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Heat Load Limits for TRU Drums on Pads (U)

by

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Summary

Some of the Trans-Uranic (TRU) waste generated at SRS is packaged in 55 gallon, galvanized steel drums and stored on concrete pads that are exposed to the weather. It was necessary to compute how much heat can be generated by the waste in these drums without exceeding the temperature limits of the contents of the drum.

This report documents the calculation of heat load limits for the drum, which depend on the temperature limits of the contents of the drum. The applicable temperature limits for the contents of the drum are the melting temperature of the polyethylene liner, 284°±8°F [Fink and Meyer, 1993], the combustion temperature of paper, 450°F [Clontz, 1973] and the decomposition temperature of anionic resin, 190°F [Clontz]. Drums that do not contain resin, the majority, are limited by the combustion temperature of paper to a heat load of 32 btu per hour (9.4 watts) based on a low thermal conductivity of 0.02 btu/hr ft °F for the waste. If the waste had a higher thermal conductivity of 0.05 the heat load limit would be 74 btu per hour (21.7 watts). The permissible heat load for a drum containing anion resin is zero for any thermal conductivity, because the interior temperature of the drum exceeds the decomposition temperature of the resin for worst case conditions of weather, absorptance and emittance, even with no heat load. Under the worst case conditions and for zero heat load, a drum lid and the liner under it reach 194°F. With an internal heat load of 32 btu per hour the lid temperature increases to only 197°F, much less than the melting temperature of the liner.

One part of the analysis leading to the heat load limits was the collection of weather records on solar flux, wind speed and air temperature. Another part of the task was an experimental measurement of two important properties of the drum lid, the emittance and the absorptance. As used here, emittance is the rate at which an object emits infrared thermal radiation divided by the rate at which a perfect black body at the same temperature emits thermal radiation. Absorptance is the rate at which an object absorbs solar radiation divided by the rate at which a perfect black body absorbs radiation. For nine locations on each of eight typical weathered drum lids the measured emittance ranged from 0.73 ± 0.05 to 1.00 ± 0.07 (95% confidence level) and the average emittance for the eight lids was 0.85. For the eight drum lids the measured absorptance ranged from 0.64 ± 0.07 to 0.79 ± 0.07 with an average absorptance for the eight lids of 0.739.

A previous report [Spatz, 1993] gave the results of heat load limits for TRU waste in other configurations, including for the case of drums under cover, but not for the present case of drums on TRU pads.

Description of Drum

The steel 55 gallon drum is made from galvanized steel with inner diameter, outer diameter and inside height of 22.5 inches, 23.5 inches and 32.8 inches, respectively. The difference between inside and outside diameters is primarily the result of circumferential ridges rather than wall thickness. Inside the drum is a high density polyethylene liner with a sealing lid, an outside diameter of 22.0 inches and a height of 32.0 inches. Therefore, the gap between the drum and the liner is 0.25 inch on the sides and is 0.8 inch at the top. A drum contains seven bags or cuts of job-control waste [Meyer and Shappell, 1993]. The cuts typically contain paper, wipes, cloth rags, uniforms, cartons and other materials. Only drums containing less than 0.5 Ci are placed on open TRU pads. Nearly all of the heat load is from the isotope Pu-238. The drums analyzed here are stored on a pad and exposed to the weather.

Thermal Analysis of Drum Lid

The drum lid was analyzed first because it was a candidate for the limiting temperature. The drum is a three dimensional object exposed to time varying conditions. It is desirable to simplify the analysis. Two simplifications were considered, making the analysis zero dimensional and making the analysis quasi-steady state. Zero dimensional means that only one temperature describes both the entire drum lid and the entire top of the liner. Quasi-steady state means that the drum lid/liner temperature has a time constant that is short compared to the length of a day. The time constant is the time required for a system initially at thermal steady state to make a 63% response to a step change in boundary conditions.

A simple analysis demonstrates that quasi-steady state analysis is appropriate for the lid and the top of the liner. The time constant for the lid alone is [Kreith, p. 140]

$$\tau_{lid} = \frac{\rho \, C \, \delta_{lid}}{h} \tag{1}$$

where ρ, C, δ_{lid} and h are the density (490 lb/ft^3), heat capacity (0.11 btu/lb°F), thickness (16 gage or 0.060 inch) and heat transfer coefficient (typically 2 btu/ft^2 hr °F). (A nomenclature appears at the end of the report) Therefore, the time constant for the lid alone is eight minutes, which is a short time compared to a day. Now consider the 0.8 inch air gap between the lid and the top of the liner. Rohsenow [p. 4-55] contains graphical solutions to transient heat conduction through a layer, where non-dimensionalized temperature is a function of the Biot and Fourier numbers,

$$Bi = \frac{h \, \delta_{air}}{k} \tag{2}$$

$$Fo = \frac{\alpha \, t}{\delta_{air}^2} \tag{3}$$

where k and α are the thermal conductivity and thermal diffusivity of the loose waste, respectively. The Biot and Fourier numbers for the layer are evaluated at 200°F to be 8 and 270 t, where time is in hours. From Figure 25d of Rohsenow the value of the Fourier number for a 63% change in the temperature of the rear face of the air gap is 0.63. Solving gives the time equal to eight seconds. The time constants for both the lid and the air layer below it are both short. Therefore, it is concluded that a quasi-steady analysis is justified for the drum lid and the top of the liner.

