within the cell
- Basket Degradation Model
  - Structural failure and disaggregation of basket structural elements
- Waste Package Breach Model
  - Effect of criticality on breach in canister overpack



Fuel Assembly Cell Model

Model Features

- Pseudo-3D model to account for proper packing
  - A thick slice of the cross section perpendicular to the axis of the canister (y-axis)
  - Periodic boundaries along the axis of the canister (y-axis), i.e., material leaving from one face will enter back from the other face.
  - Can change the orientation by specifying the direction of gravity (in the *x*-*z* plane). However, it is assumed that the axis of the canister stays horizontal.
  - Fuel rods and basket components are fixed



Model layout showing plates (green), fuel rods (red), and corrosion products (blue)

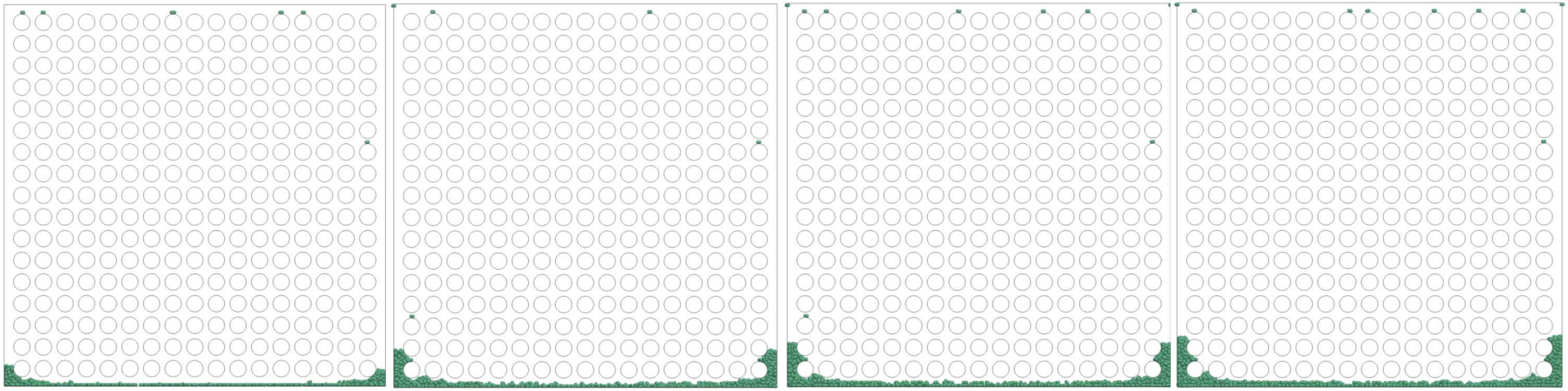
Assumptions

- The fuel cell is assumed to be filled with water
  - Buoyancy forces act on the balls (or clumps) as they settle through the model
  - A velocity-proportional drag force based on Stoke's law is also applied to each particle.

$$F_D = 6\pi\mu r v$$

- Settling assumption
  - Based on an average particle size ≈ 50 μm → terminal velocity ≈ 0.1 m/s to 0.01 m/s → settling time ≈ a few seconds to a few minutes
  - Slow rate of corrosion → not be many particles settling at the same time → a settling particle will likely interact with fuels cells, plates, and other already settled particles only and not interact with other settling particles
  - The computation time is reduced by having multiple particles settling at the same time provided they do not interact with each other.

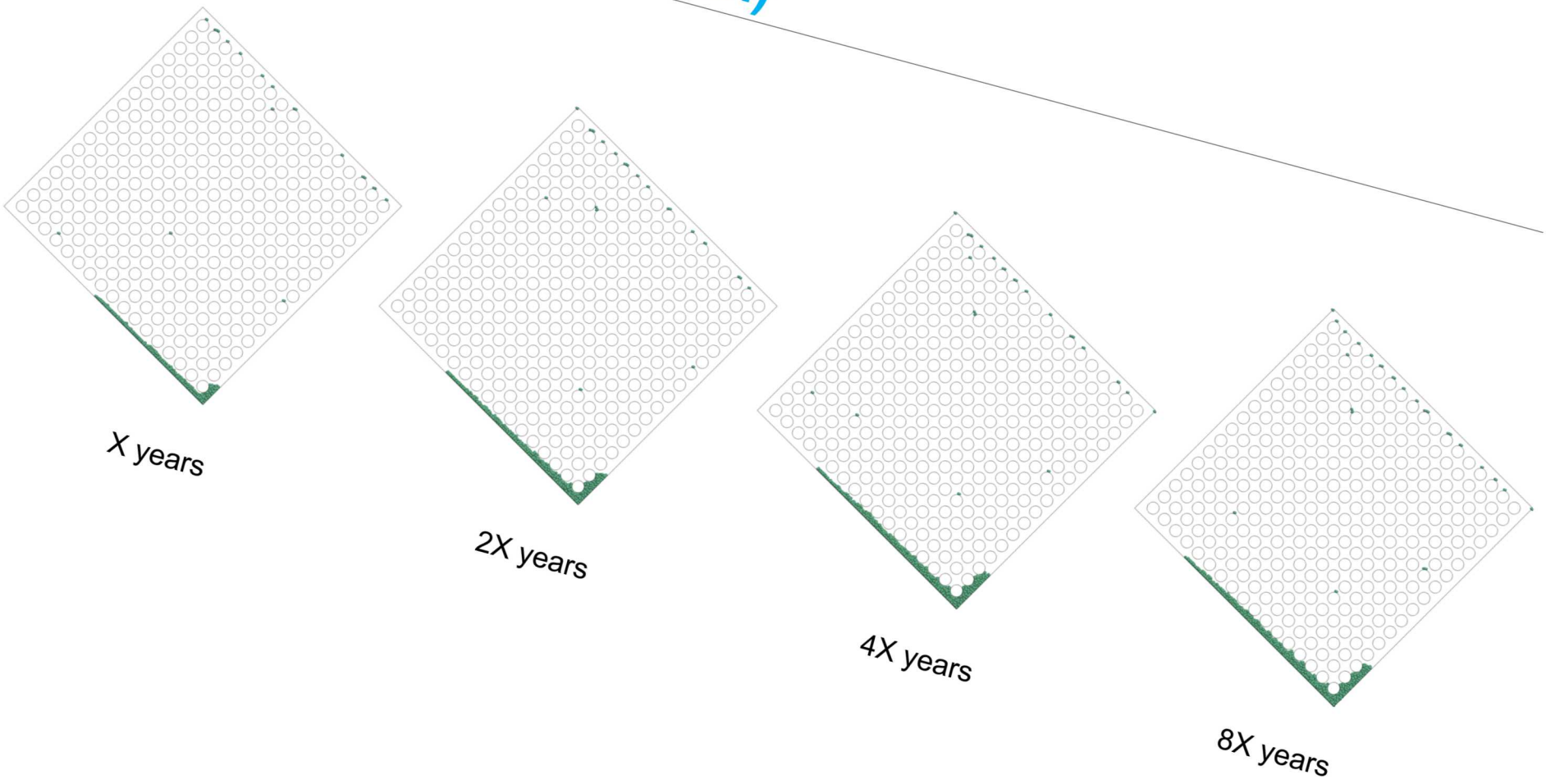
Clumps (0° Orientation)



X years | 2X years | 4X years | 8X years

More particles (clumps) can be observed sticking around on the fuel rods due to rotational resistance

