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Temperature Environment for 9975 Packages Stored in KAC

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Summary

Plutonium materials are stored in the K Area Complex (KAC) in shipping packages, typically the 9975 shipping package. In order to estimate realistic degradation rates for components within the shipping package (i.e. the fiberboard overpack and O-ring seals), it is necessary to understand actual facility temperatures, which can vary daily and seasonally.

Relevant facility temperature data available from several periods throughout its operating history have been reviewed. The annual average temperature within the Crane Maintenance Area has ranged from approximately 70 to 74 °F, although there is significant seasonal variation and lesser variation among different locations within the facility.

The long-term average degradation rate for 9975 package components is very close to that expected if the component were to remain continually at the annual average temperature. This result remains valid for a wide range of activation energies (which describes the variation in degradation rate as the temperature changes), if the activation energy remains constant over the seasonal range of component temperatures.

It is recommended that component degradation analyses and service life estimates incorporate these results. Specifically, it is proposed that future analyses assume an average facility ambient air temperature of 94 °F. This value is bounding for all packages, and includes margin for several factors such as increased temperatures within the storage arrays, the addition of more packages in the future, and future operational changes.

Background

Plutonium materials have been stored in the K Area Complex (KAC) since 2003. These materials are packaged in accordance with the DOE 3013 Standard and brought into the KAC in a shipping package (such as the 9975 package). The shipping package is retained as part of the storage configuration in KAC and is credited with performing several safety functions, including containment, criticality control, impact absorption and thermal insulation.

Two of the 9975 shipping package components – the fiberboard overpack and the containment vessel O-ring seals – are the subject of investigation to determine their service life under KAC storage conditions. A key element in this effort is understanding the storage environment. Safety basis calculations [1, 2 for example] have typically assumed a bounding ambient temperature of 137 °F, which assumes all packages contain the maximum allowed heat load of 19 watts, and the facility has lost ventilation for a sufficiently long time during mid-summer for temperatures to rise to an equilibrium value. Based on tests with instrumented 9975 packages [3, 4], temperature changes within the 9975 package typically require 2 – 5 days to reach equilibrium, depending on the magnitude of the change. In addition, the KAC facility includes massive concrete structures which moderate any short-term temperature changes. These effects have the result that component temperatures within the 9975 packages will experience very modest changes from daily facility temperature fluctuations, but will be strongly influenced by seasonal variations.

Within the 9975 surveillance program, aging data are being collected for the containment vessel O-rings (Viton® GLT and GLT-S fluoroelastomer) and the fiberboard overpack (Knight-Celotex cane- and softwood-based fiberboard). These data are analyzed and used to predict component degradation rates under storage conditions. This effort requires a realistic understanding of the component temperatures in storage. Analyses performed using bounding storage temperatures, such as those which assume an ambient temperature of 137 °F, can be unnecessarily restrictive in service life predictions. This report identifies relevant KAC facility temperature data and develops more realistic component temperature estimates for use in service life predictions.

Data

Data describing the ambient temperature in KAC storage areas are available from 2 sources. In the first source, ambient temperatures were taken from radio-frequency tamper indicating devices (RFTID) on 9975 packages in KAC between late 2002 and March 2, 2004 [5]. Detailed data are presented from two pallets in each of the three storage rooms (Process Room, Crane Maintenance Area and Stack Area). The RFTIDs capture temperature data approximately every 6 hours, so there are between 3 and 5 readings per day at each location. Given minor deviations from the 6 hour recording interval, all periods throughout the day are reasonably represented by the entire data set.

For a representative picture of seasonal variation and to maintain the correct overall average temperature, the data under consideration were limited to a one year period from March 2, 2003 to March 2, 2004. In two of the six locations, no data were available prior to late March 2003, so these locations represent slightly less than one year. However, in all six locations the annual maximum and minimum values were captured. None of the excluded data (prior to March 2, 2003) fall outside the range of the data that were analyzed. These data are shown in Figures 1-3.

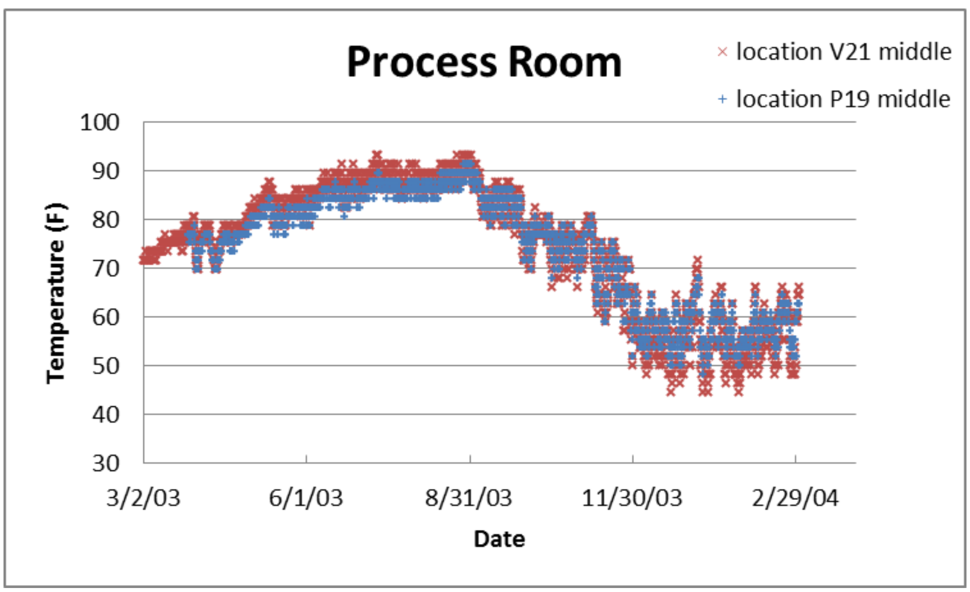

Figure 1. RFTID temperature data for two locations in the Process Room between March 2, 2003 and March 2, 2004

