RAI Volume 2, Chapter 2.1.1.4, Second Set, Number 9:

> Provide technical basis for choosing a normal distribution from series of runs for the heat-up rate that accounts for uncertainty in the rate of temperature increase in canisters while calculating pressure differentials (Section D2.1.4.5.3.3 of BSC 2008b). This information is to verify canister reliability as calculated is not underestimated.

1. RESPONSE

As discussed in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Sections D2.1.4.5.3.3 and D2.1.5), the results of the canister heatup analysis (which yields a distribution of maximum canister temperatures during a fire) and the canister failure temperature analysis are compared to determine the probability of canister failure. Both creep and limit load failure were modeled. The rate of temperature increase is only relevant to creep modeling.

Stand-alone heat transfer calculations were run using a simplified heat transfer model (BSC 2009, Sections D2.1.4.1 and D2.1.4.2) to determine the average canister heating rates expected during the fire. The average heating rate is needed because the heating rate is treated as constant in the creep failure analysis. Figure 1 is an example of a calculation for a waste package in a 30-minute, 1,400 K fire. The average canister heating rate in this example is on the order of 10 K/minute (i.e., a 400 K increase in temperature over the first 40 minutes).

The heat transfer calculations showed that the rate at which the canister temperature increases is sensitive to the configuration of the waste form (i.e., whether the canister is in a waste package, shield bell, or cask) and the intensity of the fire. Since it was recognized that only intense fires with a high fire temperature would be capable of failing a canister, the majority of the calculations were performed with temperatures exceeding 1,200 K. These calculations indicated that the heating rate for a canister in a waste package, shield bell, or transportation cask varies over a wide range from about 1 K/minute to over 10 K/minute, with the majority of the values at high fire temperatures clustered around 10 K/minute. A heating rate in this range used for all fires would, therefore, include a conservative bias toward the more severe fires.

Monte Carlo calculations using the canister failure model indicate that failure is rarely caused by creep (BSC 2009, Section D2.1.5.1), even when the heat rates are much higher or lower than 10 K/minute. Canister failure is predominantly due to limit load failure rather than creep. Consequently, the canister failure analysis is not sensitive to the characteristics of the probability distribution for the heating rate. A normal distribution is considered adequate because a) the underlying calculations did not indicate significant asymmetry (a normal distribution is symmetric), b) a conservative bias is already included by using the more severe fires to characterize the mean, and c) further refinement is not needed because this distribution is used only in the much lower probability creep failure mode.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2009. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0004.

