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Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

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TEMPERATURE-PACKAGE POWER CORRELATIONS FOR OPEN-MODE GEOLOGIC DISPOSAL CONCEPTS

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ABSTRACT

Logistical simulation of spent nuclear fuel (SNF) management in the U.S. combines storage, transportation and disposal elements to evaluate schedule, cost and other resources needed for all major operations leading to final geologic disposal. Geologic repository reference options are associated with limits on waste package thermal power output at emplacement, in order to meet limits on peak temperature for certain key engineered and natural barriers. These package power limits are used in logistical simulation software such as CALVIN, as threshold requirements that must be met by means of decay storage or SNF blending in waste packages, before emplacement in a repository.

Geologic repository reference options include enclosed modes developed for crystalline rock, clay or shale, and salt. In addition, a further need has been addressed for open modes in which SNF can be emplaced in a repository, then ventilated for decades or longer to remove heat, prior to permanent repository closure. For each open mode disposal concept there are specified durations for surface decay storage (prior to emplacement), repository ventilation, and repository closure operations. This study simulates those steps for several timing cases, and for SNF with three fuel-burnup characteristics, to develop package power limits at which waste packages can be emplaced without exceeding specified temperature limits many years later after permanent closure. The results are presented in the form of correlations that span a range of package power and peak postclosure temperature, for each open-mode disposal concept, and for each timing case. Given a particular temperature limit value, the corresponding package power limit for each case can be selected for use in CALVIN and similar tools.

ACKNOWLEDGEMENTS

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

The calculation file listed in Appendix A is based on an earlier file prepared by Harris Greenberg and colleagues at Lawrence Livermore National Laboratory.

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

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ACRONYMS

BWR	Boiling Water Reactor
d	Day
DPC	Dual-Purpose Canister
EBS	Engineered Barrier System
GW	Gigawatts
MTHM	Metric Tons Heavy Metal
PWR	Pressurized Water Reactor
WP	Waste Package

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

1. INTRODUCTION

Logistical simulation of spent nuclear fuel (SNF) management in the U.S. combines storage, transportation and disposal elements to evaluate schedule, cost and other resources needed for all major operations leading to final geologic disposal. Geologic repository reference options are associated with limits on waste package thermal power output at emplacement, in order to meet limits on peak temperature for certain key engineered and natural barriers. These package power limits are used in logistical simulation software such as CALVIN (Nutt et al. 2012) as threshold requirements that must be met by means of decay storage or SNF blending in waste packages, before emplacement in a repository.

Geologic repository reference options include enclosed modes developed for crystalline rock, clay or shale, and salt. In addition, a further need has been addressed for open modes in which SNF can be emplaced in a repository, then ventilated for decades or longer to remove heat, prior to permanent repository closure. Enclosed and open mode disposal concepts were described and analyzed previously (Hardin et al. 2012) and comprise the following list:

1. **Crystalline (enclosed)**
2. **Generic salt repository (enclosed)**
3. **Clay/shale (enclosed)**
4. **Deep borehole concept (enclosed)**
5. **Clay/shale unbackfilled open mode**
6. **Sedimentary backfilled open mode**
7. **Hard-rock unsaturated open emplacement mode concept**

The repository-based enclosed concepts (1 through 3) have temperature limits on the engineered backfill or buffer material placed into direct contact with waste packages. Correlations between peak package surface temperature and thermal power at emplacement were previously calculated using analytical solutions (for crystalline and clay/shale) and the finite-element method (for salt) (Hardin et al. 2012). Peak temperature occurs within only a few years after emplacement for these concepts, so it is strongly correlated with power at emplacement. For the deep borehole concept no thermal limits or potential over-temperature conditions have been identified.

The open modes (5 through 7) allow earlier emplacement of hotter, and potentially larger waste packages in the repository, because heat is removed by repository ventilation for decades or longer. For each open mode disposal concept there are specified durations for surface decay storage (prior to emplacement), repository ventilation, and repository closure operations. This study simulates those steps for several timing cases, and for SNF with three fuel-burnup characteristics, to develop package power limits at which waste packages can be emplaced without exceeding specified temperature limits many years later after permanent closure. Temperature limits are specified at the drift wall for unbackfilled concepts, and at the waste package surface for backfilled ones. The results are presented in the form of correlations that span a range of package power and peak postclosure temperature, for each open-mode disposal concept, and for each timing case. Given a particular temperature limit value, the corresponding package power limit for each case can be selected for use in CALVIN (Nutt et al. 2012) and similar tools.

2. ANALYSIS METHOD AND RESULTS

For this study the open modes were simplified according to sedimentary or hard rock, and backfilled or unbackfilled (remains open after closure, at least through the period of peak temperature). Thermal properties assumed for sedimentary and hard rock concepts are summarized in Table 1.

Table 1. Thermal properties for geologic settings.

Setting	Thermal Conductivity (W/m-K)	Thermal Diffusivity (m^2/sec)
Sedimentary	1.75	6.45E-7
Hard Rock	2.5	1.13E-6

For each open-mode concept the duration of surface decay storage and repository ventilation must be specified, and for this study the following timing cases are presented:

- **10/40/10 Case** – Ten years of surface decay storage, 40 yr repository ventilation, and 10 yr (unventilated, but unbackfilled) for closure operations prior to final closure.
- **10/90/10 Case** – Ten years of surface decay storage, 90 yr repository ventilation, and 10 yr (unventilated, but unbackfilled) for closure operations prior to final closure.
- **50/100/10 Case** – Fifty years of surface decay storage, 100 yr repository ventilation, and 10 yr (unventilated, but unbackfilled) for closure operations prior to final closure. This case corresponds to the longest durations of decay storage and ventilation prior to closure, that are being considered in an ongoing evaluation of direct disposal of dual-purpose canisters (Miller et al. 2012).
- **50/150/10 Case** – Fifty years of surface decay storage, 150 yr repository ventilation, and 10 yr (unventilated, but unbackfilled) for closure operations prior to final closure.
- **100/200/10 Case** – One hundred years of surface decay storage, 200 yr repository ventilation, and 10 yr (unventilated, but unbackfilled) for closure operations prior to final closure.

The 10-year repository closure operations period included with each case would be used for construction of plugs and seals, removal of any items or materials, backfilling of non-emplacement areas, and backfilling of emplacement openings or access drifts as required.

Thermal history simulations are conducted for each timing case, for three fuel burnup characteristics, and four waste package sizes. Heat generation by SNF with 20, 40 and 60 GW-d/MTHM burnup (Figure 1) was produced from isotopic calculations (Carter et al. 2012; email 15Jan2013).

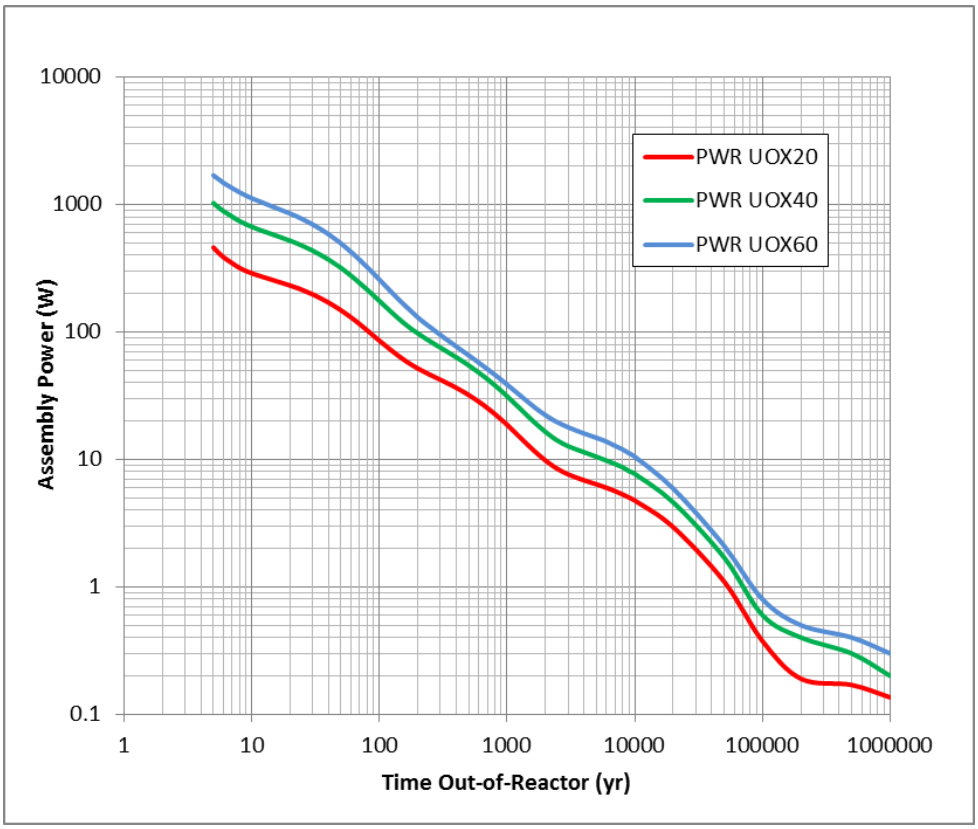


Figure 1. Heat generation curves (watts per SNF assembly) used in thermal calculations (from Carter et al. 2012).

Waste package sizes are referred to in terms of how many pressurized water reactor (PWR) assemblies they contain. The selected sizes and overall (right-circular cylinder) dimensions are given in Table 2.

Table 2. Waste package sizes and dimensions.

Waste Package	Diameter (m)	Length (m)
4 PWR assemblies	0.96	5.0
12 PWR assemblies	1.29	5.0
21 PWR assemblies	1.60	5.0
32 PWR assemblies	2.0	5.0

Thermal analysis was conducted by superposing analytical, Fourier conduction solutions for a finite line source (representing a central package), point sources (adjacent packages in the same drift or alignment), and line sources (adjacent drifts or alignments). The approach is described elsewhere (Hardin et al. 2012, Section 3 and Appendix A). The forcing function for all sources is transient, representing the decaying waste. A transient superposition solution (temperature vs. time) is generated for a point on the perpendicular mid-plane for the central package, at a distance corresponding to the rock wall (Figure 2). Temperatures for annular layers representing

the engineered barrier system (EBS; i.e., backfill, buffer, air gap, etc.) within that distance are then calculated using a steady state solution. Temperature is slowly varying and the sensible heat stored within that distance is very small compared to the overall heat output of the waste. For air gaps a gray-body, thermal radiation solution for concentric surfaces is used. Radii and thermal conductivity values for the annular layers representing the EBS, emissivity values used for thermal radiation calculations, and ventilation heat removal efficiency are summarized in Table 3.

Thermal calculations were performed to investigate the sensitivity of peak drift wall temperature to drift spacing, for 21-PWR and 32-PWR size waste packages in a sedimentary unbackfilled repository. A spacing value of 70 m is selected for this report because it incorporates much of the peak temperature reduction possible using drift spacing (Figure 3). The characteristic time for a given temperature rise in diffusive systems is proportional to the square of the distance from a heat source, but the decreasing SNF heat output in repository analyses overwhelms the effect from distance, after decay of short-lived fission products that generate most of the heat in the first hundred years. Note that drift spacing has a greater effect in later time (e.g., after 300 yr) when the entire repository heats up and the contribution from adjacent drifts dominates contributions from the package itself, or adjacent packages in the same drift.

Waste package spacing is more effective than drift diameter at lowering peak EBS temperatures outside the waste package, and slightly more effective than drift spacing. Hence two values of waste package spacing are used in this study (Table 3). The two values 10 m and 20 m represent a reasonably achievable range; spacings smaller than 10 m could significantly increase peak temperatures, while spacings greater than 20 m could greatly increase the repository layout size.

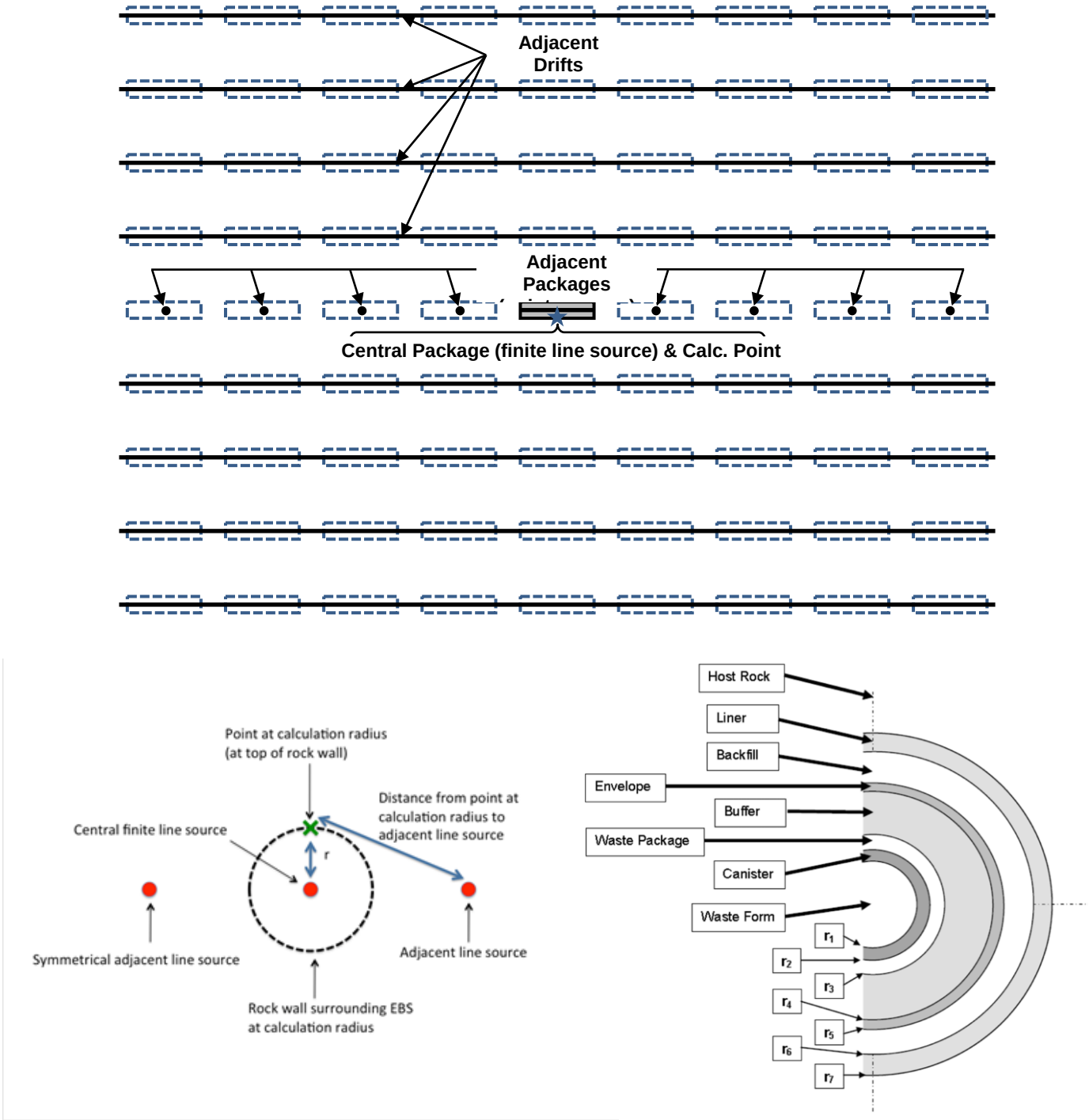


Figure 2. Schematic of analytical superposition solution and annular EBS layers.

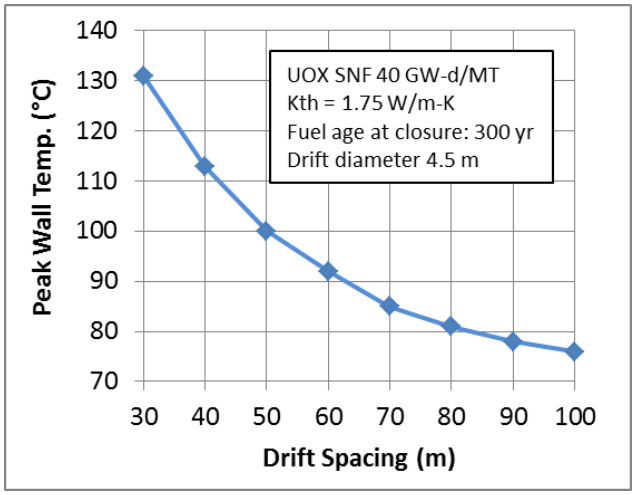


Figure 3. Effect of drift spacing on peak drift wall temperature, for typical SNF in a sedimentary repository, unbackfilled, that closes at 300 yr out-of-reactor.