Clumps (30° Orientation)



Basket Degradation Models

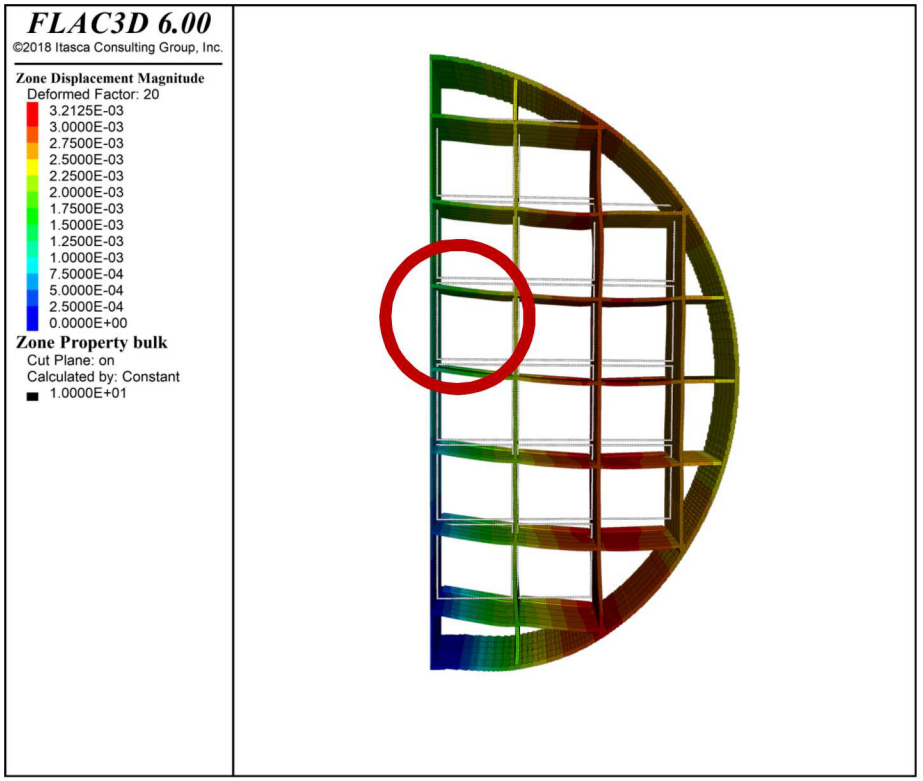
Modeling Approach

- Continuum model (*FLAC3D*) is used to investigate deformation and failure of structural components vs. time or corrosion progression
  - Elasto-plastic analysis of deformation and yielding
  - Structural components are gradually weakened to represent corrosion
  - Equivalent continuum approximation of the fuel rod assembly
  - Limits on deformation before the model stops due to extensive zone distortion
- Discrete model (*3DEC*) is used to simulate basket collapse under gravity as a result of complete degradation of structural components (e.g., plates and spacers)
  - Explicit representation of structural components and their mechanical interaction
  - Flexural stiffness and strength of fuel rods; other components are rigid
  - Simulation of complete collapse

FLAC3D Model

Magnified Displacements

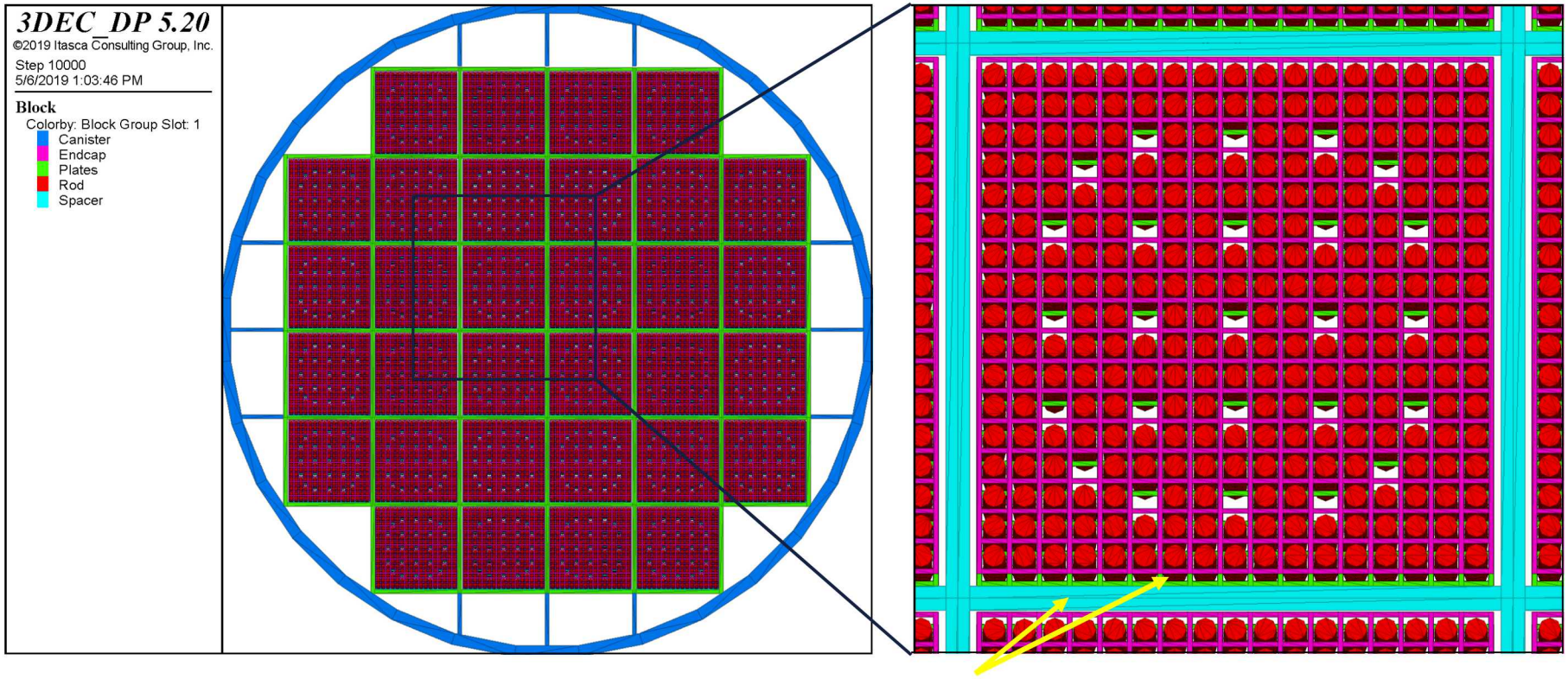
- Total displacements are shown when 80% of plate thickness is corroded (thickness reduced to 2 mm).



