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Thermal Modeling Aluminum-Clad Spent Fuel Dry Storage Configurations

September 2023

Changing the World's Energy Future

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Idaho National Laboratory

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Thermal Modeling Aluminum-Clad Spent Fuel Dry Storage Configurations

Computational Fluid Dynamics Simulation of a Generalized Dry Storage Configuration under Hypothetical Accident Conditions

Overview

- Used Fuel Management Department
  - What we do
- Intro to Advanced Test Reactor Fuel Elements
- Thermal Modelling of Accident Scenarios

C430 Used Fuel Management Department at INL

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA [1]

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Office of NUCLEAR ENERGY [1]

OFFICE OF ENVIRONMENTAL MANAGEMENT [1]

→

BEA Battelle Energy Alliance [2]

INL Idaho National Laboratory [3]

[1] US Department of Energy. 2023.
[2] Battelle Energy Alliance. 2019.
[3] Idaho National Laboratory. 2021.

C430 Used Fuel Management Department at INL

Division C Nuclear Science and Technology

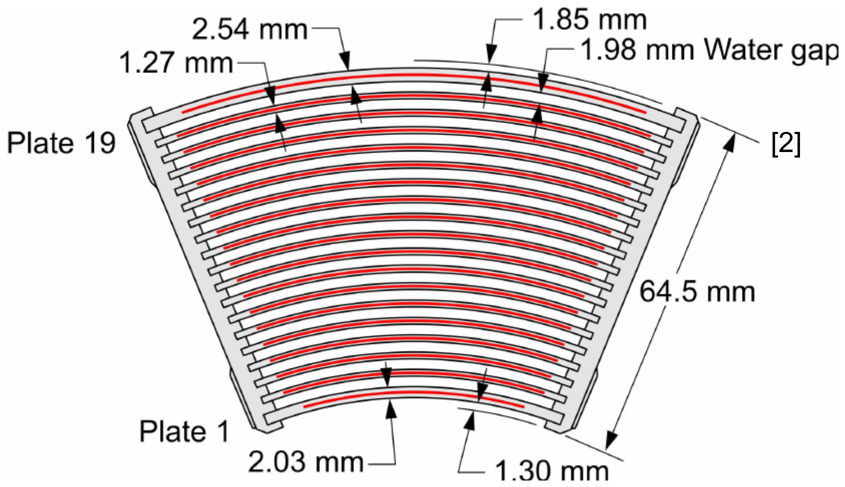
C400 Fuel Cycle Technology

C430
Used Fuel Management

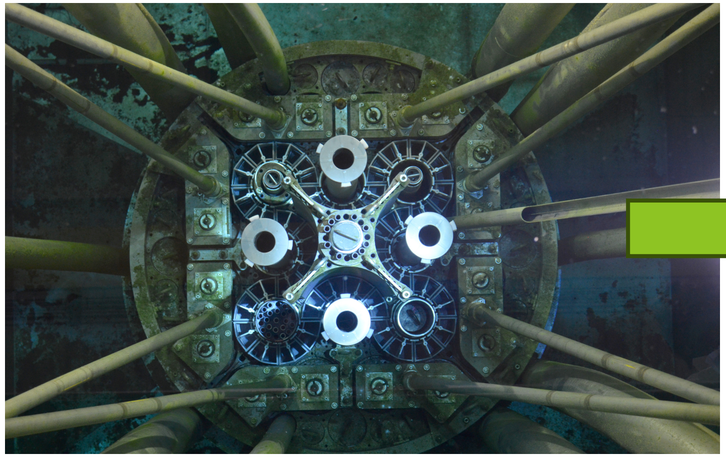
- Advanced Reactor Backend System Analysis
- Consent Based Siting
- DOE Spent Fuel Database
- Used Fuel Storage and Transportation System Analysis
- Road-Ready Dry Storage Demo
- … and other activities

