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A GENERALIZED APPROACH TO THE THERMAL ANALYSIS OF THE LONG DURATION EXPOSURE FACILITY'S FLIGHT EXPERIMENTS

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SUMMARY

The generalized method employed in the thermal analysis of a Long Duration Exposure Facility (LDEF) flight experiment is presented (ref 1). The method consists of thermal math model development, defining the orbital heating rates, and applying the appropriate temperature boundary conditions. This approach has proven to be an accurate method for predicting experiment component temperatures for the worst case orbital environments and calculating daily average component temperatures for any part or all time portions of the 5.8 year mission. The application of this method to the thermal analysis of the Ultra-Heavy Cosmic-Ray Nuclei experiment (UHCRE) is presented as an example of this approach.

INTRODUCTION

The generalized method used in the thermal analysis of LDEF's flight experiments is presented in Figure 1. The approach consists of developing a mathematical lumped parameter node representation of the experiment; calculating the albedo, infrared, and solar orbital heating fluxes; defining the source and sink temperature boundary conditions; and solving with a finite difference technique. Minimum and maximum temperature cycling due to the LDEF rotating around the Earth (Day/Night cycling) can be calculated for the worst case heat flux and structure temperature boundary conditions. Daily average component temperatures can also be calculated for any length of mission time using daily average heat flux data derived from time averaging the orbital heat flux over one complete orbit and superimposing this flux on the mission beta angle (β). Temperatures calculated by this method are the experiment's orbital average thermal equilibrium temperature for any given day over the mission lifetime. The thermal analysis of the UHCRE (A0178-C6) located on row six at bay C is presented as an example of this approach.

The High-Resolution Study of Ultra-Heavy Cosmic-Ray Nuclei Experiment was flown aboard the LDEF with the objective of studying the charge spectra of ultra-heavy cosmic-ray nuclei from Zinc to Uranium using solid-state track detectors. The experiment tray consisted of three pressurized aluminum cylinders containing four detector stack modules per cylinder. Each detector stack module was typically made up of 60 layers of 250 μm lexan, 6 layers of 0.5 mm lead sheets, and 4 layers of 750 μm CR-39 enclosed in molded polyurethane foam resin. The formation and stability of the etchable latent nuclei tracks in these solid state detectors are highly dependent upon the temperature of the detector modules during registration and the thermal history of these modules after nuclei registration. Therefore it is extremely important to have an accurate post-flight thermal analysis of each tray location in order for the experiment data reduction effort to be successful. This experiment occupied 16 peripheral tray locations (fig. 2) providing the principal investigators with a total of 192 nuclei track detector modules for collecting heavy nuclei. The experiment tray located on row six at holding bay C is used as an example.

LDEF THERMAL CONTROL AND TRAY THERMAL DESIGN

The thermal control of the LDEF was totally passive by design, thus relying on internal radiation heat transfer, heat conduction paths, and the external surface coatings (α/ε) for facility temperature control (fig. 3). Over 90% of the interior structure and tray surfaces were coated with Chemglaze Z306 high emissivity black paint ($\varepsilon = 0.90$) to minimize any circumferential thermal gradients and to maximize the radiation heat transfer across the facility. To minimize conduction heat transfer from the structure, the experiment trays were attached to the LDEF structure by eight 2" × 5" aluminum clamps along the tray perimeter. The tray mounting scheme minimizes the contact conduction area through which heat can be transferred between the facility and the experiment trays. The passive thermal control of the LDEF results in a wide variation in the experiment's structure boundary temperature due to the orbiting nature of the spacecraft. In the case of the UHCRE-C6 experiment, the average structural boundary temperature ranged from 5°C to 48°C (41°F to 119°F) over the mission lifetime.

The objectives of the UHCRE thermal design were to minimize the temperature fluctuations experienced by the detector modules, to minimize any thermal gradients through the module stacks, and to maintain the temperature of the modules at or below 30°C (86°F) over the mission lifetime. This was accomplished by :

- Using 5 mil silver teflon for the thermal cover, featuring a low solar heat absorptance (α = 0.080) and high heat dissipation to space (ε = 0.80).
- Establishing a large radiation couple from the detector case to the thermal cover.
- Establishing a small radiation couple from the detector cases to the surrounding experiment tray.
- Minimizing the heat conduction from the mounting tray to the detector cylinders by employing 5 mm delrin acetal resin insulation washers.
- Enclosing the detector modules in molded polyurethane foam resin (Eccofoam FPH) which provided mechanical stability and excellent thermal isolation from the cylindrical aluminum case.

The materials and optical properties used in the construction of the UHCRE are presented in Figure 4.

NODAL MODEL DEVELOPMENT

The objective of developing a thermal mathematical model is to accurately calculate the component temperatures of the experiment for any orbital condition. A finite difference thermal mathematical code was used to determine the temperature response of the experiment components at specific points called nodes. Temperatures are computed by performing an energy balance on each node in the model at the specified time points in the orbit or mission. The assumptions made in this analysis are that heat transfer due to convection can be neglected, each node is homogenous and isothermal, all node surfaces reflect energy diffusely, and finally there is no internal heat generation to consider for this experiment. The experiment is divided at the appropriate hardware boundaries or at desired locations into lumped-capacitance nodes which are connected to each other by the conduction and radiation conductor network. In developing a thermal math model the three essential components needed for temperature calculations are the node's thermal mass or capacitance, the conduction heat transfer paths, and the radiation interchange factors between each node. The thermal capacitance of a node is defined as its thermal energy storage capacity and is calculated by multiplying the node mass by the material's specific heat (C_p). The thermal capacitance governs the rate at which thermal energy is stored or released from the node during transient temperature calculations. Nodes which have a finite thermal mass or capacitance are known as diffusion nodes and nodes which have an infinite capacitance are considered temperature boundary nodes.

The UHCRE tray was divided into 20 diffusion nodes and three boundary temperature nodes. Each detector cylinder was divided into six nodes as shown in Figure 5. Because the detector cylinders were painted black on the top half and left bare on the bottom half for thermal control, the cylinders were split into two nodes along this line. The four modules in each cylinder were modeled as two nodes, a top layer and a bottom layer, which have the same mass and dimensions as the four separate modules. The remaining two nodes represent the top and bottom supporting eccofoam layers which were molded as two separate pieces. The experiment tray was lumped into one node and the thermal cover is represented as one node. The experiment has three temperature boundary conditions which consist of the average of the two supporting longerons and section of the center ring structure, the average LDEF interior, and the space sink temperature (0°K).

Heat conduction paths (conductance) between nodes are known as conductors and are shown schematically as electrical resistors in Figure 6. Linear conductors represent heat transfer by conduction and are calculated by taking the product of the node material's thermal conductivity (κ) and the cross sectional area (A), divided by the effective path length (L) between the two adjacent nodes. Heat conduction paths ($\kappa A/L$) were calculated between the experiment tray and each of the three detector cylinders and between each of the six nodes representing the detector module layers, eccofoam, and aluminum cylinders.

Nonlinear conductors represent heat transfer by radiation and are calculated for the nodal geometry as the product of the Stefan-Boltzmann (σ) constant, the node surface area, the surface emissivity (ε), and the gray body factor from one node surface to another. The gray body factors are a combination of the geometry shape or view factor and the reflected energy coefficients. The reflected energy coefficients account for multiple reflections which occur inside of enclosed spaces as a result of energy being emitted from one surface that strikes another node and is reflected to a third. The geometry shape factor represents the fraction of the radiative energy leaving one node surface that reaches another node surface directly. The internal radiation couplings for this analysis were calculated using the Thermal Radiation Analyzer System (TRASYS, ref. 2) computer code. A TRASYS model of the experiment tray was constructed to match the nodalization chart in Figure 5. The radiation interchange couplings were calculated using a numerical integration technique in TRASYS by calling the appropriate solution subroutines.

LDEF ORBITAL ENVIRONMENT

There are four heat sources (fig. 7) to consider when performing a thermal analysis on any LDEF experiment and they are the solar irradiation, Earth reflected solar irradiation (albedo), Earth emitted energy (planetary infrared), and any internally generated heat resulting from electronics or heaters. Since this experiment lacks any internally generated heat sources only the solar induced heat sources will be considered. The angle β is defined as the angle between the spacecraft's orbit plane and the Sun's illumination rays and its minimum and maximum amplitudes are calculated by adding the declination of the Earth's equator ($\pm 23.5°$) with the inclination of the spacecraft's orbit plane ($\pm 28.5°$). The β angle history for the LDEF mission is presented in Figure 8. The TRASYS computer program was employed to calculate the albedo, solar, and planetary incident heat fluxes. A TRASYS model of the LDEF spacecraft was constructed which represented a 12 sided polygon closed on both ends. Program inputs consisted of the LDEF spacecraft orientation (fig. 9), orbit β angle, and altitude (255 NM). Transient orbital heat fluxes were calculated for 10° beta angle increments within the range from -52° to + 52° for the row six location (figs. 10 & 11). This was done to develop a matrix of points which characterizes the orbital heat flux versus orbit β angle. The mission incident surface fluxes were calculated by time averaging the orbital heat flux over one complete orbit and plotting the average flux versus orbit β angle (fig. 12). Figure 12 shows that for the row six location, the peak heat flux occurs at a β angle of -52° and the minimum heat flux is at a β of +52°. The β angle history was used as the independent variable to interpolate between the orbit averaged flux to generate a daily average mission flux history (fig. 13) for experiments on row six.

Surface incident orbital heat fluxes in 10° increments within the β angle range and the mission daily average flux for the first 390 days of the LDEF mission have already been calculated for each row and both ends of the LDEF spacecraft. Heat flux and structure temperature boundary condition data are documented in Reference 3 for the LDEF to provide a set of thermal boundary conditions which are common to all LDEF experiments.

The thermal incident fluxes (q) in the above referenced document were evaluated with both the absorptance (α) and emissivity (ε) set to unity. These fluxes were then converted into absorbed surface heat flux(Q) by multiplying the albedo and solar component by the exposed surface node area (A) and α; this heat flux was then added to the planetary infrared heat flux ($q_{IR}A\varepsilon$) according to the following equation for each exposed experiment surface:

$$Q_{absorbed} = q_{Solar}A\alpha + q_{Albedo}A\alpha + q_{IR}A\varepsilon \qquad (1)$$

TEMPERATURE BOUNDARY CONDITIONS

Structure temperature boundary conditions have been calculated for each of the 86 LDEF tray locations. A thermal math model of the LDEF facility was constructed and the calculated temperatures were matched to flight data recorded by the Thermal Measurements System (THERM - P0003) for the first 390 days of the mission (ref 4). One of the objectives of the THERM experiment was to provide the principal investigators with a consistent set of data-matched thermal boundary conditions to be used in the math modeling of their experiments. Each LDEF tray was typically surrounded by two longeron nodes with the exception of experiments located on the ends of the facility and at the center ring. All experiments used the LDEF average interior temperature as one of their boundary temperatures. The structural boundary temperatures for the UHCRE-C6 location consisted of two longerons and a center ring. Since the experiment tray was lumped into one node the three structural temperatures were averaged into one boundary temperature for this analyses. Three sets of temperature boundary conditions were needed to predict the mission thermal history and the worst case orbital conditions for this UHCRE tray location, which were the minimum temperature boundary case of 0° β, the maximum temperature boundary case of -52° β (figs 14 & 15), and the daily average boundary temperature for the entire LDEF mission (figs 16 & 17).