3DEC Model

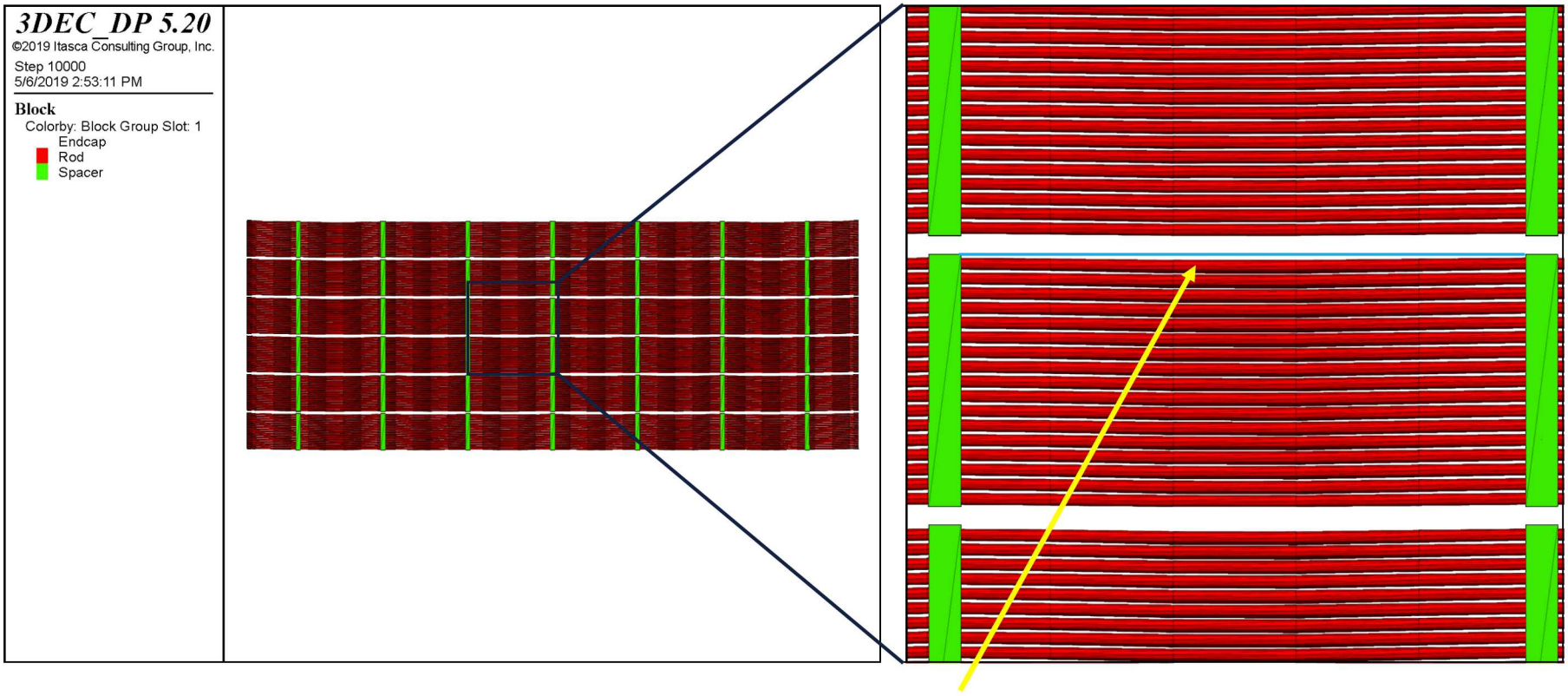
With End Caps

With End Caps (Under Gravity)



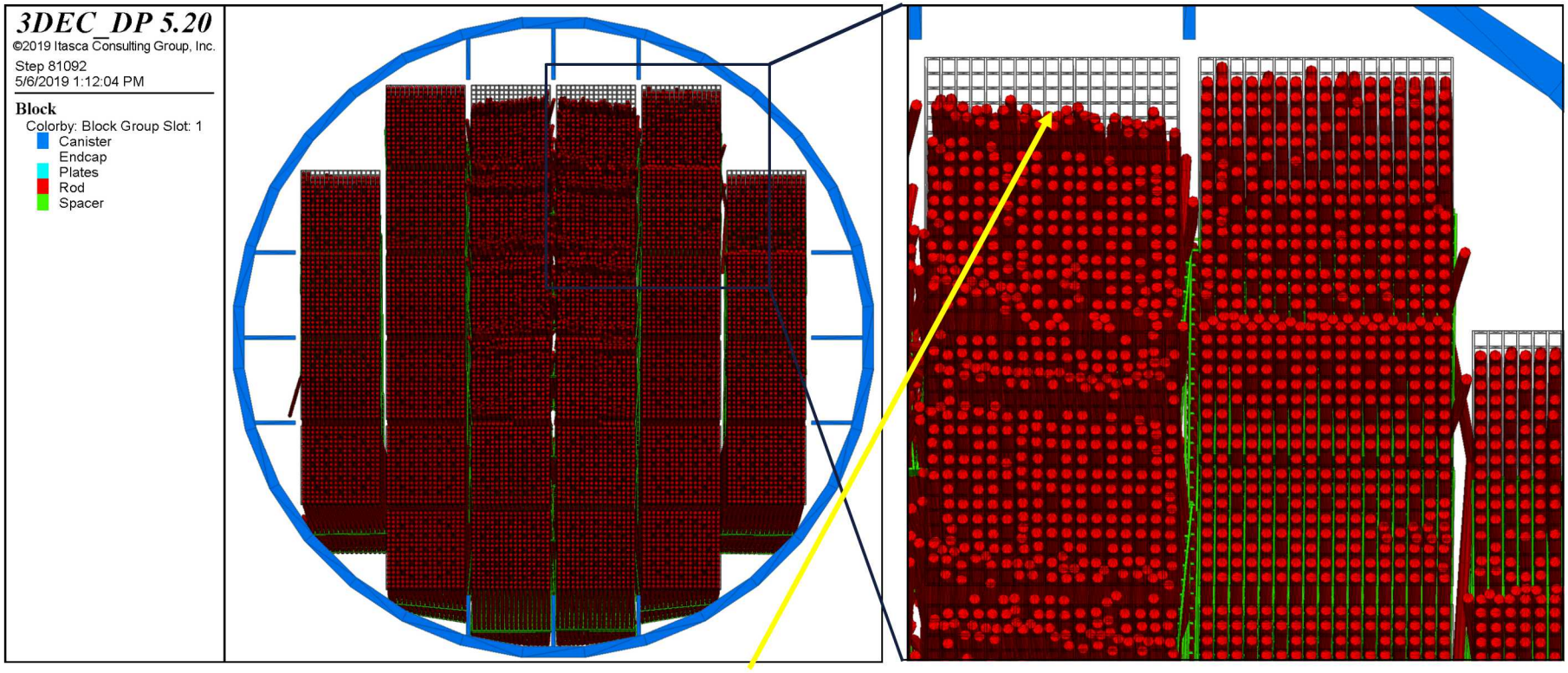
Basket and Spacer grids move downwards under gravity but end caps are fixed

With End Caps (Under Gravity)



