CASE STUDY FOR TRANSLATING FTRC RESULTS INTO PRACTICAL THERMAL ANALYSIS TECHNIQUES

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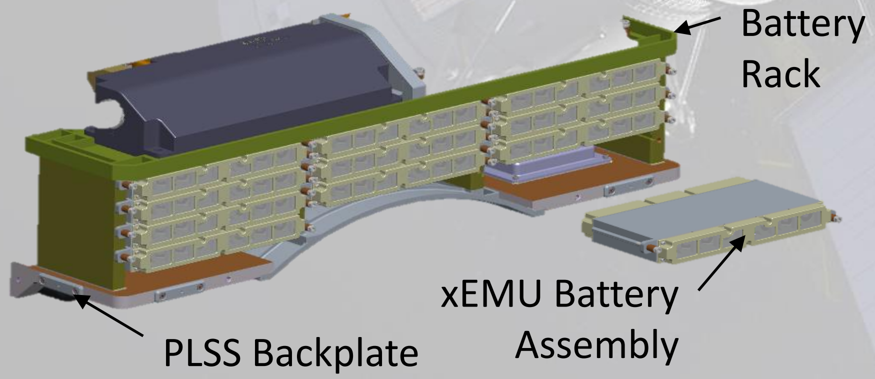
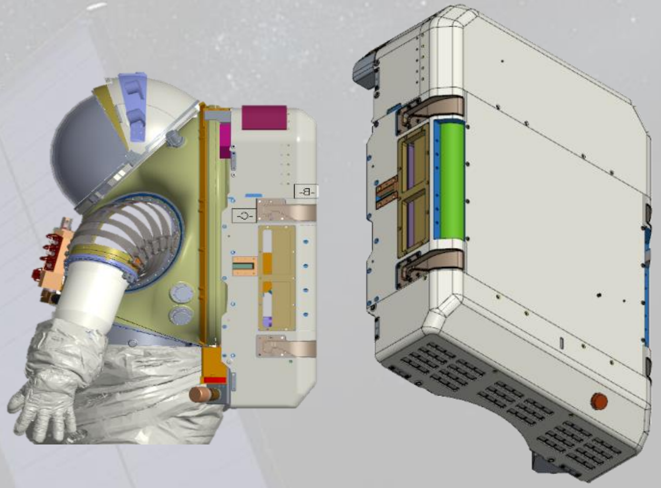
MODELING THERMAL RUNAWAY

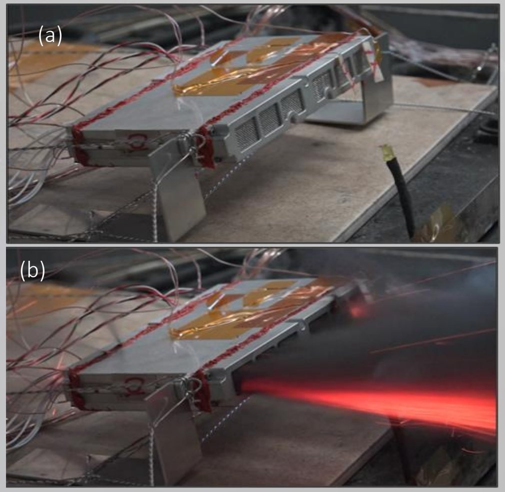
- **Effective simulation (modeling) of system level response to a thermal runaway event is a critical component to the design and optimization process of a lithium-ion (Li-ion) battery assembly.**
- **Thermal runway modeling is complex:**
  - No two thermal runaway events are the same.
  - The mass of the cell changes throughout thermal runaway as materials decompose and solids, liquids, and gases are ejected; additionally, the mass of the system *changes* as the mass of the ejected contents arrive at their final resting location.
  - Cell geometry can deform throughout event which can have impacts on the thermal network.
  - One approximately defined heat load that may correlate the thermal model to test data is not representative of the entire range of possible outcomes.
  - Thermal runaway energy fractions, which can also vary, must also be considered for effective modeling.
  - Cell selection can change throughout the design process, and subsequently the thermal runaway heat output of the new cell type can have implications on whether or not the design is still safe.
- **Effective thermal models, representative of an as-built battery assembly, must be easily configurable and should incorporate techniques for considering the variability of total energy release and fractional energy release as a function of cell selection.**

