71-3072

U.S. Department
of Transportation
**Research and
Special Programs
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

NOV 23 2004

Mr. Stewart Brown
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards (NMSS)
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Brown:

In response to your recent request for additional information concerning the thermal protection characteristics of the FS-65 package, I am pleased to provide two copies of our applicant's response to your inquiries.

Since our applicant desires to use this package in an upcoming shipment, we request you provide an estimate of the time needed to complete your review. If you have any questions or need any additional safety information, please feel free to contact me at (202) 366-4545.

Sincerely,

Richard W. Boyle, Chief
Radioactive Materials Branch
Office of Hazardous Materials
Technology

Enclosures

NMSS01

PACTEC

November 10, 2004

Richard W. Boyle, Chief
Radioactive Materials Branch
Office of Hazardous Materials Technology
Research and Special Programs Administration
US Department of Transportation
400 Seventh Street SW
Washington, DC 20590-0001

SUBJECT: Additional Information for the Revalidation Application for the FS65 Cask
Docket # 71-3072

Dear Mr. Boyle:

Packaging Technology, Inc. (PacTec) in Tacoma, WA respectfully submits additional information with respect to the questions from the NRC on the thermal aspects of the FS65.

Please contact me at 253-383-9000 ext 26 or Joe Nichols at ext 37 if you have any questions or would like to discuss this matter further.

Sincerely,

Frederick L. Yapuncich, P.E.
Packaging Technology, Inc.

encl: as stated

Packaging Technology, Inc.
1102 Broadway Plaza, Suite 300 • Tacoma, WA 98402
Telephone: 253-383-9000 • Fax: 253-383-9002

1. Justify that simulated damage on the 'component' fire test is representative, or conservative, with respect to actual or expected damage incurred on an FS65 impact limiter resulting from an HAC free drop.

Damage observed in the FS65 drop tests are described in chapter 4187-Z-1-6 of the SAR. The prototype FS65 packaging was subjected to different statutory drop tests in order to demonstrate the resistance of the FS65 packaging. During these tests, the impact limiter of the FS65 suffered the damages that are summarized below:

- Vertical 9-meter drop 1 : crushing between 30 and 60 mm (cf. photo 1-6.1.C of chapter 4187-Z-1-6)

- Horizontal 9-meter drop 2 : crushing by approximately 40 mm over an angle of about 51°. Appearance of wood on front side (cf. photo 1-6.2.D of chapter 4187-1-6) : an opening on cover closing sheet metal plate in relation to rest of cover, of 50 mm × 30°, appears on its inside diameter

- Drop 3, front impact limiter 1-meter drop on spike : the recess on the exterior of the cover is approximately 48 mm around the impact (cf. photo 1-6.3.C of chapter 4187-Z-1-6). The external sheet metal plate on the cover is not sheared over the entire diameter of the spike.

- Oblique vertical 9-meter drop 4 on front impact limiter : the cover has a 90 mm indentation at an angle of $\theta = 150°$ (cf. photo 1-6.4.C of chapter 4187-Z-1-6).

The most severely damaged areas are openings of the impact limiter external shell. Openings appear during drops 2 and 3. The results of 1-meter drop on spike assures that the external shell is not completely sheared, thus the damage on the 'component' fire test is conservative (square 100 × 100 mm² hole, depth = 80 mm). The other damage on the 'component' fire test (uncovered wood on 90° and 100 mm height) is conservative with actual opening measured after drop 2 (of 50 mm × 30°).

The wood surface that is directly exposed to fire on the 'component' fire test is greater than actual damages of FS65 impact limiter resulting from an HAC free drop, thus the damages are conservative.

2. Justify that the 'component' fire test fire test results, which used a different internal wood species, is applicable to the FS65.

As described in "*Le Comportement du Bois en Feu*"[1], the density of the wood species is one of the major elements regarding its behavior during fire. Two different types of wood were exposed to fire during the fire test: balsa (density around 0.17) and oak (density around 0.6). The density of the red cedar that is used in FS65 impact limiter is around 0.35.

According to the fire test results, even a light wood like balsa does not burn considerably during fire and stopped burning at the end of test. Further discussion is provided in the response to question #3 which supports the conclusion that red cedar will not burn after the fire test and will not increase the temperature of the packaging seals due to its combustion.