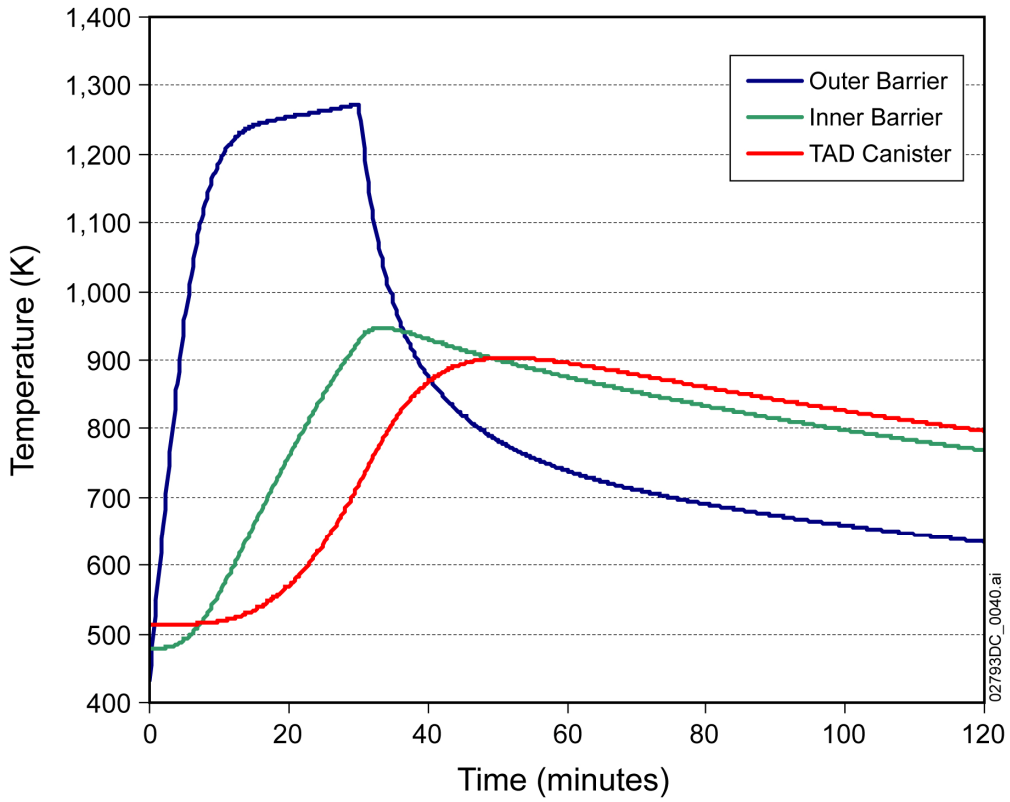

Figure 1. Calculated Temperatures for a Waste Package in a 30-minute, 1,400 K Fire

Source: BSC 2009, Attachment H

RAI Volume 2, Chapter 2.1.1.4, Second Set, Number 10:

Provide technical basis for selection of a 950 K temperature as a canister failure threshold temperature (Section D2.1.5.2 of BSC 2008b) for all canisters shown in Table D2.1-8. For example, selection of 950 K threshold appears to produce 32 observations in thin-walled canisters in which failure of canister is predicted to occur. These observations can be seen in Figure D.2.1-6, however, the corresponding observations in the response curve Figure D 2.1-4 do not seem to correlate with 950 K threshold. Relevance of Figure D 2.1-4 in the calculation is not clear. Clarification of (a) selection of 950 K threshold and (b) determination of "Total Failures" are necessary to support the failure probability found in Table D2.1-8.

1. RESPONSE

The 950 K temperature was not selected as a canister failure threshold temperature. The temperature of 950 K was used in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Section D2.1.5.2) for comparison of Figure D2.1-4 (probability distributions of canister failure temperature for thin-walled canisters) with Figure D2.1-6 (probability distribution for the maximum canister temperature for thin-walled canisters). The text notes that Figure D2.1-6 shows very few maximum canister temperatures in excess of 950 K, whereas Figure D2.1-4 shows canister failure temperatures that are generally greater than 1,100 K. The significance of this is that there is very little overlap between the two probability distributions. In fact, it is only in the upper tail of the maximum canister temperature distribution and the lower tail of the canister failure temperature distribution that the two temperatures are comparable.

With regard to the determination of "Total Failures" in Table D2.1.8 of the categorization analysis (BSC 2009), the analysis determines failure probability by performing Monte Carlo sampling of the distributions for canister failure temperature and maximum canister temperature to determine whether failure would be predicted for a given sample. If the predicted maximum canister temperature for the sample is greater than the sampled value for the canister failure temperature, then canister failure is predicted for that sample. The Monte Carlo sampling is repeated at least 100,000 times in order to get a sufficient number of samples for which failure would be predicted. A large number of samples is required because of the minimal overlap between the distributions. The resulting mean and standard deviation for the canister failure probability are provided in Table D2.1-8 of the categorization analysis (BSC 2009).

In summary, the 950 K temperature was not selected as a canister failure threshold temperature. It was provided as a point of comparison between the distributions for canister failure temperature and maximum canister temperature during a fire.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2009. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0004.

RAI Volume 2, Chapter 2.1.1.4, Second Set, Number 12:

> Justify the distribution of fire duration used in the fragility analysis, as given in Table D2.1–1 (BSC 2008b), and compare the distribution with the historical fire durations implied by data in Table F.II–2 of BSC (2008b).
>
> Table D2.1–1 (BSC 2008b) shows that only 1.1 percent of fires would last longer than 2 hours. Based on the historical data in Table F.II–2 for extent of fire damage in facilities handling radioactive material, and nuclear energy plants, it appears that 16 percent of fires would have sufficient duration and intensity to propagate through at least one (and perhaps multiple) fire resistance-rated barrier(s) within the facility. As these fire barriers are typically rated to resist substantial fires for between 1 and 4 hours, up to 16 percent of the fires could last longer than 2 hours, in contrast to 1.1 percent shown in Table D2.1-1.

1. RESPONSE

For the fragility analysis, the duration of the fire is from the perspective of the target (i.e., the cask or canister that could be compromised by the fire). Therefore, the fire duration used in the analysis is the amount of time a particular container is exposed to the fire, and not necessarily the amount of time a fire burns. As an example, a fire that propagates through a building over a four-hour period is not a four-hour hazard to a particular target. In calculating the exposure time for a specific target, it does not matter whether the fire started in the room where the target is, or it started in another room and ended where the target is, or the fire passed through the target room between its beginning and end. The exposure duration is how long the fire burns while consuming combustibles in the vicinity of the target (BSC 2009, Section D2.1.1).