However, a quasi-steady analysis is not justified for the entire drum, when considering the temperature of the center of the drum. Approximate the drum as a sphere with a radius of one foot. The thermal conductivity and heat capacity of the contents are 0.02 btu/ft hr °F and 0.6 btu/lb °F. Estimate that there are eight hours of strong sunlight every day. The corresponding Biot and Fourier numbers are 100 and 0.044. Figure 31b of Rohsenow shows that the temperature of the center of the drum changes less than 3% of the change in the temperature of the outside surface of the drum.

For the present analysis a drum has a lid and sides. The hottest part of the day and the highest incident solar flux occur near noon. Therefore, the maximum temperature of the drum lid over the course of a day will always be hotter than the maximum temperature of the sides. Thus the analysis will concentrate on the drum lid only. The temperature histories of the lid and sides of the drum are different. Heat transfer between the top and sides is by heat conduction through the drum. However, the previous paragraph made the point that transient conduction through the drum responds far more slowly than the surface temperature responds. Therefore, the temperatures of the lid and sides of the drum are nearly independent. Further, the temperature of the drum lid is a weak function of position and it is reasonable to characterize the temperature of the drum lid with a single temperature, that is, a zero-dimensional analysis.

The steady zero-dimensional energy balance equation for a drum lid follows [Kreith, 1973]

$$q_{net} = q_s + q_a + q_t - q_c - q_k - q_r \tag{4}$$

where q_{net} = net heat flux
q_s = direct solar flux intercepted by body
q_a = solar flux scattered from particles in the atmosphere
q_t = radiant flux from earth
q_c = net convection away from body
q_k = net conduction away from body
q_r = radiant flux emitted by body

The net flux is zero because the lid is quasi-steady state. The radiant flux from the earth is negligible for the upward facing drum lids. The net conduction through the drum is attributed to internal generation. After deleting the negligible terms and substituting for the rest of the terms the result follows

$$q_{int} + q_{S\,M}\,\alpha_L + (T_L - T_A)\,h_m - \sigma\,\varepsilon_L\,[(T_L + 460)^4 - (T_{sky} + 460)^4] = 0 \tag{5}$$

where q_{int} = internal heat load in drum divided by area of lid
$q_{S\,M}$ = measured solar flux, including atmospheric scattering, at a horizontal plane
α_L = absorptance of the lid for solar wavelengths
T_L = lid temperature, °F
T_{sky} = sky temperature, °F
T_A = ambient temperature, °F
h_m = heat transfer coefficient for mixed convection
σ = Boltzmann constant = 0.1714×10^{-8} btu/ft^2 hr °R^4
ε_L = emittance for lid

The measurement of absorptance and emittance will be described in a subsequent section. Mixed convection means involving both natural convection and forced convection. Rohsenow, et al. [1985] give an equation for mixed convection. After translating from Nusselt numbers to heat transfer coefficients their equation becomes the following, where h_f and h_n are heat transfer coefficients for forced convection and natural convection, respectively.

$$h_m = (h_f^3 + h_n^3)^{1/3} \tag{6}$$

Kreith recommends the following equation for natural convection from a horizontal plate.

$$h_n = \frac{L}{k}\,0.14\,(Gr_L\,Pr)^{1/3} \tag{7}$$

The symbols L, k and Pr are the length of the plate, the thermal conductivity of air and the Prandtl number for air, respectively. The Grashof number is

$$Gr_L = \frac{\Delta T\, L^3\, \beta\, g}{\nu^2} \tag{8}$$

All properties in equations 7 and 8 are evaluated at the film temperature, the average of the ambient temperature and the surface temperature, with the exception of β which is evaluated at the ambient temperature.

For the forced convection heat transfer coefficient the following correlation for a heat transfer from a flat plate in the laminar flow regime [Kreith] was used. The laminar flow regime will exist for the relatively low wind velocities that are the most restrictive situation.

$$\frac{h\, L}{k} = 0.664\, Re_L^{1/2}\, Pr^{1/3} \tag{9}$$

The Reynolds number is

$$Re_L = \frac{u\, L}{\nu} \tag{10}$$

Weather records

Evaluation of the preceding equation requires data on ambient temperature, wind speed and solar flux. As the result of a request, Kurzeja and Weber [1993] of the Environmental Technology Section transmitted weather records for wind speed, ambient temperature and solar radiant flux. The solar flux was measured at a horizontal plane and included scattering from the atmosphere. Each tabular data point is the average for a fifteen minute interval. The data were for July 1991 and July 1992 and for the period of the day from 08:00 to 19:45. The data base was limited to July to reduce the amount of data to be handled and because July is historically the hottest month of the year. Sample plots of the data are shown in Figures 1 through 3. The uncertainty for wind speed is ±1% of the reading, with the exception that the instrument will register zero for wind speeds less than 1.5 foot per second because of friction. The uncertainties for temperature and solar flux are ±2°C and ±2% of the reading, respectively.