Another major element regarding wood combustion is the heat released by wood during its combustion. The table 17-3 of "*Forest products Laboratory - Wood handbook : Wood as an engineering Material*"[2] shows that red cedar is one of the wood species that have the lowest heat release rate (at least 1.2 times lower than oak). This shows that this variety has a low combustibility.

Thus, the different internal wood species on the 'component' fire test are conservative in comparison with that of red cedar.

Table 17–3. Heat release data for selected wood species[a]

Species	Density[b] (kg/m³)	Heat release rate (kW/m²) Peak	60-s avg	180-s avg	300-s avg	Average effective heat of combustion[c] (MJ/kg)	Ignition time (s)
Softwoods							
Pine, red	525	209	163	143	132	12.9	24
Pine, white	359	209	150	117	103	13.6	17
Redcedar, eastern	—	175	92	95	85	11.7	25
Redwood	408	227	118	105	95	13.2	17
Hardwoods							
Birch	818	218	117	150	141	12.2	29
Maple, hard	826	218	128	146	137	11.7	31
Oak, red	593	214	115	140	129	11.4	28

[a]Data for 50-kW/m² heat flux in cone calorimeter. Tested in specimen holder without retaining frame. Specimens conditioned to 23°C, 50% relative humidity.
[b]Ovendry mass and volume.
[c]Tests terminated when average mass loss rate dropped below 1.5 g/s m² during 1-min period.

3. Justify the self extinguishing nature of the wood used in the impact limiter.

Wood will degrade under elevated temperature, with the severity of the degradation depending on the temperature level achieved and length of exposure[1,2,3,4]. While permanent reduction in strength can occur for prolonged exposure to temperatures greater than 65 °C, thermal degradation begins at temperatures greater than 100 °C when the chemical bonds begin to break. While the presence of minerals and moisture within the wood will tend to smear the separate pyrolysis processes of the major wood components, the major steps are as follows[4]:

- Stage 1: between 100 °C and 200 °C, the wood becomes dehydrated and generates water vapor and other noncombustible gases and liquids. The reaction is endothermic.
- Stage 2: from 200 °C to 300 °C, the majority of the water has vaporized, some wood components begin to undergo significant pyrolysis, and significant amounts of CO and high-boiling-point tar are given off. Overall, the pyrolysis reactions in this temperature range are endothermic, although exothermic reactions of the exposed char and volatiles with the atmospheric oxygen may be manifested as 'glowing combustion'. Char is the main product at internal temperatures less than 300 °C. If the external ignition source is removed with the wood in this state, the pyrolysis process will decrease and the combustion will cease.
- Stage 3: the majority of wood decomposition occurs from 300 °C to 450 °C and is characterized by the vigorous production of flammable volatiles. Significant depolymerization of cellulose occurs in the temperature range of 300 - 350 °C. Also, around 300 °C aliphatic side chains start splitting off from aromatic rings in the lignin. Finally, the carbon-carbon linkage between lignin structural units is cleaved from 370 °C to 400 °C. The degradation reaction of lignin is an exothermic reaction, with peaks occurring between 225 °C and 450 °C, with the temperatures and amplitudes of these peaks depending on the environment under which the pyrolysis occurs.
- Stage 4: The wood components rapidly form volatile and flammable gases at around 450 °C. In this "high-temperature pathway," the pyrolysis of wood results in overall low char residues of around 25% or less of original dry weight. In the range of 400 °C to 500 °C the flammable volatiles can be ignited if the air mixture is right – this gas combustion appears as flames. At > 450 °C, the remaining wood residue is char, which undergoes further degradation by being oxidized to CO2, CO, and H2O. This process is generally referred to as the 'afterglow'.

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[1] *Wood Handbook--Wood As An Engineering Material*, General Technical Report #FPL-GTR-113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 1999.

[2] Tran, H. C., and White, R. H., *Burning Rate of Solid Wood Measured in a Heat Release Calrimeter*, Fire and Materials, Vol. 16, pp 197-206, 1992.

[3] Suuberg, E. M., Milosavljevic, I., and Lily, W. D., *Behavior Of Charring Materials In Simulated Fire Environments*, NIST-GCR-94-645, U.S, Dept. of Commerce, June 1994.