SIMULATION CASE STUDY

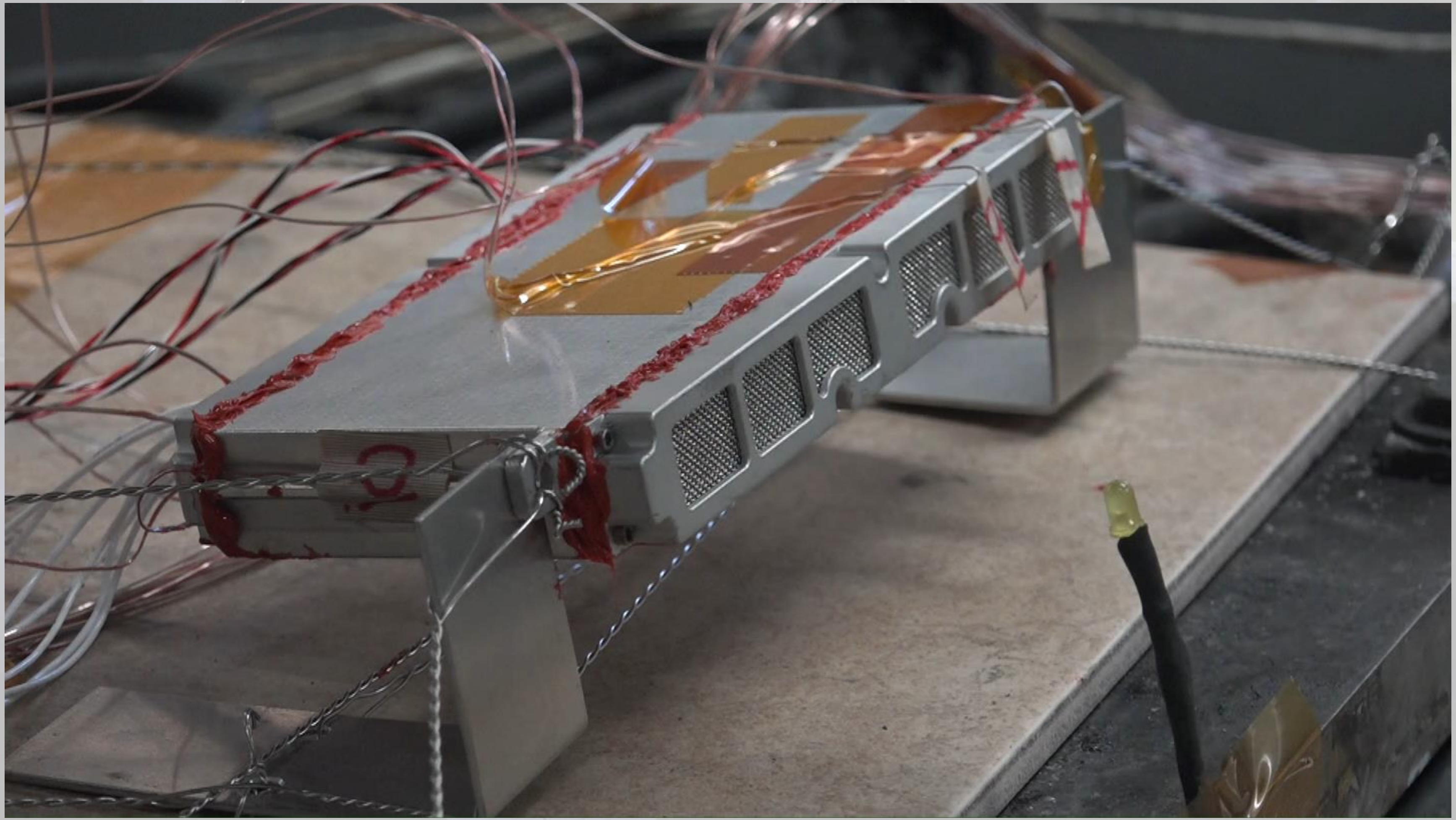
- **As a demonstration of effective thermal runaway modeling strategies, we constructed a thermal model of the xEMU battery assembly installed in the Portable Life Support System (PLSS) and analyzed the response of the battery assembly to thermal runaway heat output:**
  - The xEMU battery assembly is depicted with the images to the bottom left.
  - The battery pack was initially simulated by Ortega et al. in 2018 in Thermal Desktop and correlated to an abuse test as shown with the images to the bottom right.
  - Ortega's model was updated and then used as a case study for effective thermal runaway modeling strategies as presented in here.







