

Appendix A

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

Appendix A

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

Table Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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 Error! No text of specified style in document..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