[4] White, R. H. and Dietenberger, M. A., *Wood Products: Thermal Degradation and Fire*, Encyclopedia of Materials: Science and Technology, pp 9712-9716, 2001.

Based on the above information, the maximum allowable temperature for wood under NCT conditions is assumed to be 100 °C for peak temperatures based on the onset of thermal decomposition and 65 °C for average temperatures based upon loss of strength considerations. The maximum payload temperature is assumed to be 230 °C based on the ignition temperature of paper.

The ignition of wood, defined as the start of sustained combustion fueled by wood pyrolysis, requires the wood to be subjected to sufficient heat and in an atmosphere with sufficient oxygen. The wood surface is ignited by the flow of energy or heat flux from a fire or other heated objects, with the energy flow typically having both convective and radiative components. Therefore, unless there is sufficient heating of the wood and free passage of air, the wood will not ignite and will not burn. While there may not be active combustion in the absence of oxygen, the wood will still undergo thermal decomposition if exposed to elevated temperatures. This decomposition will be limited to the production of water vapor, carbon monoxide, and non-flammable and flammable volatiles. In the absence of oxygen, the process will be endothermic. The decomposition will be self-limiting since the wood char has a lower thermal conductivity than the virgin material.

The level of ignition temperature required depends on whether the ignition is piloted or un-piloted. Studies[5] have shown that piloted ignition occurs when the surface temperature reaches 300 °C to 400 °C, with lower ignition temperatures required for lower density woods. Un-piloted ignition temperatures depend highly on the specific circumstances. For un-piloted ignition of wood under radiant heating, temperatures as high as 600 °C are required, while un-piloted ignition under convective heating has been observed as low as 270 °C and as high as 470 °C. The difference in ignition temperatures related to the fact that un-piloted, radiant heated samples had to achieve a sufficient gas temperature of the volatized gases to promote auto ignition, whereas the elevated air temperatures associated with either the piloted ignition or the un-piloted convective heating was sufficient to ignite the volatized gases.

Studies[1,5] have shown that the redwood will ignite in as little as 3 seconds when exposed to a heat flux of 40 to 60 kW/m^2. Once ignited, the wood will burn/char at a fairly uniform rate, depending on the incident heat flux and the availability of oxygen. The observed rates for redwood[5] (see Figure 1) varied from 0.543 mm/minute for an incident heat flux of approximately 18 kW/m^2 to 0.950 mm/minute for an incident heat flux of approximately 56 kW/m^2. Therefore, the rate at which the wood will be consumed depends on the surface area vs. depth of any individual piece, and the incident heat flux.

Upon ignition, the heat release rate from wood will quickly rise to a peak level and then fall off over the next 5 to 10 minutes to a long term average heat release rate. Figure 2 illustrates the relationship between the average heat release rate, expressed as a surface heat flux, versus the incident heat flux[5]. The figure reflects the intuitively expected results that a) wood isolated from surrounding heat sources (i.e., not in a 'tight campfire') will not burn as 'hot' as when it is surrounded by other heat sources, and b) that redwood will not burn as hot as other species of wood. With the exception of the high temperature (i.e., temperatures > 450 °C) degradation of wood char, the combustion of wood occurs not in the wood itself, but

[5] Tran, H. C., and White, R. H., *Burning Rate of Solid Wood Measured in a Heat Release Calrimeter*, Fire and Materials, Vol. 16, pp 197-206, 1992.

within the volatized gas layer above the wood surface. As such, sustained combustion requires the continued heating of the wood core to a sufficient degree to pyrolyze the wood. The relatively poor thermal conductivity of wood and the even lower thermal conductivity of wood char works against this continued heating. These facts explain the characteristically good fire performance of heavy timbers[6] and the inability to sustain burning within a thick piece of wood in the absence of continued and mutual heating from surrounding heat sources.

It should be noted that, since wood combustion occurs in the gas layer above solid surface, the heat release rates depicted in Figure 2 do not reflect the energy input to the wood solids. Instead, a major portion of the released heat is transferred to the surrounding atmosphere via radiation and convection, plus mass transport via the volatiles leaving the wood. The actual heat input to the underlying wood is dependant on the transient heat balance between the heat generated by the combustion, minus the heat lost to the surroundings via radiation, convection, and mass transport. Surface temperature measurements on burning Douglas fir specimens[7] indicate peak surface temperatures of 800 to 850 °C for external heat flux loadings of 60 to 65 kW/m^2 and with no restrictions on the availability of oxygen. Douglas fir has a similar heat release rate as redwood[8].