Table 3. Geometrical and emissivity parameters.

Concept	Drift Diameter (m)	Drift Spacing (m)	Package Spacing (m)	Backfill Thermal Cond. (W/m-K)	Package Emissivity	Wall Emissivity	Preclosure Ventilation Efficiency
Sedimentary Unbackfilled	4.5	70	10 & 20	–	0.6	0.9	75%
Sedimentary Backfilled	4.5	70	10 & 20	0.6	–	–	75%
Hard rock Unbackfilled	5.5	70	10 & 20	–	0.8	0.9	75%
Hard rock Backfilled	5.5	70	20	0.6	–	–	75%

The analytical solutions are coded using MathCad 14®, and the printout of an example file is presented in Appendix A. This file offers four disposal concepts ("Rock_type") each with specified geometry and properties. Waste can be SNF ("Assembly" waste) or vitrified high-level waste ("Canister" waste), and several types of each are offered ("WF_name"). For SNF waste the number of assemblies ("WF_cnt") and package dimensions ("Assy_layer_inner_r" and "WP_len") are specified for each type. Finally, the timing case is determined by decay storage duration ("Tstore"), ventilation duration ("Tvent"), and closure operations duration ("Tclose"). Up to three timing cases can be evaluated with a single instance of the MathCad script.

Once temperature histories were obtained for each run, selecting disposal concept, timing case, SNF burnup, and package size, a statistical procedure was used to evaluate the correlation of peak temperature (drift wall, or waste package for backfilled concepts) with waste package power at emplacement. The procedure also includes confidence interval analysis to estimate the maximum package power at emplacement consistent with meeting prescribed temperature limits. For the sedimentary concepts (unbackfilled or backfilled) a limit of 100°C was assigned (protecting the host rock, or the backfill and host rock, respectively). For the hard rock

unbackfilled concept a wall temperature limit of 200°C is used, and for the hard rock backfilled concept a package temperature of 100°C. These limits are reasonably consistent with current international practice and previous work in the U.S. (Hardin et al. 2012), although they could be modified in the future based on findings from ongoing research, which may include site-specific information.

Correlation plots were generated for each disposal concept and timing case, combining burnup and package size data (Figures 4 through 9). Correlation is generally good, and could be improved using package power at repository closure instead of waste emplacement, because less time would intervene until peak temperature. However, package power limits at closure are inconsistent with use of the results with the CALVIN simulation tool (Nutt et al. 2012).

A confidence interval analysis was used for each concept and timing case (i.e., for each correlation plot) to estimate the maximum package power at emplacement, to achieve the assigned temperature limit. The procedure is based on the t-statistic (Bowker and Lieberman 1972, Section 9.9). According to this source, a confidence interval for the value of package power p corresponding to a given (limit) value of temperature T, say T', with confidence level 1-α, is given approximately by

$$Interval \approx \frac{T'}{b} \pm \frac{t_{\alpha/2;\,n-1} S_{T/p}}{b} \sqrt{1 + \frac{\left(T'/b\right)^2}{\sum_{i=1}^{n} p_i^2}}$$

$$b = \frac{\sum_{i=1}^{n} p_i T_i}{\sum_{i=1}^{n} p_i^2}$$

$$S_{T/P} = \sqrt{\frac{\sum_{i=1}^{n} T_i^2 - \left(\left(\sum_{i=1}^{n} p_i T_i\right)^2 \Big/ \sum_{i=1}^{n} p_i^2\right)}{n-1}}$$

where $t_{\alpha/2;\,n-1}$ is the $\alpha/2$ percentage point of the t-distribution for n-1 degrees of freedom, and n is the number of observations (p_i ,T_i). Thus, the maximum power is at the lower limit of this interval:

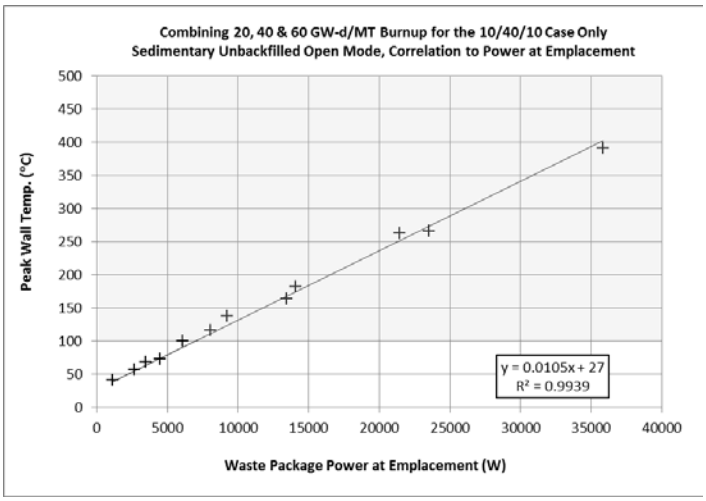
$$p_{max} \approx \frac{T'}{b} - \frac{t_{\alpha/2;\,n-1} S_{T/p}}{b} \sqrt{1 + \frac{\left(T'/b\right)^2}{\sum_{i=1}^{n} p_i^2}}$$

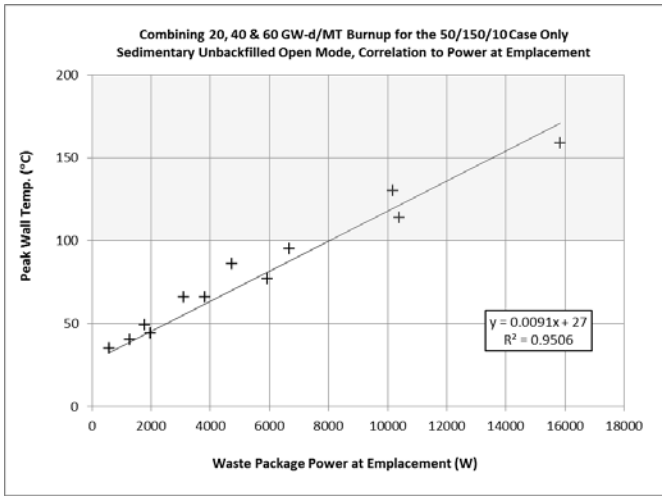
which is used in the compilation of confidence interval data for all concepts and timing cases. Correlation plots for each concept are presented as follows:

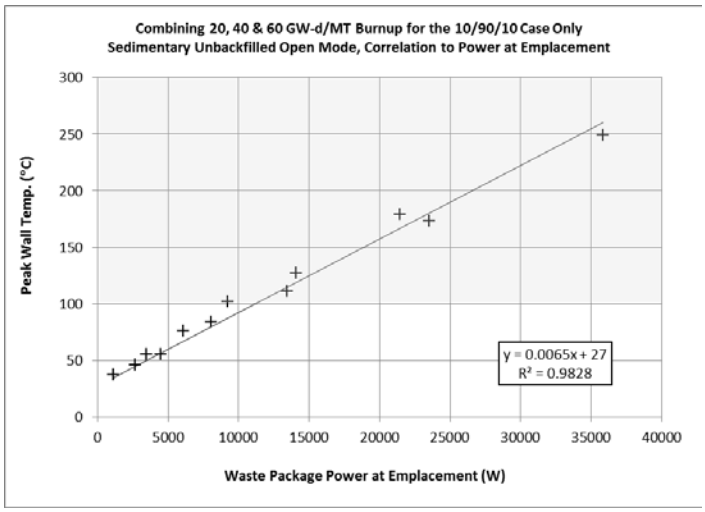
Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

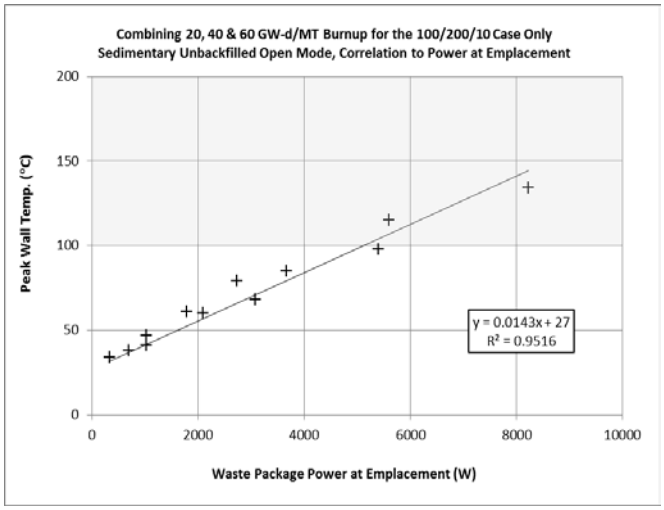
- **Sedimentary Unbackfilled (10 m Drift Spacing)** – Correlation plot (Figure 4) and peak wall and package temperature summary (Table 4).
- **Sedimentary Unbackfilled (20 m Drift Spacing)** – Correlation plot (Figure 5) and peak wall and package temperature summary (Table 5).
- **Sedimentary Backfilled (20 m Drift Spacing)** – Correlation plot (Figure 6) and peak wall and package temperature summary (Table 6).
- **Hard rock Unbackfilled (10 m Drift Spacing)** – Correlation plot (Figure 7) and peak wall and package temperature summary (Table 7).
- **Hard rock Unbackfilled (20 m Drift Spacing)** – Correlation plot (Figure 8) and peak wall and package temperature summary (Table 8).
- **Hard rock Backfilled (20 m Drift Spacing)** – Correlation plot (Figure 9) and peak wall and package temperature summary (Table 9).

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts









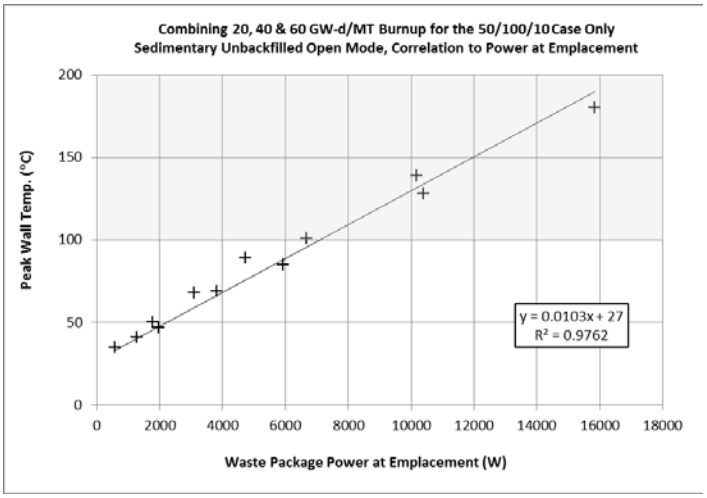
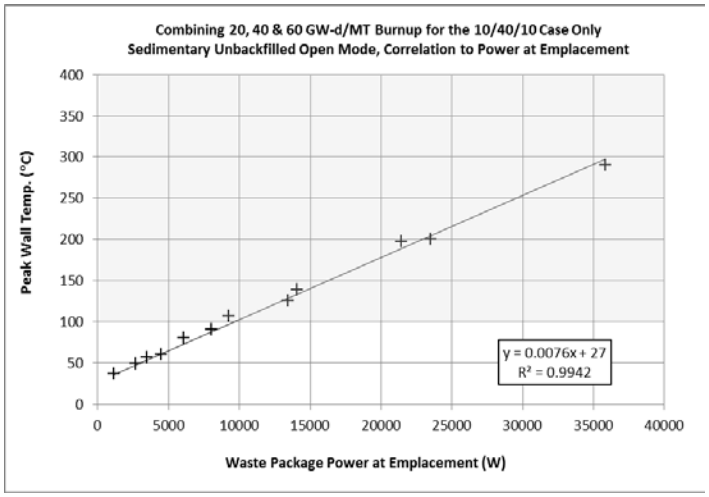
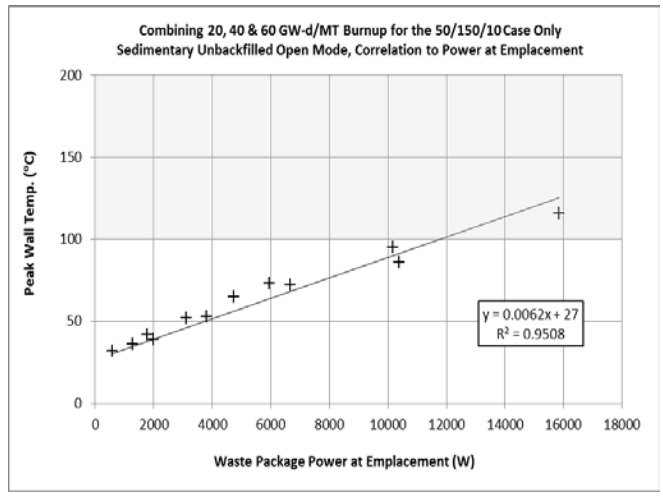
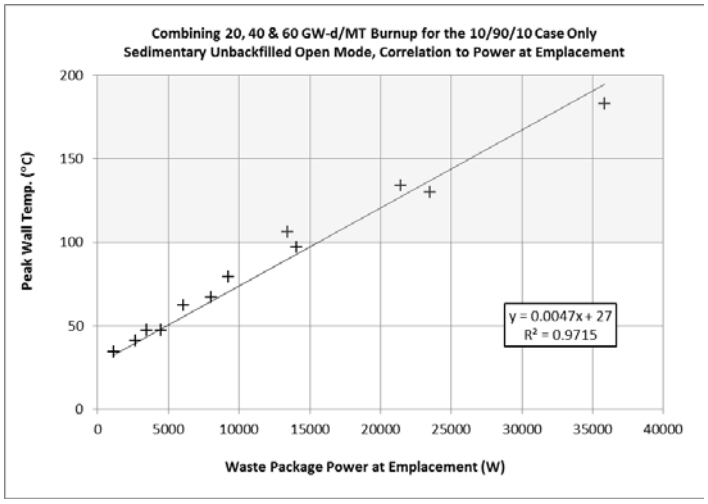
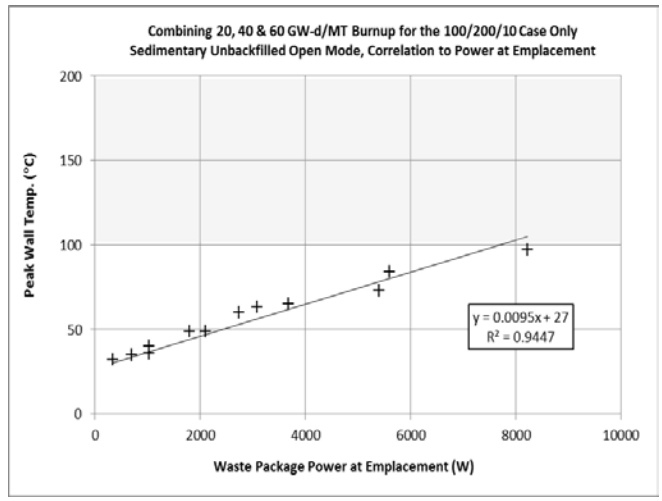


Figure 4. Correlation plots for the sedimentary unbackfilled open mode with 10 m drift spacing (timing cases as indicated).