SIMULATION CASE STUDY

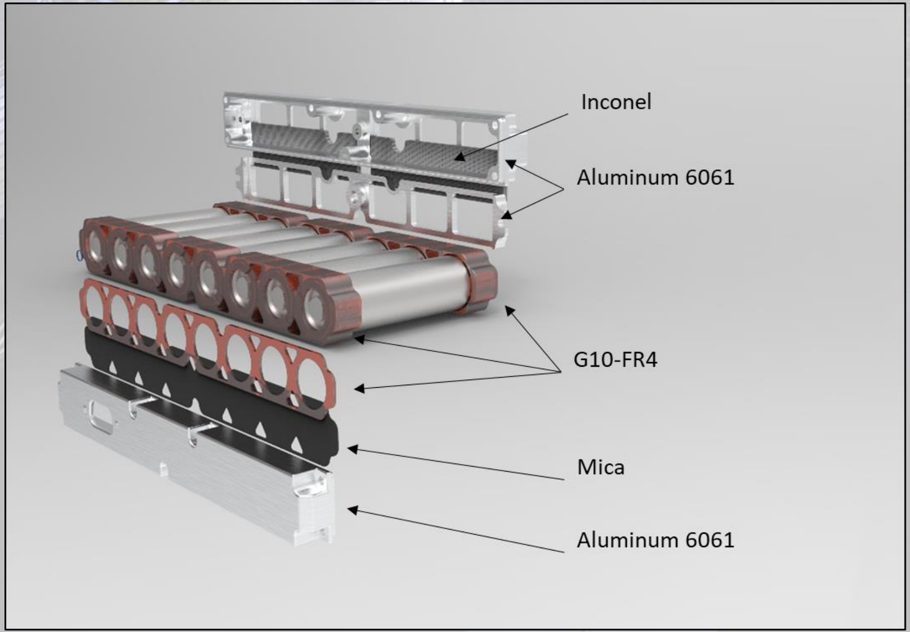


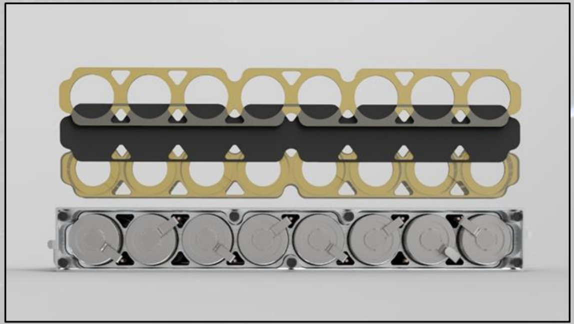
THERMAL MODEL DEVELOPMENT

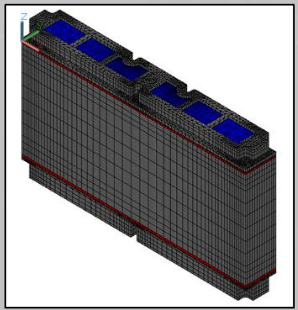
- **A thermal model of the xEMU battery assembly was constructed using a combination of SpaceClaim, TD Direct, and Thermal Desktop v6.1:**
  - The CAD of the xEMU battery assembly *(early 2018 version)* was imported into SpaceClaim and defeatured in preparation for thermal modeling activities.
  - In SpaceClaim, meshing parameters, radiation analysis groups, thermophysical properties, and optical properties were applied to each component.
  - Also in SpaceClaim, groups of surfaces of interests were created so that those groups could be easily accessed later on for analysis purposes; e.g. interfacing surfaces and surfaces for heat load applications.
  - The SpaceClaim file was linked to Thermal Desktop and meshed using TD Direct.
  - Once in Thermal Desktop, boundary conditions, contact resistances, thermal runaway heat loads, and analysis parameters were applied; additionally, a reference model of the 18650 format cells was incorporated.
- **The individual 18650 format cells were incorporated into the system level model using XREF:**
  - XREF is a feature that allows the incorporation of repeated geometries using a single input file.
  - A reference Thermal Desktop model of a general 18650 cell was constructed and brought into the system level model using the XREF feature.

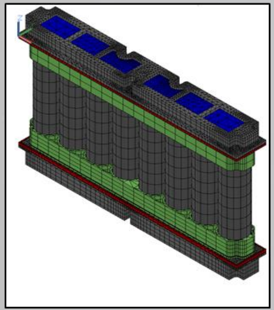
THERMAL MODEL DEVELOPMENT

- **Using these strategies, an easily configurable and modifiable thermal model of the xEMU battery assembly was constructed (see images below):**
  - Geometries can be altered in SpaceClaim and then re-synchronized with Thermal Desktop without needing to reconstruct the thermal model.
  - The reference model strategy for representing the individual 18650 cells makes it easy to swap out the cell type being considered by the simulation.









ANALYSIS MATRIX

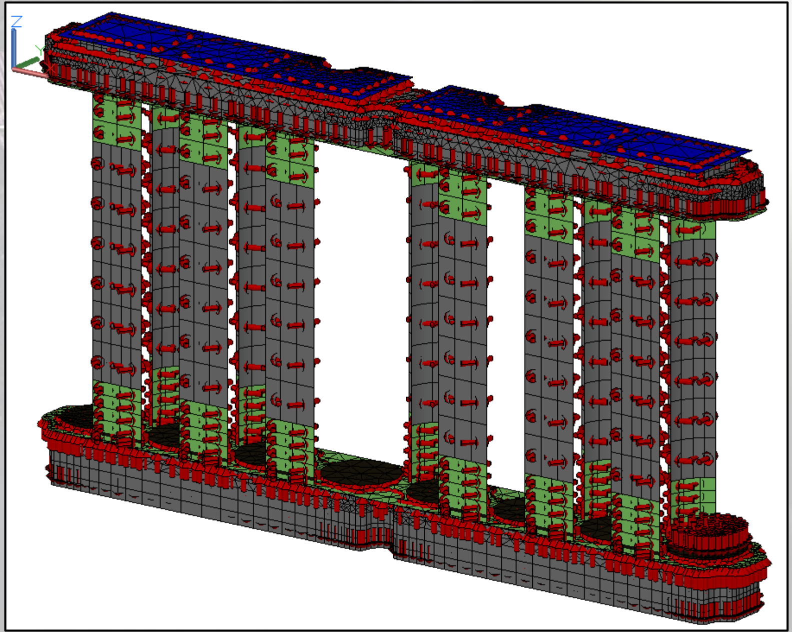
- **The purpose of this case study was also to demonstrate strategies for simulating thermal runaway.**
  - As described previously, the total and fractional energy yields can vary significantly, and this variability should be considered when designing a battery assembly.
  - In addition to energy yield, the heat rate should also be considered *(i.e. energy release time)*.
- **For this case study we considered the LG 18650-MJ1, Sony 18650-VTC6, Samsung 18650-30Q, and a 3.35 Ah LG 18650 test cell:**
  - Thermal runaway data for each cell type, as characterized by fractional thermal runaway calorimetry (FTRC), was extracted from the Battery Failure Databank and was utilized in the thermal model.
  - Analysis was conducted based on the max, min, and average total energy yields combined with the overall average cell specific fractional energy yield.
  - A 20°C boundary condition was assumed.
  - This presentation focuses on the results generated from the average total energy yield configurations; comparison of the max/min cases will be provided in a publication later this year.