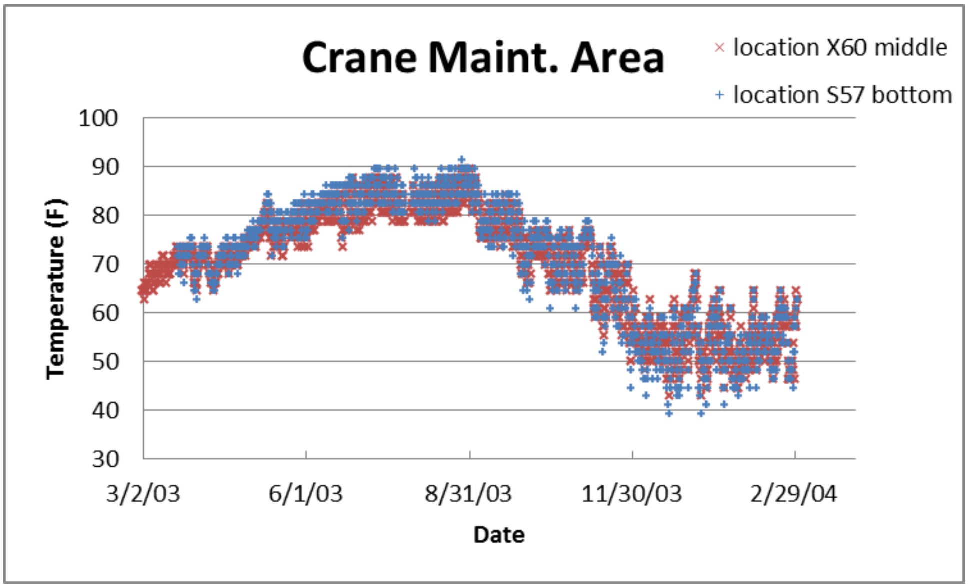

Figure 2. RFTID temperature data for two locations in the Crane Maintenance Area between March 2, 2003 and March 2, 2004

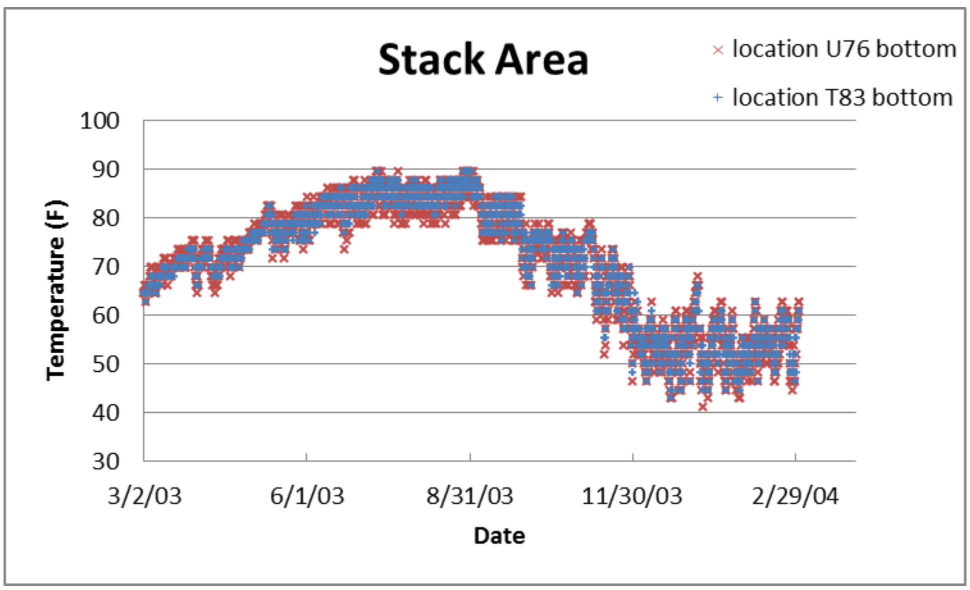

Figure 3. RFTID temperature data for two locations in the Stack Area between March 2, 2003 and March 2, 2004

The data cited above were described as representative values and are taken as indicative of the room ambient temperature. In addition to the six locations from which temperature profiles were reported, this reference also reviewed data from an additional 7 locations. A small number of temperature readings were greater than 100 °F, with a maximum of 104 °F. The reference states "The location of the 13 distinct T-1s that gave these temperature readings were generally located in the middle of a group of containers or along the outside edge of the storage array." Depending on the package and pallet orientation, any RFTID could be facing outward from the array of packages or inward toward other packages. It is assumed that the temperature readings over 100 °F are from locations within the array, and are not representative of the room ambient temperature. However, they indicate that packages in the array interior can experience an additional increase in temperature of approximately 11 °F over those on the edge of the array.

In the second data source, ambient temperatures were collected in the Crane Maintenance Area (CMA) and Assembly Area by Wayne Lindenberger (KAC Engineering) [6]. This includes limited intermittent periods in 2005 and 2007 in the CMA and longer periods during 2009 – 2014 in the CMA and assembly area. These data are summarized in Figures 4 – 6.

The CMA data are shown separately for the periods 2005 – 2007 and 2009 – 2014 since the facility underwent upgrades in the ventilation system in 2007. Separate consideration should be given to facility conditions before and after these changes.

