SID 67-373-2

FINAL REPORT

A STUDY OF ELECTRONIC PACKAGES ENVIRONMENTAL CONTROL SYSTEMS AND VEHICLE THERMAL SYSTEMS INTEGRATION

TECHNICAL REPORT

(Contract NAS8-20320)

21 July 1967

Prepared by

D. J. Watanabe
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Approved by

L. Isenberg
Project Manager

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Environmental Control and
Life Support Systems

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SPACE DIVISION

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FOREWORD

This report was prepared by the Space Division of North American Aviation, Inc., under Contract NAS8-20320, "Electronic Packages Environmental Control Systems and Vehicle Thermal Systems Integration," for NASA's George C. Marshall Space Flight Center (MSFC). The work was administered under technical direction of the Propulsion and Vehicle Engineering Laboratory, with F. Huneidi the contracting officer's representative.

This three-volume report represents the results of the 12-month study to determine the optimum environmental control systems for thermally conditioning individual electronic packages for space missions of durations ranging from 4-1/2 hours to 180 days.

The first volume (SID 67-373-1) is the summary, which contains the significant results and supporting information of the technical study.

The second volume (SID 67-373-2) is the technical report, which contains the details of the study effort and the results and conclusions drawn from the study.

The third volume (SID 67-373-3) is the appendix, which contains the CRT data plots of the thermal analysis (heat balances) conducted during the study.

The technical personnel who contributed to the study effort are C.A. Aldrich, R.C. Coda, J. Hermann, B. Mykytyn, and D.J. Watanabe of the Space Division, and H. Kamei of the Autonetics Division, North American Aviation, Inc.

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NOMENCLATURE

TERMS

Apsis	In an orbit, the point at which the distance of the body from the center of attraction is greatest (higher apsis) or least (lower apsis), $\frac{dr}{dt} = 0$
Eccentricity	The ratio of the radius vector through a point on a conic to the distance from the point to the directrix
Epoch	An instant of time or a date selected as a point of reference
Geocentric	Related to or measured from the earth's center; relating to the earth as a center
Heliocentric	Referred to the center of the sun as the origin
Inclination	Angle between orbit plane and reference plane
Perigee	The point on a geocentric orbit nearest the earth's center
Right ascension	The distance eastward or counterclockwise along the celestial equator, from the first point of Aries to the meridian passing through any celestial body
Semi-major axis	The distance from the center of an ellipse to an apsis; one-half the longest diameter; one of the orbital elements
True anomaly	The angle at the focus between the line of apsides and the radius vector measured from the perifocus in the direction of motion

ABBREVIATIONS

AAP	Apollo Applications Program
AORL	Apollo orbiting research laboratory

ASM/IU	Airlock service module/instrument unit
BSM	Basic subsystem module
CRT	Cathode ray tube
CPC	Ceramic printed circuit
CM	Command module
CSM	Command and service module
deg	Degree
ECS	Environmental control system
F	Fahrenheit
FET	Field effect transistor
GN_2	Gaseous nitrogen
GSE	Ground support equipment
HX	Heat exchanger
IC's	Integrated circuits
IMU	Inertial measuring unit
IR	Infrared
IU	Instrument unit
kwe	Kilowatts electrical
kwt	Kilowatts thermal
LEM	Lunar excursion module
LH_2	Liquid hydrogen
LM	Lunar module
LORL	Large orbiting research laboratory

LOX	Liquid oxygen
LRU	Line replaceable unit
MM	Mission module
MMH	Monomethyl hydrazine
MORL	Manned orbiting research laboratory
MOS	Metal oxide semiconductor
n. mi.	Nautical mile
OLS	Orbital launch stage
psig	Pounds per square inch gauge
RTG	Radioisotopic thermoelectric generator
RF	Radio frequency
SCR	Silicon controller rectifier
SLA	Spacecraft/lunar module adapter
SOS	Silicon on sapphire
SSGS	Standardized space guidance system
scfm	Standard cubic feet per minute
TWT	Traveling wave tube
UDMH	Unsymmetrical dimethyl hydrazine
UHF	Ultra high frequency
Veh CP	Vehicle coldplate
vm	Velocity meters

SYMBOLS

A	Heat transfer area, square feet
A_e	Total absorbed energy on a surface, Btu/(hour)(square feet)
A_r	Radiator area, square feet
C_p	Specific heat, Btu/(hour)(F)
D_B	Bolt diameter, inches
D_E	True contact diameter, inches
E	Earth emission, Btu/(hour)(square feet)
E	Voltage across one module
EI	Electrical input power, watts
h_B	Boiling heat transfer coefficient, Btu/(hour)(square feet)(F)
H_i	Initial enthalpy, Btu per pound
K or $K(\overline{T})$	Thermal conductance parameter
h_v	Heat of vaporization, Btu per pound
k	Thermal conductivity, Btu/(hour)(square feet)(F/foot)
l	Heat conduction path length, feet
N	Number of modules
P_c	Fluid critical pressure, pound per square inch absolute
Q	Heat load, watts or kilowatts
q	Heat transfer rate, Btu per hour
q_e	Earth-emitted radiation, Btu/(hour)(square feet)
Q_{el}	Total heat load, electrical equipment, kilowatts
q_{el}	Electrical equipment heat load per coldplate, watts

q_r	Earth-reflected solar radiation, Btu/(hour)(square feet)
R	Reflected solar energy, Btu/(hour)(square feet)
R or $R(\overline{T})$	Electrical resistance parameter
q_s	Direct solar radiation, Btu/(hour)(square feet)
R_f	Heat dissipator equivalent thermal resistance, C/watt
S	Solar radiation, Btu/(hour)(square feet)
T_c	Cold junction temperature, F
t_c	Coolant coldplate inlet temperature, F
T_h	Hot junction temperature, F
T_R	Radiator surface temperature, R
T_S	Effective sink temperature, R
T_s	Coolant supply temperature, F
t_s	Saturation temperature, F
$\overline{T}$	Average temperature, F
T%	Percent of maximum tightening torque
ΔT	Temperature difference
$\dot{w}$ or W_C	Coolant flow rate, pound per hour
W_{WB}	Weight of water boiler, pound
YS_S	Yield strength of material at junction surface interface, psi
YS_R	Yield strength of bolt, psi
α or $\alpha(\overline{T})$	Seebeck parameter
α_s	Solar absorptivity
ϵ	Infrared emissivity

ϵ_D	Dissipator effectiveness
ρ_v	Density of saturated vapor, pound per cubic foot
σ	Stefan-Boltzmann constant (0.1713×10^{-8} Btu/hr-ft^2-(R)^4)

1.0 INTRODUCTION

One of the important considerations involved in NASA's plans to use the Saturn instrument unit (IU) for extended operational periods in future space missions is the environmental control system (ECS) for thermal conditioning of astrionic equipment. The variety of profiles, vehicle configurations, and durations of future Saturn V missions are expected to impose increasingly stringent requirements on the thermal conditioning system (TCS).

This study was undertaken to determine the optimum thermal conditioning systems for IU electronic packages for Saturn missions ranging from 4-1/2 hours to 180 days. These systems are to be basic concepts optimized on the basis of mission duration, operational temperature limits, and heat dissipation rate.

The current IU thermal conditioning system is designed for about 6-1/2 hours of operational time. It is possible, with minor modifications, to extend this operational time. Replacing of components with limited design life and increasing the amount of stored supplies (water and gaseous nitrogen) may be sufficient in some cases, particularly for relatively short durations. Modifications could become more extensive for longer operation because weight and volume penalties of stored supplies could become prohibitive. The extent of necessary modifications depends on the mission and the on-board astrionic equipment.

Because of the high development cost of new systems, this study was directed toward uprating the current IU thermal conditioning system. Among the important considerations were maximum use of existing components, impact of possible design improvements in astrionic equipment, and changing environmental conditions and heat loads. The recommended system concepts represent a logical evolution of the current TCS concept with increasing modifications. In addition to the system concepts, system data used in establishing the recommended concepts are presented.

The study included the following tasks:

1. Defining the requirements and constraints imposed by the various missions and vehicle configuration and by the thermal limits of the astrionic equipment

2. Reviewing current IU astrionic equipment to establish possible design improvements based on present technology and on projected new developments, and determining the resulting impact on the thermal requirements

3. Synthesizing candidate thermal conditioning systems, starting with the current system, and analyzing the systems to provide the necessary data for system selection

4. Selecting the optimum thermal conditioning system concepts suitable for future Saturn missions

Several conclusions relative to the recommended system concepts are presented, as well as recommendations for future investigations.

2.0 SYSTEM REQUIREMENTS AND CONSTRAINTS

System requirements and constraints have been established to provide the basic guidelines for the technical effort. The requirements and constraints encompass the range of values or conditions representative of foreseeable future missions.

Three mission models for the Saturn V have been selected for this study: near-earth orbit, synchronous earth orbit, and lunar and planetary missions. Typical mission profiles and vehicle configurations have been established to define the thermal environment and mission/vehicle constraints that may be expected for future missions of 4-1/2-hour to 180-day durations. The vehicle configurations were assumed to be basically the Saturn V, with various combinations of the instrument unit or units with uprated upper stages and spacecraft. The current IU/S-IVB configuration was selected as the baseline.

The functional requirements of the astrionic equipment were assumed to be unchanged for the selected mission models. With the addition of a few items of equipment, the current list of astrionic equipment was assumed to be adequate. On the basis of a modified equipment list, the heat loads and temperature tolerance ranges were established. These equipment thermal requirements and the environmental thermal conditions provide the basic thermal conditioning system requirements.

2.1 SPACE MISSION MODELS

Information on future space missions was surveyed to obtain mission data required to establish the basic guidelines. The survey was limited to current studies and technical articles on future missions that utilize the Saturn stages. The missions of interest were those that fell within the range of 4-1/2-hour to 180-day durations.

Tables 2-1 and 2-2 list possible future missions and include some basic mission data. The information given in these tables and other available data were used to establish the basic mission categories: near-earth orbit, synchronous orbit, and lunar and planetary. The specific mission designations in current use that fall within the three general categories are indicated

Table 2-1. Possible Future Space Missions

Missions	Unmanned	Manned Developmental	Manned Operational
Earth-Orbital	Scientific satellites Small special purposes Orbiting observatories Application satellites Communication Meteorology Navigation Engineering research	Apollo Maneuvering reentry Interim orbital laboratories	Orbital operations Manned orbiting laboratories Operational ferry vehicle Recoverable boosters Engineering experiment and development
Lunar	Surveyor Intermediate space probes	Manned landing Apollo Lunar logistic systems (unmanned)	Lunar station Scientific observations Lunar explorations
Planetary	Deep space probes Voyager	Manned expeditions Mars landing Venus reconnaissance	Planetary operations Mars station Advanced manned expeditions Jupiter satellites Mercury Others

Mission	Designation	Mission Da	
		Duration	Ope Tim
Earth-Orbit	AAP	30-45 days	19
	MORL	1 year	19
	LORL	1-5 years	19
Lunar	Apollo	14 days	19
	Lunar Ferry		19
	Lunar Base (Temporary)		1
Planetary	Voyager		
	Mars/Venus Flyby		1
	Mars Landing		1

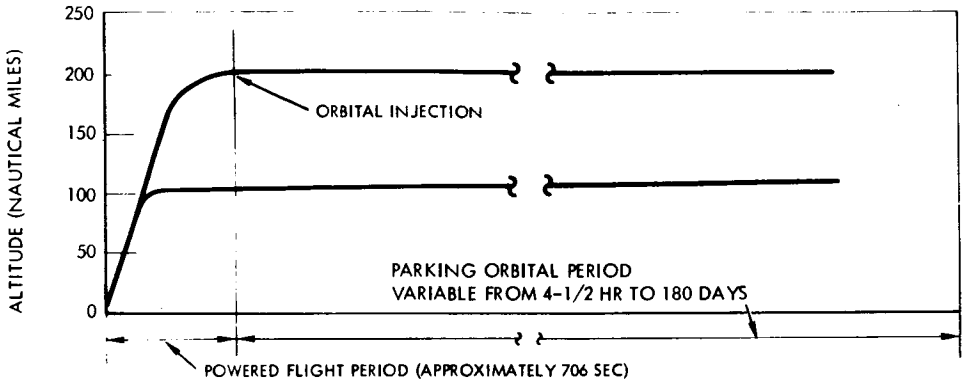
Table 2-2. Characteristics of Possible Future Missions

ıta	Mission Vehicles			Launch Methods			
rational e Period	Spacecraft	Booster or Propulsion	Support	Direct	Orbital	In-Transit Rendezvous	Target Planet Orbital Rendezvous
68	Apollo/CM	Saturn V	-	x	-	-	-
72	Modified S-IVB	Saturn V	Spent-stage utilization	x	-	-	-
77		Saturn V	Spent-stage utilization	x	-	-	-
69	Apollo/LM	Saturn V	-	x	-	-	-
980-85	CM and Pallets	Nuclear propulsion	-	-	x	-	-
974	S-IVB utilization	S-IVB	-	-	x	-	-
	Apollo/CM (Unmanned)	Saturn V	-	x	-	-	-
	New design						
975	Apollo/CM	S-IIB	LOX tanker	-	x	-	-
	Apollo/CM	S-IVC					
983-88	New design	New multi-stage design		-	x	-	-

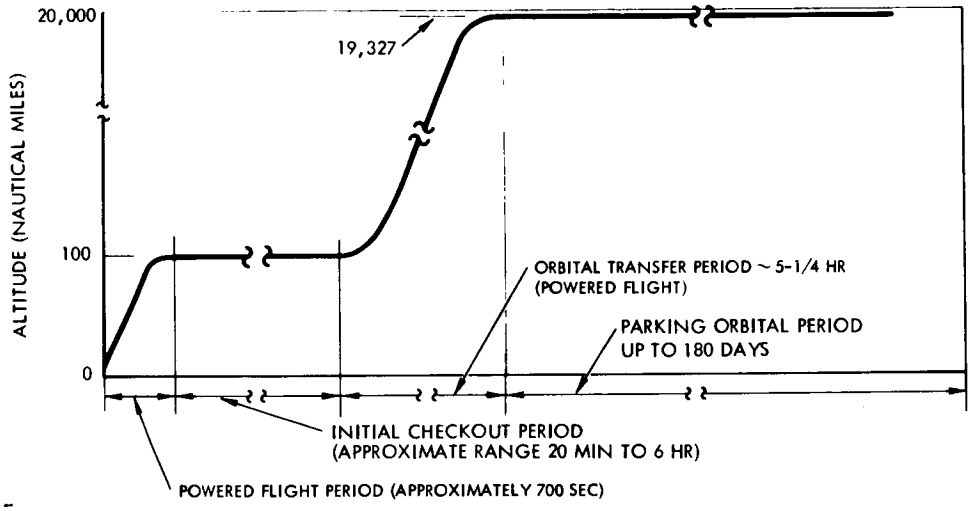
in Table 2-2. The near-earth-orbit mission includes missions such as orbiting research laboratory (AORL, MORL, LORL) and the staging phase of planetary or lunar missions. The synchronous-orbit mission includes communications and command- and control-type missions. The lunar mission includes lunar orbiting and landing and lunar ferry missions; both can be considered either direct earth launch or orbital launch. The planetary missions are assumed to be orbital launches.

For the missions selected, several assumptions were made with regard to mission characteristics. One was that the orbits would be circular and at altitudes that minimize radiation and other environmental hazards. Another was that the operational period would be selected on the basis of minimizing environmental hazards. These assumptions permit the use of a relatively simple environmental model. Another assumption was that no crew would be available to perform any maintenance or repair or be required to operate the thermal system. Thus, the system must be fully automatic and self-contained. However, it should be capable of being controlled from some remote point such as a ground station or an orbiting spacecraft. In some cases, it may be on long-term standby in orbit and activated later. A further assumption was that the IU/S-IVB always would be at a defined orientation in orbit, rather than in a random or tumbling mode, even during deactivated periods.

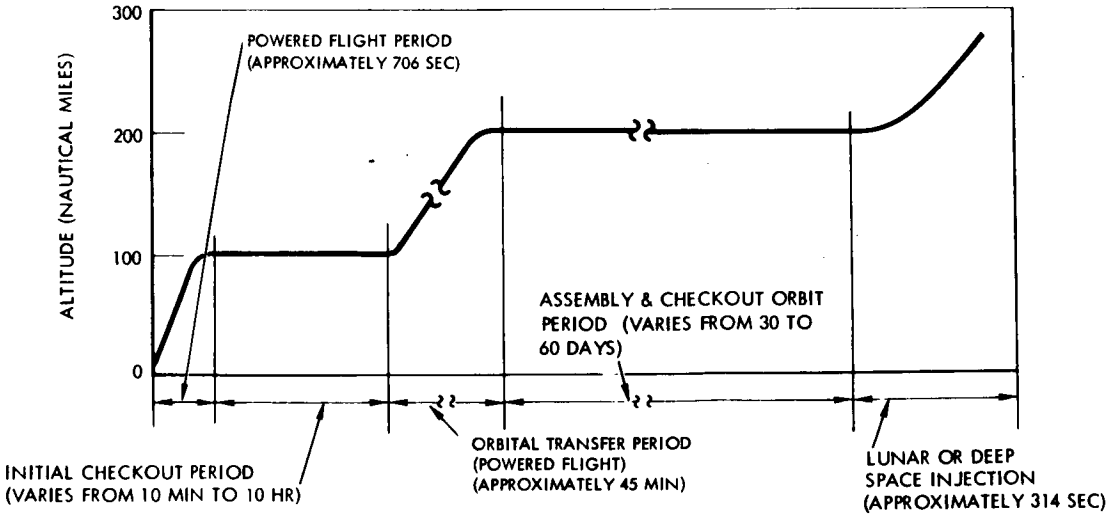
The assumed profiles for the mission models are given in Figure 2-1, establishing, together with the assumed vehicle orientations, the environmental heat loads to be expected. The mission phases and duration indicated in Figure 2-1 were assumed to be typical and, thus, adequate for this study.



NEAR EARTH CIRCULAR ORBIT



SYNCHRONOUS EARTH ORBIT



LUNAR OR PLANETARY ORBITAL LAUNCH

Figure 2-1. Basic Mission Profiles

2.2 VEHICLE CONFIGURATIONS

Several vehicle configurations have been assumed to be representative of the types that may be selected for near-term and future Saturn missions. These configurations are illustrated in Figure 2-2. The primary interest in the different configurations is the possible variation in the thermal environment imposed by the surrounding structure. Another consideration is the possible location of some of the ECS components in areas other than the instrument unit.

Configuration A is the current Saturn V arrangement, in which the spacecraft/LM adapter (SLA) containing the lunar module (LM) is mounted on the forward end of the instrument unit. Cross-sectional detail of Configuration A is given in Figure 2-3, which was assumed to be the baseline concept. In Figure 2-3, the astrionic equipment mounted on coldplates or thermal conditioning panels is shown for both the instrument unit and the S-IVB stage.

Configuration B is a possible configuration in which the forward end of the instrument unit is open to space. This may occur for a relatively brief period in orbit before assembly with another unit of the space vehicle such as the basic subsystem module (BSM). The interior of the instrument unit and the forward end of the S-IVB were assumed to be exposed to space.

Configuration C consists of the BSM mounted at the forward end of the instrument unit. The BSM is assumed to be habitable, and so the internal temperature is assumed to be maintained at 70 F. This configuration may be assembled in orbit or on the ground. It provides the possibility of containing IU power supply, as well as some redundant astrionic equipment that would improve reliability. It also could provide a closely regulated and desired environment for certain sensitive or critical astrionic packages.