Thus, the historical data for how long fires burn in a given facility are not equivalent to the fire duration used in the analysis (which is from the perspective of the waste form); consequently the comparison requested by the RAI is not a practical measure of the reasonableness of the distribution used in the analysis.

As noted above, the primary factor controlling the fire duration used in the analysis is the amount of combustible material in the vicinity of the waste form. For that reason, the fire duration was determined based largely on the results of test studies that examined the quantity and type of combustible materials common in industrial facilities. The test data indicated that the majority of the fires had durations less than 30 minutes, though there were several tests with durations in the range from 30 to 60 minutes, and two tests had durations between 60 and 80 minutes. A probability distribution was determined based on these data. The detailed rationale for the probability distribution is provided in Section D2.1.1.2 of the categorization analysis (BSC 2009) and is summarized herein.

Based on the test data, it was determined that the distribution should be characterized by a 0.1 fractile of 10 minutes and a 0.9 fractile of 60 minutes (i.e., it was concluded that 10% of the fires would result in a target exposure duration of less than 10 minutes, and 90% of the fires would result in a target exposure duration of less than 60 minutes) and a median value of approximately

25 minutes. It was also recognized that the distribution should provide a low probability for fires longer than 80 minutes to address conditions in which more combustible material may be present near the waste form than was evaluated in the tests. Therefore, a value of 120 minutes should be used to characterize the 0.99 fractile of the distribution.

A lognormal distribution was used to derive a probability distribution that adequately matched the desired characteristics. The mean and standard deviation were varied to obtain the best visual fit to the desired fractile values while minimizing the root mean square deviation between the desired and calculated percentile values. The best fit was obtained using a lognormal distribution with a mean of 3.192 and a standard deviation of 0.6943. As shown in Figure 1, this distribution adequately matches the desired fractile values.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2009. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0004.

Desired Fractile Values

Duration (minutes)	Cumulative Probability	Rationale for Fractiles
10	0.1	Near the low end of the test data
60	0.9	Near the upper end of the test data
25	0.5	Approximate median of test data
120	0.99	Assumed 1 percentile - includes potential for fires longer than in tests

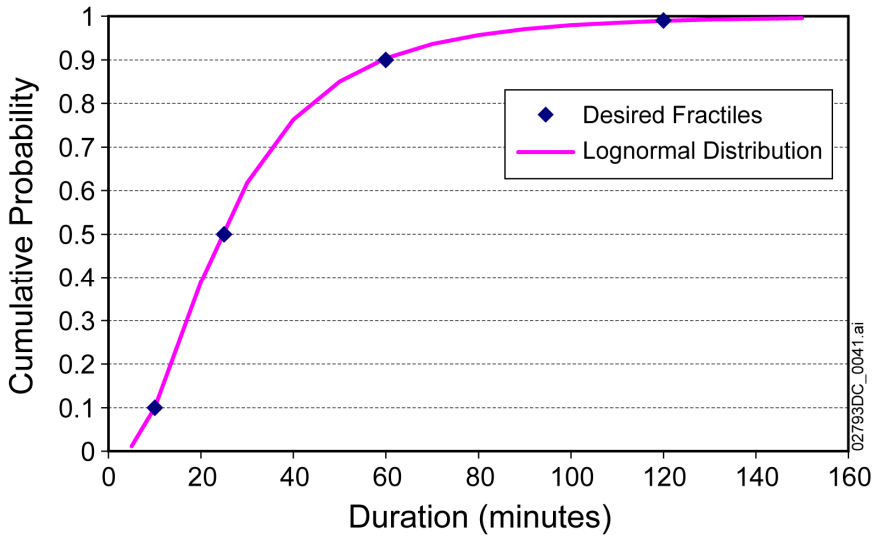

Figure 1. Excel Plot Comparing the Lognormal Distribution to the Desired Fractile Values

RAI Volume 2, Chapter 2.1.1.4, Second Set, Number 13:

> Provide technical justification of the assumed mean fire temperature 1,072 K [799ºC] and standard deviation of 172 K, assuming a normal distribution (BSC, 2008b, Section D2.1.2 Uncertainty in Fire Temperature).

1. RESPONSE

The technical justification for the assumed fire temperature distribution is provided in Section D2.1.2 of *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009) and is summarized herein.

