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Tip-Over Thermal Analysis for Holtec Hi-Storm Ventilated Concrete Spent Fuel Storage Cask

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Introduction

Thermal analyses have been completed for peak overpack temperatures that would occur as a consequence of cask tip-over. Tip-over in this case is considered as a possible result of a seismic event. Natural convection is the primary method for heat transfer from a canister within a storage system such as the Hi-Storm design. If such a cask is placed on its side, the driving force (density*gravity*"distance from entrance to exit vents") is reduced significantly, resulting in proportionally higher system component temperature. The potential for blocked vents during such a scenario is also a consideration, as is the possibility of a reduction in the annulus flow path area resulting from the tip-over event.

A structural analysis was performed first by SWRI[1], and their results were used in formulating the thermal analysis. Both nominal geometry and resulting deformed geometry were provided by SWRI as electronic files. The specific geometry was for a Hi-Storm cask, not a Hi-Storm 100S; and the canister and assembly detail is for a Hi-Star MPC-24. From the perspective of the thermal analysis, the principal result of the structural analysis was that, despite some deformation of the bottom-side spacer between the canister and overpack, the intervening space remained open and therefore could effectively pass cooling airflow. For this reason, we made the assumption that nominal geometry could be used in the thermal analysis. Therefore, the thermal consequences of the tip-over come primarily from changes in the total cooling airflow rate, not from structural flow restrictions around the canister.

Model Description

Thermal analyses were performed for two cases: one where the cask is lieing on one pair of the inlet and outlet vents, effectively blocking them; the second where the cask is lieing on the surface mid-way between vents, or 45 degrees rotated about its axis from the first case. Otherwise the analyses were identical. Common features to both analyses included:

- Geometry is for Holtec Hi-Storm Cask, with MPC-24 Canister
- Ambient temperature is 100 °F (37.8 °C)
- Material properties as in AHSM model (0.4 thermal emissivity all surfaces)
- Heat transfer coefficient on all external surfaces was 10 W/m^2K
- No gap resistance is included between canister base and pedestal
- Assembly detail is not included in thermal analysis
- Canister thermal output of 24kW is distributed with representative axial power profile over canister inner walls with a ratio of heat flux of 0.1/0.8/0.1 between middle-canister to outer-canister to canister base and top

[1] PA Cox, 1/17/02, CD-ROM of material from NRC Project 10.01405-041, Southwest Research Institute, San Antonio, TX.

No Vents Blocked Case

The cask in this case is assumed to lie on its side mid-way between vents. Symmetry is assumed about the vertical axis. Steady state simulation results are shown in Figure 1 for cooling air velocity. Cooling air enters the vents on the underside of the cask and exits out of the vents on the top-side of the cask. This figure also shows the airflow detail around the canister and in the vents. Spacers between the canister and overpack are included for reference. The velocity magnitudes around the canister (not visible in the figure) range from 0.2 to 0.8 m/s (0.6 to 2.6 ft/s). Velocities in excess of 1 m/s (3 ft/s) occur in the vents due to local flow recirculation. Total induced air flow rate is 0.22 kg/s.

