Appendix A

Material Properties for COBRA-SFS Model of TN-68 Package

Table A.1. Internal Fill Gas—Helium at Atmospheric Pressure

Temperature (°F)	Enthalpy (Btu/lbm)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Specific Volume (ft^3/lbm)	Viscosity (lbm/hr-ft)
0	100	0.078	1.24	83.33	0.0410
200	348	0.097	1.24	119.76	0.0533
400	596	0.115	1.24	156.25	0.0641
600	844	0.129	1.24	192.31	0.0727
800	1092	0.138	1.24	229.36	0.0823
1000	1340	0.138	1.24	265.25	0.0907
2552	3264	0.138	1.24	549.00	0.1138

Table A.2. External Ambient Air at Atmospheric Pressure

Temperature (°F)	Enthalpy (Btu/lbm)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Specific Volume (ft^3/lbm)	Viscosity (lbm/hr-ft)
60	124.5	0.0146	0.24	13.5669	0.0434
300	182.1	0.0193	0.243	19.8325	0.058
400	206.5	0.0212	0.245	22.4432	0.063
500	231.1	0.0231	0.247	25.0539	0.068
600	256	0.025	0.25	27.6645	0.072
700	281.1	0.0268	0.253	30.2752	0.077
800	306.7	0.0286	0.256	32.8859	0.081
900	332.5	0.0303	0.259	35.4966	0.085
1000	358.6	0.0319	0.262	38.1072	0.0889
2000	617.2	0.0471	0.2586	64.214	0.1242
4000	1522	0.0671	0.4524	116.428	0.1242

Table A.3. Summary of All Solid Material Properties Pre-Fire

Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)	Thermal Conductivity (Btu/hr-ft-°F)	Emissivity	Description
0.129	483.8	22.92	0.3	gamma shielding (SA-517 grade 70 carbon steel)
0.13	499.4	10.44	0.3	fuel tubes (SA-240 stainless steel)
0.214	165.9	41.72	0.3	borated aluminum poison plates
0.311	98.5	4.34	N/A	neutron shield (borated polyester)
0.228	165.9	99.84	0.3	Aluminum alloy basket rails
0.118	483.8	22.92	0.3	cask outer shell[a]
0.228	165.9	84.00	N/A	aluminum in neutron shield and thermal shield between cask and bottom impact limiter
0.420	23.1	0.064	N/A	wooden impact limiters (covered with sheet steel)
0.420	11.0	0.053	N/A	thin top layer of wood on impact limiter ends (covered with sheet steel)

[a]Based on nominal emissivity for carbon steel. SAR analyses use emissivity of 0.9 for painted cask surface, but cask specifications allow option for unpainted outer surface.

Table A.4. Summary of All Solid Material Properties Post-Fire

Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)	Thermal Conductivity (Btu/hr-ft-°F)	Emissivity	Description
0.129	483.8	22.92	0.3	gamma shielding (SA-517 grade 70 carbon steel)
0.13	499.4	10.44	0.3	fuel tubes (SA-240 stainless steel)
0.214	165.9	41.72	0.3	borated aluminum poison plates
0.26	0.027	0.03	N/A	hot air (replaces polyresin neutron shield vaporized in fire)
0.228	165.9	99.84	0.3	aluminum alloy basket rails
0.118	483.8	22.92	0.8	steel shell (SAR value post-fire is 0.95 for charred cask surface emissivity)
0.228	165.9	84.00	0.9	aluminum in neutron shield; inner and outer ring after polyresin evaporates
1020.0	134.8	0.00735	0.8	charcoal (impact limiters after the fire)
			0.9	tunnel wall

COBRA-SFS Material Properties Compared with Published SAR Values

Table A.5. BWR Spent Fuel Assemblies

SAR values determined using k-effective model for homogeneous representation of fuel rods and helium gas within fuel tube.				
Temperature (°F)	**Transverse Thermal Conductivity (Btu/hr-ft-°F)**	**Axial Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
195.8	0.0157		0.055	257.5
200.0		0.058		
268.4	0.0178			
365.9	0.0206			
400.0		0.0646		
463.7	0.0239			
561.8	0.0277			
600.0		0.0709		
660.3	0.0319			
758.9	0.0367			
800.0		0.0769	0.055	257.5

COBRA-SFS input— BWR fuel rods; conservative values at nominal operating temperature and above.			
Component	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
fuel pellet:	3.0	0.059	655.0
cladding:	10.0	0.1	409.0

Table A.6. Stainless Steel Type 304/304L (for fuel tubes)

SAR values			
Temperature (°F)	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
70	7.56	0.111	499.4
100	8.76		
200	9.36	0.124	
400	10.44	0.130	
600	11.28	0.134	
800	12.24	0.140	
1000	13.2		499.4
COBRA-SFS input—selected conservative representative values at nominal operating temperature and above			
all	10.44	0.13	499.4

Table A.7. Poison Plates (borated aluminum or boron carbide/aluminum matrix)

SAR values			
Temperature (°F)	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
68	69.36	0.214	169.3
212	83.76		
482	86.64		
571	86.64	0.214	169.3
COBRA-SFS input—selected conservative values based on range of allowable fabrication variations, as described for cask specifications in SAR.			
all	41.72	0.214	165.9

Table A.8. Aluminum Type 6060 (for basket support rails and shims)

SAR values			
Temperature (°F)	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
70	96.12	0.218	165.9
100	96.96	0.219	
150	98.04	0.223	
200	99	0.225	
250	99.84	0.228	
300	100.56	0.23	
350	101.28	0.233	
400	101.88	0.234	165.9
COBRA-SFS input—selected conservative representative values at nominal operating temperature and above.			
all	99.84	0.228	165.9

Table A.9. Carbon Steel SA-516 Grade 70 (for inner and outer gamma shield and lid)

SAR values			
Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)
70	22.92	0.109	483.8
200	23.76	0.118	
400	23.88	0.129	
600	22.92	0.139	
800	21.6	0.152	
1000	20.16	0.169	
1200	18.24	0.206	
1400	15.48	0.184	483.8
COBRA-SFS input—selected conservative representative values at nominal operating temperature and above.			
all	22.92	0.129	483.8

Table A.10. Neutron Shield (polyester resin with aluminum boxes)

SAR values—properties are composite values for polyester resin and aluminum boxes modeled as single homogeneous material.			
Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)
all	0.0996	0.311	98.5
COBRA-SFS input—selected conservative representative values at nominal operating temperature and above.			
borated polyester	4.34	0.311	98.5
aluminum	84.00	0.228	165.9

Table A.11. Carbon Steel SA-350 grade LF3 (for cask outer shell)

SAR values			
Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)
70	23.64	0.106	489.0
100	23.88	0.11	
200	24.36	0.118	
400	24.24	0.128	
600	23.16	0.137	
800	21.72	0.149	
1000	20.04	0.165	
1200	18.24	0.189	
1400	15.36	0.406	489.0
COBRA-SFS input—typical values for carbon steel at nominal operating temperature and above, based on range of allowable fabrication variations described for cask specifications in SAR.			
all	22.92	0.118	483.8

Table A.12. Impact Limiters (wood covered with sheet steel)

SAR values—none provided; SAR analyses assume impact limiters act as perfect insulators on cask ends for normal, off-normal, and fire accident conditions.			
COBRA-SFS input—selected conservative representative values at nominal operating temperature and above.			
Material	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
redwood	0.064	0.311	98.5
balsa	0.053	0.228	165.9
carbon steel	22.92	0.118	483.8
charcoal	0.00735	1020.0	134.8

Table A.13. Air (replacing neutron shield polyethylene after fire)

SAR values			
Temperature (°F)	**Thermal Conductivity (Btu/hr-ft-°F)**	**Specific Heat (Btu/lbm-°F)**	**Density (lbm/ft^3)**
81	0.0156	0.231	0.0734
261	0.0192	0.237	0.0551
441	0.0228	0.239	0.0440
621	0.0264	0.246	0.0367
981	0.0336	0.264	0.0275
COBRA-SFS input—selected representative values at immediate post-fire temperature and above.			
all	0.03	0.26	0.0270

Appendix B

Material Properties for ANSYS Model of HI-STAR 100 Package

Table B.1. Homogeneous Fuel Region for Westinghouse 17x17 OFA

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
0	0.04412	0.04412	0.06256	0.14353	0.05869	Fuel Region (2.25 multiplier against helium contribution to account for limited convection and pressurization enhancement)
100	0.04412	0.04412	0.06256	0.14353	0.05869	
200	0.04412	0.04412	0.06256	0.14352	0.05869	
300	0.05078	0.05078	0.06509	0.14352	0.05869	
400	0.05895	0.05895	0.06797	0.14352	0.05869	
500	0.06837	0.06837	0.07082	0.14352	0.05869	
600	0.07834	0.07834	0.07391	0.14352	0.05869	
700	0.08920	0.08920	0.07756	0.14352	0.05869	
800	0.09508	0.09508	0.08121	0.15352	0.05869	
900	0.09508	0.09508	0.08484	0.15352	0.05869	
1000	0.09508	0.09508	0.08600	0.15352	0.05869	

Table B.2. Alloy-X

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	0.70000	*	*	0.28993	0.12000	Basket Plates, Basket Supports, Boral Plate Sheathing, MPC shell, impact limiter skin shell
450	0.81667	*	*			
700	0.91667	*	*			
1400	1.19670	*	*			

Table B.3. Helium

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
0	0.00650	*	*	6.90E-06	1.24000	gas conduction between MPC and cask
200	0.00808	*	*	4.81E-06		
400	0.00958	*	*	3.69E-06		
600	0.01075	*	*	2.99E-06		
800	0.01150	*	*	2.52E-06		
1400	0.01370	*	*	1.71E-06		

Table B.4. Helium (with 2.25 multiplier to account for limited convection and pressurization enhancement)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
0	0.01400	*	*	6.90E-06	1.24000	Conduction in: central core region, between guide tubes and basket plates, between fuel and compartments, and between basket and MPC Shell
200	0.01740	*	*	4.81E-06		
400	0.02063	*	*	3.69E-06		
600	0.02315	*	*	2.99E-06		
800	0.02476	*	*	2.52E-06		
1400	0.02950	*	*	1.71E-06		

Table B.5. Boral Plates
(includes 0.004" helium gap and gap radiation on both sides of Boral)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
0	0.30836	4.62020	4.62020	0.08390	0.24762	parallel to thickness (switch x & y to define cross-width)
100	0.34331	4.62550	4.62550	0.08390		
200	0.37738	4.64850	4.64850	0.08390		
300	0.40969	4.69040	4.69040	0.08390		
400	0.44166	4.73250	4.73250	0.08390		
500	0.46611	4.74620	4.74620	0.08390		
600	0.49024	4.75200	4.75200	0.08390		
700	0.50544	4.73700	4.73700	0.08390		
800	0.52053	4.72210	4.72210	0.08390		
900	0.53517	4.70710	4.70710	0.08390		
1000	0.54970	4.69220	4.69220	0.08390		
1100	0.56438	4.68350	4.68350	0.08390		

Table B.6. Carbon Steel (SA-516, Gr. 70)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (radial)	Thermal Conductivity (Btu/hr-in-°F) (circumferential)	Thermal Conductivity (Btu/hr-in-°F) (axial)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	0.17409	2.03330	2.03330	0.28299	0.10000	Gamma Shield with 0.01" air gaps between plates
450	0.22634	1.99170	1.99170			
700	0.28273	1.86670	1.86670			
1400	0.44136	1.46670	1.46670			

Table B.7. Carbon Steel (SA-515, Gr. 70)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	2.43330	*	*	0.28299	0.10000	For radial channels of overpack and enclosure of shells of overpack (Fins)
450	2.25830	*	*			
700	2.05000	*	*			
1400	1.46670	*	*			

Table B.8. Holtite-A

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
*	0.03108	*	*	0.06076	0.39000	Neutron Shield/In impact limiter

Table B.9. HT-870

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
*	0.00340	*	*	0.00868	0.39000	Foam on back side of fins

Table B.10. Air Properties Representing Degraded Materials

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	0.00148	*	*	3.48E-05	0.24110	For degraded Holtite-A, HT-870, and Honeycomb after fire
450	0.00188	*	*	2.53E-05	0.24605	
700	0.00227	*	*	1.99E-05	0.25355	
1400	0.00336	*	*	1.31E-05	0.27445	

Table B.11. One-Quarter-Inch Fillet Weld - Carbon Steel (SA-515, Gr. 70)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	1.21670	2.43330	2.43330	0.28299	0.10000	Reduced radial channel conductivity (Fin Fillet Weld Root)
450	1.12920	2.25830	2.25830			
700	1.02500	2.05000	2.05000			
1400	0.73333	1.46670	1.46670			

Table B.12. Carbon Steel (SA-516, Gr. 70)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	2.03330	*	*	0.28299	0.10000	Gamma Shield (intimate contact) and impact limiter base structure
450	1.99170	*	*			
700	1.86670	*	*			
1400	1.46670	*	*			

Table B.13. Aluminum Honeycomb
(700 psi unidirectional w/1700 psi cross-core backing)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
68	1.11710	0.47427	1.11710	0.01406	0.20800 (assumed)	Type 1: Aluminum Honeycomb
212	1.15270	0.48944	1.15270	0.01406		
752	1.42620	0.59537	1.42620	0.01406		
1400	1.75440	0.72248	1.75440	0.01406		

Table B.14. Aluminum Honeycomb
(700 psi unidirectional and 2300 psi cross-core)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
68	0.82721	0.31682	0.82721	0.00579	0.20800 (assumed)	Type 2&5: Aluminum Honeycomb
212	0.85369	0.32693	0.85369	0.00579		
752	1.03810	0.39771	1.03810	0.00579		
1400	1.25940	0.48265	1.25940	0.00579		

Table B.14. Aluminum Honeycomb
(2300 psi cross-core)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
68	1.40690	0.63172	1.40690	0.01684	0.20800 (assumed)	Type 3: Aluminum Honeycomb
212	1.45170	0.65194	1.45170	0.01684		
752	1.81430	0.79302	1.81430	0.01684		
1400	2.24930	0.96231	2.24930	0.01684		

Table B.16. Aluminum Honeycomb
(1100 psi unidirectional and 2300 psi cross-core)

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) (x)	Thermal Conductivity (Btu/hr-in-°F) (y)	Thermal Conductivity (Btu/hr-in-°F) (z)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
68	1.40690	0.63172	1.40690	1.40630	0.20800 (assumed)	Type 4: Aluminum Honeycomb
212	1.45170	0.65194	1.45170	1.40630		
752	1.81430	0.79302	1.81430	1.40630		
1400	2.24930	0.96231	2.24930	1.40630		

Table B.17. Emissivity Values for Radiation Heat Transfer

Component	Material	Emissivity
Fuel	Zircaloy	0.80
Basket	Alloy-X	0.36
Support Bracket	Alloy-X	0.36
MPC Wall	Alloy-X	0.36
Borated Aluminum Plate	Boral	0.55
Bare Carbon Steel	Carbon Steel	0.65
Painted Surfaces		0.90
Cask and Impact Limiter Surfaces	Alloy-X	0.36
Tunnel Surface		0.90
Soot Surfaces		0.90

Appendix C

Material Properties for ANSYS Model of Legal Weight Truck Package

Table C.1. 304 Stainless Steel

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
70	0.7143	-	0.1141	Used for cask body, cask lid, spokes
212	0.7800	0.2888	0.1207	
392	0.8592	0.2872	0.1272	
572	0.9333	0.2855	0.1320	
752	1.0042	0.2839	0.1356	
932	1.0717	0.2822	0.1385	
1112	1.1375	0.2805	0.1412	

Table C.2. 6061-T6 Aluminum

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
32	9.7500	0.0984	0.2140	Used for basket, IL 1, 2 skin
212	9.9167			
572	11.0833			
932	12.9167			

Table C.3. 6061-T6 Aluminum Honeycomb

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
32	1.6965	0.017118056	0.214	Used for IL 1 (Honeycomb)
212	1.7255			
572	1.9285			
932	2.2475			

Table C.4. 6061-T6 Aluminum Honeycomb

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
32	1.4235	0.0144	0.214	Used for IL 2 (Honeycomb)
212	1.4478			
572	1.6182			
932	1.8858			

Table C.5. Helium

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)	Description
200	0.00808	4.83E-06	1.24	Used for cask gap and fuel gap
400	0.00942	3.70E-06		
600	0.01075	3.01E-06		
800	0.0115	2.52E-06		

Table C.6. Lead Gamma Shield

Temperature (°F)	Enthalpy[(1)] (Btu/lbm)	Temperature (°F)	Thermal Conductivity[(2)] (Btu/hr-in-°F)	Temperature (°F)	Density[(3)] (lbm/in^3)	Description
80.33	0.0860	80.3	1.698984	53.3	4.11060E-01	Used for lead gamma shield
260.33	5.7610	170.3	1.671552	233.3	4.07470E-01	
440.33	11.608	260.3	1.641888	413.3	4.03670E-01	
611.50	17.756	350.3	1.608588	607.7	3.99450E-01	
629.50	27.730	440.3	1.573092	622.1	3.84440E-01	
800.33	34.007	530.3	1.539792	802.1	3.80740E-01	
980.33	40.241	610.3	1.515924	982.1	3.76330E-01	
1160.33	46.432	630.3	0.746712	1162.1	3.71930E-01	
1340.33	52.580	710.3	0.796428	1342.1	3.67520E-01	
1520.33	58.641	800.3	0.84222	1522.1	3.63120E-01	
		890.3	0.884016			
		980.3	0.921852			
		1070.3	0.955764			
		1160.3	0.985716			
		1250.3	1.01171			
		1340.3	1.03378			

(1) Based on specific heat from B.J. McBride, S. Gordon and M.A. Reno, NASA Technical Paper 3287, (1993). Enthalpy as a function of temperature calculated using definition of specific heat as partial derivative of enthalpy with respect to temperature at constant pressure;

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

(2) C.Y. Ho, R.W. Powell and P.E. Liley, J. **Phys. Chem. Ref. Data**, v1, p279 (1972).