ANALYSIS MATRIX

MJ1	Samsung 30Q	LG 3.35AH NBV	Sony VTC6
Max: 100.4 kJ	Max: 81.4 kJ	Max: 88.9 kJ	Max: 64.6 kJ
Min: 69.4 kJ	Min: 59.6 kJ	Min: 61.6 kJ	Min: 60.2 kJ
Avg: 87.5 kJ	Avg: 69.3 kJ	Avg: 79.2 kJ	Avg: 62.9 kJ
Fractions: •Cell: 17% •Ejecta: 83%	Fractions: •Cell: 12% •Ejecta: 88%	Fractions: •Cell: 23.6% •Ejecta: 76.4%	Fractions: •Cell: 20% •Ejecta: 80%

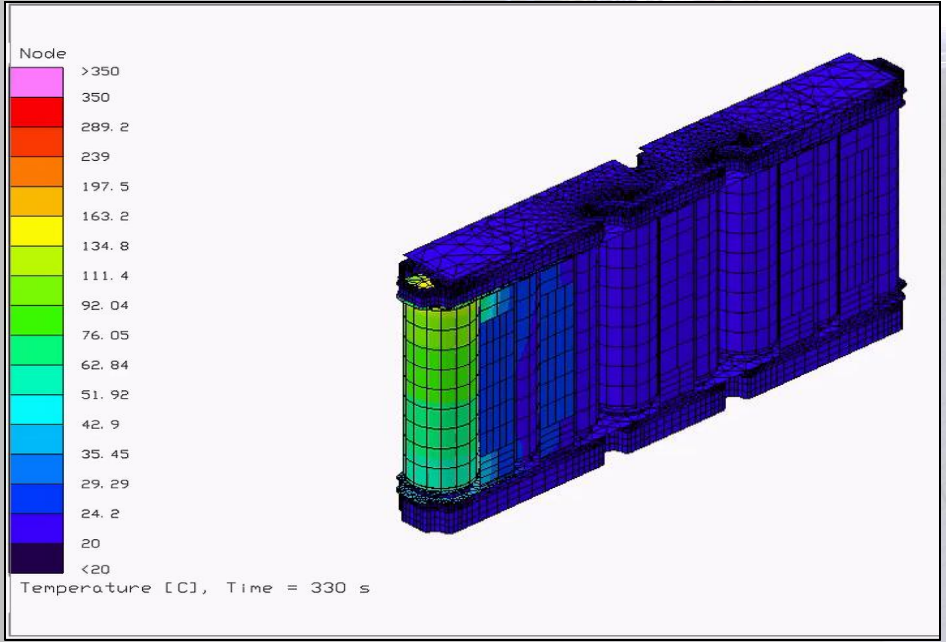
APPLICATION OF CONFIGURABLE HEAT LOADS

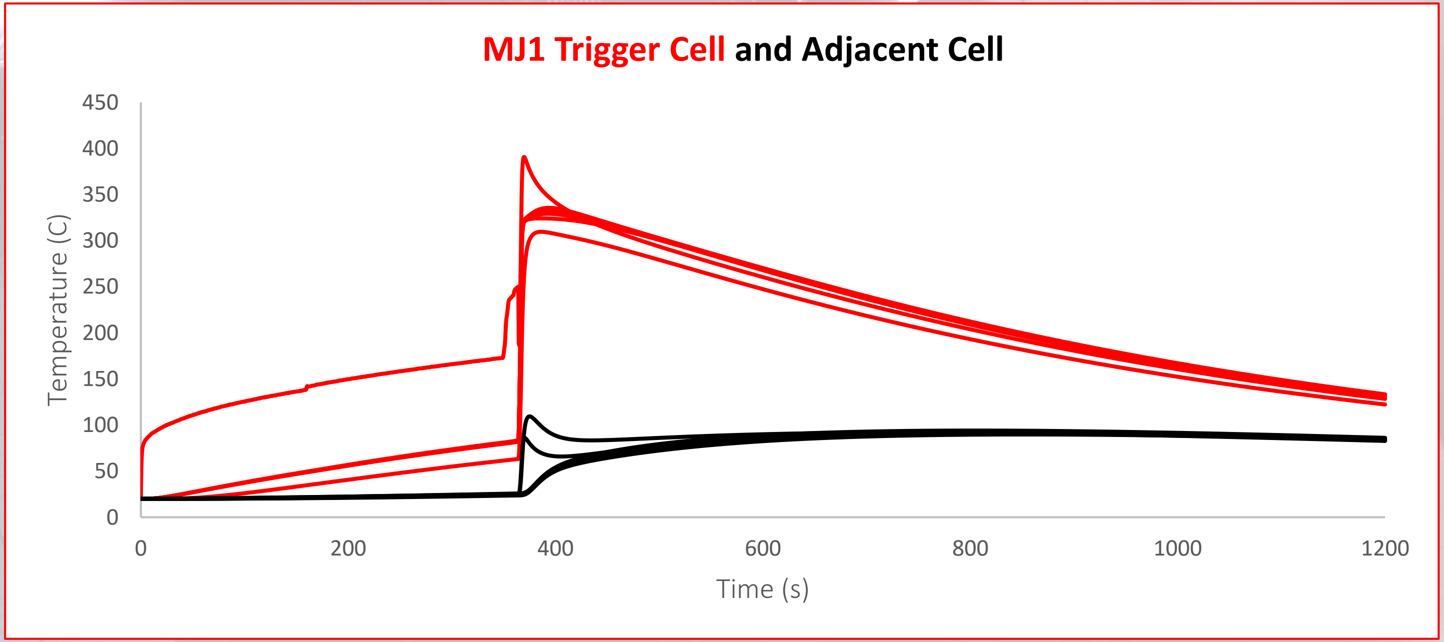
- **In Thermal Desktop, heat loads were applied to the trigger cell jellyroll for the cell body heating and to all internal surfaces for the ejecta heating:**
  - Ejecta directly impinge on the mica shield directly above the trigger cell and then disperse throughout the battery assembly until they exit through the Inconel shields via a reverse flow process.
  - For this case study the ejecta heat is assumed to be evenly distributed on the internal surfaces.
  - The red arrows in the image to the right depict the ejecta heat loads.
  - These heat loads were varied in Thermal Desktop based on the FTRC data using symbols that were set to values specific for each cell configuration.