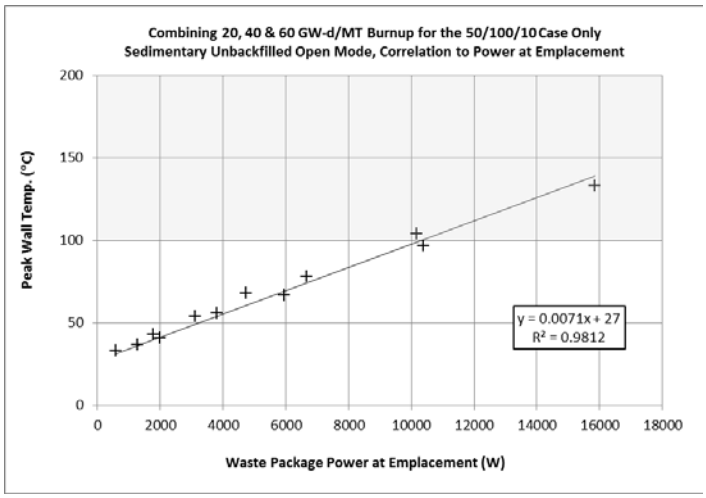


Figure 5. Correlation plots for the sedimentary unbackfilled open mode with 20 m drift spacing (timing cases as indicated).

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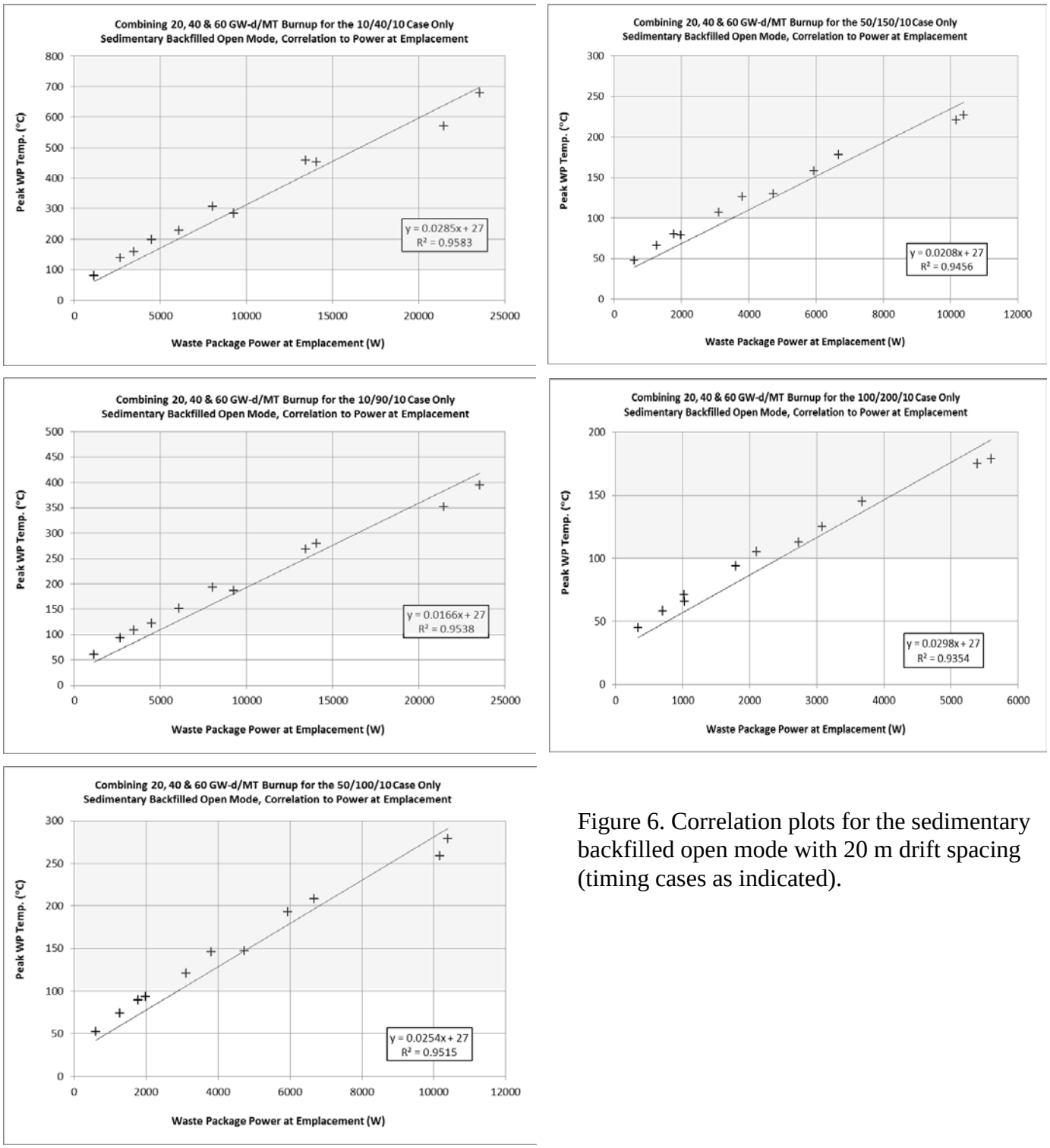
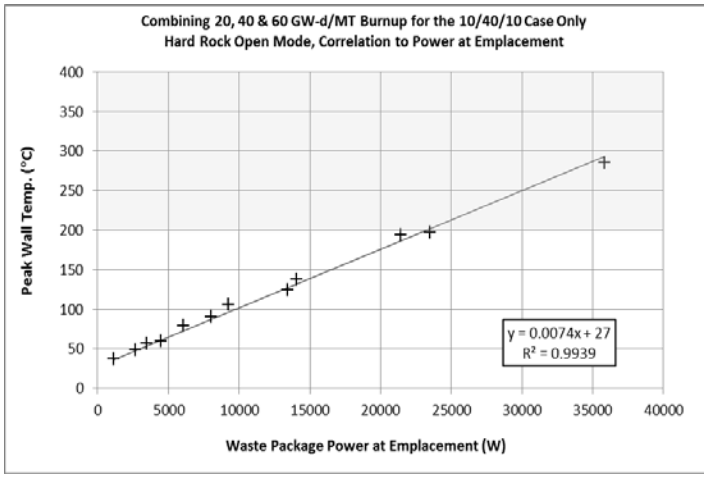
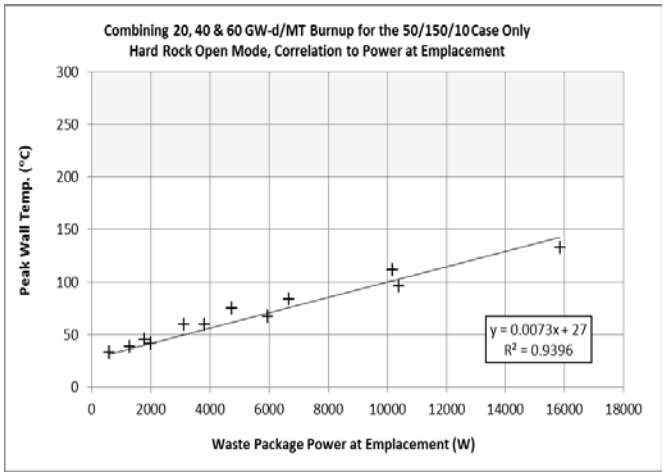
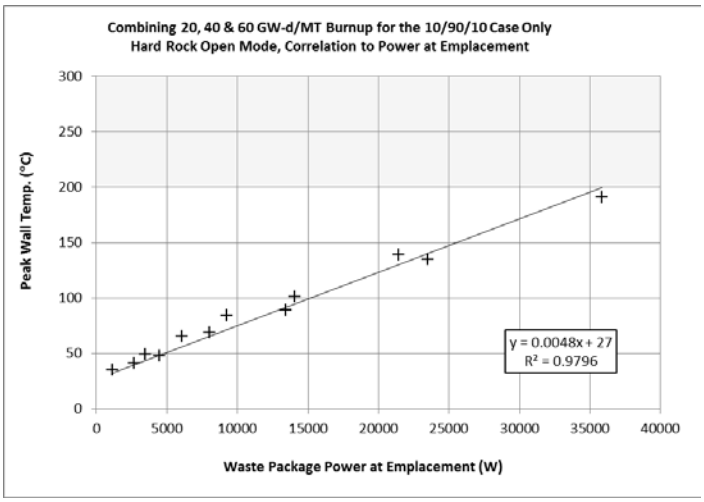
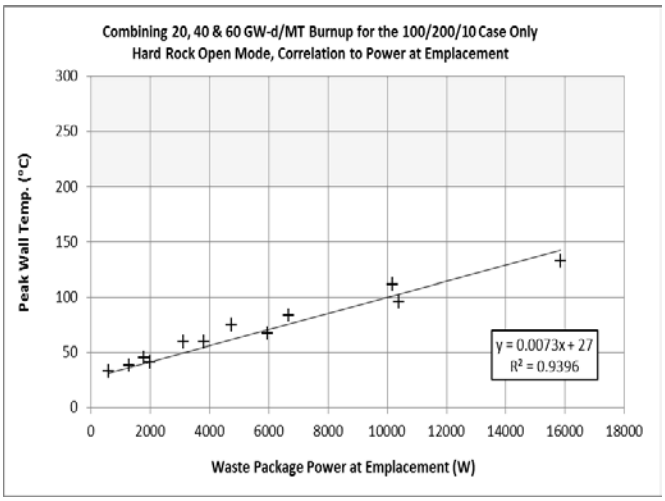


Figure 6. Correlation plots for the sedimentary backfilled open mode with 20 m drift spacing (timing cases as indicated).









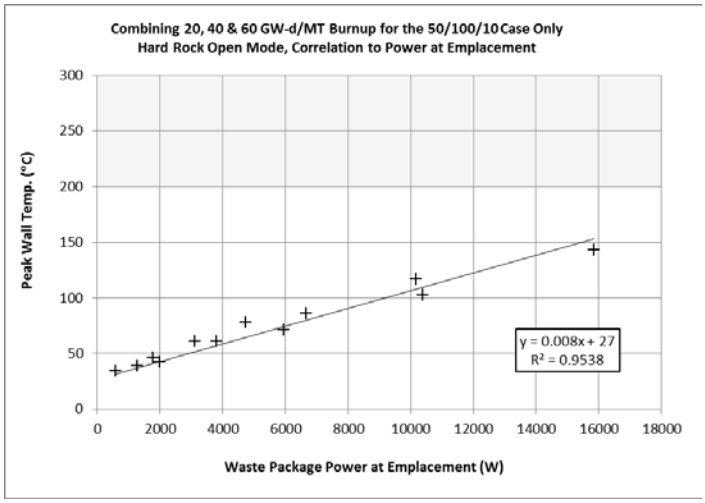
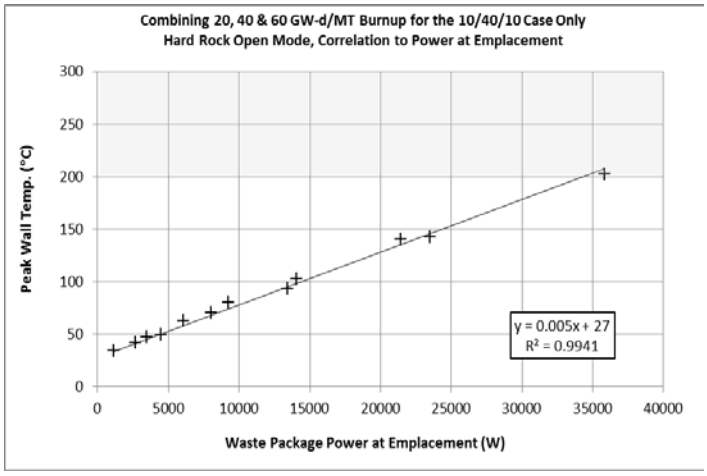
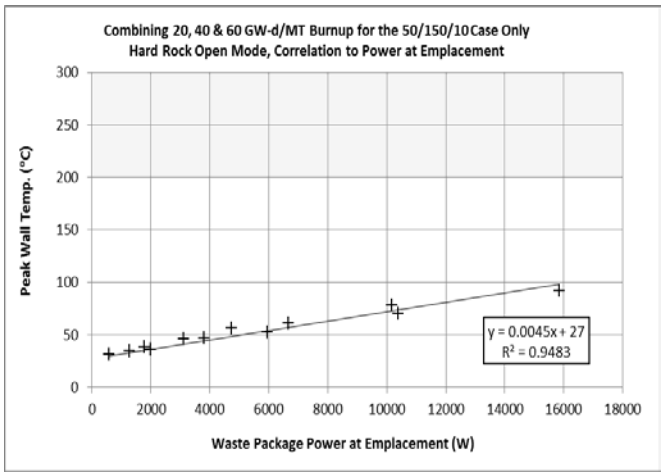
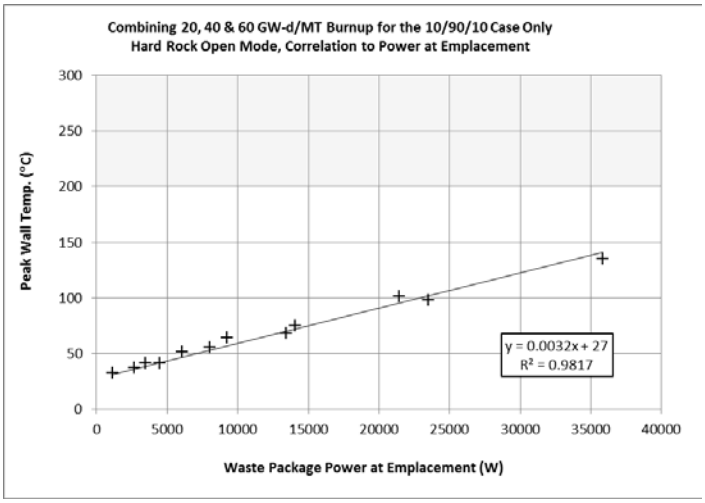
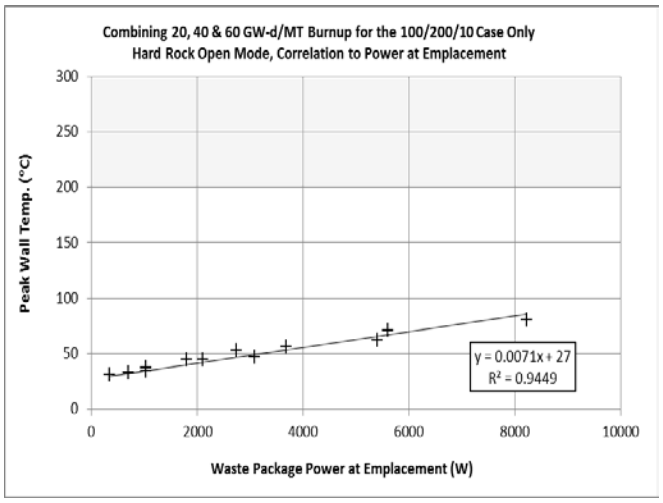


Figure 7. Correlation plots for the hard rock unbackfilled open mode with 10 m drift spacing (timing cases as indicated).









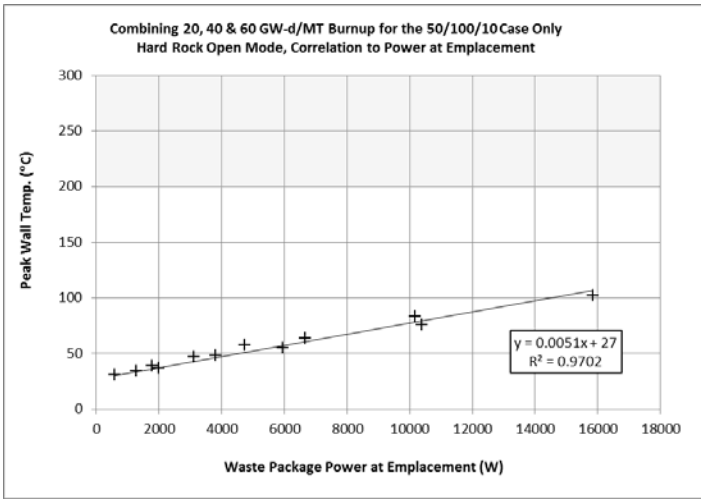


Figure 8. Correlation plots for the hard rock unbackfilled open mode with 20 m drift spacing (timing cases as indicated).

