Donaldson Active Regeneration PM System

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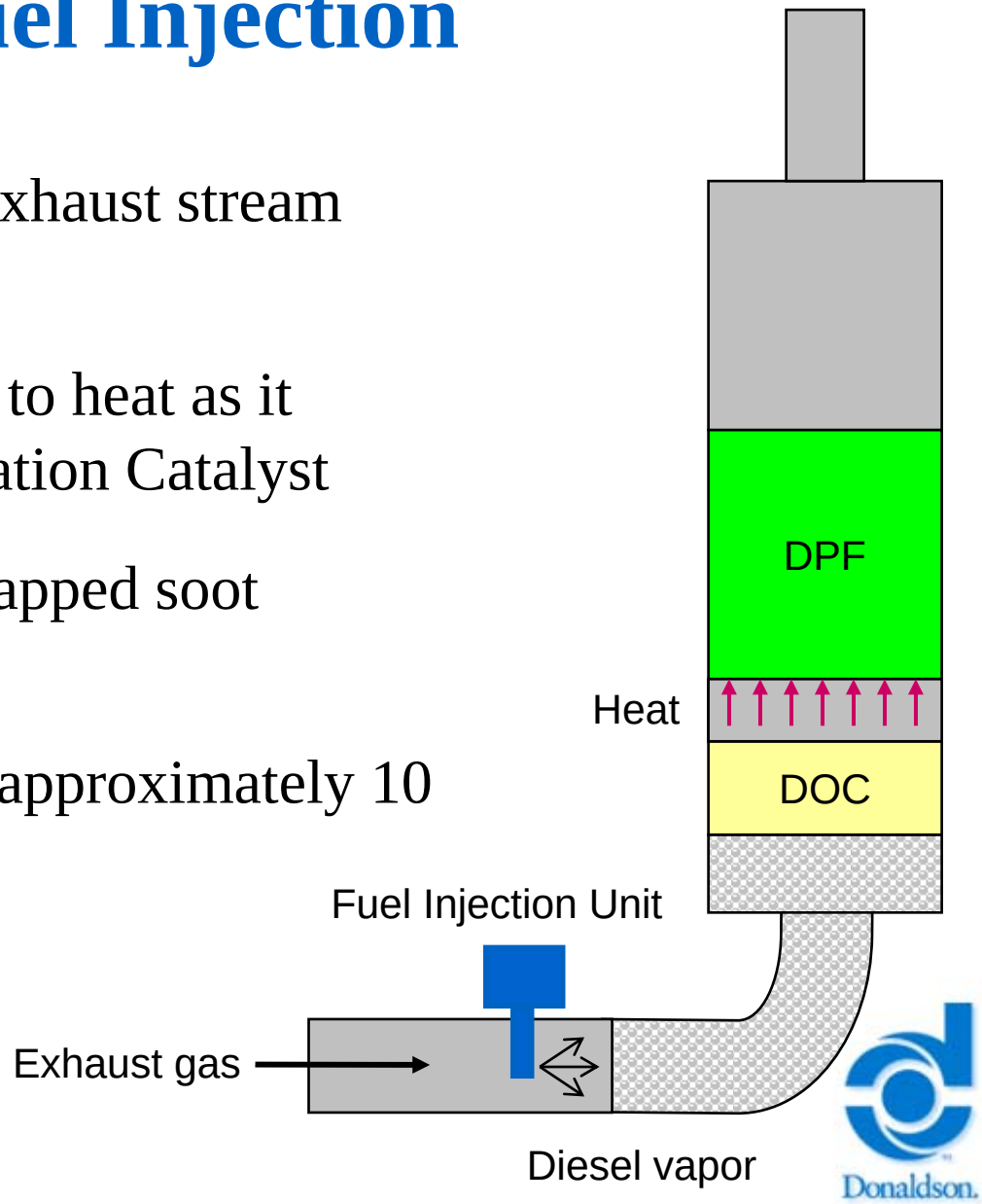
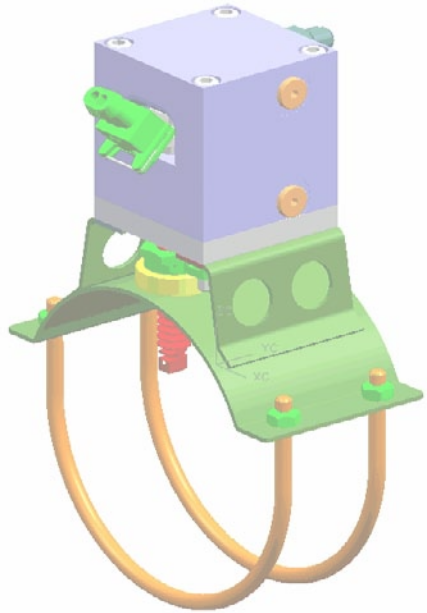
Principals of Active Regeneration Using Fuel Injection