Configuration D differs from the others in that the instrument unit may be one of several elements of an orbital launch vehicle. The instrument unit would be operated during the ground launch and ascent periods and then deactivated until assembly in orbit and orbital launch. A unique feature is the long-term exposure to the low temperature environment imposed by the S-IVC stages at the aft and forward ends of the instrument unit.

Figure 2-4 illustrates a possible configuration in which the SLA and the airlock service module (ASM) are mounted at the forward end of the

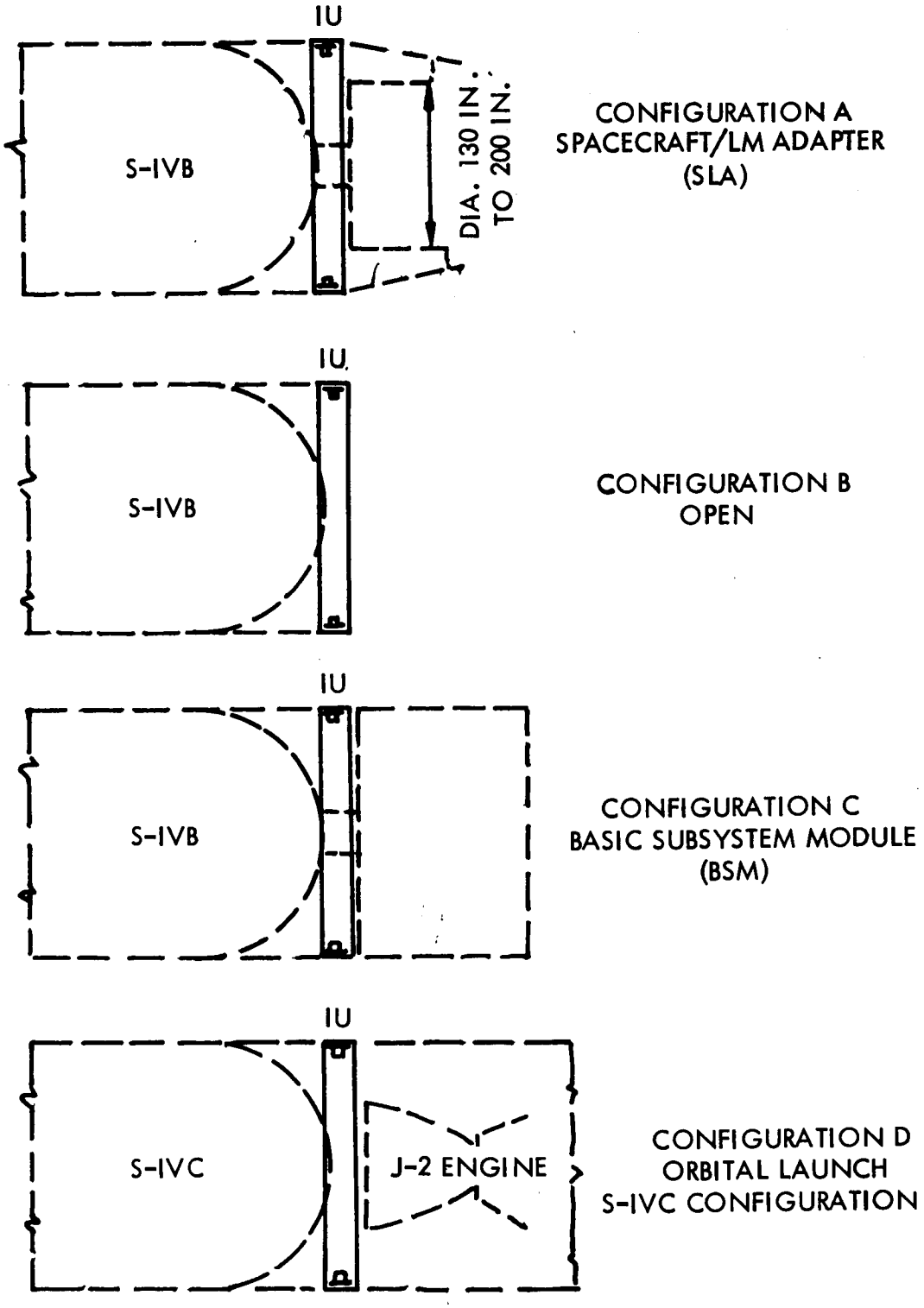


Figure 2-2. Vehicle Configurations

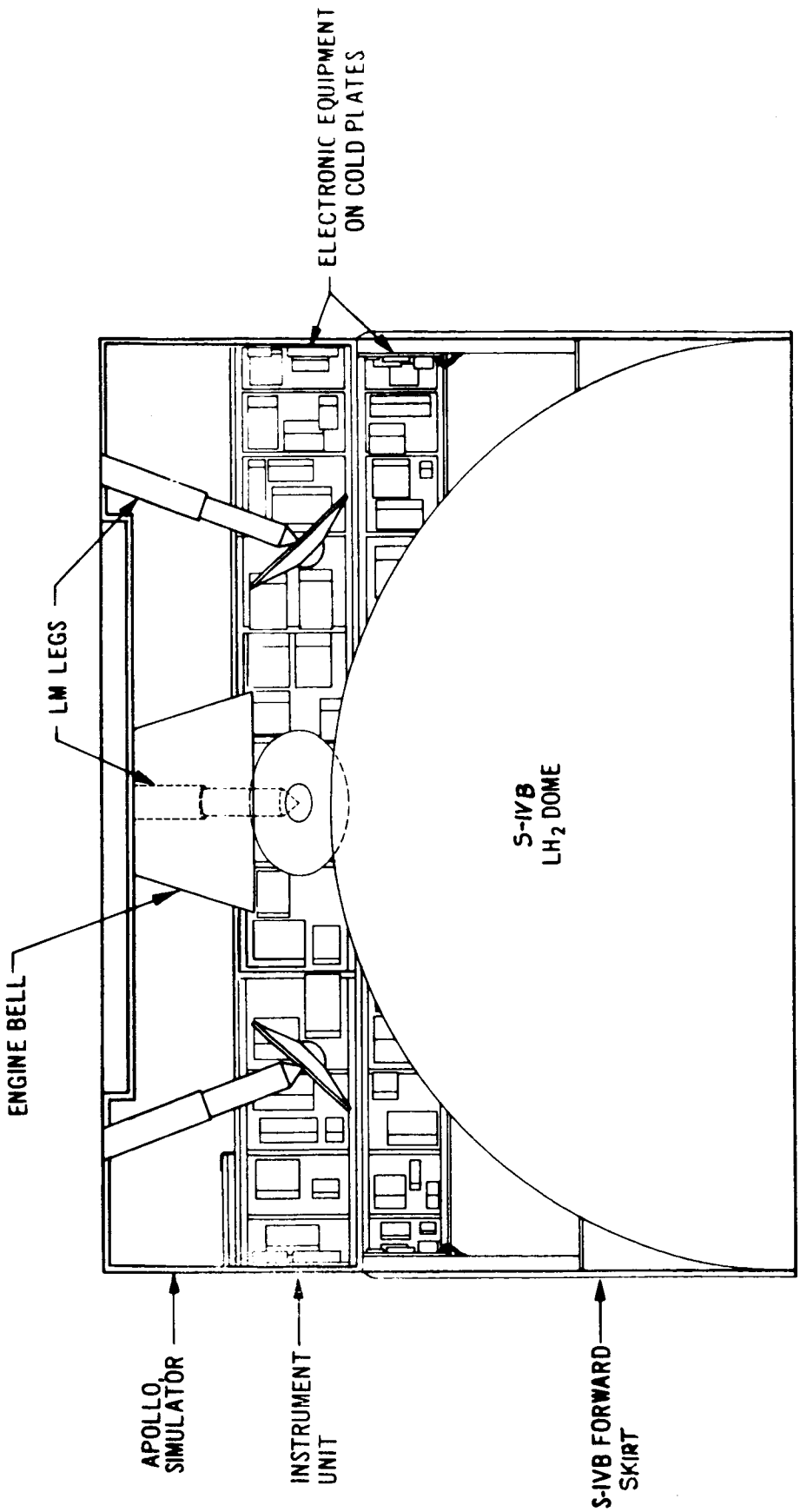


Figure 2-3. Cross-Sectional Detail of Configuration A

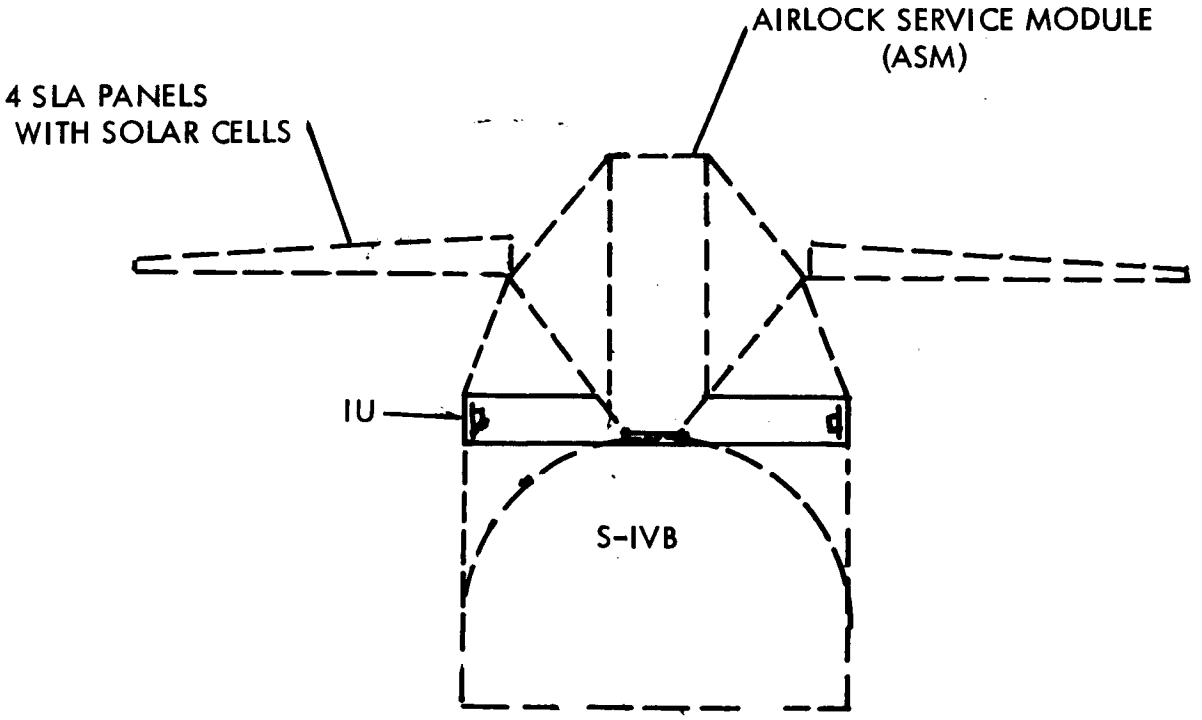


Figure 2-4. ASM/IU Configuration

instrument unit. This configuration is similar to Configuration A, except the SLA panels are used for mounting solar cells to provide electrical energy directly or for recharging storage batteries. The solar cell/battery combination has been assumed as the prime power supply for the mission. The influence of the SLA panels in the open position on the instrument unit and the environmental control system is of interest.

The possible mission vehicle configurations are illustrated in Figure 2-5, which is intended to aid in defining the overall thermal environment imposed by the vehicle and the space environment. Various possible configurations have been considered to provide the widest possible range of conditions that may be expected for the future missions.

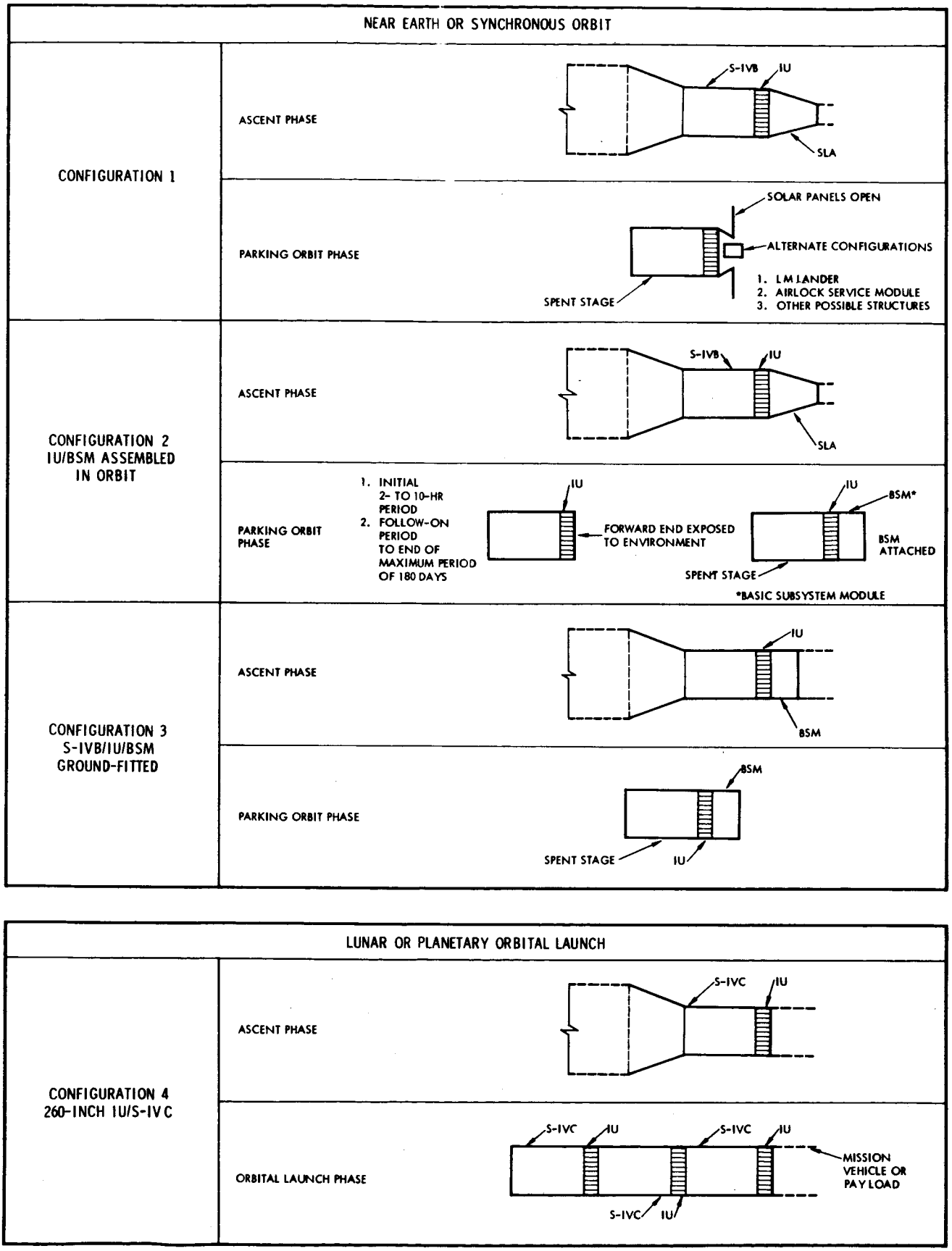


Figure 2-5. Potential Mission Vehicle Configurations

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2.3 SPACE ENVIRONMENT

A relatively simple model for the space environment was assumed for purposes of the study. The significant environmental factors are low density or vacuum condition, zero gravity, and thermal radiation. The other environmental factors were considered to have negligible effect, based on the assumption that mission trajectories and operational periods will be selected to minimize environmental hazards such as radiation and particles. It is recognized, however, that the thermal coatings on radiating surfaces could be affected by the space environment. Meteoroids could have an erosive effect on radiating surfaces over an extended period, thus altering the spectral properties and reducing the radiating quality of the surface. Meteoroid impacts also could result in puncture of space radiator tubes or other components. The effects of degradation of the thermal coatings, probability of meteoroid penetration on system design, and thermal radiation must all be considered.

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2.4 INCIDENT HEAT FLUX

Thermal radiation from planetary bodies striking the vehicle surface is a prime consideration in the design of a thermal conditioning system. For this reason, incident heat fluxes have been obtained for a simulated spacecraft (or IU) for various orbits and vehicle orientations associated with the three mission models selected for the study. The various orbits and vehicle orientations for which the incident heat fluxes were computed are identified in Table 2-3. Cases IU-1, IU-2, IU-3, and IU-11 describe orbits and vehicle orientations applicable to the mission profile for a 200-n. mi. near-earth circular orbit, as shown in the upper portion of Figure 2-1. Cases IU-1, IU-2, and IU-11 are also applicable to the assembly and checkout orbit period for a lunar or planetary mission in the lower portion of Figure 2-1. The 100-n. mi. near-earth circular orbit and the initial checkout orbit period for a lunar or planetary mission are described by Cases IU-7, IU-8, and IU-10, and the initial checkout orbit period for the synchronous earth orbit mission is described by Case IU-4. The synchronous orbit itself is referred to by Cases IU-5 and IU-6, and Case IU-9 applies to lunar or deep space injections.

The relationship between the vehicle coordinate axes, IU location numbers, and vehicle orientation is illustrated in Figure 2-6 for a 200-n. mi. earth orbit at 29-degree inclination. This figure indicates that the positive y axis was chosen to pass through IU location 21, the positive z axis was chosen to pass through IU location 15, and the positive x axis was chosen to coincide with the vehicle longitudinal axis. The three vehicle orientations used in the calculation of incident heat flux are illustrated for the position of the vehicle at the subsolar point. When the x axis is tangent to the flight path (x tan), the negative z axis (IU location 3) faces the earth continuously. When the x axis is sun-oriented (x-solar), the forward end of the vehicle faces the sun continuously; when the y axis is sun-oriented (y-solar), the positive y axis (IU location 21) faces the sun continuously.

The incident heat fluxes were obtained with the aid of an IBM 7094 digital computer program that calculates direct solar radiation, planet-reflected solar radiation, and planet-emitted radiation for the IU surface as a function of orbital position. The computer program is one of several developed at NAA and is described in Reference 2-1. The procedure used to determine the heat fluxes to the IU outer surface is described in the following paragraph.