(3) F.C. Nix and D. MacNair, Physical Review, v60, p597 (1941) and R. Feder, A.S. Norwick, Physical Review, v109, p1959 (1958); calculated from the linear expansion.

Table C.7. 56% Ethylene Glycol Solution

Avg. Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/in^3)
50	0.0188	0.7405	0.0391
70	0.0187	0.7522	0.0389
100	0.0185	0.7696	0.0385
150	0.0182	0.7979	0.0378
200	0.0179	0.8255	0.0370
250	0.0177	0.8522	0.0362
260	0.0176	0.8575	0.0360
270	0.0176	0.8627	0.0358
280	0.0175	0.8679	0.0357
290	0.0175	0.8731	0.0355
300	0.0174	0.8782	0.0353
310	0.0174	0.8833	0.0351
320	0.0173	0.8884	0.0349
330	0.0173	0.8934	0.0347
340	0.0172	0.8984	0.0345
350	0.0172	0.9034	0.0343

Table C.8. Air

Avg. Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/in^3)
350	0.0017	0.2467	0.0000283
450	0.0018	0.2494	0.0000252
550	0.0020	0.2516	0.0000227
650	0.0022	0.2533	0.0000206
750	0.0023	0.2546	0.0000189
850	0.0025	0.2556	0.0000175
950	0.0026	0.2562	0.0000162
1050	0.0027	0.2566	0.0000152
1150	0.0029	0.2568	0.0000142
1250	0.0030	0.2570	0.0000134
1350	0.0031	0.2571	0.0000126
1450	0.0033	0.2571	0.0000120
1550	0.0034	0.2573	0.0000114
1650	0.0035	0.2576	0.0000108
1750	0.0036	0.2581	0.0000104
1850	0.0038	0.2589	0.0000099
1950	0.0039	0.2599	0.0000095
2050	0.0040	0.2614	0.0000091

Table C.9. Effective Conductivity for Liquid Neutron Shield with 1°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol Effective Conductivity Neutron Shield (Btu/hr-in-°F)	56% Ethylene Glycol Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Air Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Air Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	0.364	0.149	0.003	0.002
260	0.374	0.153	0.003	0.002
270	0.384	0.157	0.003	0.002
280	0.393	0.161	0.003	0.002
290	0.398	0.163	0.003	0.002
300	0.396	0.162	0.003	0.002
310	0.395	0.162	0.003	0.002
320	0.394	0.161	0.003	0.002
330	0.393	0.161	0.003	0.002
340	0.391	0.160	0.003	0.002
350	0.390	0.160	0.003	0.002
351	*	*	0.003	0.002
400	*	*	0.003	0.002
500	*	*	0.003	0.002
600	*	*	0.003	0.002
700	*	*	0.003	0.002
800	*	*	0.003	0.002
1000	*	*	0.003	0.003
1200	*	*	0.003	0.003
1500	*	*	0.003	0.003
2000	*	*	0.004	0.004
2500	*	*	0.004	0.004

Table C.10. Effective Conductivity for Liquid Neutron Shield with 10°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	0.654	0.268	0.006	0.002
260	0.673	0.276	0.006	0.002
270	0.691	0.283	0.006	0.002
280	0.704	0.288	0.006	0.002
290	0.705	0.289	0.006	0.002
300	0.703	0.288	0.006	0.002
310	0.701	0.287	0.006	0.002
320	0.699	0.286	0.006	0.002
330	0.697	0.286	0.006	0.002
340	0.695	0.285	0.006	0.002
350	*	*	0.006	0.002
351	*	*	0.006	0.002
400	*	*	0.006	0.002
500	*	*	0.006	0.002
600	*	*	0.005	0.002
700	*	*	0.005	0.002
800	*	*	0.005	0.002
1000	*	*	0.005	0.003
1200	*	*	0.005	0.003
1500	*	*	0.004	0.003
2000	*	*	0.004	0.004
2500	*	*	0.004	0.004

Table C.11. Effective Conductivity for Liquid Neutron Shield with 25°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	0.840	0.344	0.008	0.003
260	0.863	0.353	0.008	0.003
270	0.882	0.361	0.008	0.003
280	0.888	0.364	0.008	0.003
290	0.885	0.363	0.007	0.003
300	0.883	0.361	0.007	0.003
310	0.880	0.360	0.007	0.003
320	0.877	0.359	0.007	0.003
330	0.875	0.358	0.007	0.003
340	0.872	0.357	0.007	0.003
350	*	*	0.007	0.003
351	*	*	0.007	0.003
400	*	*	0.007	0.003
500	*	*	0.007	0.003
600	*	*	0.007	0.003
700	*	*	0.007	0.003
800	*	*	0.006	0.003
1000	*	*	0.006	0.003
1200	*	*	0.006	0.003
1500	*	*	0.005	0.003
2000	*	*	0.005	0.004
2500	*	*	0.005	0.004

Table C.12. Effective Conductivity for Liquid Neutron Shield with 50°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	1.061	0.434	0.009	0.004
260	1.058	0.433	0.009	0.004
270	1.055	0.432	0.009	0.004
280	1.052	0.431	0.009	0.004
290	1.049	0.430	0.009	0.004
300	1.046	0.428	0.009	0.004
310	1.043	0.427	0.009	0.004
320	1.039	0.426	0.009	0.004
330	*	*	0.009	0.004
340	*	*	0.009	0.004
350	*	*	0.009	0.004
351	*	*	0.009	0.004
400	*	*	0.009	0.003
500	*	*	0.008	0.003
600	*	*	0.008	0.003
700	*	*	0.008	0.003
800	*	*	0.008	0.003
1000	*	*	0.007	0.003
1200	*	*	0.007	0.003
1500	*	*	0.006	0.003
2000	*	*	0.006	0.004
2500	*	*	0.006	0.004

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Table C.13. Effective Conductivity for Liquid Neutron Shield with 70°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	1.151	0.471	0.010	0.004
260	1.148	0.470	0.010	0.004
270	1.144	0.469	0.010	0.004
280	1.141	0.467	0.010	0.004
290	1.138	0.466	0.010	0.004
300	1.134	0.464	0.010	0.004
310	1.131	0.463	0.010	0.004
320	*	*	0.010	0.004
330	*	*	0.010	0.004
340	*	*	0.009	0.004
350	*	*	0.009	0.004
351	*	*	0.009	0.004
400	*	*	0.009	0.004
500	*	*	0.009	0.004
600	*	*	0.009	0.004
700	*	*	0.008	0.003
800	*	*	0.008	0.003
1000	*	*	0.008	0.003
1200	*	*	0.007	0.003
1500	*	*	0.007	0.003
2000	*	*	0.006	0.004
2500	*	*	0.006	0.004

Table C.14. Effective Conductivity for Liquid Neutron Shield with 100°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	1.253	0.513	0.011	0.004
260	1.249	0.512	0.011	0.004
270	1.245	0.510	0.011	0.004
280	1.242	0.509	0.011	0.004
290	1.238	0.507	0.011	0.004
300	1.234	0.505	0.011	0.004
310	*	*	0.010	0.004
320	*	*	0.010	0.004
330	*	*	0.010	0.004
340	*	*	0.010	0.004
350	*	*	0.010	0.004
351	*	*	0.010	0.004
400	*	*	0.010	0.004
500	*	*	0.010	0.004
600	*	*	0.009	0.004
700	*	*	0.009	0.004
800	*	*	0.009	0.004
1000	*	*	0.008	0.003
1200	*	*	0.008	0.003
1500	*	*	0.008	0.003
2000	*	*	0.007	0.004
2500	*	*	0.007	0.004

Table C.15. Effective Conductivity for Liquid Neutron Shield with 200°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	1.468	0.601	0.013	0.005
260	*	*	0.013	0.005
270	*	*	0.013	0.005
280	*	*	0.013	0.005
290	*	*	0.013	0.005
300	*	*	0.012	0.005
310	*	*	0.012	0.005
320	*	*	0.012	0.005
330	*	*	0.012	0.005
340	*	*	0.012	0.005
350	*	*	0.012	0.005
351	*	*	0.012	0.005
400	*	*	0.012	0.005
500	*	*	0.012	0.005
600	*	*	0.011	0.004
700	*	*	0.011	0.004
800	*	*	0.011	0.004
1000	*	*	0.010	0.004
1200	*	*	0.010	0.004
1500	*	*	0.009	0.004
2000	*	*	0.008	0.004
2500	*	*	0.008	0.005

Table C.16. Effective Conductivity for Liquid Neutron Shield with 300°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	*	*	0.014	0.005
260	*	*	0.014	0.005
270	*	*	0.014	0.005
280	*	*	0.014	0.005
290	*	*	0.014	0.005
300	*	*	0.014	0.005
310	*	*	0.014	0.005
320	*	*	0.014	0.005
330	*	*	0.014	0.005
340	*	*	0.014	0.005
350	*	*	0.013	0.005
351	*	*	0.013	0.005
400	*	*	0.013	0.005
500	*	*	0.013	0.005
600	*	*	0.012	0.005
700	*	*	0.012	0.005
800	*	*	0.012	0.005
1000	*	*	0.011	0.004
1200	*	*	0.011	0.004
1500	*	*	0.010	0.004
2000	*	*	0.009	0.004
2500	*	*	0.009	0.005

Table C.17. Effective Conductivity for Liquid Neutron Shield with 500°F Temperature Gradient

Avg. Temperature (°F)	56% Ethylene Glycol		Air	
	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)	Effective Conductivity Neutron Shield (Btu/hr-in-°F)	Effective Conductivity Expansion Tank (Btu/hr-in-°F)
250	*	*	0.016	0.006
260	*	*	0.016	0.006
270	*	*	0.016	0.006
280	*	*	0.016	0.006
290	*	*	0.016	0.006
300	*	*	0.015	0.006
310	*	*	0.015	0.006
320	*	*	0.015	0.006
330	*	*	0.015	0.006
340	*	*	0.015	0.006
350	*	*	0.015	0.006
351	*	*	0.015	0.006
400	*	*	0.015	0.006
500	*	*	0.014	0.006
600	*	*	0.014	0.005
700	*	*	0.014	0.005
800	*	*	0.013	0.005
1000	*	*	0.013	0.005
1200	*	*	0.012	0.005
1500	*	*	0.011	0.005
2000	*	*	0.011	0.004
2500	*	*	0.010	0.005

Table C.18. Emissivity Values for Radiation Heat Transfer

Component	Material	Emissivity Before Fire	Emissivity During/After Fire
Canister	stainless steel	0.36	0.36
Cask	stainless steel	0.36	0.36
Outer Neutron Shield		0.34	0.34
Inner Neutron Shield		0.34	0.34
Basket	stainless steel	0.36	0.36
Fuel Clad	zircaloy	0.8	0.8
Boral Plate	aluminum clad	0.55	0.55
Shell Interior	stainless steel	0.36	0.36
Cask Exterior	stainless steel	0.85	0.9
Tunnel/ISO	various		0.9

Appendix D

Boundary Conditions from FDS Simulation of Fully Ventilated Fire Scenario

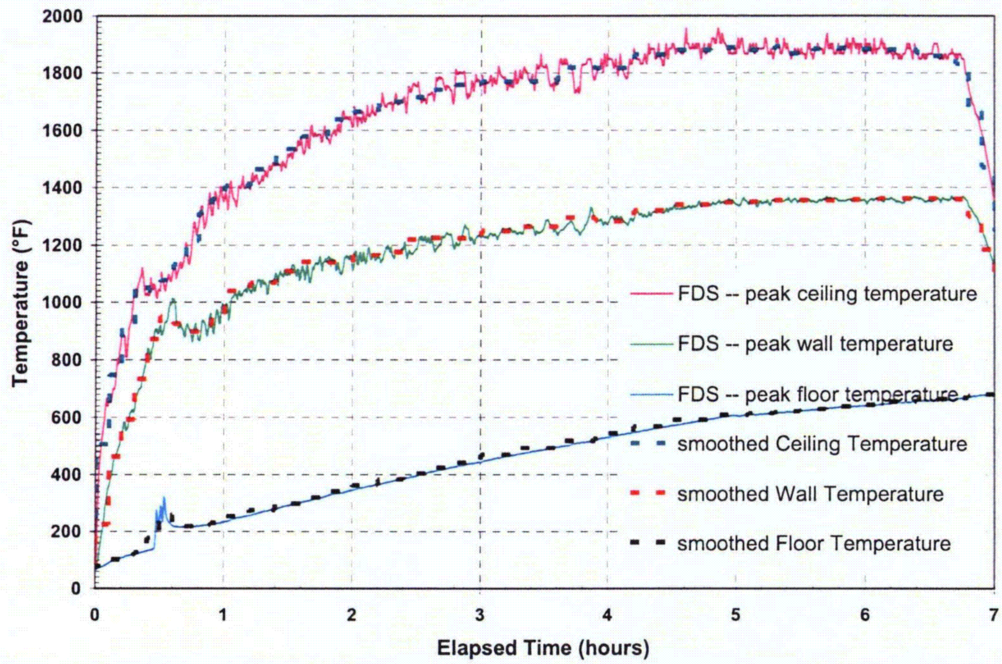

Figure D.1. Peak Surface Temperatures Calculated with FDS for Tunnel Ceiling, Wall, and Floor Regions at 20 meters from Fire Location during 7-hr Fire