Advanced Test Reactor Fuel

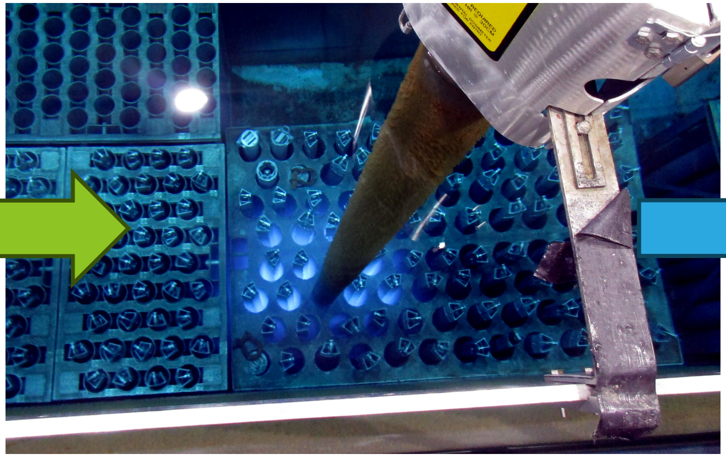
- The Advanced Test Reactor uses an aluminum clad fuel.
- Aluminum corrodes and oxide layers can form on the cladding surface. These layers retain water making aluminum cladded spent fuel hard to dry.
- Gamma radiation exposure could lead to radiolytic gas generation which could increase canister pressure.



Cross Section of ATR Fuel



[2]



[2]

[1]

Irradiated in Reactor → Cooled Down in Pool → ? → Extended Dry Storage

[1] US Department of Energy. 2023.
[2] Idaho National Laboratory. 2023

Thermal Modelling and Simulating Accident Scenarios

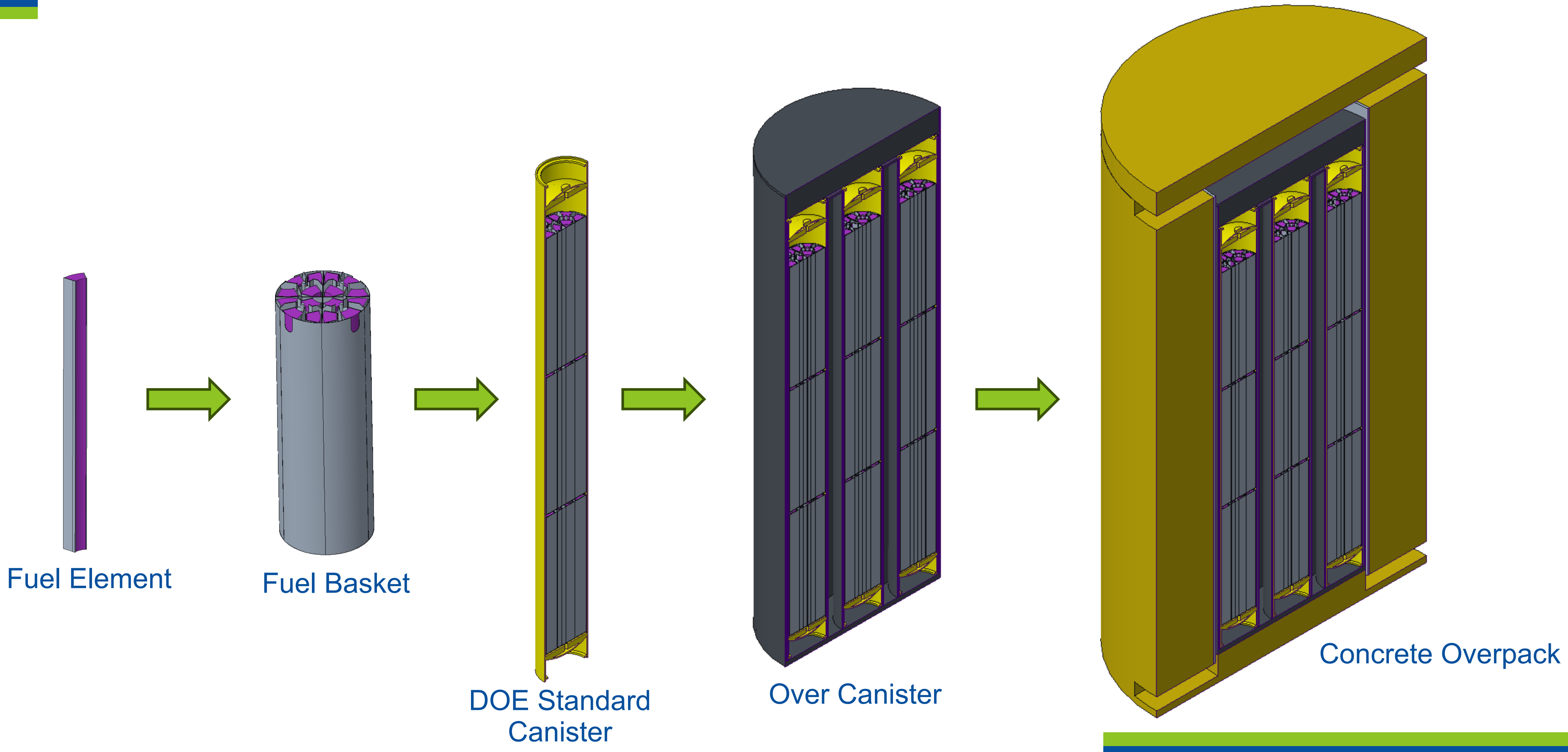
- Thermal experiments can be costly.
- Computational fluid dynamics is a low-cost alternative to physical experiments.
  - Can be used to build informed experiments