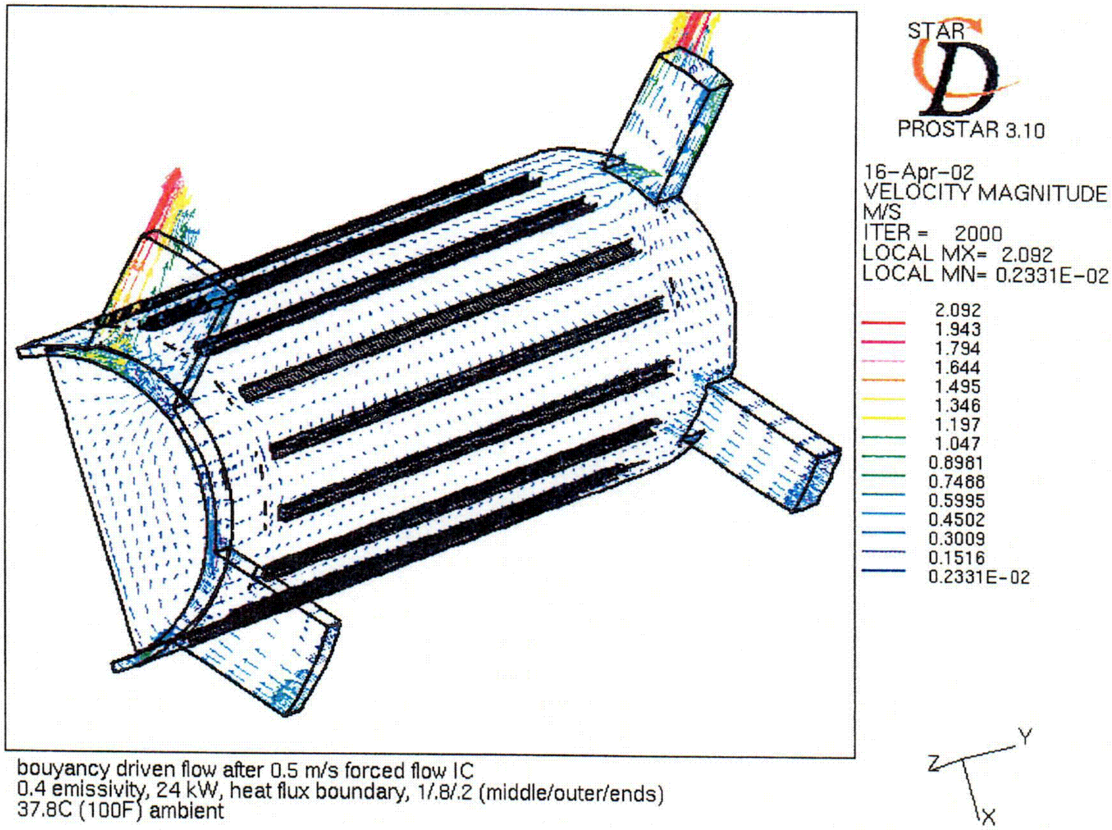


Figure 1 – Cooling air velocity for No Vents Blocked Case (gravity aligned with X-axis)

The associated cask temperatures for this case are shown in Figure 2. Temperatures are averages for each computational cell, and this section view shows details for the overpack steel and concrete. Maximum temperatures in the overpack occur at mid-length of the canister. The cell average maximum temperatures there are 190 °C (374 °F) for the concrete and 210 °C (410 °F) for the steel liner. A cross-sectional view of the overpack is provided in Figure 3, which illustrates the distribution of concrete and steel temperatures at that axial location.