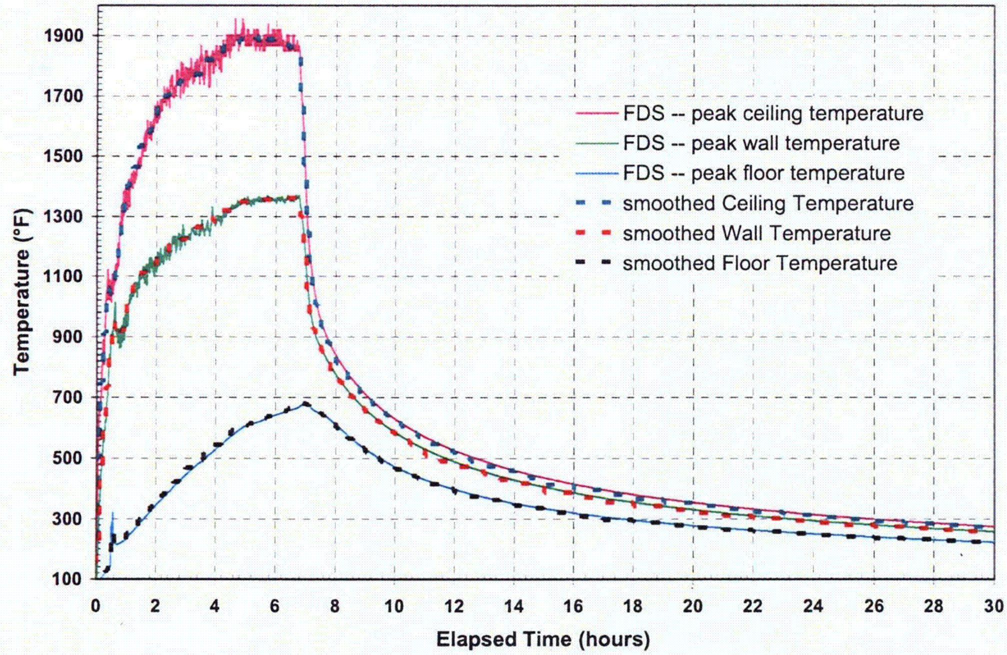

Figure D.2. Peak Surface Temperatures Calculated with FDS for Tunnel Ceiling, Wall, and Floor Regions at 20 meters from Fire Location during 7-hr Fire and 23-hr Cool Down

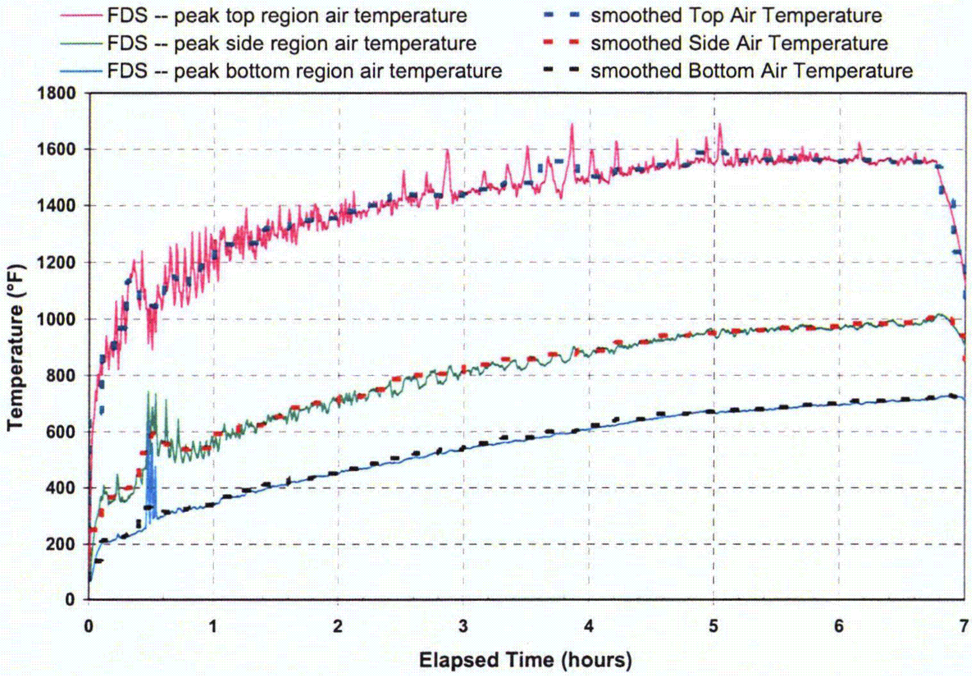

Figure D.3. Peak Air Temperatures Calculated with FDS for Top, Side, and Bottom Regions at 20 meters from Fire Location during 7-hr Fire

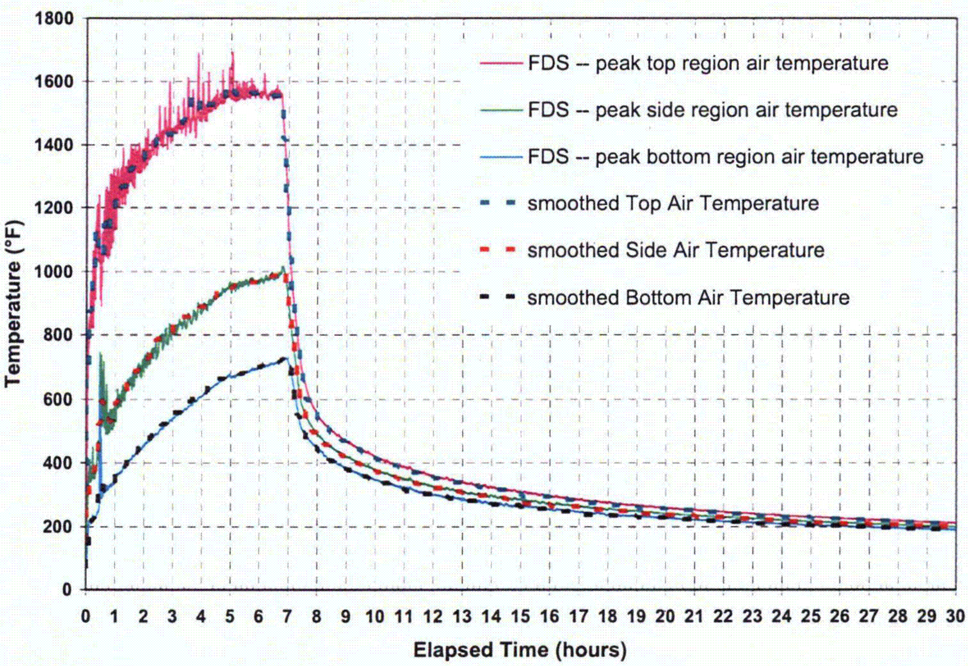

Figure D.4. Peak Air Temperatures Calculated with FDS for Top, Side, and Bottom Regions at 20 meters from Fire Location during 7-hr Fire and 23-hr Cool Down

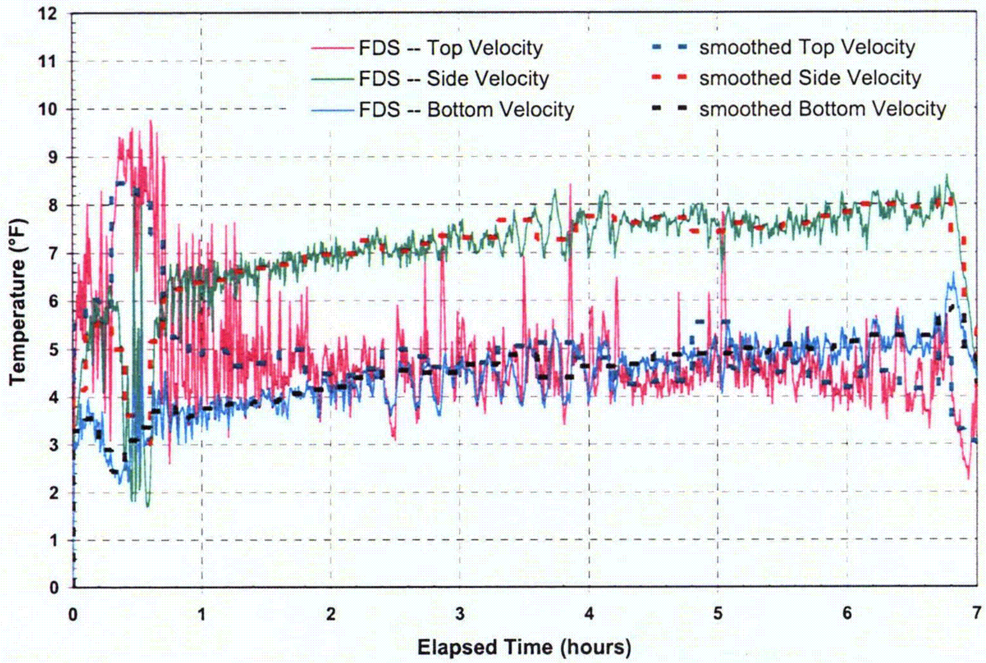

Figure D.5. Velocities at Peak Air Temperature Locations Calculated with FDS for Top, Side, and Bottom Regions at 20 meters from Fire Location during 7-hr Fire

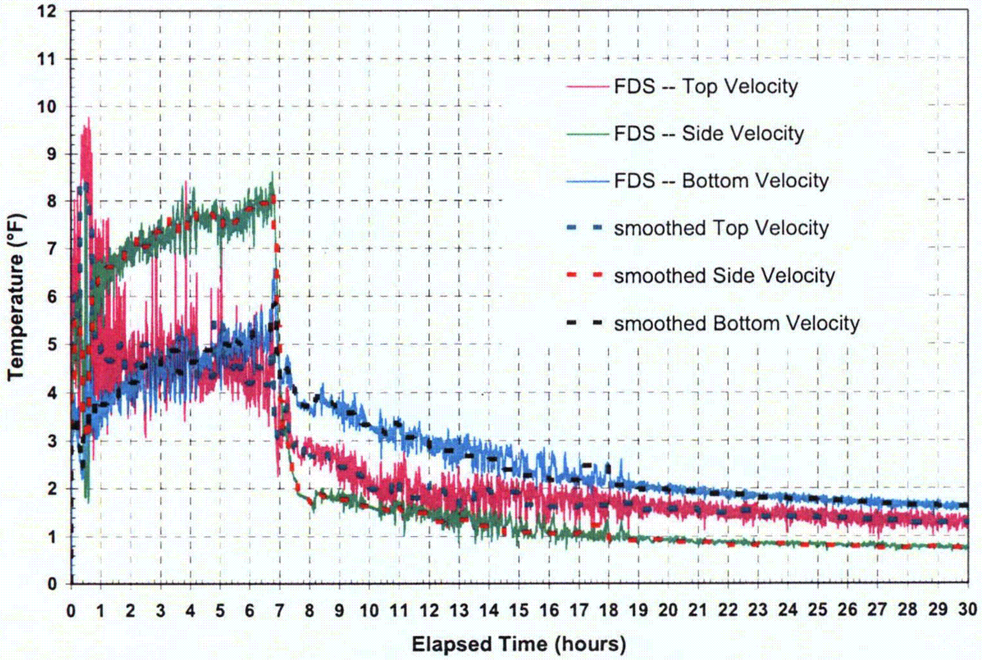

Figure D.6. Velocities at Peak Air Temperature Locations Calculated with FDS for Top, Side, and Bottom Regions at 20 meters from Fire during 7-hr Fire and 23-hr Cool Down