- Earlier work determined that the maximum service temperature of the DOE Standard Canister enclosed in another canister is 343°C.
- Bounding pressure calculations of radiolytic gas generation indicate canister over pressurization at 316°C.

Sandia National Laboratory Fire Testing at FLAME

STAR-CCM+®

Packaging of DOE-Managed Used Nuclear Fuel



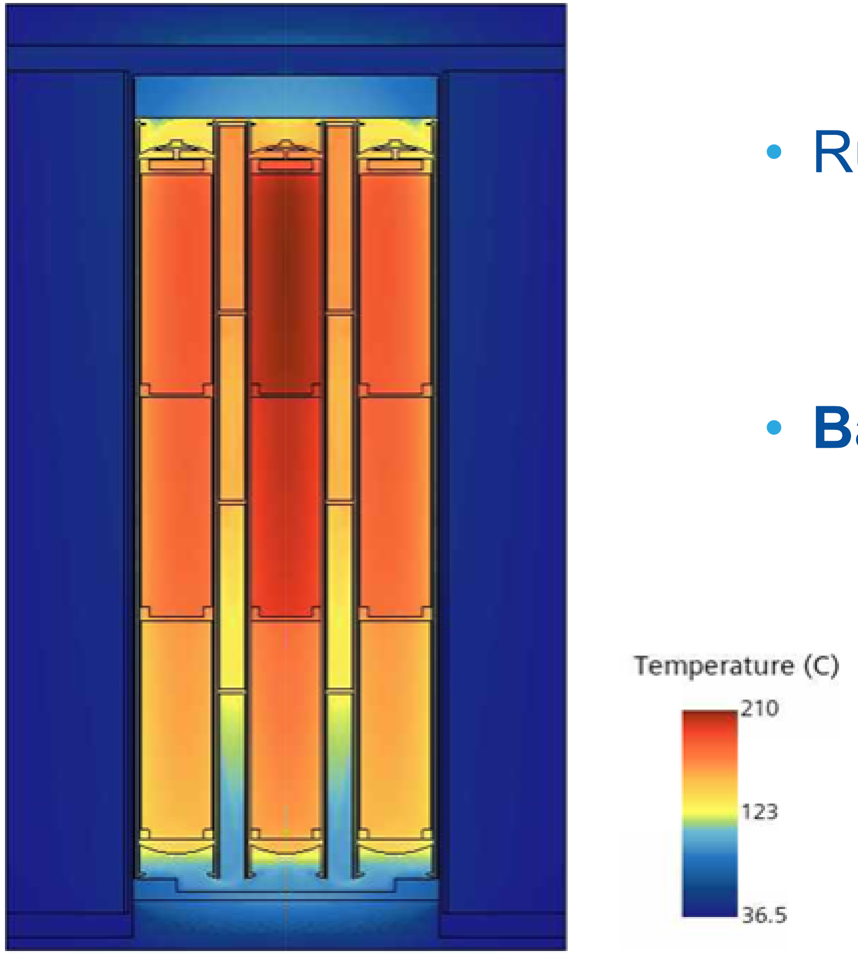
Boundary Conditions

Boundary Conditions → Steady State Scenario → Adjust Boundary Conditions → Accident Scenario → After Accident Scenario