LG 18650-MJ1 | AVERAGE TOTAL ENERGY YIELD

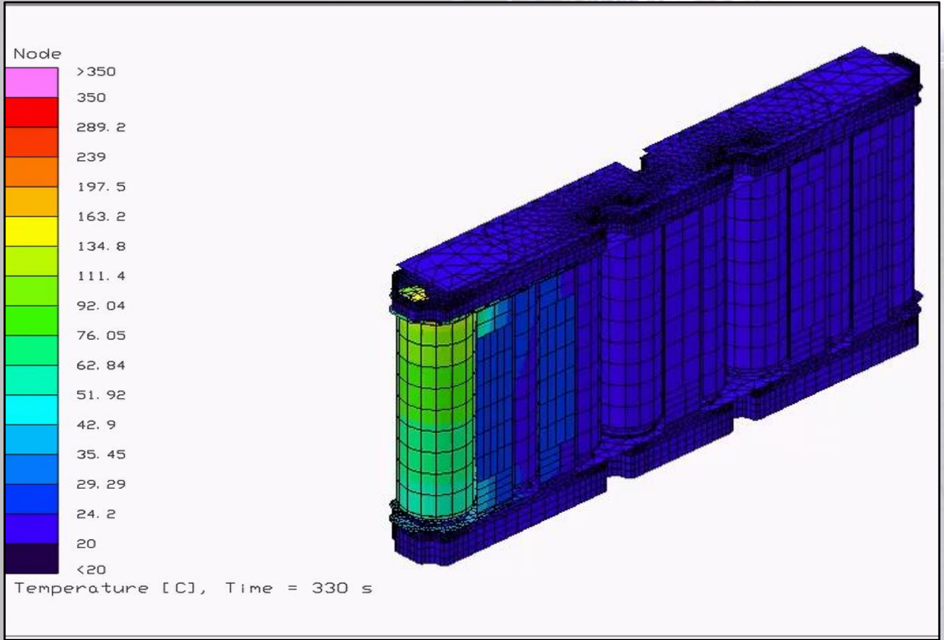
- **The LG 18650-MJ1 is the cell that was installed during the original abuse test and is also the most energetic cell included in this case study at an average total energy yield of 87.5kJ:**
  - Resultant trigger cell casing maximum temperature > 350°C.
  - Resultant adjacent cell maximum temperature < 109°C.

