LA-UR-21-24997
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Title: Tunnel Event 2020 (G-tunnel event modeling)

Author(s): Rougier, Esteban
Knight, Earl E.
Euser, Bryan Jeffry
Swanson, Erika

Intended for: Report

Issued: 2022-04-20 (rev.1)

Los Alamos
NATIONAL LABORATORY

Low Yield Nuclear Monitoring

Tunnel Event 2020 (G-tunnel event modeling)

Esteban Rougier

26 May 2021

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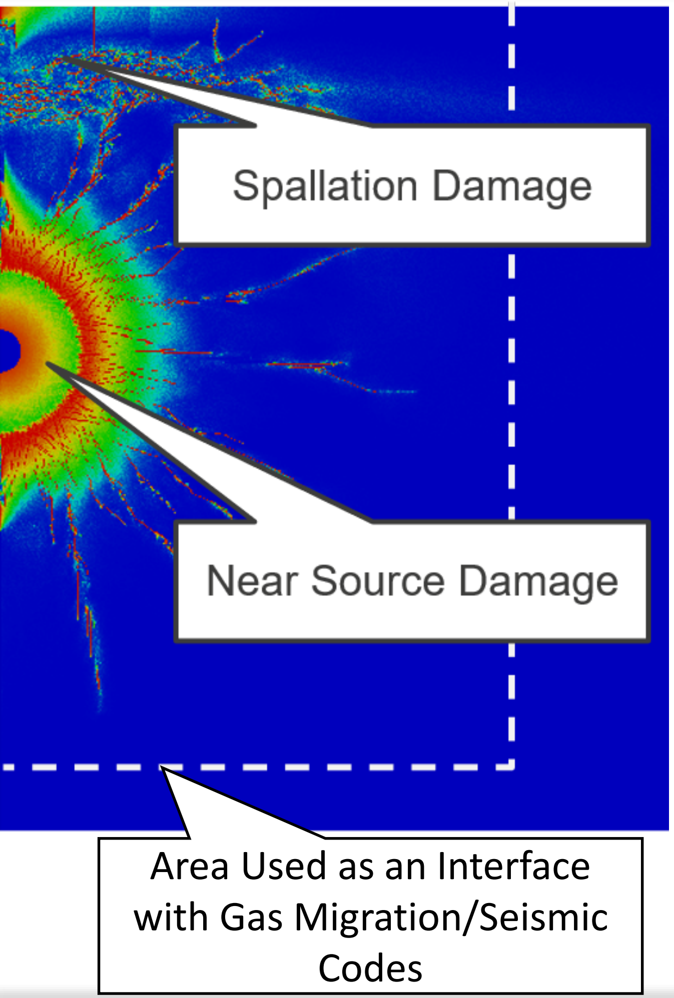
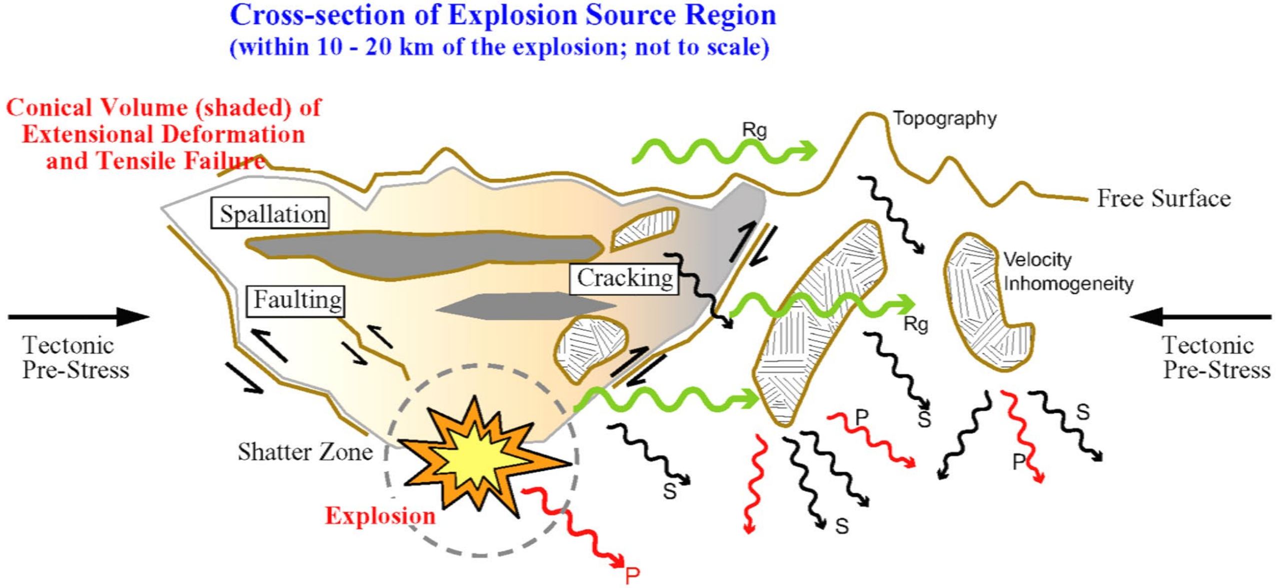
With contributions from Earl E. Knight, Bryan Euser, Erika Swanson

HOSS at LANL

Why HOSS?



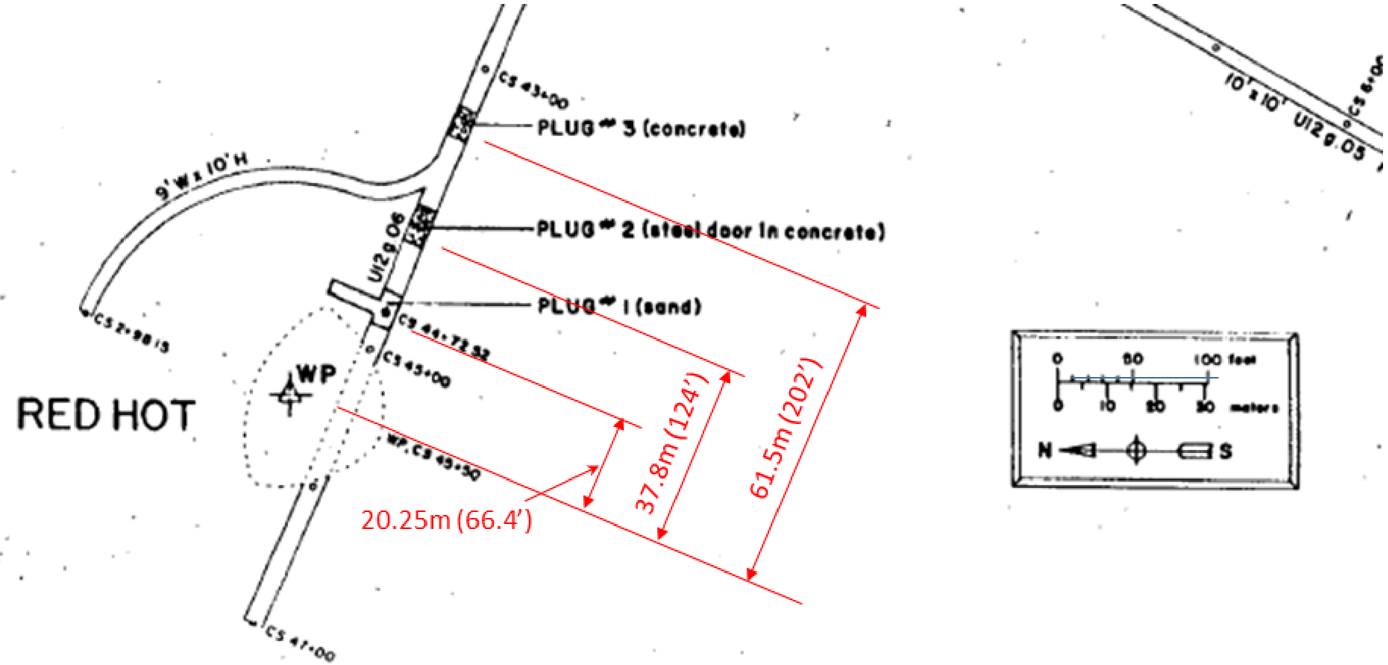
EES-17 developed HOSS to provide 1st principle physics-based source region damage and surface spallation effects for gas migration and seismic analysis efforts



HOSS (Hybrid Optimization Software Suite): A fracture mechanics code that properly conserves mass, energy and momentum. EST. 2004.

G-tunnel Event 2020

Tunnel Damage Analysis



Reference: Townsend, D.R. Red Hot Reentry. A Report on the Results of Four Phases of Reentry Mining and Drilling Conducted by the Defense Nuclear Agency Between 1981 and 1985. Raytheon Services Nevada NTS Operations Geology /Hydrology Section. 1994.

Utilize HOSS-FSIS to conduct exploratory calculations (2D plane strain/3D) for the G-tunnel event 2020 where a pseudo NPE 1.1kt HE equivalent source is used. The purpose of this analysis is to determine if the HOSS fluid-solid coupling solver can capture relevant down-tunnel phenomenology.