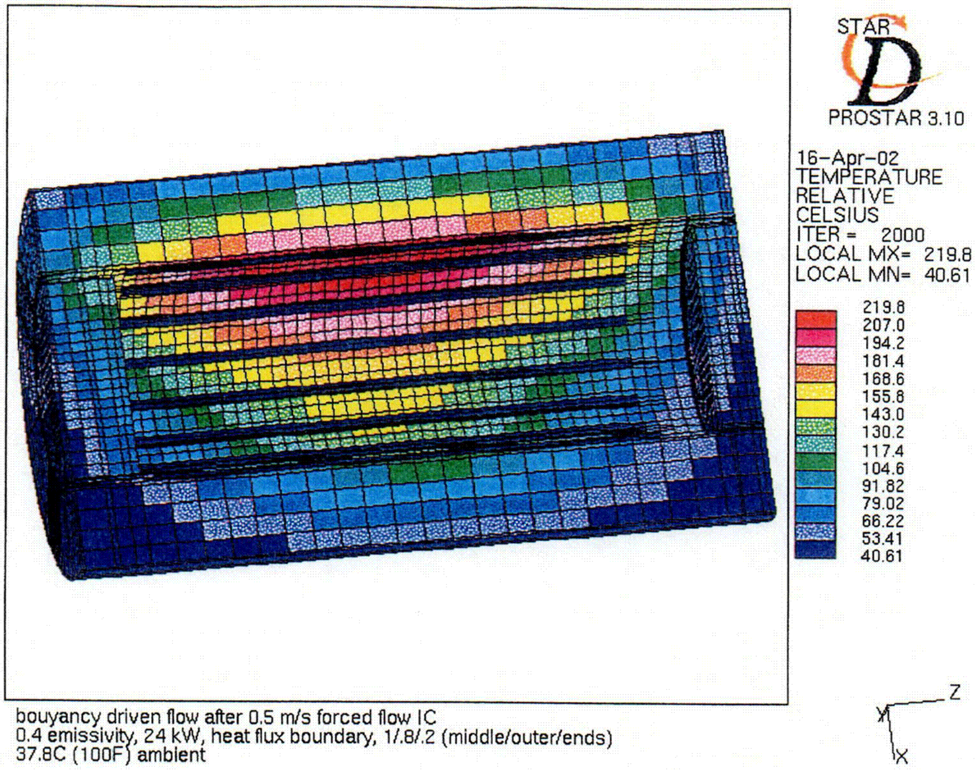


Figure 2 – Concrete overpack temperatures for No Vents Blocked Case

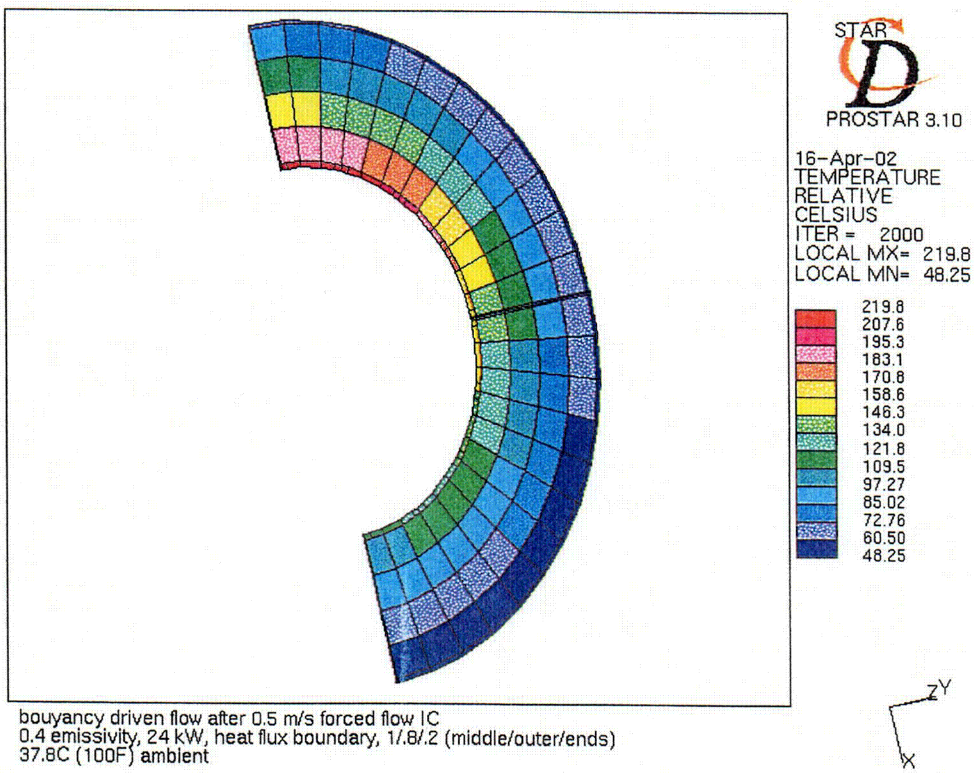


Figure 3 – Concrete overpack cross-section at axial location with maximum temperatures

Vents Blocked Case

In this case, the cask is assumed to lie on its side directly on a pair of vent openings resulting in a flow blockage. No air was allowed to enter these vents in the simulation. Steady state simulation results are shown in Figure 4 for cooling air velocity. Cooling air enters the vents on the side of the cask and is driven out of the vents on the top. Note that despite the blocked bottom vents, airflow circulates to the bottom of the canister and has similar velocity magnitudes to that in the No Vents Blocked Case. No apparent 'dead flow' zones are indicated. However, total induced air flow in this case is 0.16 kg/s, considerably less than for the previous case.