Measurement of Emittance and Absorptance for Drum Lids

Eight typical drum lids were delivered to the Heat Transfer Laboratory (HTL). Emittance was measured at the HTL using an Omega infrared pyrometer, model 2102S (Measuring and Test Equipment # EA-413). Ordinarily a known emittance is input to the pyrometer before it is pointed at the surface whose temperature is to be measured. The pyrometer measures the radiant flux from the surface and computes the surface's temperature, taking into account the input emittance. This process was inverted to measure emittance of the drum lids. First, the pyrometer was calibrated. Part of the calibration checked that the functional relationship between the emittance and indicated temperature was correct. Then, a thermocouple was silver soldered to the underside of each of the eight lids. Low temperature silver solder was used to avoid discoloration of the surface. The emittance of part of the surface was changed to a high value by applying a piece of masking tape, known to have an emittance of 0.95 [Omega, 1988], to the surface. The entire surface was heated to approximately 100°C by boiling water underneath the surface. The pyrometer emittance was set at 0.95 and the pyrometer was used to measure the temperature of the masking tape on the surface. Then, the pyrometer was pointed at an adjacent part of the surface at the same temperature but with no masking tape. The input emittance was adjusted until the indicated temperature was the same as for the masking tape. The pyrometer input emittance was the emittance of the surface. This was repeated for a total of nine spots on each of eight drum lids.

To measure absorptance the masking tape was removed and the holes that some of the lids had were patched using small pieces of shim stock. The thermocouples on the backs of the lids remained in place. A square wooden frame one inch thick and about one foot square was placed on the surface and air leaks were sealed with masking tape. Polyethylene film (0.9 mil thick) was attached to the top side of the frame to prevent air currents across the lid. Glass was initially considered for the glazing material but glass blocks almost all of the infrared radiation emitted by the lid. Polyethylene film transmitted 86.5% of the infrared radiation and thus allowed a more accurate measurement of absorptance. The back of the lid was insulated with fiberglass insulation. The purpose of the frame, glass and insulation was to greatly reduce convective losses and therefore, increase the accuracy of the measurement. The lid was placed horizontally in the sun near noon in a position that was largely sheltered from the prevailing light winds. After allowing time for thermal equilibrium the ambient temperature, the lid temperature and the solar flux were measured. Solar flux was measured using an Eppley Model 8-48 Black and White Pyranometer, borrowed from the SRS Meteorology Group [Kurzeja and Weber, 1993]. It measures whole sky solar radiation impinging on a horizontal surface.

Analysis of Absorptance Data

Heat transfer for the measurement of absorptance was modeled with energy balances around the lid and the polyethylene film as illustrated in Figure 4. The steady state energy balance for the lid follows.

$$q_S \tau_{FS} \alpha_L + q_S \tau_{FS} (1 - \alpha_L) \rho = (T_L - T_F) \frac{k_{air} Nu}{\delta} + \sigma \varepsilon_L \tau_{FR} [(T_L + 460)^4 - T_{sky} + 460)^4]$$

$$+ \sigma \varepsilon_F \varepsilon_L [(T_L + 460)^4 - (T_F + 460)^4] \qquad (11)$$

The first term is the part of the solar flux that both penetrates the film and is absorbed by the lid. The second term is the part of the solar flux that penetrates the film, is reflected by the lid, is reflected by the film and then is absorbed by the lid. It is usually a small term. The third term is the flux convected through air from the lid to the film. For pure conduction the Nusselt number is one. However, for this geometry the Rayleigh number is high enough that the Nusselt number is greater than one, as will be shown. The fourth term is the flux radiated from the lid, through the film, to the sky. The temperature of the sky is usually lower than the ambient temperature. The fifth term is the flux radiated from the lid to the film. Radiant shape factors for the last two terms are not explicitly stated but are nearly unity.

The energy balance for the polyethylene film follows.

$$q_S \alpha_F + q_S \alpha_F \tau_{FS} (1 - \alpha_L) + \sigma \varepsilon_F \varepsilon_L [(T_L + 460)^4 - (T_F + 460)^4] + \frac{Nu\, k_{air}}{\delta} (T_L - T_F)$$

$$= (T_F - T_{amb}) h_m + \sigma \varepsilon_F [(T_F + 460)^4 - (T_{sky} + 460)^4] \qquad (12)$$

The first term is the part of the incoming solar flux that is absorbed by the film. The second term is the part of the flux reflected from the lid that is absorbed by the film. The third term is the net radiant flux from the lid to the film. The fourth term is the flux convected through air from the lid to the film. The fifth term is the convective flux from the film to the environment. The sixth term is the radiant flux from the film to the sky. All terms in equations 11 and 12 were either measured or found in handbooks with the exception of the absorptance of the lid and the temperature of the film. Having two equations with two unknowns, α_L and T_F, allowed a unique solution.