Based on the above data, the following conclusions can be drawn:

- The wood needs to be heated to 300 °C to 400 °C to initiate piloted combustion.
- The pyrolysis process of wood is endothermic below the ignition point.
- The absence of oxygen will prevent combustion, but not thermal degradation of the wood.
- The heat release from the combustion of redwood will average approximately 90 kW/m^2 with an incident heat flux of 60 kW/m^2.
- With an incident heat flux of approximately 60 kW/m^2, the peak surface temperature of the wood will be 800 to 850 °C.
- Reducing the incident heat flux from 60 kW/m^2 to 18 kW/m^2 will reduce the average heat release for redwood from approximately 90 kW/m^2 to approximately 40 kW/m^2, a 56% reduction.

Due to the relatively poor thermal conductivity of wood, removal of the incident heat flux for thick pieces of wood will reduce the heating of the core region of the wood to the point that combustion can not be sustained.

[6] Andersson, Stefan, *An Analysis of the Combustion Properties of Wood*, Center for Fire Safety Studies, Worcester Polytechnic Institute.

[7] Urbas, J., and Parker, W. J., *Surface Temperature Measurements on Burning Wood Specimens in the Cone Calorimeter and the Effect of Grain Orientation*, Fire And Materials, Vol. 17, pp 205-208, 1993.

[8] Tran, H. C., *Experimental Data On Wood Materials*, Heat Release In Fires, Elsevier Applied Science, Chapter 11, part b, 1992.