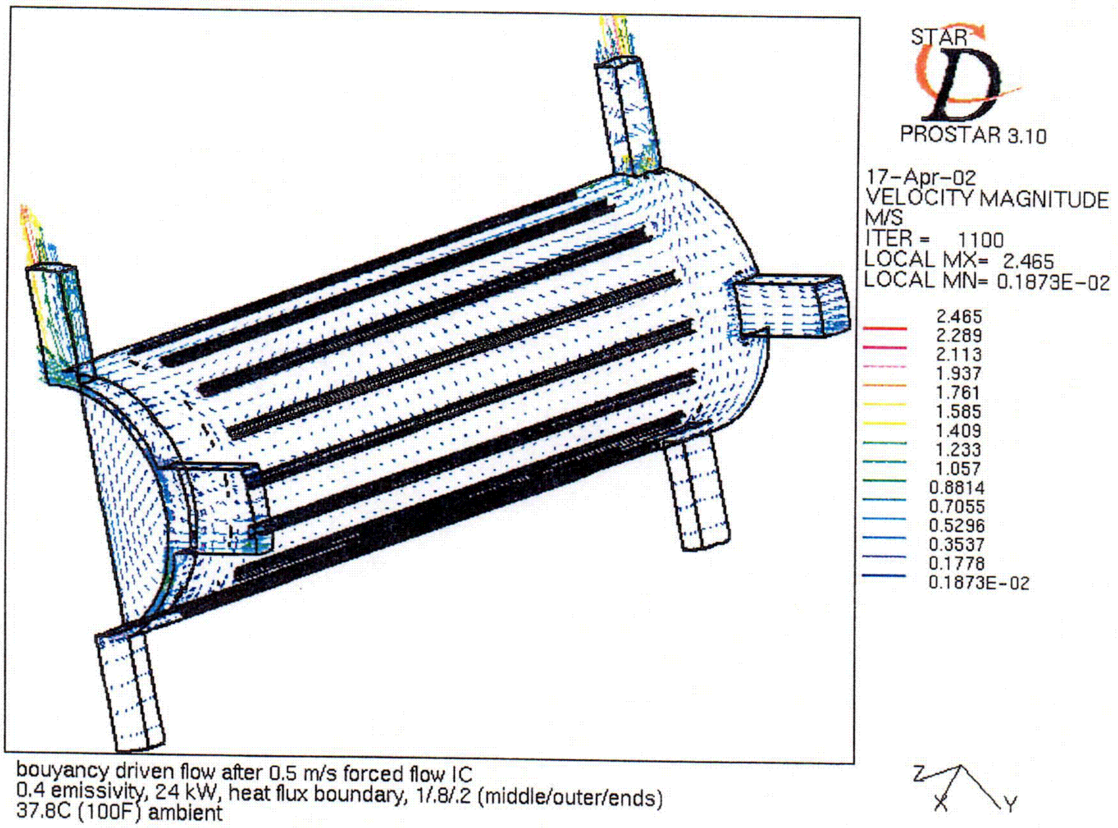


Figure 4 – Cooling air velocity for Vents Blocked Case (gravity vector mid-way between X and Y axes)

The overpack temperatures associated with this case are shown in Figure 5. Again the peak occurs at mid-canister, and the overpack cross-sectional temperature distribution at that location is provided in Figure 6. Peak temperatures are essentially the same as for the No Vents Blocked Case.