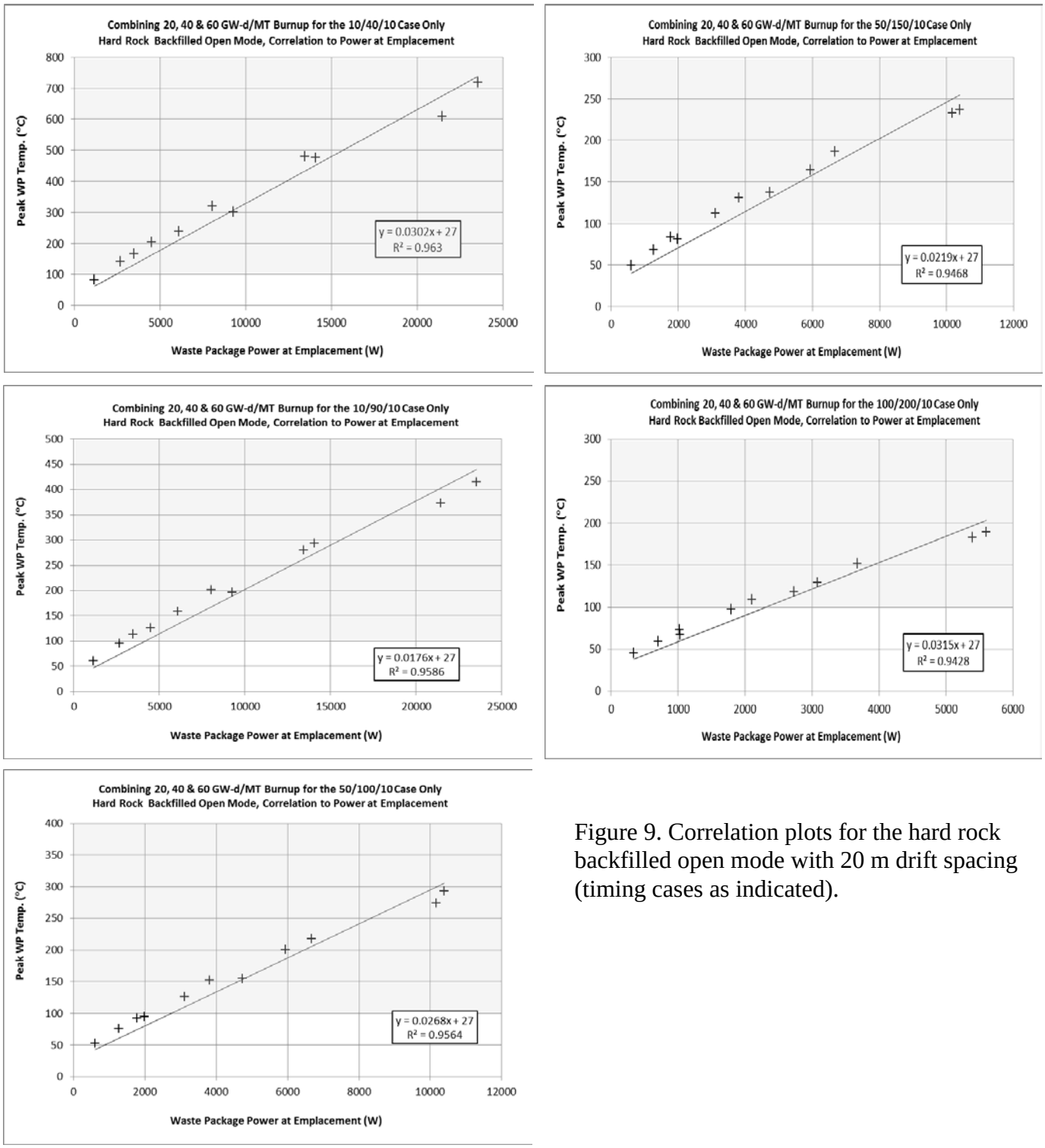


Figure 9. Correlation plots for the hard rock backfilled open mode with 20 m drift spacing (timing cases as indicated).

Table 4. Peak wall and package temperature results for the sedimentary open unbackfilled (10 m package spacing) concept.

UOX20, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	41	63	1156	520	501	37	123	1156	319	289	35	421	592	238	142	35	498	592	202	128	34	628	341	164	110
12	69	63	3468	1560	1502	55	123	3468	956	866	50	419	1776	715	427	49	498	1776	606	385	47	628	1024	492	330
21	100	63	6069	2730	2628	76	123	6069	1674	1516	68	419	3108	1252	747	66	498	3108	1061	674	61	628	1791	861	577
32	138	63	9248	4160	4005	102	125	9248	2550	2282	89	419	4736	1907	1138	86	498	4736	1616	1027	79	628	2730	1312	879
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	49	58	1156	520	534	42	113	1156	319	308	38	177	592	238	222	37	288	592	202	172	36	432	341	164	140
12	82	59	3468	1560	1580	64	115	3468	956	913	56	190	1776	715	639	54	380	1776	606	450	50	482	1024	492	393
21	114	61	6069	2730	2695	86	117	6069	1674	1576	73	241	3108	1252	986	71	380	3108	1061	788	65	532	1791	861	646
32	150	62	9248	4160	4056	112	119	9248	2550	2370	94	314	4736	1907	1321	91	415	4736	1616	1144	83	585	2730	1312	925

UOX40, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	57	62	2680	1104	1074	46	119	2680	648	594	41	216	1272	462	370	40	380	1272	378	261	38	628	700	296	186
12	116	62	8040	3312	3223	84	119	8040	1944	1783	69	216	3816	1385	1111	66	380	3816	1134	784	60	628	2100	889	557
21	182	62	14070	5796	5639	127	119	14070	3402	3121	101	216	6678	2423	1944	95	380	6678	1985	1372	85	628	3675	1556	974
32	263	62	21440	8832	8593	179	119	21440	5184	4755	139	216	10176	3693	2962	130	380	10176	3024	2091	115	628	5600	2371	1485
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	71	58	2680	1104	1135	55	111	2680	648	635	48	171	1272	462	436	45	236	1272	378	350	42	406	700	296	251
12	134	60	8040	3312	3312	98	113	8040	1944	1872	79	177	3816	1385	1273	74	270	3816	1134	965	66	454	2100	889	700
21	198	61	14070	5796	5717	140	115	14070	3402	3222	111	190	6678	2423	2120	103	304	6678	1985	1571	92	489	3675	1556	1166
32	275	61	21440	8832	8711	190	117	21440	5184	4831	148	201	10176	3693	3110	137	340	10176	3024	2237	121	544	5600	2371	1650

UOX60, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	73	61	4480	1696	1671	55	117	4480	944	873	47	181	1980	643	570	44	277	1980	500	403	41	628	1028	371	222
12	164	61	13440	5088	5013	111	117	13440	2832	2618	85	181	5940	1930	1709	77	277	5940	1500	1209	68	629	3084	1114	666
21	266	61	23520	8904	8773	173	117	23520	4956	4582	128	181	10395	3377	2991	114	277	10395	2625	2116	98	629	5397	1949	1166
32	391	61	35840	13568	13370	249	117	35840	7552	6982	180	181	15840	5146	4558	159	277	15840	4000	3225	134	629	8224	2970	1777
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	91	57	4480	1696	1775	67	111	4480	944	921	55	166	1980	643	618	50	226	1980	500	470	45	366	1028	371	328
12	184	59	13440	5088	5165	126	113	13440	2832	2714	98	171	5940	1930	1802	87	239	5940	1500	1353	75	410	3084	1114	907
21	281	61	23520	8904	8773	187	115	23520	4956	4664	140	177	10395	3377	3055	124	251	10395	2625	2282	105	496	5397	1949	1386
32	401	61	35840	13568	13370	260	115	35840	7552	7107	191	177	15840	5146	4654	168	262	15840	4000	3366	141	496	8224	2970	2111

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

Table 5. Peak wall and package temperature results for the sedimentary open unbackfilled (20 m package spacing) concept.

UOX20, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	37	59	1156	520	527	34	115	1156	319	304	33	241	592	238	188	32	380	592	202	150	32	515	341	164	126
12	57	59	3468	1560	1580	47	116	3468	956	907	43	244	1776	715	560	42	380	1776	606	450	40	532	1024	492	369
21	80	59	6069	2730	2765	62	116	6069	1674	1587	54	257	3108	1252	955	52	380	3108	1061	788	49	532	1791	861	646
32	107	59	9248	4160	4214	79	116	9248	2550	2418	68	257	4736	1907	1455	65	380	4736	1616	1200	60	532	2730	1312	985
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	46	54	1156	520	562	39	107	1156	319	322	36	164	592	238	233	35	236	592	202	190	34	358	341	164	155
12	72	55	3468	1560	1665	57	108	3468	956	960	50	168	1776	715	689	47	247	1776	606	557	45	387	1024	492	446
21	97	57	6069	2730	2838	73	111	6069	1674	1643	63	172	3108	1252	1189	59	261	3108	1061	948	55	410	1791	861	756
32	124	57	9248	4160	4325	92	111	9248	2550	2503	77	177	4736	1907	1779	72	288	4736	1616	1377	67	423	2730	1312	1132

UOX40, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	49	58	2680	1104	1135	41	113	2680	648	624	37	190	1272	462	404	36	288	1272	378	309	35	470	700	296	228
12	91	58	8040	3312	3406	67	113	8040	1944	1872	56	187	3816	1385	1225	53	288	3816	1134	927	49	470	2100	889	684
21	139	58	14070	5796	5960	97	113	14070	3402	3276	78	187	6678	2423	2143	72	288	6678	1985	1623	65	470	3675	1556	1198
32	197	58	21440	8832	9082	134	113	21440	5184	4992	104	189	10176	3693	3242	95	288	10176	3024	2473	84	470	5600	2371	1825
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	64	54	2680	1104	1201	50	106	2680	648	663	44	161	1272	462	457	41	220	1272	378	366	39	345	700	296	277
12	114	55	8040	3312	3553	83	108	8040	1944	1953	68	164	3816	1385	1350	63	226	3816	1134	1078	57	370	2100	889	797
21	161	57	14070	5796	6044	115	109	14070	3402	3389	92	168	6678	2423	2318	83	239	6678	1985	1820	74	382	3675	1556	1368
32	216	57	21440	8832	9211	150	111	21440	5184	5076	117	171	10176	3693	3484	107	247	10176	3024	2718	94	410	5600	2371	1994

UOX60, Clay, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	60	58	4480	1696	1748	47	111	4480	944	921	41	172	1980	643	598	39	255	1980	500	430	36	423	1028	371	296
12	126	58	13440	5088	5244	106	108	13440	2832	2844	67	171	5940	1930	1802	73	221	5940	1500	1436	63	337	3084	1114	1044
21	200	58	23520	8904	9187	130	111	23520	4956	4837	97	170	10395	3377	3171	86	249	10395	2625	2296	73	423	5397	1949	1551
32	290	58	35840	13568	13990	183	111	35840	7552	7371	133	170	15840	5146	4832	116	249	15840	4000	3498	97	423	8224	2970	2364
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	82	54	4480	1696	1860	60	106	4480	944	967	50	159	1980	643	643	46	215	1980	500	489	41	337	1028	371	348
12	153	55	13440	5088	5493	86	111	13440	2832	2764	83	162	5940	1930	1895	61	249	5940	1500	1312	54	423	3084	1114	887
21	223	57	23520	8904	9320	149	109	23520	4956	4930	114	164	10395	3377	3279	100	226	10395	2625	2470	84	358	5397	1949	1750
32	307	57	35840	13568	14200	200	110	35840	7552	7441	149	166	15840	5146	4941	129	231	15840	4000	3701	108	374	8224	2970	2584

Table 6. Peak wall and package temperature results for the sedimentary open backfilled (20 m package spacing) concept.

UOX20, Clay, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	37	59	1156	520	527	34	115	1156	319	304	33	241	592	238	188	32	280	592	202	150	32	515	341	164	126
12	57	59	3468	1560	1580	47	116	3468	956	907	43	244	1776	715	560	42	380	1776	606	450	40	532	1024	492	369
21	80	59	6069	2730	2765	62	116	6069	1674	1587	54	257	3108	1252	955	52	380	3108	1061	788	49	532	1791	861	646
32	107	59	9248	4160	4214	79	116	9248	2550	2418	68	257	4736	1907	1455	65	380	4736	1616	1200	60	532	2730	1312	985
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	79	61	1156	520	513	60	111	1156	319	313	52	161	592	238	236	48	211	592	202	201	45	312	341	164	166
12	159	61	3468	1560	1540	109	111	3468	956	939	89	161	1776	715	709	80	211	1776	606	603	71	313	1024	492	496
21	227	61	6069	2730	2695	152	111	6069	1674	1643	121	161	3108	1252	1240	107	211	3108	1061	1055	94	317	1791	861	863
32	284	61	9248	4160	4107	187	111	9248	2550	2503	147	161	4736	1907	1889	130	212	4736	1616	1603	113	322	2730	1312	1304

UOX40, Clay, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	49	58	2680	1104	1135	41	113	2680	648	624	37	190	1272	462	404	36	288	1272	378	309	35	470	700	296	228
12	91	58	8040	3312	3406	67	113	8040	1944	1872	56	187	3816	1385	1225	53	288	3816	1134	927	49	470	2100	889	684
21	139	58	14070	5796	5960	97	113	14070	3402	3276	78	187	6678	2423	2143	72	288	6678	1985	1623	65	470	3675	1556	1198
32	197	58	21440	8832	9082	134	113	21440	5184	4992	104	198	10176	3693	3242	95	288	10176	3024	2473	84	470	5600	2371	1825
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	138	61	2680	1104	1089	93	111	2680	648	635	74	161	1272	462	457	66	211	1272	378	376	58	311	700	296	295
12	307	61	8040	3312	3267	193	111	8040	1944	1904	146	161	3816	1385	1370	126	211	3816	1134	1128	105	311	2100	889	885
21	452	61	14070	5796	5717	280	111	14070	3402	3331	208	161	6678	2423	2397	178	211	6678	1985	1975	145	313	3675	1556	1543
32	571	61	21440	8832	8711	352	111	21440	5184	5076	259	161	10176	3693	3653	221	211	10176	3024	3009	179	316	5600	2371	2338

UOX60, Clay, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	60	58	4480	1696	1748	47	111	4480	944	921	41	172	1980	643	598	39	255	1980	500	430	36	423	1028	371	296
12	126	58	13440	5088	5244	86	111	13440	2832	2764	67	171	5940	1930	1802	61	249	5940	1500	1312	54	423	3084	1114	887
21	200	58	23520	8904	9178	130	111	23520	4956	4837	97	170	10395	3377	3171	86	249	10395	2625	2296	73	423	5397	1949	1551
32	290	58	35840	13568	13990	183	111	35840	7552	7371	133	170	15840	5146	4832	116	249	15840	4000	3498	97	423	8224	2970	2364
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	197	61	4480	1696	1671	122	111	4480	944	921	93	161	1980	643	636	79	211	1980	500	497	66	311	1028	371	369
12	458	61	13440	5088	5013	269	111	13440	2832	2764	193	161	5940	1930	1907	158	211	5940	1500	1490	125	311	3084	1114	1107
21	680	61	23520	8904	8773	395	111	23520	4956	4837	279	161	10395	3377	3336	227	211	10395	2625	2608	175	311	5397	1949	1938
32	864	61	35840	13568	13370	500	111	35840	7552	7371	351	161	15840	5146	5084	284	211	15840	4000	3974	218	313	8224	2970	2939

Table 7. Peak wall and package temperature results for the hard rock open unbackfilled (10 m package spacing) concept.