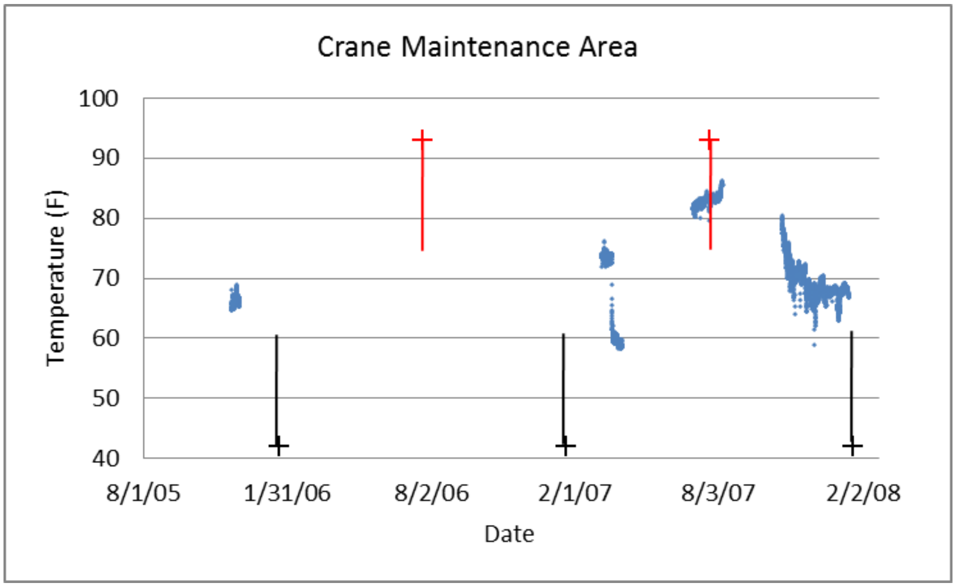

Figure 4. Ambient temperature data for the CMA, 2005 – 2007

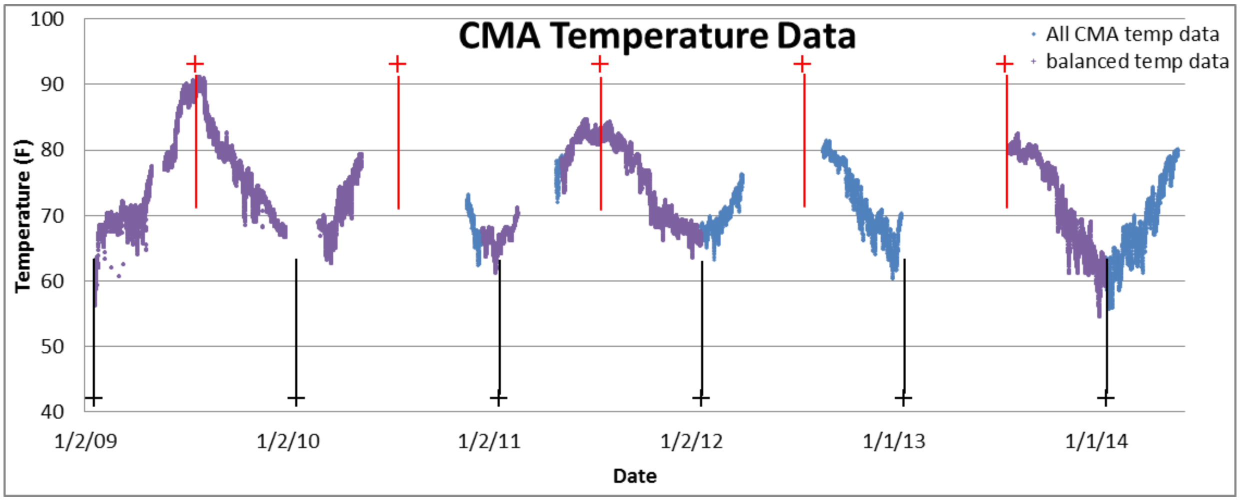

Figure 5. Ambient temperature data for the CMA, 2009 – 2014

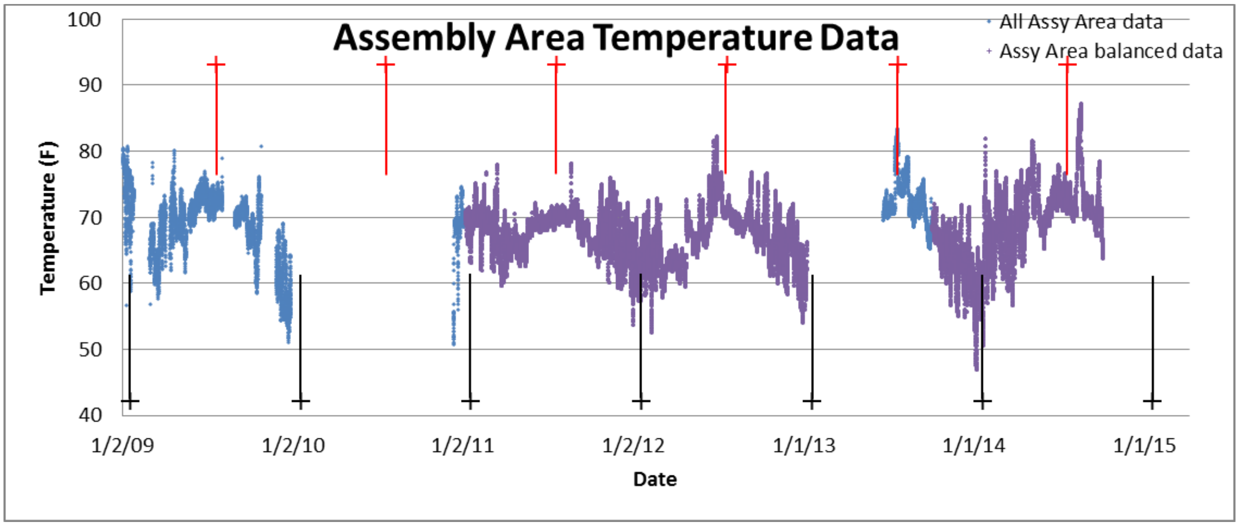

Figure 6. Ambient temperature data for the Assembly Area, 2009 - 2014

In Figures 4 - 6, the black and red symbols identify January 20 and July 22 each year as approximate indicators of the coldest and hottest days. In order to accurately understand the facility temperatures, it is important to capture data uniformly throughout the year. At a minimum, it is desirable to consider data in 6 month increments that fall between the coldest and hottest periods. The 2005 – 2007 data in Figure 4 do not include any sequences of data as long as 6 months, but they do include shorter periods around one hottest period and one coldest period. These data are of relatively little use in establishing long-term average trends, but they do show limited periods between 2005 and 5007 that are consistent with the data available from other time periods.