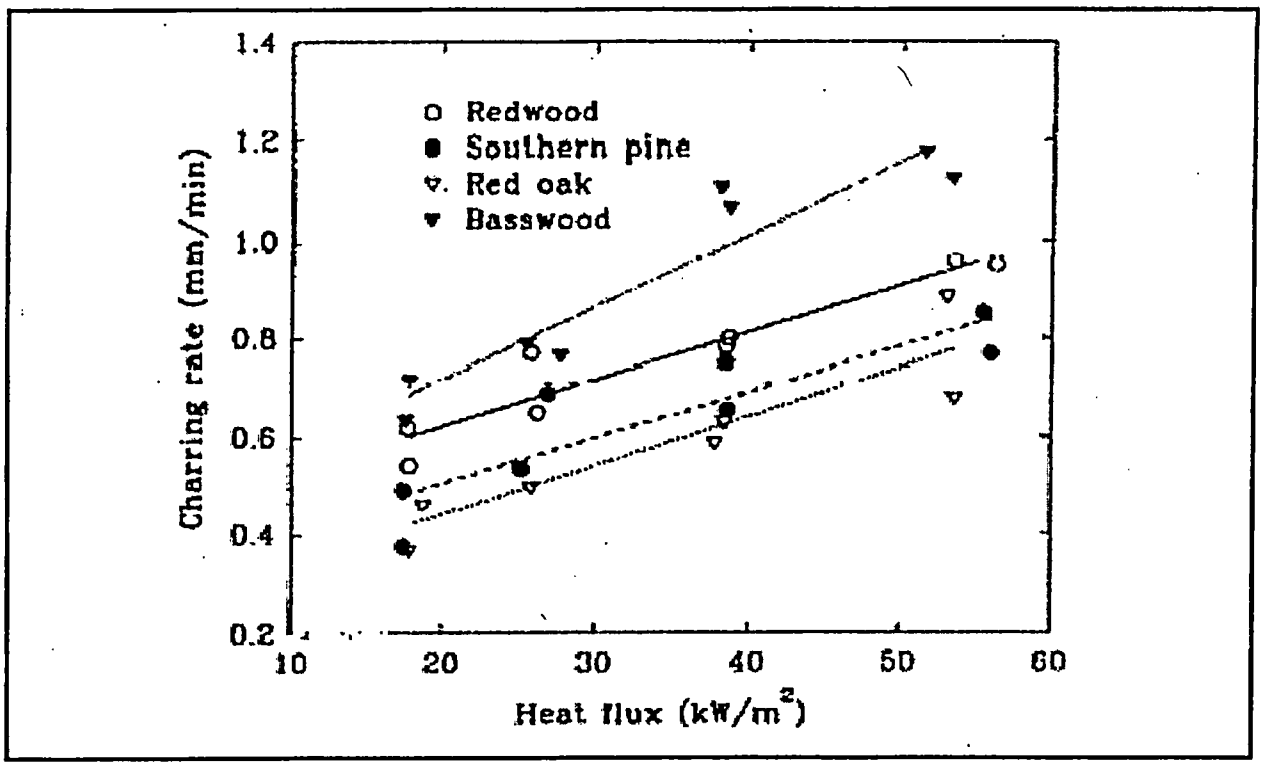

Figure 1 – Average Wood Charring Rate vs. Incident Heat Flux

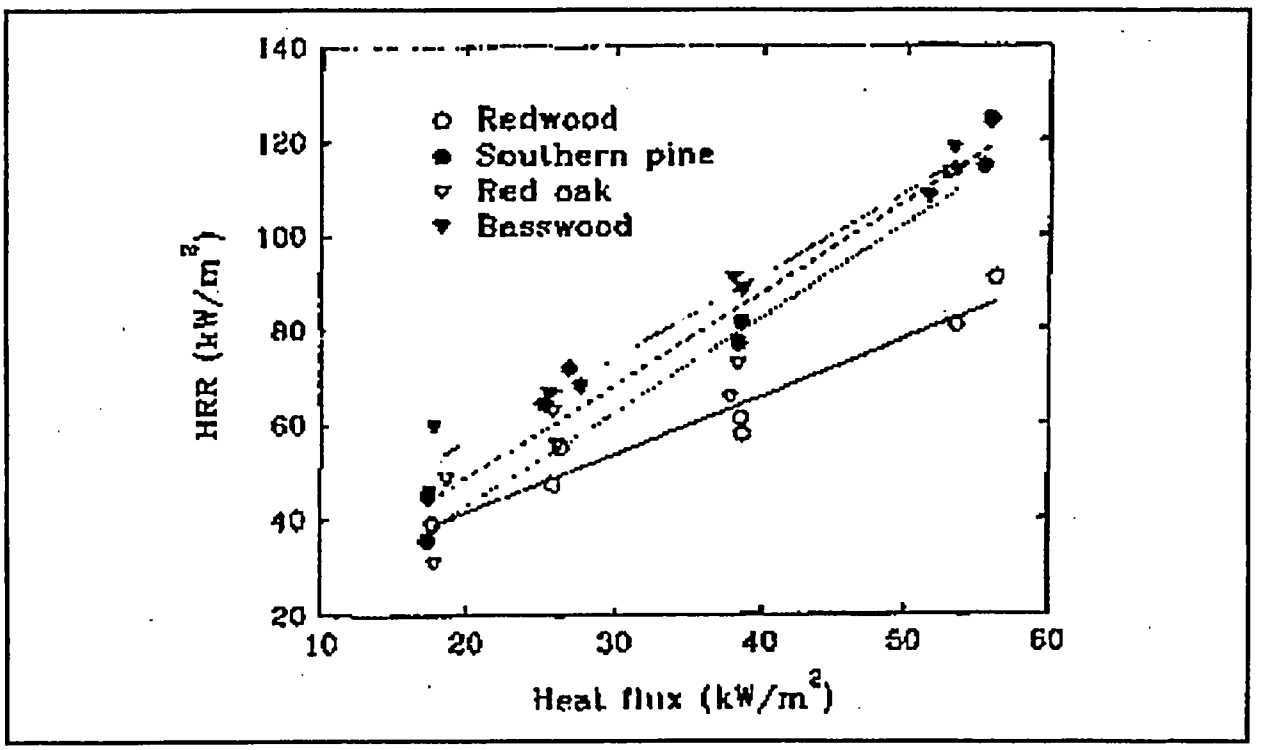

Figure 2 – Average Wood Heat Release Rate vs. Incident Heat Flux

4. Explain the FS65 ISO container name in more detail.

A description of the containers is provided in COGEMA LOGISTICS document 13366-B-18 which contains the thermal analysis of 4 FS65 packages within a CBTO6M/1 or CBTO6M/2 container. CBTO6M/1 and CBTO6M/2 containers are identical. The numbers /1 and /2 refer to the serial number of the container.