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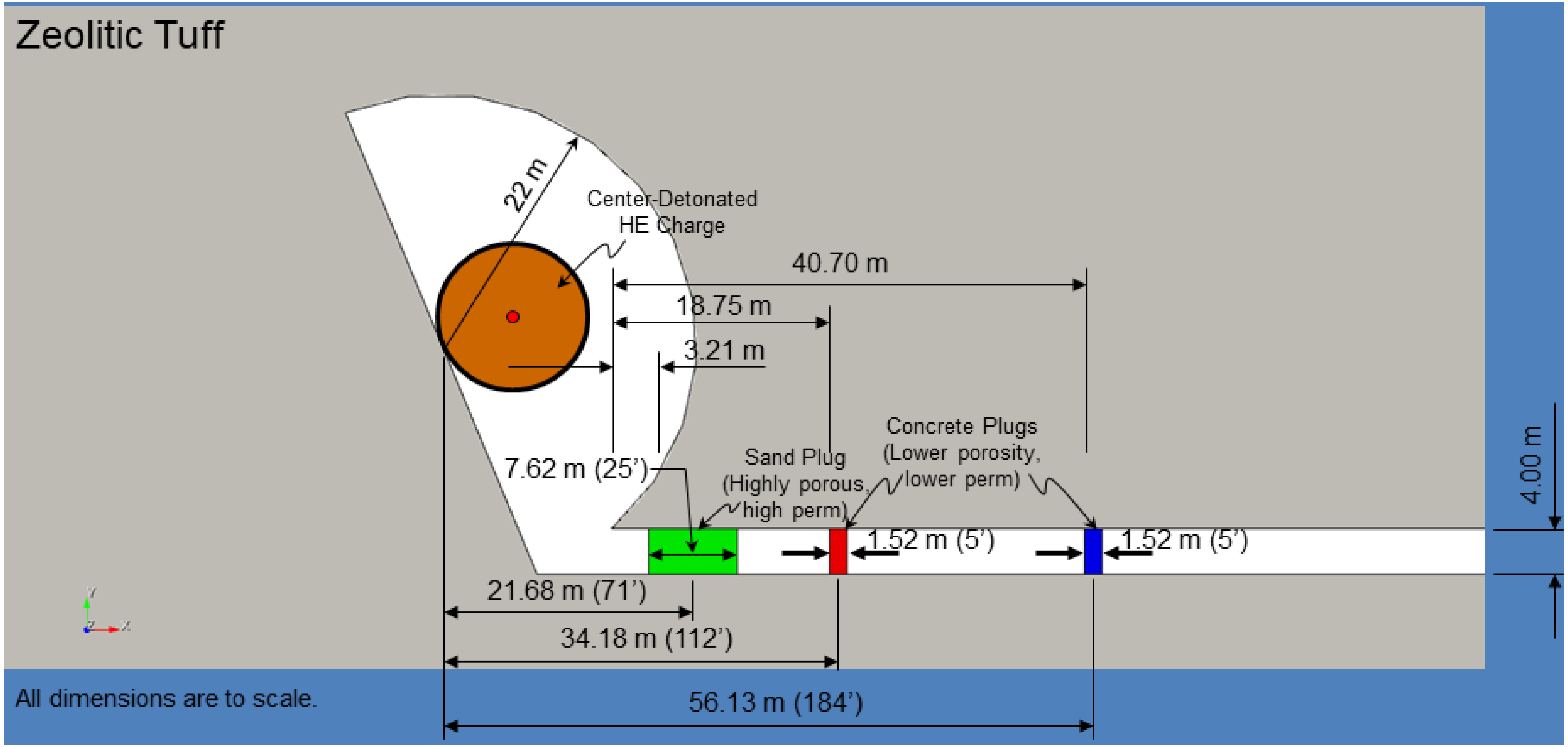
Tunnel Damage Analysis: 2D Model Setup



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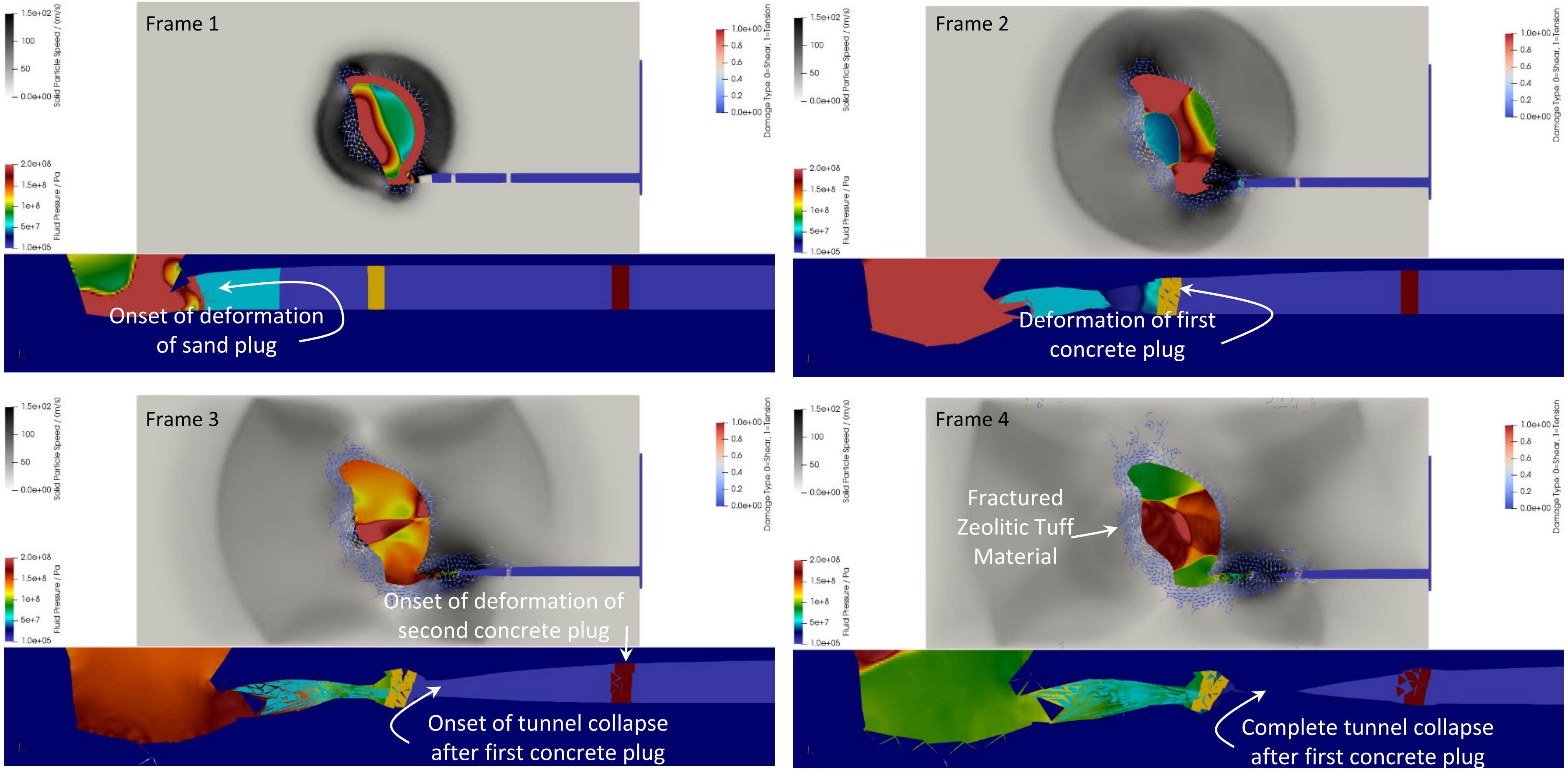
HOSS-FSIS fluid pressure and solid deformation sequence



Pressure values are abnormally high. This is attributed to the fact that the simulations are 2D plane strain, which will overestimate the gas pressures.

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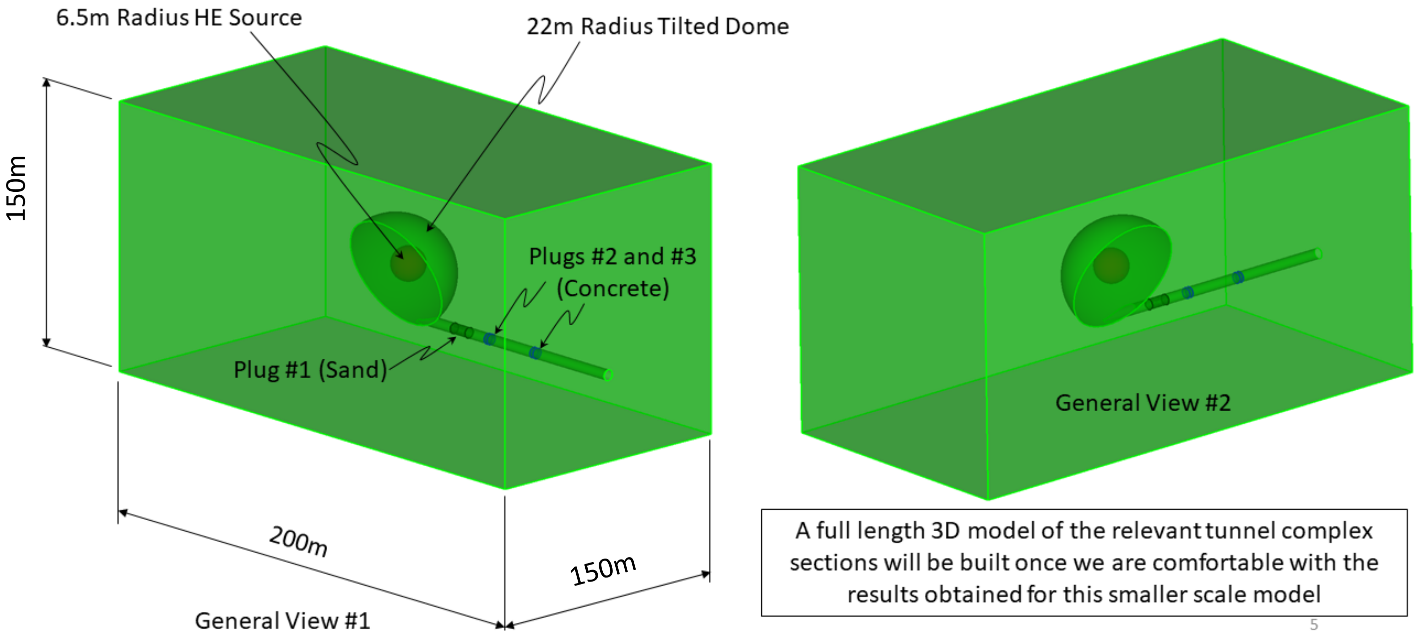
Need to move forward to 3D analysis