The Figure 5 and 6 data include multiple periods of extended length. In some cases, portions of one period can be combined with another period to create data sets covering one or more 6 month increments. This is illustrated in the figures with the purple symbols. These balanced periods provide a total combined period of 2.5 years for the CMA, and a total combined period of 3 years for the Assembly Area.

The Assembly Area temperatures are generally lower than those of the CMA. Since there is no long-term storage of loaded packages in the Assembly Area, and using the CMA data would be conservative relative to the Assembly Area data, these data will not be considered further. The CMA data were typically recorded every 15 minutes. The frequency of data was reduced to hourly for this analysis, and it was verified that none of the extreme (hottest, coldest) values were lost in this reduction.

The relative differences between the two data sets are seen in Figure 7, where the CMA data from each set are plotted on a shifted time scale. The first data set includes the data prior to March 2, 2003 that was excluded in Figure 2, and the segments of the second data set have been shifted to provide a more continuous presentation.

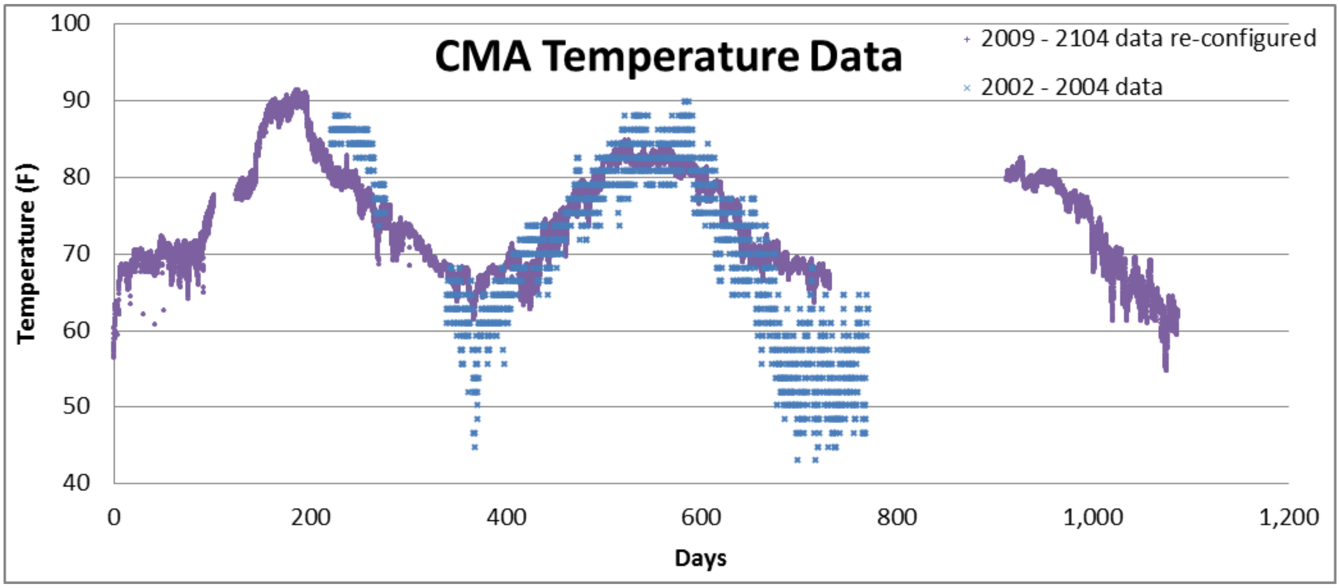

Figure 7. Superposition of the two data sets for the CMA with the time scale shifted to provide easier comparison.

Site Climate Data

Site meteorological data available from the SRNL Atmospheric Technologies Center was reviewed for trends relevant to longer-term periods. Figure 9 shows daily high and low temperatures recorded in A-Area from 2002 through 2014. The CMA data described above are superimposed on these daily extremes, and are seen to consistently fall within an intermediate range. The annual maximum and minimum temperatures vary by up to ~10 °F from year to year, but the overall trends are much more consistent. Specifically, the KAC temperature data are seen to occur in years which are very typical of the overall climate patterns.

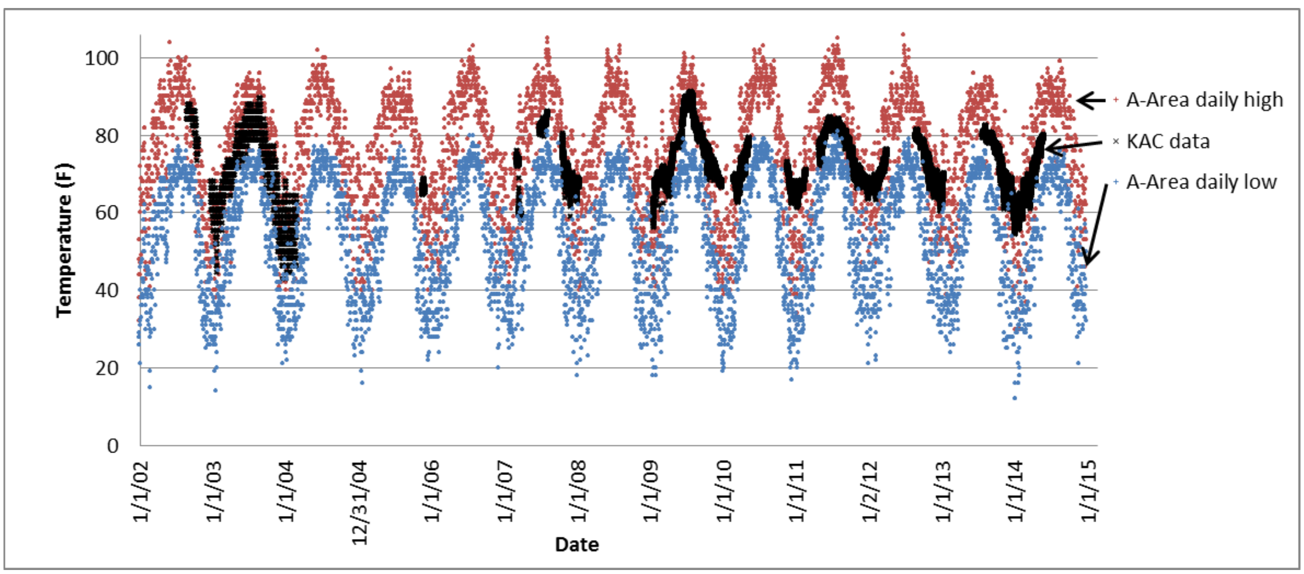

Figure 9. Daily temperature extremes reported by the SRNL Atmospheric Technologies Center, with KAC CMA data superimposed.