- The **maximum temperature of the backfill gas internal to the canisters** is the main report of interest as it is used to calculate the maximum internal pressure of the canisters.
- Selected conditions listed in 10 CFR 71.71 & 73 have credible scenarios that can be used to evaluate dry storage safety.
- **Boundary Conditions for Normal Condition of Storage (NCS):**
  - Ambient air temperature = 38°C
  - Insolation = 390 W/m^2, for “curved surfaces”; 780 W/m^2, for the “roof”
  - Heat transfer coefficient on outer walls = 5 W/m-K
  - Fuel elements set to generate 30 W of heat

Steady State Scenario Results

Boundary Conditions | **Steady State Scenario** | Adjust Boundary Conditions | Accident Scenario | After Accident Scenario



- Run to steady state (NCS)
  - Heat transfers and temperatures being sampled are no longer changing with iteration and have converged.
- **Backfill gas max temperature: 208.5°C**

Adjust Boundary Conditions

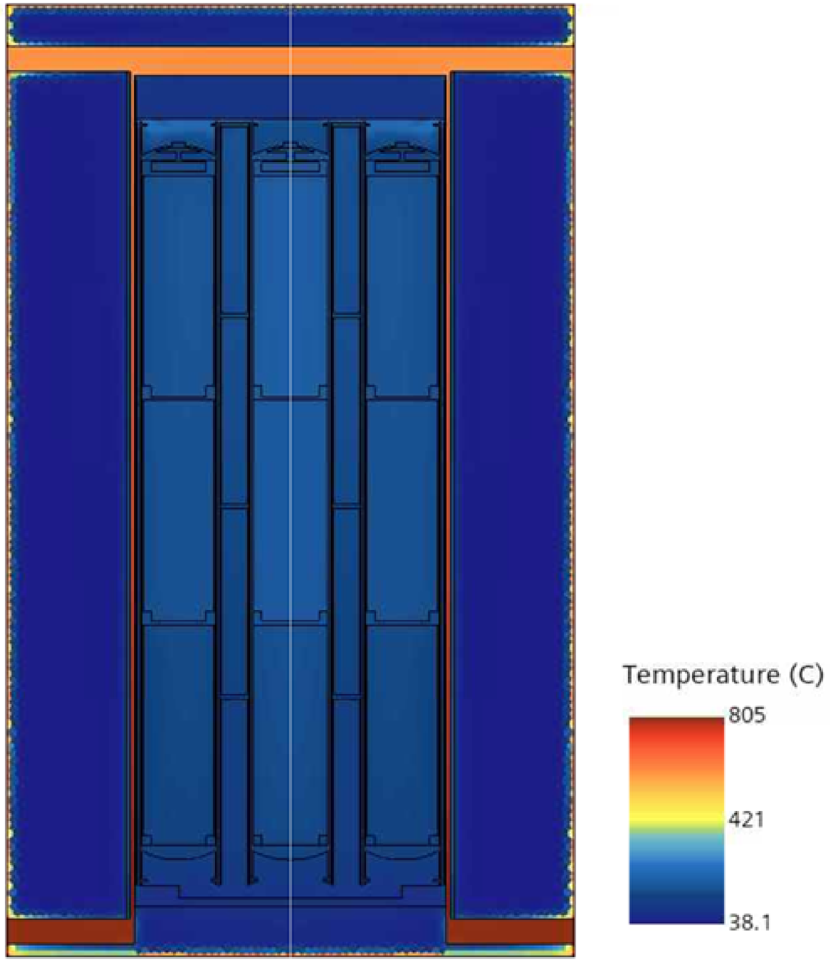
Boundary Conditions → Steady State Scenario → **Adjust Boundary Conditions** → Accident Scenario → After Accident Scenario

- Hypothetical Accident Conditions
  - A thermally bounding scenario that is meant to simulate how the cask would perform if exposed to a fire for a duration of 30 minutes.