The terms in equations 11 and 12 were evaluated as follows. The solar flux, q_s, was measured. The transmittance of the film to solar wavelengths, $\tau_{F\,S}$, was computed by comparing the solar fluxes measured with and without the film in front of the flux meter. The absorptance of the lid was the variable to be solved for. The reflectance of the film was determined using the following equation [Siegel and Howell, 1981].

$$\rho = \left(\frac{n-1}{n+1}\right)^2 \qquad (13)$$

The term n is the refractive index of the film, which has a value of 1.54 [CRC]. Therefore, the reflectance is 0.045. T_L is the measured temperature of the lid. T_F is the computed film temperature. The Nusselt number for convection across the air gap was determined using the following correlation [Rohsenow, et al., 1985]

$$Nu = 1 + \left[1 - \frac{1708}{Ra}\right]\left[1.4 + 2\left(\frac{Ra^{1/3}}{400}\right)^{1 - \ln\left(\frac{Ra^{1/3}}{400}\right)}\right]\left[\left(\frac{Ra}{5830}\right)^{1/3} - 1\right] \qquad (14)$$

where the Rayleigh number is

$$Ra = \frac{\delta^3 g\, \beta\, \Delta T\ Pr}{\nu^2} \qquad (15)$$

The transmittance of the film to infrared radiation was measured by measuring the temperature of a piece of masking tape on a hot surface both with and without the film interposed. With the pyrometer emittance set at 0.95 the temperature readings were 196° and 208°F, respectively and the ambient temperature was 88°F. The radiant fluxes to the pyrometer follow, where C is a constant containing geometric factors and emittance.

$$q_{no\ film} = C\,\sigma\ [(208 + 460)^4 - (88 + 460)^4] \qquad (16)$$

$$q_{film} = C\,\sigma\ [(196 + 460)^4 - (88 + 460)^4] \qquad (17)$$

Transmittance was the ratio of the two fluxes or 86.5%.

The temperature of the sky was determined by setting the emittance of the infrared pyrometer to 1.00, pointing it straight up and taking temperature readings. A typical sky temperature was 19°F.

The radiant energy striking a transparent object like the film is divided between reflection, transmission and absorptance (or emittance). Therefore, the absorptance of the film was found by subtracting the sum of reflectance and transmission from one.

The heat transfer coefficient from the film to ambient was evaluated using equations 6 through 10.

Results of Tests

Table 1 shows the emittances measured for the eight weathered drum lids. The average emittance for a drum lid varied from 0.762 to 0.968 with a mean of 0.848. In addition, the emittance for shiny new galvanized steel sheet was measured to verify that it was much lower.

Raw data for the absorptance tests are listed in Table 2. Equations 11 and 12 were solved to determine absorptance of the lids, listed in Table 3. Absorptance ranged from 0.643 to 0.791 with a mean of 0.738. In addition, the absorptance for shiny new galvanized steel sheet was measured at two different times to verify that it was much lower. Generally, the lower the absorptance and the higher the emittance, the lower the drum lid temperature.

Uncertainty Analysis

Emittance was measured using an infrared pyrometer. After calibration at the Savannah River Standards Laboratory, the uncertainty of the pyrometer for a single reading was ±3°C. Part of that uncertainty was bias error and part was random error. Averaging a number of readings effectively removed the random error leaving a residual bias error of 2°C. The calibration was performed with different emittance settings. Review of the calibration records indicates that the 2°C error translated to an uncertainty of 7% of the emittance reading. The lower the emittance, the higher the lid temperature. The lowest spot emittance anywhere on the lids was 0.73. A further reduction of 7% gives a worst case emittance of 0.68.

The tests for absorptance involved a number of measurements, all of which had uncertainty. The uncertainty of the thermocouples used to measure the temperatures of the drum lid and the ambient temperature was ±2°C. Solar flux was measured with an accuracy of ±2%. Wind velocity at the HTL could have been 4 feet per second inaccurate. The temperature of the sky could have been 13°F inaccurate. The correlation for mixed convection heat transfer coefficient could have been 20% inaccurate. The correlation for Nusselt number for the air gap could have been 20% inaccurate. Uncertainty in absorptance was propagated using the root sum square of the contributions from the different sources. The resulting uncertainty in absorptance was 0.069. The higher the absorptance, the higher the lid temperature. The highest lid absorptance was 0.791. A further increase of 0.069 gives a worst case absorptance of 0.860.

Computed Temperatures of Drum Lids

The equation of the drum lid is given by equation 5. This equation was linearized to allow solution of the drum lid temperature for the actual weather conditions in July 1991 and July 1992. The lid temperature in equation 5 was replaced by the sum of a high side estimate of the temperature, T_E, and a fluctuating part, T'.

$$T_L = T_E + T' \tag{18}$$

After substitution into equation 5, the result was

$$q_{int} + q_{S\,M}\,\alpha_L + (T_E + T' - T_A)\,h_m - \sigma\,\varepsilon_L\,[(T_E + T' + 460)^4 - (T_{sky} + 460)^4] = 0 \tag{19}$$

The Taylor series expansion of the term involving T_E raised to the fourth power follows.