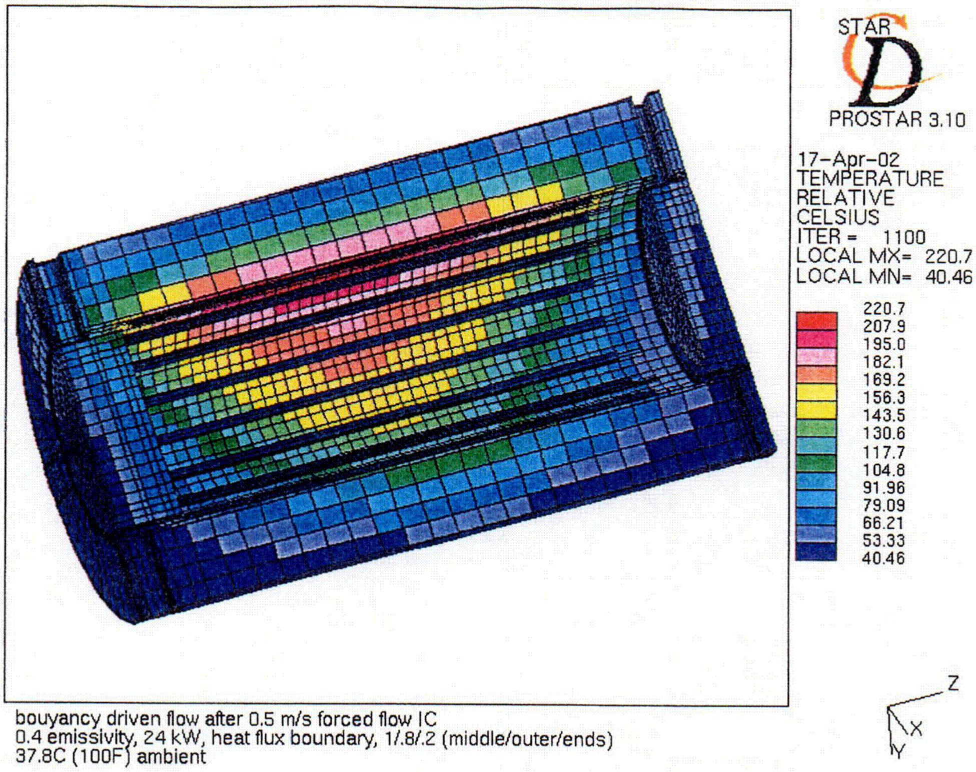


Figure 5 – Concrete overpack temperatures for Vents Blocked Case