The instrument unit was divided into 12 equal segments and approximated by plane surfaces as illustrated in Figure 2-7. The 12 segments were

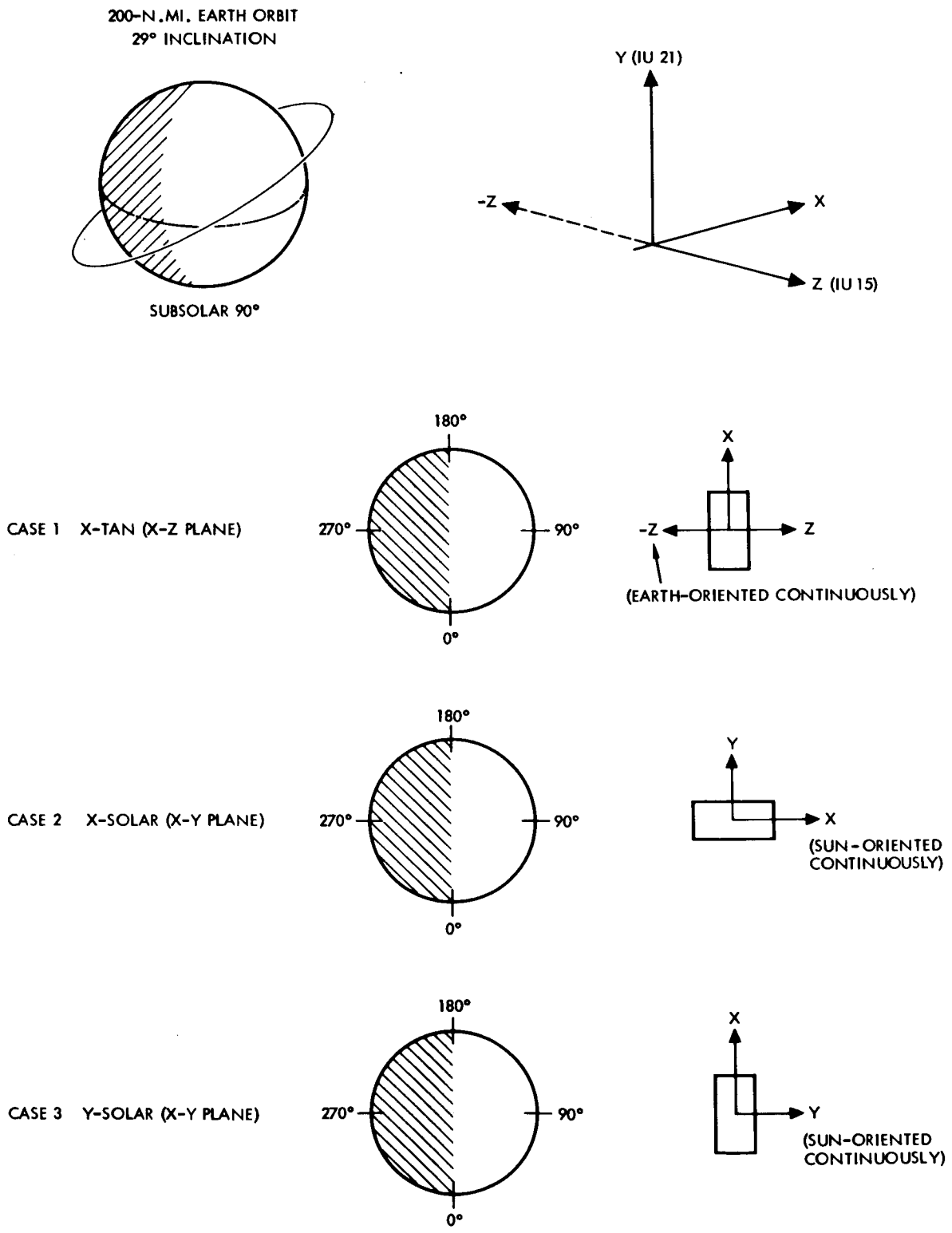

Figure 2-6. Vehicle Orbit Orientations

assumed to be sufficient for the thermal analysis, which used 24 equal segments. The error introduced by the approximation was calculated to be less than one percent. The area vectors (vectors normal to the plane surface) for these 12 sectors were oriented to the vehicle orthogonal coordinate system used in the computer program. This vehicle coordinate system was then oriented to the program's earth orthogonal coordinate system. The computer program allows the vehicle coordinate system to be inertially oriented, sun-oriented, or earth-oriented. The data presented in Table 2-3 and the additional orbital information summarized in Table 2-4 give the information necessary to perform the computation.

To avoid needlessly complicated expressions for obtaining shadow intersection points, the following three simplifying assumptions concerning shadow geometry are made in the computer program: (1) the earth is assumed spherical, with its radius equal to 3960 statute miles; (2) the earth's shadow is assumed cylindrical and umbral (sun at infinity); (3) atmospheric refraction and penumbral effects are neglected.

The validity of these assumptions was verified through telescopic observations of satellites as they entered the earth's shadow. Actual entrance times observed during several transits of 1959 Alpha II and 1960 Iota I usually differed from predictions by only a few seconds.

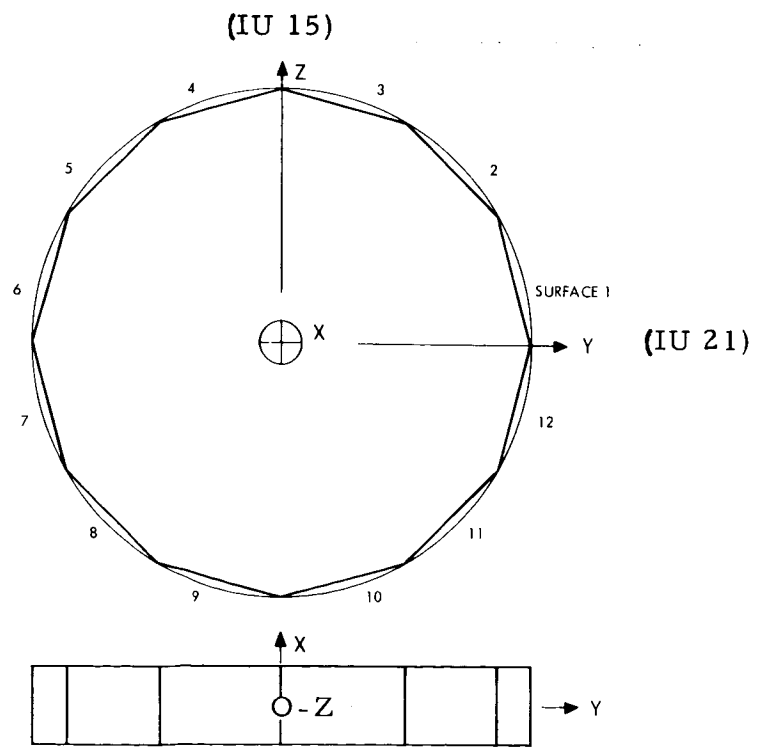

Figure 2-7. Vehicle Coordinate System

Table 2-3. Orbits and Vehicle Orientation Data

Case No.	Orbit	Vehicle Orientation (see Figure 2-6)
IU-1	200-n. mi., circular orbit, angle of inclination = 29 deg, launch date approximately June 21 (right ascension - 0 deg)	a. X axis tangent to flight path, -Z axis earth-oriented b. X axis sun-oriented, Z axis perpendicular to orbit plane c. Y axis sun-oriented, Z axis perpendicular to orbit plane
IU-2	200-n. mi., circular orbit, angle of inclination = 34 deg, launch date approximately Dec. 21 (right ascension - 0 deg)	a. Same as Case IU-1a b. Same as Case IU-1b c. Same as Case IU-1c
IU-3	200-n. mi., circular orbit in plane of terminator, angle of inclination = 90 deg, launch date approximately March 21 (right ascension - 0 deg)	a. Same as Case IU-1a b. X axis sun-oriented, Z axis in orbit plane c. Y axis sun-oriented, Z axis in orbit plane
IU-4	100-n. mi., equatorial circular orbit, angle of inclination = 0 deg, launch date approximately March 21 (right ascension - 0 deg)	a. Same as Case IU-1a
IU-5	19, 327-n. mi., (synchronous altitude) circular orbit, angle of inclination = 10 deg (continuous solar exposure), launch date approximately March 21 (right ascension - 0 deg)	a. Y axis sun oriented, Z axis perpendicular to orbit plane b. X axis sun oriented, Z axis perpendicular to orbit plane c. X axis tangent to flight path, -Z axis earth oriented
IU-6	19, 327-n. mi., (synchronous altitude) circular orbit, angle of inclination = 0 deg (max. shadow period), launch date approximately March 21 (right ascension - 0 deg)	a. Same as Case IU-5a b. Same as Case IU-5b c. Same as Case IU-5c
IU-7	100-n. mi. circular orbit, angle of inclination = 29 deg, launch date approximately June 12 (right ascension - 0 deg)	a. Same as Case IU-1a b. Same as Case IU-1b c. Same as Case IU-1c

Table 2-3. Orbits and Vehicle Orientation Data (Cont)

Case No.	Orbit	Vehicle Orientation (see Figure 2-6)
IU-8	100-n. mi. circular orbit, angle of inclination = 34 deg, launch date approximately Dec. 21 (right ascension - 0 deg)	a. Same as Case IU-1a b. Same as Case IU-1b c. Same as Case IU-1c
IU-9	Lunar or deep space injection	
IU-10	100-n. mi. circular orbit, angle of inclination = 34 deg, launch date approximately Dec. 21 (right ascension - 180 deg)	X axis tangent to flight path
IU-11	200-n. mi. circular orbit, angle of inclination = 34 deg, launch date approximately Dec. 21 (right ascension - 180 deg)	X axis tangent to flight path

Table 2-4. Orbital Elements and Planetary Data

	Earth Orbit		Synchronous Earth Orbit	Polar Earth Orbit
Epoch of orbital elements	172	355	80	80
Semi-major axis (statute miles)	4075	4075	26,217	4190
Eccentricity	0	0	0	0
Right ascension of ascending node (deg)	0	0,180	0	90
Argument of perigee	0	0	0	0
Inclination (deg)	0, 29	34	0, 10	90
Solar constant (Btu/(hr)(sq ft)	443	443	443	443
Albedo	0.4	0.4	0.4	0.4
Earth emission (Btu/(hr)(sq ft)	66.4	66.4	66.4	66.4

The results were obtained in three forms: (1) a tabular listing of the heat fluxes — direct solar, earth albedo, and earth emission — as a function of true anomaly and orbit time; (2) a CRT plot of the heat fluxes versus true anomaly; and (3) punched IBM cards with heat fluxes versus time (to be used in conjunction with the NAA Thermal Analyzer Program). The CRT plots are presented in Appendix 2A. The curve symbol E represents the earth emission, S represents the direct solar radiation, and A_e represents the total absorbed energy on the surface.

A comparison of the heat fluxes for all the cases indicated that, in a number of cases, the fluxes were either identical or sufficiently close that only one case needs to be considered. This was true for Cases IU-2, IU-7, and IU-8, which can be approximated by Case IU-1. The results of the comparison (Table 2-5) indicate that the average heat flux increment for Cases IU-2, IU-7, and IU-8 are approximately 10 percent of the heat flux values for Case IU-1 and that the durations in the shadow period are within approximately two minutes of each other. As indicated in Table 2-5, similar heat fluxes occur on different surfaces for each case, and so the heat fluxes of Surfaces 1 through 12 in IU-1a can be applied to the corresponding surfaces of Cases IU-2a, IU-7a, and IU-8a.

Cases IU-3a, -3b, -3c, and IU-4 were considered to be distinct. Case IU-4 is the parking orbit before injection into synchronous orbit.

Cases IU-6a, -6b, and -6c were chosen for the thermal analysis to determine (1) the thermal effect on the IU thermal control system of 1-1/2 hours in the earth's shadow, after exposure to solar radiation for 22 hours, and (2) whether during quasi-steady state, at any period in the orbit other than the shadow period, the thermal results obtained for the IU section would be the same as for Case IU-5, provided all the other variables were the same. The thermal results obtained for Cases IU-6a and -6b during nonshadow periods represent the maximum and minimum thermal conditions for Case IU-9, because the earth albedo and earth emission heat fluxes are negligible at this altitude.

On the basis of the review, six cases that would adequately represent the possible variation in the orbital heat fluxes on the instrument unit were selected. These cases contain the maximum and minimum heat fluxes. Table 2-6 indicates the four cases to be used in the thermal analysis and equivalent cases for those not to be used. This reduces the total number of cases to be investigated by eliminating duplications.

Table 2-5. Comparison of Orbital Heat Fluxes

IU-1a (Time in Earth Shadow = 35.7 min)		IU-2a (Time in Earth Shadow = 35.7 min)		IU-7a (Time in Earth Shadow = 36.7 min)		IU-8a (Time in Earth Shadow = 36.7 min)		IU-1b		IU-2b		IU-7b		IU-8b		IU-1c		IU-2c		IU-7c		IU-8c	
Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux	Surface	Flux
1	119	6	80	1	130	6	90	1	122	7	120	1	133	7	132	1	452	12	452	1	452	12	452
2	290	5	260	2	295	5	265	2	100	8	93	2	110	8	105	2	339	11	340	2	342	11	348
3	415	4	400	3	415	4	400	3	70	9	62	3	81	9	74	3	169	10	168	3	182	10	190
4	435	3	440	4	435	3	440	4	70	10	62	4	81	10	74	4	112	9	122	4	128	9	138
5	350	2	372	5	355	2	380	5	100	11	93	5	111	11	105	5	172	8	180	5	185	8	193
6	200	1	235	6	211	1	248	6	122	12	120	6	133	12	132	6	212	7	214	6	225	7	225
7	100	12	135	7	115	12	115	7	127	1	128	7	138	1	139	7	203	6	195	7	215	6	207
8	161	11	160	8	175	11	175	8	110	2	115	8	123	2	128	8	150	5	140	8	165	5	155
9	210	10	208	9	220	10	220	9	88	3	95	9	100	3	110	9	90	4	80	9	105	4	92
10	210	9	208	10	220	9	220	10	88	4	95	10	100	4	110	10	150	3	148	10	160	3	155
11	161	8	160	11	175	8	175	11	110	5	115	11	123	5	128	11	340	2	340	11	342	2	340
12	100	7	100	12	115	7	115	12	128	6	128	12	138	6	139	12	452	1	452	12	452	1	452

NOTE: Total incident heat flux in Btu/hr ft^2 (maximum values)

Table 2-6. Applicable Orbital Cases for Thermal Analysis

Case No.	Cases Used	Cases Not Used	Equivalent Case
IU-1	X		
IU-2		X	IU-1
IU-3	X		
IU-4	X		
IU-5		X	IU-6
IU-6	X		
IU-7		X	IU-1
IU-8		X	IU-2
IU-9		X	IU-6
IU-10	X		
IU-11	X		

2.5 ASTRIONIC EQUIPMENT

The IU astrionic packages perform the functions of guidance, flight control, instrumentation, telemetry, tracking, and range safety. It is expected that the IU would perform at least these same functions in any extension of its life capability.

Astrionics that presently perform these functions are described in Reference 2-2. Therefore, this section of the report does not describe these instruments functionally; instead, it describes, qualitatively, their characteristics and replacements, as they influence and are influenced by the vehicle ECS. The baseline for this appraisal will be the present IU instruments.

Nor does this section of the report delve into specific electronic and functional changes necessary to the astrionic equipment to extend the operational life of the present Saturn V hardware, because this aspect was considered outside the scope of this essentially vehicle-related TCS study, and because studies already were in progress in this area (Reference 2-3). Reference 2-3 considers the life extension of the IU to periods of up to 30 days. A significant result of this IBM study was that very little change to the astrionic equipment was required for life extension of up to 30 days. For mission life extensions of up to 180 days, however, it is expected that drastic changes in the design of astrionic equipment are required.

As a result of microminiaturization, the following are some of the general design changes which are anticipated:

1. Heat loads of individual instrument packages will be smaller. As 50-watt packages have become more common than 200-watt packages, so will 15-watt packages become more common than 50-watt packages.

2. Total astrionic system heat loads will become only slightly smaller. The system will consist of more packages performing more functions despite consolidation.

3. The astrionic unit will depend more on forced cooling to meet higher reliability goals and to counter otherwise higher temperatures resulting from increased heat densities.

4. The integral coldplate packaging concept will become increasingly dominant. This concept is one in which the coldplate is a physical and usually a structural part of the instrument package and is contained within the package envelope.

5. Active vehicle cooling systems that supply coolant to the individual instruments will continue to be required. The larger number of smaller heat load packages will permit series and series-parallel coolant-loop connections to permit the coolant to return to the vehicle TCS at the warmest possible temperature.

PRESENT IU ASTRIONICS BASELINE

The IU has been developed on a building-block concept, which allows it to be easily modified for various missions by adding or deleting various instruments and by reprogramming the launch vehicle digital computer (LVDC). This concept is expected to be continued not only for the Apollo program but also for future missions in which Saturn V hardware could be utilized. From the astrionics viewpoint, this concept allows the improvement of any instrument or equipment group independent of other instruments.

A suggested list of vehicle electronic systems to be studied (Reference 2-4) is:

1. Guidance Systems
   - a. Inertial stable platforms
   - b. Data adapter
   - c. Digital computer
   - d. Horizon sensor
   - e. Star tracker
2. Control System
   - a. Rate gyros
3. Measuring and Telemetry
   - a. Measuring racks

4. Radio Frequency Systems

   a. Radar altimeter

   b. C-Band radar

   c. Minitrack

   d. Azusa transponder

5. Electrical Systems

   a. Batteries

   b. Power distributors

   c. Switch selector

6. Radar System

The items of electronic equipment listed, except for the guidance optical sensors and radars, are current IU inventory items. The thermal characteristics of this IU equipment are shown in Figure 2-8, in which the ordinate is the tolerable case temperature range of the instrument and the abscissa is the heat load of the equipment. The equipment list, temperature range, and heat load data were provided by NASA/MSFC for this study (References 2-5 and 2-6).

In Figure 2-8, the equipment is plotted in the order of diminishing lower temperature limit. That is, batteries, which have a lower operating temperature limit of 68 F, are plotted first, and the flight control computer and the control signal processor, which have a lower operating temperature limit of -67 F, are plotted last. This readily shows the heat loads associated with the temperature sensitivity of the equipment and allows grouping of the equipment on a thermal capability basis. A similar plot of increasingly higher upper temperature limit could be constructed, but it was felt that Figure 2-8 was more meaningful because the present IU has a tendency to be too cold rather than too hot.