METHOD OF SOLUTION

The Systems Improved Numerical differencing Analyzer (SINDA, ref. 5) finite differencing computer code is used for the problem solution. SINDA is a general thermal analyzer which utilizes resistor - capacitor (R-C) network representation of lumped parameter thermal systems for solving physical problems governed by diffusion-type equations. Analyzer inputs needed for problem solution include thermal node capacitance, conduction and radiation conductor networks, exposed surface absorbed heating fluxes, and temperature boundary conditions. Tray transient thermal analyses for both the worst case orbital and the full length mission were performed using SINDA's implicit forward-backward differencing solution subroutine. The assembled thermal model was used to calculate the extreme temperatures encountered by the experiment during the LDEF mission. Three cases were analyzed, the minimum and maximum thermal boundary orbital environments and the daily average for the 5.8 year mission history. The worst case orbital environment thermal conditions for any LDEF experiment can be determined by inspecting both the structural temperature boundaries and the orbital heat fluxes for the combinations which yield both the minimum and maximum heat flux and temperature boundary conditions. For the UHCRE experiment located at C6, the maximum combined thermal boundary conditions occur when β equals -52° and the minimum is at a β of 0°. The two orbit conditions were investigated to determine the maximum thermal gradient between the top and bottom nodes of the detector modules and to calculate the magnitude of the temperature variations caused by the orbiting day-to-night flux cycling. Mission component temperature histories are computed by substituting the mission thermal flux and structure temperature boundary conditions in place of the orbital boundary conditions. The mission minimum and maximum experiment component temperatures were determined using this method. The analysis method was then repeated for the remaining 15 UHCRE trays.

If flight temperature data were available for this LDEF experiment (no flight data available for this experiment), the thermal model calculations would be compared to the flight data so that any necessary model adjustments could be made, such as model geometry changes, conduction contact resistance, or radiation network assumptions, before proceeding with the final analysis. Figure 1 shows this step in the procedure.

RESULTS and CONCLUSIONS

The minimum and maximum temperatures for the experiment tray, thermal cover, and both detector node layers are presented in Figures 18 and 19 for the worst case orbit environments of 0° and -52° beta angles. The largest calculated thermal gradient between the detector top and bottom node layers was found to be no more than 0.20°C for any of the 16 UHRCE locations. Orbital detector module temperature variations were found to be small with an average temperature for both layers of -2.2± 0.02°C at β equals -52° and -31.0 ±0.003°C for the cold case of 0° β. The C6 component mission thermal history shown in figure 20 represents the thermal equilibrium temperatures reached for any given day during the 69 months spent in space. The mode temperature for each detector module (Table 1) is defined as the most days spent at a given temperature in the range experienced by the nuclei track detectors. The mode temperature is calculated from the full length mission analysis by counting the number of days spent at each temperature in the range. Since the charge resolution of the etchable nuclei tracks is highly dependent upon the temperature of the detector stacks during and after nuclei registration, the mode temperature gives the principal investigator important information which is needed to control the stack etching process used to develop the nuclei tracks. Tables 2 and 3 summarize the minimum and maximum daily mission temperatures reached by the experiment components for all 16 UHCRE tray locations. All detector modules were below the target maximum of 30.0°C by a comfortable margin with the warmest detector temperature of -2.2°C occurring at the C6 location.

It was concluded that the UHCRE experiment successfully met its thermal design objectives which were to maintain the detector modules at or below 30°C over the mission lifetime and to thermally isolate the detector stacks from the orbital day and night temperature fluctuations as well as minimizing any detector stack thermal gradients.

The generalized method presented in this paper is intended to provide a sense of direction for performing thermal analyses to obtain accurate temperature calculations of LDEF experiments. Since the heat flux and temperature boundary conditions have already been calculated, the analysis needs only to build a nodal math model of the experiment and assemble the given information from the reference into the desired thermal analyzer format for problem solution.

REFERENCES

1. Long Duration Exposure Facility (LDEF) Mission 1 Experiments, NASA SP-473, 1984.

2. Thermal Radiation Analysis System (TRASYS), User's Manual, NAS9-15832, June 1983.

3. Berrios,W. M.; Sampair, T.R.: Long Duration Exposure Facility Post-Flight Thermal Analysis, NASA TM-104208 Part 1 and 2, January 1992.

4. Berrios, W. M.: Use of the Long Duration Exposure Facility's Thermal Measurement System for the Verification of Thermal Models, First LDEF Post-Retrieval Symposium June 2-8 1991, NASA CP- 3134.

5. Systems Improved Numerical Differencing Analyzer (SINDA), User's Manual, NASA 9-15800, March 1983,

Table 1. UHCRE Mode Temperatures for Each Tray Location (69 Month Mission).

	LOCATION															
Tray Temp -°C	A2 Days	A4 Days	A10 Days	B5 Days	B7 Days	C5 Days	C6 Days	C8 Days	C11 Days	D1 Days	D5 Days	D7 Days	D11 Days	E2 Days	E10 Days	F4 Days
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
-3	0	0	0	0	12	0	29	0	0	0	0	0	0	0	0	0
-4	0	0	0	0	35	0	35	0	0	0	0	0	0	0	0	0
-5	3	0	0	0	29	0	18	0	18	0	0	25	0	0	0	0
-6	29	0	0	0	25	0	22	0	14	18	0	40	0	0	0	0
-7	27	0	0	20	17	0	21	0	21	14	0	26	0	0	0	0
-8	55	0	0	45	24	11	20	20	34	24	5	21	24	0	0	0
-9	47	2	44	26	35	36	36	50	38	41	21	25	11	0	0	0
-10	46	75	81	23	33	38	36	29	34	41	47	28	33	0	0	0
-11	59	68	68	29	44	28	34	37	37	29	28	38	44	0	0	0
-12	84	115	101	43	39	34	36	57	33	27	31	34	42	28	0	6
-13	93	111	134	51	27	38	29	72	57	21	31	43	38	34	0	87
-14	77	129	101	60	35	53	32	56	58	29	53	36	33	60	21	128
-15	77	185	199	43	31	65	25	53	76	47	65	28	53	64	83	171
-16	128	411	322	47	38	43	35	73	58	49	53	33	75	57	86	156
-17	158	821	868	67	45	64	30	100	58	56	61	39	80	98	133	209
-18	218	30	76	76	51	66	51	106	65	44	56	33	64	110	131	344
-19	290	43	37	91	63	86	37	119	104	46	71	56	62	90	147	428
-20	475	70	38	84	62	93	56	204	118	44	93	53	81	120	308	274
-21	185	42	25	158	117	130	45	361	167	42	82	61	135	195	696	205
-22	41	5	13	234	167	235	91	598	211	58	121	63	143	282	400	37
-23	13	0	0	398	215	379	121	21	364	97	207	77	199	355	37	39
-24	2	0	0	460	316	562	165	61	461	130	264	156	366	564	36	23
-25	0	0	0	56	408	52	237	52	29	208	514	223	520	35	22	0
-26	0	0	0	42	152	45	286	34	33	275	209	283	60	13	7	0
-27	0	0	0	45	38	43	383	4	17	353	42	435	32	2	0	0
-28	0	0	0	9	33	6	134	0	2	366	41	180	10	0	0	0
-29	0	0	0	0	14	0	29	0	0	22	12	39	2	0	0	0
-30	0	0	0	0	2	0	26	0	0	19	0	27	0	0	0	0
-31	0	0	0	0	0	0	3	0	0	7	0	5	0	0	0	0
-32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Detector Module Mission Temperature Summary 4/7/84 to 1/12/90.

Tray Location	Detector Node	Min-°C	Max-°C	Mission Average-°C	Standard Devation-°C	Mission Median-°C
A2	Top Layer	-23.8	-5.4	-16.9	4.0	-18.2
	Bottom Layer	-23.7	-5.3	-16.8	4.0	-18.2
A4	Top Layer	-21.7	-9.4	-15.7	2.3	-16.4
	Bottom Layer	-21.6	-9.3	-15.7	2.3	-16.4
A10	Top Layer	-22.2	-8.5	-15.6	2.5	-16.5
	Bottom Layer	-22.1	-8.4	-15.5	2.5	-16.4
B5	Top Layer	-28.1	-6.5	-20.5	4.6	-22.3
	Bottom Layer	-28.1	-6.6	-20.5	4.5	-22.3
B7	Top Layer	-29.6	-3.0	-20.7	6.0	-23.0
	Bottom Layer	-29.5	-2.9	-20.8	5.9	-23.0
C5	Top Layer	-27.9	-7.5	-20.9	4.2	-22.6
	Bottom Layer	-27.9	-7.6	-20.9	4.3	-22.6
C6	Top Layer	-31.1	-2.2	-21.9	6.8	-24.7
	Bottom Layer	-31.1	-2.3	-22.0	6.6	-24.7
C8	Top Layer	-26.7	-7.7	-19.2	4.0	-20.7
	Bottom Layer	-26.6	-7.9	-19.2	3.9	-20.7
C11	Top Layer	-27.8	-4.9	-19.8	4.9	-21.8
	Bottom Layer	-27.6	-4.8	-19.8	4.9	-21.7
D1	Top Layer	-31.2	-5.9	-23.0	5.8	-25.4
	Bottom Layer	-31.0	-5.9	-23.0	5.8	-25.4
D5	Top Layer	-29.0	-7.8	-21.8	4.6	-23.6
	Bottom Layer	-28.9	-7.8	-21.8	4.5	-23.6
D7	Top Layer	-31.1	-4.6	-22.5	6.3	-25.2
	Bottom Layer	-31.1	-4.4	-22.6	6.1	-25.1
D11	Top Layer	-28.7	-7.6	-21.3	4.5	-23.2
	Bottom Layer	-28.4	-7.6	-21.3	4.5	-23.1
E2	Top Layer	-26.8	-11.9	-21.1	3.2	-22.2
	Bottom Layer	-26.6	-11.9	-21.1	3.2	-22.2
E10	Top Layer	-26.1	-14.2	-20.1	2.2	-20.8
	Bottom Layer	-25.9	-14.1	-20.0	2.2	-20.8
F4	Top Layer	-24.2	-12.1	-18.0	2.4	-18.3
	Bottom Layer	-24.1	-12.0	-18.0	2.4	-18.3

Table 3. UHCRE Tray Component Minimum and Maximum Mission Temperatures.