- **The previous 2D Cartesian simulation results served to provide compelling evidence of the complex interaction taking place between the explosion by-products and the series of plugs placed along the main tunnel.**
- **This was a first step towards a full-scale analysis of this type of problem. In reality, a full 3D model of the tunnel complex must be considered in order to properly capture damage, pressures, temperatures, etc.**



A full length 3D model of the relevant tunnel complex sections will be built once we are comfortable with the results obtained for this smaller scale model

- **The HE source is represented using an initial deposition of energy (equivalent to the NPE yield).**
- **The gaseous phase is modeled using an ideal gas EOS.**
- **Rock model: Zeolitic Tuff**

G-Tunnel Event 2020

3D Analysis: General Near Source Behavior

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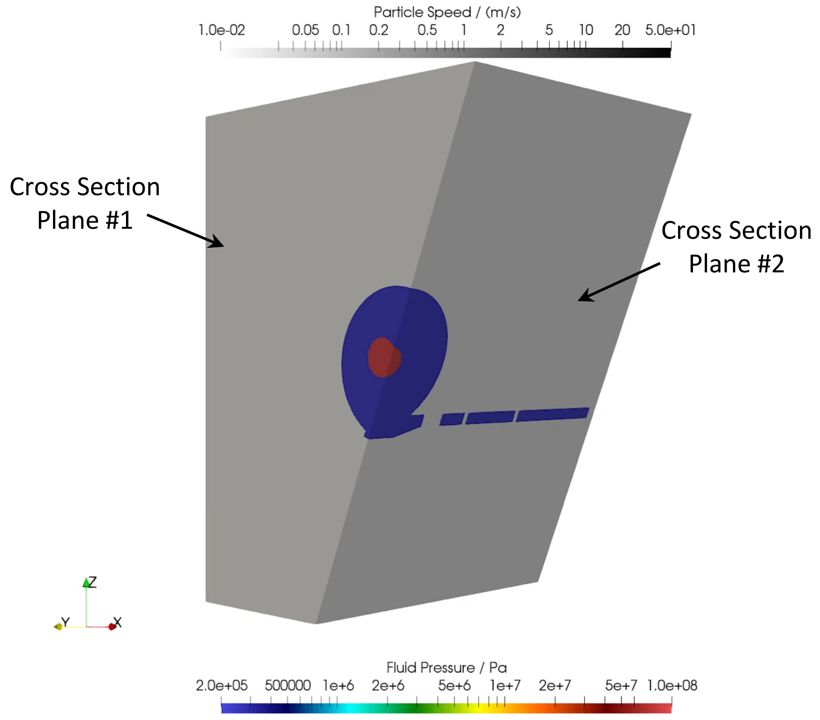
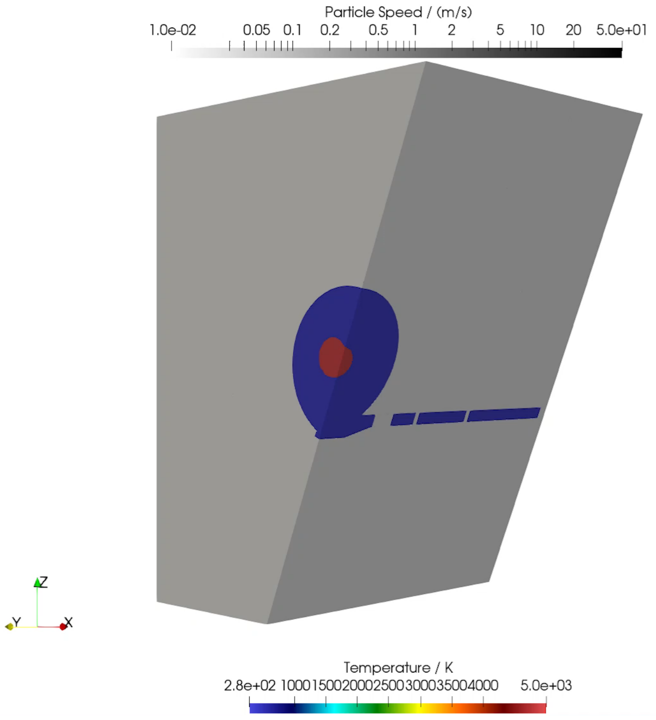
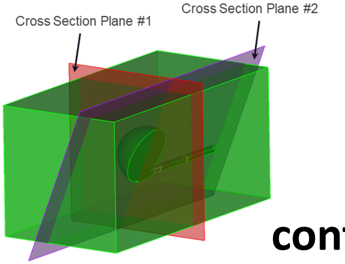
Pressure



Temperature



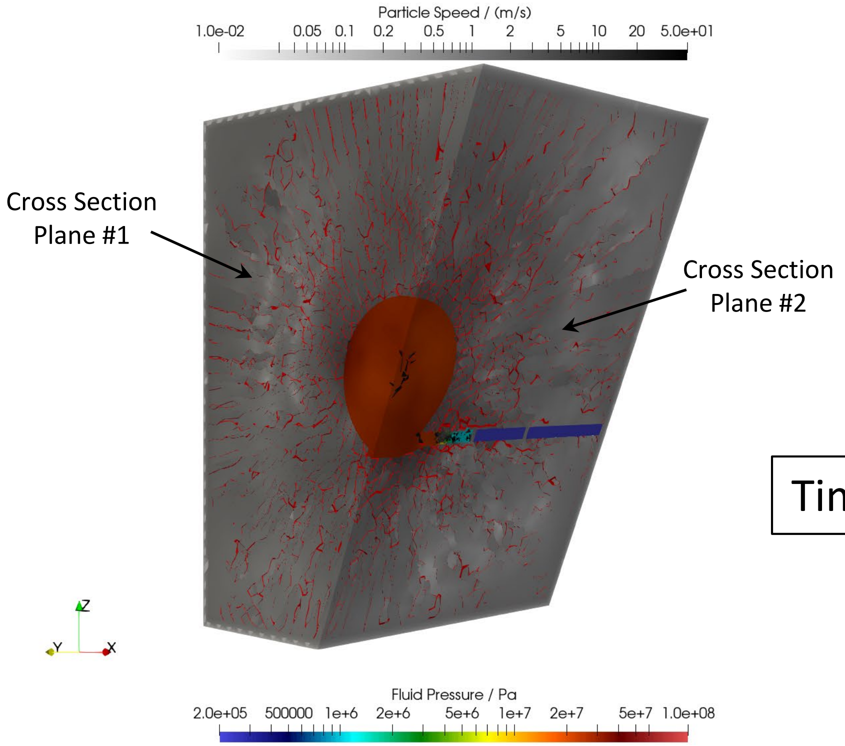


Animation of the gas pressure and temperature evolution inside the cavity and its interaction with the containment plugs. Note that the cavity “sloshing” effect seen above generates later time stress waves in the rock.

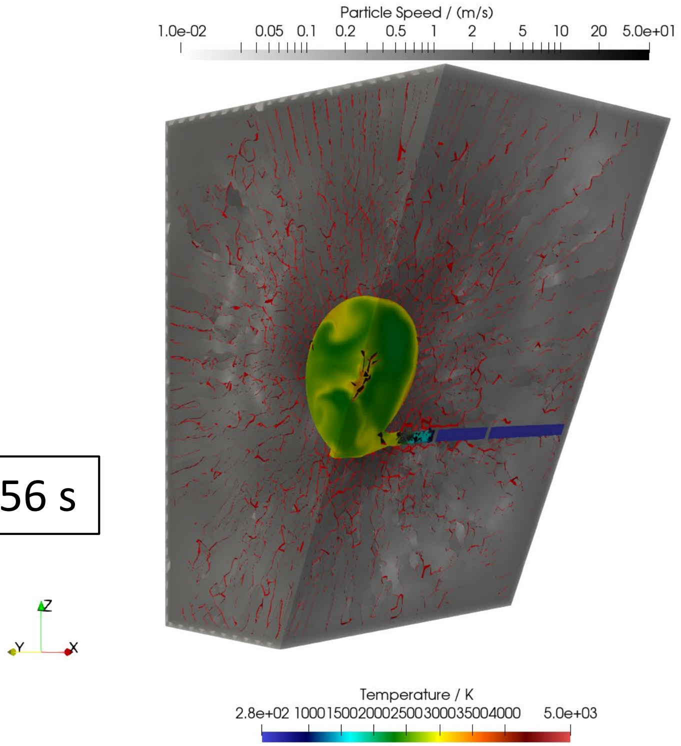
G-Tunnel Event 2020

3D Analysis: General Near Source Behavior

Pressure



Temperature



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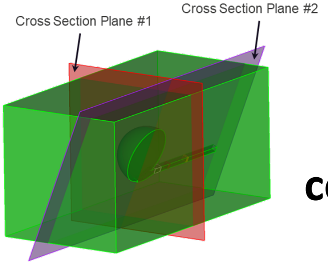

Cross section view of the gas pressure and temperature inside the cavity and interaction with containment plugs. As expected, temperature and pressure maps are much more reasonable given the 3D nature of the problem.