UOX20, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	37	65	1156	520	488	35	414	1156	319	143	34	523	592	238	488	33	582	592	202	116	33	721	341	164	99
12	57	65	3468	1560	1465	49	402	3468	956	437	46	525	1776	715	372	45	582	1776	606	348	43	721	1024	492	297
21	79	65	6069	2730	2564	65	417	6069	1674	749	61	525	3108	1252	652	59	582	3108	1061	609	55	721	1791	861	519
32	106	65	9248	4160	3907	84	417	9248	2550	1141	78	536	4736	1907	980	75	582	4736	1616	928	70	721	2730	1312	791
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	43	57	1156	520	541	38	113	1156	319	308	36	314	592	238	165	35	380	592	202	150	34	557	341	164	119
12	68	59	3468	1560	1580	55	117	3468	956	901	50	406	1776	715	1580	48	477	1776	606	395	46	628	1024	492	330
21	91	61	6069	2730	2695	72	233	6069	1674	1526	65	421	3108	1252	745	63	512	3108	1061	662	58	628	1791	861	577
32	118	61	9248	4160	4107	91	126	9248	2550	2268	82	468	4736	1907	1066	79	540	4736	1616	976	73	628	2730	1312	879

UOX40, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	48	63	2680	1104	1060	41	126	2680	648	564	39	468	1272	462	229	38	512	1272	378	215	37	721	700	296	167
12	90	63	8040	3312	3179	69	126	8040	1944	1692	61	469	3816	1385	685	59	512	3816	1134	646	55	687	2100	889	520
21	137	63	14070	5796	5564	101	126	14070	3402	2960	86	469	6678	2423	1199	83	537	6678	1985	1093	75	687	3675	1556	910
32	194	63	21440	8832	8478	139	126	21440	5184	4511	117	469	10176	3693	8478	111	537	10176	3024	1665	100	687	5600	2371	1387
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	60	57	2680	1104	1151	48	111	2680	648	635	43	177	1272	462	424	41	303	1272	378	300	39	489	700	296	222
12	107	59	8040	3312	3358	80	113	8040	1944	1872	67	211	3816	1385	1128	64	380	3816	1134	784	59	569	2100	889	599
21	154	61	14070	5796	5717	112	117	14070	3402	3171	92	314	6678	2423	1540	88	458	6678	1985	1219	80	628	3675	1556	974
32	208	61	21440	8832	8711	149	118	21440	5184	4793	123	380	10176	3693	2091	117	477	10176	3024	1807	105	628	5600	2371	1485

UOX60, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	60	61	4480	1696	1671	48	122	4480	944	836	42	263	1980	643	420	41	477	1980	500	271	39	690	1028	371	207
12	124	61	13440	5088	5013	89	122	13440	2832	2509	71	264	5940	1930	1255	67	473	5940	1500	819	61	687	3084	1114	632
21	197	61	23520	8904	8773	135	122	23520	4956	4391	103	264	10395	3377	2196	96	474	10395	2625	1431	85	687	5397	1949	1091
32	285	61	35840	13568	13370	191	122	35840	7552	6691	143	264	15840	5146	3347	132	474	15840	4000	2180	116	687	8224	2970	1662
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	75	57	4480	1696	1775	57	110	4480	944	930	48	169	1980	643	607	45	239	1980	500	451	41	470	1028	371	274
12	144	59	13440	5088	5165	103	113	13440	2832	2714	81	177	5940	1930	1745	74	270	5940	1500	1234	65	536	3084	1114	749
21	214	61	23520	8904	8773	148	117	23520	4956	4582	113	186	10395	3377	2917	103	311	10395	2625	1938	91	628	5397	1949	1167
32	298	61	35840	13568	13370	202	118	35840	7552	6922	151	195	15840	5146	4255	138	380	15840	4000	2554	121	628	8224	2970	1779

Table 8. Peak wall and package temperature results for the hard rock open unbackfilled (20 m package spacing) concept.

UOX20, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	34	61	1156	520	513	32	129	1156	319	278	31	387	592	238	149	31	477	592	202	132	31	628	341	164	110
12	47	61	3468	1560	1540	41	128	3468	956	840	39	406	1776	715	434	38	477	1776	606	395	37	628	1024	492	330
21	62	61	6069	2730	2695	51	128	6069	1674	1470	47	406	3108	1252	760	46	477	3108	1061	692	44	628	1791	861	577
32	80	61	9248	4160	4107	64	129	9248	2550	2226	58	406	4736	1907	1158	56	477	4736	1616	1054	53	628	2730	1312	879
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	41	54	1156	520	562	36	107	1156	319	322	34	169	592	238	229	33	255	592	202	183	32	406	341	164	145
12	60	56	3468	1560	1643	49	109	3468	956	953	44	185	1776	715	649	42	295	1776	606	511	40	432	1024	492	419
21	77	56	6069	2730	2875	61	111	6069	1674	1643	53	185	3108	1252	1137	51	332	3108	1061	843	48	482	1791	861	687
32	96	57	9248	4160	4325	74	113	9248	2550	2468	64	248	4736	1907	1481	62	380	4736	1616	1200	57	511	2730	1312	1010

UOX40, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	42	60	2680	1104	1104	37	118	2680	648	599	34	314	1272	462	293	34	380	1272	378	261	33	577	700	296	198
12	70	60	8040	3312	3312	55	119	8040	1944	1783	48	289	3816	1385	926	47	380	3816	1134	784	44	569	2100	889	599
21	102	60	14070	5796	5796	75	119	14070	3402	3121	64	289	6678	2423	1620	61	380	6678	1985	1372	56	569	3675	1556	1048
32	140	60	21440	8832	8832	101	119	21440	5184	4755	83	289	10176	3693	2468	78	380	10176	3024	2091	71	569	5600	2371	1597
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	54	54	2680	1104	1201	44	106	2680	648	663	39	162	1272	462	454	38	239	1272	378	347	36	374	700	296	264
12	91	56	8040	3312	3503	68	108	8040	1944	1953	57	169	3816	1385	1318	54	239	3816	1134	1040	49	410	2100	889	748
21	124	57	14070	5796	6044	91	110	14070	3402	3360	74	179	6678	2423	2210	69	277	6678	1985	1662	63	442	3675	1556	1247
32	161	58	21440	8832	9082	116	112	21440	5184	5034	93	195	10176	3693	3174	87	295	10176	3024	2438	78	482	5600	2371	1795

UOX60, Hard Rock, 70-m drift spacing, unbackfilled (assume drifts stay open)

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	49	59	4480	1696	1722	41	115	4480	944	888	37	186	1980	643	556	36	303	1980	500	376	34	536	1028	371	250
12	93	59	13440	5088	5165	68	115	13440	2832	2665	55	186	5940	1930	1667	52	295	5940	1500	1152	47	536	3084	1114	749
21	142	59	23520	8904	9039	98	115	23520	4956	4664	76	186	10395	3377	2917	70	295	10395	2625	2016	62	536	5397	1949	1311
32	202	59	35840	13568	13770	135	115	35840	7552	7107	102	186	15840	5146	4444	92	295	15840	4000	3073	80	536	8224	2970	1997
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	67	54	4480	1696	1860	51	106	4480	944	967	44	160	1980	643	639	41	218	1980	500	484	38	354	1028	371	336
12	119	55	13440	5088	5493	85	108	13440	2832	2844	68	164	5940	1930	1874	61	239	5940	1500	1353	54	380	3084	1114	958
21	167	57	23520	8904	9320	117	109	23520	4956	4930	90	169	10395	3377	3189	81	239	10395	2625	2367	70	406	5397	1949	1598
32	223	58	35840	13568	13990	152	111	35840	7552	7371	116	177	15840	5146	4654	103	255	15840	4000	3436	88	442	8224	2970	2291

Table 9. Peak wall and package temperature results for the hard rock open backfilled (20 m package spacing) concept.

UOX20, Hard Rock, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	34	61	1156	520	513	32	129	1156	319	278	31	387	592	238	149	31	477	592	202	132	31	628	341	164	110
12	47	61	3468	1560	1540	41	128	3468	956	840	39	406	1776	715	434	38	477	1776	606	395	37	628	1024	492	330
21	62	61	6069	2730	2695	51	128	6069	1674	1470	47	406	3108	1252	760	46	477	3108	1061	692	44	628	1791	861	577
32	80	61	9248	4160	4107	64	129	9248	2550	2226	58	406	4736	1907	1158	56	477	4736	1616	1054	53	628	2730	1312	879
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	82	61	1156	520	513	61	111	1156	319	313	53	161	592	238	236	49	211	592	202	201	45	311	341	164	166
12	166	61	3468	1560	1540	113	111	3468	956	939	92	161	1776	715	709	83	211	1776	606	603	73	311	1024	492	498
21	239	61	6069	2730	2695	158	111	6069	1674	1643	126	161	3108	1252	1240	112	211	3108	1061	1055	97	312	1791	861	869
32	301	61	9248	4160	4107	197	111	9248	2550	2503	155	161	4736	1907	1889	137	211	4736	1616	1607	118	314	2730	1312	1321

UOX40, Hard Rock, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	42	60	2680	1104	1104	37	118	2680	648	599	34	314	1272	462	293	34	380	1272	378	261	33	577	700	296	198
12	70	60	8040	3312	3312	55	119	8040	1944	1783	48	289	3816	1385	926	47	380	3816	1134	784	44	569	2100	889	599
21	102	60	14070	5796	5796	75	119	14070	3402	3121	64	289	6678	2423	1620	61	380	6678	1985	1372	56	569	3675	1556	1048
32	140	60	21440	8832	8832	101	119	21440	5184	4755	83	289	10176	3693	2468	87	380	10176	3024	2091	71	569	5600	2371	1597
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	142	61	2680	1104	1089	95	111	2680	648	635	76	161	1272	462	457	68	211	1272	378	376	59	311	700	296	295
12	321	61	8040	3312	3267	201	111	8040	1944	1904	152	161	3816	1385	1370	131	211	3816	1134	1128	109	311	2100	889	885
21	476	61	14070	5796	5717	293	111	14070	3402	3331	218	161	6678	2423	2397	186	211	6678	1985	1975	152	311	3675	1556	1549
32	608	61	21440	8832	8711	373	111	21440	5184	5076	274	161	10176	3693	3653	233	211	10176	3024	3009	189	311	5600	2371	2361

UOX60, Hard Rock, 70-m drift spacing, backfilled

	~50 yr (store/vent/close = 10/40/10 total=60 yr)					~100 yr (store/vent/close = 10/90/10 total=110 yr)					~150 yr (store/vent/close = 50/100/10 total=160 yr)					~200 yr (store/vent/close = 50/150/10 total=210 yr)					~300 yr (store/vent/close = 100/200/10 total=310 yr)				
	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak Wall T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	49	59	4480	1696	1722	41	115	4480	944	888	37	186	1980	643	556	36	303	1980	500	376	34	536	1028	371	250
12	93	59	13440	5088	5165	68	115	13440	2832	2665	55	196	5940	1930	1667	52	295	5940	1500	1152	47	536	3084	1114	749
21	142	59	23520	8904	9039	98	115	23520	4956	4664	76	186	10395	3377	2917	70	295	10395	2625	2016	62	536	5397	1949	1311
32	202	59	35840	13568	13770	135	115	35840	7552	7107	102	186	15840	5146	4444	92	295	15840	4000	3073	80	536	8224	2970	1997
	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T	Peak WP T	Time of Peak	Power at Empl.	Power at Closure	Power at Peak T
WP size	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)	(°C)	(yr OoR)	(W)	(W)	(W)
4	204	61	4480	1696	1671	126	111	4480	944	921	95	161	1980	643	636	81	211	1980	500	497	67	311	1028	371	369
12	479	61	13440	5088	5013	280	111	13440	2832	2764	201	161	5940	1930	1907	164	211	5940	1500	1490	129	311	3084	1114	1107
21	717	61	23520	8904	8773	415	111	23520	4956	4837	293	161	10395	3377	3336	237	211	10395	2625	2608	183	311	5397	1949	1938
32	919	61	35840	13568	13370	530	111	35840	7552	7371	372	161	15840	5146	5084	300	211	15840	4000	3974	230	311	8224	2970	2953

3. SUMMARY

The timing cases have different emphasis on decay storage vs. ventilation time, which causes the maximum power for the 10/90/10 case to be greater than for the others (Table 10). With 90 yr ventilation for decay of short-lived fission products, relatively high power can be tolerated at emplacement, for the unbackfilled cases.

The backfilled cases present a special challenge with the 100°C backfill temperature limit. Thermal resistance through the annular backfill element dominates the other aspects of heat transfer in these cases. The hard rock backfilled maximum power values are slightly less than the sedimentary backfilled case, because the drift diameter is greater so the backfill annulus is thicker (drift diameter 5.5 m vs. 4.5 m).

The confidence interval analysis for the backfilled cases was repeated with temperature limits of 120°C, 150°C and 200°C. These cases represent situations where: 1) backfill material is demonstrated to have temperature tolerance; and/or 2) the innermost and hottest part of the backfill annulus is impacted by temperature. The results (Table 11) indicate that some improvement is possible although the maximum power values for these backfilled cases are still much less than for the unbackfilled cases.

Table 10. Summary of confidence interval statistics (maximum package power to meet temperature limits) for open mode disposal concepts and timing cases.

Timing Case	b	Confidence Level	Mean	± C.I.	CALVIN Limit (W at emplacement)
Sedimentary Unbackfilled Open Concept (Drift Spacing 10 m, Temperature Limit 100°C)					
10/40/10	0.010464	0.95	6976	2916	5238
10/90/10	0.006516	0.95	11203	3706	8287
50/100/10	0.010260	0.95	7115	1532	5583
50/150/10	0.009092	0.95	8029	2189	5840
100/200/10	0.014283	0.95	5111	1154	3957
Sedimentary Unbackfilled Open Concept (Drift Spacing 20 m, Temperature Limit 100°C)					
10/40/10	0.007558	0.95	9659	3778	7943
10/90/10	0.004675	0.95	15615	3706	11838
50/100/10	0.007072	0.95	10323	1419	8904
50/150/10	0.006204	0.95	11767	2276	9491
100/200/10	0.009468	0.95	7710	1308	6401
Sedimentary Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 100°C)					
10/40/10	0.026247	0.95	2781	5284	-1997 [A]
10/90/10	0.015114	0.95	4830	3706	-454 [A]
50/100/10	0.023303	0.95	3133	2302	831
50/150/10	0.018867	0.95	3869	2560	1309
100/200/10	0.027162	0.95	2688	1407	1280
Hard Rock Unbackfilled Open Concept (Drift Spacing 10 m, Temperature Limit 200°C)					
10/40/10	0.007422	0.95	23310	3706	21427
10/90/10	0.004824	0.95	35864	3706	32158
50/100/10	0.007956	0.95	21744	2692	19052
50/150/10	0.007312	0.95	23661	3180	20481
100/200/10	0.011835	0.95	14618	1619	12999
Hard Rock Unbackfilled Open Concept (Drift Spacing 20 m, Temperature Limit 200°C)					
10/40/10	0.005030	0.95	34391	4166	32381
10/90/10	0.003172	0.95	54538	3706	50373
50/100/10	0.005053	0.95	34237	2816	31421
50/150/10	0.004502	0.95	38429	3923	34506
100/200/10	0.007101	0.95	24362	2413	21949
Hard Rock Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 100°C)					
10/40/10	0.030208	0.95	2417	5068	-491 [A]
10/90/10	0.015995	0.95	4564	3706	-504 [A]
50/100/10	0.024697	0.95	2956	2205	751
50/150/10	0.019951	0.95	3659	2502	1157
100/200/10	0.028743	0.95	2540	1353	1186

Notes: [A] Negative values indicate thermal limit is not likely to be achieved.