- Diesel fuel is injected into exhaust stream stream
- Vaporized fuel is converted to heat as it passes through Diesel Oxidation Catalyst
- Heated exhaust gas burns trapped soot (regeneration) in DPF
- Regeneration process takes approximately 10 approximately 10 minutes



Subsystem Review

- Control – Model-Based, Feed-Forward, Adaptive
  - Energy balance to model system - uses fewer sensors
  - Adaptive - learns and adapts over time
  - Full Diagnostics package
  - Integration capabilities with vehicle Databus
- Fuel Delivery
  - Excellent transient response and installation flexibility
  - Simple system with few components
- Catalysts and Substrates
  - Optimized for cost and performance
  - Completed baseline durability



Fuel Injector Assembly

System Operation and Temperature Requirements

- Regeneration Frequency
  - Retrofit – every 2-5 days depending upon duty cycle
- To Initiate Regeneration
  - Exhaust temperature greater than 250 ^{0}C
    - Brief excursions up to 2 minutes
- To Sustain Regeneration
  - Once initiated, system is able to sustain regeneration through low temperature, << 250 ^{0}C, and low flow / idle idle conditions

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Minnesota Field Testing

- **Residential Refuse Hauler**
  - 2002 Mack LE-613, 300HP E7
  - Installed May, 2004
  - 2693 operational hours
- **Line-Haul Fleet Truck**
  - 1997 Freightliner FLD120, 350HP DDC S60
  - Field-test vehicle since June, 2003 2003
- **Roll-Off Refuse Hauler**
  - 2002 Mack RD688S, 350 HP E7
  - Installed November, 2004
  - 2039 operational hours

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California and 2007 OEM Field Testing

- **Residential Refuse Hauler**
  - 2003 Cummins ISL-330
  - Installed December, 2004
  - 1002 operational hours
- **Los Angeles Public Works Sewer Vac**
  - 2000 International DT530 Engine
  - 364 operational hours
- **2007 OEM Field Testing**
  - 5 trucks in high-mileage accumulation
  - 4 more trucks in September
  - Large scale field-testing starting this fall / fall / winter

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Field Testing
Weekly Inspection

Weekly Tasks

- Filter Weight
- Visual and Mechanical Inspection
- Retrieve Logger Data
- Operational Checkout
- Install Software and Calibration Updates
- Fuel and Air filter replacement (per maintenance schedule)