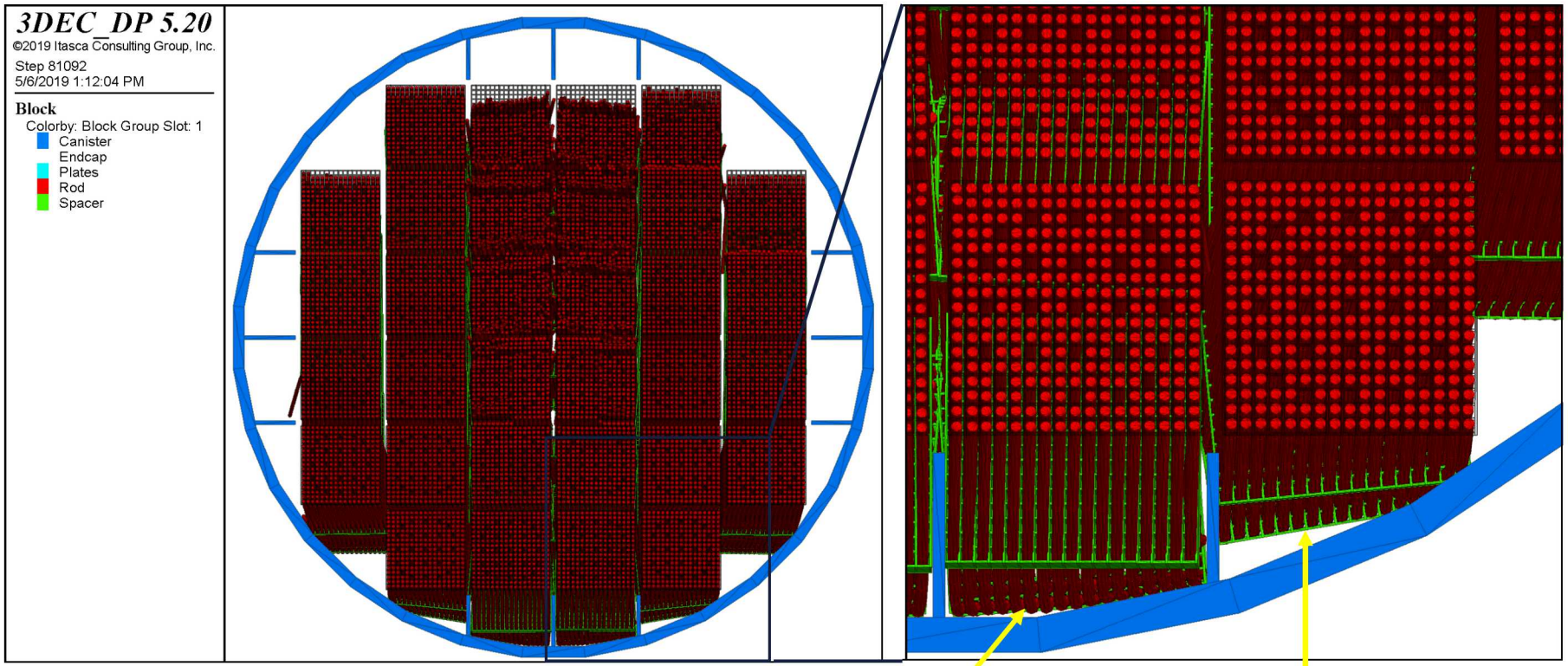
Slight bending of rods under gravity

With End Caps (Basket Plates Corroded)



Rods sliding out of end caps due to bending

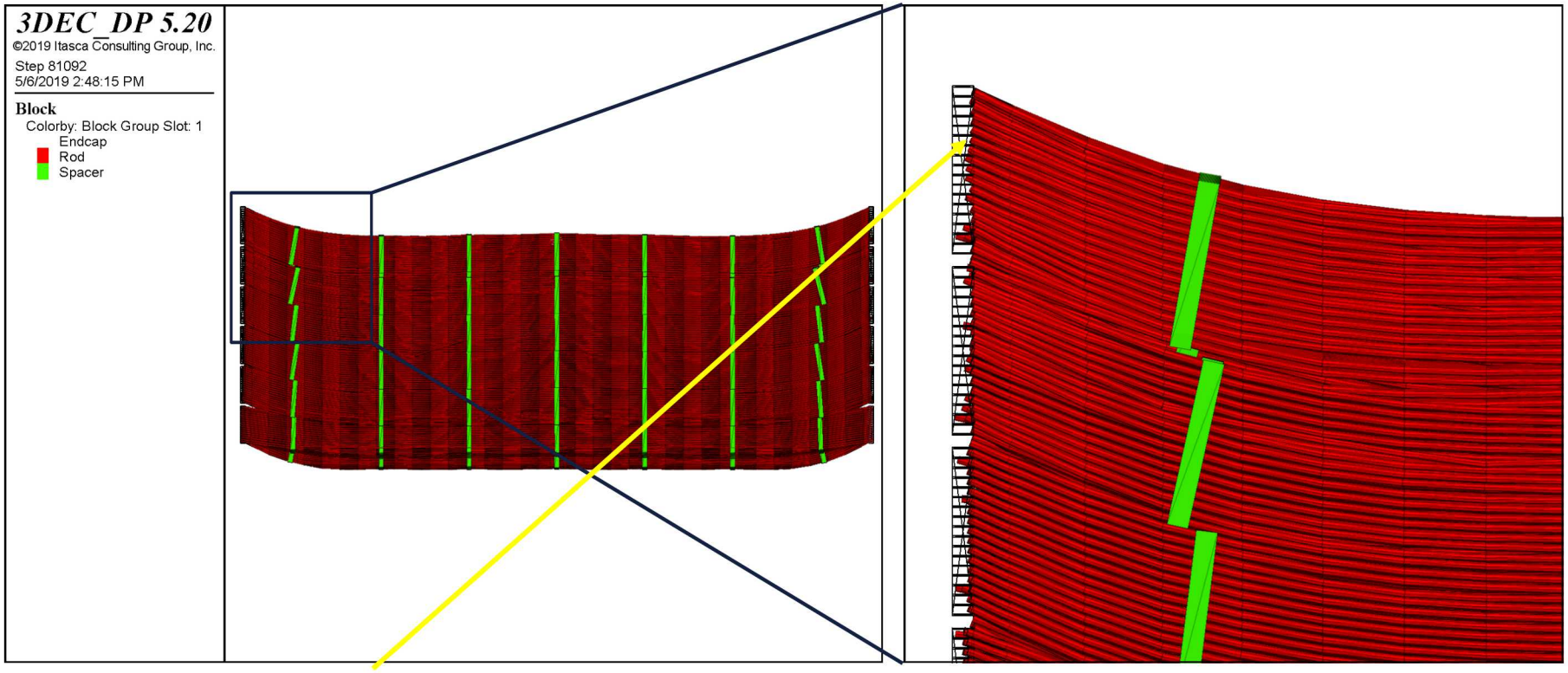
With End Caps (Basket Plates Corroded)