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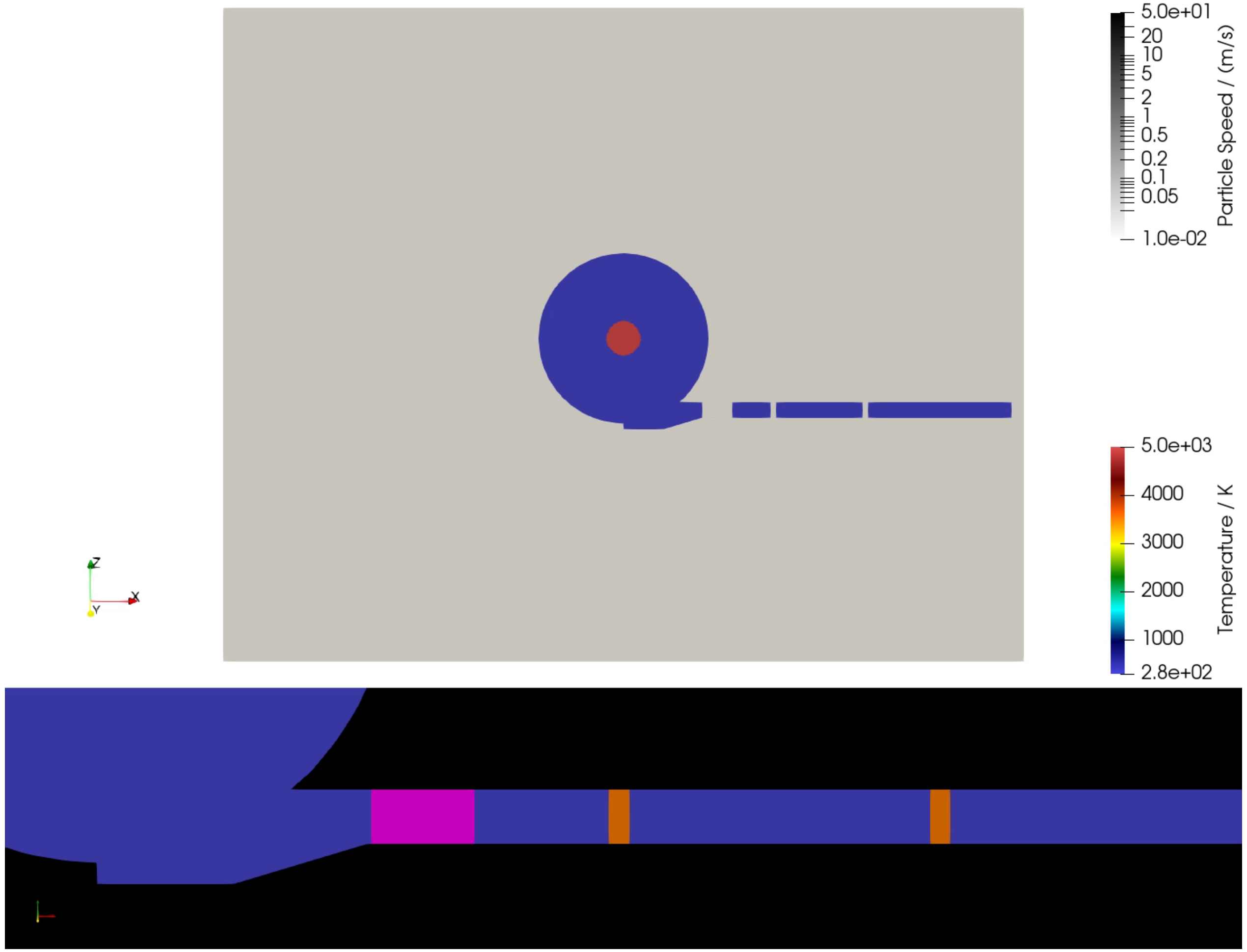
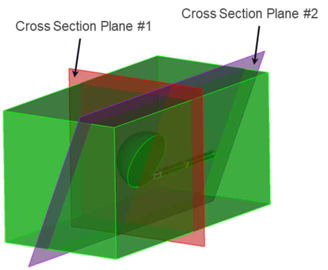
3D Analysis: Down-Tunnel Dynamics





Animation of the gas temperature evolution inside the cavity and its interaction with the containment plugs.

The tetrahedral finite elements representing the sand plug survive throughout the interaction with the explosive shock wave. The sand plug fails to contain the event and its debris travels down the tunnel at relatively high speeds (~150 m/s).

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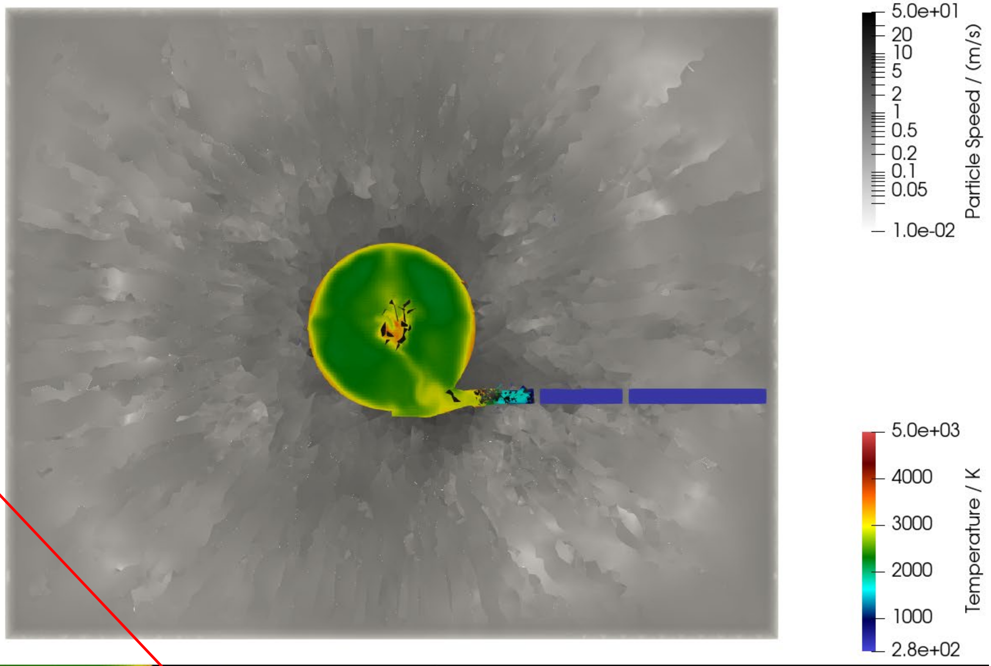
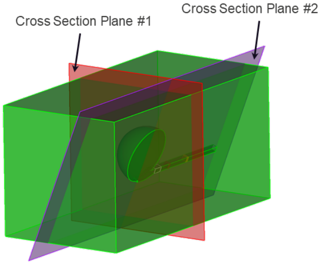
3D Analysis: Down-Tunnel Dynamics

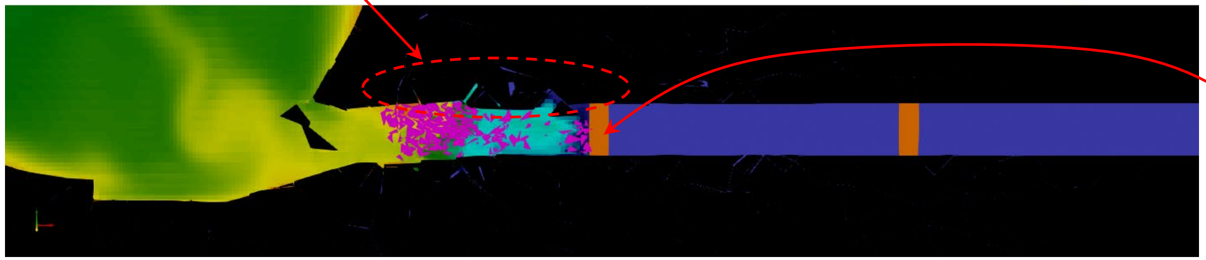
Time: 0.156 s



Damage observed in the top part of the tunnel, before the sand plug

The concrete plugs are represented using a reinforced concrete material model. This may be too conservative (i.e., too strong), therefore further analysis is needed.