$$(T_E + T' + 460)^4 = (T_E + 460)^4 + 4\,T'\,(T_E + 460)^3 + \ldots \tag{20}$$

Substituting equation 20 into equation 19 and solving for T' gives

$$T' = \frac{q_{int} + q_{S\,M}\,\alpha_L - h_m\,(T_E - T_{amb}) - \varepsilon_L\,\sigma\,(T_E + 460)^4 + \varepsilon_L\,\sigma\,(T_{sky} + 460)^4}{h_m + \varepsilon_L\,\sigma\,4\,(T_E + 460)^3} \qquad (21)$$

Equation 21 was evaluated for T' using the worst case absorptance of 0.860, the worst case emittance of 0.68 and weather records for T_{amb} and $q_{S\,M}$. The heat transfer coefficient for mixed convection was computed for equations 6 through 10 using weather records. The term T_E was adjusted so that the maximum value of T' was about zero. This resulted in the greatest accuracy of the Taylor series approximation corresponding to the maximum daily drum lid temperature. The computed values of T' were added to T_E to give the drum lid temperature at fifteen minute intervals. The maximum lid temperature each day for a zero internal heat load was extracted and plotted in Figure 5. The overall maximum lid temperature for the two years was 194°F. For an internal heat load of 100 btu per hour the lid temperatures increase about 12°F. This is much less than the polyethylene liner melting temperature of 284°±8°F and the paper ignition temperature of 450°F. However, even the zero heat load lid temperature exceeds the decomposition temperature of anion resin, 190°. Assuming that resin could be positioned near the lid, the resin would decompose under worst case conditions of weather, emittance and absorptance, even with no internal heat load.

Heat Conduction Inside Drum

The contents of the drum generate heat which must be dissipated. In the worst case all of the heat generation occurs in one cut, which is located in the worst possible position in the drum. A single waste cut has a volume of five gallons [Meyer, 1990]. To simplify the computation assume that the cut is in the shape of a cylinder with height and diameter both equal to 0.95 feet. The drums are stacked two high. Consider first that the cut in the top drum is at bottom center and the cut in the bottom drum is at top center forming a heat producing cylinder almost two feet long. As a conservative approximation, all heat transfer is in the radial direction to the sides of the drums. Any axial heat conduction would decrease the maximum temperature.

The total temperature drop from the centerline of the drum to ambient conditions follows.

$$\Delta T_t = \frac{Q_D\,D_i^2}{16\,k\,V_{cut}} + \frac{Q_D \ln\frac{D_o}{D_i}}{2\,\pi\,k\,H} + \frac{Q_D}{\pi\,D_o\,H\,h} \qquad (22)$$

The first term is the temperature drop across the heat generating region where Q_D is the heat production of both the drum and the cut and V_{cut} is the volume of the cut. The second term is the temperature drop through the non-heat producing region where the terms D_o, D_i and H are the diameter of the drum, the diameter of the cut and the height of the cut. The third term is the temperature drop from the surface of the drum to ambient where h is the heat transfer coefficient in the restricted space between the stacked drums. The restricted heat transfer coefficient was set to one-third the unrestricted heat transfer coefficient from a vertical surface to air [Holman, 1976].

$$h_{vert,\,air} = 0.23\,\Delta T^{1/3} \qquad (23)$$

Using one-third of equation 23 should be conservative because the rectangular packing of the drums and the corrugated ridges leave a good deal of air around each drum. In any event, the heat load limit is a weak function of the heat transfer coefficient. Equation 22 was solved to give the permissible heat load. The maximum permissible temperature difference is the combustion temperature of paper, 450°F, minus the ambient temperature. At the limit the temperature at the centerline of the cut is just less than 450°F. For a high ambient temperature of 110°F the temperature difference is 340°F. Solving equations 22 and 23 gives a drum heat load limit equal to 32 btu/hr for the low thermal conductivity of 0.02 btu/ft hr °F for the drum contents recommended by Spatz [1993]. The earlier report by Clontz [1977] recommended a thermal conductivity of 0.05 which gives a drum heat load limit of 74 btu per hour.

Consider another possible worst location for the heat producing cut, just under the lid of the top drum. The temperature of the drum lid under the worst weather and solar condition is much less than 450°F. Therefore, the drum lid serves as an additional heat path to cool the cut and having the cut at the top of the drum is less severe than the case analyzed above.

Nomenclature

Bi	Biot number
C	heat capacity
Fo	Fourier number
Gr	Grashof number
h_f	heat transfer coefficient for forced convection
h_m	heat transfer coefficient for mixed convection
h_n	heat transfer coefficient for natural convection
n	refractive index
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
Q_D	drum heat load
q_s	solar flux
Pr	Prandtl number
Ra	Rayleigh number
t	time
T_F	film temperature
T_L	lid temperature
α	thermal diffusivity
β	expansion coefficient
δ_{air}	air gap thickness
δ_L	lid thickness
ε	emittance
μ	viscosity
ν	kinematic viscosity
ρ	density

ρ	reflectance
σ	Boltzmann constant
$\tau_{F\,IR}$	transmittance of the film to infrared wavelengths
$\tau_{F\,S}$	transmittance of the film to solar wavelengths