A0178 Location	Silver Teflon Cover Blanket Min-°C	Silver Teflon Cover Blanket Max-°C	Top Detector Case Min-°C	Top Detector Case Max-°C	Top Eccofoam Layer Min-°C	Top Eccofoam Layer Max-°C	Bottom Eccofoam Layer Min-°C	Bottom Eccofoam Layer Max-°C	Bottom Detector Case Min-°C	Bottom Detector Case Max-°C	Tray Min-°C	Tray Max-°C
A2	-42.2	-23.8	-26.1	-8.5	-25.3	-7.4	-21.7	-3.2	-20.6	-2.1	5.3	28.8
A4	-40.7	-28.8	-24.4	-12.6	-23.5	-11.5	-19.8	-7.2	-18.9	-6.1	7.4	24.9
A10	-39.7	-26.7	-24.7	-11.6	-23.8	-10.5	-20.2	-6.4	-19.2	-5.3	6.4	24.4
B5	-47.1	-22.4	-30.9	-9.4	-29.9	-8.5	-26.2	-4.7	-25.3	-3.6	0.1	25.2
B7	-49.1	-18.1	-32.4	-5.6	-31.4	-4.7	-27.7	-1.1	-26.8	0.0	-0.8	27.8
C5	-47.2	-24.5	-30.7	-10.4	-29.7	-9.5	-26.1	-5.6	-25.2	-4.4	0.1	23.7
C6	-50.4	-17.2	-33.9	-4.9	-32.9	-4.1	-29.3	-0.5	-28.4	0.6	-2.6	28.4
C8	-45.9	-24.3	-29.4	-10.7	-28.4	-9.8	-24.8	-6.0	-23.9	-5.0	1.1	23.3
C11	-45.7	-20.6	-30.0	-7.6	-29.2	-6.7	-25.8	-3.0	-24.8	-1.9	-0.2	25.1
D1	-49.7	-21.6	-33.4	-8.6	-32.6	-7.8	-29.1	-4.1	-28.1	-3.1	-3.5	23.7
D5	-48.4	-24.7	-29.0	-7.8	-28.9	-7.8	-30.7	-9.8	-28.9	-7.8	-1.1	23.3
D7	-50.3	-19.2	-33.8	-7.1	-32.9	-6.2	-29.3	-2.6	-28.4	-1.5	-2.9	26.2
D11	-46.3	-22.6	-30.8	-10.2	-30.1	-9.3	-26.7	-5.8	-25.7	-4.8	-1.5	20.7
E2	-44.3	-28.6	-28.9	-14.6	-28.2	-13.7	-24.8	-10.0	-23.9	-9.0	-0.2	18.8
E10	-42.8	-31.2	-28.3	-17.0	-27.6	-16.0	-24.2	-12.3	-23.2	-11.3	1.0	16.9
F4	-43.6	-30.8	-27.0	-15.1	-26.0	-14.1	-22.3	-10.0	-21.3	-8.9	5.1	20.6

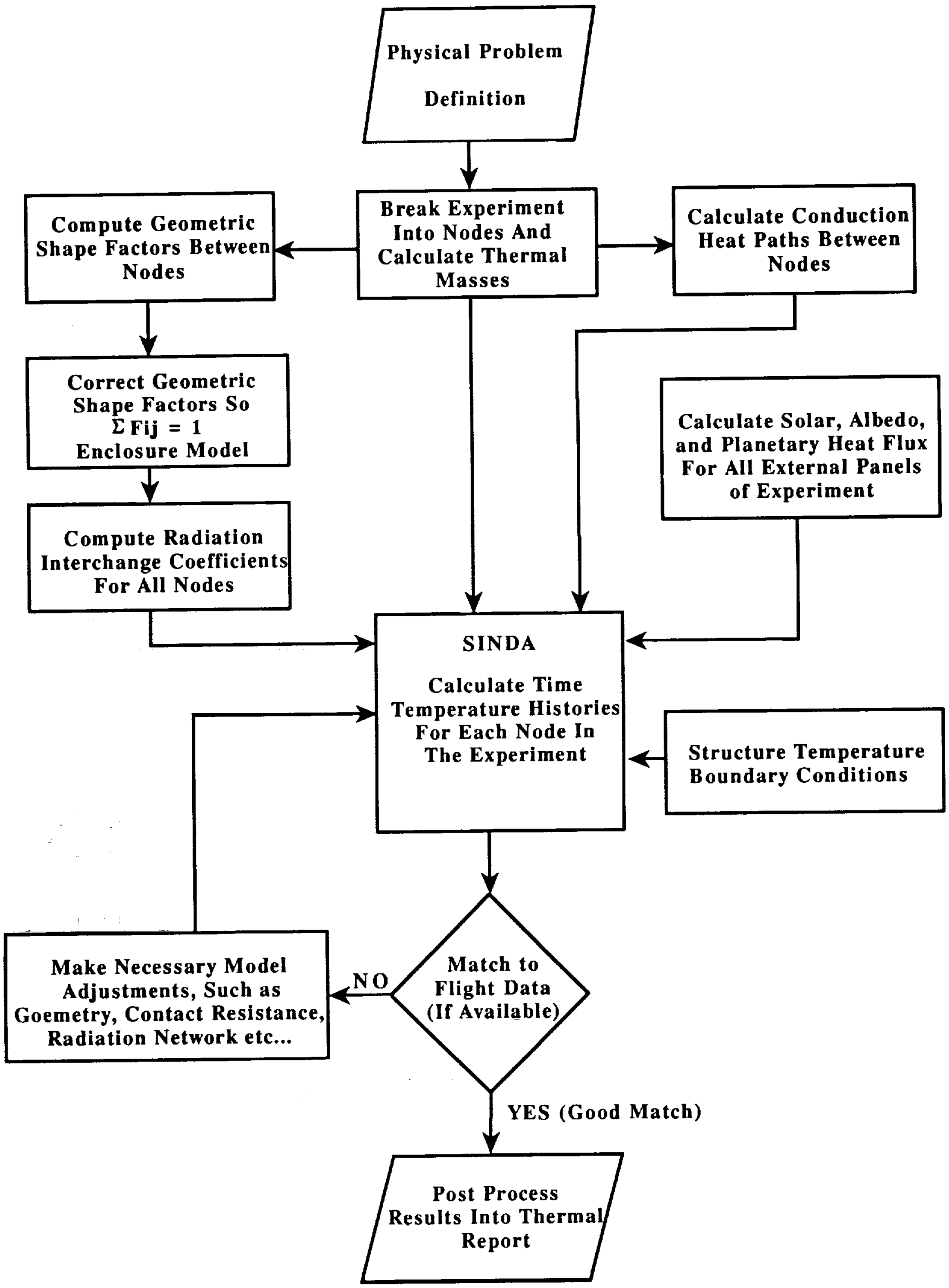


Figure 1. Experiment thermal analysis summary.

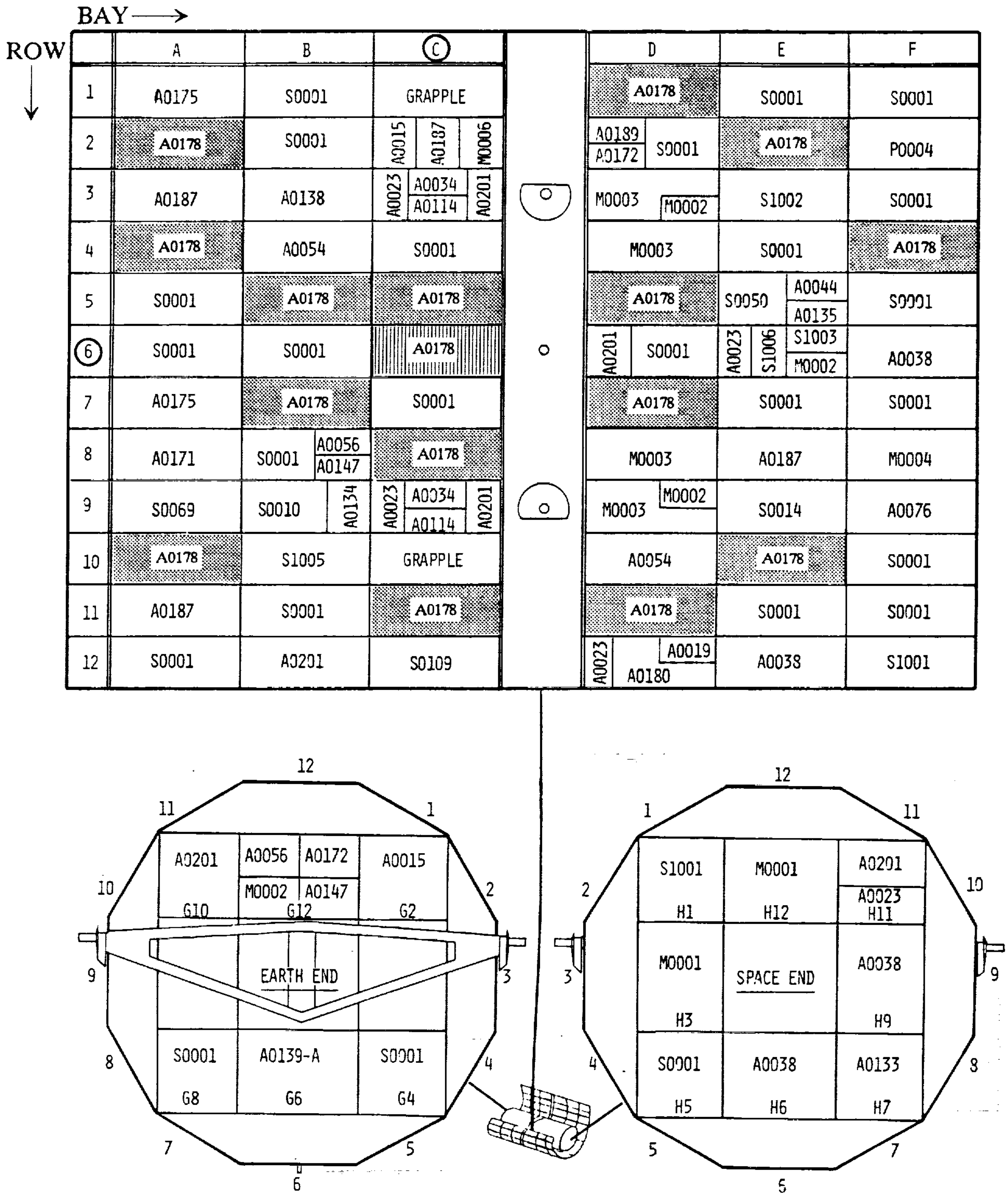


Figure 2. Experiment intergration chart showing the locations of the 16 Ultra-Heavy Cosmic-Ray trays.

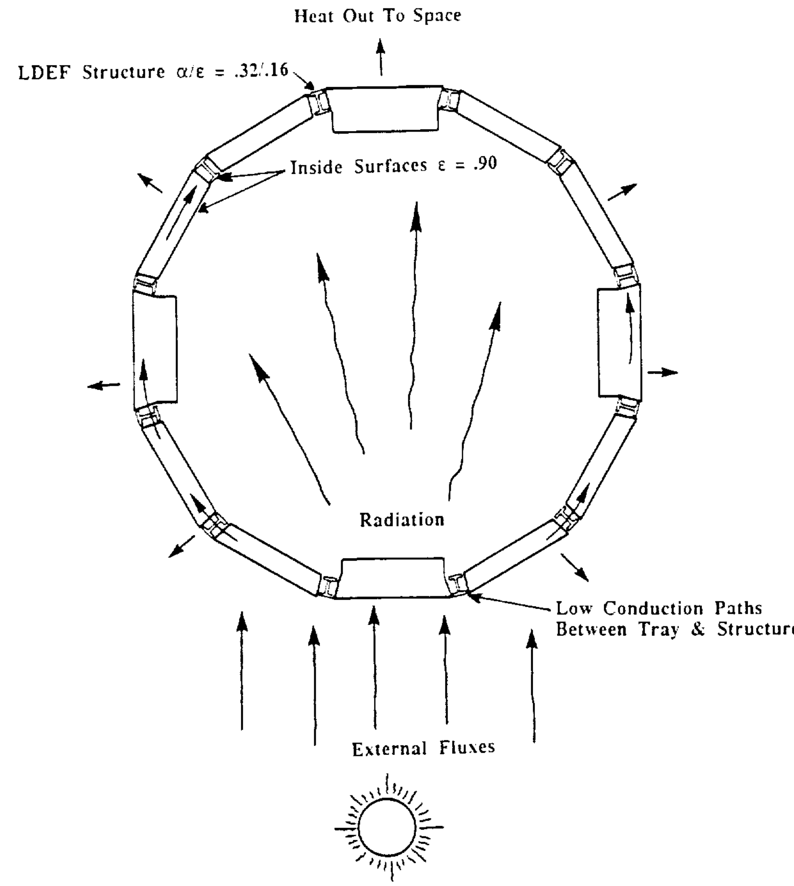


Figure 3. LDEF temperature control is passive by design.