First concrete plug resists the initial impact of the debris generated by the failure of the sand plug

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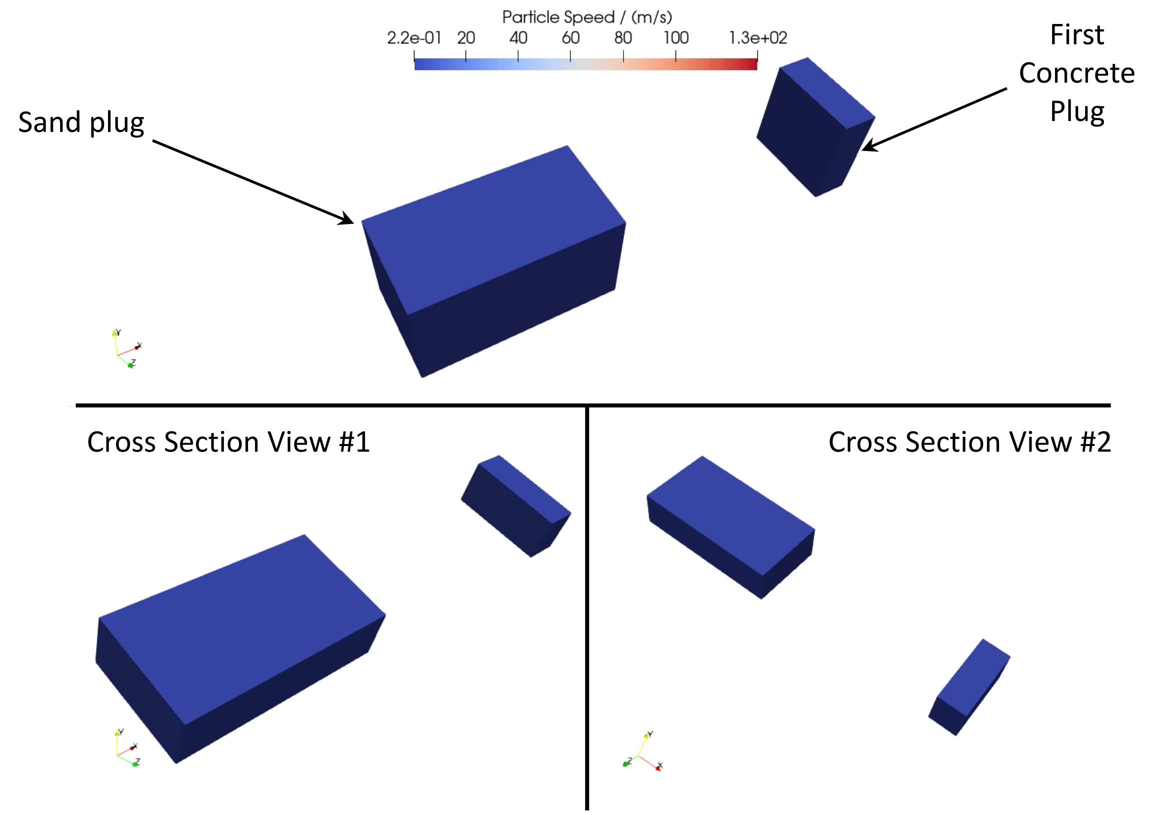
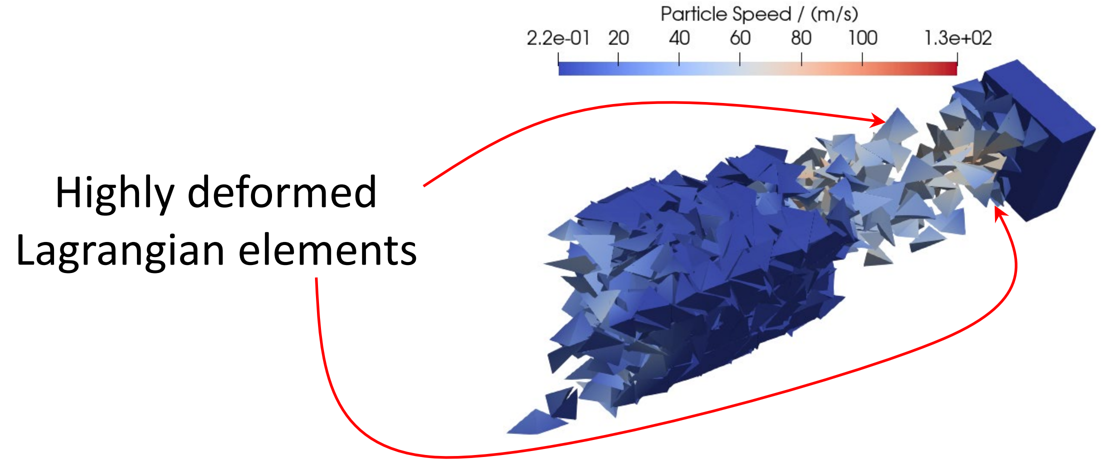
3D Analysis: Sand Plug Dynamics



The sand plug is currently handled using the HOSS Lagrangian formulation. This presents some challenges mainly when the level of deformation of the elements become significant. To alleviate this a donation algorithm is being implemented into the HOSS-FSIS solver. This algorithm will allow for the transference of highly distorted Lagrangian elements to the Eulerian domain. Subsequently, the sand material may be treated as one more phase within the fluid solver.



Animation of the evolution of the sand plug after the event. Note the evidence of the cavity "sloshing" effect on the plug dynamics.

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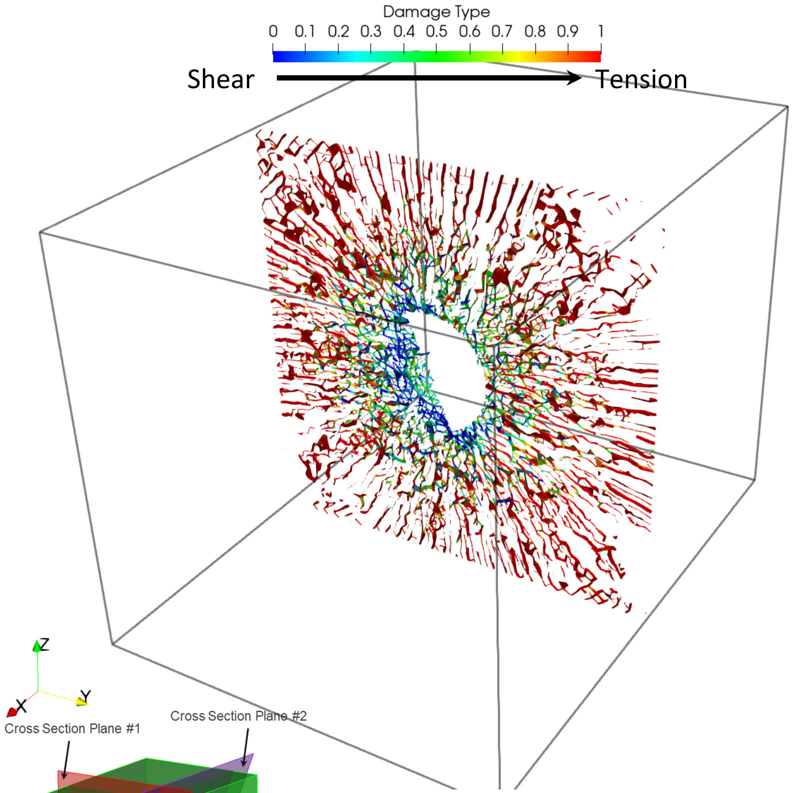
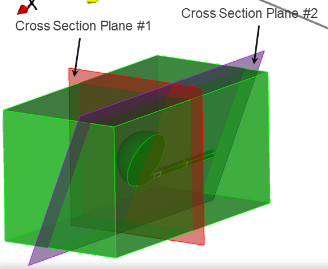
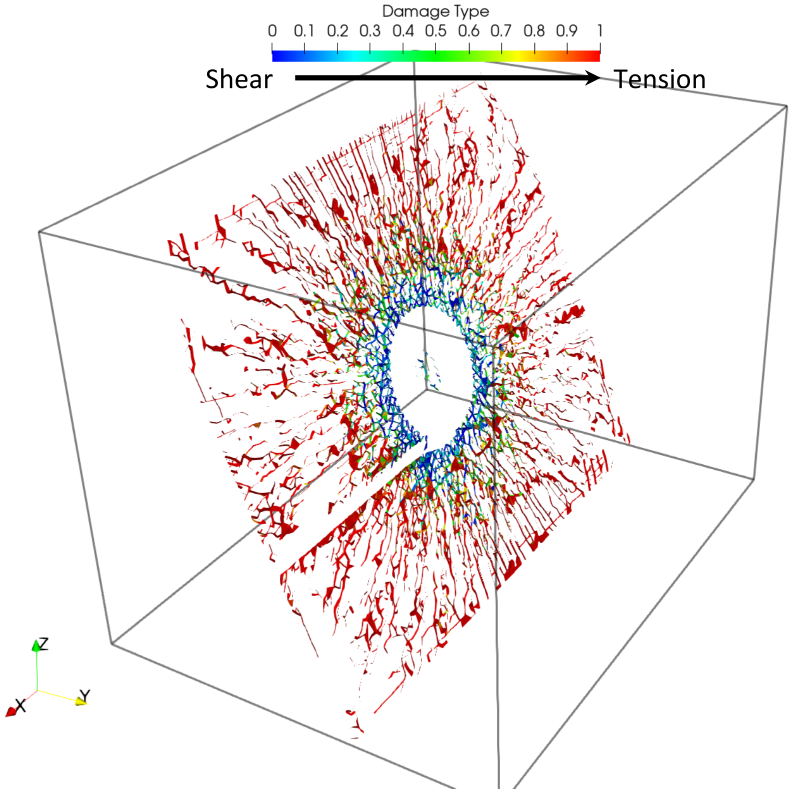
3D Analysis: Close-In Material Damage View





Plane #1



Plane #2 Rotated

The HOSS-FSIS can also describe the type of failure experienced by the material.