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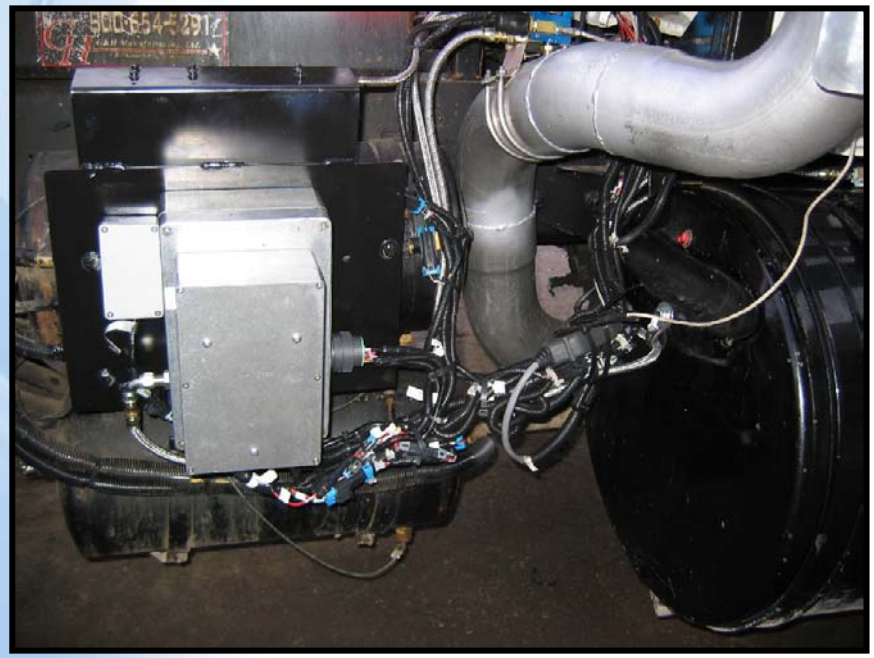
Field-Testing
Performance Monitoring

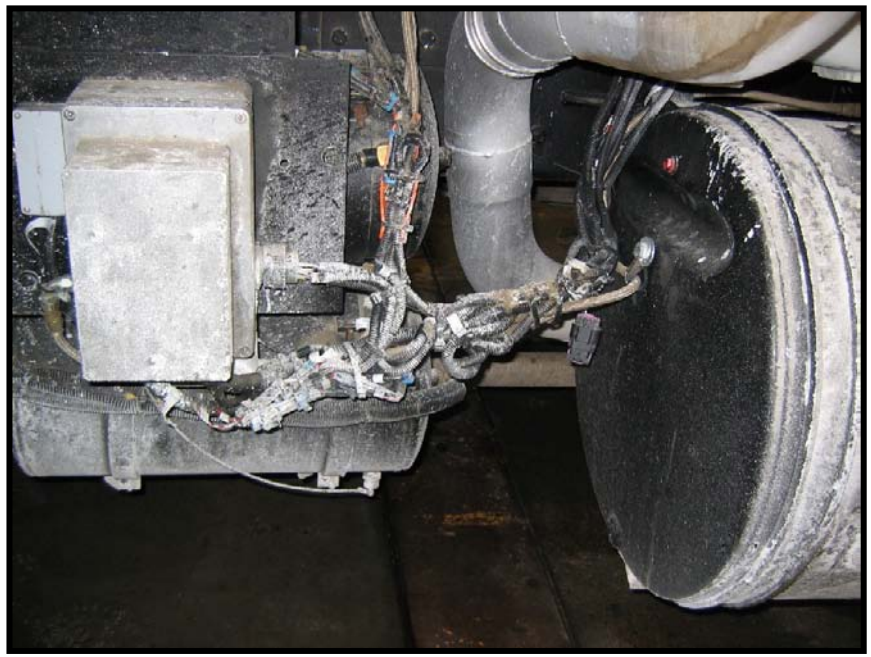
- Five-Second Data Collection Rate
  - Upstream temperature
  - Backpressure
  - Post DOC temperatures
  - Post DPF temperature
  - Active system fuel injection parameters
- Data Analysis
  - Inspected and analyzed on a per-regeneration regeneration basis
  - Operational trend reports
    - Daily, weekly and monthly basis

Cold-Weather Field-Testing
Minnesota Winters are Fun!