The fire temperature distribution reflects experimental measurements for both hydrocarbon pool fires and fires involving combustible solids. Two different sets of tests with hydrocarbon fuels indicated fire temperatures in the range from 1,200 to 1,600 K and 1,089 to 1,200 K. The former values represent the temperature of the flame itself, whereas the latter values represent average fire temperatures, including the effects of soot and smoke. The latter values are considered more realistic for predicting heating by the fire. In addition to these data, data for the emissive power of hydrocarbon pool fires, which are shown in *SFPE Handbook for Fire Protection Engineering* (SFPE 1988, Figure 2.4.11), can be used to determine effective fire temperatures. The figure shows emissive powers ranging from about 40 to 130 kW/m^2 for pool fires with diameters from 1 to 15 m. These values correspond to effective blackbody fire temperatures from 920 to 1,230 K. Experimental data for solid combustibles discussed in *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (BSC 2009, Section D2.1.2) indicate peak temperatures in the range of 673 to 1,473 K.

The temperatures reported in the literature were generally peak temperatures and corresponded to the maximum heat release by the fire. In contrast, the model for canister heating in a fire treats the fire temperature as being constant during the entire fire duration. In other words, no attempt is made to model the time-dependent temperature variation that is typical of most fires. Consequently, the peak temperatures reported in the literature constitute a conservative use of the data.

In considering the fire temperature data discussed above, it was recognized that a fire within one of the repository facilities is likely to involve both combustible solid and liquid materials. Therefore, the probability distribution for fire temperature must include a wide range of potential values. A probability distribution was developed that captured the range of fire temperatures shown in the data. The desired characteristics of the distribution were as follows:

1. A practical upper bound (99.9 percentile) of 1,600 K, which was the maximum hydrocarbon pool fire temperature reported in the literature.

2. A one-percentile value of 400°C (673 K), which was the lowest peak temperature reported for solid combustible fuels (Note that the text in Section D2.1.2 of the categorization analysis (BSC 2009) mistakenly listed this temperature as the 5th percentile.)

3) A mean temperature comparable to the design basis fire temperature (800°C or 1,073 K) used in the safety analyses of spent fuel transportation casks to characterize a hypothetical fire accident, as mandated in 10 CFR 71.73.

A normal distribution was used to derive a probability distribution that adequately matched the desired characteristics. The mean and standard deviation were varied to obtain the best visual fit to the desired fractile values while minimizing the root mean square deviation between the desired and calculated values. The best fit was obtained using a normal distribution with a mean of 1,072 K and a standard deviation of 172 K. As shown in Figure 1, this normal distribution accurately matches the desired fractile values.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2009. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0004.

SFPE (Society of Fire Protection Engineers) 1988. *SFPE Handbook of Fire Protection Engineering*. 1st Edition. Quincy, Massachusetts: National Fire Protection Association. TIC: 101351.

Desired Fractile Values

Temperature (K)	Cumulative Probability	Rationale for Fractiles
673	0.01	From test data for solid combustibles
1,073	0.5	Near the midpoint of the solid and liquid combustible fire data
1,600	0.999	Upper bound from liquid hydrocarbon fires

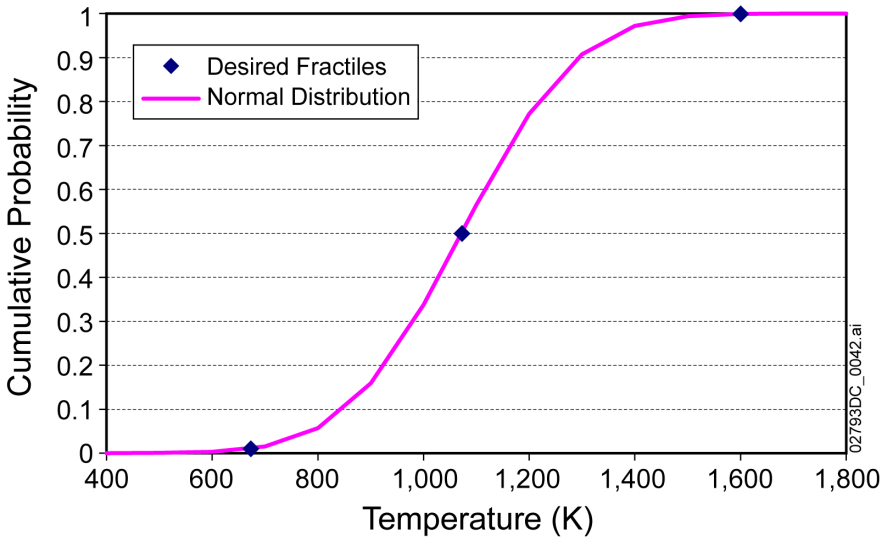

Figure 1. Excel Plot Comparing the Normal Distribution to the Desired Fractile Values