To minimize the number of groups, the tolerable temperature range of some packages is extended beyond the range specified by NASA. In these instances, it is believed that the NASA limits are overly conservative and that the wider temperature limits are inherently tolerable by the equipment. Extension of the upper limit will theoretically cause decreased reliability of the equipment, but any reliability degradation should be minor

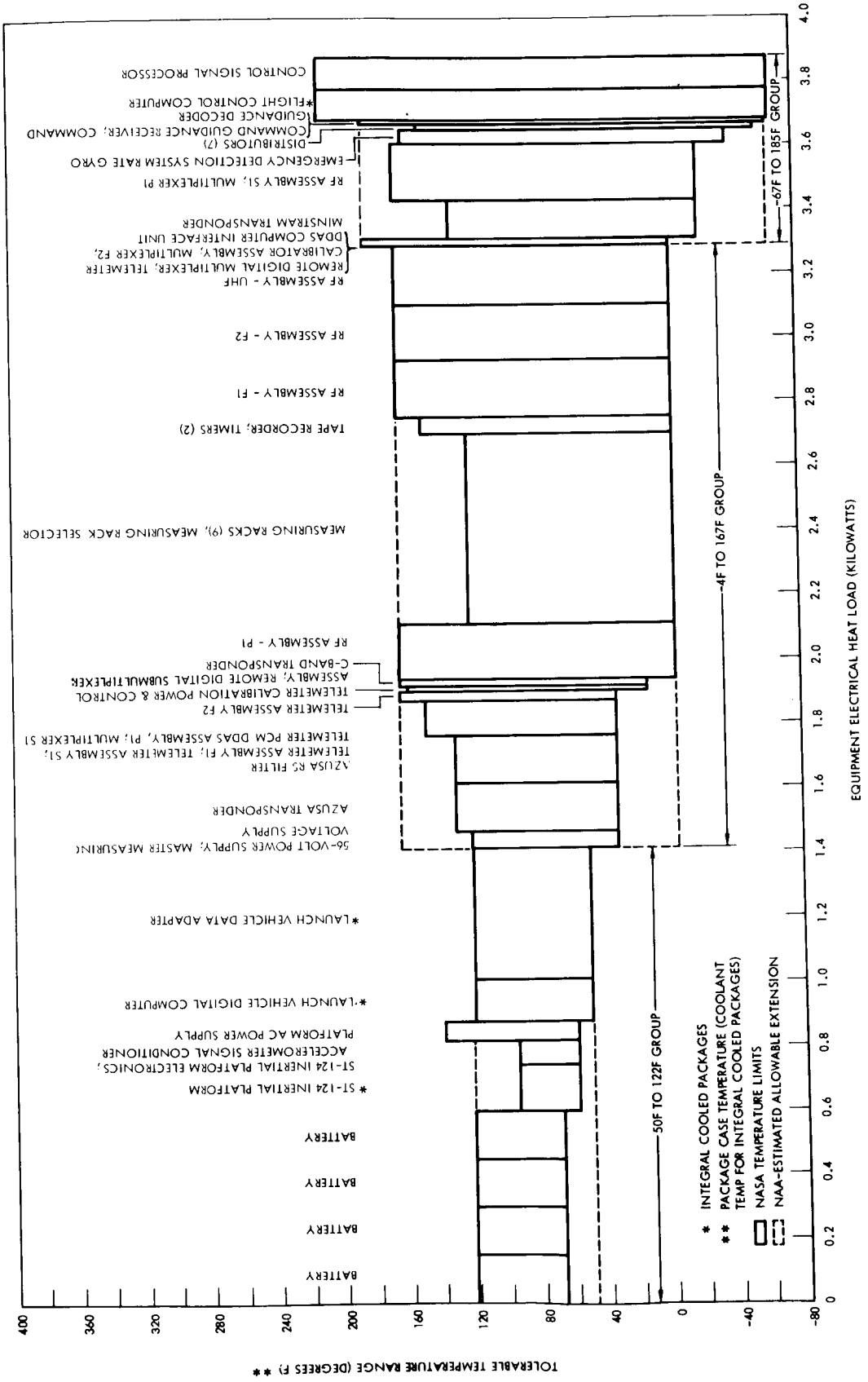

Figure 2-8. Tolerable Case Temperature Range

and easily compensated for with minor thermal design improvements in the packages. Also, as was pointed out previously, the equipment actual operating temperatures will tend to the lower limit where reliability is not degraded.

For the present IU packages, three groups appear logical: the 50 F to 122 F group (Group I), the -4 F to 167 F group (Group II), and the -67 F to 185 F group (Group III). Group I requires an active ECS in which a recirculating coolant under some temperature control is used. An ECS with a recirculating coolant system also is required for Group II, but temperature control probably will not be required. The recirculation of the coolant system in a closed liquid-coolant loop, using the vehicle coldplates as radiators, may be sufficient. Group III equipment could be treated passively; the thermal mass of the equipment and the vehicle coldplate or structure to which it is mounted do not allow it to exceed its tolerable limits.

One exception to a completely passive ECS in Group III is the integrally cooled flight control computer. Although this unit is in Group III, from a standpoint of temperature range tolerance, the need for a coolant flow would require that it be placed in Group II.

PRESENT, INTERMEDIATE FUTURE, AND FUTURE ASTRIONICS

The equipment function (i.e., the generic equipment) required for the postulated missions may be grouped in the three following categories: guidance and control; measuring, RF, and telemetry; and electrical. For the purposes of this study, the primary power supply (batteries, fuel cells, solar cells, etc.) is not considered astrionic equipment and is discussed in another section. Primary mission experiments and sensors also are not included because this is special equipment whose requirements could vary widely.

Table 2-7 gives probable typical equipment characteristics for IU applications for the present (1966 to 1969), the intermediate future (1968 to 1971), and the future (1970 to 1975). The equipment type, supplier, probable package heat load, package weight, tolerable case temperature range, tolerable nonoperating temperature range, and probable cooling methods are listed in the table. The present IU equipment shown in Figure 2-8 is listed under present equipment, along with probable candidate units such as the horizon sensor, star tracker, auxiliary computer memory storage, tape recorder, radar altimeter, rendezvous radar, and HF- and S-band communications.

It should be emphasized that the equipment shown is not intended to be typical; rather, it is a complete shopping list from which a specific list can

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	Equipment	Present Operational Time Period (1966-1969)										
		Equipment Type (Suppliers)	Heat Load (watts)	Weight (lb)	Case Temp Tolerance (F) (NASA Data)		Case Temp Tolerance (F) (NAA Est)		Nonoperating Temp Tolerance (F)(NAA)		Cooling Method	
Guidance & Control	Inertial navigator	SV - ST 124 plat (Bendix)	70	118	50	95	50	122	30	185	Integral	Strap
		SV - ST 124 plat elec (Bendix)	46	40	59	95	50	122	-65	200	Veh CP	instru
		SV - Plat a-c PS (Bendix)	70	30	59	140	50	122	-65	185	Veh CP	power
		SV - Bearing gas supply	5	35	-65	160	-65	160	-80	250	Veh CP	
	Computer complex	SV - LVDC (IBM)	142	88	50	122	50	122	-65	185	Integral	4 Pi t
		SV - LVDA (IBM)	400	190	50	122	50	122	-65	185	Integral	4 Pi t
	Flight controls	SV - Flt cont computer (ECS)	100	125	-67	212	-65	185	-80	200	Integral	Modifi
		SV - Rate gyros	45	10	-40	160	-65	185	-80	200	Veh CP	SV wi
		SV - Control accel	20	12	-20	160	-40	160	-65	185	Veh CP	SV co
		SV - Accel sig cond (Bendix)	6	10	59	95	50	122	-65	185	Veh CP	Impro
		SV - Control sig proc (Martin)	100	38	-67	212	-65	185	-80	200	Veh CP	Micro
	Flight sequencer	SV - Timers	7	1	- 4	140	- 4	165	-65	185	Veh CP	Apollo
	Sensors	Horizon sensor - OGO	10	17	—	—	0	140	-40	160	Veh CP	Horiz
		Star tracker - lunar orb (ITT)	15	10	—	—	-65	160	-65	185	Veh CP	Star t
	Aux memory store	Miniature computer memory (IBM)	20	2.5	0	140	50	122	-40	160	Veh CP	NDRO
	Flight sequencer	SV - Selector switch (ECI)	0	20	-13	175	-65	180	-80	200	Veh CP	Impro
Measuring, RF and Telemetry	Telemetry	SV - TM - F1	35	17.5	32	149	- 4	167	-65	200	Veh CP	Impro
		SV - PCM/DDAS, - P1	60	27	32	149	- 4	167	-65	200	Veh CP	Impro
		SV - TM - S1	8	17.5	32	149	- 4	167	-65	200	Veh CP	Impro
		SV - TM - F2	30	14	32	149	- 4	167	-65	200	Veh CP	Impro
	Telemetry RF	SV - RF assy - F1	177	13.4	- 4	167	- 4	167	-65	200	Veh CP	Impro
		SV - RF assy - PCM	177	15	- 4	95	- 4	167	-65	200	Veh CP	Impro
		SV - RF assy - S1	177	13.4	-22	167	-65	185	-65	200	Veh CP	Impro
		SV - RF assy - F2	177	13.4	- 4	167	- 4	167	-65	200	Veh CP	Impro
		SV - RF assy - VHF	180	11	- 4	167	- 4	167	-65	200	Veh CP	Impro
	Telemetry accessories	SV - TM calib	4.9	5.3	- 4	185	-65	185	-65	200	Veh CP	Impro
		SV - TM calib control	5.6	3.5	14	185	- 4	167	-65	200	Veh CP	Impro
	Signal conditioner	SV - Meas rack	60	21	- 4	122	- 4	167	-65	200	Veh CP	New m
		SV - Meas rack sel	5	2.4	- 4	122	- 4	167	-65	200	Veh CP	SV wi
	Multiplexer	SV - P1 multiplexer	6	21.3	-22	185	-65	185	-80	200	Veh CP	New m
		SV - Remote dig.	3	13	- 4	185	-65	185	-80	200	Veh CP	New m
		SV - Remote dig. sub	4	13.2	14	158	- 4	167	-80	200	Veh CP	New m
		SV - Slow speed	14	12.5	32	149	- 4	167	-80	200	Veh CP	New m
		SV - F2	6	21.3	- 4	185	-65	185	-80	200	Veh CP	New m
	Miscellaneous equipment	SV - Tape recorder	40	10	- 4	149	- 4	167	-40	185	Veh CP	Apollo
		SV - DDAS interface unit	3	11.6	- 4	185	-65	185	-80	200	Veh CP	SV - I
		SV - Coaxial switch	7	1	—	—	-65	185	-80	200	Veh CP	SV - c
		Lunar mod TV camera (Westhse)	7	8	—	—	- 4	167	-40	185	Veh CP	Lunar
	Radars	SV - C-Band Xponder (Motorola)	24	5.5	14	167	- 4	167	-65	200	Veh CP	SV C-
		SV - Radar altimeter (Westhse)	65	15	—	—	- 4	167	-65	200	Veh CP	Impro
		Gemini rendezvous radar (Westhse)	65	15	—	—	- 4	167	-65	200	Veh CP	Impro
	Radio command	SV Command receiver	4	3	-65	185	-65	185	-65	200	Veh CP	SV co
		SV Command decoder	4.5	6	-65	185	-65	185	-65	200	Veh CP	SV co
	Range tracking	SV Azusa transponder	135	19	32	131	- 4	167	-65	200	Veh CP	Impro
		SV Minstram transponder	140	16.5	-22	131	- 4	167	-65	200	Veh CP	Impro
		SV Azusa RI filter	135	10	32	131	- 4	167	-65	200	Veh CP	Impro
	Communications	Apollo Uni-S band (Collins)	18	38	—	—	0	150	-65	185	Veh CP	Apoll
		Apollo - HF transceiver	50	7	—	—	0	150	-65	185	Veh CP	Impr
Electrical	Primary power source	SV Battery (Eagle Picher)	150	165	68	122	50	122	-65	160	Veh CP	
		Apollo fuel cell (P&W)										
		Solar cells										
		Radioisotopic thermal gen										
	Secondary power supply	SV 56-v power supply	50	9.5	32	122	- 4	167	-65	200	Veh CP	
		SV master meas voltage	7	2	32	122	- 4	167	-65	200	Veh CP	Impr
	Distributors	SV (various types)	5	30	-58	149	-65	185	-65	200	Veh CP	Impr

Table 2-7. Astrionic Equipment List

Intermediate Future Operational Time Period (1968-1971)						Future Operational Time Period (1970-1975)					
Equipment Type (Supplier)	Heat Load (watts)	Weight (lb)	Case Temp Tolerance (F) (NAA Est)	Nonoperating Temp Tolerance (F)	Probable Cooling Method	Equipment Type (Supplier)	Heat Load (watts)	Weight (lb)	Case Temp Tolerance (F) (NAA Est)	Nonoperating Temp Tolerance (F)	Probable Cooling Method
wn guidance inertial	150	100	0 125	-65 200	Veh CP	Improved strapdown guidance	50	50	0 125	-65 200	Integral
ents, electronics, and	—	—	— —		—	(inertial instruments, elec-	—	—	— —	— —	—
upply)	—	—	— —		—	tronics, and power supplies)	—	—	— —	— —	—
	—	—	— —		—		—	—	— —	— —	—
e (IBM)	70	20	30 125	-65 185	Integral	Advanced micromin	25	10	30 125	-65 185	Integral
e (IBM)	200	40	30 125	-65 185	Integral	Advanced micromin	60	20	30 125	-65 185	Integral
d SV with IC's	50	75	-65 185	-80 200	Integral	Advanced micromin/dig	25	30	-65 140	-80 200	Integral
improvements	40	10	-65 185	-80 200	Veh CP	SV with improvements	40	10	-65 185	-80 200	Veh CP
rol acc	20	12	-40 160	-65 185	Veh CP	SV control acc	20	12	-40 160	-80 200	Veh CP
ed SV	4	7	0 125	-65 185	Veh CP	Improved SV	4	7	0 125	-80 200	Veh CP
in SV	30	15	-65 140	-80 200	Integral	Micromin SV	30	15	-65 140	-80 200	Integral
lt sequencer (NAA)	7					Apollo flt sequencer (NAA)	7				
sensor (OGO)	10	17	0 140	-40 160	Veh CP	Horizon sensor - impr OGO	8	12	-65 160	-40 160	Veh CP
cker - lunar orb (ITT)	15	10	-65 160	-65 185	Veh CP	Star tracker - lunar orb (ITT)	15	10	-65 160	-65 185	Veh CP
ove memory	5	5	0 140	-40 160	Veh CP	NDRO core memory	5	5	0 140	-40 160	Veh CP
ed SV	0	10	-65 185	-80 200	Veh CP	Improved SV	0	10	-65 175	-80 200	Veh CP
ed SV	20	10	-4 167	-65 200	Veh CP	New micromin	5	5	-65 140	-80 200	Integral
ed SV	40	17	-4 167	-65 200	Veh CP	New micromin	10	10	-65 140	-80 200	Integral
ed SV	8	10	-4 167	-65 200	Veh CP	New micromin	2	5	-65 140	-80 200	Integral
ed SV	20	10	-4 167	-65 200	Veh CP	New micromin	5	5	-65 140	-80 200	Integral
ed SV	50	10	-4 167	-65 200	Veh CP	Improved SV	50	10	-4 167	-65 200	Veh CP
ed SV	50	10	-4 167	-65 200	Veh CP	Improved SV	50	10	-4 167	-65 200	Veh CP
ed SV	50	10	-4 167	-65 200	Veh CP	Improved SV	50	10	-4 167	-65 200	Veh CP
ed SV	50	10	-4 167	-65 200	Veh CP	Improved SV	50	10	-4 167	-65 200	Veh CP
ed SV	50	10	-4 167	-65 200	Veh CP	Improved SV	50	10	-4 167	-65 200	Veh CP
ed SV	4	4	-65 185	-65 200	Veh CP	Improved SV	4	4	-65 185	-65 200	Veh CP
ed SV	4	2	-65 185	-65 200	Veh CP	Improved SV	4	2	-65 185	-65 200	Veh CP
cromin design	20	8	-4 167	-65 200	Veh CP	Advanced micromin	10	5	-65 140	-80 200	Integral
improvements	4	2	-4 167	-65 200	Veh CP	SV with improvements	4	2	-4 167	-65 200	Veh CP
cromin design	4	4	-65 160	-80 200	Integral	New micromin	4	4	-65 160	-80 200	Integral
cromin design	4	4	-65 160	-80 200	Integral	New micromin	4	4	-65 160	-80 200	Integral
cromin design	4	4	-65 160	-80 200	Integral	New micromin	4	4	-65 160	-80 200	Integral
cromin design	4	4	-65 160	-80 200	Integral	New micromin	4	4	-65 160	-80 200	Integral
cromin design	4	4	-65 160	-80 200	Integral	New micromin	4	4	-65 160	-80 200	Integral
tape recorder (Leach)	26	22	-4 167	-65 185	Veh CP	Improved Apollo tape recorder	20	15	-4 167	-65 185	Veh CP
DAS interface unit	3	11.6	-65 185	-80 200	Veh CP	SV DDAS interface unit	3	11.6	-65 185	-80 200	Veh CP
axial switch	7	1	-65 185	-80 200	Veh CP	SV coaxial switch	7	1	-65 185	-80 200	Veh CP
nod TV camera (Westhse)	7	8	-4 167	-40 185	Veh CP	Lunar mod TV camera	7	8	-4 167	-40 185	Veh CP
and transponder	24	5.5	-4 167	-65 200	Veh CP	Improved SV C-band Xponder	15	5	-4 167	-65 200	Integral
ed SV rad alt	40	25	-4 167	-65 200	Veh CP	Improved SV rad alt	40	25	-4 167	-65 200	Veh CP
ed Gemini rendez rad	40	10	-4 167	-65 200	Veh CP	Improved Gemini rendez rad	40	10	-4 167	-65 200	Veh CP
mmand receiver	4	3	-65 185	-65 200	Veh CP	SV command receiver	4	3	-65 185	-65 200	Veh CP
mmand decoder	4.5	6	-65 185	-65 200	Veh CP	SV command decoder	4.5	6	-65 185	-65 200	Veh CP
ed SV	80	15	-4 167	-65 200	Veh CP	Improved SV	80	15	-4 167	-65 200	Veh CP
ed SV	80	12	-4 167	-65 200	Veh CP	Improved SV	80	12	-4 167	-65 200	Veh CP
ed SV	80	8	-4 167	-65 200	Veh CP	Improved SV	80	8	-4 167	-65 200	Veh CP
Uni-S-band	18	38	0 150	-65 185	Veh CP	Improved Uni-S-band	15	20	-4 167	-65 200	Veh CP
ed HF transceiver	40	7	-4 167	-65 185	Veh CP	Improved HF transceiver	40	7	-4 167	-65 185	Veh CP
ed SV	5	2	-4 167	-65 200	Veh CP	Improved SV	5	2	-4 167	-65 200	Veh CP
ed SV	5	20	-65 185	-65 200	Veh CP	Improved SV	5	20	-65 185	-65 200	Veh CP

be selected for a specific mission or experiment, in keeping with the building-block concept followed by NASA-MSFC. In practice, a final list is selected for each type of mission from exhaustive tradeoff studies and could not be performed as part of this study. These tradeoff studies utilize data such as individual equipment reliability, size, weight, and power, the required probability of mission success, and the availability of alternate modes of operation. Backup and redundancy requirements are determined. Whether the vehicle is manned (or capable of being manned) in orbit also has considerable influence on the equipment functions required.

The intermediate future equipment shown in Table 2-7 is, for the most part, improved Saturn V hardware. The basic improvement assumed is the incorporation into existing electronic circuits of integrated circuits. Significant improvement in size, weight, reliability, power, cooling requirements, and cost are expected to be realized.

The future equipment listed is assumed to be predominantly newly designed, fully microminiaturized electronics. It is expected that an all-integrated circuit or similar microelectronic approach would be followed. It is felt that, in this period, in which most of the longer missions would be made, the microelectronic approach would be mandatory on the basis of required reliability improvements alone. The microelectronic approach could also very well be demanded by any one of the following reasons: improved volume, lower equipment cost, reduced equipment weight, or reduced power and heat load. The trends and effects of microminiaturization and microelectronics are presented in Appendix 2B. Equipment listed in the Present column in Table 2-7 is carried over into the Intermediate Future and Future columns. This was done for comparative purposes only and does not imply that equipment functions or packages would not be consolidated. Where feasible, consolidation can be expected to minimize the number of small units. For example, a typical present IU contains nine measuring racks. The microelectronic versions of these might be packaged so that there would be only three racks, each with the capability of three present racks. As another example, the power supplies associated specifically with the ST-124 of the present system undoubtedly would become a part of the platform electronic package in the future systems.

The selection of a strapdown inertial navigator for the intermediate future and future merits futher discussion. The development of strapdown inertial navigators is such that, with the use of a horizon sensor, attitude reference in the order of ±1 degree is readily achieved. More precise reference or specific mission/experiment requirements may necessitate a gimbaled platform, perhaps with stellar supervision (star tracker). If the ST-124 is considered for this gimbaled platform, the gas-bearing nitrogen supply requirement imposes severe penalties. A closed-loop (recirculating) nitrogen supply, although mandatory for mission durations of approximately

24 hours, is not a satisfactory solution. A more reasonable solution would be to replace the three single-axis gyros of the ST-124 with two self-lubricating, spherical gas-bearing gyros.