Rods bending and breaking under gravity

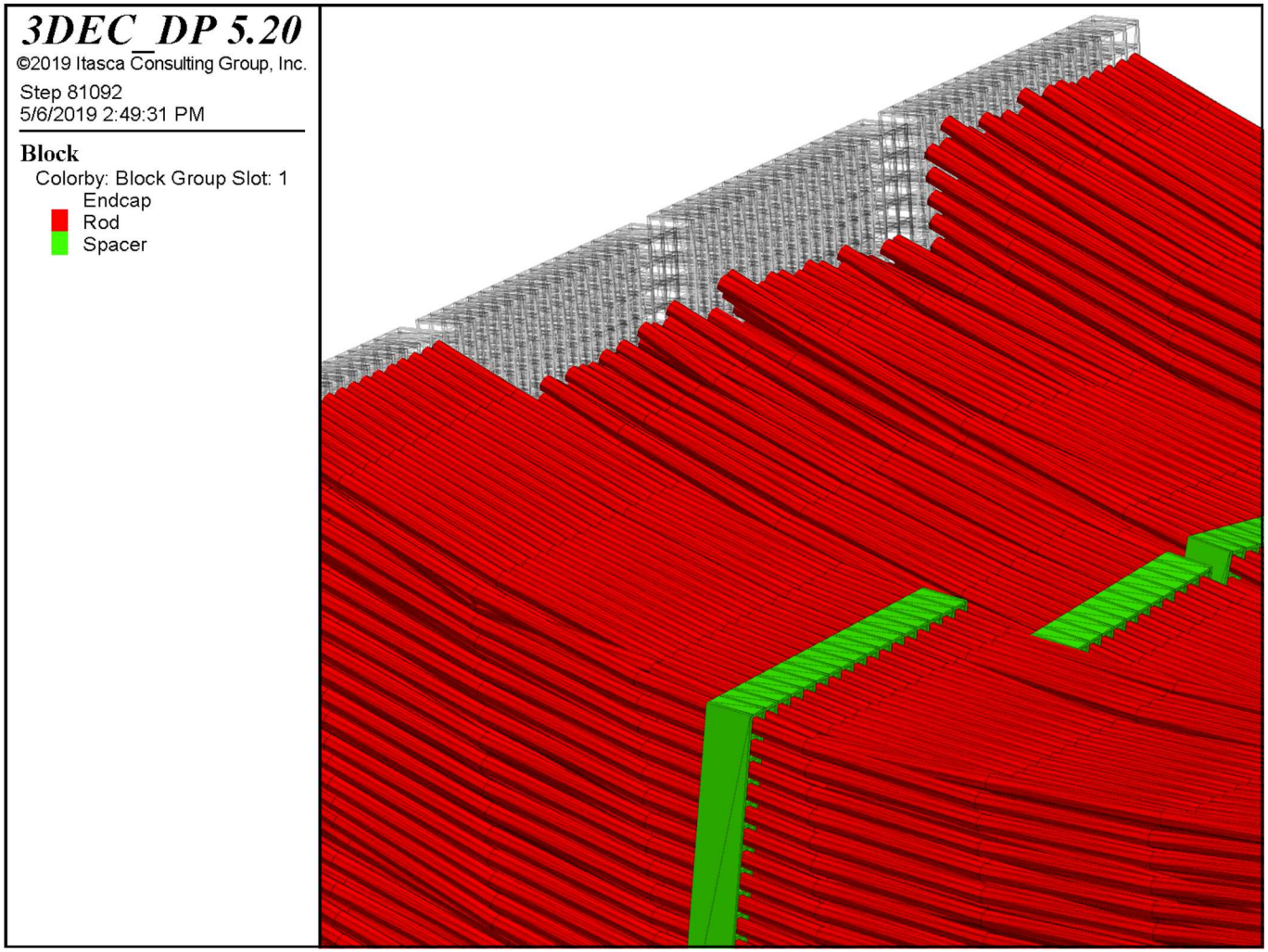
Spacer grids stacking

With End Caps (Basket Plates Corroded)