Controller and Fuel Delivery System



As Installed



Salt and Ice After Two Days
Days on the Road

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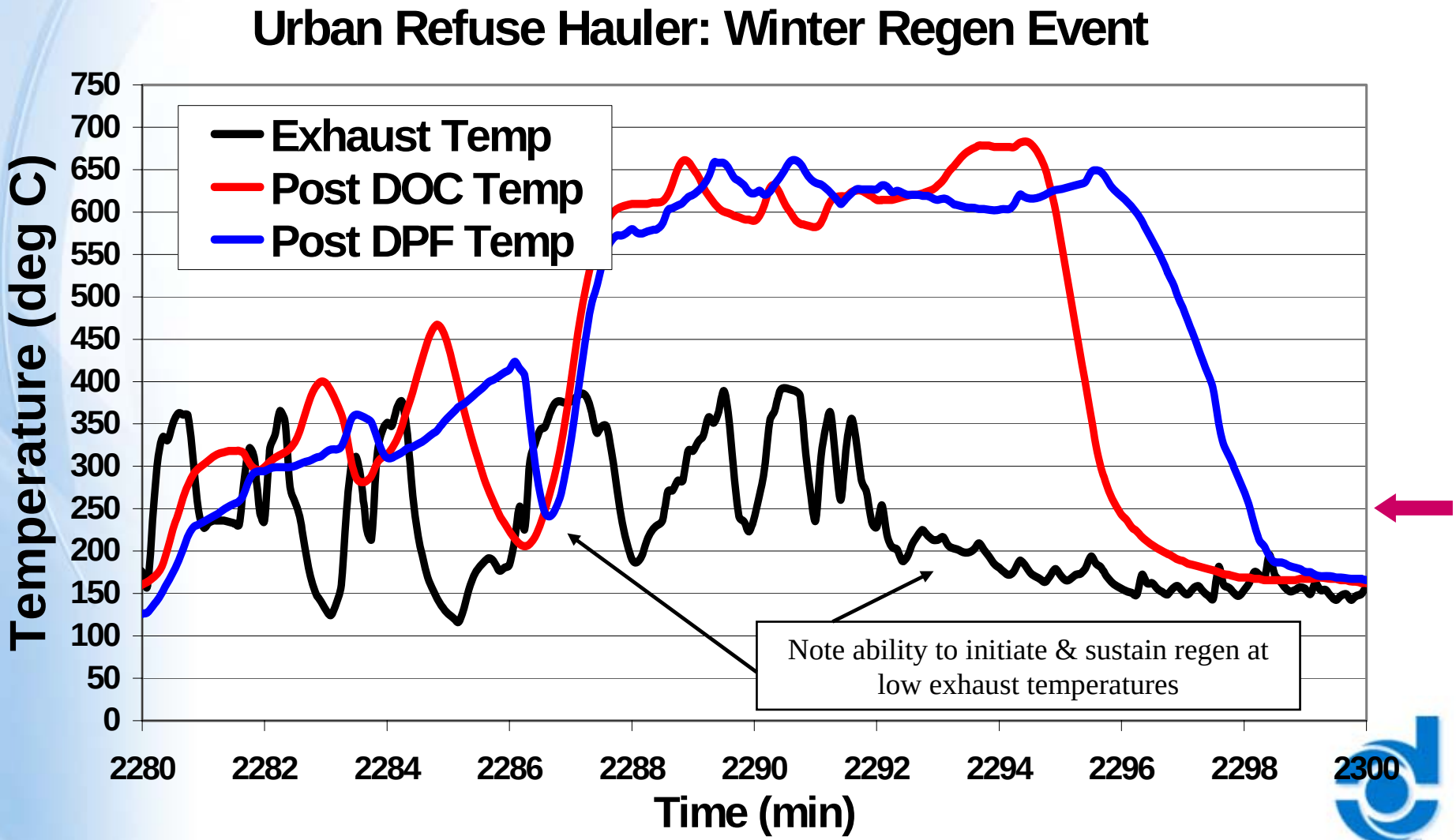
Cold-Weather Field-Testing