In Figure 10, the site annual average temperatures from 1968 to 2013 are plotted. In addition, the average is shown for each decade in this period. These data show that for much of the time packages have been stored in KAC, the site decade-average temperature has been 1 – 2 °F lower than the previous 3 decades. It is therefore likely that the site temperature may again increase to the previous historic values, leading to higher facility ambient temperatures.

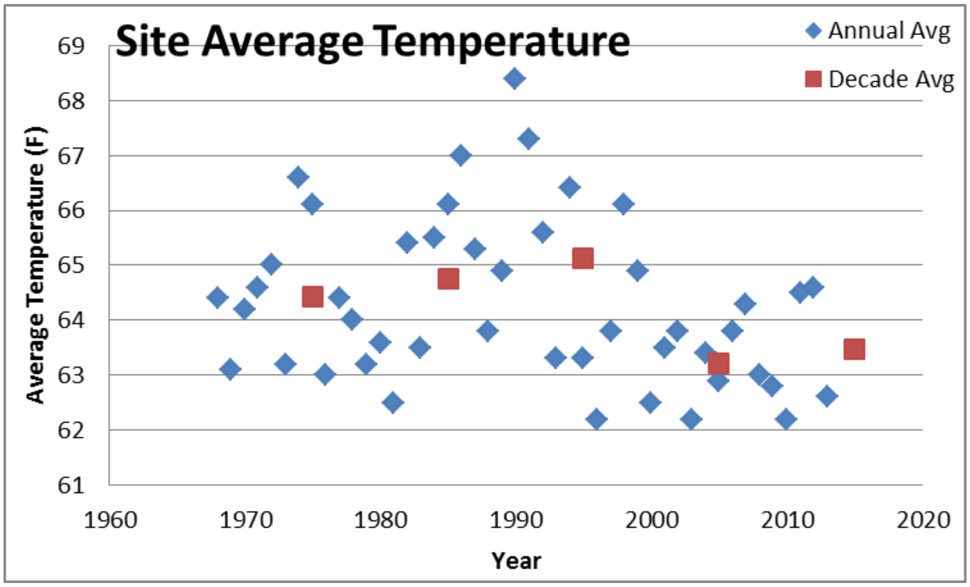

Figure 10. Site average temperatures since 1968 on an annual and decade basis.

Analysis of Data

Some statistics from the March 2, 2003 – March 2, 2004 data are shown in Table 1. Data from the two locations in each room are combined for these statistics. During this period, approximately 1800 – 2000 packages were stored in the facility. Subsequently, the number of packages in the facility has grown to over 5000. Some statistics from the 2009 - 2014 data are shown in Table 2.

Table 1. Statistics from the March 2, 2003 – March 2, 2004 data

	Process Room	Crane Maint. Area	Stack Area
# data points	3003	2852	3178
Maximum ambient temperature (°F)	93.2	91.4	89.6
Average ambient temperature (°F)	73.9	70.2	70.7
Minimum ambient temperature (°F)	44.6	39.2	41.0
Standard deviation (σ) °F)	12.3	12.1	12.1

Table 2. Statistics for CMA ambient temperature data from a balanced 2.5 year period between 2009 and 2014

	Crane Maint. Area
# data points	21173
Maximum ambient temperature (°F)	91.1 F
Average ambient temperature (°F)	74.1 F
Minimum ambient temperature (°F)	54.5 F
Standard deviation (σ) (°F)	7.0 F

During the March 2, 2003 – March 2, 2004 period, the temperature at a given location varied by ~5 °F or less on the hottest days, although as much as 14 °F daily variation was recorded at other times. For the 2009 – 2014 data, the temperature typically varied by 5 °F or less per day.

Since the 9975 package internal components typically require 2 days or more to reach equilibrium with external temperature changes, daily extrema are unlikely to influence internal package temperatures. Current laboratory data on instrumented 9975 packages indicates that daily temperature fluctuations at the fiberboard ID surface are, on average, only 38% as large as fluctuations at the fiberboard OD surface. Even greater suppression of fluctuations would be expected at the O-rings relative to ambient room temperature changes. Nevertheless, the extremes from daily ambient temperature fluctuations will be conservatively included in the thermal history.

As component temperatures fluctuate seasonally, the corresponding degradation rates also fluctuate. The relative change in degradation rate with temperature is described by the activation energy, E_a. The activation energy based on compression stress relaxation data is 60 kJ/mol for GLT O-rings and 81 kJ/mol for GLT-S O-rings [7]. These estimates are based on Arrhenius theory, which relates reaction rate (or degradation rate) to temperature as follows.

$$\text{Rate} = \text{constant} * \exp(-Ea / R*T)$$

where R is the ideal gas constant (0.0083145 kJ/mol-K), and
T is the absolute temperature (K)

With an estimate of activation energy, the effective degradation rate can be calculated for a varying range of temperatures, relative to the degradation rate for a reference temperature. The fraction of time the package component (e.g. O-rings) spends at each temperature provides weight factors to use in calculating an overall average degradation rate. This process is developed as follows, with an example calculation provided in Table 3.

- The ambient temperature range is divided into increments of 2 °F (Table 3 column A).
- Based on the CMA data in Figure 5, calculate the relative amount of time the ambient temperature falls within each temperature increment (column B).
- For a bounding heat load of 19 watts, calculate the maximum O-ring temperature for each temperature increment (column C). Per References 1 and 2, the bounding O-ring temperature is 62 °F above the ambient temperature.
- For a reference O-ring temperature of 138 °F, calculate the ratio between the degradation rate at the O-ring temperature for each increment and the degradation rate at the reference

temperature (column D). In the Table 3 example, this is calculated for an assumed activation energy of 60 kJ/mol.