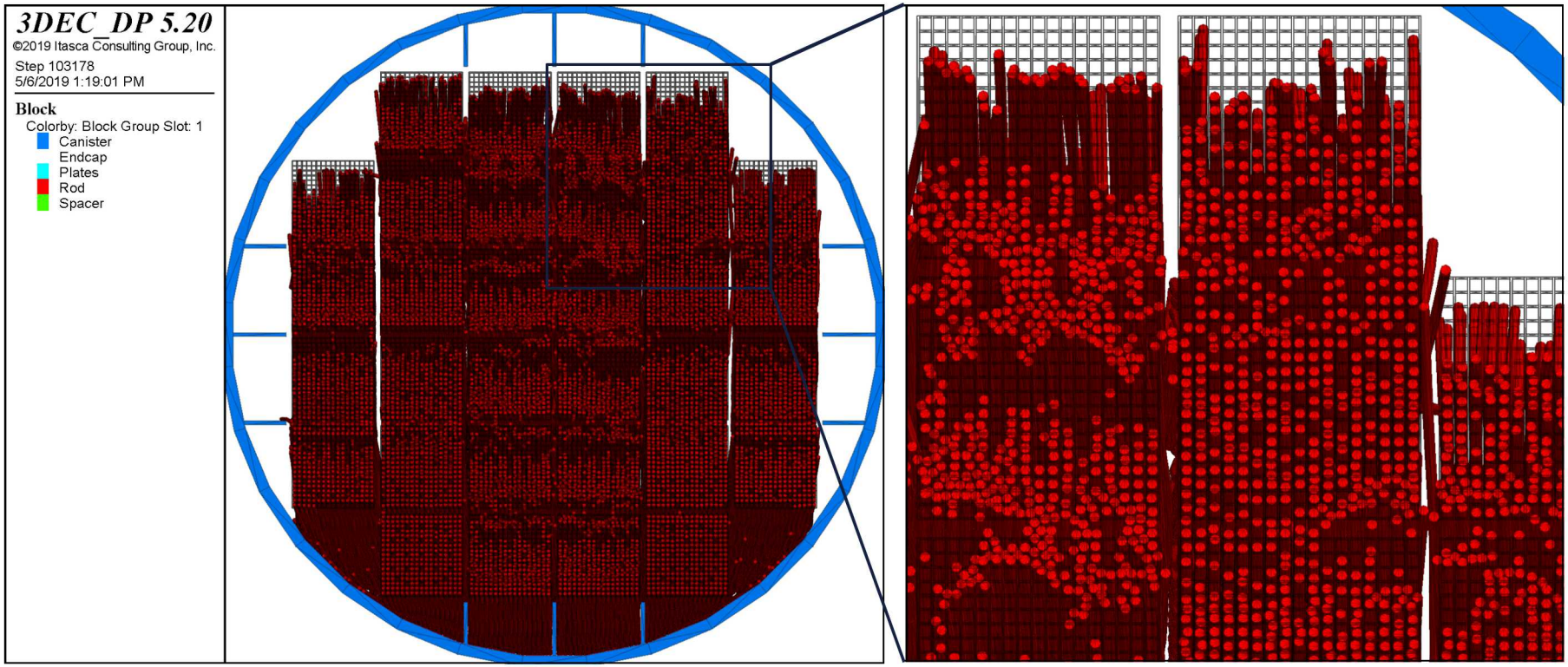


Rods sliding out of end caps due to bending

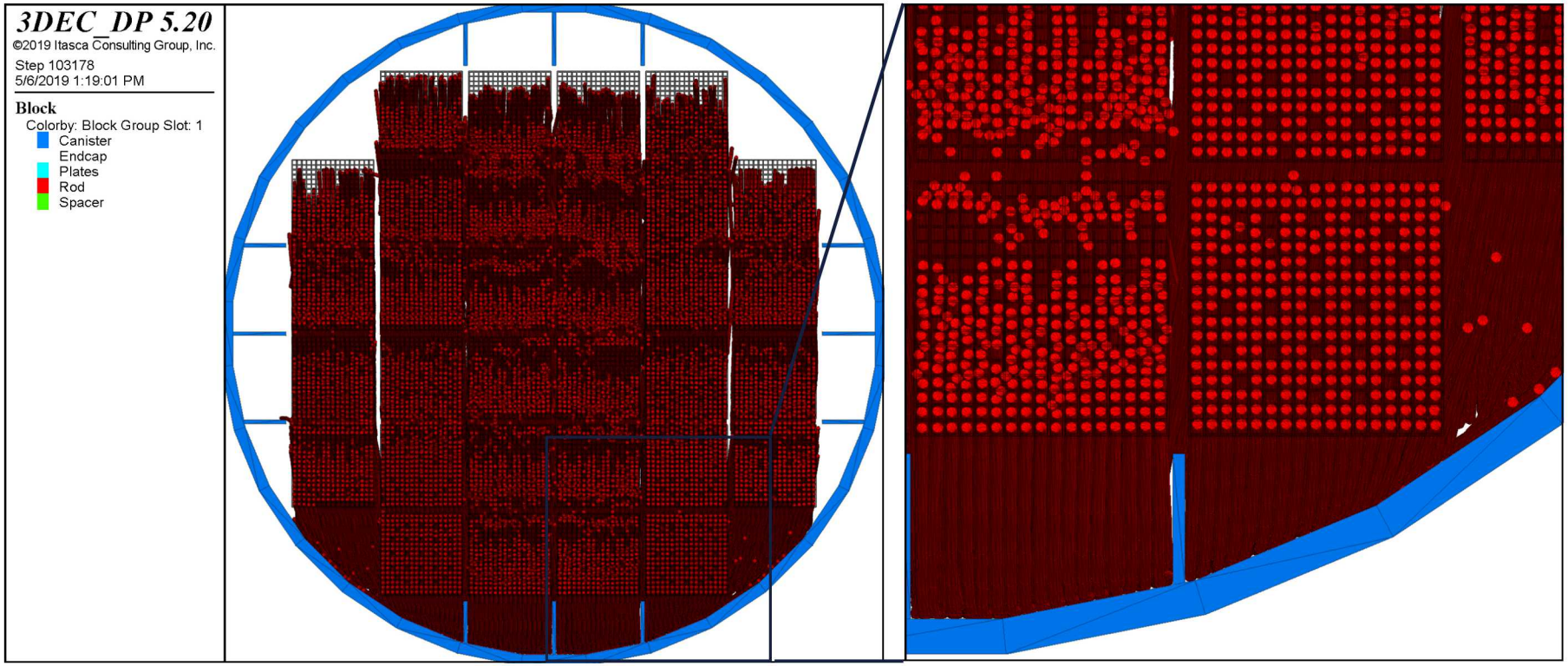
With End Caps (Basket Plates Corroded)



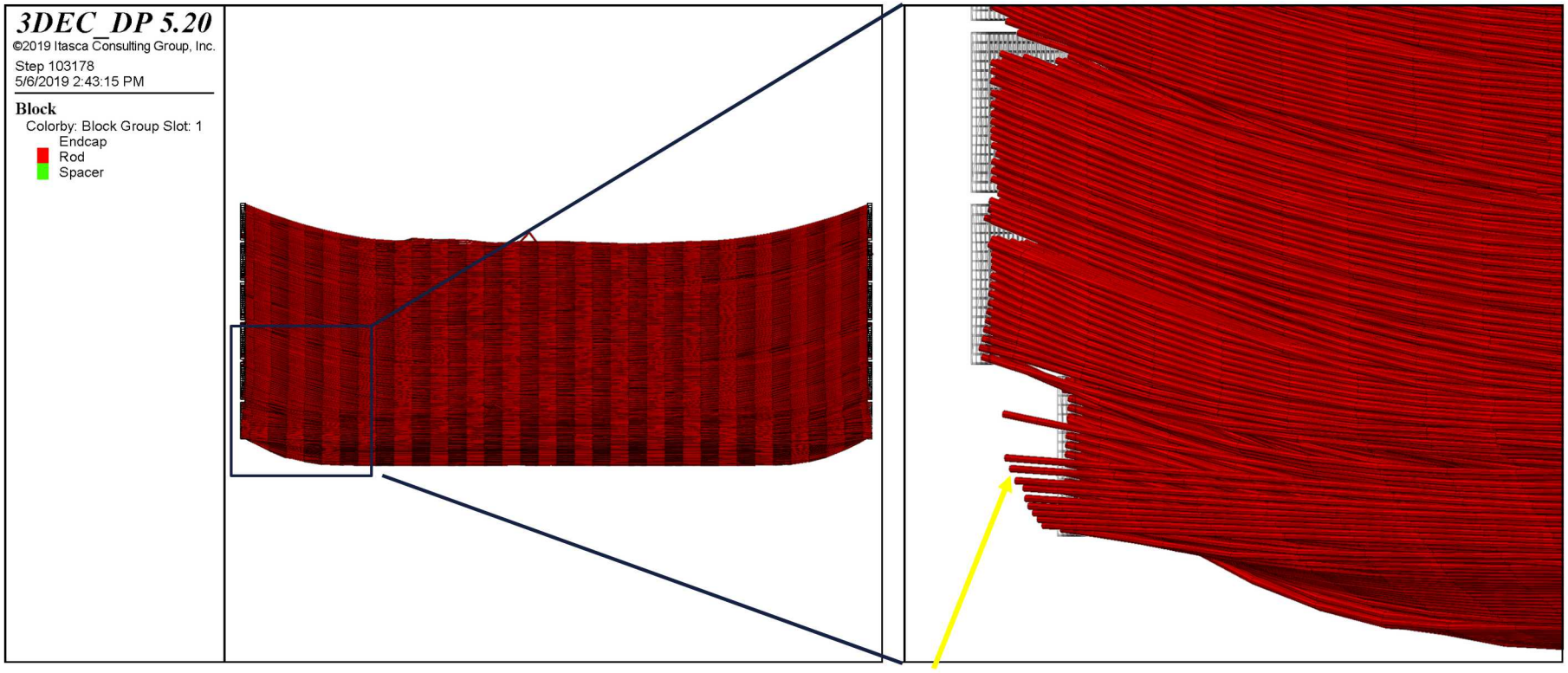
With End Caps (Spacer Grid Corroded)



With End Caps (Spacer Grid Corroded)