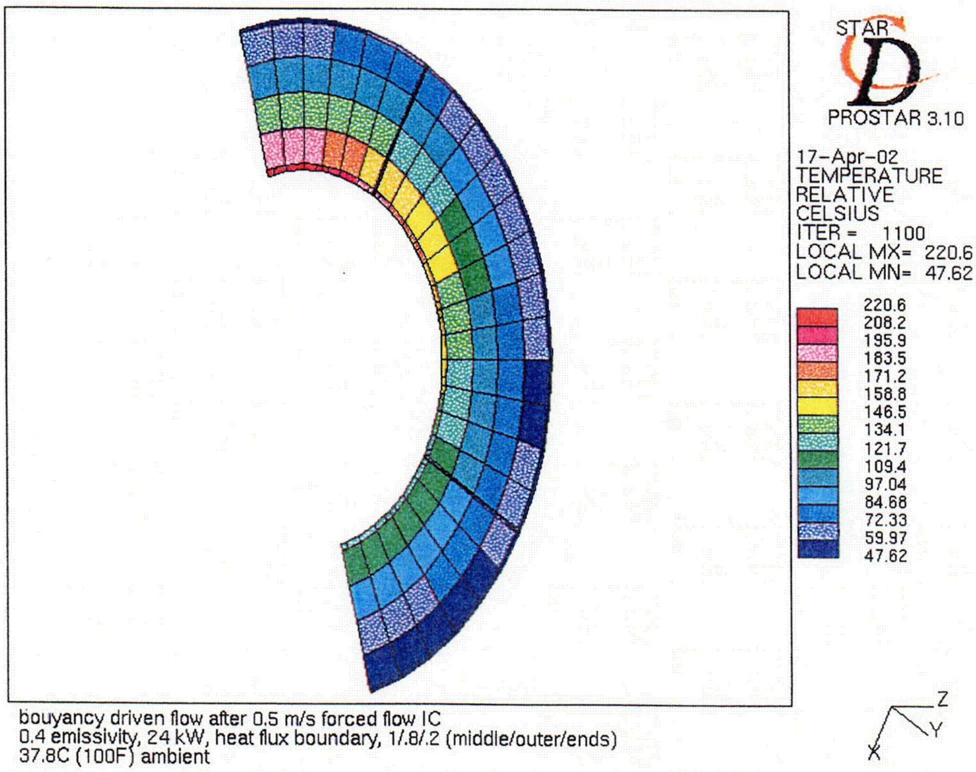
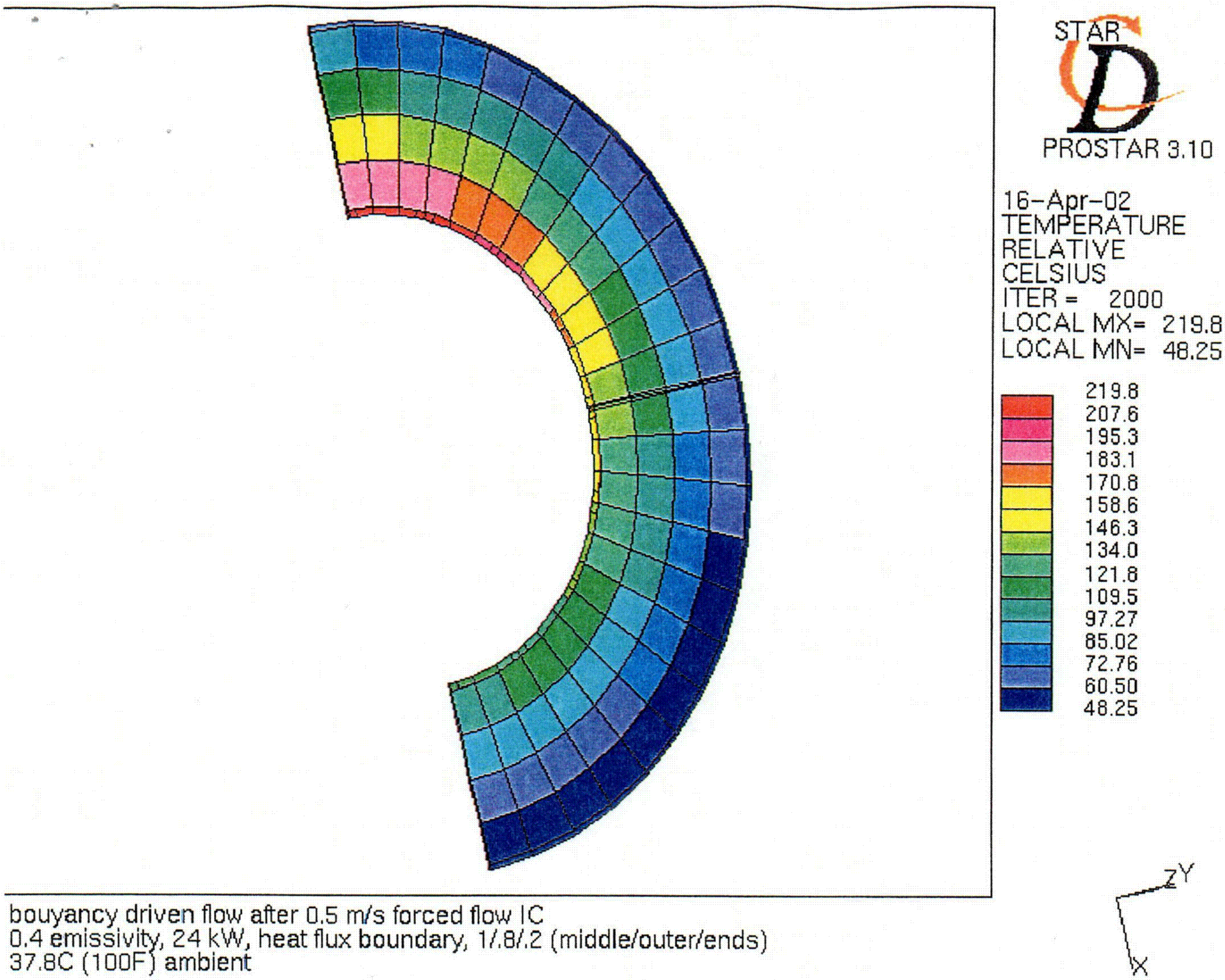