Appendix E

Blackbody Viewfactors for COBRA-SFS Model of TN-68 Package

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C TUNNEL.1=TOP  TUNNEL.2=SIDE  TUNNEL.3=BOTTOM
Cnode_1     node_2      Area*e*Bij  $      Bij       Bji
 CASK.101,  TUNNEL.1,   137.54      $      0.79418,0.00045040
 CASK.101,  TUNNEL.2,   25.477      $      0.14711,7.5761e-005
 CASK.101,  TUNNEL.3,   6.3683      $     0.036772,2.1839e-005
 CASK.102,  TUNNEL.1,   67.819      $      0.39161,0.00022209
 CASK.102,  TUNNEL.2,   87.635      $      0.50603,0.00026060
 CASK.102,  TUNNEL.3,   13.723      $     0.079241,4.7061e-005
 CASK.103,  TUNNEL.1,   12.951      $     0.074781,4.2410e-005
 CASK.103,  TUNNEL.2,   90.996      $      0.52544,0.00027059
 CASK.103,  TUNNEL.3,   65.443      $      0.37789,0.00022443
 CASK.104,  TUNNEL.1,   6.2714      $     0.036213,2.0538e-005
 CASK.104,  TUNNEL.2,   31.022      $      0.17913,9.2251e-005
 CASK.104,  TUNNEL.3,   132.32      $      0.76404,0.00045376
 CASK.201,  TUNNEL.1,   138.22      $      0.79812,0.00045264
 CASK.201,  TUNNEL.2,   24.978      $      0.14423,7.4277e-005
 CASK.201,  TUNNEL.3,   6.3135      $     0.036456,2.1651e-005
 CASK.202,  TUNNEL.1,   68.135      $      0.39343,0.00022313
 CASK.202,  TUNNEL.2,   87.392      $      0.50463,0.00025988
 CASK.202,  TUNNEL.3,   13.599      $     0.078527,4.6637e-005
 CASK.203,  TUNNEL.1,   12.937      $     0.074702,4.2365e-005
 CASK.203,  TUNNEL.2,   90.689      $      0.52367,0.00026968
 CASK.203,  TUNNEL.3,   65.701      $      0.37938,0.00022531
 CASK.204,  TUNNEL.1,   6.1691      $     0.035622,2.0203e-005
 CASK.204,  TUNNEL.2,   31.104      $      0.17961,9.2494e-005
 CASK.204,  TUNNEL.3,   132.31      $      0.76399,0.00045373
 CASK.301,  TUNNEL.1,   137.98      $      0.79676,0.00045187
 CASK.301,  TUNNEL.2,   25.169      $      0.14533,7.4844e-005
 CASK.301,  TUNNEL.3,   6.3354      $     0.036583,2.1726e-005
 CASK.302,  TUNNEL.1,   68.192      $      0.39376,0.00022331
 CASK.302,  TUNNEL.2,   87.312      $      0.50417,0.00025964
 CASK.302,  TUNNEL.3,   13.687      $     0.079031,4.6936e-005
 CASK.303,  TUNNEL.1,   12.880      $     0.074375,4.2180e-005
 CASK.303,  TUNNEL.2,   91.267      $      0.52700,0.00027140
 CASK.303,  TUNNEL.3,   65.225      $      0.37663,0.00022368
 CASK.304,  TUNNEL.1,   6.1435      $     0.035475,2.0119e-005
 CASK.304,  TUNNEL.2,   31.213      $      0.18024,9.2819e-005
 CASK.304,  TUNNEL.3,   132.07      $      0.76261,0.00045291
 CASK.401,  TUNNEL.1,   138.03      $      0.79704,0.00045202
 CASK.401,  TUNNEL.2,   25.096      $      0.14491,7.4627e-005
 CASK.401,  TUNNEL.3,   6.3204      $     0.036496,2.1675e-005
 CASK.402,  TUNNEL.1,   68.295      $      0.39436,0.00022365
 CASK.402,  TUNNEL.2,   87.210      $      0.50358,0.00025934
 CASK.402,  TUNNEL.3,   13.632      $     0.078717,4.6750e-005
 CASK.403,  TUNNEL.1,   13.054      $     0.075376,4.2748e-005
 CASK.403,  TUNNEL.2,   90.720      $      0.52385,0.00026977
 CASK.403,  TUNNEL.3,   65.460      $      0.37799,0.00022448
 CASK.404,  TUNNEL.1,   6.0468      $     0.034916,1.9802e-005
 CASK.404,  TUNNEL.2,   30.945      $      0.17868,9.2020e-005
 CASK.404,  TUNNEL.3,   132.46      $      0.76484,0.00045424
 CASK.501,  TUNNEL.1,   138.12      $      0.79752,0.00045230
 CASK.501,  TUNNEL.2,   25.031      $      0.14454,7.4434e-005
 CASK.501,  TUNNEL.3,   6.3279      $     0.036539,2.1701e-005
 CASK.502,  TUNNEL.1,   68.608      $      0.39616,0.00022468
 CASK.502,  TUNNEL.2,   86.890      $      0.50173,0.00025838
 CASK.502,  TUNNEL.3,   13.693      $     0.079069,4.6959e-005
 CASK.503,  TUNNEL.1,   12.946      $     0.074757,4.2397e-005
 CASK.503,  TUNNEL.2,   91.115      $      0.52613,0.00027095
 CASK.503,  TUNNEL.3,   65.179      $      0.37636,0.00022352
 CASK.504,  TUNNEL.1,   5.9701      $     0.034474,1.9551e-005
 CASK.504,  TUNNEL.2,   30.931      $      0.17860,9.1979e-005
 CASK.504,  TUNNEL.3,   132.45      $      0.76480,0.00045422
 CASK.601,  TUNNEL.1,   138.18      $      0.79788,0.00045250
 CASK.601,  TUNNEL.2,   24.944      $      0.14403,7.4176e-005
 CASK.601,  TUNNEL.3,   6.2188      $     0.035909,2.1326e-005
 CASK.602,  TUNNEL.1,   68.688      $      0.39663,0.00022494
 CASK.602,  TUNNEL.2,   86.987      $      0.50229,0.00025867
 CASK.602,  TUNNEL.3,   13.491      $     0.077899,4.6264e-005
 CASK.603,  TUNNEL.1,   13.037      $     0.075278,4.2692e-005
 CASK.603,  TUNNEL.2,   91.088      $      0.52597,0.00027087
 CASK.603,  TUNNEL.3,   65.088      $      0.37584,0.00022321
 CASK.604,  TUNNEL.1,   5.9256      $     0.034216,1.9405e-005
 CASK.604,  TUNNEL.2,   31.061      $      0.17936,9.2367e-005
 CASK.604,  TUNNEL.3,   132.28      $      0.76385,0.00045365
 CASK.701,  TUNNEL.1,   138.29      $      0.79854,0.00045288
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CASK.701,	TUNNEL.2,	24.847	$	0.14347,7.3886e-005
CASK.701,	TUNNEL.3,	6.2483	$	0.036080,2.1428e-005
CASK.702,	TUNNEL.1,	68.225	$	0.39395,0.00022342
CASK.702,	TUNNEL.2,	87.042	$	0.50261,0.00025884
CASK.702,	TUNNEL.3,	13.824	$	0.079826,4.7408e-005
CASK.703,	TUNNEL.1,	13.006	$	0.075103,4.2593e-005
CASK.703,	TUNNEL.2,	90.921	$	0.52501,0.00027037
CASK.703,	TUNNEL.3,	65.304	$	0.37709,0.00022395
CASK.704,	TUNNEL.1,	5.8582	$	0.033827,1.9184e-005
CASK.704,	TUNNEL.2,	31.026	$	0.17916,9.2263e-005
CASK.704,	TUNNEL.3,	132.40	$	0.76454,0.00045406
CASK.801,	TUNNEL.1,	138.10	$	0.79744,0.00045225
CASK.801,	TUNNEL.2,	25.102	$	0.14495,7.4647e-005
CASK.801,	TUNNEL.3,	6.2315	$	0.035983,2.1370e-005
CASK.802,	TUNNEL.1,	67.889	$	0.39201,0.00022232
CASK.802,	TUNNEL.2,	87.307	$	0.50414,0.00025963
CASK.802,	TUNNEL.3,	13.869	$	0.080083,4.7561e-005
CASK.803,	TUNNEL.1,	12.847	$	0.074182,4.2071e-005
CASK.803,	TUNNEL.2,	90.805	$	0.52434,0.00027003
CASK.803,	TUNNEL.3,	65.535	$	0.37842,0.00022474
CASK.804,	TUNNEL.1,	5.7617	$	0.033270,1.8868e-005
CASK.804,	TUNNEL.2,	31.064	$	0.17937,9.2374e-005
CASK.804,	TUNNEL.3,	132.36	$	0.76430,0.00045391
CASK.901,	TUNNEL.1,	138.13	$	0.79764,0.00045236
CASK.901,	TUNNEL.2,	25.128	$	0.14510,7.4724e-005
CASK.901,	TUNNEL.3,	6.2207	$	0.035921,2.1333e-005
CASK.902,	TUNNEL.1,	68.091	$	0.39318,0.00022298
CASK.902,	TUNNEL.2,	87.277	$	0.50396,0.00025953
CASK.902,	TUNNEL.3,	13.700	$	0.079107,4.6981e-005
CASK.903,	TUNNEL.1,	12.952	$	0.074789,4.2415e-005
CASK.903,	TUNNEL.2,	90.982	$	0.52536,0.00027055
CASK.903,	TUNNEL.3,	65.132	$	0.37609,0.00022336
CASK.904,	TUNNEL.1,	5.7522	$	0.033215,1.8837e-005
CASK.904,	TUNNEL.2,	31.124	$	0.17972,9.2553e-005
CASK.904,	TUNNEL.3,	132.31	$	0.76400,0.00045374
CASK.1001,	TUNNEL.1,	137.84	$	0.79593,0.00045139
CASK.1001,	TUNNEL.2,	25.412	$	0.14674,7.5569e-005
CASK.1001,	TUNNEL.3,	6.2311	$	0.035981,2.1369e-005
CASK.1002,	TUNNEL.1,	68.564	$	0.39591,0.00022453
CASK.1002,	TUNNEL.2,	86.856	$	0.50153,0.00025828
CASK.1002,	TUNNEL.3,	13.655	$	0.078849,4.6828e-005
CASK.1003,	TUNNEL.1,	12.716	$	0.073426,4.1642e-005
CASK.1003,	TUNNEL.2,	90.924	$	0.52502,0.00027038
CASK.1003,	TUNNEL.3,	65.500	$	0.37822,0.00022462
CASK.1004,	TUNNEL.1,	5.6573	$	0.032667,1.8526e-005
CASK.1004,	TUNNEL.2,	31.197	$	0.18014,9.2770e-005
CASK.1004,	TUNNEL.3,	132.27	$	0.76378,0.00045361
CASK.1101,	TUNNEL.1,	138.17	$	0.79782,0.00045247
CASK.1101,	TUNNEL.2,	25.006	$	0.14440,7.4362e-005
CASK.1101,	TUNNEL.3,	6.1872	$	0.035727,2.1218e-005
CASK.1102,	TUNNEL.1,	68.446	$	0.39523,0.00022415
CASK.1102,	TUNNEL.2,	87.049	$	0.50265,0.00025886
CASK.1102,	TUNNEL.3,	13.505	$	0.077980,4.6312e-005
CASK.1103,	TUNNEL.1,	12.985	$	0.074982,4.2524e-005
CASK.1103,	TUNNEL.2,	91.145	$	0.52630,0.00027104
CASK.1103,	TUNNEL.3,	65.061	$	0.37568,0.00022312
CASK.1104,	TUNNEL.1,	5.6898	$	0.032855,1.8633e-005
CASK.1104,	TUNNEL.2,	30.943	$	0.17868,9.2016e-005
CASK.1104,	TUNNEL.3,	132.40	$	0.76453,0.00045405
CASK.1201,	TUNNEL.1,	137.88	$	0.79616,0.00045153
CASK.1201,	TUNNEL.2,	25.412	$	0.14674,7.5567e-005
CASK.1201,	TUNNEL.3,	6.1750	$	0.035657,2.1176e-005
CASK.1202,	TUNNEL.1,	67.908	$	0.39212,0.00022238
CASK.1202,	TUNNEL.2,	87.439	$	0.50490,0.00026002
CASK.1202,	TUNNEL.3,	13.717	$	0.079208,4.7041e-005
CASK.1203,	TUNNEL.1,	12.998	$	0.075055,4.2566e-005
CASK.1203,	TUNNEL.2,	90.706	$	0.52377,0.00026973
CASK.1203,	TUNNEL.3,	65.409	$	0.37769,0.00022431
CASK.1204,	TUNNEL.1,	5.5919	$	0.032289,1.8312e-005
CASK.1204,	TUNNEL.2,	31.129	$	0.17975,9.2567e-005
CASK.1204,	TUNNEL.3,	132.27	$	0.76380,0.00045362
CASK.1301,	TUNNEL.1,	138.25	$	0.79830,0.00045274
CASK.1301,	TUNNEL.2,	24.993	$	0.14432,7.4320e-005
CASK.1301,	TUNNEL.3,	6.1782	$	0.035675,2.1187e-005
CASK.1302,	TUNNEL.1,	68.155	$	0.39355,0.00022319

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CASK.1302,  TUNNEL.2,  87.155    $    0.50326,0.00025917
CASK.1302,  TUNNEL.3,  13.671    $    0.078943,4.6884e-005
CASK.1303,  TUNNEL.1,  12.737    $    0.073546,4.1710e-005
CASK.1303,  TUNNEL.2,  91.130    $    0.52622,0.00027099
CASK.1303,  TUNNEL.3,  65.245    $    0.37674,0.00022375
CASK.1304,  TUNNEL.1,  5.6600    $    0.032683,1.8535e-005
CASK.1304,  TUNNEL.2,  31.047    $    0.17928,9.2325e-005
CASK.1304,  TUNNEL.3,  132.30    $    0.76396,0.00045372
CASK.1401,  TUNNEL.1,  138.04    $    0.79707,0.00045204
CASK.1401,  TUNNEL.2,  25.121    $    0.14506,7.4703e-005
CASK.1401,  TUNNEL.3,  6.2019    $    0.035812,2.1269e-005
CASK.1402,  TUNNEL.1,  68.195    $    0.39378,0.00022332
CASK.1402,  TUNNEL.2,  87.073    $    0.50279,0.00025893
CASK.1402,  TUNNEL.3,  13.807    $    0.079729,4.7351e-005
CASK.1403,  TUNNEL.1,  12.669    $    0.073153,4.1487e-005
CASK.1403,  TUNNEL.2,  91.365    $    0.52757,0.00027169
CASK.1403,  TUNNEL.3,  65.069    $    0.37573,0.00022314
CASK.1404,  TUNNEL.1,  5.5888    $    0.032272,1.8302e-005
CASK.1404,  TUNNEL.2,  31.163    $    0.17994,9.2668e-005
CASK.1404,  TUNNEL.3,  132.22    $    0.76345,0.00045341
CASK.1501,  TUNNEL.1,  138.17    $    0.79785,0.00045249
CASK.1501,  TUNNEL.2,  25.075    $    0.14479,7.4565e-005
CASK.1501,  TUNNEL.3,  6.1911    $    0.035749,2.1231e-005
CASK.1502,  TUNNEL.1,  68.139    $    0.39346,0.00022314
CASK.1502,  TUNNEL.2,  87.197    $    0.50350,0.00025930
CASK.1502,  TUNNEL.3,  13.646    $    0.078797,4.6798e-005
CASK.1503,  TUNNEL.1,  12.784    $    0.073818,4.1864e-005
CASK.1503,  TUNNEL.2,  91.009    $    0.52552,0.00027063
CASK.1503,  TUNNEL.3,  65.230    $    0.37666,0.00022370
CASK.1504,  TUNNEL.1,  5.6144    $    0.032419,1.8386e-005
CASK.1504,  TUNNEL.2,  31.011    $    0.17907,9.2217e-005
CASK.1504,  TUNNEL.3,  132.37    $    0.76434,0.00045394
CASK.1601,  TUNNEL.1,  138.38    $    0.79906,0.00045317
CASK.1601,  TUNNEL.2,  24.861    $    0.14355,7.3928e-005
CASK.1601,  TUNNEL.3,  6.1468    $    0.035493,2.1079e-005
CASK.1602,  TUNNEL.1,  68.267    $    0.39420,0.00022356
CASK.1602,  TUNNEL.2,  87.153    $    0.50325,0.00025917
CASK.1602,  TUNNEL.3,  13.587    $    0.078457,4.6595e-005
CASK.1603,  TUNNEL.1,  12.646    $    0.073025,4.1414e-005
CASK.1603,  TUNNEL.2,  90.521    $    0.52270,0.00026918
CASK.1603,  TUNNEL.3,  65.886    $    0.38045,0.00022595
CASK.1604,  TUNNEL.1,  5.5843    $    0.032245,1.8287e-005
CASK.1604,  TUNNEL.2,  30.824    $    0.17799,9.1661e-005
CASK.1604,  TUNNEL.3,  132.56    $    0.76547,0.00045461
CASK.1701,  TUNNEL.1,  137.89    $    0.79623,0.00045156
CASK.1701,  TUNNEL.2,  25.339    $    0.14632,7.5351e-005
CASK.1701,  TUNNEL.3,  6.1499    $    0.035511,2.1090e-005
CASK.1702,  TUNNEL.1,  68.793    $    0.39723,0.00022528
CASK.1702,  TUNNEL.2,  86.707    $    0.50067,0.00025784
CASK.1702,  TUNNEL.3,  13.529    $    0.078123,4.6397e-005
CASK.1703,  TUNNEL.1,  12.704    $    0.073359,4.1604e-005
CASK.1703,  TUNNEL.2,  91.173    $    0.52646,0.00027112
CASK.1703,  TUNNEL.3,  65.193    $    0.37645,0.00022357
CASK.1704,  TUNNEL.1,  5.5697    $    0.032161,1.8240e-005
CASK.1704,  TUNNEL.2,  31.366    $    0.18112,9.3274e-005
CASK.1704,  TUNNEL.3,  132.07    $    0.76260,0.00045290
CASK.1801,  TUNNEL.1,  138.30    $    0.79856,0.00045289
CASK.1801,  TUNNEL.2,  24.981    $    0.14425,7.4286e-005
CASK.1801,  TUNNEL.3,  6.1334    $    0.035416,2.1034e-005
CASK.1802,  TUNNEL.1,  68.068    $    0.39304,0.00022291
CASK.1802,  TUNNEL.2,  87.271    $    0.50393,0.00025952
CASK.1802,  TUNNEL.3,  13.649    $    0.078815,4.6808e-005
CASK.1803,  TUNNEL.1,  12.694    $    0.073297,4.1569e-005
CASK.1803,  TUNNEL.2,  91.352    $    0.52750,0.00027165
CASK.1803,  TUNNEL.3,  65.097    $    0.37589,0.00022324
CASK.1804,  TUNNEL.1,  5.5500    $    0.032047,1.8175e-005
CASK.1804,  TUNNEL.2,  31.344    $    0.18099,9.3208e-005
CASK.1804,  TUNNEL.3,  132.06    $    0.76255,0.00045287
CASK.1901,  TUNNEL.1,  138.28    $    0.79848,0.00045284
CASK.1901,  TUNNEL.2,  24.841    $    0.14344,7.3870e-005
CASK.1901,  TUNNEL.3,  6.1732    $    0.035646,2.1170e-005
CASK.1902,  TUNNEL.1,  68.778    $    0.39714,0.00022523
CASK.1902,  TUNNEL.2,  86.557    $    0.49981,0.00025739
CASK.1902,  TUNNEL.3,  13.637    $    0.078746,4.6767e-005
CASK.1903,  TUNNEL.1,  12.841    $    0.074146,4.2051e-005
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CASK.1903,	TUNNEL.2,	91.151	$	0.52633,0.00027105
CASK.1903,	TUNNEL.3,	65.209	$	0.37654,0.00022362
CASK.1904,	TUNNEL.1,	5.6276	$	0.032496,1.8429e-005
CASK.1904,	TUNNEL.2,	30.798	$	0.17784,9.1584e-005
CASK.1904,	TUNNEL.3,	132.57	$	0.76549,0.00045462
CASK.2001,	TUNNEL.1,	138.26	$	0.79837,0.00045278
CASK.2001,	TUNNEL.2,	24.969	$	0.14418,7.4252e-005
CASK.2001,	TUNNEL.3,	6.1633	$	0.035589,2.1136e-005
CASK.2002,	TUNNEL.1,	67.893	$	0.39204,0.00022234
CASK.2002,	TUNNEL.2,	87.430	$	0.50485,0.00025999
CASK.2002,	TUNNEL.3,	13.778	$	0.079561,4.7251e-005
CASK.2003,	TUNNEL.1,	12.702	$	0.073347,4.1597e-005
CASK.2003,	TUNNEL.2,	90.326	$	0.52157,0.00026860
CASK.2003,	TUNNEL.3,	66.063	$	0.38147,0.00022655
CASK.2004,	TUNNEL.1,	5.6088	$	0.032387,1.8368e-005
CASK.2004,	TUNNEL.2,	30.836	$	0.17806,9.1696e-005
CASK.2004,	TUNNEL.3,	132.54	$	0.76530,0.00045451
CASK.2101,	TUNNEL.1,	137.99	$	0.79682,0.00045190
CASK.2101,	TUNNEL.2,	25.223	$	0.14564,7.5005e-005
CASK.2101,	TUNNEL.3,	6.2208	$	0.035921,2.1333e-005
CASK.2102,	TUNNEL.1,	68.122	$	0.39336,0.00022308
CASK.2102,	TUNNEL.2,	87.248	$	0.50380,0.00025945
CASK.2102,	TUNNEL.3,	13.695	$	0.079082,4.6967e-005
CASK.2103,	TUNNEL.1,	12.623	$	0.072889,4.1338e-005
CASK.2103,	TUNNEL.2,	91.084	$	0.52595,0.00027086
CASK.2103,	TUNNEL.3,	65.444	$	0.37790,0.00022443
CASK.2104,	TUNNEL.1,	5.6251	$	0.032481,1.8421e-005
CASK.2104,	TUNNEL.2,	30.935	$	0.17863,9.1992e-005
CASK.2104,	TUNNEL.3,	132.48	$	0.76497,0.00045431
CASK.2201,	TUNNEL.1,	138.00	$	0.79686,0.00045192
CASK.2201,	TUNNEL.2,	25.240	$	0.14575,7.5057e-005
CASK.2201,	TUNNEL.3,	6.1738	$	0.035650,2.1172e-005
CASK.2202,	TUNNEL.1,	68.741	$	0.39693,0.00022511
CASK.2202,	TUNNEL.2,	86.917	$	0.50189,0.00025847
CASK.2202,	TUNNEL.3,	13.480	$	0.077838,4.6228e-005
CASK.2203,	TUNNEL.1,	12.900	$	0.074490,4.2246e-005
CASK.2203,	TUNNEL.2,	91.269	$	0.52702,0.00027141
CASK.2203,	TUNNEL.3,	64.953	$	0.37506,0.00022275
CASK.2204,	TUNNEL.1,	5.6790	$	0.032793,1.8598e-005
CASK.2204,	TUNNEL.2,	30.883	$	0.17833,9.1837e-005
CASK.2204,	TUNNEL.3,	132.53	$	0.76527,0.00045449
CASK.2301,	TUNNEL.1,	137.99	$	0.79683,0.00045190
CASK.2301,	TUNNEL.2,	25.190	$	0.14546,7.4909e-005
CASK.2301,	TUNNEL.3,	6.2267	$	0.035955,2.1354e-005
CASK.2302,	TUNNEL.1,	68.414	$	0.39504,0.00022404
CASK.2302,	TUNNEL.2,	86.942	$	0.50203,0.00025854
CASK.2302,	TUNNEL.3,	13.674	$	0.078957,4.6892e-005
CASK.2303,	TUNNEL.1,	12.930	$	0.074664,4.2344e-005
CASK.2303,	TUNNEL.2,	90.672	$	0.52357,0.00026963
CASK.2303,	TUNNEL.3,	65.491	$	0.37816,0.00022459
CASK.2304,	TUNNEL.1,	5.6849	$	0.032826,1.8617e-005
CASK.2304,	TUNNEL.2,	31.044	$	0.17926,9.2315e-005
CASK.2304,	TUNNEL.3,	132.32	$	0.76406,0.00045377
CASK.2401,	TUNNEL.1,	137.91	$	0.79636,0.00045164
CASK.2401,	TUNNEL.2,	25.207	$	0.14555,7.4957e-005
CASK.2401,	TUNNEL.3,	6.2003	$	0.035803,2.1263e-005
CASK.2402,	TUNNEL.1,	68.065	$	0.39303,0.00022290
CASK.2402,	TUNNEL.2,	87.281	$	0.50399,0.00025955
CASK.2402,	TUNNEL.3,	13.655	$	0.078847,4.6827e-005
CASK.2403,	TUNNEL.1,	12.813	$	0.073989,4.1961e-005
CASK.2403,	TUNNEL.2,	90.843	$	0.52456,0.00027014
CASK.2403,	TUNNEL.3,	65.521	$	0.37834,0.00022470
CASK.2404,	TUNNEL.1,	5.7547	$	0.033229,1.8845e-005
CASK.2404,	TUNNEL.2,	31.095	$	0.17955,9.2466e-005
CASK.2404,	TUNNEL.3,	132.32	$	0.76405,0.00045377
CASK.2501,	TUNNEL.1,	138.26	$	0.79836,0.00045277
CASK.2501,	TUNNEL.2,	25.000	$	0.14436,7.4342e-005
CASK.2501,	TUNNEL.3,	6.1776	$	0.035672,2.1185e-005
CASK.2502,	TUNNEL.1,	68.473	$	0.39539,0.00022424
CASK.2502,	TUNNEL.2,	87.067	$	0.50275,0.00025891
CASK.2502,	TUNNEL.3,	13.573	$	0.078375,4.6547e-005
CASK.2503,	TUNNEL.1,	12.768	$	0.073729,4.1814e-005
CASK.2503,	TUNNEL.2,	91.066	$	0.52584,0.00027080
CASK.2503,	TUNNEL.3,	65.294	$	0.37703,0.00022391
CASK.2504,	TUNNEL.1,	5.8355	$	0.033696,1.9110e-005