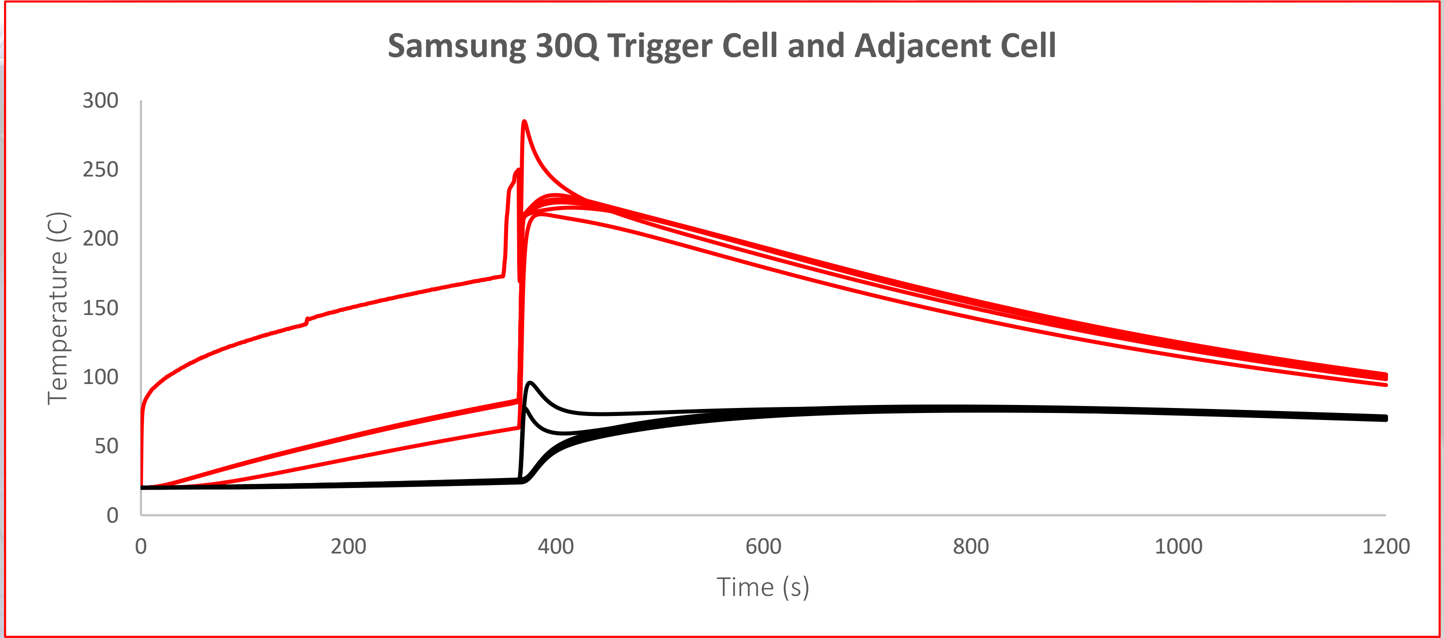




SAMSUNG 18650-30Q | AVERAGE TOTAL ENERGY YIELD

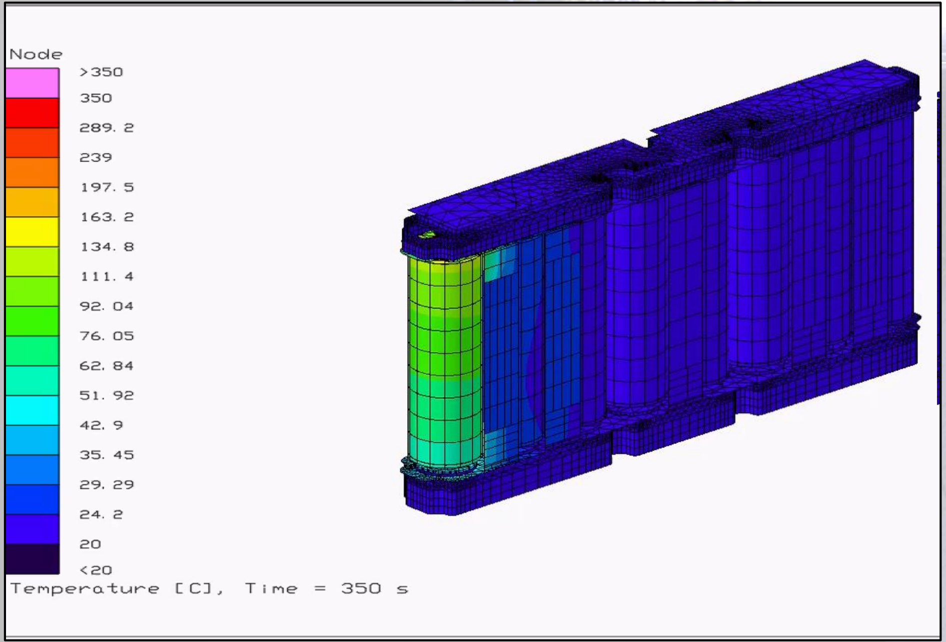
- **Thermal model results for the Samsung 18650-30Q with an average total energy yield of 69.3kJ:**
  - Resultant trigger cell casing maximum temperature > 250^{o}C.
  - Resultant adjacent cell maximum temperature < 96^{o}C.