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Table 1
Emittance Measurements for Eight Drum Lids Plus Sample of Shiny New Galvanized Steel

drum lid	average emittance for lid	standard dev. of emit. times two	maximum emittance	minimum emittance
1	0.774	0.039	0.800	0.750
2	0.871	0.087	0.940	0.820
3	0.968	0.048	1.000	0.940
4	0.821	0.052	0.860	0.780
5	0.880	0.020	0.900	0.870
6	0.762	0.037	0.790	0.730
7	0.844	0.073	0.890	0.790
8	0.866	0.011	0.870	0.860
9 shiny new	0.14			

Table 2 Raw Data for Absorptance Test

lid#	lid temp.	ambient temp.	flux mv	flux mv through film
1	82	36	7.8	7.3
2	78	34	7.6	7.1
3	71	36	7.4	7.0
4	80	38	8.9	8.4
5	83	38	8.9	8.3
6	84	35	8.3	7.8
7	87	39	8.8	8.2
8	85	37	8.7	8.2
9 new	56	32	5.6	5.1
9a	76	38	9.4	8.8

Table 3 Results of Absorptance Test

lid#	absorptance	film transmittance °C	film temperature °C	solar flux btu/ft^ hr
1	0.743	0.936	51.8	758
2	0.791	0.934	49.4	739
3	0.762	0.946	47.4	719
4	0.643	0.944	52.0	865
5	0.729	0.933	54.0	865
6	0.714	0.940	51.6	807
7	0.763	0.932	56.0	855
8	0.764	0.943	53.1	845
9 new	0.142	0.911	42.0	544
9a	0.133	0.936	51.0	914