The results show that around the cavity shear failure is dominant, while away from the cavity the failure mode transitions to tensile failure.

This is highly relevant for subsequent gas migration analyses, since the increase in permeability created by shear fractures is different (i.e., higher) than the one created by purely tensile fractures.

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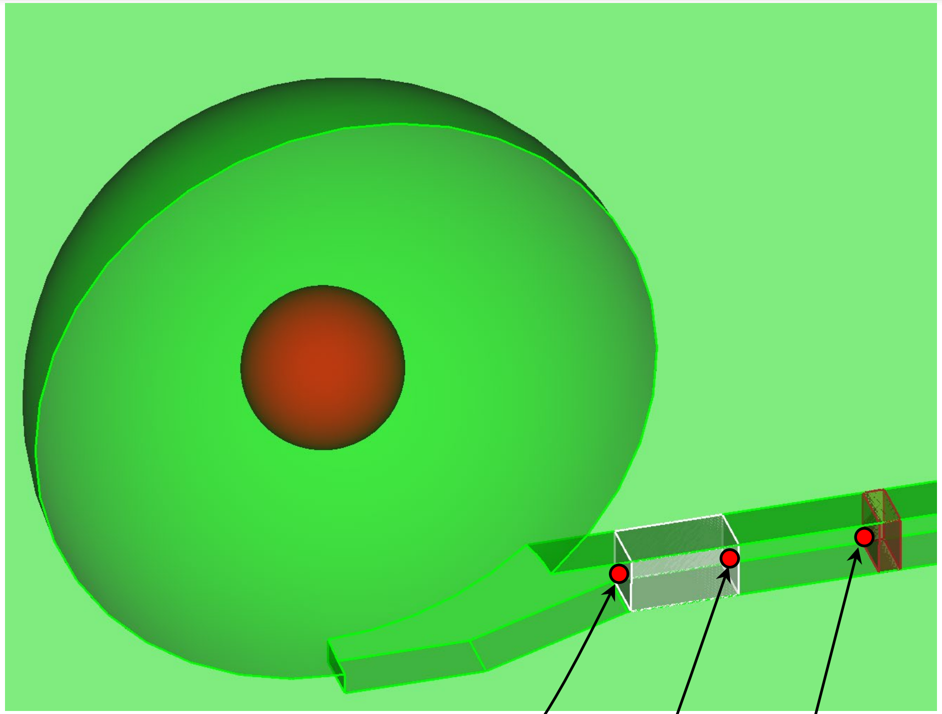
3D Analysis: Relevant Quantities



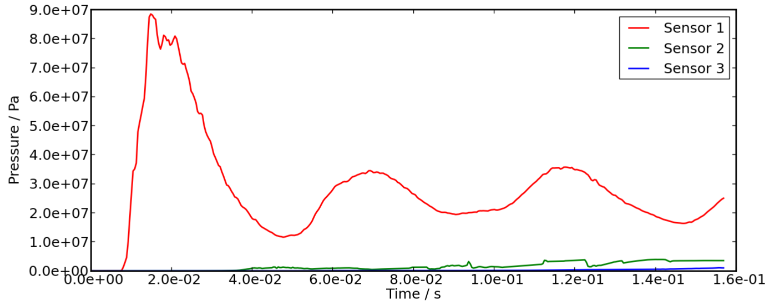
Sensor 1: Before sand plug

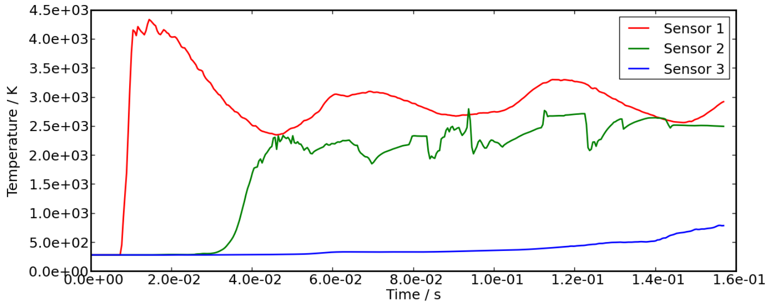
Sensor 2: After sand plug

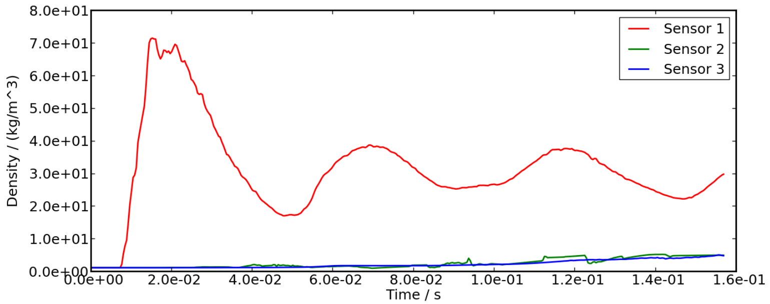
Sensor 3: Before concrete plug #1

Physical quantities, such as pressure, temperature, density, are recorded at specific points close to the plugs.

This information will be used in future analysis to understand the seepage processes originating from the cavity and propagating through the access tunnel.







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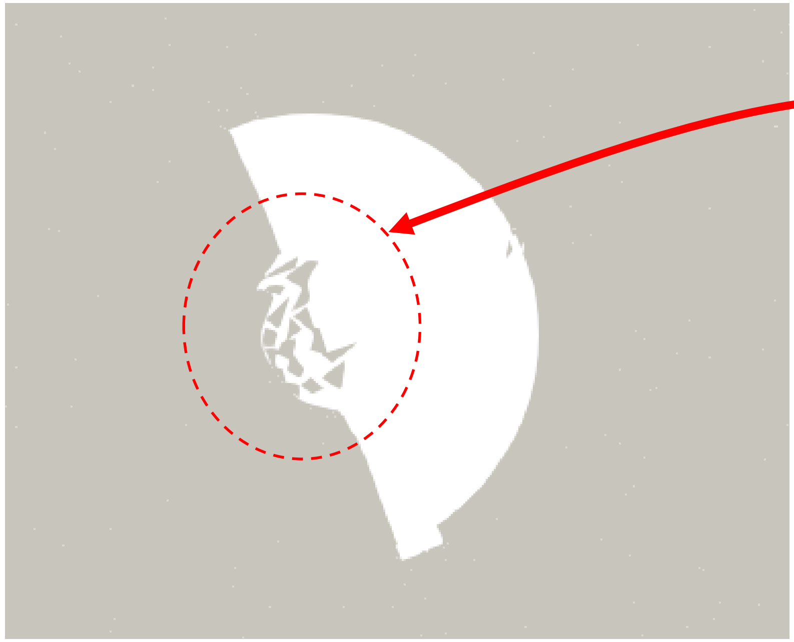
3D Analysis: Qualitative Comparison with Experiments

Cross Section Plane #1



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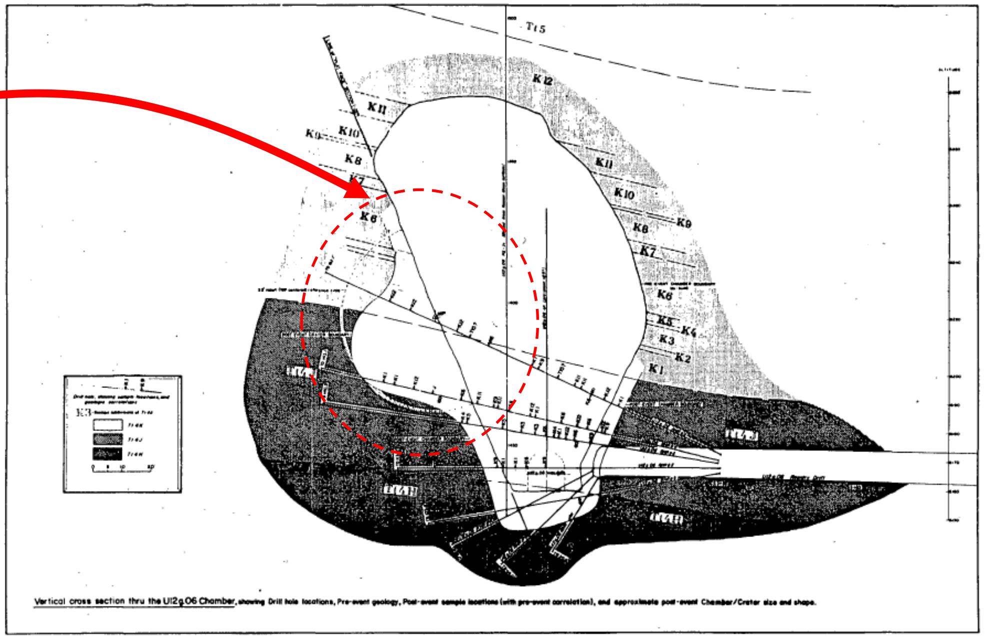
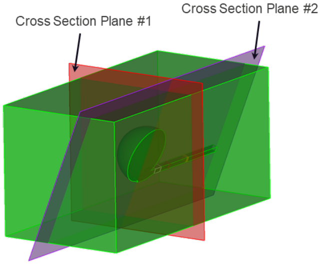


Figure 2-7 Vertical geologic cross section through the U12g.06 chamber, showing drill hole locations, pre-event geology and the approximate size and shape of the post-event cavity and explosion crater.