Heat load, weight, temperature tolerance, and cooling method requirements for Table 2-7 equipment applicable to the present operational period (1966-1969) are based on information supplied by NASA (References 2-5 and 2-6). Listed characteristics of equipment applicable to the two future operational periods (1968-1971 and 1970-1975) represent best estimates based on the experience of NAA and other manufacturers of this equipment.

Table 2-8 gives the probable equipment quantity per system and is intended to show the increased equipment quantity (complexity) with increased mission duration. The indicated increases are due primarily to the need for backup and redundancy. Functional requirements remain fairly constant with mission duration (i.e., longer missions do not necessarily imply increased functions). The quantities shown in Table 2-8 for durations other than up to 12 hours are relative to the quantities indicated in the 12-hour column. For example, two LVDC's are indicated for mission durations greater than 30 days while only one is required for a 12-hour mission. This does not mean that there will physically be two computers in the longer missions (although there may be), but it does mean that the computer for the longer duration is about twice the complexity and capacity of the first, due primarily to redundancy requirements. These quantities will affect the total vehicle astrionic heat load, discussed in another section.

ASTRIONIC EQUIPMENT HEAT LOADS

The discussion on microelectronics (Appendix 2B) indicates that heat loads for the same functional requirements will continually decrease. At the present pace of microelectronics, a conservative estimate is that the total electrical heat load will decrease perhaps by half every two years; but with continually increasing functional requirements and astrionic system complexity (made possible and attractive by smaller size, weight, and cost, and improved reliability), the total heat load may decrease more slowly, perhaps halving every four or five years. This seemingly slow improvement is dictated by economic and other factors rather than by technological capability.

Much equipment, particularly of the digital circuitry type, will decrease at the much faster rate. Other equipment, such as the transmitter (output) stage of radars and RF units, which depend on transmitted power, will not decrease as significantly. Even here, however, available techniques—such as trading off digital storage of information against transmitting information in high-frequency, short-duration bursts—will be used to reduce heat dissipation.

Table 2-8. Probable Equipment Quantity Per System Requirement *

Equipment	Mission Duration					
	To 12 hr	To 48 hr	To 10 days	To 30 days	To 90 days	To 180 days
Inertial navigator	1	1	1	2**	2**	2**
Launch vehicle digital computer	1	1	1	2	2**	2**
Launch vehicle data adapter	1	1	1	1	1	1
Auxiliary memory storage	0	0	1	1	1	1
Flight control computer	1	1	1	2	2	2
Rate gyro	3	3	3	3	3	3
Control accelerometer	2	2	2	2	2	2
Accelerometer signal conditioner	1	1	1	1	1	1
Control signal processor	1	1	1	1	2	2
Flight sequencer	2	2	2	2	2	2
Horizon sensor	1	1	1	1	1	1
Star tracker	1	1	1	1	1	1
Selector switch	1	1	1	2	2	2
Telemetry	4	5	6	7	8	10
Telemetry RF	5	6	7	8	9	11
Telemetry signal conditioner	9	9	9	10	12	14**
Telemetry multiplexer	6	7	8	9	10	12
Tape recorder	0	0	1	1	1	2
TV camera	0	0	0	1	1	1
C-band transponder	1	1	0	0	0	0
Radar altimeter	1	1	1	1	1	1
Rendezvous radar	0	1	1	1	1	1
Radio command	1	1	2	2	2	2
Range tracking	2	2	2	2	2	2
S-band communication	0	0	1	1	1	2
Distributor	5	5	5	5	6	8
Special power supplies	7	1	7	2	2	2

*Includes backup and redundancy requirements
**Present operational time period equipment not practical for long-duration mission

Table 2-9 is a comparison of a modern digital computer, the D-37C computer in production for Minuteman II, with more advanced computers that can be available within the next two to six years. Heat dissipation is reduced from about 300 to 15 watts. It was recently found that a digital computer to perform the hypothetical space vehicle computation requirements shown in Table 2-10 could be built by conventional microelectronic techniques to dissipate only 12 to 15 watts. The hypothetical mission was a composite of missions studied for standardized space guidance system (SSGS) for the USAF having the mission phases of (1) prelaunch, (2) atmospheric ascent, (3) exo-atmospheric ascent, (4) orbital coast, (5) orbital change, (6) rendezvous, (7) de-orbit, and (8) reentry. By using a distributed logic computer system (Reference 2-7) it was found that the same computational requirements could be implemented with dissipation of only 5 to 6 watts.

Table 2-11 indicates the equipment required to be either completely or partially operative during various phases of a typical mission. These phases include: (1) preflight, (2) ascent, (3) orbital checkout, (4) orbit transfer, (5) parking orbit full power on, (6) parking orbit standby, (7) parking orbit deactivated, (8) parking orbit rendezvous, and (9) translunar or planetary injection. Orbital checkout is concerned with the checkout of on-board equipment while in orbit but before use. Parking orbit standby includes the operation of only that equipment necessary to reactivate other on-board equipment and to maintain attitude control. In parking orbit deactivated, only equipment necessary to reactivate other equipment remains operative and attitude is not controlled. The other mission phases are self-explanatory.

Table 2-9. Computer Characteristics Summary

	D-37C	Advanced Computer		
Availability	Production Item	1 year	2 to 3 years	3 to 5 years
Weight (lb)	39	19	13	9
Volume (cu ft)	0.73	0.26	0.13	0.08
Dimensions (in.)	20.9x5.7x10.5	5 1/2x7 1/2x11	5 1/2x7 1/2x5 1/2	4 1/2x6 1/2x4 1/2
Power (watts)	300	72	45	15
Clock Rate (kc)	345.6	750	750 2ϕ	750 4ϕ
Add Time (sec)	78.25	4	4	4
Memory Capacity:				
words	7222	17,408	17,408	17,408
bits	24	24	24	24
Technology	Integrated circuits, disc memory	MOS IC's, laminated ferrite memory	Polytab MOS IC's, laminated ferrite memory	Reg bond MOS IC's, epitaxial ferrite memory

Table 2-10. General Purpose Computer Requirements

	Storage, Instructions, and Constants	Operations per Mission	Seconds per Iteration	Operations per Second
Prelaunch				
Accelerometer calibration	520	660	Not Critical	
Platform alignment and gyro bias calculation	340	540	Not Critical	
Mission targeting	380	340	300	1
Subtotal	1240			1
Atmospheric Ascent				
IMU Mechanization	320	280	0.1	2800
Navigation computation	290	440	0.1	4400
Steering	220	170	0.1	1700
Subtotal	830			8900
Exo-Atmospheric Ascent				
IMU mechanization	320	280	0.1	2800
Navigation computation	290	440	0.1	4400
Attitude control	290	70	0.1	700
Subtotal	900			7900
Orbit Coast				
Integrate free-fall navigation equations of motion	60	1800	10	180
Orbit determination by smoothing and filtering	4660	8700	10	870
Sensor pointing	360	1930	0.33	5790
IMU alignment and gyro bias calculation by smoothing and filtering	80	430	Not Critical	
Subtotal	5160			6840
Orbit Change				
Set up rendezvous injection	1280	1940	300	7
Set up midcourse maneuver	220	8000	60	14
IMU mechanization	320	280	0.2	1400
Navigation computations	290	440	0.2	2200
Orbit change steering	470	210	0.1	2100
Subtotal	2580			5721
Rendezvous				
Rendezvous sensor pointing	200	1930	0.1	1930
IMU mechanization	320	280	0.5	560
Navigation computation	290	440	0.5	880
Rendezvous vehicle control	370	490	0.1	4900
Subtotal	1180			8270
Deorbit				
Set up deorbit	690	14,870	30	496
IMU mechanization	320	280	0.5	560
Navigation computations	290	440	0.5	880
Optimal estimating	2650	14,930	30	498
Subtotal	3950			2434
Reentry				
IMU mechanization	320	280	1	280
Navigation computation	290	440	1	440
Reentry vehicle control	620	1130	0.2	5650
Subtotal	1230			6370

Table 2-11. Equipment Required to be Operative

Equipment	Preflight	Ascent	Orbital Checkout	Orbit Transfer	Parking Orbit Full On	Parking Orbit Standby	Parking Orbit De-activated	Parking Orbit Rendezvous	Translunar or Planetary Injection
Inertial navigator	x	x	x	x	x			x	x
LV digital computer	x	x	x	x	x			x	x
LV data adapter	x	x	x	x	x			x	x
FC computer	x	x	x	x	x	x		x	x
Rate gyros	x	x	x	x	x	x		x	x
Control accelero	x	x							
Accelero sig	x	x							
Cont sig proc	x	x							
Flight sequencer	x	x	x	x	x			x	x
Horizon sensor	x		x		x	x			
Star tracker	x		x	x	x				x
Aux.mem. store	x		x		x				
Selector switch	x	x	x	x	x			x	x
TM	x	x	x	x	x	x	x	x	x
TM RF	x	x	x	x	x	x	x	x	x
TM sig cond	x	x	x	x	x	x	x	x	x
TM multiplexer	x	x	x	x	x	x	x	x	x
Tape recorder	x	x	x	x	x			x	x
TV camera	x	x	x		x				
C-band Xponder	x		x		x				
Radar altimeter	x		x		x				
Rendezvous radar	x							x	
Radio command	x	x	x	x	x	x	x	x	x
Range tracking	x	x	x	x	x			x	x
S-band command	x	x	x	x	x			x	x
Distributors	x	x	x	x	x			x	x
Spec power sup	x	x	x	x	x			x	x

On the basis of Tables 2-7, 2-8, and 2-11, the maximum heat load for various mission phases and durations was determined. The results are shown in Figures 2-9, 2-10, and 2-11 for the present, intermediate future, and future operational time period equipment, respectively. Mission durations of 10 hours, 48 hours, 10 days, 30 days, 90 days, and 180 days are represented. It should be noted that the heat loads are maximum or, more properly, worst-case. They assume that the full shopping list of equipment is utilized (i. e., they do not account for the possibility that specific equipment may be deleted for specific missions). In addition, they assume that all redundant and backup equipment is energized, except for the cases of orbit standby and orbit deactivated.

Typical mission maximum electrical heat load profiles are presented in Figures 2-12, 2-13, and 2-14 for present equipment for near-earth orbit, synchronous earth orbit, and orbital launch lunar or planetary missions, respectively. The maximum heat load is as previously defined; the actual heat loads are expected to be significantly lower. Figure 2-15 gives a typical heat load profile, including periods of orbit standby, for present equipment for the orbit-launch lunar or planetary mission. These heat load profiles were used in the TCS parametric studies which are discussed in another section.

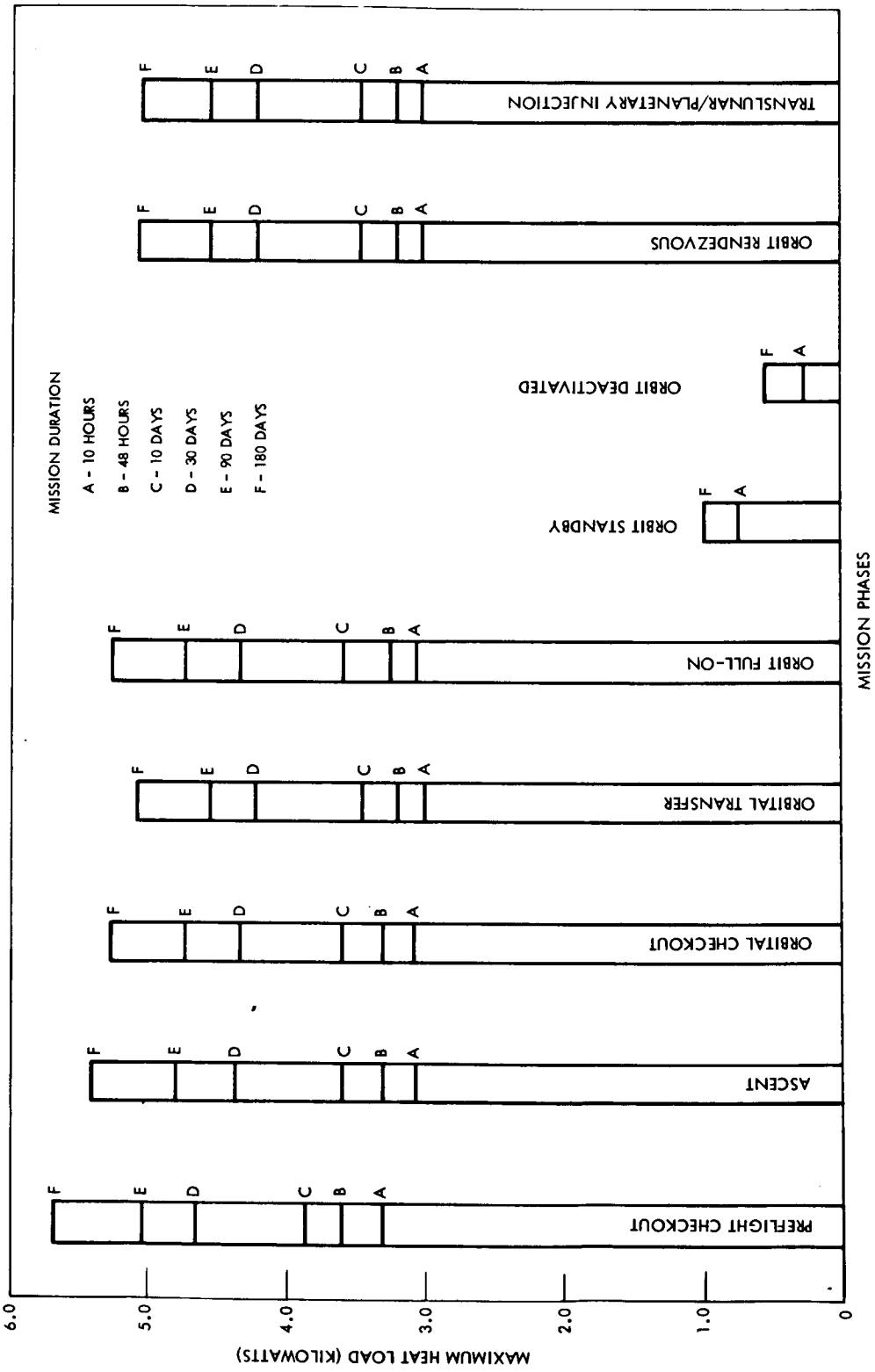

Figure 2-9. Astrionic Equipment Heat Load for Mission Phases (Operational Time Period 1966-1969)

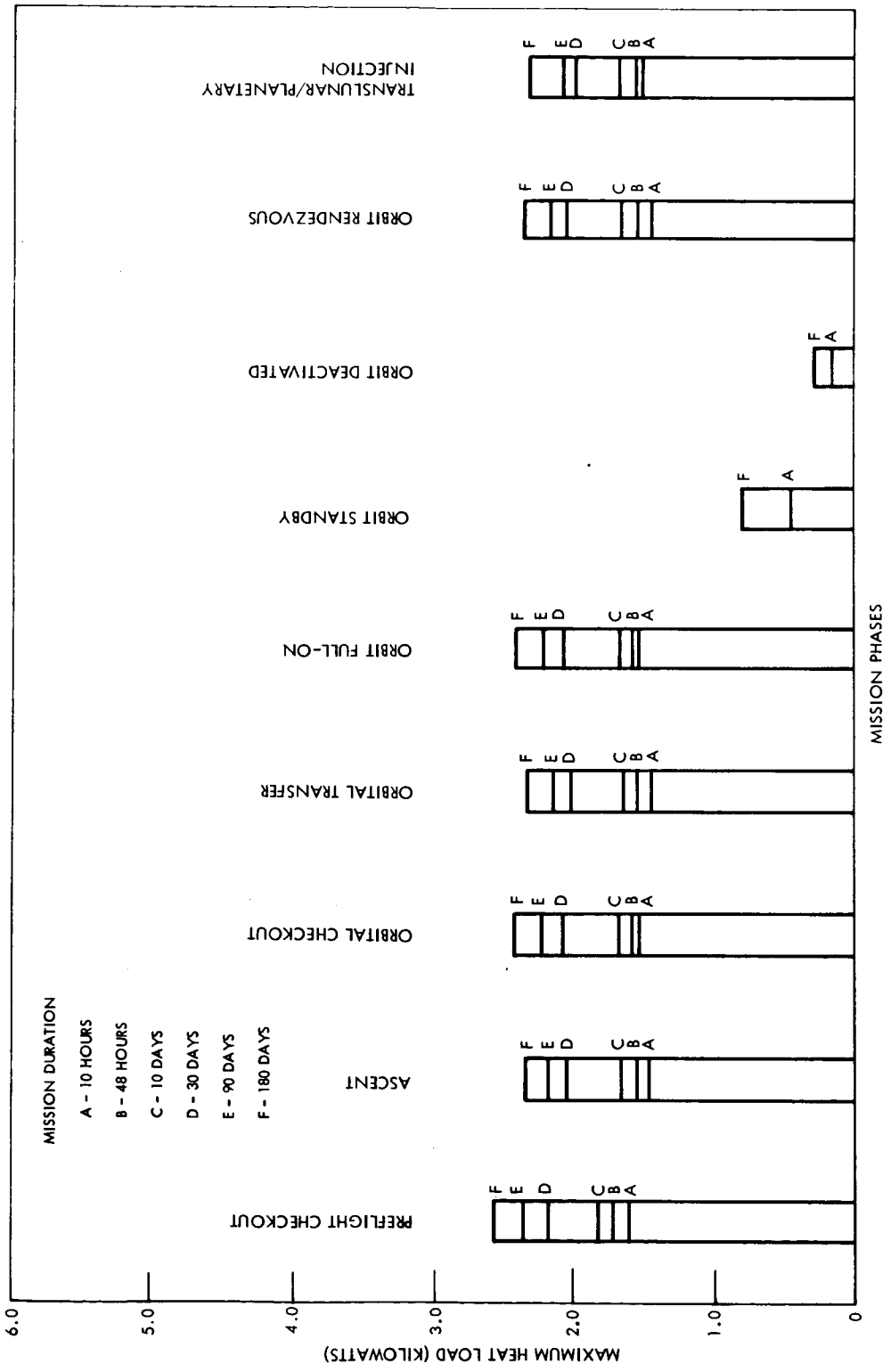

Figure 2-10. Astrionic Equipment Heat Load for Mission Phases (Operational Time Period 1968-1971)