- Calculate the degradation contribution from each increment by multiplying the degradation rate ratio by the amount of time spent in that temperature increment (column D * column B = column E).
- Add the degradation contributions from all temperature increments. This total describes the total degradation that would occur in one year from exposure to the KAC temperature distribution relative to the degradation that would occur from a one year exposure at the reference temperature.

Table 3. Calculation of a weighted average of O-ring degradation rate relative to a reference temperature of 138 °F for an activation energy of 60 kJ/mol

A	B	C	D	E
Ambient Temp. Interval (°F)	Amount of Time in Temp. Interval (%)	Max O-ring Temp. (°F)	Relative Degradation for Temp. Interval vs 138 °F	Degradation Contribution from Temp. Interval (col. B x col. D)
			(for 60 kJ/mol)	
54 - 56	0.10	118	0.50	0.05
56 - 58	0.23	120	0.51	0.12
58 - 60	0.51	122	0.55	0.28
60 - 62	1.11	124	0.59	0.66
62 - 64	3.14	126	0.64	2.01
64 - 66	4.54	128	0.69	3.12
66 - 68	11.17	130	0.74	8.31
68 - 70	16.25	132	0.80	13.03
70 - 72	9.45	134	0.86	8.16
72 - 74	5.85	136	0.93	5.43
74 - 76	4.67	138	1.00	4.67
76 - 78	8.88	140	1.08	9.55
78 - 80	11.24	142	1.16	13.00
80 - 82	9.36	144	1.24	11.61
82 - 84	6.62	146	1.33	8.82
84 - 86	1.41	148	1.43	2.02
86 - 88	1.27	150	1.53	1.95
88 - 90	3.28	152	1.64	5.40
90 - 92	0.92	154	1.76	1.62
Total degradation contribution from all temperatures (%):				99.82

In this example calculation, the calculated total degradation from exposure to the O-ring temperature distribution is 99.82% of the degradation from a constant exposure to the reference temperature of 138 °F. This is reasonable since the ambient temperature distribution is fairly symmetric around the average temperature of 74 °F, and the selected reference temperature corresponds closely to the O-ring temperature for this average value. This result can be used to more directly estimate the relative degradation rate compared to other reference temperatures with the following equation, which is based on the Arrhenius relationship.

$DR_2 = \exp[\ln(DR_{ref}) – (1/T_2 – 1/T_{ref})*(E_a / R)]$
where: DR = degradation rate (at temperature 2 or at reference temperature)
T = absolute temperature (degrees Kelvin)
Ea = activation energy (must match that used above)
R = ideal gas constant (0.008145 kJ/mol-K)

For example, using this equation, the degradation rate at a constant O-ring temperature of 154 °F is 1.76 times the degradation rate at the reference temperature of 138 °F. Note that this result can also be obtained from Table 3 – it is the ratio of the column D value for 154 °F to the column D value for 138 °F.

The above calculation was performed by assuming a specific value of the activation energy. It was repeated with alternate assumed E_a values of 30 and 90 kJ/mol to identify how sensitive the result is to this parameter (Table 4). At 30 kJ/mol, the ratio of degradation rate from the temperature distribution to that for a constant 138F is 99.08%. At 90 kJ/mol, the ratio of degradation rate from the temperature distribution to that for a constant 138 °F is 102.29%. This indicates that the result at this average temperature is not very sensitive to the E_a value. As with the first result, this results from the relative symmetry of the temperature distribution and the selection of a target temperature near the middle of the range. However, for other temperatures of interest, the results will vary significantly depending on the activation energy. From Table 4, for a constant O-ring temperature of 154 °F, the degradation rate is 1.33 times as high as at 138 °F for an assumed activation energy of 30 kJ/mol, while it is 2.34 times as high for an assumed activation energy of 90 kJ/mol. These estimates of relative change in degradation rate with temperature are valid so long as the activation energy does not change over the range of temperatures considered. To date, there are insufficient data available at lower temperatures to verify if this is the case for all temperatures of interest for the O-rings in a storage environment.

Table 4. Calculation of a weighted average of O-ring degradation rate relative to a reference temperature of 138 °F for alternate activation energy values

A	B	C	D		E	
Ambient Temp. Interval (°F)	Amount of Time in Temp. Interval (%)	Max O-ring Temp. (°F)	Relative Degradation for Temp. Interval vs 138 °F		Degradation Contribution from Temp. Interval (col. B x col. D)	
			(for 30 kJ/mol)	(for 90 kJ/mol)	(for 30 kJ/mol)	(for 90 kJ/mol)
54 - 56	0.10	118	0.69	0.32	0.07	0.03
56 - 58	0.23	120	0.71	0.36	0.16	0.08
58 - 60	0.51	122	0.74	0.41	0.38	0.21
60 - 62	1.11	124	0.77	0.46	0.86	0.51
62 - 64	3.14	126	0.80	0.51	2.51	1.61
64 - 66	4.54	128	0.83	0.57	3.77	2.61
66 - 68	11.17	130	0.86	0.64	9.63	7.17
68 - 70	16.25	132	0.90	0.72	14.55	11.68
70 - 72	9.45	134	0.93	0.80	8.78	7.58
72 - 74	5.85	136	0.96	0.90	5.64	5.24
74 - 76	4.67	138	1.00	1.00	4.67	4.67
76 - 78	8.88	140	1.04	1.11	9.22	9.90
78 - 80	11.24	142	1.08	1.24	12.09	13.96
80 - 82	9.36	144	1.11	1.38	10.42	12.94
82 - 84	6.62	146	1.15	1.54	7.64	10.18
84 - 86	1.41	148	1.20	1.71	1.69	2.41
86 - 88	1.27	150	1.24	1.90	1.57	2.42
88 - 90	3.28	152	1.28	2.11	4.21	6.93
90 - 92	0.92	154	1.33	2.34	1.22	2.16
Total degradation contribution from all temperatures (%):					99.08	102.29

Another parameter to consider is the package heat load. The above calculations use an O-ring temperature distribution based on a maximum 19 watts in every package. The other extreme is to assume 0 watts heat load. In this case, the O-ring temperature distribution will approximate the ambient temperature distribution (but with lower peak and higher minimum values due to the lag in temperature caused by the thermal insulation in the package). With a conservative assumption that the O-ring temperature matches the ambient temperature distribution (ignoring the reduced extreme values), the following results are obtained (Table 5). As with the previous calculations, this case indicates that the net degradation rate for the distribution of O-ring temperatures is essentially equal to the degradation rate expected for the approximate average temperature of 76 °F.