CASK.2504,	TUNNEL.2,	30.930	$	0.17860,9.1976e-005
CASK.2504,	TUNNEL.3,	132.43	$	0.76468,0.00045414
CASK.2601,	TUNNEL.1,	138.10	$	0.79746,0.00045226
CASK.2601,	TUNNEL.2,	25.102	$	0.14495,7.4647e-005
CASK.2601,	TUNNEL.3,	6.2378	$	0.036019,2.1392e-005
CASK.2602,	TUNNEL.1,	68.554	$	0.39585,0.00022450
CASK.2602,	TUNNEL.2,	86.943	$	0.50203,0.00025854
CASK.2602,	TUNNEL.3,	13.613	$	0.078605,4.6684e-005
CASK.2603,	TUNNEL.1,	12.843	$	0.074160,4.2058e-005
CASK.2603,	TUNNEL.2,	91.332	$	0.52738,0.00027160
CASK.2603,	TUNNEL.3,	64.991	$	0.37528,0.00022288
CASK.2604,	TUNNEL.1,	5.8796	$	0.033951,1.9254e-005
CASK.2604,	TUNNEL.2,	31.149	$	0.17987,9.2628e-005
CASK.2604,	TUNNEL.3,	132.23	$	0.76355,0.00045347
CASK.2701,	TUNNEL.1,	138.10	$	0.79741,0.00045224
CASK.2701,	TUNNEL.2,	25.040	$	0.14459,7.4462e-005
CASK.2701,	TUNNEL.3,	6.3016	$	0.036387,2.1610e-005
CASK.2702,	TUNNEL.1,	68.016	$	0.39275,0.00022274
CASK.2702,	TUNNEL.2,	87.294	$	0.50407,0.00025959
CASK.2702,	TUNNEL.3,	13.821	$	0.079805,4.7396e-005
CASK.2703,	TUNNEL.1,	12.778	$	0.073785,4.1846e-005
CASK.2703,	TUNNEL.2,	90.618	$	0.52326,0.00026947
CASK.2703,	TUNNEL.3,	65.768	$	0.37977,0.00022554
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CASK.2704,	TUNNEL.2,	31.135	$	0.17978,9.2585e-005
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CASK.2801,	TUNNEL.1,	137.92	$	0.79641,0.00045167
CASK.2801,	TUNNEL.2,	25.255	$	0.14583,7.5100e-005
CASK.2801,	TUNNEL.3,	6.2785	$	0.036254,2.1531e-005
CASK.2802,	TUNNEL.1,	68.305	$	0.39442,0.00022369
CASK.2802,	TUNNEL.2,	87.253	$	0.50383,0.00025946
CASK.2802,	TUNNEL.3,	13.602	$	0.078545,4.6648e-005
CASK.2803,	TUNNEL.1,	12.785	$	0.073827,4.1869e-005
CASK.2803,	TUNNEL.2,	91.110	$	0.52610,0.00027094
CASK.2803,	TUNNEL.3,	65.358	$	0.37740,0.00022414
CASK.2804,	TUNNEL.1,	6.0104	$	0.034706,1.9683e-005
CASK.2804,	TUNNEL.2,	31.037	$	0.17922,9.2294e-005
CASK.2804,	TUNNEL.3,	132.37	$	0.76435,0.00045394
CASK.2901,	TUNNEL.1,	137.95	$	0.79655,0.00045175
CASK.2901,	TUNNEL.2,	25.208	$	0.14556,7.4961e-005
CASK.2901,	TUNNEL.3,	6.3047	$	0.036405,2.1621e-005
CASK.2902,	TUNNEL.1,	68.094	$	0.39320,0.00022299
CASK.2902,	TUNNEL.2,	87.286	$	0.50402,0.00025956
CASK.2902,	TUNNEL.3,	13.756	$	0.079430,4.7173e-005
CASK.2903,	TUNNEL.1,	12.735	$	0.073535,4.1704e-005
CASK.2903,	TUNNEL.2,	91.049	$	0.52575,0.00027075
CASK.2903,	TUNNEL.3,	65.491	$	0.37817,0.00022459
CASK.2904,	TUNNEL.1,	6.0330	$	0.034837,1.9757e-005
CASK.2904,	TUNNEL.2,	31.507	$	0.18193,9.3691e-005
CASK.2904,	TUNNEL.3,	131.85	$	0.76133,0.00045215
CASK.3001,	TUNNEL.1,	137.97	$	0.79670,0.00045183
CASK.3001,	TUNNEL.2,	25.049	$	0.14464,7.4489e-005
CASK.3001,	TUNNEL.3,	6.3339	$	0.036574,2.1721e-005
CASK.3002,	TUNNEL.1,	68.734	$	0.39689,0.00022509
CASK.3002,	TUNNEL.2,	86.655	$	0.50038,0.00025769
CASK.3002,	TUNNEL.3,	13.815	$	0.079771,4.7376e-005
CASK.3003,	TUNNEL.1,	12.791	$	0.073857,4.1886e-005
CASK.3003,	TUNNEL.2,	91.080	$	0.52592,0.00027084
CASK.3003,	TUNNEL.3,	65.432	$	0.37783,0.00022439
CASK.3004,	TUNNEL.1,	6.1398	$	0.035453,2.0106e-005
CASK.3004,	TUNNEL.2,	31.115	$	0.17967,9.2525e-005
CASK.3004,	TUNNEL.3,	132.27	$	0.76378,0.00045361
CASK.3101,	TUNNEL.1,	137.70	$	0.79510,0.00045093
CASK.3101,	TUNNEL.2,	25.393	$	0.14663,7.5511e-005
CASK.3101,	TUNNEL.3,	6.3698	$	0.036781,2.1844e-005
CASK.3102,	TUNNEL.1,	68.267	$	0.39420,0.00022356
CASK.3102,	TUNNEL.2,	87.177	$	0.50339,0.00025924
CASK.3102,	TUNNEL.3,	13.703	$	0.079126,4.6993e-005
CASK.3103,	TUNNEL.1,	12.902	$	0.074502,4.2252e-005
CASK.3103,	TUNNEL.2,	91.407	$	0.52781,0.00027182
CASK.3103,	TUNNEL.3,	65.078	$	0.37578,0.00022317
CASK.3104,	TUNNEL.1,	6.2118	$	0.035869,2.0342e-005
CASK.3104,	TUNNEL.2,	30.914	$	0.17851,9.1928e-005
CASK.3104,	TUNNEL.3,	132.43	$	0.76470,0.00045415
CASK.3201,	TUNNEL.1,	138.23	$	0.79819,0.00045268

CASK.3201,	TUNNEL.2,	24.820	$	0.14332,7.3808e-005
CASK.3201,	TUNNEL.3,	6.3863	$	0.036877,2.1901e-005
CASK.3202,	TUNNEL.1,	67.949	$	0.39236,0.00022252
CASK.3202,	TUNNEL.2,	87.413	$	0.50475,0.00025994
CASK.3202,	TUNNEL.3,	13.866	$	0.080068,4.7552e-005
CASK.3203,	TUNNEL.1,	13.070	$	0.075471,4.2802e-005
CASK.3203,	TUNNEL.2,	90.901	$	0.52489,0.00027031
CASK.3203,	TUNNEL.3,	65.388	$	0.37757,0.00022424
CASK.3204,	TUNNEL.1,	6.2751	$	0.036235,2.0550e-005
CASK.3204,	TUNNEL.2,	31.217	$	0.18026,9.2829e-005
CASK.3204,	TUNNEL.3,	132.12	$	0.76292,0.00045309

Appendix F

HOLTEC HI-STAR 100 Component Temperature Distributions

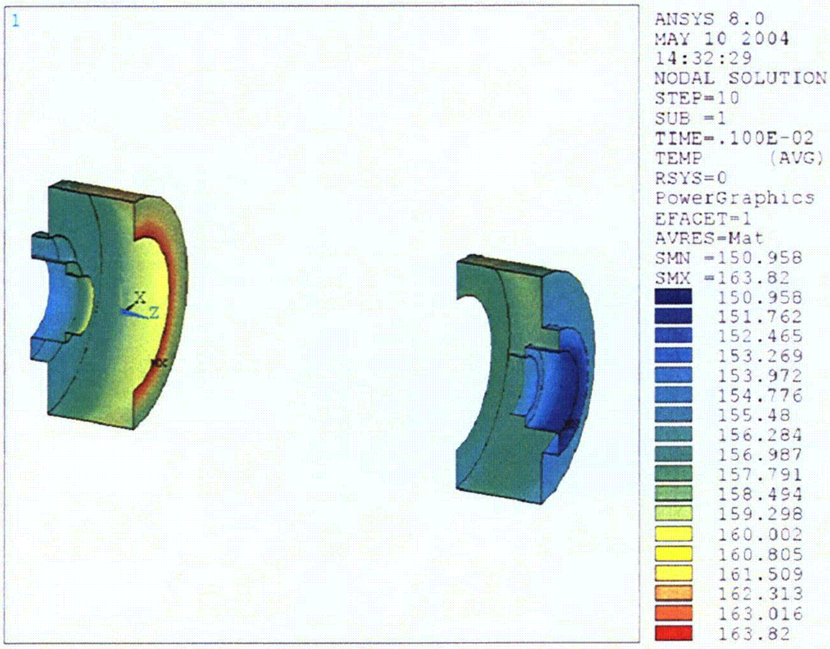

Figure F.1. Impact Limiter Skin Temperature Distribution - Normal Transport Conditions.