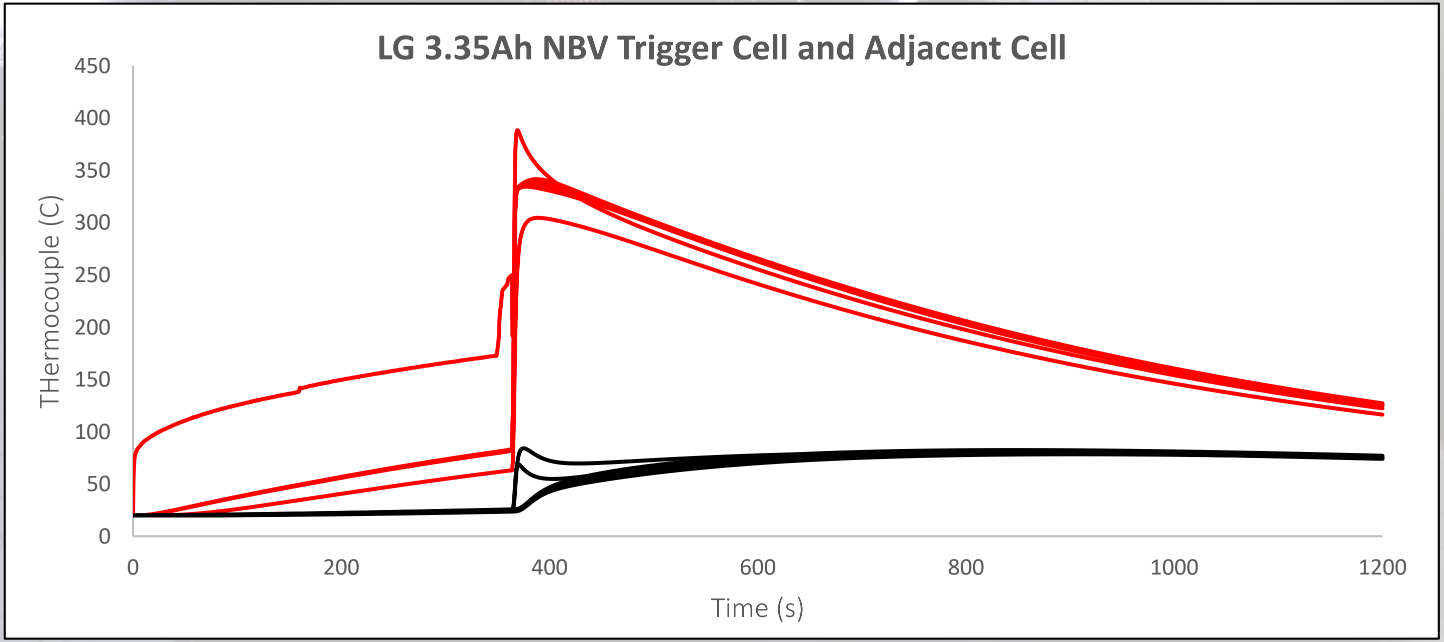




3.35 AH LG 18650 TEST CELL | AVERAGE TOTAL ENERGY YIELD

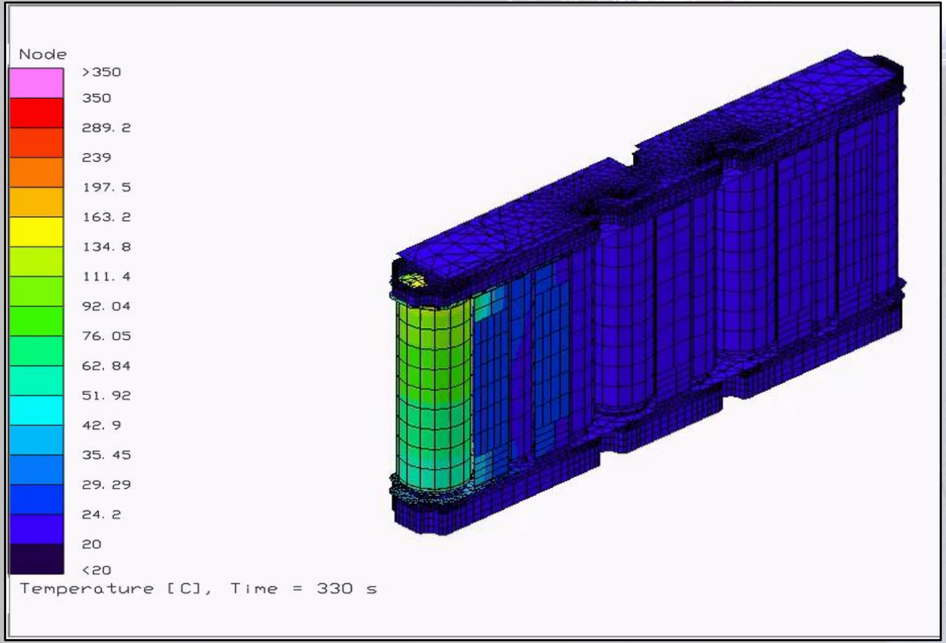
- **3.35 Ah LG 18650 test cell with an average total energy yield of 79.2kJ:**
  - Resultant trigger cell casing maximum temperature > 350°C.
  - Resultant adjacent cell maximum temperature < 100°C.

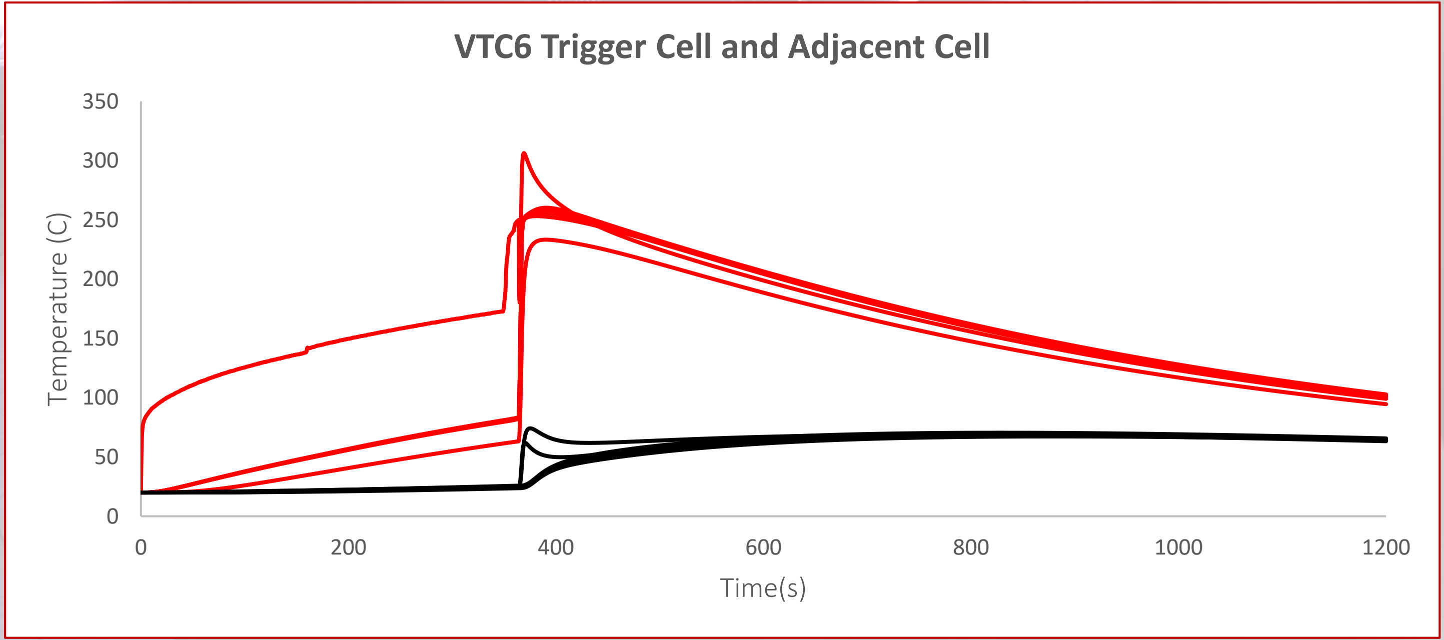




SONY 18650-VTC6 | AVERAGE TOTAL ENERGY YIELD

- **Thermal model results for the Sony 18650-VTC6 with an average total energy yield of 62.9kJ:**
  - Resultant trigger cell casing maximum temperature > 250°C.
  - Resultant adjacent cell maximum temperature < 75°C.