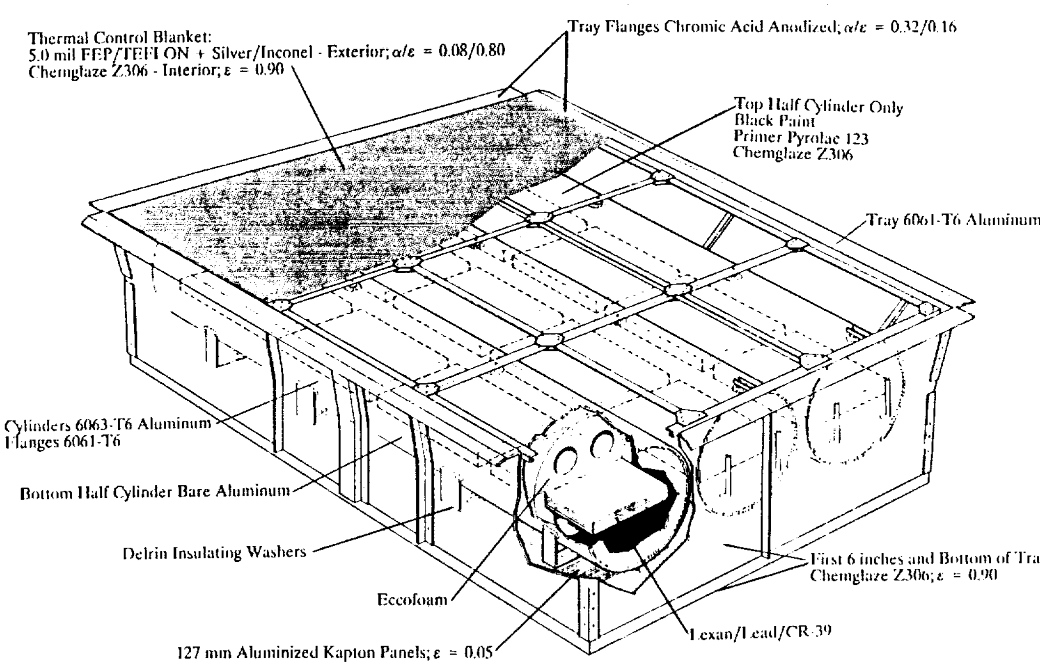


Figure 4. Construction and materials of the UHCRE tray.

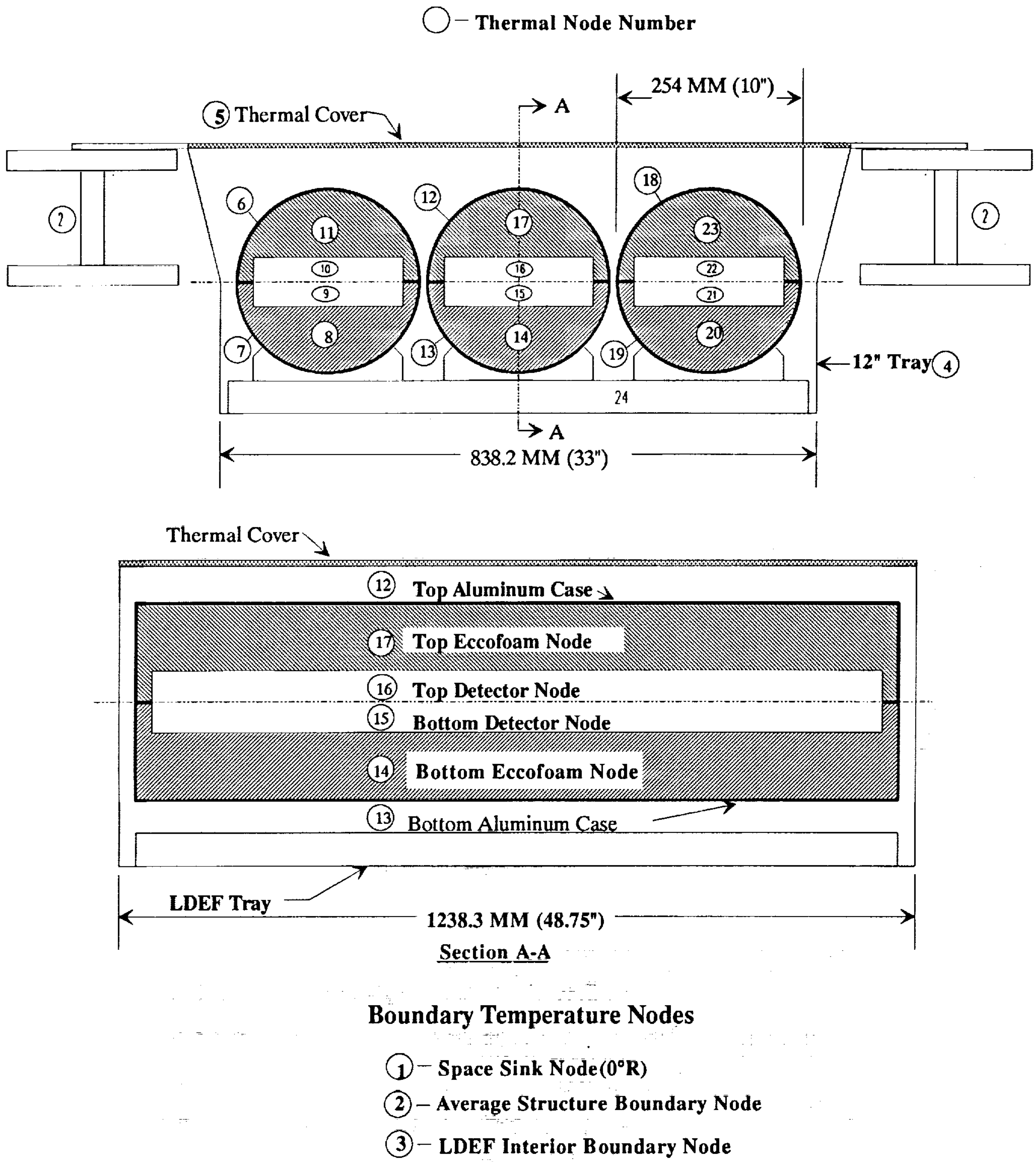
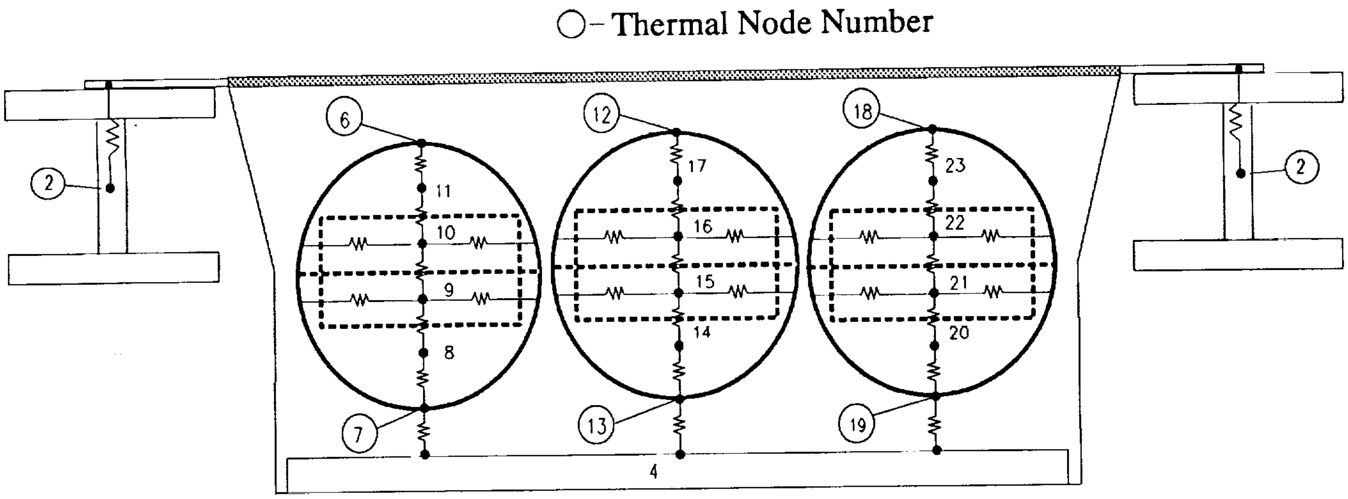
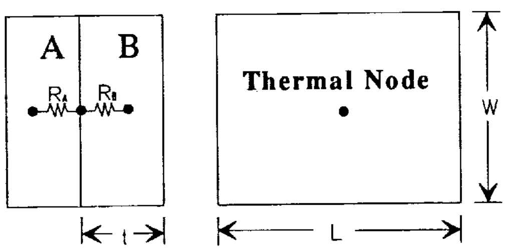


Figure 5. Thermal nodalization of the UHCRE experiment.





Thermal Conductor Sample Calculation:

$R_{A,B}$ = KA/t

Area A = L*W

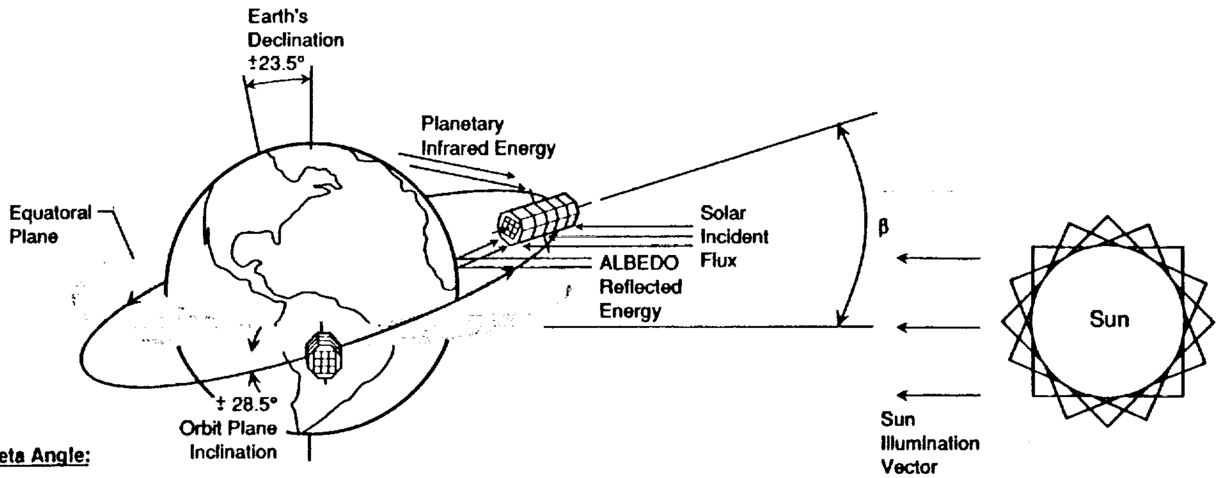
t = Node Thickness (Effective lenght)

$K_{A,B}$ = Thermal Conductivity of the Material

R = $R_A + R_B$

U = 1/R (Conductance)

Figure 6. Thermal conduction network for the UHCRE experiment.