Winter Test Results



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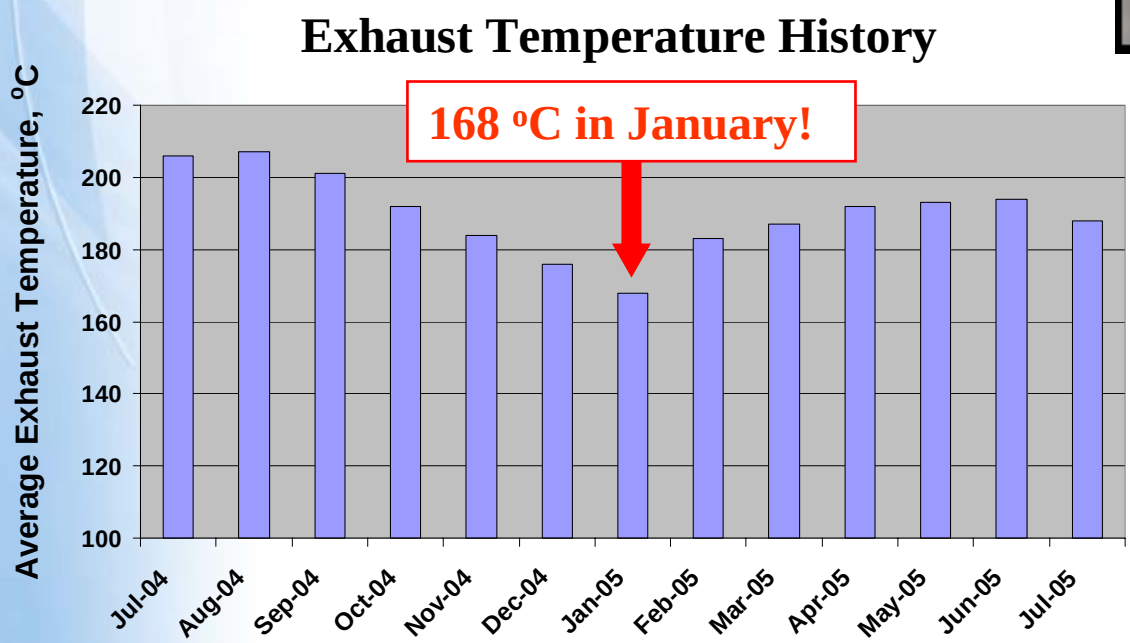
Cold-Weather Field-Testing
System Verification on Urban Refuse Vehicle

- Successful multiple-vehicle operation through cold Minnesota Winter.
- This is the most difficult duty cycle we've we've encountered!



Average Exhaust Temp
- **Aug = 207 °C**
- **Jan = 168 °C**

Percent of Time > 250 °C
- **Aug = 19.2%**
- **Jan = 9.8%**

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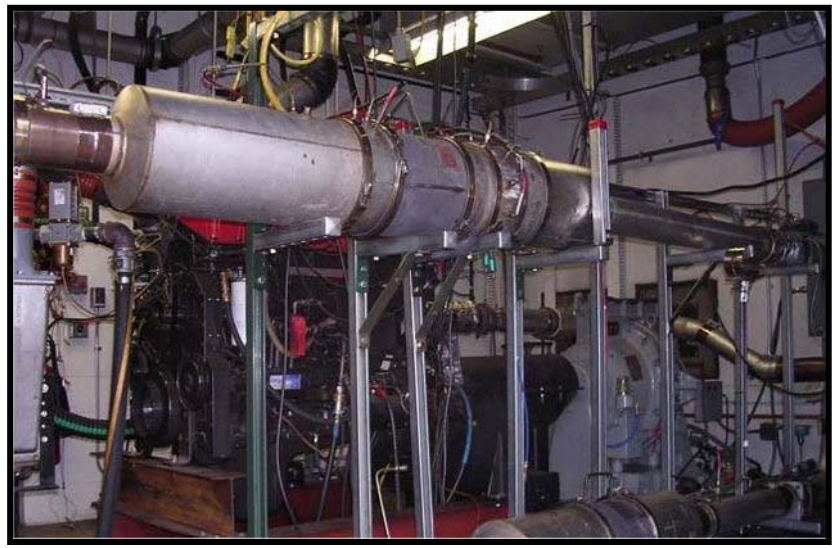
Active System Durability & Reliability