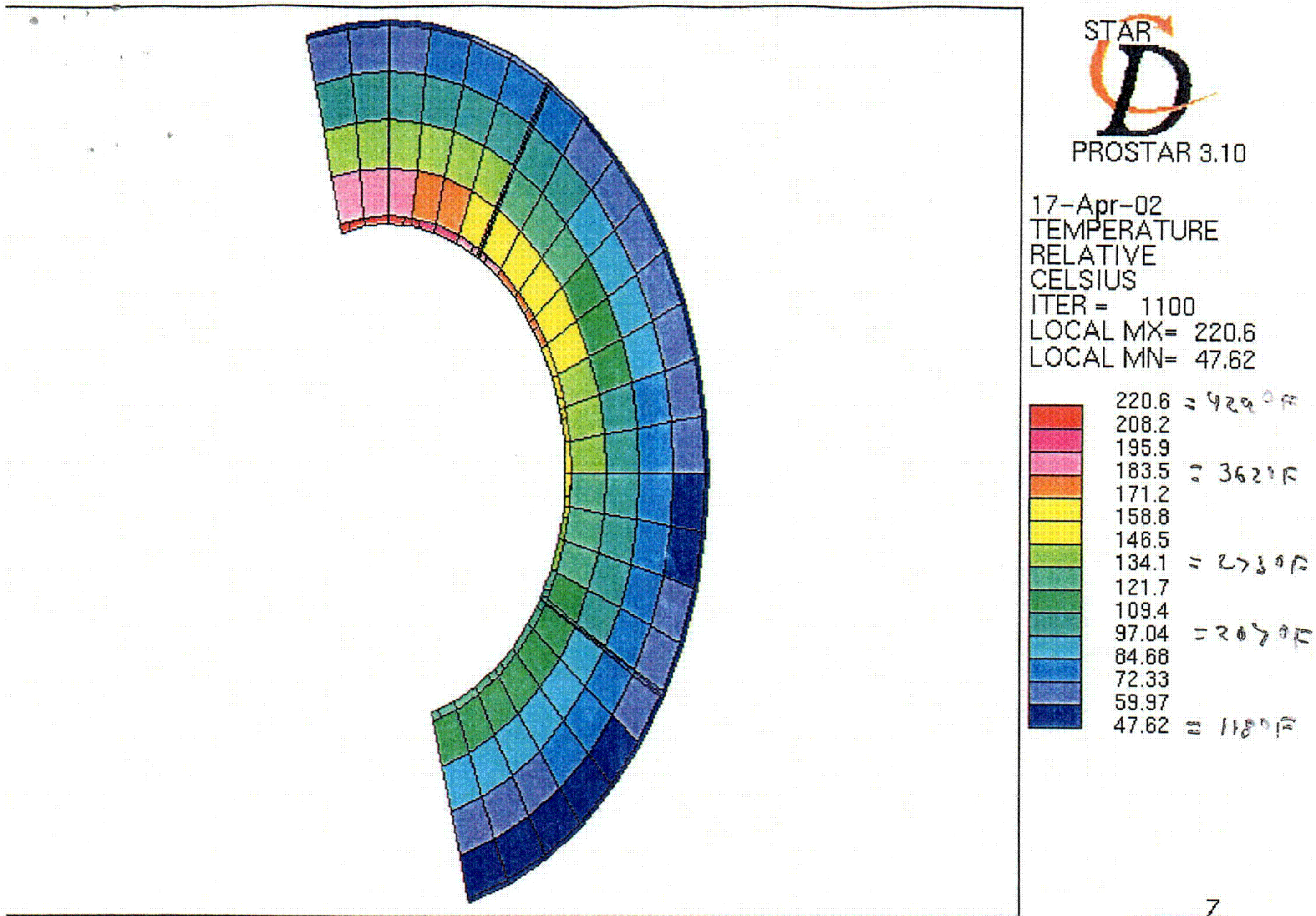
Figure 6 – Concrete overpack cross-section at axial location with maximum temperatures

Discussion
It is surprising that peak overpack temperatures are so close in both cases. The Vents Blocked Case was expected to result in higher component temperatures due to its expected lower induced air flow rate. The simulation results do show the expected lower air flow rate but compensating effects moderate the peak temperatures. First, it appears that an adequate flow of inlet air reaches the bottom-side of the canister where the vents are blocked. Air is heated as it sweeps around the canister, and this is replaced by cool air dropping in from the vents. Second, the location of the top vent in the Vents Blocked case allows a direct upward path to remove the air on top of the canister. In contrast, the No Vents Blocked case traps the hottest air layer above the canister since there is no effective driving force to move the air downward to the level of the vent outlet. Conduction out through the overpack plays a more important role in the No Vents Blocked Case as a means of cooling this region.

Conclusion
Simulations were performed for two cases representing the possible orientations of cask positions in a tip-over scenario. Peak cell-average overpack temperatures were 210 °C (410 °F) for the steel liner and 190 °C (374 °F) for the adjacent concrete. This enables us to state that our Star-CD thermal analysis predicts a maximum concrete surface temperature of approximately 210 °C (410 °F).



bouyancy driven flow after 0.5 m/s forced flow IC
0.4 emissivity, 24 kW, heat flux boundary, 1/.8/.2 (middle/outer/ends)
37.8C (100F) ambient



bouyancy driven flow after 0.5 m/s forced flow IC
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