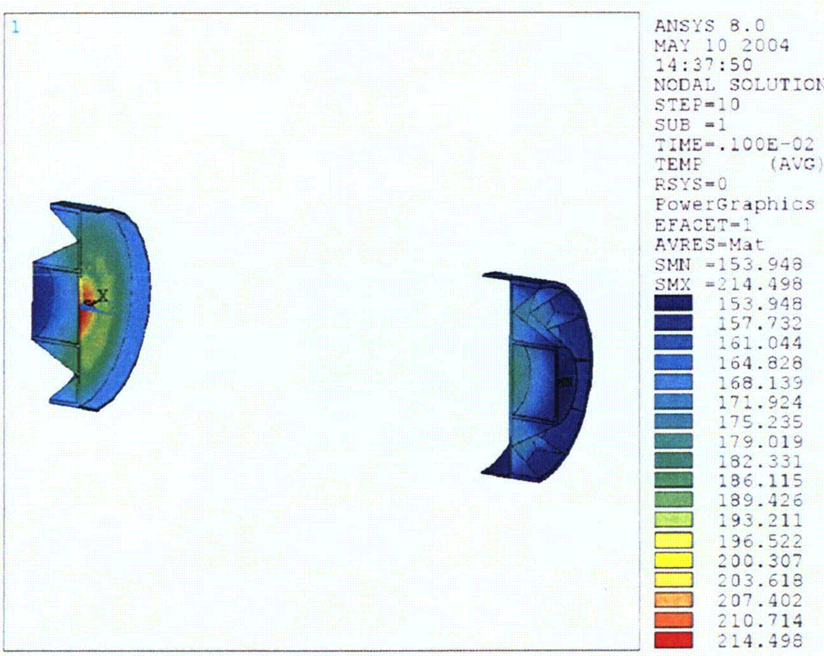

Figure F.2. Impact Limiter Structure Temperature Distribution - Normal Transport Conditions.

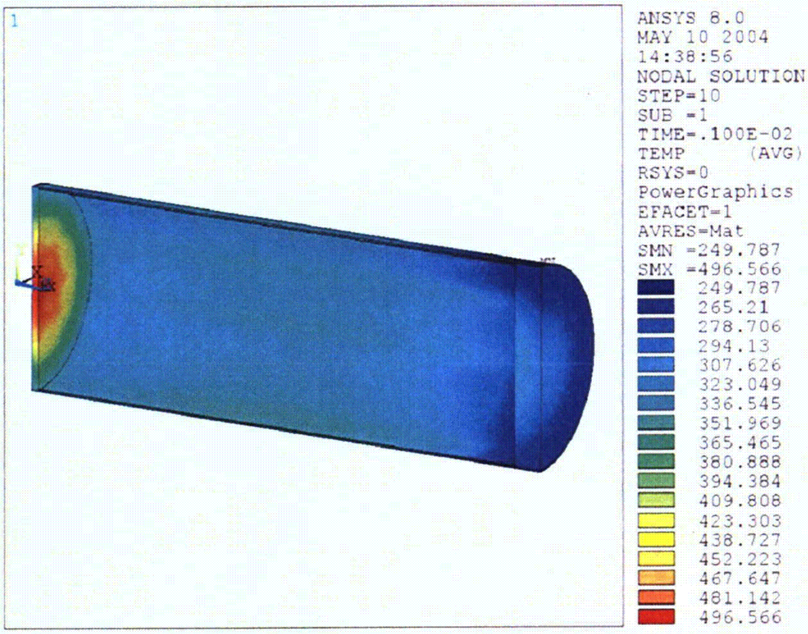

Figure F.3. Canister Shell Temperature Distribution - Normal Transport Conditions.

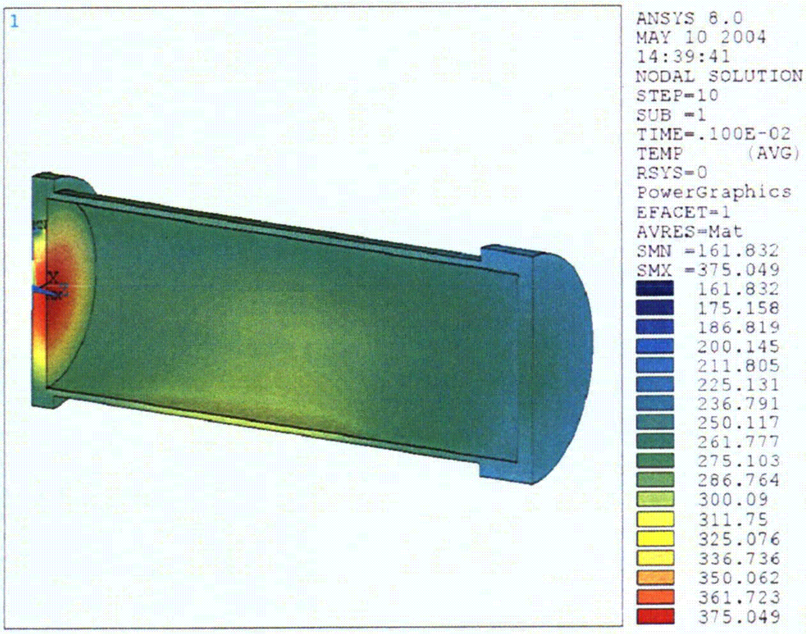

Figure F.4. Cask Inner Shell (Primary Containment Boundary) Temperature Distribution - Normal Transport Conditions.

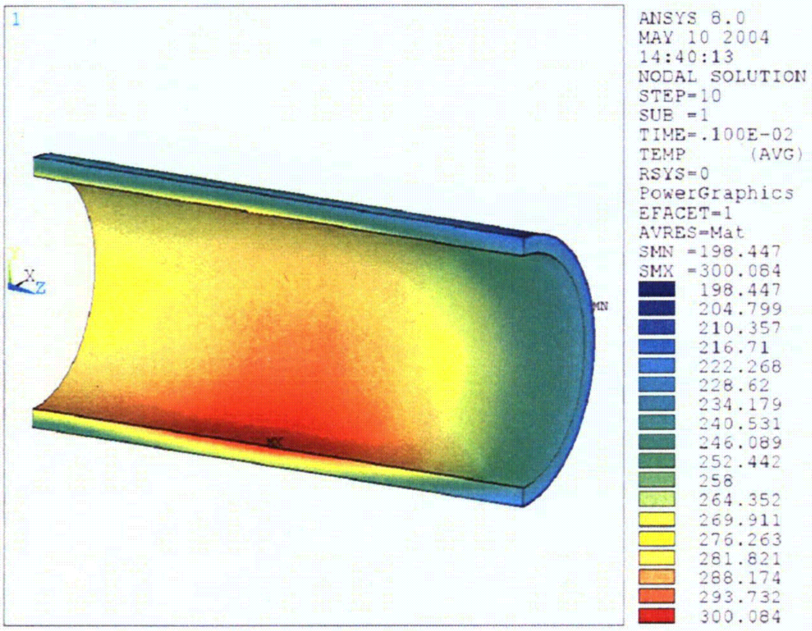

Figure F.5. Gamma Shield Temperature Distribution - Normal Transport Conditions.

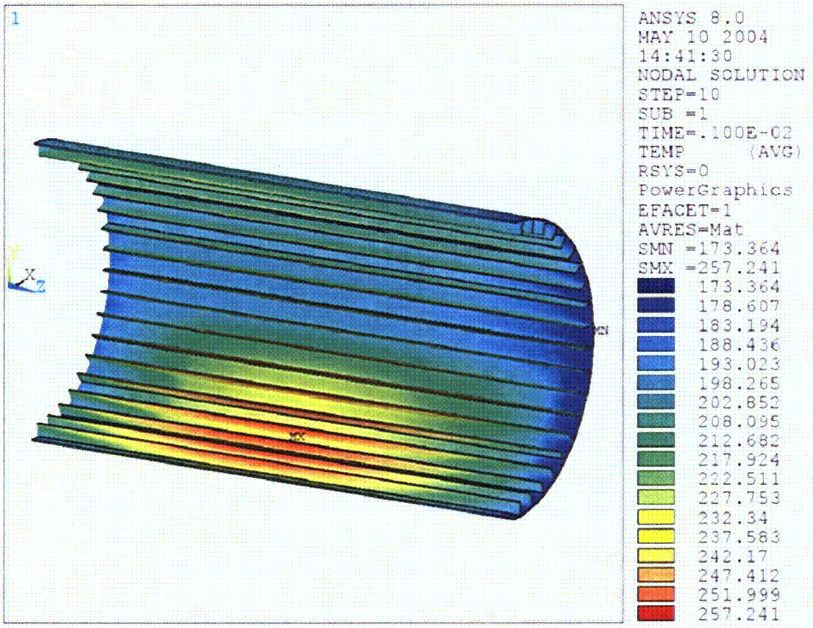

Figure F.6. Fin Structure Temperature Distribution - Normal Transport Conditions.

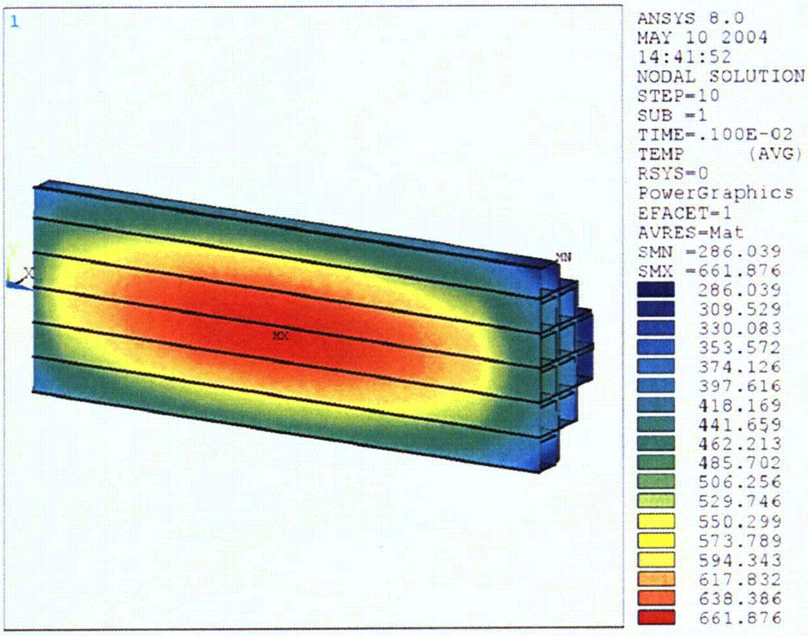

Figure F.7. Basket Axial Temperature Distribution - Normal Transport Conditions.

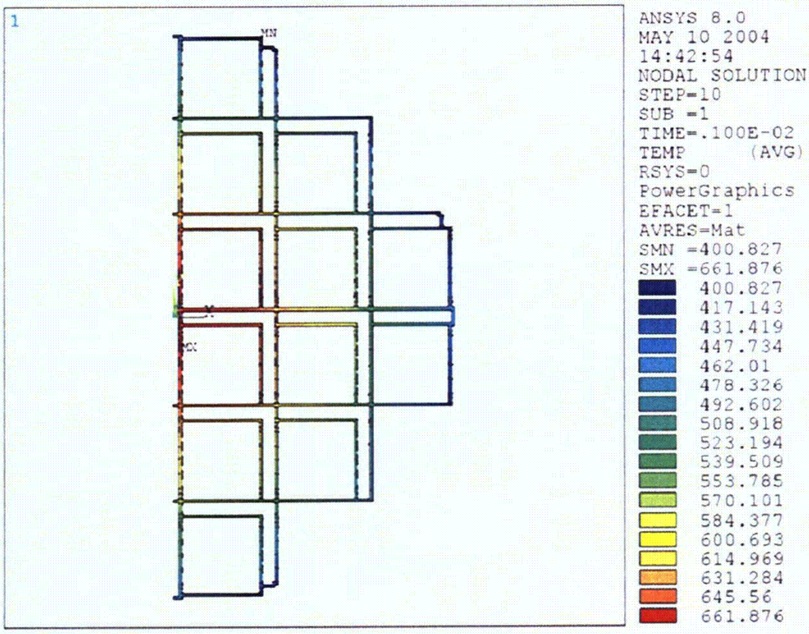

Figure F.8. Basket Radial Temperature Distribution - Normal Transport Conditions.

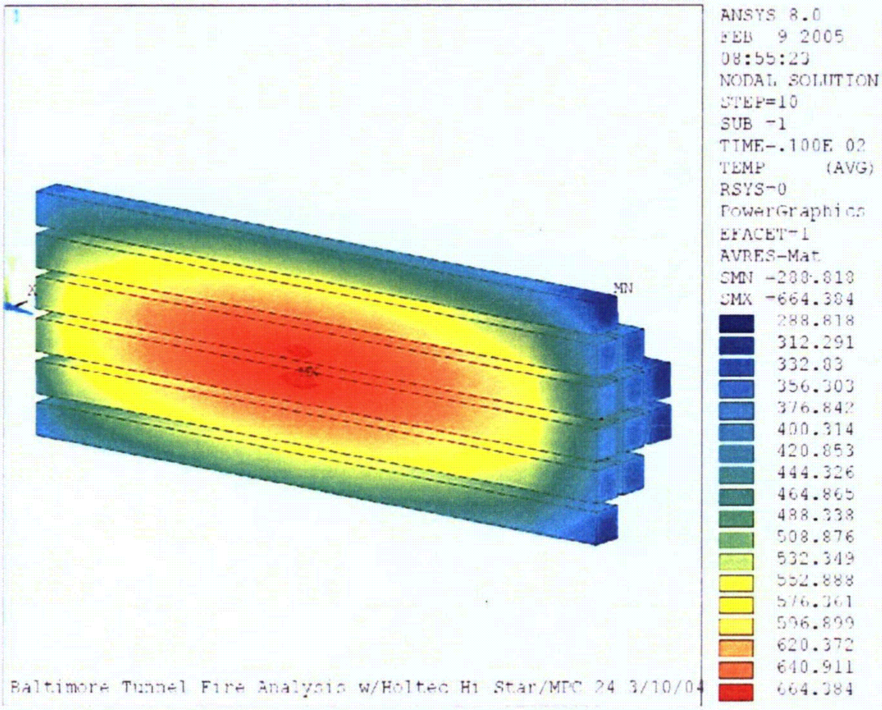

Figure F.9. Spent Fuel Axial Temperature Distribution - Normal Transport Conditions.

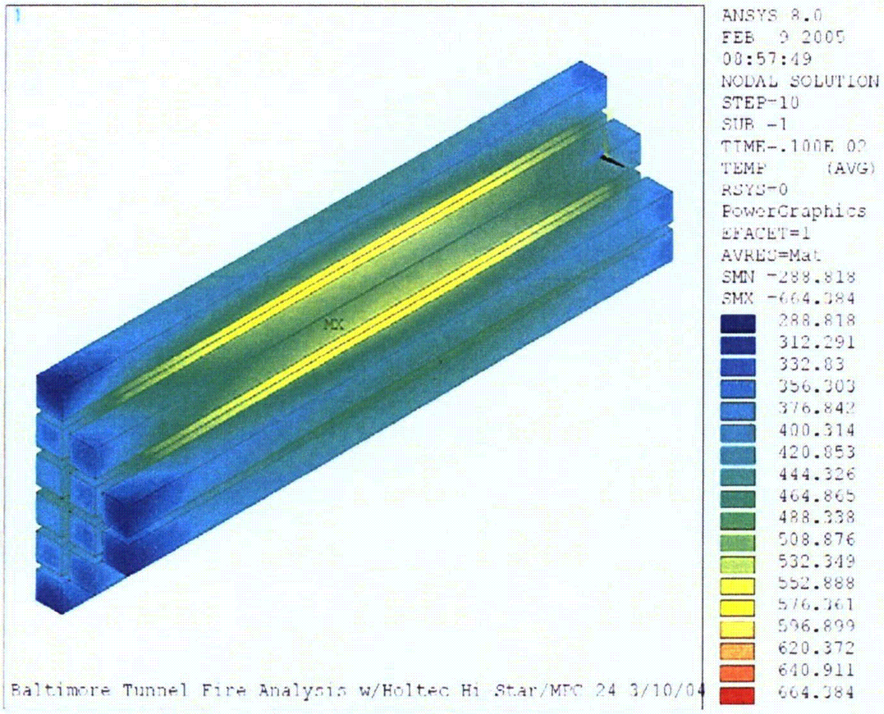

Figure F.10. Spent Fuel Axial Temperature Distribution - Normal Transport Conditions.