Comparison between 3D HOSS results and post event cavity profile.

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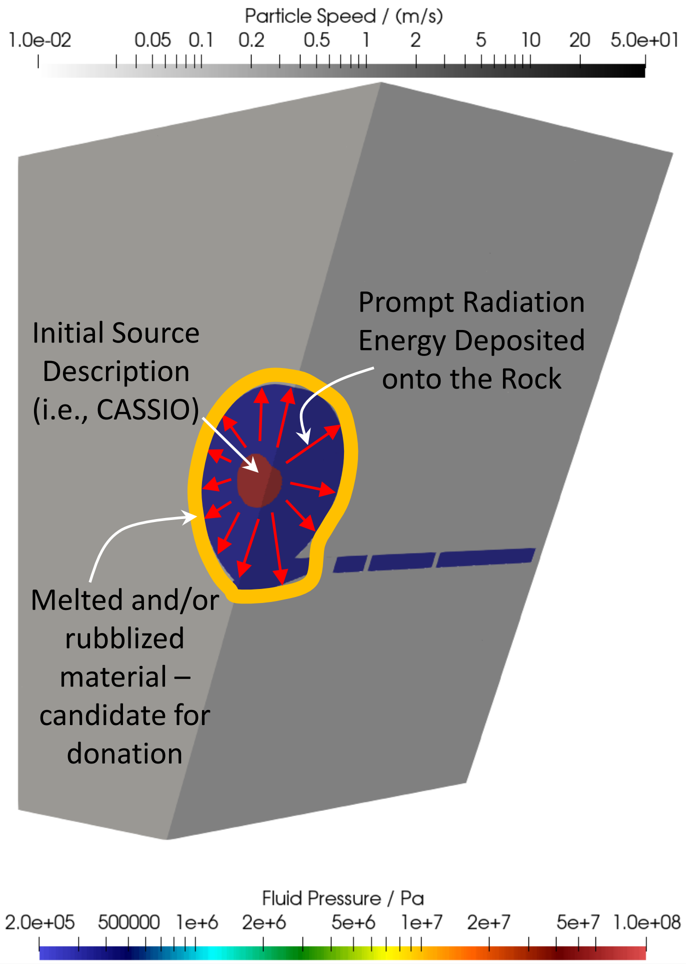
Next Steps

- **Analysis:**
  - **Run the same example but with an energy pill resembling a nuclear source**
  - **Conduct a one-way coupling with a weapons source code.**
- **Code Enhancements:**
  - **Incorporate 3D multi-phase and solid donation solvers within HOSS-FSIS. 2D prototypes have been developed and are being tested (Funded by ASC Program).**
  - **Implement a JWL EOS into HOSS-FSIS (Funded by ASC Program).**
  - **Incorporate radiation solver to account for proper energy deposition into the rock (Funded by LDRD-ER Program).**



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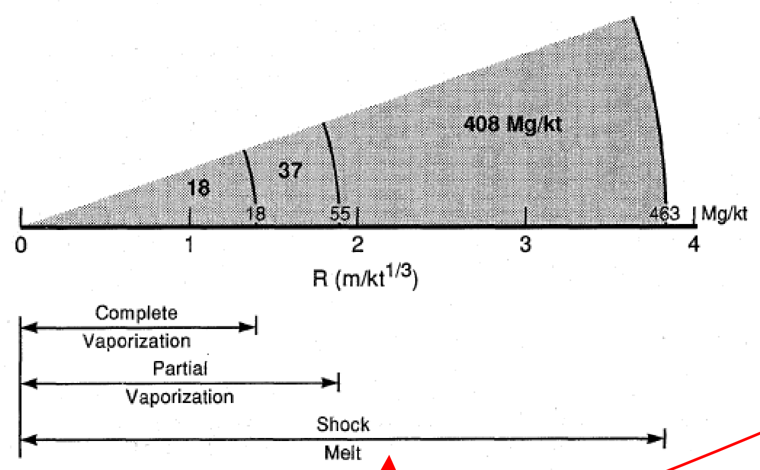
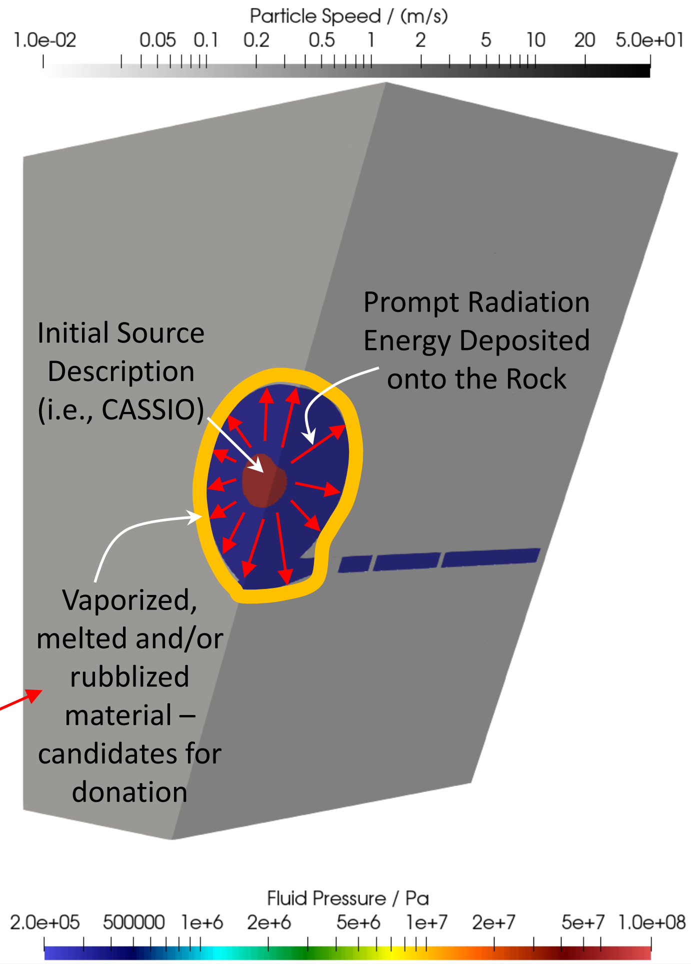
Next Steps

- **Code Enhancements:**
  - **The importance of having a valid EOS and proper material handling cannot be overstated. Ongoing efforts in the Containment and Source Ventures will advance simulation capabilities in this regard.**

Depiction of material response as a function of range. Taken from: Thermodynamics Evolution of Nuclear Cavities. E. Peterson et al.





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Summary

- **The real world is not homogenous. Geologic site and material property characterization are imperative requirements for any proper containment analysis. Tunnel damage analysis must be conducted in a 3D setting.**
- **HOSS FSIS exploratory G-tunnel calculations clearly show that full fluid-solid coupling is necessary in order to capture the behavior of complex systems such as the one shown for our G-Tunnel Event 2020 event.**
- **The emerging 3D HOSS FSIS technology shows great promise and will be able to provide future G-tunnel calculations with an enhanced multi-physics data set.**

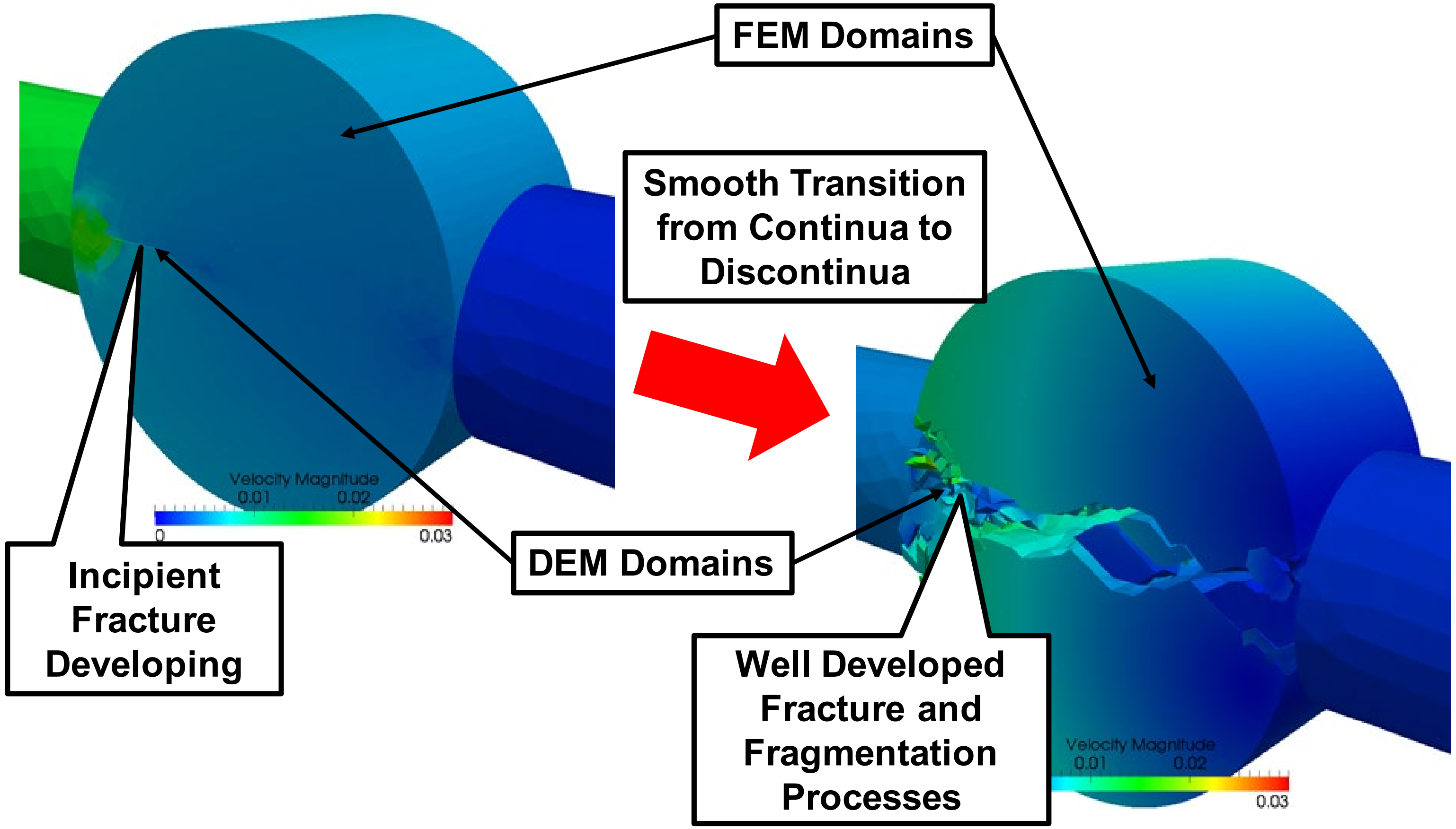
POCs:

– Esteban Rougier, erougier@lanl.gov, 505-667-1733
– Earl E. Knight, knighte@lanl.gov, 505-667-5584
– Bryan Euser, beuser@lanl.gov, 505-665-3790
– Erika Swanson, emswanson@lanl.gov, 505-665-649

BACKUP SLIDES

HOSS

Fracture and Fragmentation

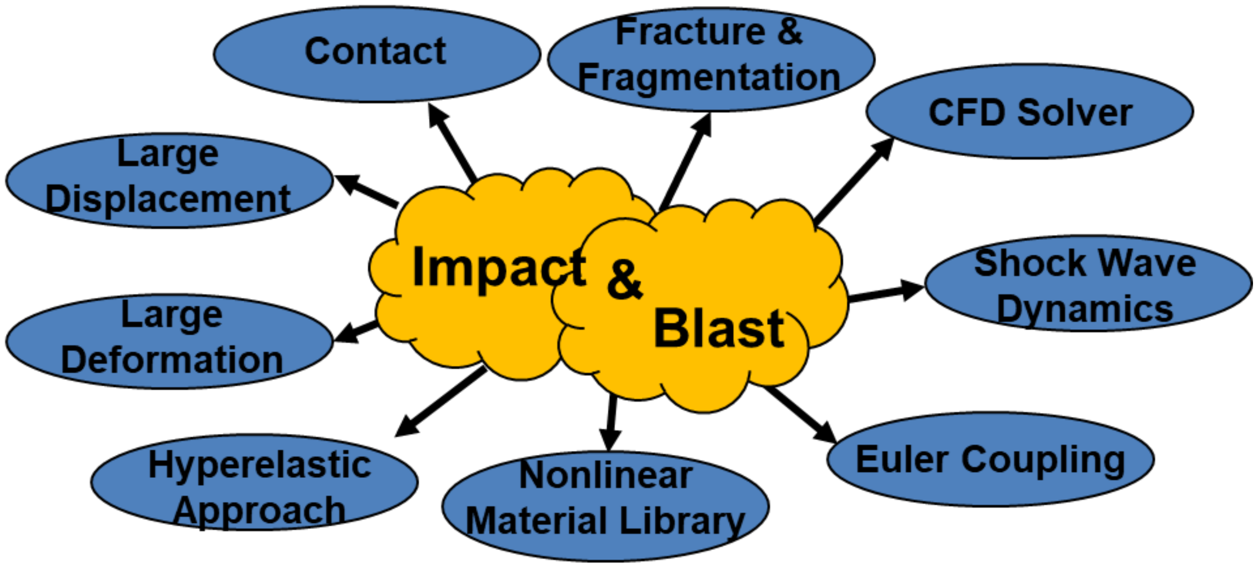


HOSS is based on a hybrid numerical method called the ***Combined Finite-Discrete Element Method (FDEM)***

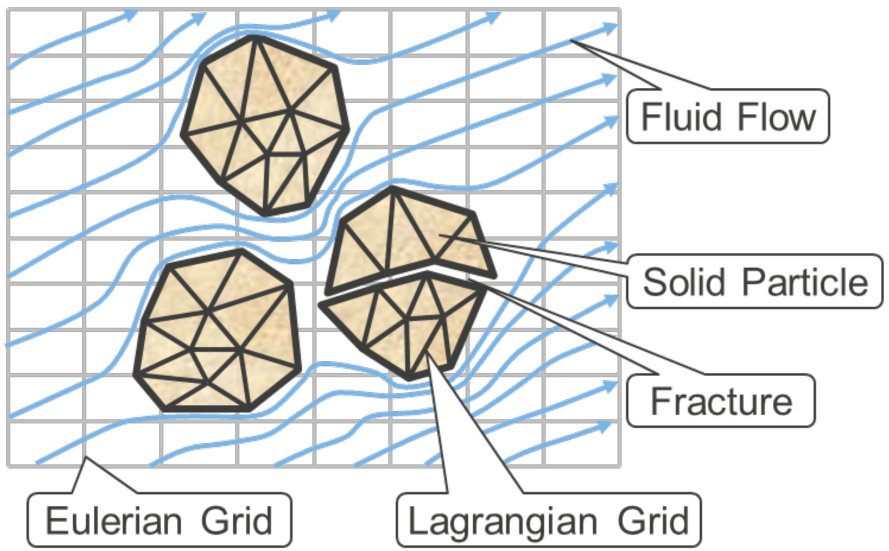
HOSS FSIS

Technology Breakthrough

HOSS Fluid-Structure Integration Solver (FSIS): A multi-physics approach designed to describe fluid-solid interaction



FSIS in Action



HOSS FSIS, in combination with the code's hyperelastic elasto-plastic material model formulation and energy-based EOSs, will allow explicit representation of full material failure due to extreme shock conditions.

HOSS FSIS

Programmatic Synergy via Above Ground NE Analysis

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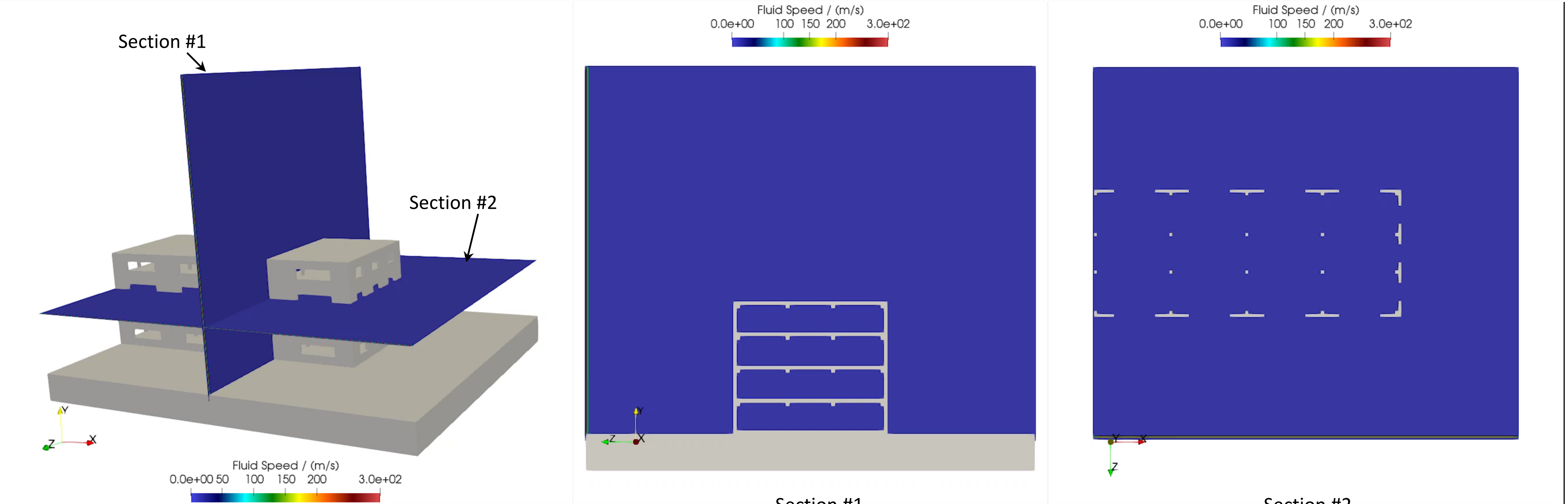

Section #1

Section #2

Here a building experiences a significant NE blast wave that generates damage on its front face. Note the complex flow pattern is captured by the 3D FSIS capability.