Table 11. Summary of confidence interval statistics for backfilled open mode concepts with different backfill temperature limits (120°C, 150°C and 200°C)

Timing Case	b	Confidence			CALVIN Limit
		Level	Mean	± C.I.	(W at emplacement)
Sedimentary Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 120°C)					
10/40/10	0.028543	0.95	3258	3187	177
10/90/10	0.016635	0.95	5591	3706	2403
50/100/10	0.025362	0.95	3667	1489	2178
50/150/10	0.020776	0.95	4476	1570	2907
100/200/10	0.029791	0.95	3122	912	2210
Sedimentary Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 150°C)					
10/40/10	0.028543	0.95	4309	3210	1221
10/90/10	0.016635	0.95	7394	3706	4184
50/100/10	0.025362	0.95	4850	1509	3341
50/150/10	0.020776	0.95	5920	1601	4319
100/200/10	0.029791	0.95	4129	941	3187
Sedimentary Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 200°C)					
10/40/10	0.028543	0.95	6061	3261	2955
10/90/10	0.016635	0.95	10400	3706	7139
50/100/10	0.025362	0.95	6821	1555	5266
50/150/10	0.020776	0.95	8327	1672	6655
100/200/10	0.029791	0.95	5807	1006	4801
Hard Rock Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 120°C)					
10/40/10	0.030208	0.95	3079	3031	167
10/90/10	0.017551	0.95	5299	3706	2268
50/100/10	0.026805	0.95	3469	1415	2055
50/150/10	0.021915	0.95	4244	1550	2694
100/200/10	0.028743	0.95	3236	1369	1867
Hard Rock Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 150°C)					
10/40/10	0.030208	0.95	4072	3050	1154
10/90/10	0.017551	0.95	7008	3706	3958
50/100/10	0.026805	0.95	4589	1432	3156
50/150/10	0.021915	0.95	5613	1578	4034
100/200/10	0.028743	0.95	4279	1399	2881
Hard Rock Backfilled Open Concept (Drift Spacing 20 m, Temperature Limit 200°C)					
10/40/10	0.030208	0.95	5727	3094	2795
10/90/10	0.017551	0.95	9857	3706	6763
50/100/10	0.026805	0.95	6454	1472	4982
50/150/10	0.021915	0.95	7894	1641	6253
100/200/10	0.028743	0.95	6019	1464	4555

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Sutton, M., J.A. Blink, M. Fratoni, H.R. Greenberg and A.D. Ross 2011. *Investigations on Repository Near-Field Thermal Modeling – Repository Science/Thermal Load Management & Design Concepts (M41UF033302) Rev. 1.* Lawrence Livermore National Laboratory, LLNL-TR-491099-REV-1.

APPENDIX A. MATHCAD 14® SCRIPT FOR THERMAL ANALYSIS

A printout of the file: *Example MathCad.xmcd* follows. User-defined settings are highlighted in yellow. Note that 8 of the page images run over the right margin and are displayed in two parts as noted.

This worksheet was adapted from an earlier version produced by Harris Greenberg and colleagues at Lawrence Livermore National Laboratory (Sutton et al. 2011). Additional fuel types, radiative coupling in open unventilated drifts, and the closure operations period were among the features added.

$$Rock_type := \begin{pmatrix} \text{"Hard Rock Backfilled"} \\ \text{"Shale Unbackfilled"} \\ \text{"Sed. Backfilled"} \\ \text{"Salt (enclosed)"} \end{pmatrix} \qquad Rock_Kth := \begin{pmatrix} 2.5 \\ 1.75 \\ 1.2 \\ 3.2 \end{pmatrix} \qquad Rock_alpha := \begin{pmatrix} 1.13\cdot10^{-6} \\ 6.45\cdot10^{-7} \\ 8.22\cdot10^{-7} \\ 1.58\cdot10^{-6} \end{pmatrix}$$

$$Tsurface := 15$$

$$geothermal_gradient := 25\cdot10^{-3}$$

$$RT := 1$$

$$RT_name := Rock_type_{RT} \qquad Ndrifts := 4 \qquad N_{adj_pkgs} := 4$$

$$Kth := Rock_Kth_{RT}$$

$$\alpha := Rock_alpha_{RT}$$

$$Drift_spacing := \begin{pmatrix} 70 \\ 70 \\ 30 \\ 20 \end{pmatrix} \qquad WP_space := \begin{pmatrix} 20 \\ 10 \\ 10 \\ 20 \end{pmatrix} \qquad WP_depth := \begin{pmatrix} 500 \\ 500 \\ 500 \\ 500 \end{pmatrix} \qquad Tlim := \begin{pmatrix} 200 \\ 100 \\ 100 \\ 200 \end{pmatrix}$$

$$Tamb := Tsurface + geothermal_gradient\cdot WP_depth_{RT}$$

$$Assembly_drift_r := \begin{pmatrix} 2.75 \\ 2.25 \\ 2.25 \\ 3.048 \end{pmatrix} \qquad Assy_layers := \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

Time in years after emplacement:

$$itmax := 1000$$

$$i := 1 .. itmax$$

$$tt_i := i$$

$$Canister_drift_r := \begin{pmatrix} 2.75 \\ 2.25 \\ 2.25 \\ 3.048 \end{pmatrix} \qquad Can_layers := \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

$$Tlim_{RT} = 200$$

$$Assy_layer_inner_r := \begin{pmatrix} 0.48 & Assembly_drift_r_1 & 0 & 0 \\ 0.48 & Assembly_drift_r_2 & 0 & 0 \\ 0.8 & Assembly_drift_r_3 & 0 & 0 \\ 0.8 & Assembly_drift_r_4 & 0 & 0 \end{pmatrix} \qquad Can_layer_inner_r := \begin{pmatrix} 0.8 & Canister_drift_r_1 & 0 & 0 \\ 0.8 & Canister_drift_r_2 & 0 & 0 \\ 0.8 & Canister_drift_r_3 & 0 & 0 \\ 0.8 & Canister_drift_r_4 & 0 & 0 \end{pmatrix}$$

Outer layer radii for SNF and HLW configurations.

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$Assy_layer_Kth := \begin{pmatrix} 0.60 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 3.21 \cdot 0.75 & 0 & 0 \end{pmatrix} \quad Assy_layer_emiss1 := \begin{pmatrix} 0.8 & 0 & 0 \\ 0.6 & 0 & 0 \\ 0.6 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad Assy_layer_emiss2 := \begin{pmatrix} 0.9 & 0 & 0 \\ 0.9 & 0 & 0 \\ 0.9 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$Can_layer_Kth := \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 3.21 \cdot 0.75 & 0 & 0 \end{pmatrix} \quad Can_layer_emiss1 := \begin{pmatrix} 0.8 & 0 & 0 \\ 0.6 & 0 & 0 \\ 0.6 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad Can_layer_emiss2 := \begin{pmatrix} 0.9 & 0 & 0 \\ 0.9 & 0 & 0 \\ 0.9 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Emmissivities are defined only for layer 1, coupling disposal overpack to drift wall. For the hard-rock concept (corrosion resistant overpack) use 0.8 for oxidized Ni-Cr-Fe surface. For the other open modes (carbon steel overpack) use 0.6 for an oxidized surface. For the drift wall use a value of 0.9 (see ANL-EBS-MD-000049). For supporting data see Incropera and DeWitt 1996, www.omega.com, and FCRD-UFD-2012-00219 Rev. 2.

$$WF_name := \begin{pmatrix} \text{"UOX40"} \\ \text{"UOX60"} \\ \text{"UOX20"} \\ \text{"MOX"} \\ \text{"New_Ext"} \\ \text{"E_CHEM_C"} \\ \text{"E_CHEM_M"} \end{pmatrix} \quad WF_type := \begin{pmatrix} \text{"Assembly"} \\ \text{"Assembly"} \\ \text{"Assembly"} \\ \text{"Assembly"} \\ \text{"Canister"} \\ \text{"Canister"} \\ \text{"Canister"} \end{pmatrix} \quad WF_cnt := \begin{pmatrix} 4 \\ 4 \\ 4 \\ 12 \\ 5 \\ 5 \\ 5 \end{pmatrix} \quad WP_len := \begin{pmatrix} 5 \\ 5 \\ 5 \\ 5 \\ 4.572 \\ 4.572 \\ 3.048 \end{pmatrix}$$

$WF := 3$

$WFname := WF_name_{WF}$ $\quad Vstoreff := 1.00$ $\quad$ Use Vstoreff = 1.0 to represent surface decay storage

$WFtype := WF_type_{WF}$ $\quad Venteff := 0.75$ $\quad$ Preclosure ventilation heat removal efficiency

$WF_count := WF_cnt_{WF}$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$Tstore := \begin{pmatrix} 10 \\ 50 \\ 100 \end{pmatrix}$ Must be ascending values, no zeroes.

$Tvent := \begin{pmatrix} 90 \\ 150 \\ 200 \end{pmatrix}$ $Tclose := \begin{pmatrix} 10 \\ 10 \\ 10 \end{pmatrix}$

Note: Tvent and Tclose should be all zeroes for enclosed modes (enclosed and open modes cannot both be calculated with one set of values).

TooR (yr)	UOX (40 GW-d/MT)	UOX (60 GW-d/MT)	UOX (20 GW-d/MT)	Pu-MOX (51 GW-d/MT)	New_Ext	E-CHEM Cer.	E-CHEM Metal
5.00E+00	1.03E+03	1.70E+03	4.61E+02	3.45E+03	1.38E+04	2.31E+03	2.96E+03
5.10E+00	1.01E+03	1.67E+03	4.51E+02	3.42E+03	1.36E+04	2.30E+03	2.84E+03
5.50E+00	9.49E+02	1.58E+03	4.18E+02	3.32E+03	1.22E+04	2.25E+03	2.43E+03
5.75E+00	9.17E+02	1.53E+03	4.01E+02	3.26E+03	1.15E+04	2.22E+03	2.23E+03
6.00E+00	8.88E+02	1.48E+03	3.86E+02	3.21E+03	1.09E+04	2.20E+03	2.07E+03
8.00E+00	7.43E+02	1.25E+03	3.19E+02	2.96E+03	7.92E+03	2.02E+03	1.44E+03
1.00E+01	6.70E+02	1.12E+03	2.89E+02	2.82E+03	6.54E+03	1.89E+03	1.23E+03
1.15E+01	6.34E+02	1.06E+03	2.76E+02	2.74E+03	5.92E+03	1.81E+03	1.14E+03
1.50E+01	5.77E+02	9.53E+02	2.54E+02	2.60E+03	5.03E+03	1.65E+03	9.79E+02
2.00E+01	5.20E+02	8.50E+02	2.32E+02	2.44E+03	4.27E+03	1.46E+03	8.12E+02
2.30E+01	4.92E+02	7.99E+02	2.21E+02	2.36E+03	3.92E+03	1.36E+03	7.34E+02
2.50E+01	4.74E+02	7.68E+02	2.13E+02	2.31E+03	3.71E+03	1.30E+03	6.88E+02
3.00E+01	4.35E+02	6.98E+02	1.97E+02	2.18E+03	3.26E+03	1.16E+03	5.90E+02
3.50E+01	4.00E+02	6.37E+02	1.83E+02	2.08E+03	2.87E+03	1.03E+03	5.11E+02
4.00E+01	3.70E+02	5.84E+02	1.70E+02	1.98E+03	2.54E+03	9.17E+02	4.45E+02
4.50E+01	3.42E+02	5.36E+02	1.58E+02	1.89E+03	2.25E+03	8.16E+02	3.90E+02
5.00E+01	3.18E+02	4.95E+02	1.48E+02	1.81E+03	1.99E+03	7.26E+02	3.43E+02
6.00E+01	2.76E+02	4.24E+02	1.30E+02	1.68E+03	1.57E+03	5.75E+02	2.68E+02
7.00E+01	2.42E+02	3.68E+02	1.15E+02	1.57E+03	1.24E+03	4.56E+02	2.10E+02
8.00E+01	2.15E+02	3.23E+02	1.03E+02	1.47E+03	9.84E+02	3.61E+02	1.66E+02
9.00E+01	1.93E+02	2.87E+02	9.34E+01	1.39E+03	7.80E+02	2.86E+02	1.31E+02
1.00E+02	1.75E+02	2.57E+02	8.53E+01	1.32E+03	6.19E+02	2.26E+02	1.04E+02
1.25E+02	1.42E+02	2.04E+02	7.13E+01	1.18E+03	3.47E+02	1.26E+02	5.77E+01
1.50E+02	1.21E+02	1.70E+02	6.20E+01	1.07E+03	1.95E+02	7.05E+01	3.22E+01
1.75E+02	1.07E+02	1.47E+02	5.60E+01	9.85E+02	1.10E+02	3.94E+01	1.80E+01

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

DK_heat_data :=

2.00E+02	9.75E+01	1.30E+02	5.17E+01	9.13E+02	6.20E+01	2.20E+01	1.00E+01
2.25E+02	9.01E+01	1.18E+02	4.86E+01	8.53E+02	3.52E+01	1.23E+01	5.60E+00
2.50E+02	8.43E+01	1.09E+02	4.61E+01	8.00E+02	2.01E+01	6.85E+00	3.13E+00
3.00E+02	7.54E+01	9.48E+01	4.22E+01	7.14E+02	6.93E+00	2.14E+00	9.76E-01
3.50E+02	6.87E+01	8.47E+01	3.91E+01	6.45E+02	2.74E+00	6.68E-01	3.05E-01
4.00E+02	6.33E+01	7.69E+01	3.65E+01	5.89E+02	1.38E+00	2.09E-01	9.56E-02
4.50E+02	5.87E+01	7.07E+01	3.41E+01	5.42E+02	9.18E-01	6.65E-02	3.04E-02
5.00E+02	5.47E+01	6.56E+01	3.20E+01	5.02E+02	7.46E-01	2.19E-02	1.00E-02
6.00E+02	4.80E+01	5.75E+01	2.84E+01	4.37E+02	6.25E-01	3.67E-03	1.68E-03
7.00E+02	4.27E+01	5.12E+01	2.53E+01	3.85E+02	5.67E-01	1.89E-03	8.62E-04
8.00E+02	3.82E+01	4.62E+01	2.27E+01	3.42E+02	5.25E-01	1.72E-03	7.83E-04
9.00E+02	3.45E+01	4.21E+01	2.05E+01	3.07E+02	4.90E-01	1.70E-03	7.75E-04
1.00E+03	3.13E+01	3.86E+01	1.87E+01	2.77E+02	4.62E-01	1.70E-03	7.74E-04
1.25E+03	2.53E+01	3.21E+01	1.50E+01	2.20E+02	4.07E-01	1.70E-03	7.74E-04
1.50E+03	2.12E+01	2.76E+01	1.26E+01	1.81E+02	3.70E-01	1.70E-03	7.74E-04
1.75E+03	1.84E+01	2.44E+01	1.09E+01	1.54E+02	3.44E-01	1.70E-03	7.74E-04
2.00E+03	1.64E+01	2.22E+01	9.79E+00	1.36E+02	3.26E-01	1.70E-03	7.74E-04
2.25E+03	1.50E+01	2.06E+01	8.98E+00	1.23E+02	3.13E-01	1.70E-03	7.74E-04
2.50E+03	1.40E+01	1.95E+01	8.39E+00	1.14E+02	3.04E-01	1.70E-03	7.74E-04
3.00E+03	1.27E+01	1.79E+01	7.64E+00	1.02E+02	2.91E-01	1.70E-03	7.74E-04
4.00E+03	1.14E+01	1.60E+01	6.86E+00	8.89E+01	2.77E-01	1.69E-03	7.74E-04
5.00E+03	1.05E+01	1.48E+01	6.38E+00	8.12E+01	2.67E-01	1.69E-03	7.73E-04
6.00E+03	9.80E+00	1.38E+01	5.99E+00	7.50E+01	2.59E-01	1.69E-03	7.73E-04
7.00E+03	9.20E+00	1.28E+01	5.64E+00	6.95E+01	2.52E-01	1.69E-03	7.73E-04
8.00E+03	8.70E+00	1.20E+01	5.32E+00	6.45E+01	2.45E-01	1.69E-03	7.73E-04
9.00E+03	8.10E+00	1.12E+01	5.03E+00	6.00E+01	2.39E-01	1.69E-03	7.72E-04
1.00E+04	7.70E+00	1.05E+01	4.76E+00	5.59E+01	2.33E-01	1.69E-03	7.72E-04
1.00E+05	6.00E-01	8.00E-01	3.75E-01	3.85E+00	1.09E-01	1.65E-03	7.52E-04
2.00E+05	4.00E-01	5.00E-01	1.90E-01	2.56E+00	6.99E-02	1.60E-03	7.31E-04
5.00E+05	3.00E-01	4.00E-01	1.70E-01	2.05E+00	2.38E-02	1.47E-03	6.70E-04
1.00E+06	2.00E-01	3.00E-01	1.36E-01	1.34E+00	6.40E-03	1.27E-03	5.79E-04