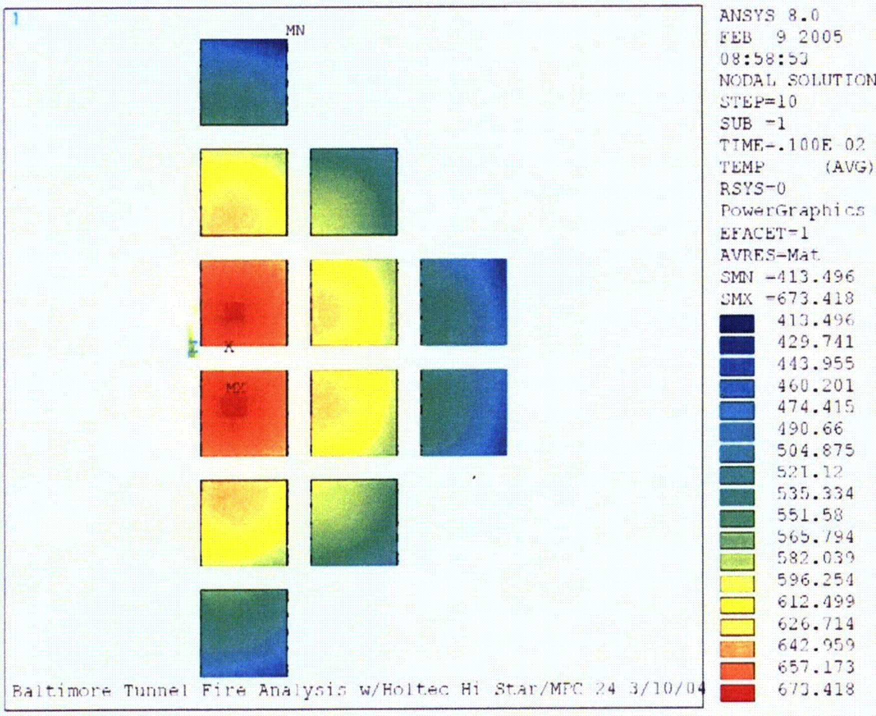

Figure F.11. Spent Fuel Radial Temperature Distribution - Normal Transport Conditions.

APPENDIX G

Comments and Responses from Public Posting in the Federal Register

Comments on NUREG/CR-6886 were solicited via a Federal Register Notice dated September 16, 2005. A second Federal Register Notice was posted on November 30, 2005, extending the comment period on this document to December 30, 2005. The NRC received comments from a diverse group of external stakeholders, consisting of

Northeast High Level Radioactive Waste Transportation Project
Brotherhood of Locomotive Engineers and Trainmen
Agency for Nuclear Projects, State of Nevada
William Rothman, M.D. (private citizen)

Comments ranged from concerns about the potential consequences of the effects of the fire transient on spent fuel transportation packages to comments that raised questions related to the basis for the staff's analysis. A revised version of this document (NUREG/CR-6886, Revision 1) has been developed, which includes additional discussion addressing the issues raised in these comments, an expanded level of detail in the explanation of the analysis methodology, and additional analysis of the potential consequences of the accident scenario. The comments[19] submitted by external stakeholders and the staff's responses to those comments are summarized in the following table.

[19] Some comments have been condensed slightly to remove redundancies or edited to correct typographical errors, without omitting any relevant point of the comment. Full text of the original comments, as submitted to the NRC point of contact for this document, can be obtained from the Agencywide Documents Access and Management System (ADAMS) under the accession number **ML062340334**.

Summary of Comments and Responses from Public Posting on the Federal Register (9/16/2005 through 12/30/2005) of NUREG/CR-6886
Spent Fuel Transportation Package Response to the Baltimore Tunnel Fire Scenario

No.	Comment	Response
1	On page 5.1 the statement is made that 66 ft. down-stream from the fire source is the shortest possible distance between the fire center and an SNF package because of the existence of a buffer car. This assumption seems problematic: even in the Baltimore Tunnel and certainly in wider tunnels with more than one track – it seems possible that the cask car and a buffer car could become uncoupled and slide past each other, that the buffer car could over-ride or be overridden by the package car or that the derailment could realign the cars in such a way that the minimum distance between the fire Center and the package could be only a few feet.	The 66-ft (20-m) location was chosen as a reasonable estimate of where the package could have been located in this particular fire, based on Federal regulations issued by the Department of Transportation (DOT). DOT regulations, in 49CFR174.85, require very specifically defined spacing between rail cars carrying hazardous materials of any kind, including flammable liquids and radioactive materials. Typical requirements specify that a rail car carrying radioactive material must be separated from cars carrying other hazardous material by at least one buffer car. Therefore, the package was placed in a realistic location for this particular accident, not a 'worst possible location' for any tunnel fire scenario. Additions to Chapter 5 address this issue in an expanded discussion of the fire scenario, the configuration of the derailed train cars, and the modeling approach. Additions to Chapter 1 evaluate the Baltimore tunnel fire in relation to the frequency and severity of rail transportation accidents involving hazardous material and severe fires.

No.	Comment	Response
2	The study assumes that the package remains horizontal with one end facing the fire source. It states that this orientation results in the maximum possible exposure and in the least post-fire free convection cooling. While I do not doubt that that is true, it would seem that there should be some discussion or study of an inclined or vertical package particularly, as I believe is pointed out later, because of the vertical temperature distributions both in the air and on the tunnel walls. (Would the seals in a vertical [c]ask where the end is near the heated ceiling of the Tunnel – or sitting just above a pool of flammable liquid – exceed rated service temperatures sooner than in the assumed position?)	The position and orientation of the package within the tunnel was selected to maximize heat input to the package from convection and radiation heat transfer. Peak gas and tunnel surface temperatures were used as boundary conditions on the package surface, as a conservative estimate of the distributed temperature gradients the package would actually see within the tunnel environment at any orientation. This is of particular importance in terms of maximizing heat input to the seals, because the package ends (and therefore the seals) are covered by the impact limiters, which shield the seal region from direct convection and thermal radiation from the tunnel environment. The heat input to the package side governs the rate of heat up of the seals, rather than heat input to the package ends, since the seals heat up primarily because of conduction from the package side. Additions to Chapters 5 and 6, which expand the discussion of the modeling approach, include a review of the conservative assumptions underlying the selection of the package orientation, location relative to the fire, and boundary conditions.
3	on page 5.7, the analysis assumed that the center axis of the package would be 8.2 ft. above the Tunnel floor. ... it is not obvious that it is a worst-case position .... (While I understand from the comment in the first numbered paragraph of section 6.1 that the peak gas temperature at the top of the Tunnel was used as the ambient temperature for active heat transfer to the upper surfaces of the packages, it is not clear to me that this is equivalent to assuming that the package itself were higher in the Tunnel.)	Using the peak gas temperatures for the boundary conditions is equivalent to assuming the package is located at that corresponding position in the tunnel. The 'worst case' for convection would be to assume that the package is positioned near the tunnel ceiling, and the peak air temperature is seen by all package surfaces; however, radiation view factors to the tunnel walls and floor would be attenuated. Since radiation heat transfer is at least an order of magnitude greater than convection, this position would not produce the worst heat transfer conditions for the package. The 'worst case' for radiation assumes the package is oriented horizontally, near the center of the tunnel, so that it has the most direct radiation view factors on all surfaces, particularly the sides of the package. This orientation is used in the analysis, and is arguably the 'most adverse orientation' for heat transfer during the fire and in the post-fire cool down. Additions to Chapters 5 and 6 expand the discussion of the modeling approach, including discussion of the conservative assumptions underlying the selection of the package orientation, location relative to the fire, and boundary conditions.

No.	Comment	Response
4	regarding the use of a seven-hour fire [based on the predictions of the NIST Fire Dynamics Simulator code calculations for the tunnel fire], ...there should be some discussion of both the confidence of the 7-hr FDS prediction and of the [potential consequences] of a fire lasting 10 or more hours.	Seven hours is an extremely conservative estimate of the possible duration of the Baltimore tunnel fire. Based on known facts about the Baltimore tunnel fire (e.g., from NTSB accounts of the accident and testimony of emergency responders at the scene), the most severe portion of the Howard Street tunnel fire lasted approximately 3 hours. Sensitivity studies conducted by NIST with the FDS model of the Howard Street tunnel evaluated variables in the fire scenario (e.g., tunnel geometry, fuel pool size, wall material properties), and determined that the heat release rate of the fire was limited to about 50 MW, due to oxygen starvation. Varying the fuel pool size can yield longer a duration fire, but peak fire temperatures are limited due to lack of sufficient oxygen in the confines of the tunnel. The 7-hr fire duration used to define the boundary conditions for the current study was obtained by assuming a fully ventilated fire that burned until all available fuel was consumed. The heat release rate for this fire scenario is approximately 500 MW, an order of magnitude higher than the heat rate predicted for a realistic representation of the fire conditions. Simulation of a longer fire requires reducing the burn rate or limiting the available oxygen for the fire, or both, which would result in lower fire temperatures. The scenario selected for the current study is a conservative representation of a potentially 'worst case' fire scenario for this accident. Additions to Chapter 2 expand the discussion of the fire scenario assumed in the FDS simulation used to determine the boundary conditions for the analyses of the SNF transportation packages.

No.	Comment	Response
5	In NRC's report on the Baltimore Tunnel fire, it appears that far too much emphasis is placed on investigating the possibility of loss of containment and not enough on the possibility of a loss of shielding scenario regarding the TN-68, Hi-Star 100, and NAC LWT SNF shipping casks. Loss of shielding is of particular concern to the Brotherhood of Locomotive Engineers and Trainmen for the following reasons:	Licensing regulations specified in 10 CFR 71 require that neutron and gamma shielding must be maintained within specified limits in all design basis accidents, including the regulatory fire transient. All three packages evaluated are expected to lose their neutron shield in the regulatory fire, and still maintain required neutron shielding. How this is accomplished is described in their respective SARs. Additions to Chapter 8 discuss the possible consequences of loss of neutron shielding and gamma shielding in terms of potential exposure. These analyses show that the potential dose would be below the limit of 1000 mrem/hr prescribed in 10CFR49 and 10CFR71 for all three packages in this fire scenario.
6	Shielding is an internal component of the cask design and any damage to the shielding would not be visually apparent to railroad employees.	All three packages evaluated can lose their neutron shield and still maintain external dose rates within regulatory limits, as documented in their respective SARs. Gamma shielding is provided by steel in the TN-68 and the HI-STAR 100 packages, and this shielding will not be reduced by any fire scenario. Some reduction of gamma shielding due to lead slumping as a consequence of melting and resolidifying is possible with the NAC LWT package. However, a significant increase in radiation dose from the NAC LWT would require physical damage to the package outer shell (such as a puncture), which could result in loss of lead shielding due to molten lead leaking from the package. Analysis of the conditions of this fire scenario show that the physical forces are not sufficient to result in damage to the package shell, and the lead shielding would remain within the cavity between the inner and outer shell during melting and resolidification. Potential dose increases due to possible slumping of the lead within the cavity are below the regulatory limit for accident conditions. Additions to Chapter 8 discuss the potential consequences of reduction in gamma shielding in the NAC LWT due to this fire scenario.
7.	Train crews are not expected to be provided with dosimetry to measure off-link or on-link exposure during normal transportation, let alone emergency situations.	Additions to Chapter 8 discuss the potential consequences of loss of neutron shielding in all three packages, and potential reduction in gamma shielding in the NAC LWT due to this fire scenario. All three packages are designed to operate within regulatory limits without neutron shielding in place, and analysis shows

No.	Comment	Response
		that the NAC LWT also maintains radiation shielding within regulatory limits even when the potential reduction in gamma shielding is considered. Train crews that observe current regulations and procedures (e.g., 49 CFR part 171: §§ 171.15 and 171.16, 49 CFR part 172: subparts C G, and H, 49 CFR part 174: subparts A through D and K) governing the transportation of hazardous materials (including radioactive material) would not be at risk of exposure to hazards beyond the current regulatory limits for accident conditions from an SNF package subjected to the conditions of the Baltimore tunnel fire. It is the purpose of OCRWM and DOE to ensure that all appropriate measures are taken to protect carriers, workers, and the general public from adverse consequences associated with shipments of spent nuclear fuel and high-level radioactive waste. Regulations and procedures are currently in place that are designed to further the safety and security of SNF shipments. This includes instituting a "no pass" rule in tunnels for trains carrying radioactive material and trains carrying hazardous or flammable materials, to further reduce the extremely low probability of a tunnel fire accident involving an SNF transportation package (See discussion of AAR Circular OT-55 in Chapter 1.) This analysis of the Baltimore tunnel fire and previous evaluations (as discussed in Chapter 1) show that the risks associated with SNF shipments are extremely low. Additional measures under consideration to further mitigate the risk of this activity include - providing dosimeters for specific workers involved in the normal handling of SNF shipments - instituting 'dedicated' rail lines on specific sections of transportation routes where the consequences of an accident are deemed severe enough to warrant such precaution, despite the low probability of a severe accident

No.	Comment	Response
8	There are no plans to equip locomotives with radiation detectors to alert crews to dangerous spikes in dose rate.	See response to Comment 7 above.
9	In all three models, the loss of neutron shielding was a given, but loss of gamma shielding was scarcely touched upon. Lead has a melting point of 621 degrees[F (328°C)]. In all three models, the gamma shield exceeded that temperature. The TN-68 exceeded that temperature after 5 hours, both the Hi-Star 100 and the NAC LWT casks reached that point in just two hours. The NAC LWT uses lead rather than carbon steel as its gamma shield. The shielding would have likely failed at the two-hour mark, eventually reaching 1378 degrees[F (748°C)] after 6.75 hours in the fire.	Gamma shielding is not lost in the TN-68 or HI-STAR 100 during the Baltimore tunnel fire, since these packages use steel for gamma shielding, not lead. For the NAC LWT, the lead reaches its melting point, but in this accident scenario, the lead remains encapsulated within the steel shell of the package body and base, and continues to function as a gamma shield. Additions to Chapter 8 provide an expanded discussion of the consequences of the lead melting during the fire, and the consequent effect on gamma shielding in the NAC LWT. The analyses presented show that this package maintains shielding such that the dose rate at 1 meter from the package surface is below 1000 mrem/hr, as required in all accident conditions. (See response to Comments 5, 6, and 7.)
10	The final version of NUREG/CR-6886 should include an expanded introductory section summarizing previous NRC studies of spent fuel shipping cask response to severe fire environments, including an explanation of the relationship between this report and NUREG/CR-6672 (SAND2000-0234).	There is no direct relationship between NUREG/CR-6672 and NUREG/CR-6886. NUREG/CR-6672 undertakes a detailed study of the risks associated with the transport of spent nuclear fuel by all possible modes, considering both mechanical loads and thermal loads imposed by conservatively defined bounding accident scenarios. Thermal loads were evaluated by postulating an extremely long duration (11 hours) fully engulfing pool fire at 1832°F (1000°C), which readily envelopes the "worst case" possibilities presented by any historical fire accident, including the Baltimore tunnel fire. The analyses in NUREG/CR-6672 use extremely conservative assumptions and highly simplified models of SNF packages for the thermal analyses, which tend to severely over-estimate the peak temperatures within the package, and do not consider the three-dimensional effects of a tunnel fire or any specific historic accident scenarios. The main effect of the modeling simplifications and conservatisms in