Figure 1
Air Temperature at SRS for the First Five Days of July 1991

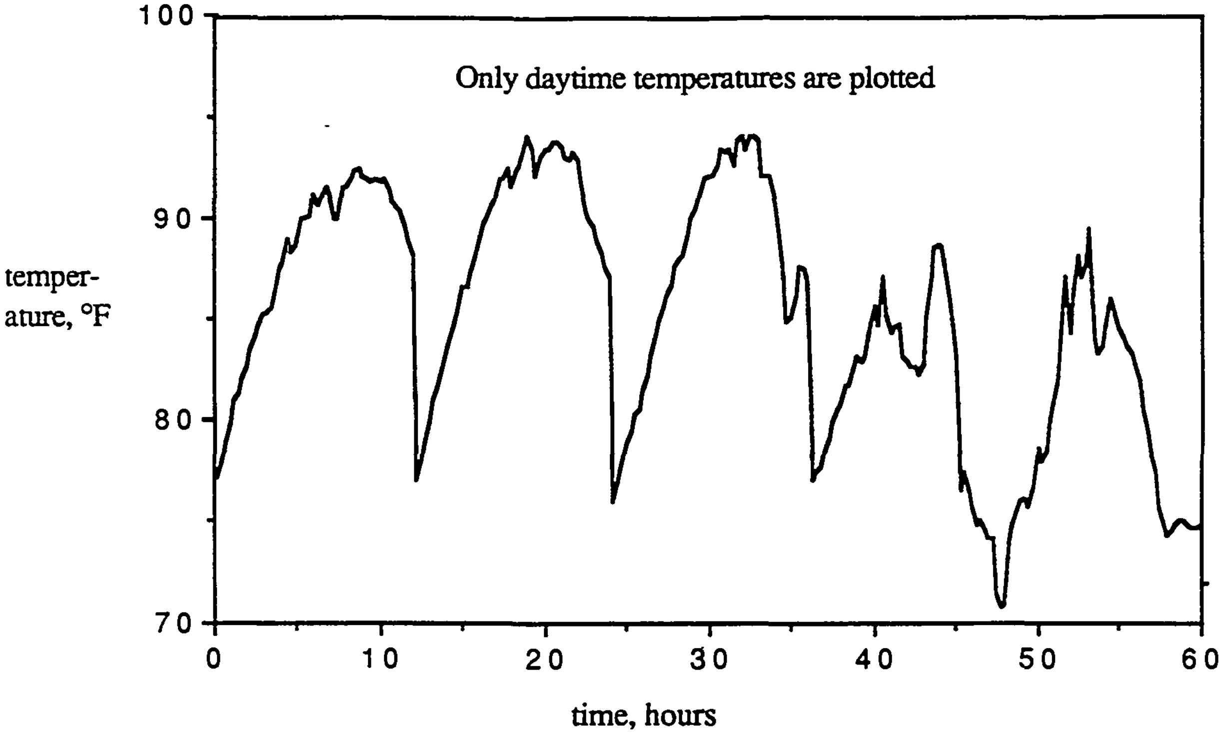

Figure 2
Solar Flux at SRS for the First Five Days of July 1991

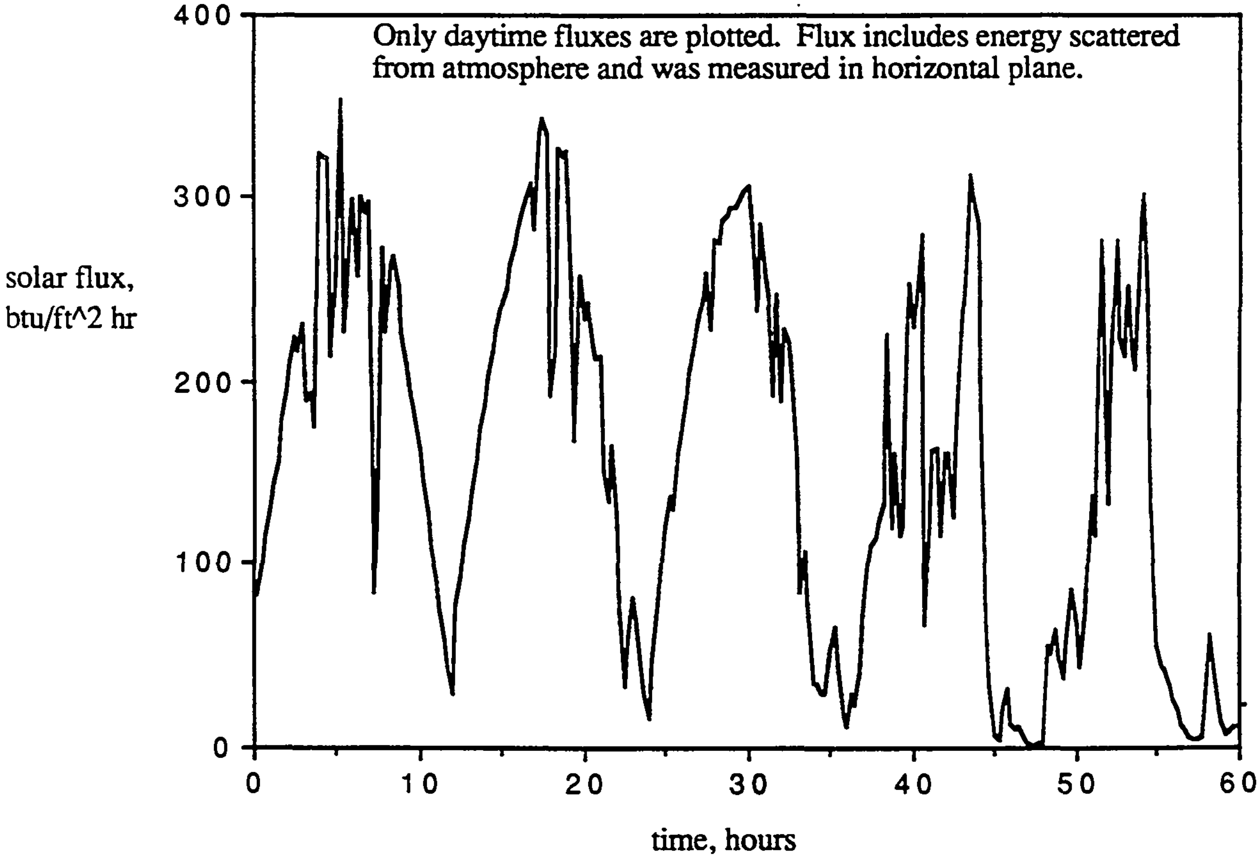

Figure 3
Wind Speed at SRS for the First Five Days of July 1991