Dynamometer Durability Testing

- Accelerated Dynamometer Testing of Testing of Complete System
  - Rapid, simulated regenerations repeated repeated 24/7
  - Real-world, transient operating conditions
- Monitor Components Performance Performance over Useful Life
  - Catalyst systems
  - Fuel injection unit
  - Sensors /wiring harness, etc.



Transient Dynamometer Regen Testing

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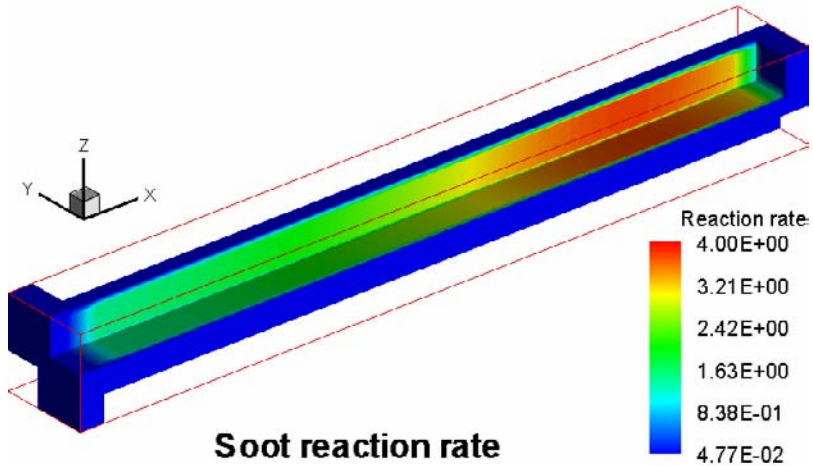
Active System Durability & Reliability
Analysis Techniques

- Fundamental System Analysis to Ensure Durability
  - DPF Regeneration Modeling
  - Model-Based, Adaptive Control
  - Flow Distribution & Thermal Management



- Specific Reliability Analysis Procedures
  - Thermal Stress Investigation
    - Thermal Stress Modeling - FEA
    - Failure Mode Analysis & Life Prediction
  - Reliability Analysis
    - FMEA, Fault Tree Analysis, Risk Assessment, etc.