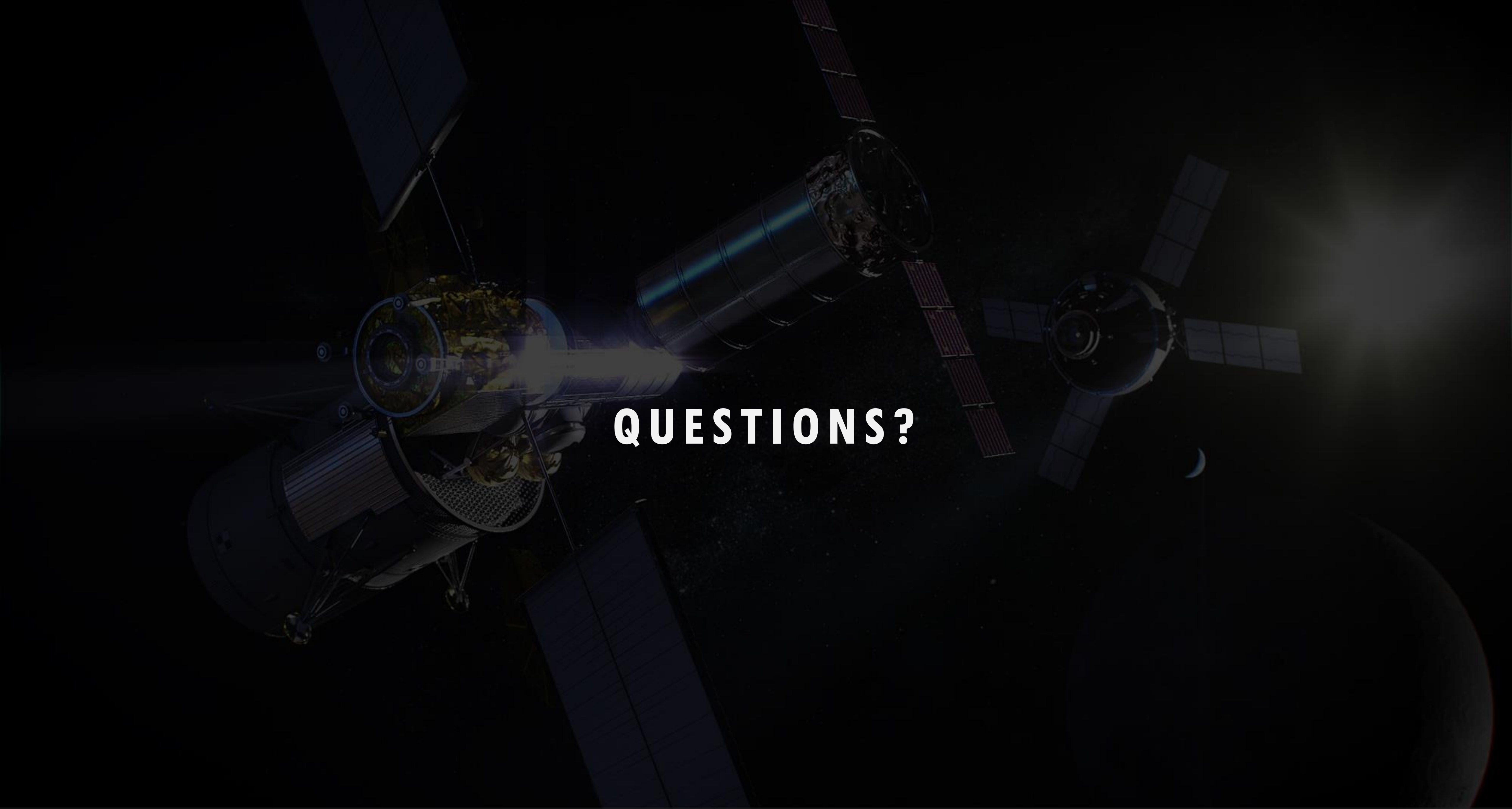


CONCLUSION

- **Case study description:**
  - Analyzed the xEMU PLSS battery assembly to evaluate strategies for thermal runaway simulation using heat loads determined from fractional calorimetry experiments.
  - Demonstration of extracting and incorporating total energy yield and fractional energy yield FTRC data as stored in the Battery Failure Databank.
  - Analyzed the xEMU battery pack response to the average thermal runaway event for the LG 18650-MJ1, Samsung 18650-30Q, Sony 18650-VTC6, 3.35 Ah LG 18650 test cell.
  - Additional results for battery pack response to min/max heat loads will be published later this year.
- **Provided recommendation for model construction techniques that result in an easily configurable and modifiable product.**
- **Technique provides the capability for rapid turnaround evaluation of a battery assembly thermal response to thermal runaway as a function of total energy yield, fractional energy yield, and cell type.**

CONCLUSION

- **Challenges:**
  - Large heat fluxes into small components cause massive temperature gradients and model failures. Reconciling these simulated fluxes with material degradation and gaseous propagation throughout the system is not an easily accomplishable task.
  - Determining how to correctly apply the ejected thermal yield throughout the system without CFD.
  - Determining appropriate thermal interface resistance values.
- **Benefits of using FTRC Data:**
  - Ability to analyze assembly level response for the overall range of expected thermal runaway behavior for a given cell type.
  - Complimenting the design process with effective thermal models can help with system level optimization can, reduce material waste, and can increases design confidence.
  - Analysis of worst case scenario conditions, and showing survival through those conditions, can minimize risk.



QUESTIONS?