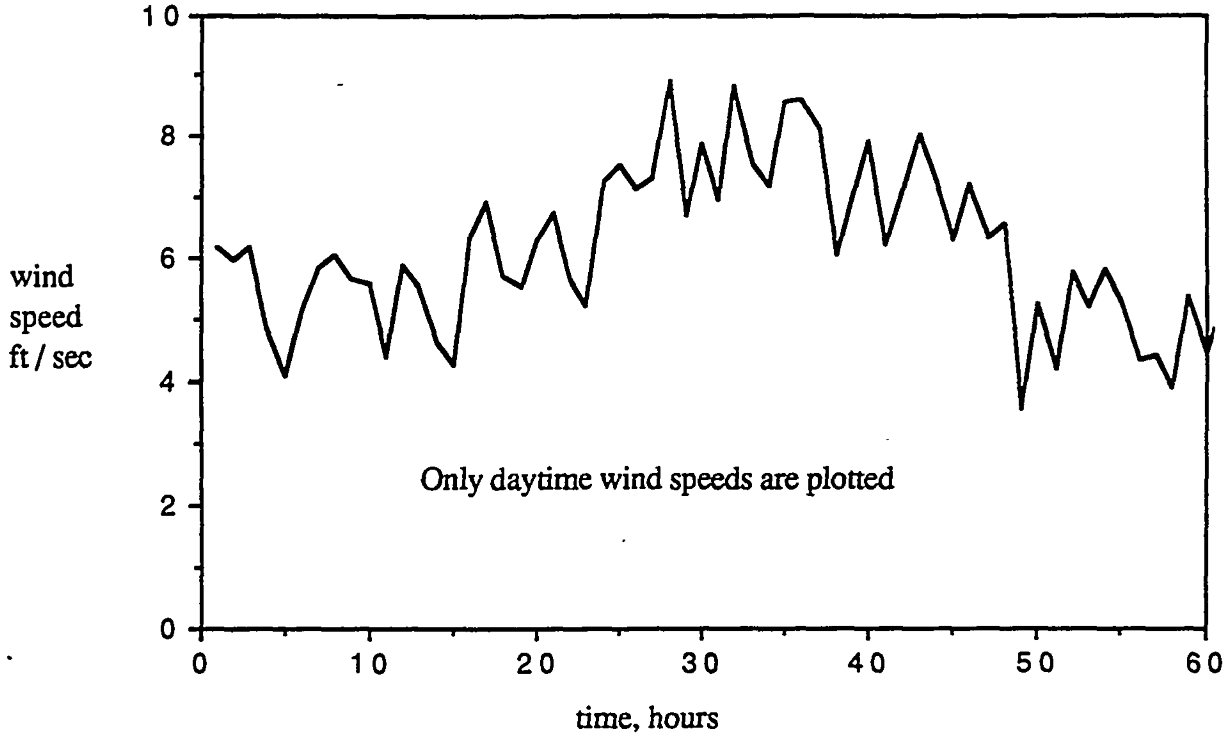

Figure 4
Heat Flows for Absorptance Measurement

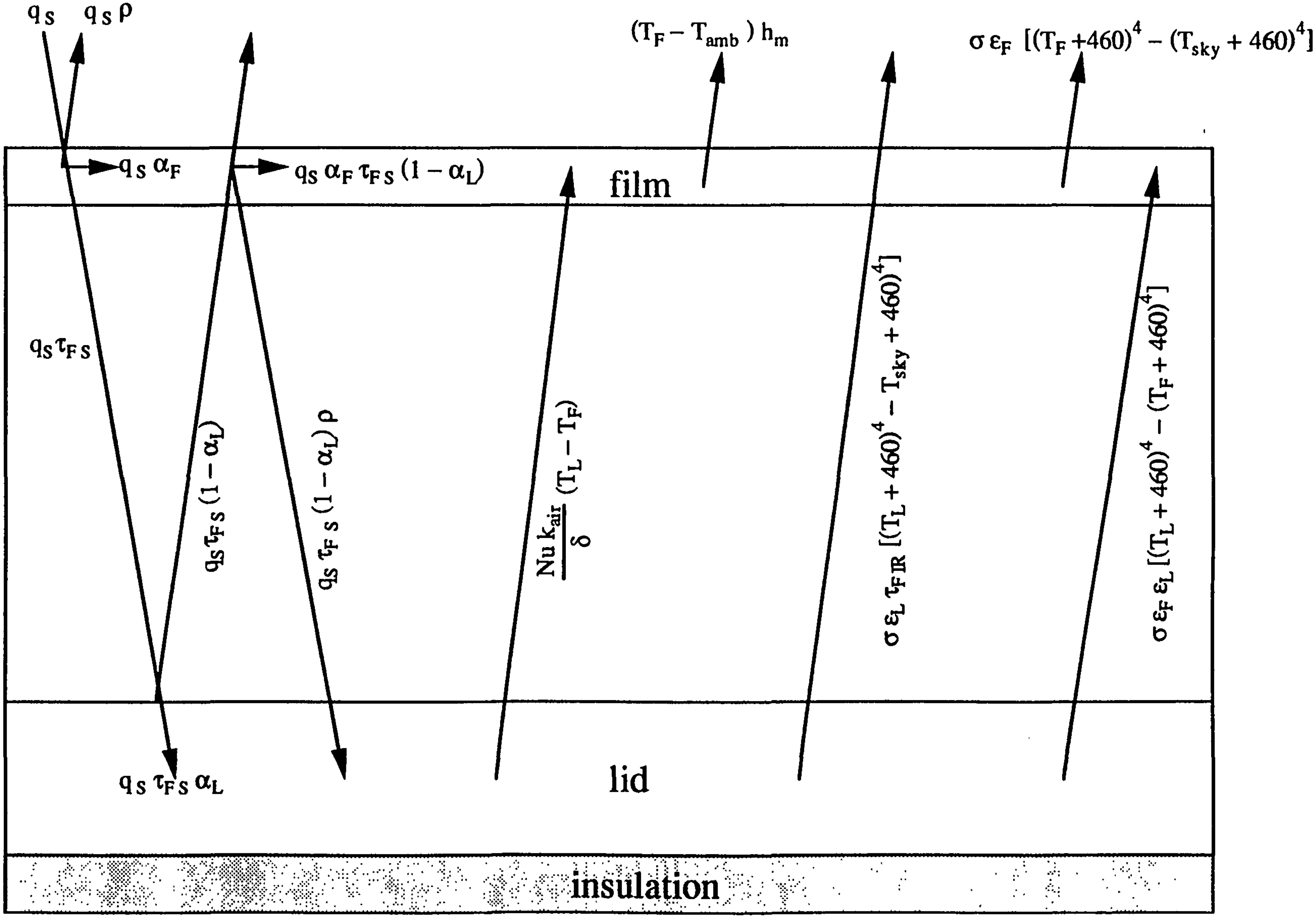

Figure 5
Maximum Daily Drum Lid Temperature for Weather Conditions of July 1991 and July 1992   Zero Internal Heat Load