Beta Angle:

β - Angle between the plane of the orbit and the sun illumination vector.
Range - -52° < β > +52°, Calculated by adding the declination of the Earth (± 23.5°) to the inclination of the orbit plane (± 28.5°).

Principal Heating sources in Space:

Solar Incident Flux - Heat due to the direct illumination from the sun (Watts/M²).
Albedo - Heat due to the portion of the solar incident energy reflected from the planet on to the LDEF (23% - 32% for this type of orbit, Watts/M²).
Planetary - Heat emitted from the planet (Watts/M²).

Altitude:

Apogee - Point in the elliptical orbit which is the farthest from the Earth.
Perigee - Point in the elliptical orbit which is the closest to the Earth.
Semi-Major Axis - The distance between the center of the ellipse and the apogee or the perigee.
Line of Apsides - The major axis (2a) of the ellipse which passes through both the apogee and the perigee.

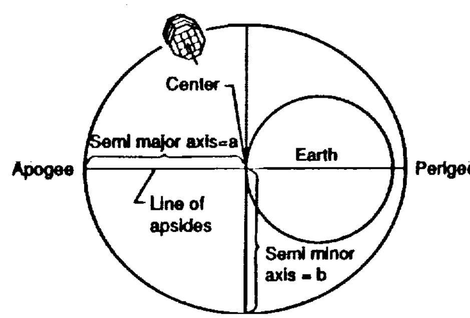


Figure 7. LDEF orbital environment definition.

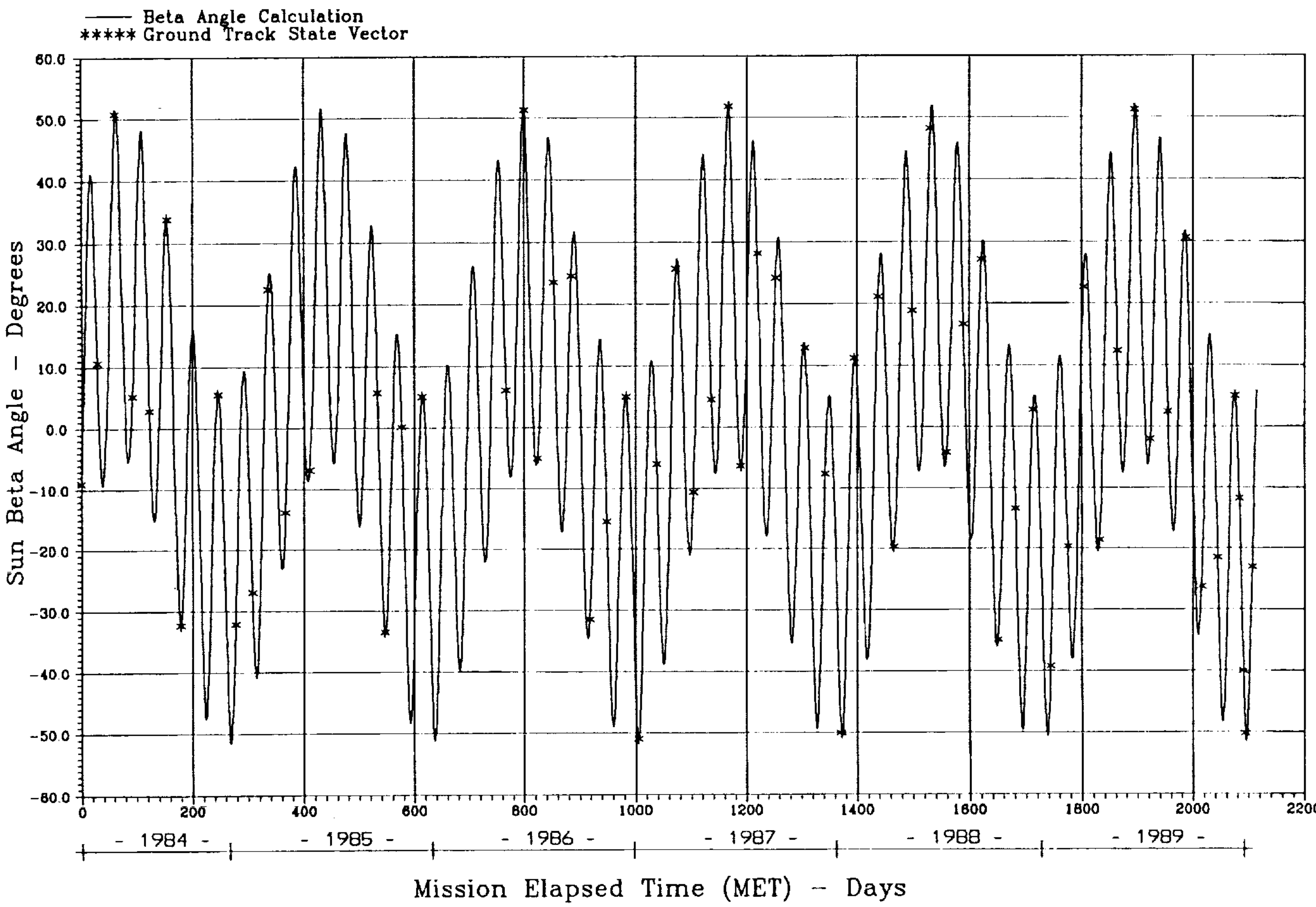


Figure 8. LDEF Beta angle history: April 7, 1984 – January 12, 1990.

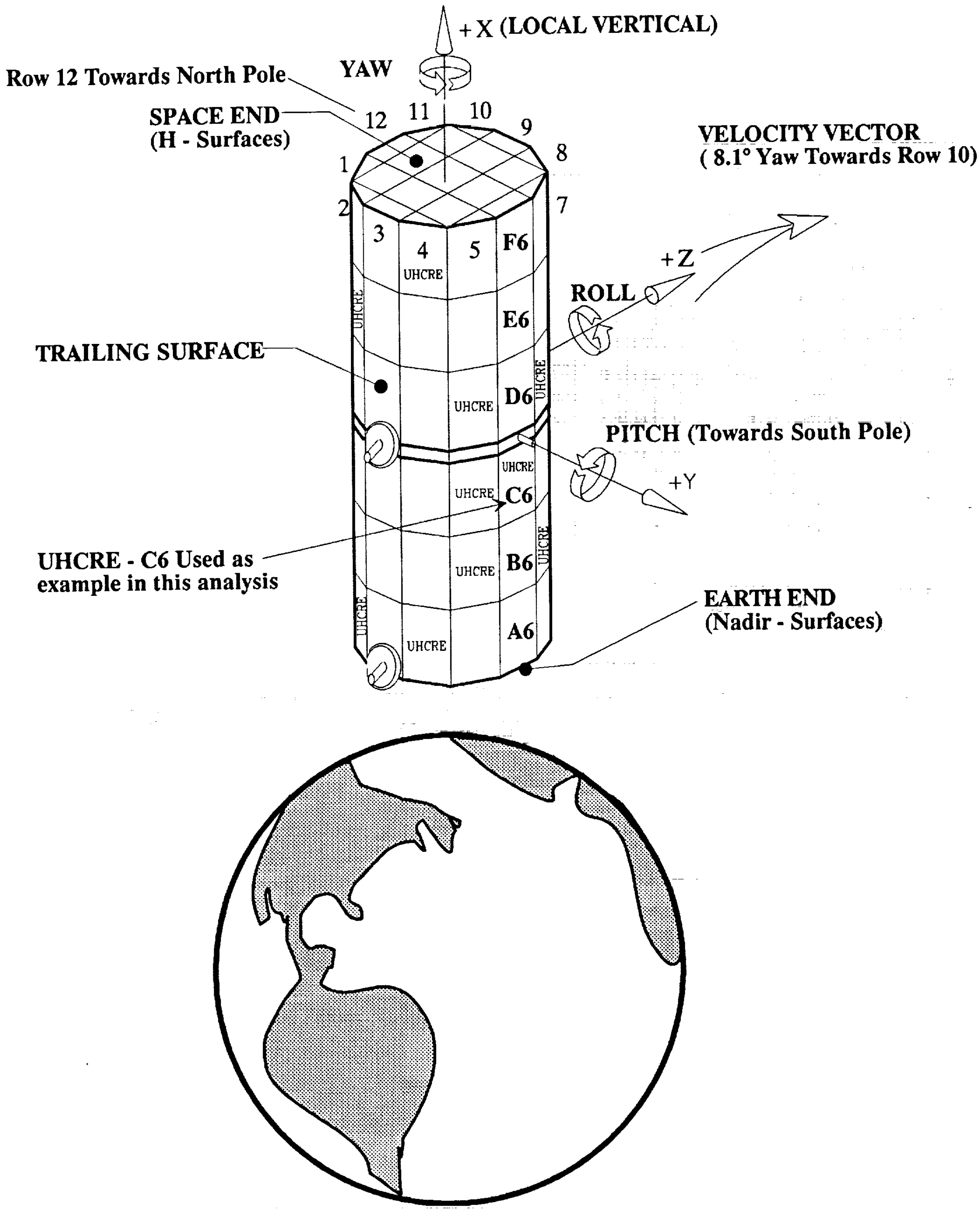


Figure 9. LDEF's orientation in free flight.