Table 5. Calculation of a weighted average of O-ring degradation rate relative to a reference temperature of 76 °F for an activation energy of 60 kJ/mol and no heat load in the package

A	B	C	D	E
Ambient Temp. Interval (°F)	Amount of Time in Temp. Interval (%)	Max O-ring Temp. (°F)	Relative Degradation for Temp. Interval vs 76 °F	Degradation Contribution from Temp. Interval (col. B x col. D)
			(for 60 kJ/mol)	
54 - 56	0.10	56	0.390	0.04
56 - 58	0.23	58	0.430	0.10
58 - 60	0.51	60	0.474	0.24
60 - 62	1.11	62	0.521	0.58
62 - 64	3.14	64	0.573	1.80
64 - 66	4.54	66	0.630	2.86
66 - 68	11.17	68	0.692	7.73
68 - 70	16.25	70	0.760	12.35
70 - 72	9.45	72	0.833	7.88
72 - 74	5.85	74	0.913	5.34
74 - 76	4.67	76	1.000	4.67
76 - 78	8.88	78	1.094	9.72
78 - 80	11.24	80	1.198	13.46
80 - 82	9.36	82	1.309	12.25
82 - 84	6.62	84	1.429	9.45
84 - 86	1.41	86	1.560	2.20
86 - 88	1.27	88	1.701	2.16
88 - 90	3.28	90	1.855	6.09
90 - 92	0.92	92	2.020	1.86
Total degradation contribution from all temperatures (%):				100.78

The above calculations show that the CMA ambient temperature distribution since 2007 has averaged approximately 74 °F, and the effective average ambient temperature in terms of producing the same overall degradation rate is approximately 76 °F. The CMA ambient temperature distribution from 2003 is slightly cooler, on average, than the later data. A similar calculation of the effective average ambient temperature based on the 2003 data is shown in Table 6. For this earlier data, the ambient temperature averaged approximately 70 °F, and the effective average ambient temperature in terms of producing the same overall degradation rate is approximately 74 °F.

Table 6. Calculation of a weighted average of O-ring degradation rate relative to a reference temperature of 136 °F for an activation energy of 60 kJ/mol based on the 2003 ambient temperature distribution

A	B	C	D	E
Ambient Temp. Interval (°F)	Amount of Time in Temp. Interval (%)	Max O-ring Temp. (°F)	Relative Degradation for Temp. Interval vs 136 °F	Degradation Contribution from Temp. Interval (col. B x col. D)
			(for 60 kJ/mol)	
38 - 40	0.07	102	0.27	0.02
40 - 42	0.14	104	0.29	0.04
42 - 44	0.25	106	0.31	0.08
44 - 46	1.02	108	0.34	0.35
46 - 48	1.61	110	0.37	0.60
48 - 50	2.63	112	0.40	1.05
50 - 52	6.91	114	0.43	2.99
52 - 54	3.30	116	0.47	1.54
54 - 56	3.16	118	0.51	1.60
56 - 58	2.66	120	0.55	1.46
58 - 60	2.95	122	0.59	1.74
60 - 62	2.45	124	0.64	1.57
62 - 64	1.68	126	0.69	1.16
64 - 66	2.31	128	0.74	1.72
66 - 68	3.30	130	0.80	2.64
68 - 70	8.66	132	0.86	7.47
70 - 72	5.61	134	0.93	5.21
72 - 74	7.22	136	1.00	7.22
74 - 76	5.47	138	1.08	5.89
76 - 78	5.43	140	1.16	6.29
78 - 80	6.77	142	1.24	8.41
80 - 82	6.35	144	1.34	8.47
82 - 84	7.36	146	1.43	10.56
84 - 86	5.61	148	1.54	8.63
86 - 88	6.10	150	1.65	10.07
88 - 90	0.95	152	1.77	1.68
90 - 92	0.04	154	1.90	0.07
Total degradation contribution from all temperatures (%):				98.52

As was done for the O-rings, comparable activation energy estimates can be developed for fiberboard. Weight loss data for cane fiberboard in dry environments are shown in Figure 8. In a semi-logarithmic plot of a rate vs reciprocal temperature, the activation energy is obtained by multiplying the slope of the curve (given by the coefficient within the exponential) by the ideal gas constant (0.0083145 kJ/mol-K). For the Figure 8 data, the lowest temperature point (125 °F) does not fall in line with the higher temperature data, suggesting a possible change in activation energy at lower temperatures. For the higher temperatures (185 °F and above), the fiberboard activation energy is (9734 * 0.0083145 =) 81 kJ/mol. The slope suggested by the lower temperatures gives an activation energy of (4384 * 0.0083145 =) 36 kJ/mol.

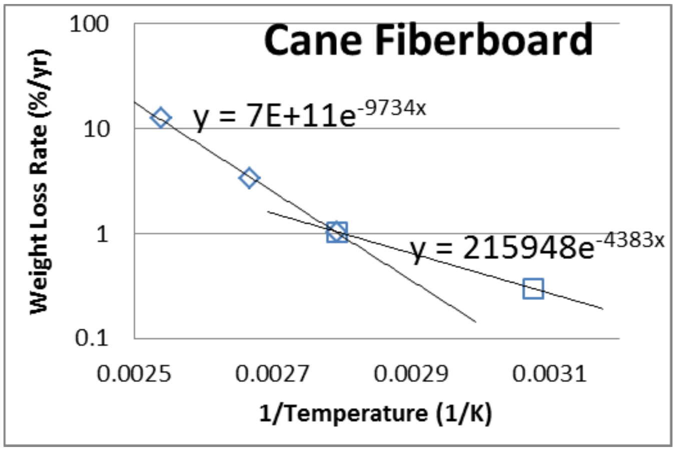

Figure 8. Weight loss rate for cane fiberboard in dry environments as a function of reciprocal temperature.