Cubic spline interpolation for decay heat

UOX40_DK_heat := $DK_heat_data^{\langle 2 \rangle}$

UOX60_DK_heat := $DK_heat_data^{\langle 3 \rangle}$

UOX20_DK_heat := $DK_heat_data^{\langle 4 \rangle}$

MOX_DK_heat := $DK_heat_data^{\langle 5 \rangle}$

New_Ext_DK_heat := $DK_heat_data^{\langle 6 \rangle}$

E_Chem_c_DK_heat := $DK_heat_data^{\langle 7 \rangle}$

E_Chem_m_DK_heat := $DK_heat_data^{\langle 8 \rangle}$

Time_out_of_Reactor := $DK_heat_data^{\langle 1 \rangle}$

UOX40_Q(t) := interp(cspline(Time_out_of_Reactor, UOX40_DK_heat), Time_out_of_Reactor, UOX40_DK_heat, t)

UOX60_Q(t) := interp(cspline(Time_out_of_Reactor, UOX60_DK_heat), Time_out_of_Reactor, UOX60_DK_heat, t)

UOX20_Q(t) := interp(cspline(Time_out_of_Reactor, UOX20_DK_heat), Time_out_of_Reactor, UOX20_DK_heat, t)

MOX_Q(t) := interp(cspline(Time_out_of_Reactor, MOX_DK_heat), Time_out_of_Reactor, MOX_DK_heat, t)

New_Ext_Q(t) := interp(cspline(Time_out_of_Reactor, New_Ext_DK_heat), Time_out_of_Reactor, New_Ext_DK_heat, t)

E_CHEM_C_Q(t) := interp(cspline(Time_out_of_Reactor, E_Chem_c_DK_heat), Time_out_of_Reactor, E_Chem_c_DK_heat, t)

E_CHEM_M_Q(t) := interp(cspline(Time_out_of_Reactor, E_Chem_m_DK_heat), Time_out_of_Reactor, E_Chem_m_DK_heat, t)

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$Q(t) := \begin{pmatrix} UOX40_Q(t) \\ UOX60_Q(t) \\ UOX20_Q(t) \\ MOX_Q(t) \\ New_Ext_Q(t) \\ E_CHEM_C_Q(t) \\ E_CHEM_M_Q(t) \end{pmatrix}$$

The calculation radius is the radius of the host rock / engineered barriers systems interface. In the case of salt, it is a distance close to the boundary between the crushed salt backfill and the intact salt of the host rock.

$$zRadius := \begin{cases} Assembly_drift_r_{RT} & \text{if } WFtype = \text{"Assembly"} \\ Canister_drift_r_{RT} & \text{otherwise} \end{cases}$$

$WF_count := WF_cnt_{WF}$

$WP_length := WP_len_{WF}$

$WP_spacing := WP_space_{RT}$

$zDrift := Drift_spacing_{RT}$

$tdy := 365.25 \cdot 24 \cdot 60 \cdot 60$

Define Line Load Decay Heat as a function of time out of reactor:

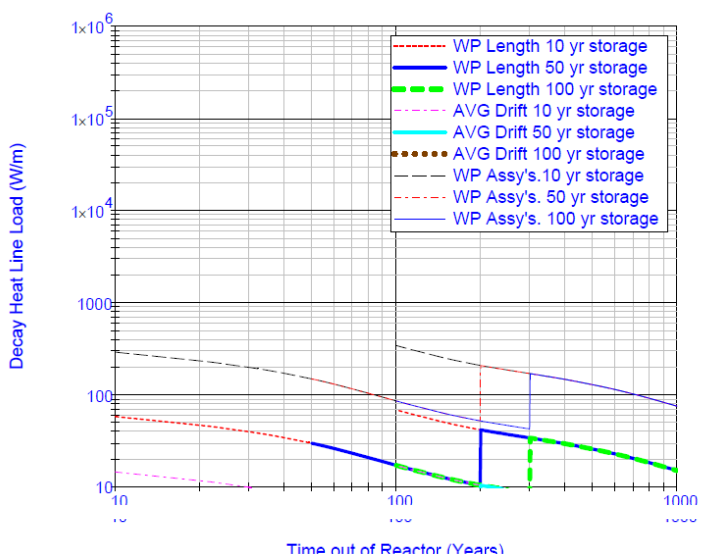
$$Q_{L_wp}(t) := \frac{Q(t)_{WF} \cdot WF_count}{WP_length}$$ Line load within a single waste package of type WF

$$Q_{L_avg}(t) := Q_{L_wp}(t) \cdot \frac{WP_length}{WP_spacing}$$ Average line load accounting for spacing of waste packages of type WF

$$Q_{L_wp}(t, ts, tv) := \begin{cases} Q_{L_wp}(t) \cdot (1 - Vstoreff) & \text{if } t \le ts \\ Q_{L_wp}(t) & \text{if } t > (ts + tv) \\ \left[Q_{L_wp}(t) \cdot (1 - Venteff)\right] & \text{otherwise} \end{cases}$$

$$Q_{L_avg}(t, ts, tv) := \begin{cases} Q_{L_avg}(t) \cdot (1 - Vstoreff) & \text{if } t \le ts \\ Q_{L_avg}(t) & \text{if } t > (ts + tv) \\ \left[Q_{L_avg}(t) \cdot (1 - Venteff)\right] & \text{otherwise} \end{cases}$$

$$Q_{wp}(t, ts, tv) := \begin{cases} Q(t)_{WF} \cdot WF_count \cdot (1 - Vstoreff) & \text{if } t \le ts \\ Q(t)_{WF} \cdot WF_count & \text{if } t > (ts + tv) \\ \left[Q(t)_{WF} \cdot WF_count \cdot (1 - Venteff)\right] & \text{otherwise} \end{cases}$$



WFname = "UOX20"

WFtype = "Assembly"

WF_count = 4

$$Tstore = \begin{pmatrix} 10 \\ 50 \\ 100 \end{pmatrix} \qquad Tvent = \begin{pmatrix} 90 \\ 150 \\ 200 \end{pmatrix}$$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$DW_T_infinite_line_avg(t, zRadius, T_{store}, T_{vent}) := \left[\int_0^t \frac{Q_{L_avg}(\tau, T_{store}, T_{vent})}{4\cdot(\pi\cdot Kth)\cdot(t-\tau)}\cdot e^{\frac{-(zRadius^2)}{4\cdot\alpha\cdot tdy\cdot(t-\tau)}}\, d\tau\right]$$

$$DW_T_drifts(t, zRadius, T_{store}, T_{vent}) := 2\left[\sum_{id=1}^{Ndrifts}\int_0^t \frac{Q_{L_avg}(\tau, T_{store}, T_{vent})}{4\cdot(\pi\cdot Kth)\cdot(t-\tau)}\cdot e^{\frac{-\left[zRadius^2+(id\cdot zDrift)^2\right]}{4\cdot\alpha\cdot tdy\cdot(t-\tau)}}\, d\tau\right]$$

$$DW_T_finite_line(t, zRadius, y, T_{store}, T_{vent}) := \left[\int_0^t \frac{Q_{L_wp}(\tau, T_{store}, T_{vent})}{8\cdot(\pi\cdot Kth)\cdot(t-\tau)}\cdot e^{\frac{-(zRadius^2)}{4\cdot\alpha\cdot tdy\cdot(t-\tau)}}\cdot\left[erf\left[\frac{1}{2}\cdot\frac{\left(y+\frac{WP_length}{2}\right)}{\sqrt{\alpha\cdot tdy\cdot(t-\tau)}}\right]-erf\left[\frac{1}{2}\cdot\frac{\left(y-\frac{WP_length}{2}\right)}{\sqrt{\alpha\cdot tdy\cdot(t-\tau)}}\right]\right] d\tau\right]$$

FORMULA FOR A SINGLE FINITE LINE SOURCE - MDL-EBS-MD-000001 REV 00 AD 01 - *In-Drift Natural Convection and Condensation*, Section 6.3.5.1.1, equation 6.3-8 an page 6-72.

$$DW_T_adjacent_pkgs(t, zRadius, y, T_{store}, T_{vent}, N_{adj}) := 2\left[\sum_{j=1}^{N_{adj}}\int_0^t \frac{Q_{wp}(\tau, T_{store}, T_{vent})}{8\cdot Kth\cdot\sqrt{tdy\cdot\alpha}\cdot\pi^{1.5}\cdot(t-\tau)^{1.5}}\cdot e^{\frac{-\left[zRadius^2+(j\cdot WP_spacing)^2\right]}{4\cdot\alpha\cdot tdy\cdot(t-\tau)}}\, d\tau\right]$$

$$Wall_deltaT_infinite_line_wp_st1_i := DW_T_infinite_line_avg(tt_i, zRadius, Tstore_1, Tvent_1)$$

$$Wall_deltaT_drifts_st1_i := DW_T_drifts(tt_i, zRadius, Tstore_1, Tvent_1)$$

$$Wall_T_st1 := Tamb + Wall_deltaT_infinite_line_wp_st1 + Wall_deltaT_drifts_st1$$

$$Max_T_st1 := max(Wall_T_st1)$$

$$Max_time_st1 := lookup(Max_T_st1, Wall_T_st1, tt)_1$$

$$Wall_deltaT_infinite_line_wp_st2_i := DW_T_infinite_line_avg(tt_i, zRadius, Tstore_2, Tvent_2)$$

$$Wall_deltaT_drifts_st2_i := DW_T_drifts(tt_i, zRadius, Tstore_2, Tvent_2)$$

$$Wall_T_st2 := Tamb + Wall_deltaT_infinite_line_wp_st2 + Wall_deltaT_drifts_st2$$

$$Max_T_st2 := max(Wall_T_st2)$$

$$Max_time_st2 := lookup(Max_T_st2, Wall_T_st2, tt)_1$$

$$Wall_deltaT_infinite_line_wp_st3_i := DW_T_infinite_line_avg(tt_i, zRadius, Tstore_3, Tvent_3)$$

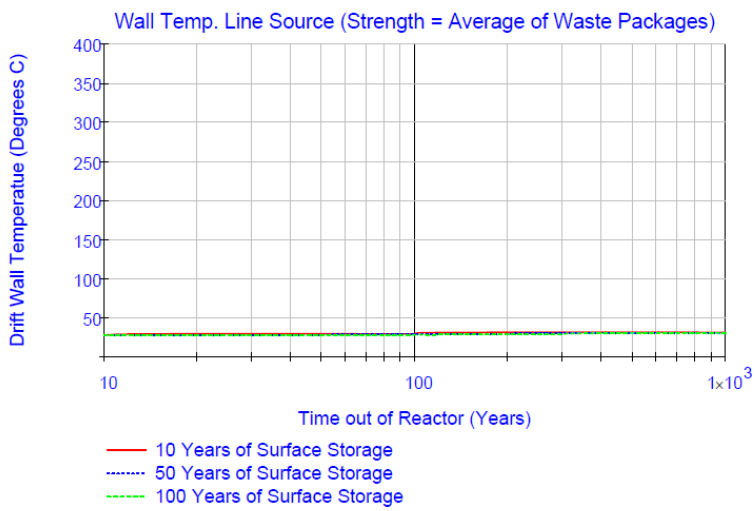
$$Wall_deltaT_drifts_st3_i := DW_T_drifts(tt_i, zRadius, Tstore_3, Tvent_3)$$

$$Wall_T_st3 := Tamb + Wall_deltaT_infinite_line_wp_st3 + Wall_deltaT_drifts_st3$$

$$Max_T_st3 := max(Wall_T_st3)$$

$$Max_time_st3 := lookup(Max_T_st3, Wall_T_st3, tt)_1$$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts



$Max_T_st1 = 31$ $Max_time_st1 = 405$

$Q_{L_wp}(Max_time_st1, Tstore_1, Tvent_1) = 29$

$Max_T_st2 = 31$ $Max_time_st2 = 640$

$Q_{L_wp}(Max_time_st2, Tstore_2, Tvent_2) = 22$

$Max_T_st3 = 30$ $Max_time_st3 = 724$

$Q_{L_wp}(Max_time_st3, Tstore_3, Tvent_3) = 19.7$

$Tamb = 27.5$

$Wall_deltaT_finite_line_st1_i := DW_T_finite_line(tt_i, zRadius, 0, Tstore_1, Tvent_1)$

$Wall_T_F_st1 := Tamb + Wall_deltaT_finite_line_st1 + Wall_deltaT_drifts_st1$

$Max_T_F_st1 := max(Wall_T_F_st1)$

$Max_t_F_st1 := lookup(Max_T_F_st1, Wall_T_F_st1, tt)_1$

$Wall_deltaT_finite_line_st2_i := DW_T_finite_line(tt_i, zRadius, 0, Tstore_2, Tvent_2)$

$Wall_T_F_st2 := Tamb + Wall_deltaT_finite_line_st2 + Wall_deltaT_drifts_st2$

$Max_T_F_st2 := max(Wall_T_F_st2)$

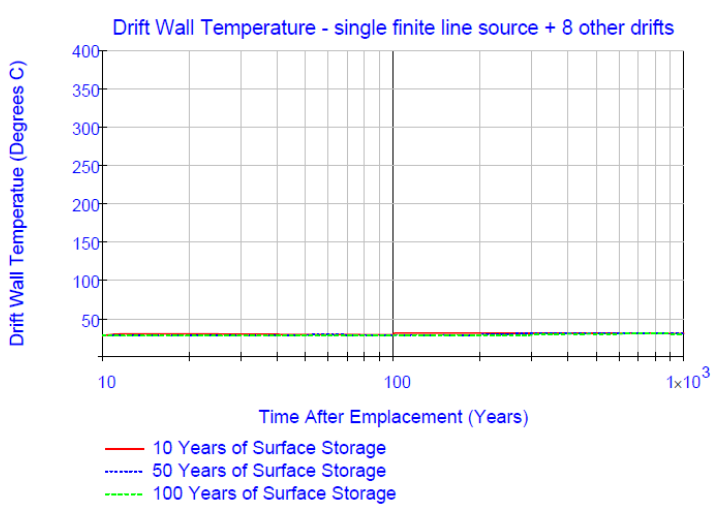
$Max_t_F_st2 := lookup(Max_T_F_st2, Wall_T_F_st2, tt)_1$

$Wall_deltaT_finite_line_st3_i := DW_T_finite_line(tt_i, zRadius, 0, Tstore_3, Tvent_3)$

$Wall_T_F_st3 := Tamb + Wall_deltaT_finite_line_st3 + Wall_deltaT_drifts_st3$

$Max_T_F_st3 := max(Wall_T_F_st3)$

$Max_t_F_st3 := lookup(Max_T_F_st3, Wall_T_F_st3, tt)_1$



$Max_T_F_st1 = 31$ $Max_t_F_st1 = 107$

$Q_{wp}(Max_t_F_st1, Tstore_1, Tvent_1) = 322$

$Max_T_F_st2 = 30$ $Max_t_F_st2 = 582$

$Q_{wp}(Max_t_F_st2, Tstore_2, Tvent_2) = 116$

$Max_T_F_st3 = 30$ $Max_t_F_st3 = 721$

$Q_{wp}(Max_t_F_st3, Tstore_3, Tvent_3) = 99$

$Wall_deltaT_adjacent_pkgs_st1_i := DW_T_adjacent_pkgs(tt_i, zRadius, 0, Tstore_1, Tvent_1, N_{adj_pkgs})$

$Wall_T_F_A_st1 := Wall_T_F_st1 + Wall_deltaT_adjacent_pkgs_st1$

$Max_T_F_A_st1 := max(Wall_T_F_A_st1)$

$Max_t_F_A_st1 := lookup(Max_T_F_A_st1, Wall_T_F_A_st1, tt)_1$

$Wall_deltaT_adjacent_pkgs_st2_i := DW_T_adjacent_pkgs(tt_i, zRadius, 0, Tstore_2, Tvent_2, N_{adj_pkgs})$