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		NUREG/CR-6672 is to grossly over-estimate the peak predicted temperatures in an SNF package in the response to any fire scenario. Even with extremely conservative bounding assumptions, including assumptions related to accident frequency, severity and consequences, the analysis in NUREG/CR-6672 shows that the risks associated with the shipment of spent nuclear fuel by truck or rail are very small. The report further concludes that current regulations governing the transportation of spent nuclear fuel "adequately protect public health and safety."
11	The final version of NUREG/CR-6886 should include a more detailed discussion of the Nation[al] Transportation Safety Board (NTSB) investigation of the Baltimore Tunnel Fire, including the NTSB safety recommendations (R-04-15 and -16, issued January 5, 2005) and the NTSB decision not to issue an official report on the cause and history of the fire.	As discussed in Chapters 1, 2, 3, 4, 5 and 6 of NUREG/CR-6886, information from the NTSB was used in the process of determining a conservative representation of the Baltimore tunnel fire scenario, as well as consultations with experts at NIST and CNWRA. The NTSB performed a thorough investigation of this accident, but declined to issue a final report because the Board could not come to a decision on the cause of the accident. The cause of the accident is not relevant to the analyses presented in NUREG/CR-6886, which accepts as a given that the accident did indeed occur. Similarly, the NTSB safety recommendations R-04-15 and -16 are not relevant to the fire analysis. These recommendations concern the need for improved communications between CSX and the city of Baltimore, and improvements to the city's emergency preparedness plans.
12	The final version of NUREG/CR-6886 should include a detailed discussion of the 2001 analysis of the Baltimore Tunnel Fire prepared by Radioactive Waste Management Associates for the State of Nevada.	NUREG/CR-6886 is a case study of a historical event, not a peer review of other work related to general transportation accidents involving radioactive materials. The RWMA study is particularly problematic, since it is based on significantly different assumptions regarding the fire and the properties of the SNF packages, such that it is impossible to make meaningful comparisons between the two reports. The RWMA study was released less than 3 months after the accident, long before the NTSB, CNWRA, NIST, and NRC had finished investigating the event, and as a result the RWMA study is based on inaccurate and unsubstantiated assumptions about the nature, duration, and intensity of this fire scenario. The RWMA report overstates the intensity and duration of the fire (assuming a 5-day

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		fire duration for the intense portion of the fire vs. the 3-hour duration confirmed by NTSB investigations.) The RWMA study inappropriately uses temperature predictions from the long-duration pool fires analyzed in NUREG/CR-6672 to estimate the tunnel fire environment. The RWMA report incorrectly models the behavior of the package and spent fuel, assuming an incorrect failure mechanism for fuel cladding (i.e., creep vs. pressure rupture), and neglects credible resistances in the release pathway (e.g., metal to metal contact and lid torque.) The RWMA report also overestimates the amount of Cesium that is available for release from the fuel rods. As a result, the RWMA report vastly overestimates the potential consequences of the Baltimore tunnel fire scenario when applied to an SNF package, and does not present a reliable analysis that could assist in determining the risks associated with transportation of spent nuclear fuel by rail.
13	The final version of NUREG/CR-6886 should include a detailed discussion of the 2002 analysis of the Baltimore Tunnel Fire prepared by the U.S. Department of Energy as part of the Final Environmental Impact Statement for Yucca Mountain (DOE/EIS-0250).	A direct comparison between the analyses in NUREG/CR-6886 and in DOE/EIS-0250 is not meaningful. The analysis in EIS-0250 does not evaluate the Baltimore tunnel fire specifically; instead it considers the maximum reasonable foreseeable accident, which is considered to envelope events such as the Baltimore tunnel fire scenario.
14	The final version of NUREG/CR-6886 should include side-by-side fire transient results and consequence analyses of the NAC LWT cask, with and without enclosure in an ISO container. (The discussion at page 7.17 implies that these analyses were performed, but they apparently were not reported.)	The NAC LWT was not analyzed without an ISO container in this study. This package was analyzed enclosed in an ISO container because that is the anticipated mode of transport when it is shipped by rail. The CoC for the NAC LWT requires that it be enclosed in either a personnel barrier (PB) or an ISO container. PBs commonly used for trucks are not shippable by rail, so for rail transport, an ISO would generally be required. Current DOE policy requires an ISO for truck packages shipped by rail, and every rail shipment of the LWT to date has been in an ISO container. The discussion on p. 7.17 is intended to show that the ISO container does not substantially shield the NAC LWT package from the fire, and peak component temperatures would be essentially the same, with or without an ISO container.

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15	The final version of NUREG/CR-6886 should include an additional cask analysis, parallel to the approach described in Section 5, of a General Atomics GA-4 legal-weight truck cask, shipped on a rail car without enclosure in an ISO container.	This study evaluated the performance of three representative packages currently in service, based on resources that are postulated to be used. Including analyses for the GA-4 package in NUREG/CR-6886 would not be expected to substantially alter the results or conclusions obtained in this study. In addition, the thermal performance of the GA-4 package in an extra-regulatory fire has already been examined in NUREG-1768, *United States Nuclear Regulatory Commission Package Performance Study Test Protocols*. Additional analyses may be warranted for future studies, if the staff believes large scale use of a particular package is expected.
16	The final version of NUREG/CR-6886 should include an additional thermal analysis for each of the four casks, parallel to the approach described in Section 5, assuming that the cask is located 5 meters (16 feet) from the fire center.	As noted in the response to Comments 1, 2, and 3, the selected location of the SNF packages for this analysis is consistent with the physical attributes of the tunnel and the possible shipping configurations for an SNF package in the Baltimore tunnel fire scenario.
17	The final version of NUREG/CR-6886 should include an additional thermal analysis for each of the four casks, parallel to the approach described in Section 5, assuming that the cask is located within the hottest region of the fire.	See response to Comments 1, 2, 3, and 16.
18	The final version of NUREG/CR-6886 should include a re-examination of the potential for fuel cladding failure and release of radioactive materials, including fission products, at temperatures below the projected burst temperature of 1382°F (750°C) for Zircaloy cladding. (Additional attention should be given to the presence of older fuel with brittle and/or previously failed cladding.)	The limit of 1382°F (750°C) is a conservative lower bound on the temperature at which Zircaloy cladding might be expected to fail by burst rupture. There is no reason to suppose that this limit is not sufficient for fuel within the TN-68 cask when exposed to the Baltimore tunnel fire scenario, since this cask is licensed to carry only intact fuel assemblies. The HI-STAR 100 is licensed to carry failed fuel, but this analysis shows that this cask would not be expected to lose containment in the Baltimore tunnel fire scenario. This package design employs an inner canister (MPC) that is conservatively predicted to maintain its integrity throughout the entire fire transient. Radioactive materials, including fission

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		products, would not be released from this package, even under conditions as severe as the Baltimore tunnel fire scenario. The NAC LWT is also licensed to carry failed fuel, but this package is quite small and can carry only a limited amount of spent nuclear material, its largest payload consisting of a single PWR assembly. Analysis of the consequences of postulating 100% failure of all rods in a single PWR assembly consisting of high burn-up, 3-yr-cooled fuel (see NUREG/CR-6672) shows that the potential release from this package remains below an A_2 quantity for this fire scenario, as discussed in Chapter 8.2.5. The available fission products from one PWR assembly of this type far exceeds that of any failed fuel the NAC LWT is licensed to carry. A payload that includes failed fuel does not adversely affect the potential consequences of the Baltimore tunnel fire scenario. Additional discussion of the potential consequences of the Baltimore tunnel fire scenario for the HI-STAR 100 and the NAC LWT when carrying failed fuel has been added to Chapter 8.
19	The final version of NUREG/CR-6886 should include a reexamination of the potential for fuel cladding failure and release of radioactive materials for higher burn-up fuels, specifically addressing the issues of radiation embrittlement, pellet degradation due to thermal cycling, and fission product buildup.	This analysis was performed assuming that all of the packages would be loaded with design basis fuel, based on the cask's licensing qualifications. The TN-68 and HI-STAR 100 packages are not licensed to carry high burn-up fuel. The NAC LWT is the only package considered in this study that is licensed to carry high burn-up fuel, in which case the total fuel load is limited to no more than 25 rods. As noted in the response to Comment 18, an analysis assuming 100% failure of all rods in a single high burn-up, 3-yr-cooled PWR assembly shows that the potential release from this package remains below an A_2 quantity for this scenario. The available fission products from one PWR assembly of this type far exceeds that of the maximum of 25 high burn-up fuel rods the NAC LWT is licensed to carry.

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20	The final version of NUREG/CR-6886 should include a reexamination of the potential for release of radioactive materials for fuel assemblies with higher levels of CRUD activity (e.g., BWR assemblies with surface concentration up to150 μCi/cm^2).	The current analysis (see Chapter 8) was performed assuming maximum CRUD activity of 300 μCi/cm^2, and corresponding average activity of 150 μCi/cm^2 for the TN-68. Given the conservative assumptions on the amount of CRUD that can detach from the rod surfaces and plate out, and the fact that 90% of the rods are cleaner than this assumed level of activity, this assumption is appropriately conservative for this analysis.
21	The final version of NUREG/CR-6886 should include a reexamination of the mechanisms for seal failure and release of radioactive materials, including seal failure long before maximum seal temperatures are reached, bolt failure, and pressure-induced blowout of failed seals.	Failure due to exceeding temperature limits is the only credible cause of seal failure in this accident scenario. The specified limits are inherently conservative, in that they are based on long-term service temperature limits, rather than transient limits. Temperatures are not high enough to consider bolt failure possible, and internal pressure increase is not sufficient by itself to compromise seals. As discussed in Chapter 8, the potential release of radioactive materials is not limited by the condition of the seals or by the time required for the seals to fail. The conclusion that there would be no release from the HI-STAR 100 is based on the welded inner canister remaining intact, not simply the integrity of the seals. For the TN-68 and the NAC LWT, the seals are assumed to fail, and the amount of the potential release is based primarily on the amount of CRUD material available for release from the package. It is not dependent on the time or mode of seal failure. The potential release is determined using a model developed by Sandia National Laboratory for analysis of CRUD contribution to shipping package containment requirements (SAND88-1358; see Ref. 26).
22	The final version of NUREG/CR-6886 should include a reexamination of the role of the HI-STAR 100 train carriage and cask restraints regarding heat shielding and heat conduction.	Heat shielding effects of these structures during the fire would act to decrease the heat load on the package during the fire; heat conduction after the fire would serve to hasten cool-down. Assumptions made in the analysis are conservative for both the fire and post-fire cool down.

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23	The final version of NUREG/CR-6886 should include a discussion of the emergency response implications, and cask recovery implications, of the predicted damage to the neutron shielding for all three considered casks, and the loss of gamma shielding for the NAC LWT.	The loss of neutron shielding is expected in all 3 designs as a consequence of the regulatory fire (i.e., 30 minutes at 800°C). Existing regulations and procedures regarding emergency response should be sufficient for this scenario, as well. The NAC LWT does not lose its gamma shielding in this scenario. The lead melts during the fire, but is confined and held in place by the steel package body. Additional discussion has been added to Section 8.1 evaluating the consequences of lead melting and resolidification in this package. (See responses to Comments 5 through 9 above.)
24	The final version of NUREG/CR-6886 should include a reexamination of the uncertainties associated with the NIST FDS simulations of gas and wall temperatures 20-30 meters from the fire center. (These issues include the construction and benchmarking of the FDS code, selection of the conductivity value for the tunnel bricks, and potential inconsistencies with the materials analyses.)	Because of uncertainties and unknowns related to the fire scenario, the FDS simulation and the package analyses were performed using conservative assumptions. The results of the FDS simulations using realistic assumptions are in close agreement with the peak temperatures estimated from analyses of material recovered from the tunnel after the fire. (See the discussion in Chapter 3.) In addition, sensitivity studies were performed with FDS to determine the effect of varying parameters that could potentially affect peak predicted temperatures, including the thermal conductivity of the tunnel wall surfaces. The analysis predicting a fire duration of 7 hours is the result of specifying parameters that assume an unrealistically high rate of oxygen flow to the fire, in order to achieve complete combustion of the entire inventory of available fuel. The resulting fire conditions are an order of magnitude hotter than conditions predicted using realistic assumptions for the fire scenario. Variation in parameters due to uncertainties would generally result in a less severe fire transient. Additions to Chapters 2, 4, 5 and 6 expand the discussion of the conservatisms in the FDS analysis of the fire scenario and the modeling approach used in the analyses of the SNF packages.

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25	The final version of NUREG/CR-6886 should include a comprehensive analysis of uncertainties in the following factors, and how these uncertainties might affect the results of the consequence assessment: fire size, location, and duration; gas and wall temperatures from the NIST FDS simulations; CNWRA metallurgical analyses; uncertainties in the package models; seal and cladding temperature limits; and heat transfer models for the neutron shield (including gap radiation in charred solid, and boiling heat transfer in liquid) and impact limiters.	Relevant discussions of all of these issues are included in the publicly posted version of the report, and have been expanded in Chapters 2, 5, 6, and 8 of the current Revision 1. Uncertainties related to all of these enumerated issues were considered and accounted for in a conservative manner in these analyses. Evaluation of less conservative variations within the range of uncertainties in these factors would result in shorter fire durations and lower fire temperatures, which would lower predicted package component temperatures.
26	The final version of NUREG/CR-6886 should include a discussion of any peer reviews conducted for this report, and any peer reviews conducted for two of the major supporting studies, NUREG/CR-6793 (NIST) and NUREG/CR-6799 (CNWRA).	NUREG/CR-6886 has not been subjected to external peer reviews. Instead, this document has undergone intense internal technical peer reviews by PNNL and NRC before publication, and was made available for public comment for a period of approximately 3 months. This permitted independent review by any and all interested parties. All public comments on this document are included in the final publication. An external peer review was not deemed necessary because of the very low risks associated with this scenario. This is due to the low frequency of the type of accident and the minimal consequences of postulated accident conditions. The observed frequency is once during 21 billion miles of train travel, which comprises the last 30 years of historical rail shipments. The potential consequences are estimated to be less than 0.3 of an A_2 quantity of release, and the analysis predicts large margins of temperature against cladding failure. For this study, a peer review would not be cost effective.

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27	The possibility of fuel oil fire temperatures of 1650-2000°C for periods of time far in excess of the 30-minute test characteristic of Type B casks, make it impossible to consider that the circumstances know[n] about the Baltimore tunnel fire would be the worst circumstances that would be likely to apply in a fire situation affecting nuclear waste casks, during their transport.	The analyses in NUREG/CR-6886 predict the effects that a particular historical fire accident could be expected to have on three specific SNF transportation packages. This report does not attempt to define the worst possible fire accident. However, this is an extremely severe accident with a statistical frequency on the order of one such accident in 21 billion miles of train travel. This accident is bounded by the analyses in NUREG/CR-6672 and NUREG-0170 evaluating the risks associated with transportation of spent nuclear fuel.
28	The Advisory Committee on Nuclear Waste (ACNW) inquired during a public meeting on September 21, 2006, as to whether or not the figure of 21 billion rail miles traveled between 1975 and 2005, cited in the report, included DOE Naval Nuclear Propulsion Program waste shipments.	This mileage figure includes all commercial rail transportation for this period of time; however, it was not broken down into specific categories of rail transportation. DOE Naval Nuclear Propulsion Program waste shipments are commonly done on commercial railways and, as a result, would be included in this number.

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10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

On July 18, 2001, a freight train carrying hazardous (non-nuclear) materials derailed and caught fire while passing through the Howard Street railroad tunnel in downtown Baltimore, Maryland. The United States Nuclear Regulatory Commission (USNRC), one of the agencies responsible for ensuring the safe transportation of radioactive materials in the United States, undertook an investigation of the train derailment and fire to determine the possible regulatory implications of this particular event for the transportation of spent nuclear fuel by railroad.

The USNRC assembled a team of experts from the National Transportation Safety Board, the National Institute of Standards and Technology, the Center for Nuclear Waste Regulatory Analyses, and the Pacific Northwest National Laboratory to determine the thermal conditions that existed in the Howard Street tunnel fire and analyze the potential effects of those conditions on various spent nuclear fuel (SNF) transportation package designs.

The staff's evaluation indicates that neither SNF particles nor fission products would be released from a package, carrying intact SNF, involved in a severe tunnel fire such as the Baltimore tunnel fire. A release of CRUD from the surface of fuel cladding, while a possibility for certain package designs, is highly unlikely, and would be within regulatory limits.

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