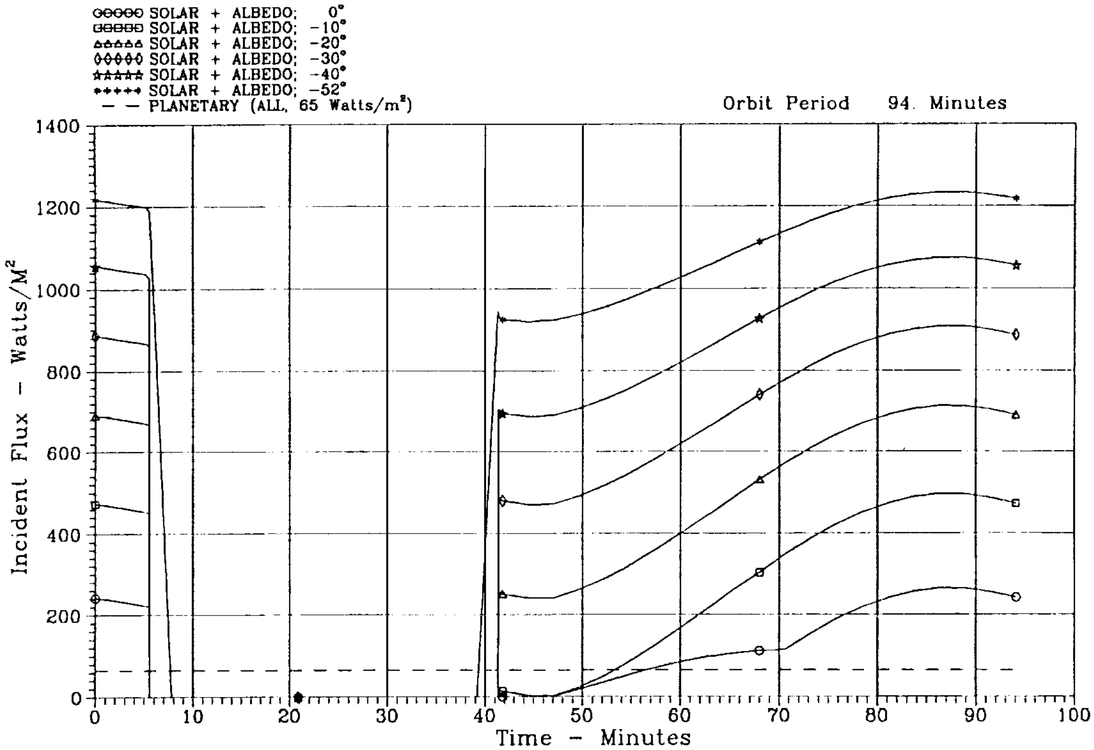


Figure 10. Row 6 orbital heat flux for negative beta angles.

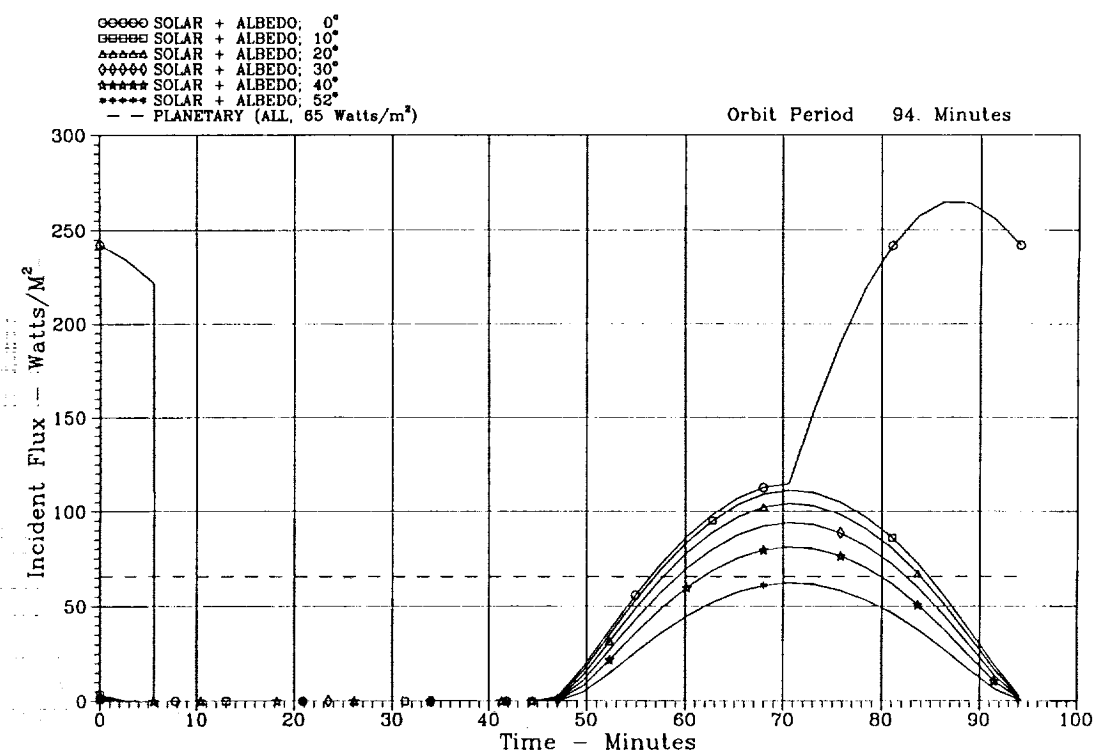


Figure 11. Row 6 orbital heat flux for postive beta angles.

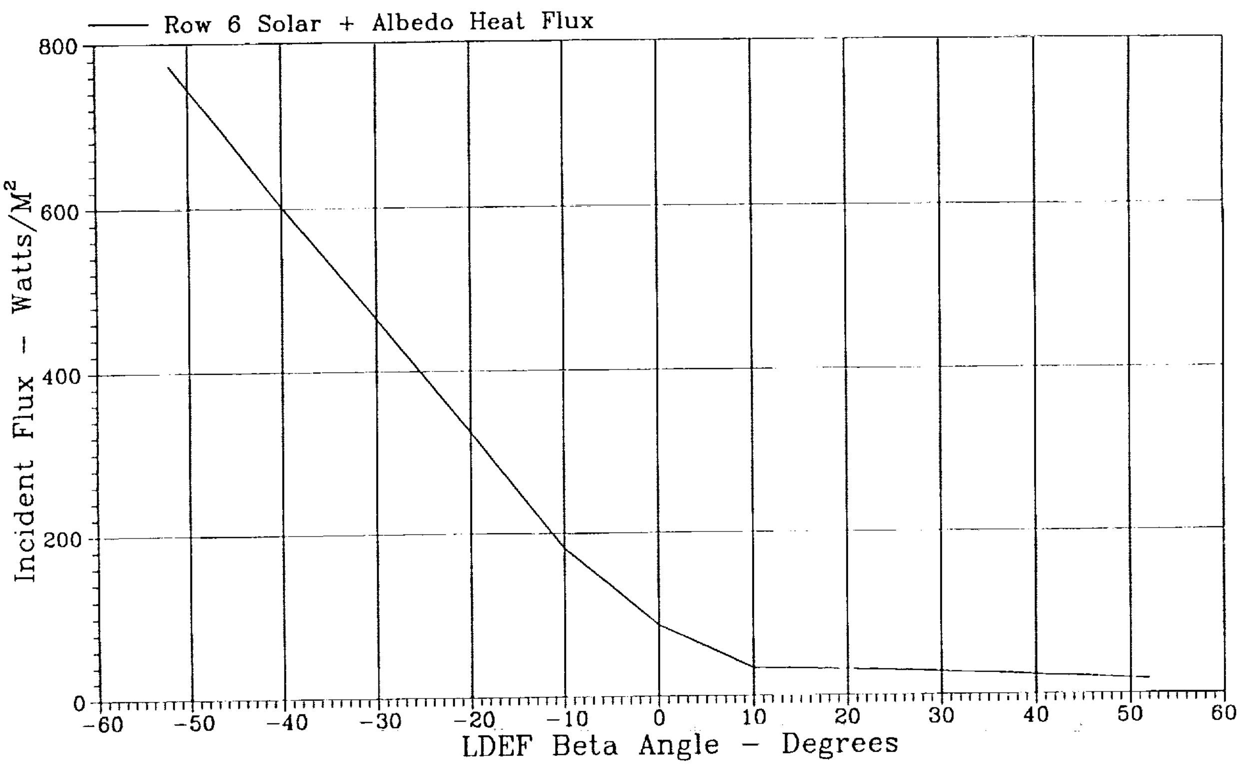


Figure 12. Row 6 orbital average heat flux vs LDEF beta angle.

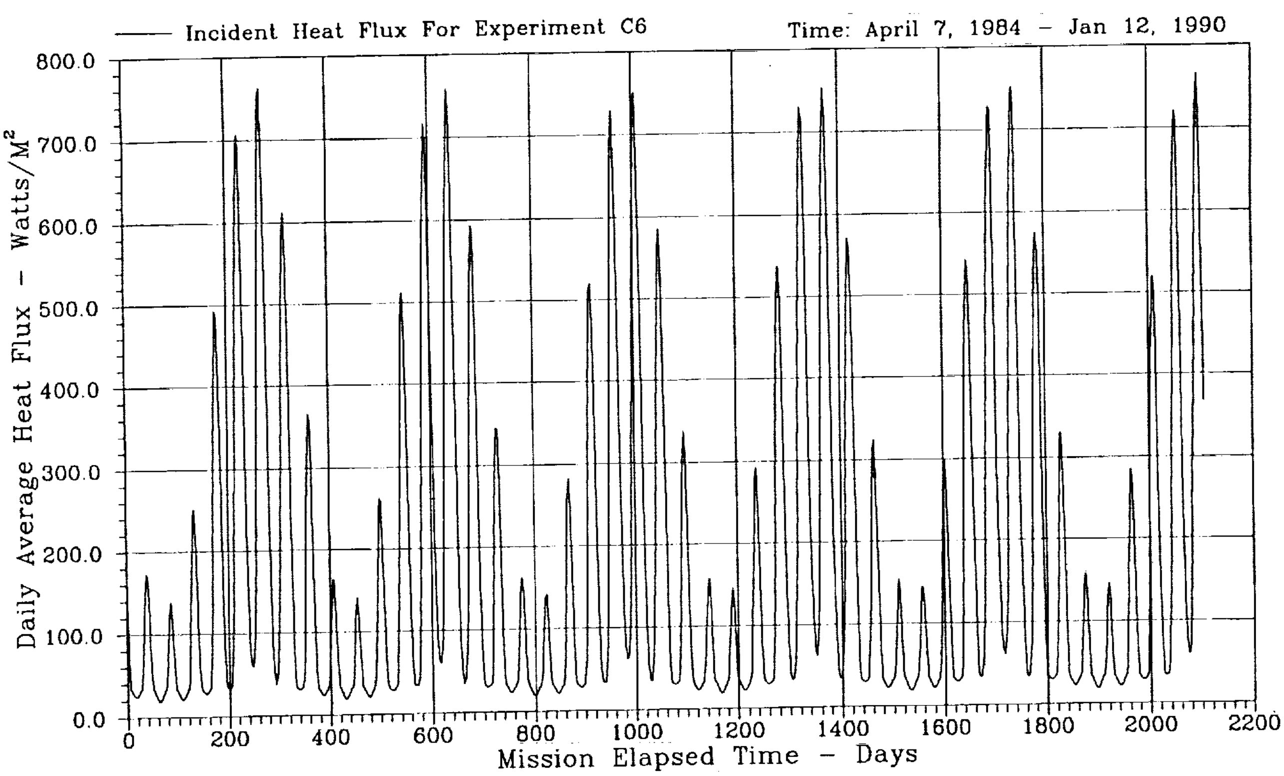


Figure 13. Solar plus albedo mission incident heat flux for the UHCRE located on row 6.