This lower temperature Ea estimate includes significant uncertainty due to fitting a line to only two data points, with the break point between the two temperature regimes not defined. However, it is likely that the break point falls between 155 (the temperature at which the slope of the higher temperature data extrapolates to the 125 °F degradation rate) and 185 °F. Therefore the line fit to the lower temperature regime provides an upper bound estimate of the activation energy. Accordingly, it is likely that the actual activation energy for the lower temperature regime is less than 36 kJ/mol.

This illustrates that fiberboard may experience a significant drop in activation energy over the temperature range relevant to the storage environment. Therefore, it is likely that a different calculation of the effective average temperature for fiberboard would be needed to address the changing activation energy. In addition, it would be necessary to verify whether this activation energy behavior based on weight loss data is applicable to other forms of fiberboard degradation.

Application of Analysis

As seen from comparing Tables 3 and 6, the effective average ambient temperature based on the 2003 data is slightly lower than that from the 2009 – 2014 data. Therefore, it is conservative to use the 2009 – 2014 data to describe the behavior for the entire period.

The 2003 data are relevant as an indication of the relative difference in temperature between the different storage rooms. Since the general air flow was from the Stack Area to the CMA to the Process Room, the Process Room is expected to have the highest ambient temperature, and the Stack Area is expected to have the lowest. As seen in Table 1, the average temperature in the Process Room is 3 – 4 °F higher than that in the Stack Area and CMA.

The overall average CMA temperature increased from 70 °F to 74 °F between the two data sets. This is the net result of two factors. First, the total number of packages stored in KAC increased from ~2000 to ~5000. Second, the building HVAC system was re-designed in 2007. The second data set shows reduced daily fluctuations, likely a result of improved performance of the HVAC system. In addition, the later data also show higher winter temperatures, and slightly lower summer temperatures in the facility, while Figure 9 shows the outside temperatures were essentially unchanged. This skewing of the reduced temperature range is consistent with the increase in overall average temperature.

There are several factors to consider in applying the data in this report to analysis of the degradation of package components. Specifically:

- It is possible that the average facility ambient temperature will increase in the future as still more packages are added to the KAC. This would lead to further increases in the average ambient temperature.
- The air temperature within the package arrays can be up to 11 °F higher than the air temperature away from the arrays.
- The calculations in this report used temperature data for the CMA, since that was the location for which the most complete data were available. Since the Process Room is slightly hotter than the CMA, a bounding estimate of the long-term ambient temperature needs to reflect this difference of 3 - 4 °F.
- Additional operational changes may occur in the future which would lead to significant changes in the facility average temperature or temperature distribution.
- The outside temperature may increase over time, possibly leading to a comparable increase in the KAC ambient temperature. It should be assumed that the annual average outside temperature could increase by 2 °F, based on the average site temperature recorded in the 1990s.

Given these considerations, it is recommended that service life calculations for 9975 package components be based on a long-term facility average ambient temperature of 94 °F. This increases the average temperature on which the above calculations are based by 20 °F, to account for the listed factors. While it is possible that short-term upset conditions may arise that will temporarily increase the ambient temperature, such conditions do not need to be considered in long-term degradation estimates. It is assumed that such conditions will be addressed and corrected within a reasonable time frame such that the overall long-term average temperature will not be impacted significantly.

For an assumed average ambient temperature of 94 °F, the maximum O-ring temperature in a 19 watt package will be 156 °F. The maximum fiberboard temperature is assumed to match the maximum shield temperature, which will be approximately 158 °F. These temperature estimates are based on the temperature gradients (component temperature – ambient temperature) reported in References 1 and 2. The temperatures are slightly lower in packages with cane fiberboard than in packages with softwood fiberboard. However, the above estimates are based on the softwood fiberboard numbers.

Case-by-case consideration can be given to packages known to experience less than these bounding conditions. For example, packages with internal heat loads less than 19 watts will have lower internal temperatures. Similarly, packages known to have been stored along the outer edges of an array for a significant period will also have a lower temperature profile during that period.

It is noted that many of the packages stored in KAC have accumulated significant storage time already. It would take an extended period of future operation with higher average temperatures to invalidate the long-term average exposure conditions proposed for these packages, since much of their history to date has included the earlier years with somewhat lower average temperatures than observed more recently. Should there be significant changes in future operations that invalidate these assumptions, then the assumptions and analyses of this report should be revised. However, significant time should be available to make these adjustments before enough operating time under different conditions accumulates to change any conclusions based on these assumptions and analyses.

Conclusions

The ambient air temperature within the KAC can vary daily and seasonally, although the impact of daily fluctuations on the temperature of components within the 9975 packages is minimal. The rate of degradation of 9975 components (such as O-rings and fiberboard) will be driven primarily by temperature (with moisture also contributing to fiberboard behavior). Therefore, the actual degradation rates will vary seasonally as the facility temperatures change.

The overall net degradation rate has been calculated for several example cases. The long-term average degradation rate is very close to the rate which would occur if the component remained continually at the overall average temperature. Specifically, the average ambient facility air temperature has been 74 °F over several recent years, and the net component degradation rate over the varying seasonal temperature distribution is the same as would be experienced for a constant ambient temperature of 76 °F. This result remains valid for a wide range of activation energies, if the activation energy remains constant over the seasonal range of component temperatures.

It is recommended that component degradation analyses and service life estimates incorporate these results. Specifically, it is proposed that future analyses assume an average facility ambient air temperature of 94 °F, which includes margin for several factors such as increased temperatures within the storage arrays, the addition of more packages in the future, and future operational changes.

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