$Wall_T_F_A_st2 := Wall_T_F_st2 + Wall_deltaT_adjacent_pkgs_st2$

$Max_T_F_A_st2 := max(Wall_T_F_A_st2)$

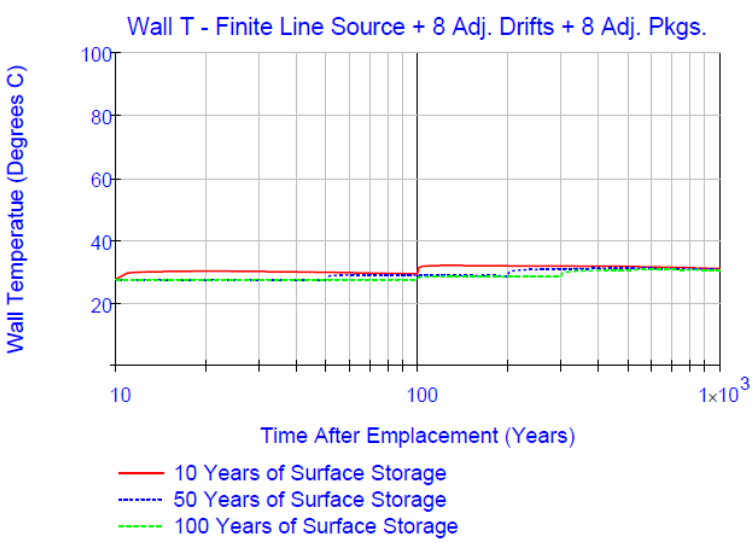
$Max_t_F_A_st2 := lookup(Max_T_F_A_st2, Wall_T_F_A_st2, tt)_1$

$Wall_deltaT_adjacent_pkgs_st3_i := DW_T_adjacent_pkgs(tt_i, zRadius, 0, Tstore_3, Tvent_3, N_{adj_pkgs})$

$Wall_T_F_A_st3 := Wall_T_F_st3 + Wall_deltaT_adjacent_pkgs_st3$

$Max_T_F_A_st3 := max(Wall_T_F_A_st3)$

$Max_t_F_A_st3 := lookup(Max_T_F_A_st3, Wall_T_F_A_st3, tt)_1$



$Max_T_F_A_st1 = 32$ $Max_t_F_A_st1 = 129$

$Q_{wp}(Max_t_F_A_st1, Tstore_1, Tvent_1) = \blacksquare$

$Max_T_F_A_st2 = 31$ $Max_t_F_A_st2 = 477$

$Q_{wp}(Max_t_F_A_st2, Tstore_2, Tvent_2) = 132$

$Max_T_F_A_st3 = 31$ $Max_t_F_A_st3 = 628$

$Q_{wp}(Max_t_F_A_st3, Tstore_3, Tvent_3) = 110$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$Topen := Tstore_1 + Tvent_1 + Tclose_1$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Layer1_dT_st1_i := \begin{cases}
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
0 & \text{otherwise}
\end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 1$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 1$$

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 1 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 1 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Layer2_dT_st1_i := \begin{cases}
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
0 & \text{otherwise}
\end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 2$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 2$$

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 2 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 2 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 3\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 3\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 3\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 4\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 3\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 3\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 4\rangle}\right)_{RT}$$

$$Layer3_dT_st1_i := \begin{cases}
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_1 + Tclose_1 = 0 \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_1, Tvent_1)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st1_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st1_i - 273.16\right] & \text{if } WFtype \\
0 \quad \text{otherwise}
\end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 3$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 3$$

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 3 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 3 \wedge Tvent_1 + Tclose_1 > 0 \wedge tt_i \leq Topen$$

$$WP_T_F_A_st1_i := Wall_T_F_A_st1_i + Layer1_dT_st1_i + Layer2_dT_st1_i + Layer3_dT_st1_i$$

$$Max_WP_T_F_A_1 := \max(WP_T_F_A_st1)$$

$$Max_WP_t_F_A_1 := lookup\left(Max_WP_T_F_A_1, WP_T_F_A_st1, tt\right)_1$$

$$Topen := Tstore_2 + Tvent_2 + Tclose_2$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Layer1_dT_st2_i := \begin{cases}
\dfrac{-Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + \left(Wall_T_F_A_st2_i + 273.16\right)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + \left(Wall_T_F_A_st2_i + 273.16\right)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + \left(Wall_T_F_A_st2_i + 273.16\right)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}\left(tt_i, Tstore_2, Tvent_2\right)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + \left(Wall_T_F_A_st2_i + 273.16\right)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
0 & \text{otherwise}
\end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 1$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 1$$

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 1 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 1 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Layer2_dT_st2_i := \begin{cases}
\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
0 & \text{otherwise}
\end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 2$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 2$$

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 2 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 2 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$Ae1 := \left(Assy_layer_emiss1^{\langle 3\rangle}\right)_{RT}$ $Ae2 := \left(Assy_layer_emiss2^{\langle 3\rangle}\right)_{RT}$ $Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 3\rangle}\right)_{RT}$ $Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 4\rangle}\right)_{RT}$

$Ce1 := \left(Can_layer_emiss1^{\langle 3\rangle}\right)_{RT}$ $Ce2 := \left(Can_layer_emiss2^{\langle 3\rangle}\right)_{RT}$ $Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT}$ $Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 4\rangle}\right)_{RT}$

$$
Layer3_dT_st2_i := \begin{cases}
\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_2 + Tclose_2 = 0 \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\dfrac{-Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
\left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_2, Tvent_2)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st2_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st2_i - 273.16\right] & \text{if } WFtype \\
0 & \text{otherwise}
\end{cases}
$$

Lines that printed over the right-hand margin above:

$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 3$

$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 3$

$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 3 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$

$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 3 \wedge Tvent_2 + Tclose_2 > 0 \wedge tt_i \leq Topen$

$WP_T_F_A_st2_i := Wall_T_F_A_st2_i + Layer1_dT_st2_i + Layer2_dT_st2_i + Layer3_dT_st2_i$

$Max_WP_T_F_A_2 := \max(WP_T_F_A_st2)$

$Max_WP_t_F_A_2 := lookup(Max_WP_T_F_A_2, WP_T_F_A_st2, tt)_1$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$Topen := Tstore_3 + Tvent_3 + Tclose_3$$

$$Ae1 := \left(Assy_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 1\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 1\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 1\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT}$$

$$Layer1_dT_st3_i := \begin{cases} \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\ \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ 0 & \text{otherwise} \end{cases}$$

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$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 1$$

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$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Assy_layers_{RT} \geq 1 \wedge Tvent_3 + Tclose_3 > 0 \wedge tt_i \leq Topen$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 1\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 1 \wedge Tvent_3 + Tclose_3 > 0 \wedge tt_i \leq Topen$$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts

$$Ae1 := \left(Assy_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ae2 := \left(Assy_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Ad1 := 2\cdot\left(Assy_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Ad2 := 2\cdot\left(Assy_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Ce1 := \left(Can_layer_emiss1^{\langle 2\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 2\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 2\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT}$$

$$Layer2_dT_st3_i := \begin{cases} \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\ \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} \neq 0 \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ 0 & \text{otherwise} \end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 2$$

$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 2\rangle}\right)_{RT} = 0 \wedge Can_layers_{RT} \geq 2$$

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$$Ce1 := \left(Can_layer_emiss1^{\langle 3\rangle}\right)_{RT} \quad Ce2 := \left(Can_layer_emiss2^{\langle 3\rangle}\right)_{RT} \quad Cd1 := 2\cdot\left(Can_layer_inner_r^{\langle 3\rangle}\right)_{RT} \quad Cd2 := 2\cdot\left(Can_layer_inner_r^{\langle 4\rangle}\right)_{RT}$$

$$Layer3_dT_st3_i := \begin{cases} \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge Tvent_3 + Tclose_3 = 0 \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\ \dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Ad1}{Ad2}\right) & \text{if } WFtype = \text{"Assembly"} \wedge tt_i > Topen \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\ \left[\dfrac{-Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{2\cdot\pi\cdot\left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT}}\cdot\ln\left(\dfrac{Cd1}{Cd2}\right)\right] & \text{if } WFtype = \text{"Canister"} \wedge tt_i > Topen \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Ad1}\cdot\left[\dfrac{1}{Ae1} - \dfrac{(1-Ae2)\cdot Ad1}{Ae2\cdot Ad2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ \left[\left[\dfrac{Q_{L_wp}(tt_i, Tstore_3, Tvent_3)}{\pi\cdot 5.67\cdot 10^{-8}\cdot Cd1}\cdot\left[\dfrac{1}{Ce1} - \dfrac{(1-Ce2)\cdot Ad1}{Ce2\cdot Cd2}\right] + (Wall_T_F_A_st3_i + 273.16)^4\right]^{0.25} - Wall_T_F_A_st3_i - 273.16\right] & \text{if } WFtype \\ 0 & \text{otherwise} \end{cases}$$

Lines that printed over the right-hand margin above:

$$= \text{"Assembly"} \wedge \left(Assy_layer_Kth^{\langle 3\rangle}\right)_{RT} = 0 \wedge Assy_layers_{RT} \geq 3$$

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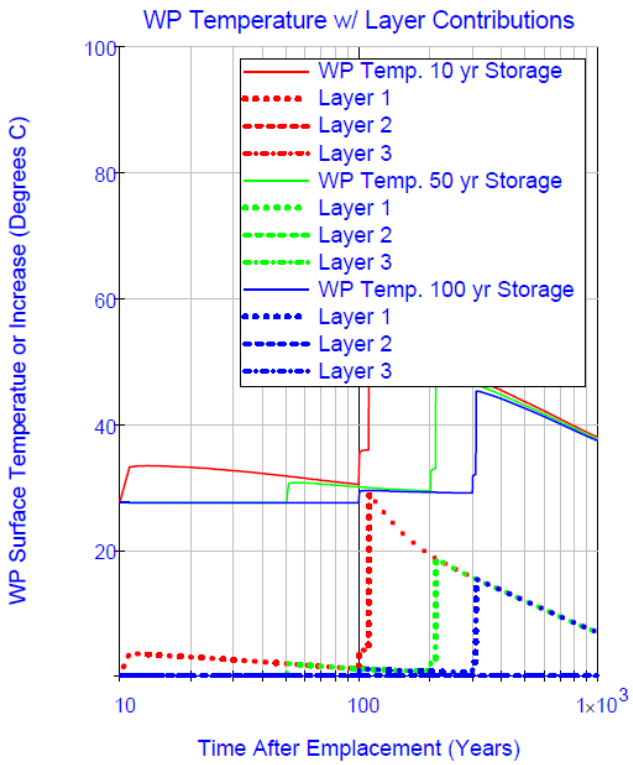
$$= \text{"Canister"} \wedge \left(Can_layer_Kth^{\langle 3\rangle}\right)_{RT} \neq 0 \wedge Can_layers_{RT} \geq 3 \wedge Tvent_3 + Tclose_3 > 0 \wedge tt_i \leq Topen$$

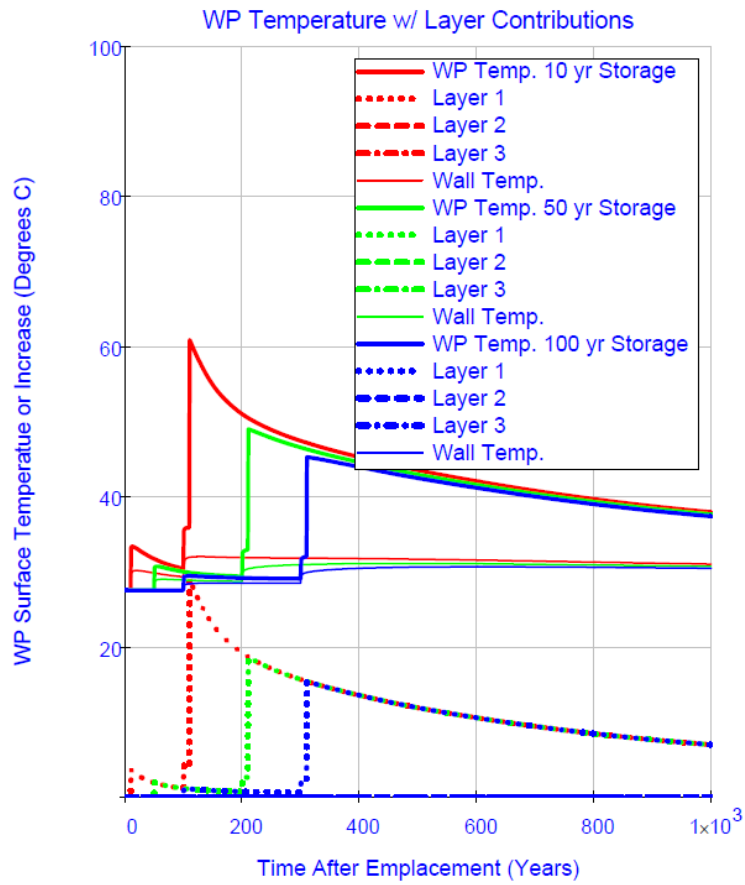
$$WP_T_F_A_st3_i := Wall_T_F_A_st3_i + Layer1_dT_st3_i + Layer2_dT_st3_i + Layer3_dT_st3_i$$

$$Max_WP_T_F_A_3 := \max(WP_T_F_A_st3)$$

$$Max_WP_t_F_A_3 := lookup\left(Max_WP_T_F_A_3, WP_T_F_A_st3, tt\right)_1$$

Temperature-Package Power Correlations for Open-Mode Geologic Disposal Concepts





$Max_WP_T_F_A_1 = 61$ $\quad$ $Max_WP_t_F_A_1 = 111$

$Q_{wp}(Max_WP_t_F_A_1, Tstore_1, Tvent_1) = 313$

$Max_WP_T_F_A_2 = 49$ $\quad$ $Max_WP_t_F_A_2 = 211$

$Q_{wp}(Max_WP_t_F_A_2, Tstore_2, Tvent_2) = 201$

$Max_WP_T_F_A_3 = 45$ $\quad$ $Max_WP_t_F_A_3 = 311$

$Q_{wp}(Max_WP_t_F_A_3, Tstore_3, Tvent_3) = 166$

Minimum decay storage time calculation for enclosed modes (requires Tstore include values resulting in temperature results above and below Tlim).

$vs := regress(Max_WP_T_F_A, Max_WP_t_F_A, 2)$

$Min_store_time := interp(vs, Max_WP_T_F_A, Max_WP_t_F_A, Tlim_{RT})$

$Min_store_time = 2.363 \times 10^4$

$file_st1 := concat(Rock_type_{RT}, "_", WF_name_{WF}, "-", num2str(WF_cnt_{WF}), "_Tstore=", num2str(Tstore_1), ".txt")$

file_st1 = "Hard Rock Backfilled_UOX20-4_Tstore=10.txt"

$output := \text{for } i \in 1..itmax$

$\quad output_{i,1} \leftarrow tt_i$

$\quad output_{i,2} \leftarrow Wall_T_F_A_st1_i$

$\quad output_{i,3} \leftarrow WP_T_F_A_st1_i$

$\quad output$

:/Oper_Hard_Rock_Backfilled_UO2O20-4 (70 m)_T=100 WP20ru.tu

output

$file_st2 := concat(Rock_type_{RT}, "_", WF_name_{WF}, "-", num2str(WF_cnt_{WF}), "_Tstore=", num2str(Tstore_2), ".txt")$

file_st2 = "Hard Rock Backfilled_UOX20-4_Tstore=50.txt"

$output := \text{for } i \in 1..itmax$

$\quad output_{i,1} \leftarrow tt_i$

$\quad output_{i,2} \leftarrow Wall_T_F_A_st2_i$

$\quad output_{i,3} \leftarrow WP_T_F_A_st2_i$

$\quad output$

:/Oper_Hard_Rock_Backfilled_UO2O20-4 (70 m)_T=200 WP20ru.tu

output

$file_st3 := concat(Rock_type_{RT}, "_", WF_name_{WF}, "-", num2str(WF_cnt_{WF}), "_Tstore=", num2str(Tstore_3), ".txt")$

file_st3 = "Hard Rock Backfilled_UOX20-4_Tstore=100.txt"

$output := \text{for } i \in 1..itmax$

$\quad output_{i,1} \leftarrow tt_i$

$\quad output_{i,2} \leftarrow Wall_T_F_A_st3_i$

$\quad output_{i,3} \leftarrow WP_T_F_A_st3_i$

$\quad output$

:/Oper_Hard_Rock_Backfilled_UO2O20-4 (70 m)_T=300 WP20ru.tu

output

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