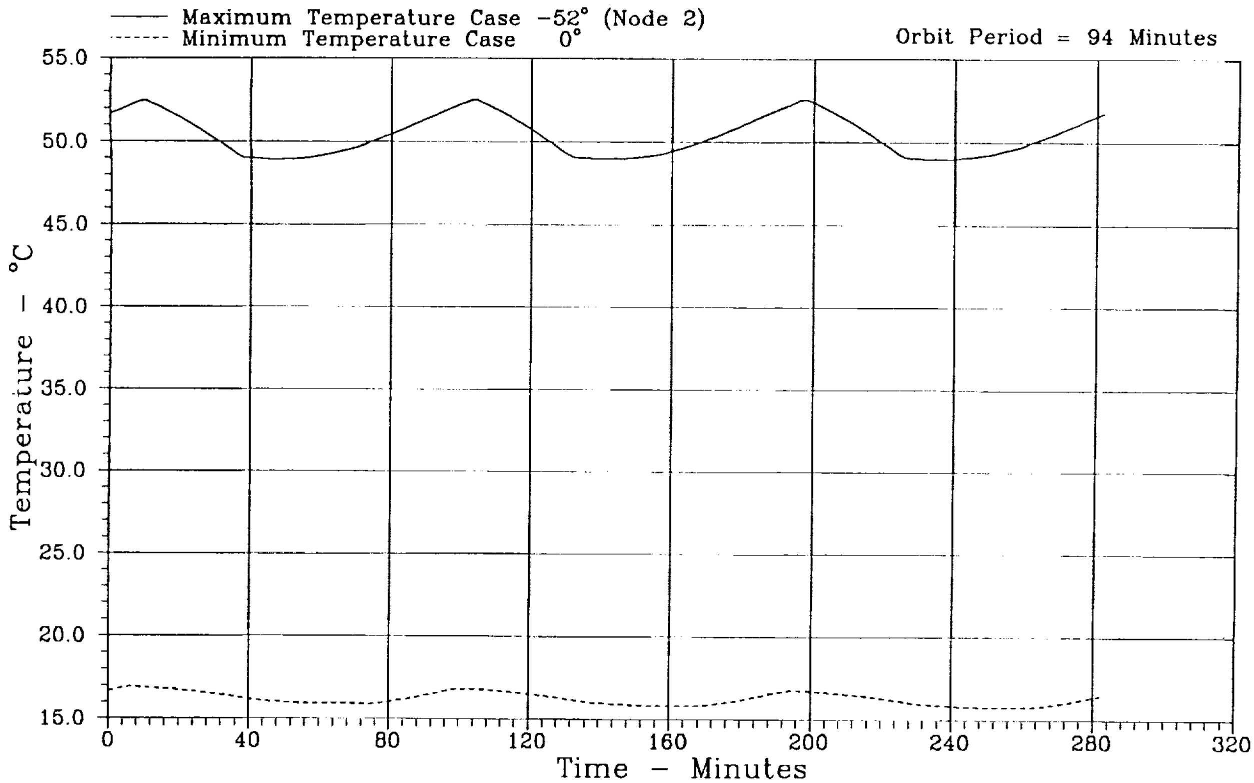


Figure 14. Average structure orbital boundary temperature.

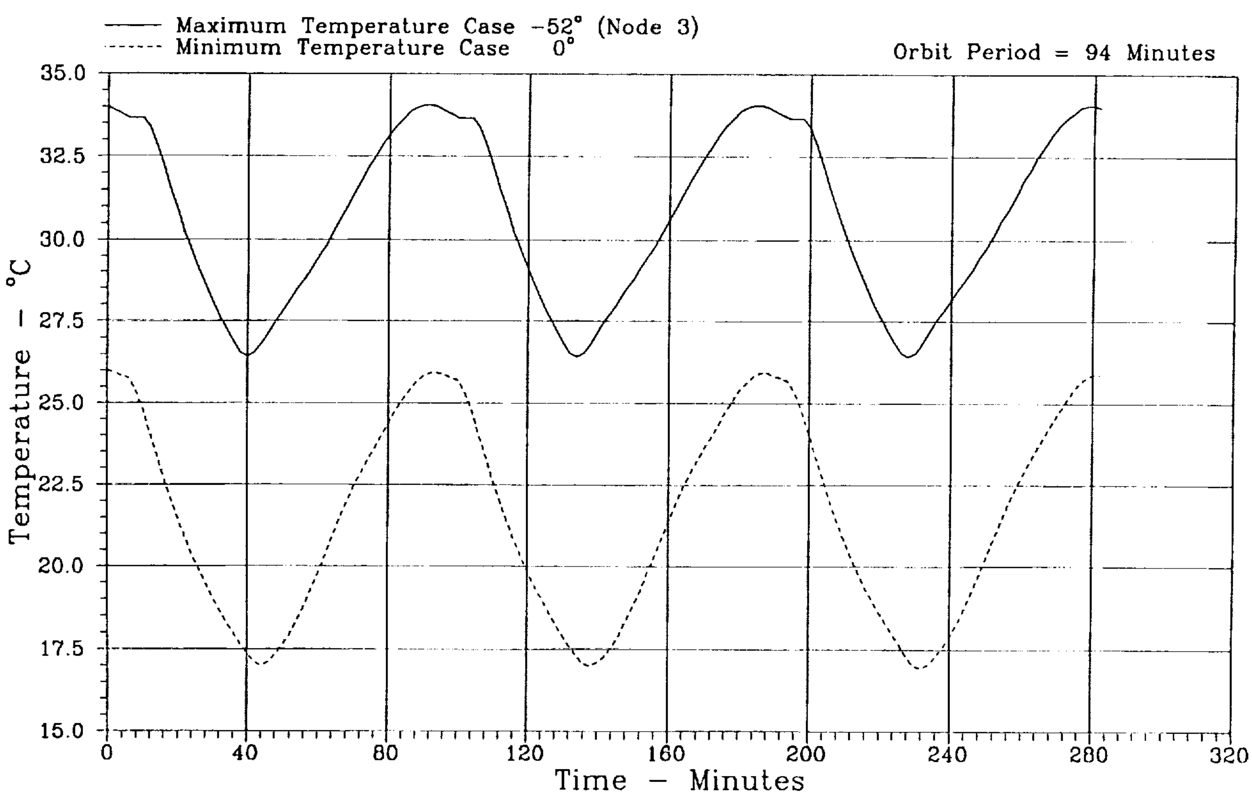


Figure 15. LDEF interior average orbital boundary temperature.

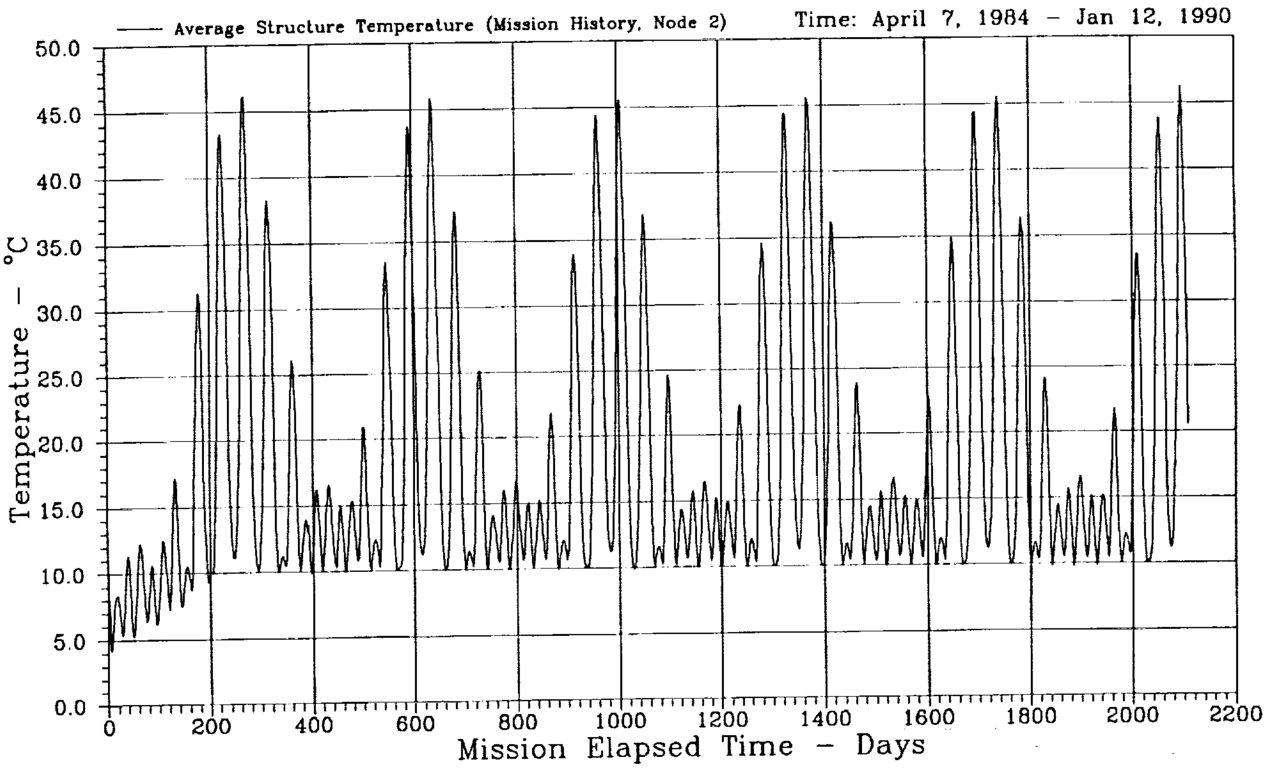


Figure 16. Mission average structure boundary temperature.

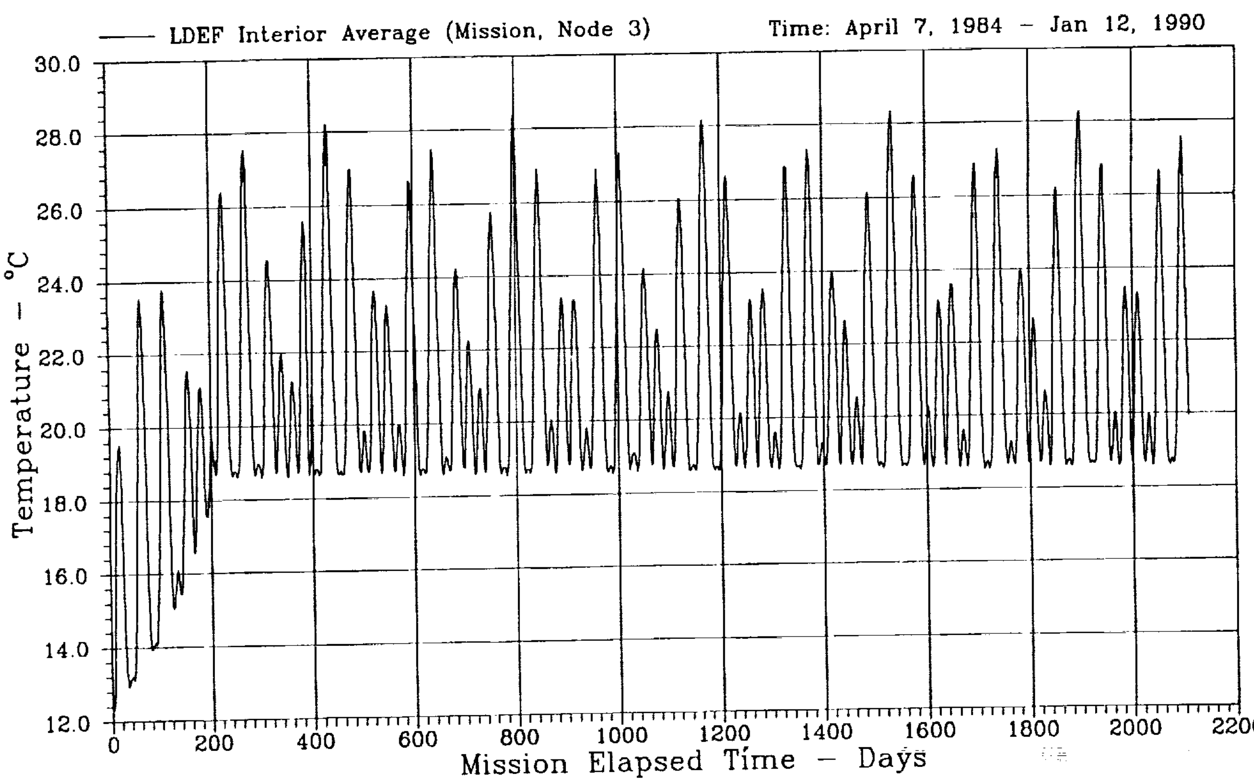


Figure 17. LDEF interior average mission boundary temperature.