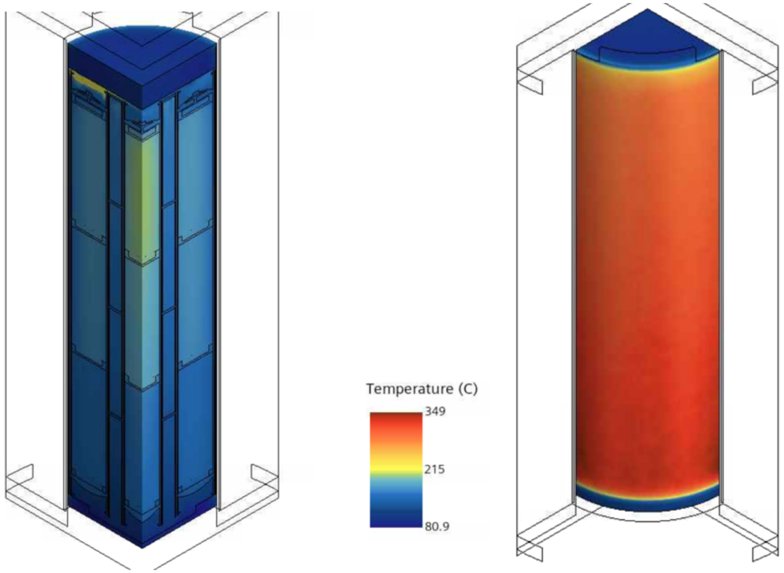
- **Boundary Conditions**
  - **Ambient air temperature = 800°C for 30 min of simulation time**
  - Insolation and heat transfer coefficient are not changed

Accident Scenario

Boundary Conditions → Steady State Scenario → Adjust Boundary Conditions → **Accident Scenario** → After Accident Scenario



- Transient simulation run to 30 minutes
- **Backfill gas of DOESC's maximum temperature: 208.5°C**



After Accident Scenario

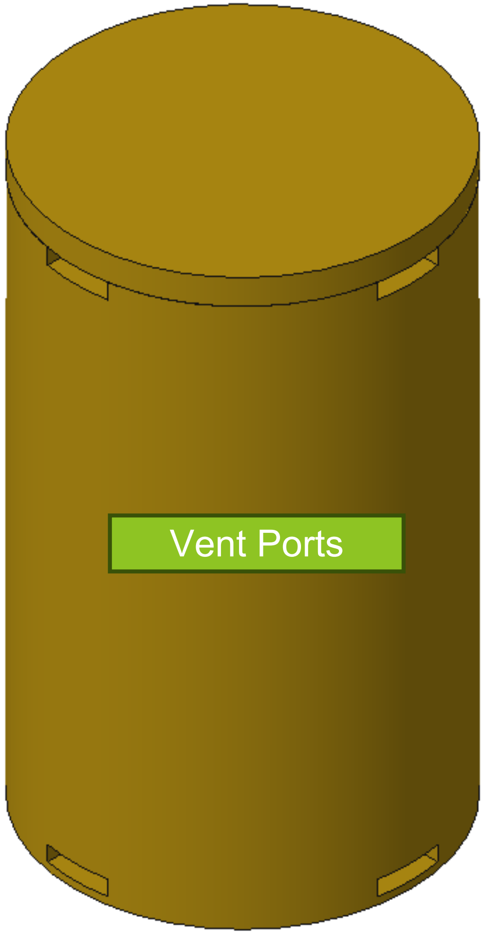
Boundary Conditions → Steady State Scenario → Adjust Boundary Conditions → Accident Scenario → **After Accident Scenario**

Region	T_{MAX} [°C]	t [hr]	$\Delta T_{t=0\ min}$	$\Delta T_{t=30\ min}$
[redacted]				
Outer Gas	190.87	10.8	5.37	5.36