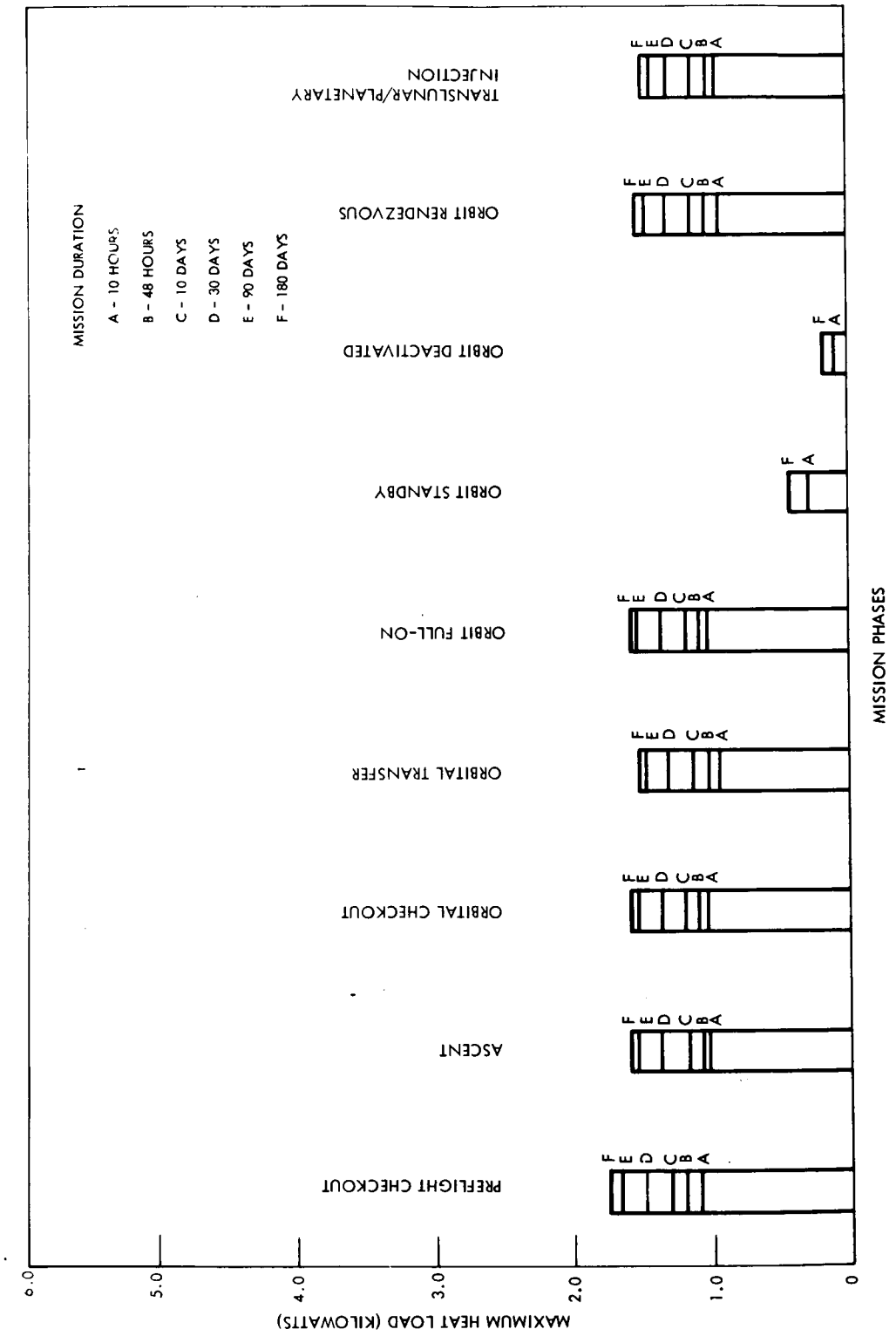

Figure 2-11. Astrionic Equipment Heat Load for Mission Phases (Operational Time Period 1970-1975)

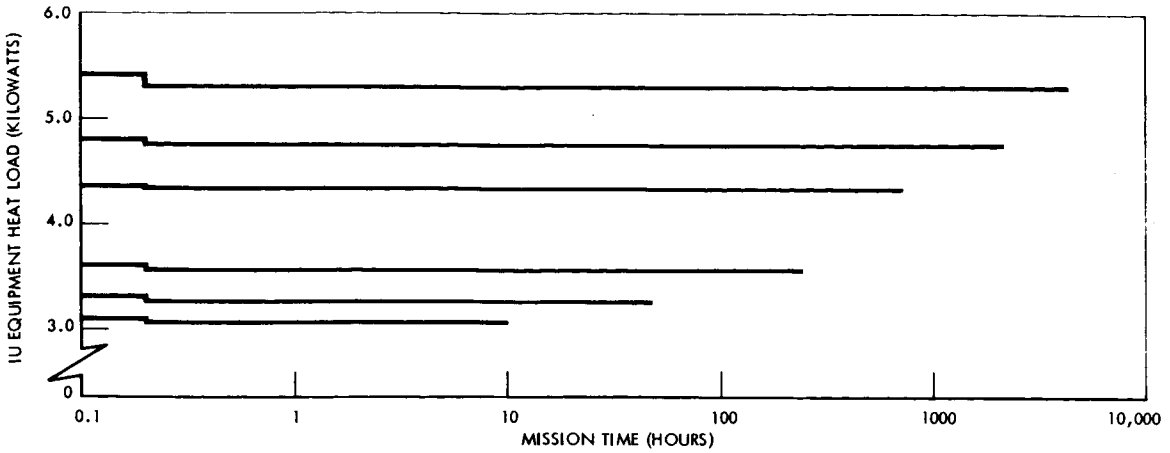

Figure 2-12. Near-Earth Orbit, Maximum Heat Load (Present Equipment)

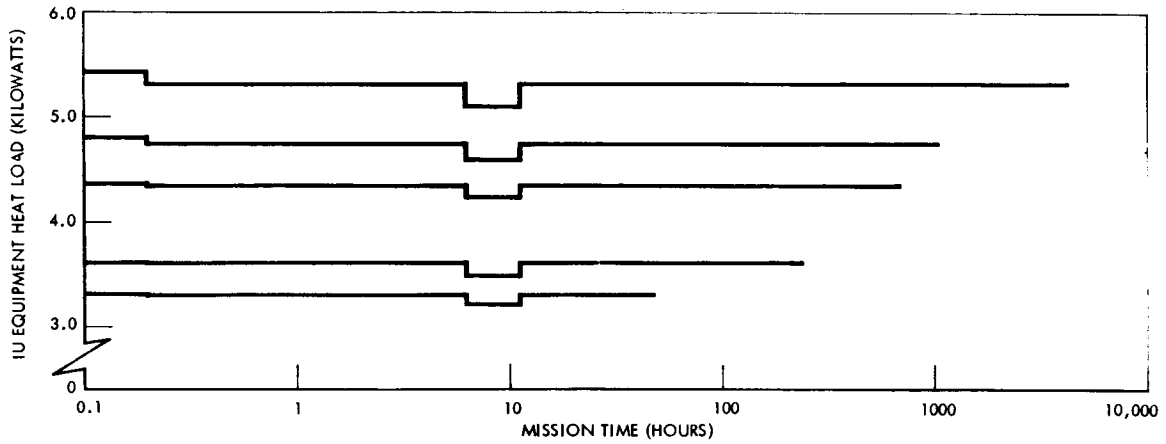

Figure 2-13. Synchronous Orbit, Maximum Heat Load (Present Equipment)

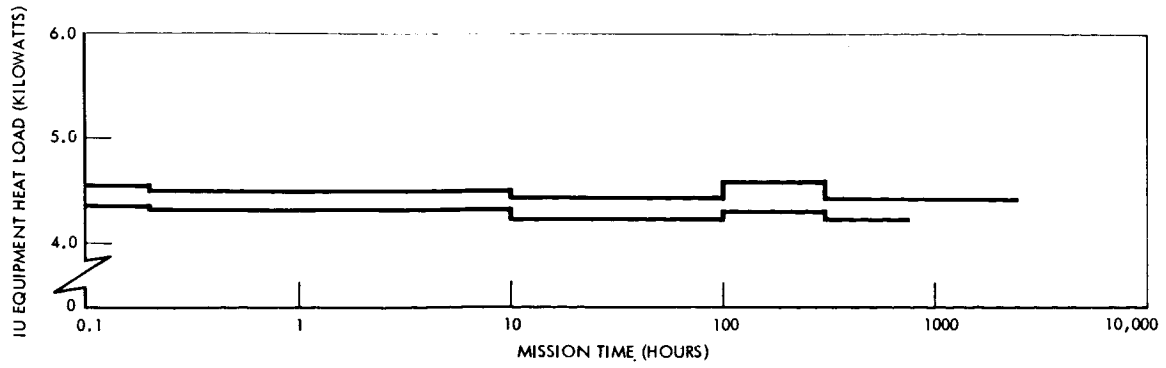

Figure 2-14. Lunar or Planetary Mission, Orbital Launch, Maximum Heat Load (Present Equipment)

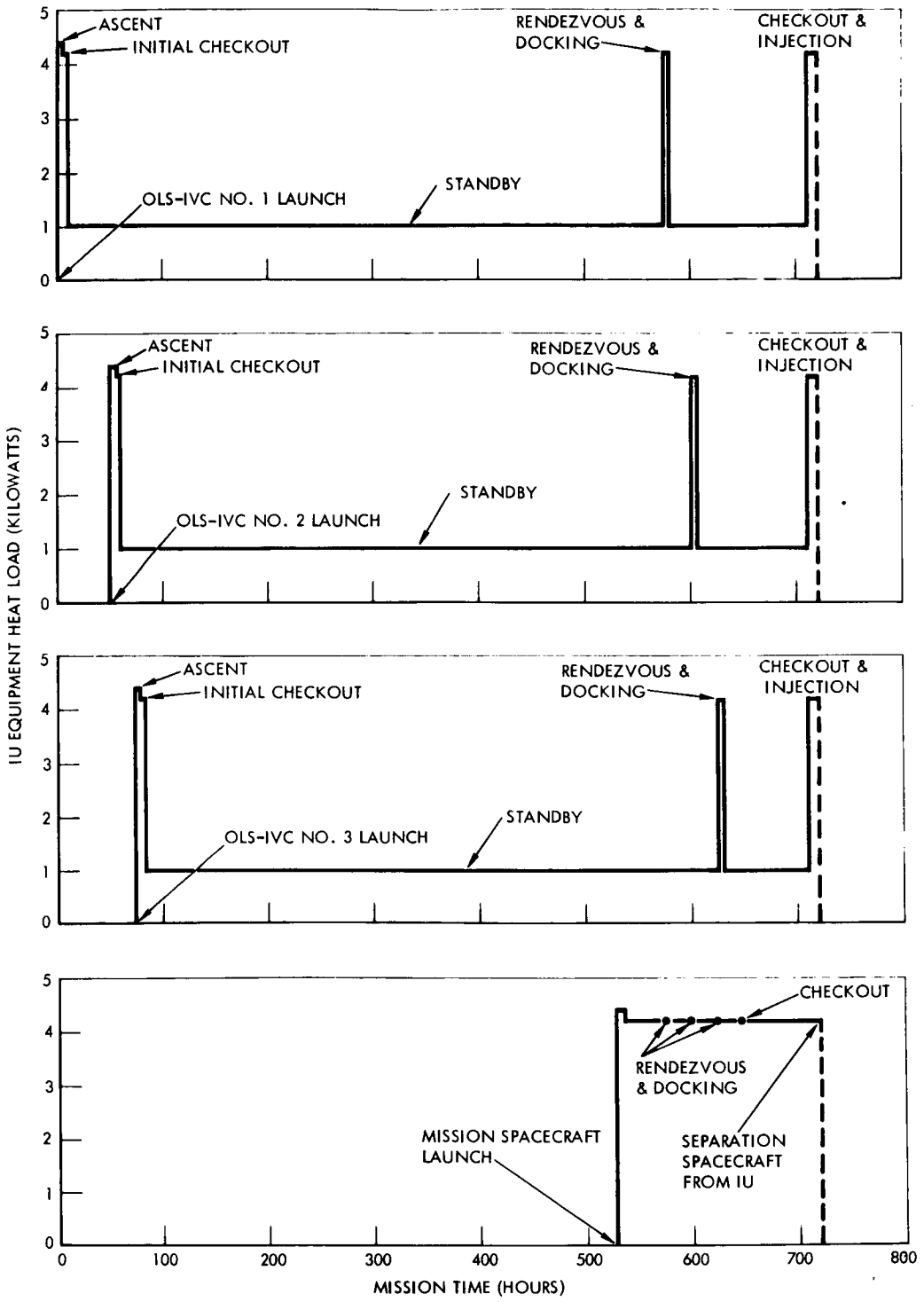

Figure 2-15. Lunar or Planetary Mission, Orbital Launch, Typical Heat Load (Present Equipment)

2.6 SPACE POWER SYSTEMS

Space power systems have been evaluated for their applicability to IU missions based on 1968 hardware. Power system alternatives evaluated include radioisotopic thermoelectric generators (RTG), fuel cells, solar cells-rechargeable batteries, combined operation of fuel cells and solar cells, concepts of solar cell array integration with the Saturn vehicle, and primary batteries (for short-duration missions e.g., less than one day). Space power systems having less than one kilowatt rating have been evaluated for their applicability to IU missions on the basis of power-service time potentiality (Figure 2-16), specific weight-service time (Figure 2-17), and parametric comparisons among power systems that are applicable to the missions.

In Figure 2-16, the potentiality assigned to the fuel cell is much greater in service time than that in previous charts of a similar nature, which appear frequently, with the fuel cell limited to an egg-shaped region so that the usefulness of a low power fuel cell is limited to a service time of five to ten days. With improvements in 1966, notably a 5.0-watt, one-year hydrogen-oxygen ion-exchange membrane fuel cell, the potentiality region has been increased to that depicted in Figure 2-16.

For short-duration missions, primary batteries provide the best service at the least expense, as can be seen from Figures 2-16 and 2-17, and Table 2-12, which provide direct comparison of many parameters among RTG, solar cells-batteries, and fuel cells, and indicate that primary batteries are limited to missions of less than eight hours.

For longer missions, fuel cells, RTG, and solar cells-batteries are useful alternative power systems (Figures 2-16 and 2-17 and Table 2-12). For these alternatives, peaking batteries have been assumed to be a necessary part of the total power system.

No attempt has been made to select the specific power system for the various mission periods, although the data presented indicate the suitable alternatives. Rather, the intent was to indicate the leading contenders on the basis of service time and power level. For purposes of this study, the prime interest is the thermal interface between the power system and the environmental control system.

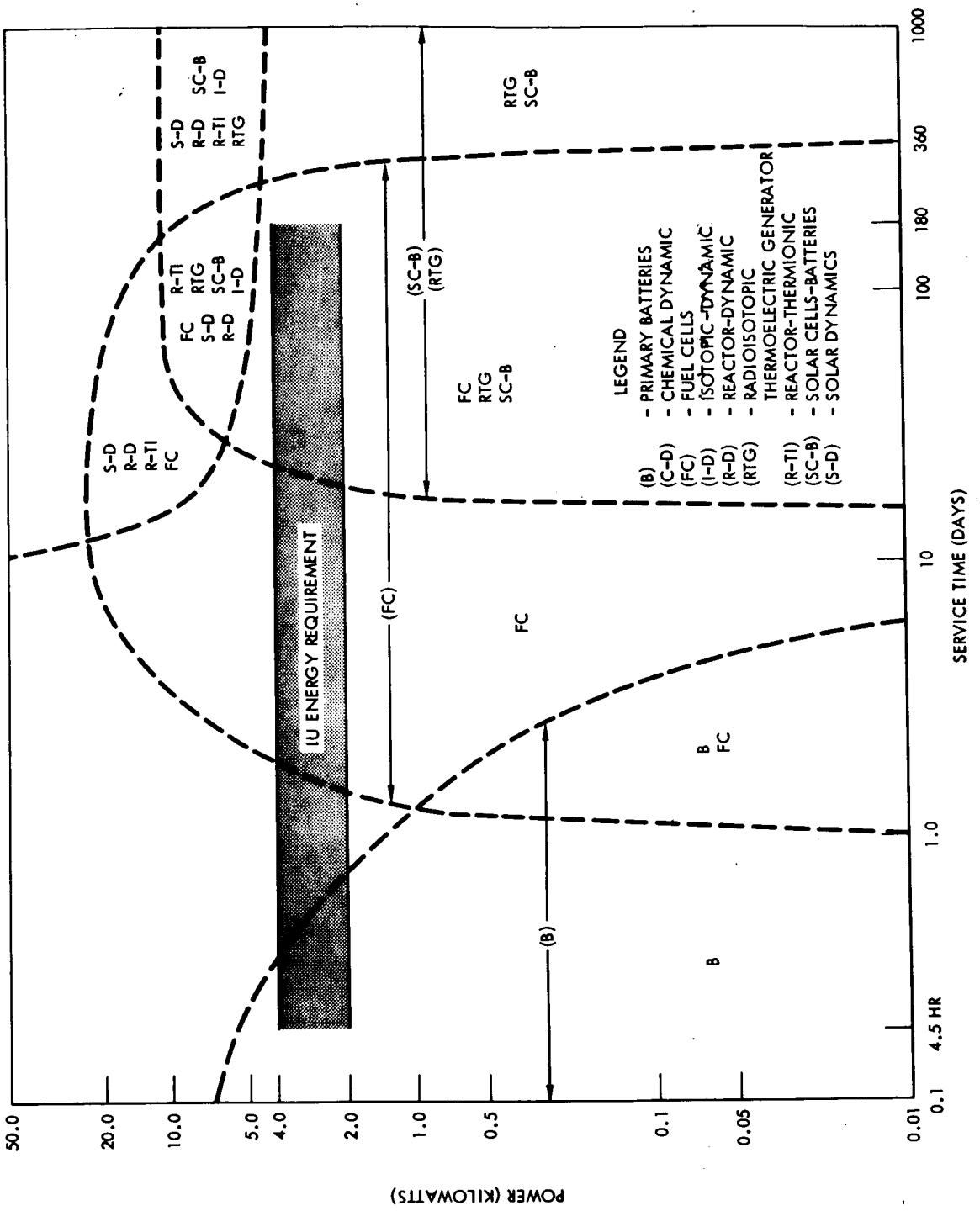

Figure 2-16. Space Power System Potentialities on Service Time Basis

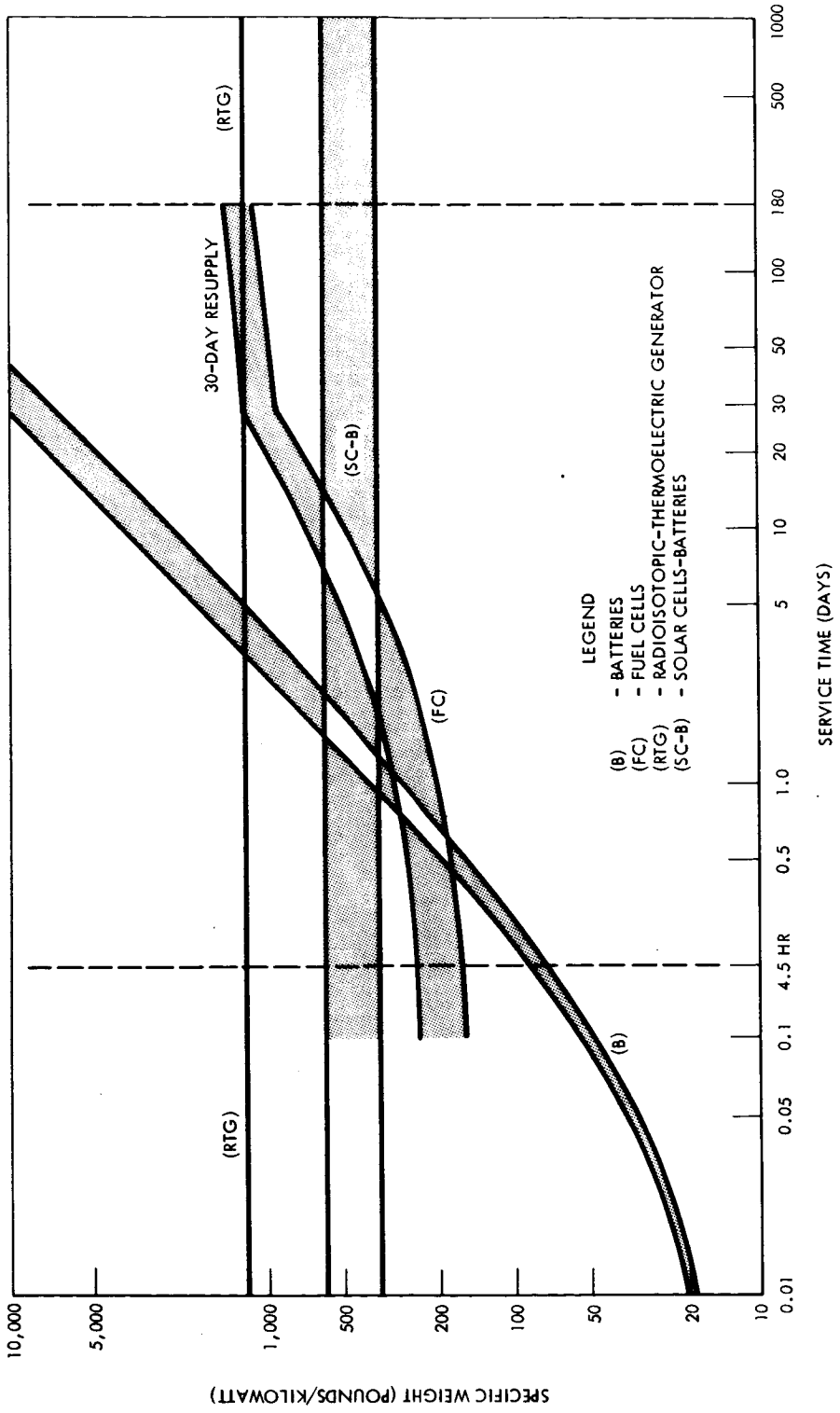

Figure 2-17. Specific Weight-Service Time Characteristics of Space Power Systems (Applicable Up to 4.0 Kilowatt Output Capacity)