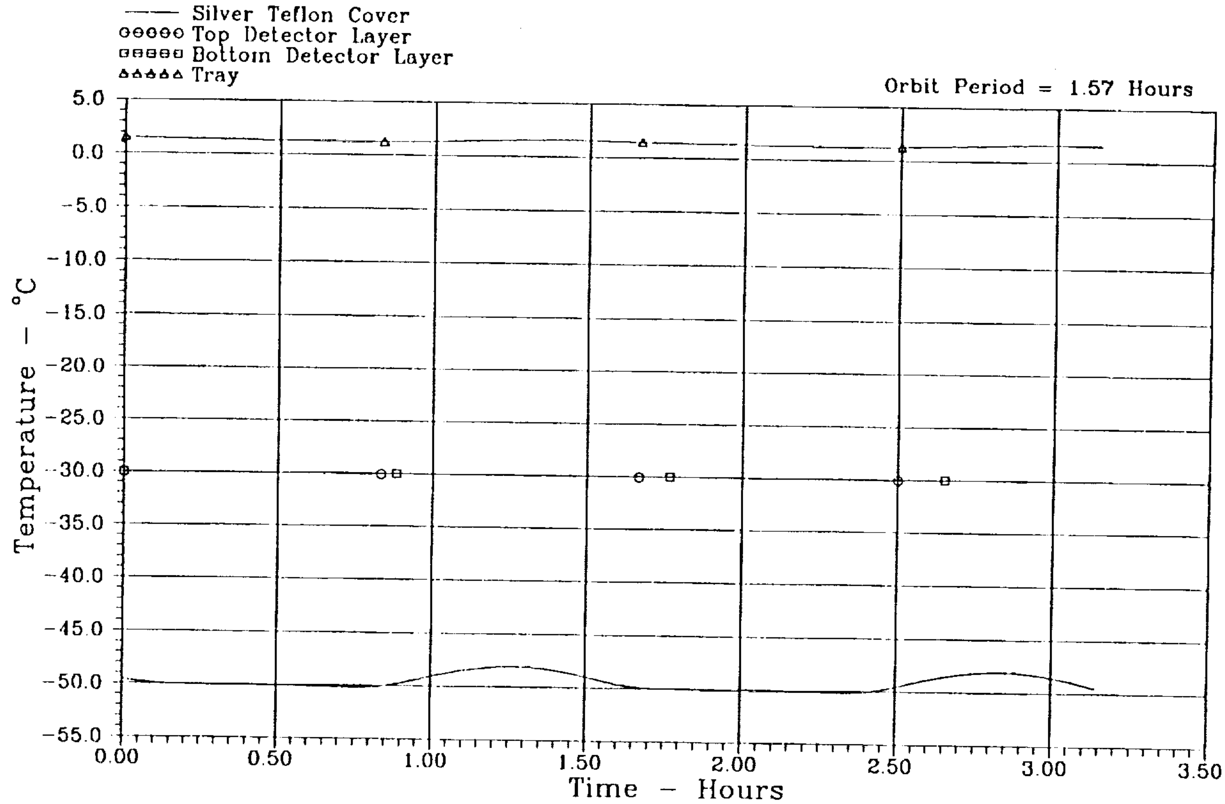


Figure 18. UHCRE-C6 Minimum orbtial temperature at 0°.

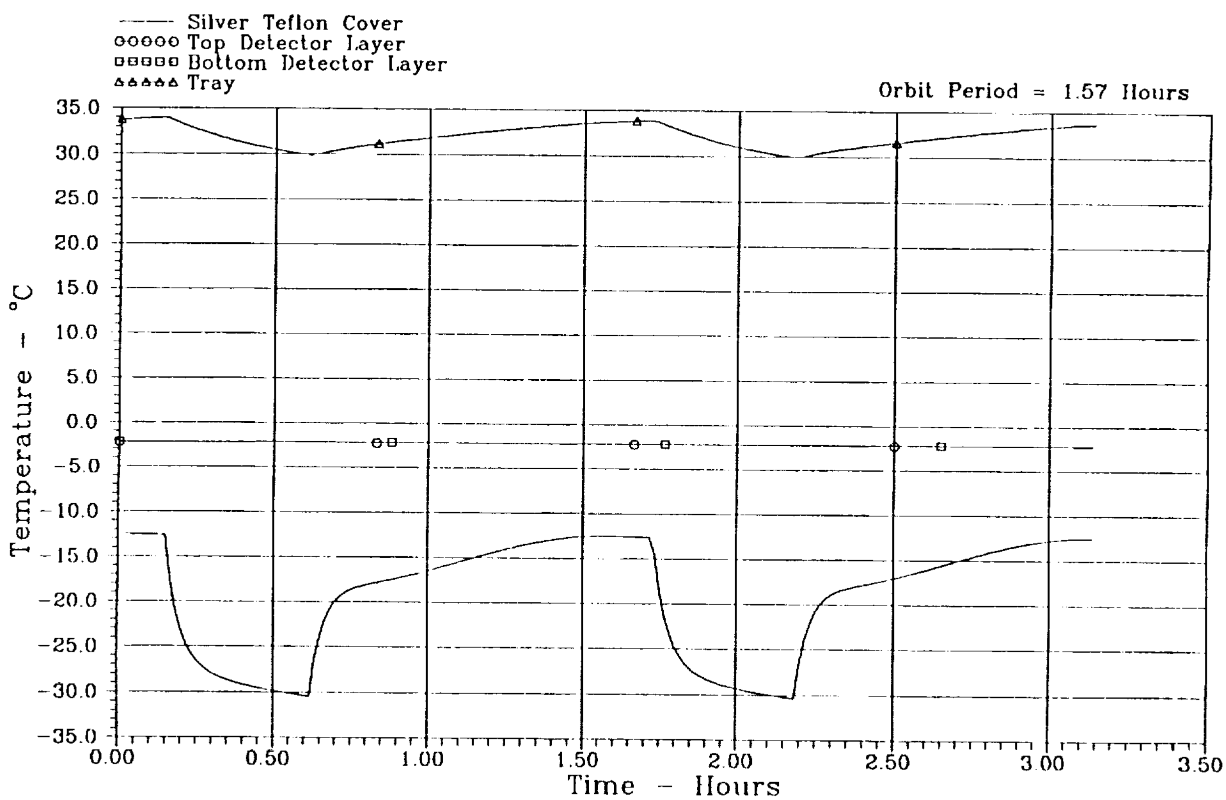


Figure 19. UHCRE-C6 Maximum orbital temperature at -52°.

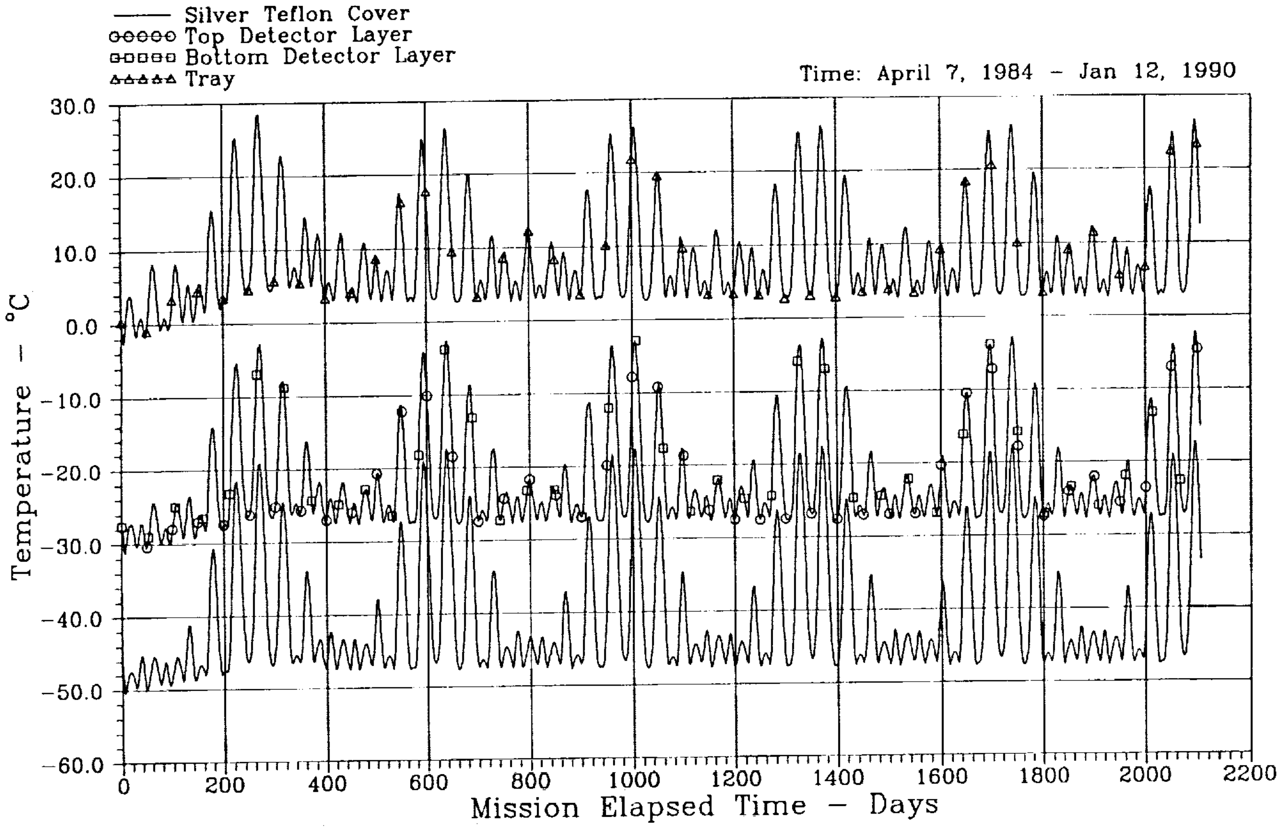


Figure 20. A0178-C6 Mission temperature history.