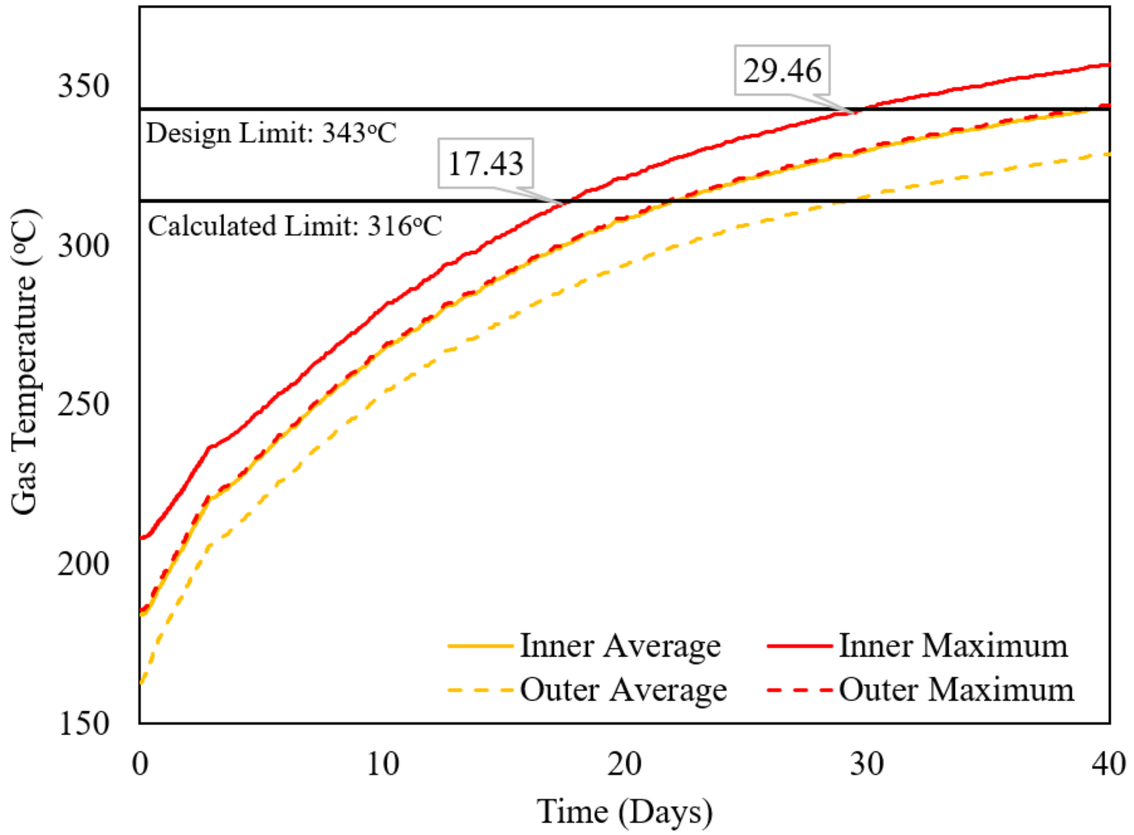
- The boundary conditions were returned to NCS (38°C).
- **Residual heat** in the system left from the fire will continue to increase the temperature of internal components.
- T = Temperature, t = time, $\Delta T_{t\,=\,x}$ = Difference in temperature from time x

What if the vent ports get blocked?

- Initialized from the steady state used to simulate the fire scenario
- The vent ports are turned into adiabatic walls.
  - No flow, no energy through the boundary



What if the vent ports get blocked?



- It takes the maximum gas temperature more than **17 days** to exceed the critical temperature of 316°C and 29 days to exceed the DOESC design limit.

Conclusions

Simulation results suggest:

- These calculations apply to a bounding radiolytic gas generation scenario only and thus, are highly conservative.
- Under NCS the maximum gas temperature remains significantly below the critical level.
- During a fire, the maximum gas temperature increases insignificantly.
- Considering fully blocked vent ports, it takes more than 17 days for gas temperature to reach critical level.

Questions?

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