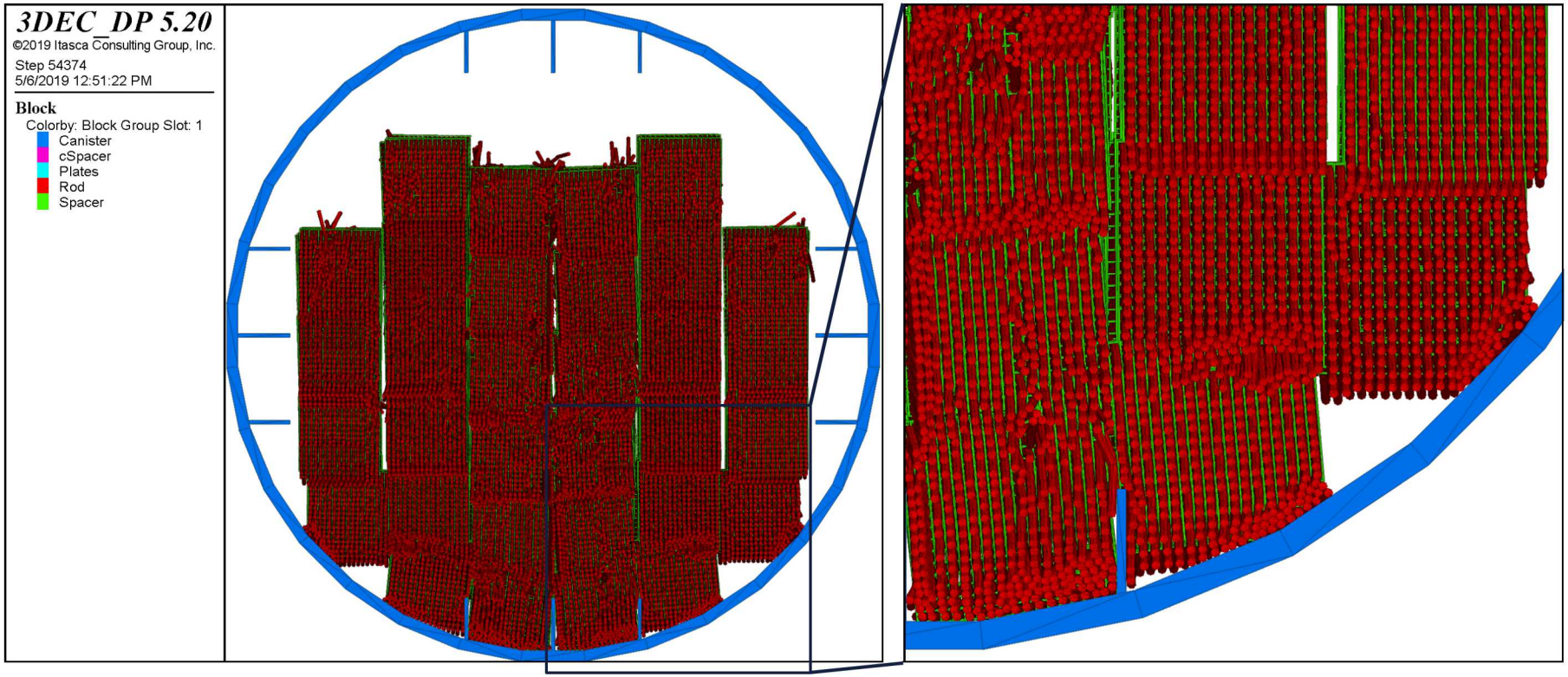
With End Caps (Spacer Grid Corroded)



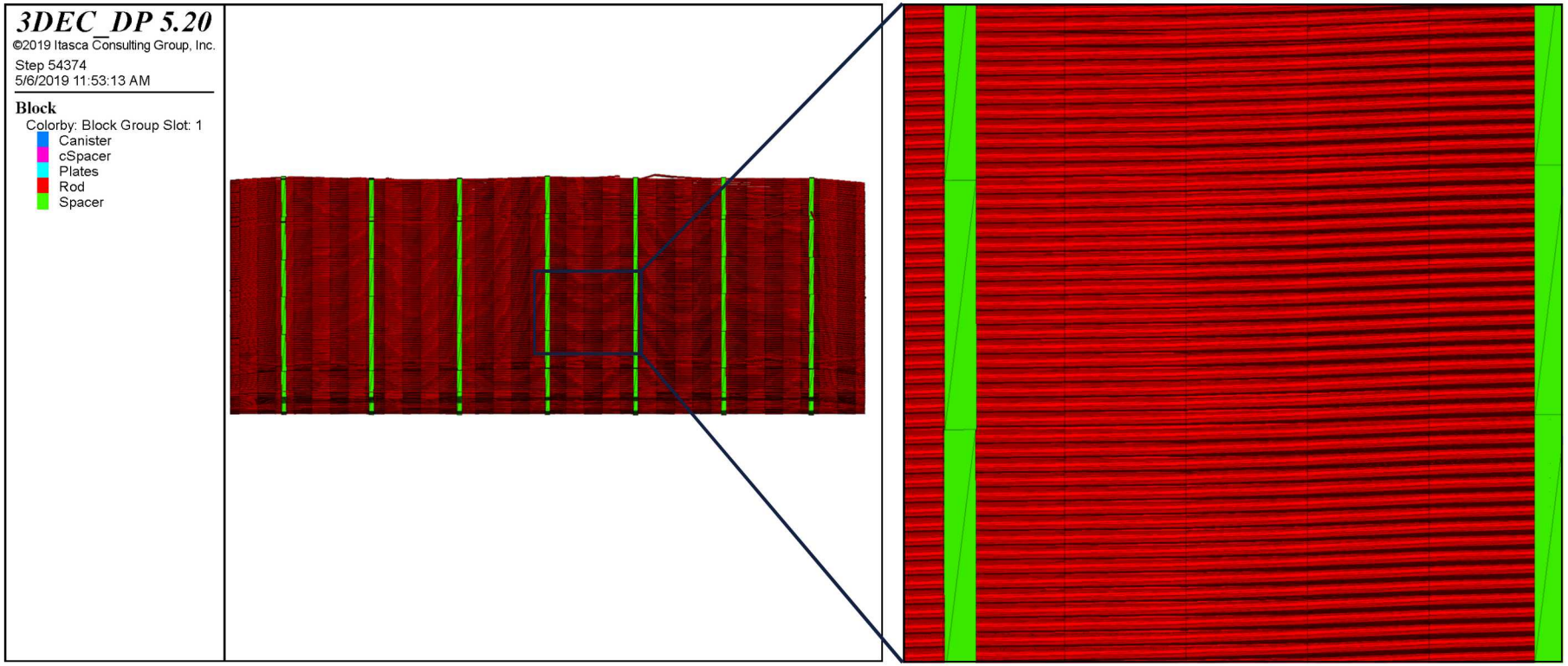
Rods falling down after sliding out of end caps

No End Support

No End Support (Basket Plates Corroded)



No End Support (Basket Plates Corroded)