Table 2-12. Comparison Matrix of Two-to-Four-Kilowatt Alternative Power Systems for Instrument Unit

Parameter	Radioisotopic Thermoelectric Generator	Solar Cells Batteries	Fuel Cells
State of the art	Technology	Hardware	Hardware
Reliability	0.90	0.99	0.99 (at 50 percent redundancy)
Specific weight, lb/kwe	1160 ±100	500 ±125	1060 ±120
Specific shield weight, lb/kwe (5-10 rem/180 days at 16.0 ft)	205 ±15	DNA	DNA
Specific volume, ft3/kwe	11.5 ±1.0	DNA	33 ±5
Time rate of specific volume, ft3/kwe x 30 days	DNA	DNA	33 ±5
Specific area, ft2/kwe	125 ±20	100	20 ±5
Environmental effects	Insignificant	Radiation sensitive	Insignificant
Orientation constraints	None	±25 deg to sun 10 percent loss	None
Major advantages	Continuous radiation from heat source; integrates readily with vehicle	No refueling	Water produced, lb/day (2.0 kw) 43 (4.0 kw) 87
Major disadvantages	Loss of heat with time; crew receives radiation	Orientation requirements; atmospheric drag at altitudes below 200 n. mi.	Crew must operate fuel cell; cryogenic tanks require refueling, typically at 30-day intervals
Orbit altitude attitude inclination effects	None	Sun eclipse; thermal effects on power output	None
Efficiency, percent	4.6 ±.5	9.0-10.0	50-65
Source specific thermal power, kwt/kwe	19.6-24.4	DNA	DNA
Specific thermal power radiated, kwt/kwe	188 ±1.9	DNA	0.65-0.70

DNA: Does not apply
*Assumes 10 percent heat loss to vehicle structure

A summary of the thermal interface between the candidate power systems and the environmental control systems is presented in Table 2-13. The interface with all candidate systems is indicated because batteries are considered an integral part of all systems, either as a primary power source for short duration or as peaking batteries. The battery cooling requirements and temperature range have been estimated for the various applications and are similar to the current thermal requirements of the instrument unit batteries. With the exception of the battery, the other primary power sources are generally designed with their own thermal conditioning system or method. The possible interfacing with a separate thermal conditioning system varies with each of the primary sources.

Current and advanced fuel cells, which are designed for forced, internal cooling, require coolant supply at temperatures in the 30 F-to-150 F range, depending upon the type of fuel cell. Heat rejection from a fuel cell or from a bank of fuel cells depends primarily on the power produced from the cell or cells. Therefore, for an assumed efficiency range between 59 and 67 percent, the total heat rejection for a 1-to-4-kilowatt power system would be 600 to 2680 watts. For the indicated temperature range and heat loads, the thermal conditioning requirements could be satisfied by a thermal conditioning loop similar to the present instrument unit environmental control system. A 4-kilowatt power system would require four to six fuel cells (depending on the type) which, based on the present design, could be located within the instrument unit compartment. If the fuel cells are located in another area (such as the SLA or ASM), it may be more logical for the fuel cell power system to be designed with its own thermal conditioning system, in which case a heat exchange between the fuel cell cooling loop and the instrument unit cooling loop could be readily accomplished by adding a heat exchanger and associated controls.

Another possible interface with the fuel cell system is the water output, which could be utilized for heat rejection in a water boiler or a sublimator. The condition of the water, particularly its purity, is satisfactory for use directly or for long-term storage with no preconditioning required.

One of the objectives of a NASA (Huntsville) study contract with Martin Company is the examination of a proposed RTG power system that consists of four SNAP 29 (P_o^{210}) units located in the Saturn IU. If this concept is determined to be feasible and practical, the power system will deliver 2.0 ±0.4 kilowatts; weigh 2300 ±200 pounds, including radiator and peaking batteries; and occupy 7.51 ±0.5 cubic feet. The RTG will be completely self-contained. It fits along the exterior of the spacecraft, between structural load-bearing members, like a window fits into the load-bearing wall of a residential dwelling. Each of the four modules is anticipated to be approximately 5 to 8 inches thick, and so almost all the IU interior space is available for instruments. Batteries, power controls, and distribution wiring require additional volume of two to three cubic feet within the IU proper, located most conveniently according to spacecraft design practice.

Table 2-13. Summary of Thermal Interface Requirements of the IU Power System With ECS

Parameter	Primary Battery	RTG	Solar Cells Batteries	Fuel Cell
Battery type	Ag-Zn	Ni-Cd or Ag-Cd	Ni-Cd or Ag-Cd	Ni-Cd or Ag-Cd
Battery temperature, degrees F	20-90	20-110 or 20-90	20-110 or 20-90	20-110 or 20-90
Power system specific battery capacity (kw-hr battery per kw output of power system)	DNA	1.0±0.1	1.0±0.1	1.0±0.1
Battery specific cooling requirement, kwt/kwe*	0.40±0.04	0.23±0.03	0.23±0.03	0.23±0.03
Primary power source, specific cooling requirement (maximum), kwt/kwe	0.40±0.04	**	**	**
Water Delivery from Fuel Cell				
Specific rate, lb/kw hr Mission average (based on an average power requirement for 1 hour)				0.90±0.15 0.70-1.20
Temperature, degrees F				
Normal operation				160
Maximum				200
Minimum				140

DNA: Does not apply

*Assumes that peaking power requirement equals rating of power system; e.g., a 4-kw system is occasionally expected to supply 8 kw for periods of one to three hours

**See text for discussion

If an RTG is located in the basic subsystem module (BSM) or the SLA, the same considerations apparently apply. A power generator in the BSM or SLA can be sized for power requirements of BSM-IU or SLA-IU. This approach appears to be most advantageous in that it eliminates difficulties related to multiple grounding and power sharing and minimizes electromagnetic interferences.

Heat can be diverted from the RTG radiator heat rejection loop for use in the ECS. To avoid any radiation carry-over by the heat transfer fluid, the heat must be transferred through a heat exchanger that physically separates the fluids, thereby reducing radiation in the ECS loop to an insignificant level. (This is a current practice in space power technology.)

A power system consisting of a solar cell/battery combination may not have a direct interface with an environmental control system in the instrument unit except for the batteries. The solar cell arrays as the prime power source would generally be mounted on a separate structure and would use passive means for thermal control. One such application that has been examined is the vehicle configuration that utilizes the SLA (Figure 2-18) and consists of a CSM/MM/S-IVB spacecraft. The four SLA panels are deployed 90 degrees, without articulation. The interior surface of the four SLA panels, or portions thereof, are used as the mounting structure for the solar cell array. Solar cells can be mounted as an electrically integrated array on all or part of the available surface on the four SLA panels. Total available area is 877 square feet. The entire spacecraft requires orientation toward the sun. While the orientation and spacecraft configuration represent maximum mass, maximum moments of inertia, most severe spacecraft thermal considerations, and greatest propellant requirements for attitude control, they provide maximum solar cell utilization of SLA panel area and minimum modification to the SLA deployment system.

As shown in Figure 2-18, with the SLA panels in the deployed position and solar-oriented, the undersurface acts as a passive radiator for the solar cells and has thermal interface with the instrument unit.

Numerous alternative combinations of two and four SLA panel configurations have been examined. One combination can provide a large solar array and minimize the effects of prolonged solar venting of one part of the spacecraft, and propellant ejection for attitude control. This combination uses four SLA panels with two degrees of panel articulation (Figure 2-18).

Two concepts of auxiliary flat solar array panels have been examined. The auxiliary panels are folded and stowed within the SLA and deployed in a series section arrangement.

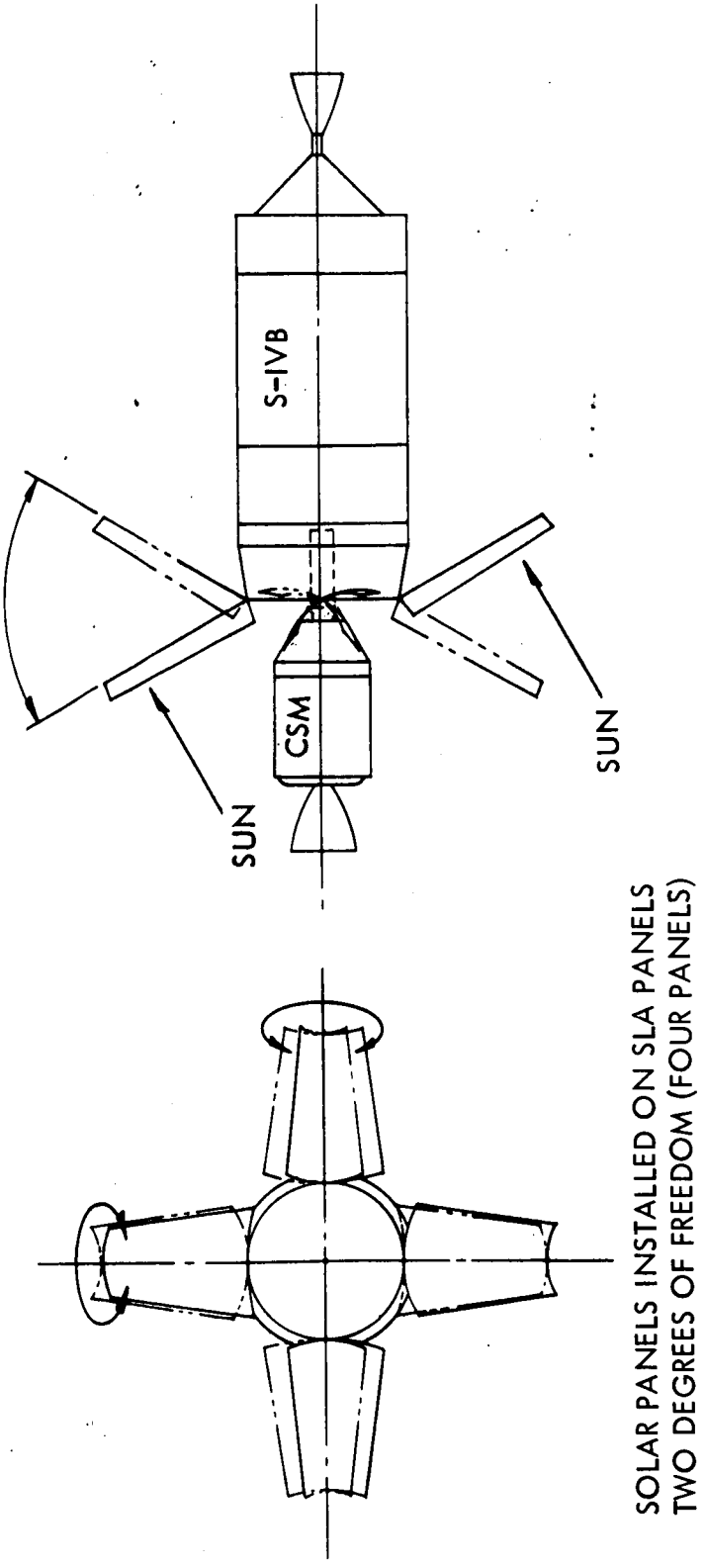

Figure 2-18. CSM/MM/S-IVB, Four SLA Panels, Two-Degree Articulation

An alternate configuration to the solar cell/battery combination is the solar cell/fuel cell combination, which has the advantages of lower weight, greater operational flexibility (that is, the capability of responding effectively to greater variations in power demand), and, possibly, higher reliability. For this system, the thermal interface would be similar to the solar cell/battery combination, except that water would be available for cooling purposes.

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APPENDIX 2.0 ENVIRONMENTAL HEAT FLUX DATA

APPENDIX 2A. INCIDENT RADIATION VERSUS TRUE ANOMALY HEAT FLUX DATA

This appendix contains the cathode-ray tube (CRT) plots for the following cases, described in Table 2-3: IU-1, IU-2, IU-3, IU-4, IU-5, IU-6, IU-7, IU-8, IU-10, and IU-11.

For these plots, the symbol (E) represents the earth emission, (R) the reflected solar energy, (S) the direct solar radiation, and (A_e) the total absorbed energy on the surface.

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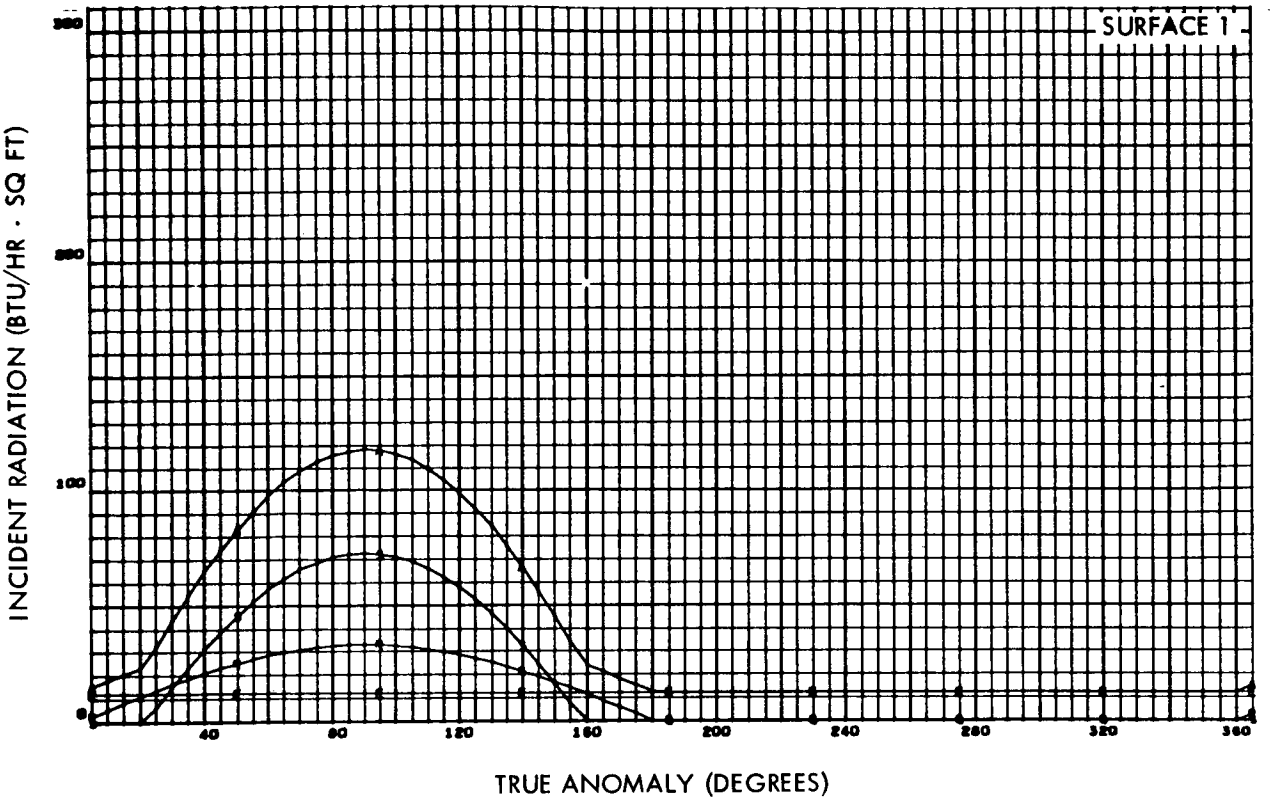


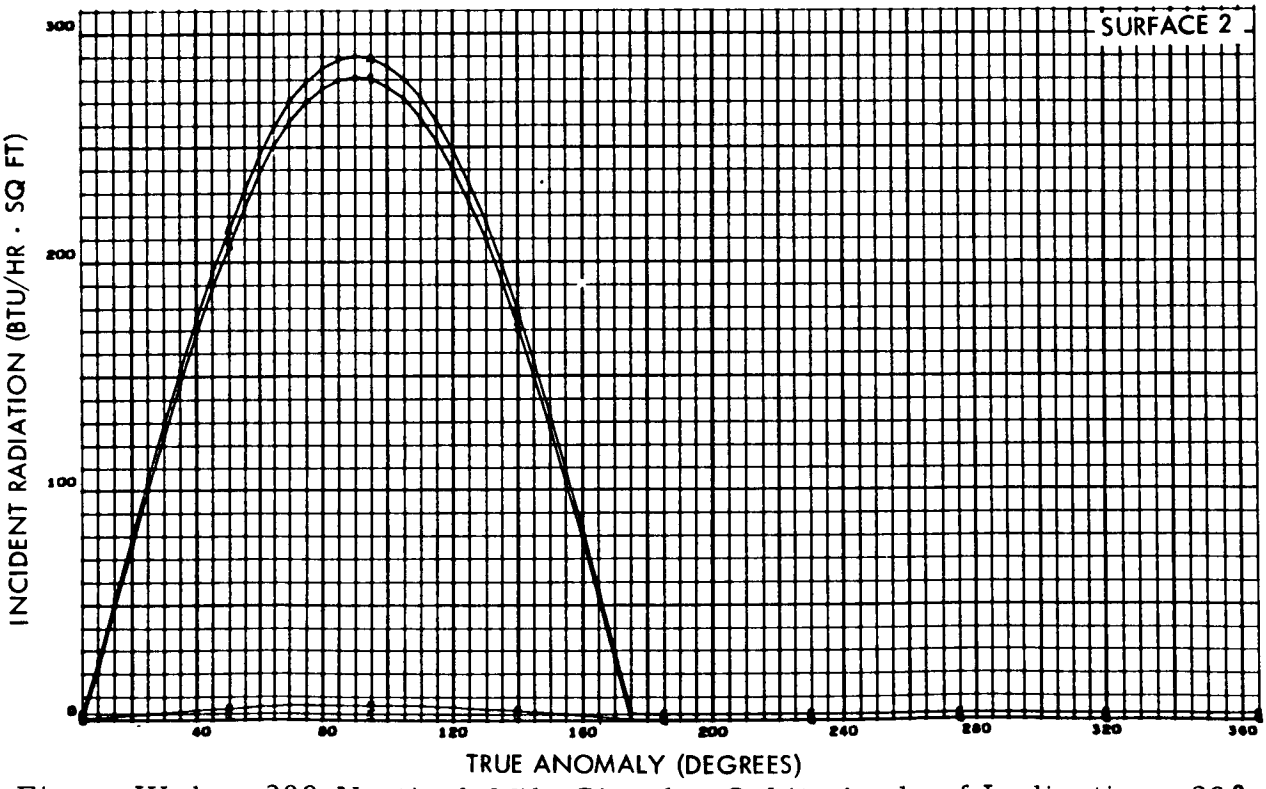


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 1 of 8)