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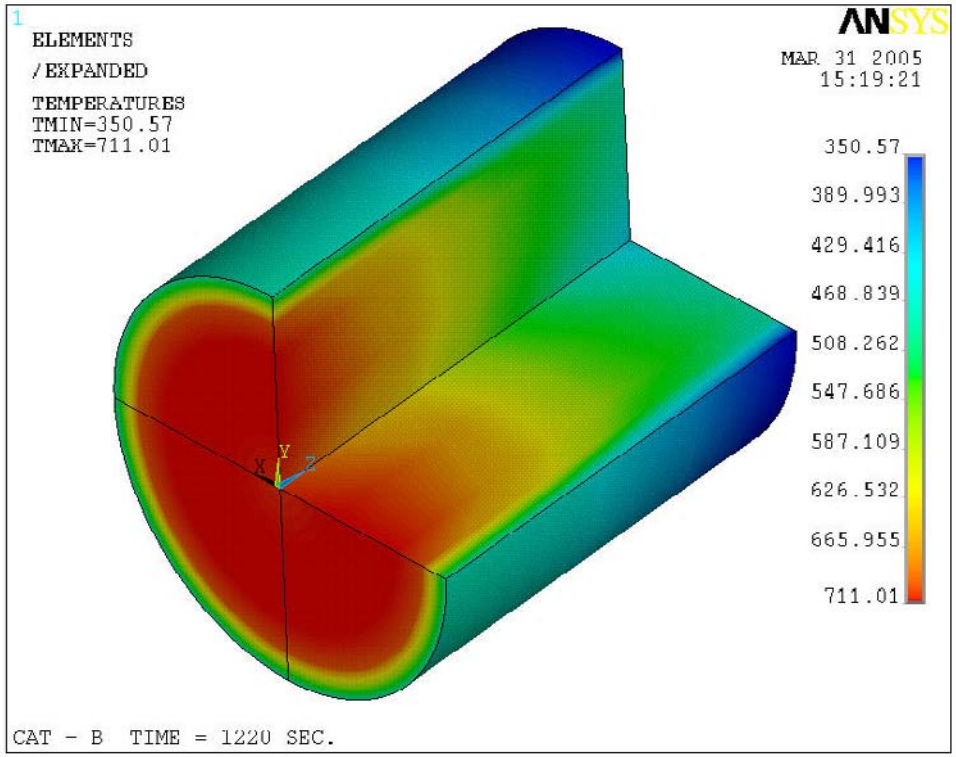
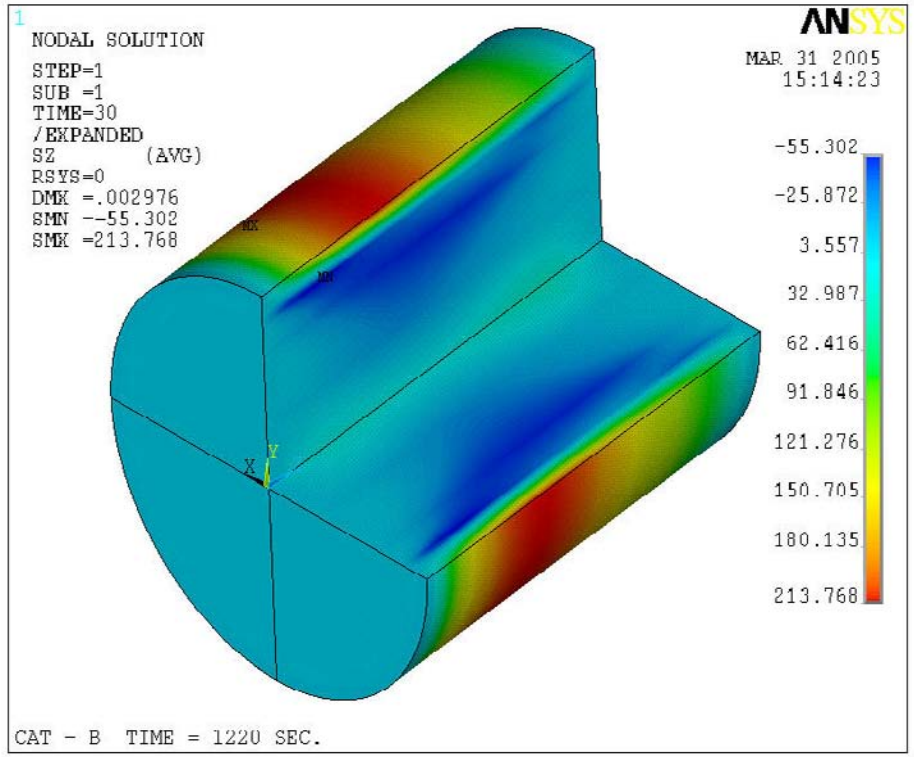
Active System Durability & Reliability

Thermal Stress Modeling



Temperature



Axial stress

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