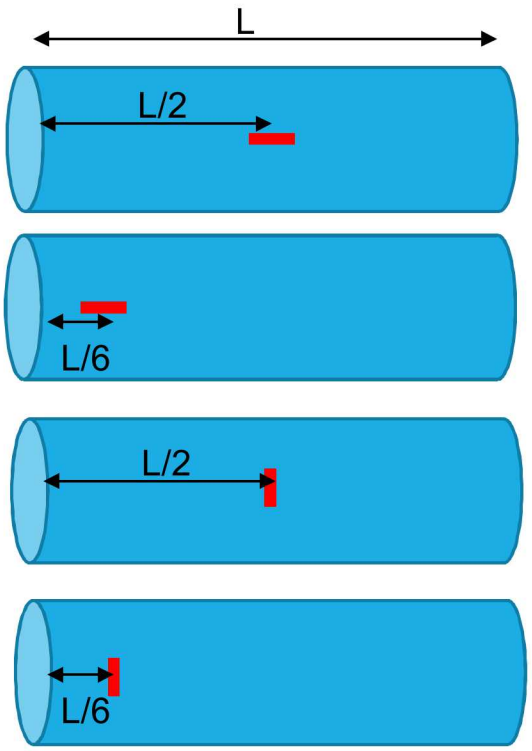


Waste Package Breach Model

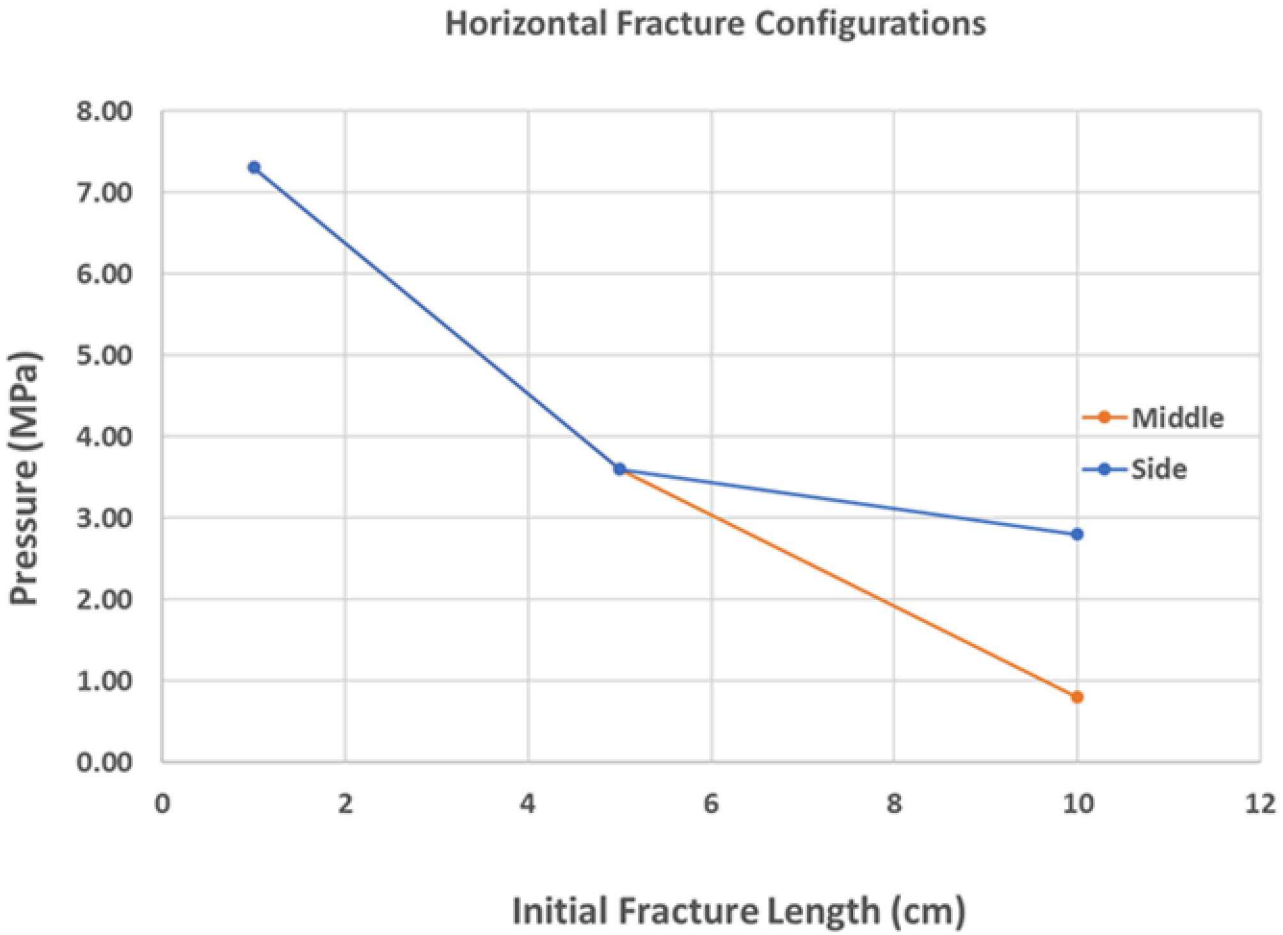
Modeling Approach

- Investigate conditions of initial crack (flaw) propagation as a function of internal pressure
- No coupling with fluid pressure (effect of canister deformation and potential venting) or thermal effects
- Only one canister is considered (no overpack)
- Four initial crack configurations (positions and orientations) are considered
- Elasto-plastic continuum analysis with discrete fracture propagation based on fracture toughness

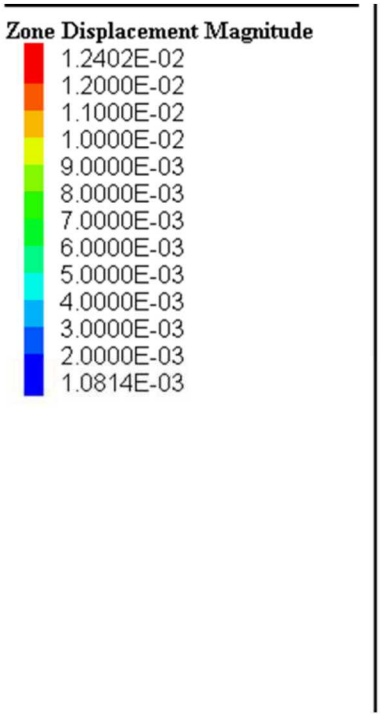
Different Fracture Configurations

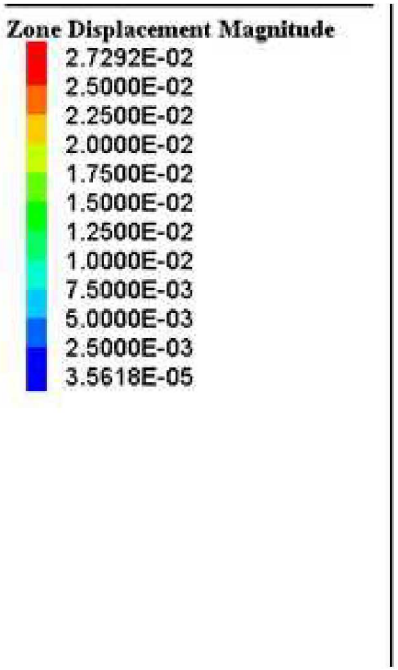


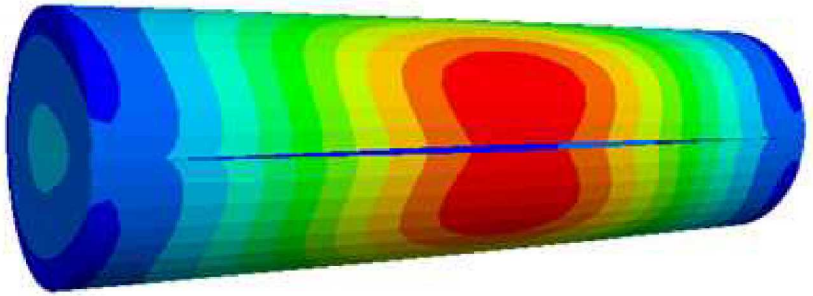
Longitudinal Fracture (1/2)

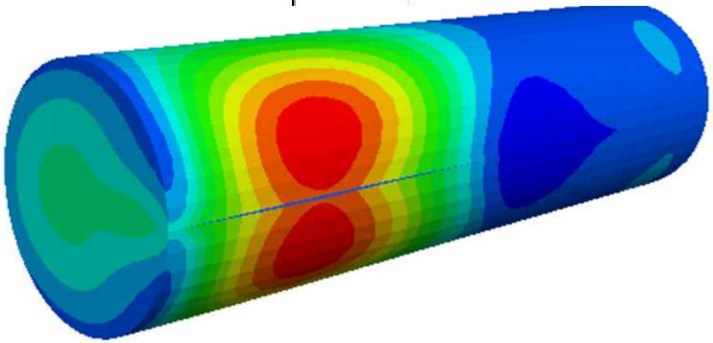


Longitudinal Fracture (2/2)









QUESTIONS?

SFWD

SPENT FUEL &
WASTE DISPOSITION

Annual Working Group Meeting
May 21-23, 2019

UNLV-SEV – *Las Vegas, Nevada*