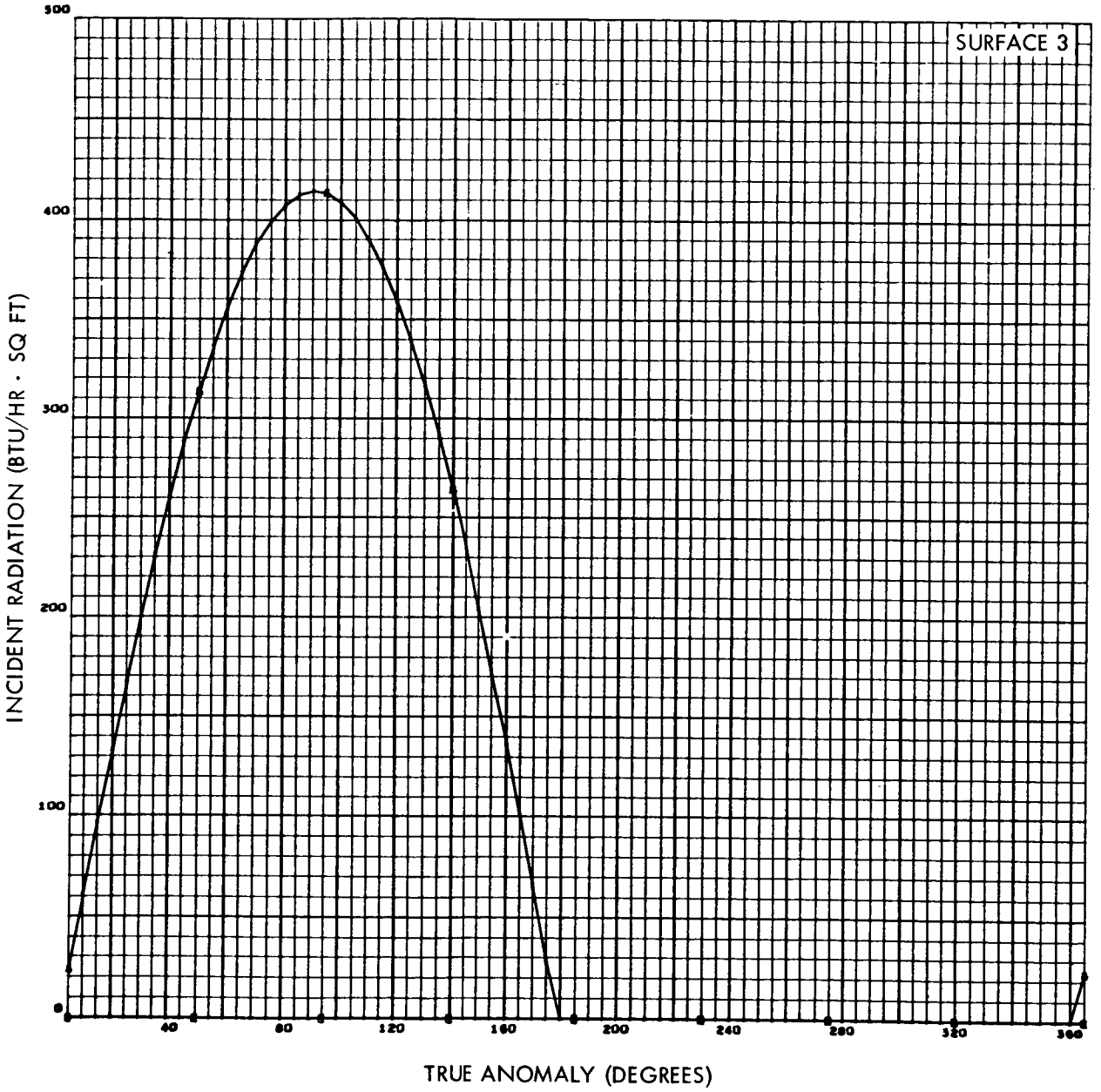


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 2 of 8)

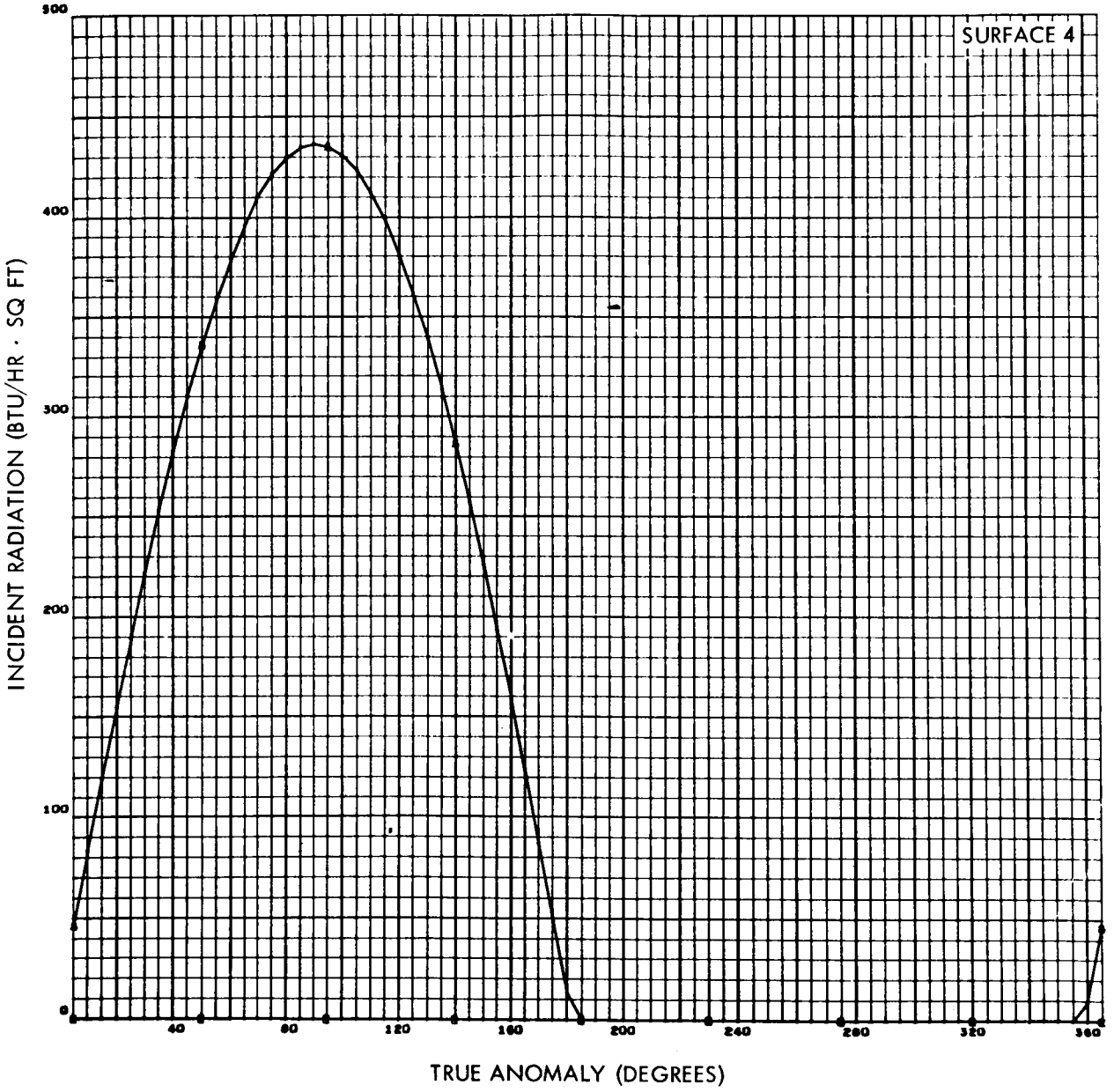


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 3 of 8)

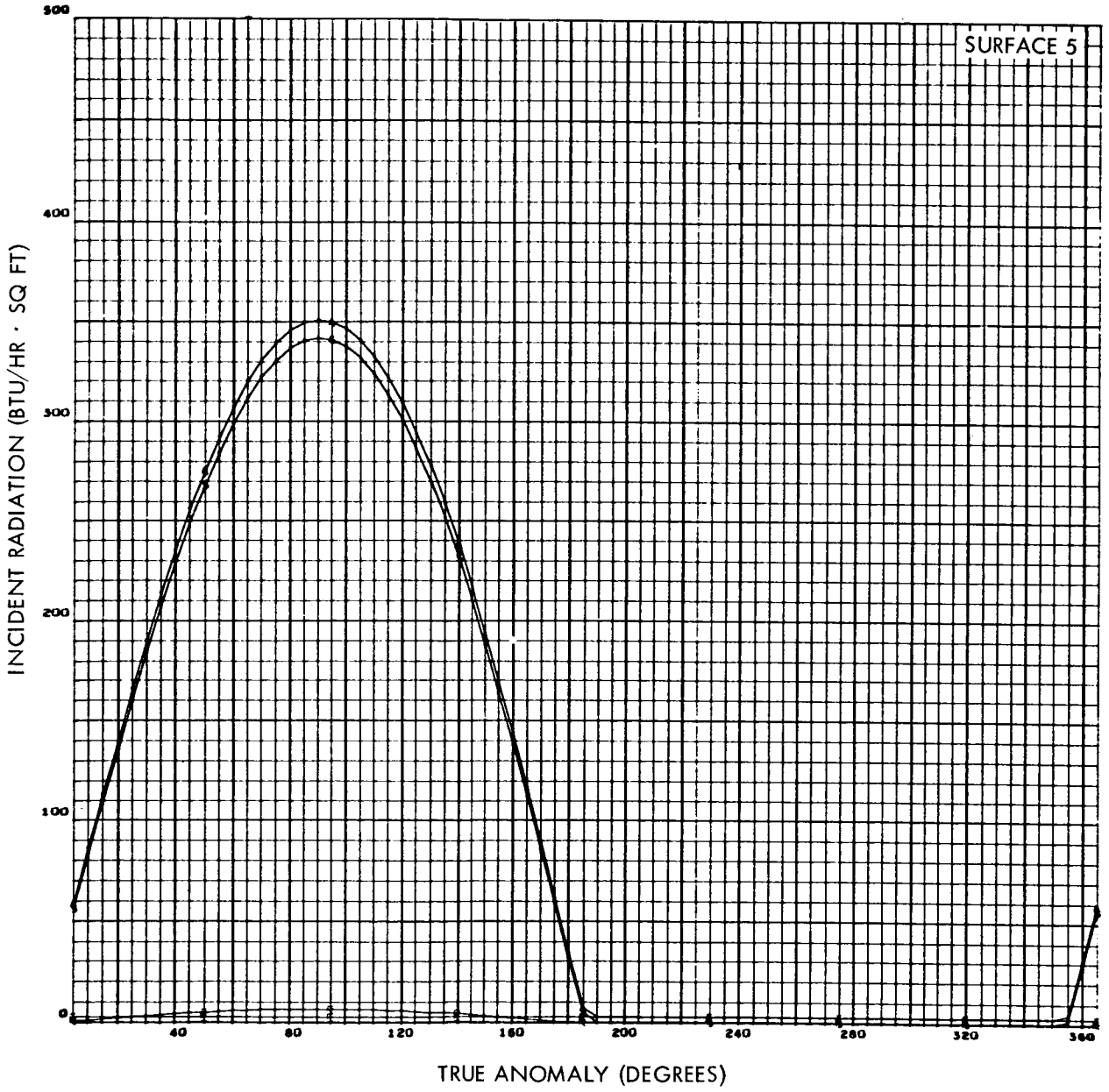


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 4 of 8)

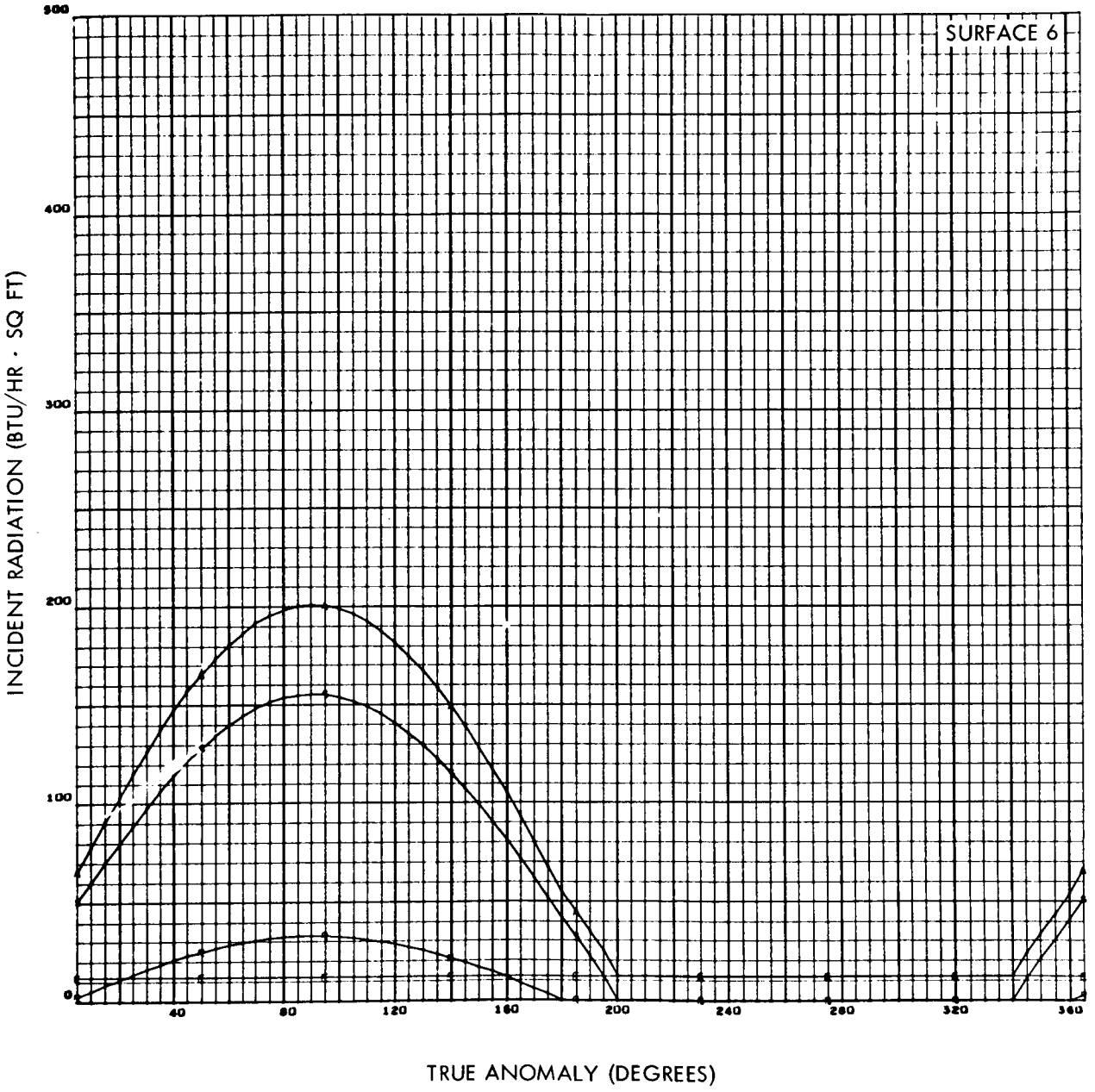
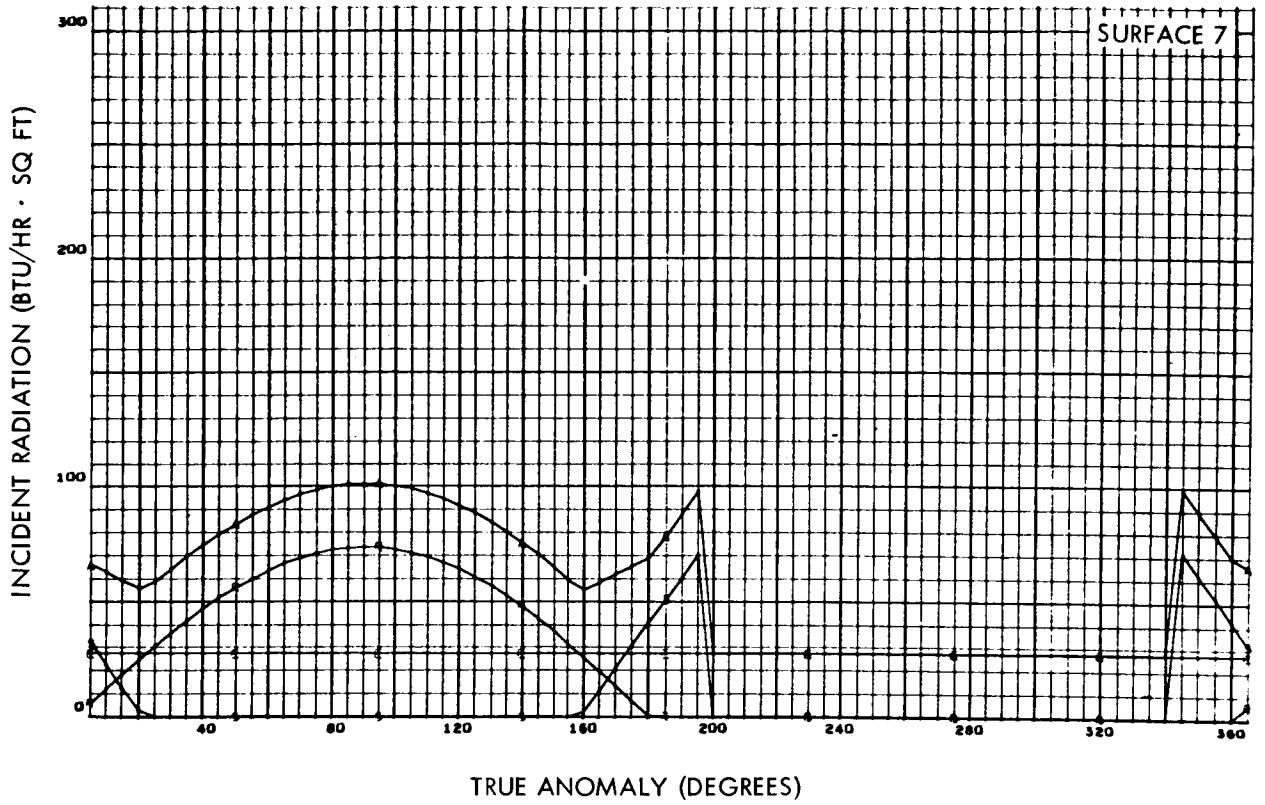


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 5 of 8)



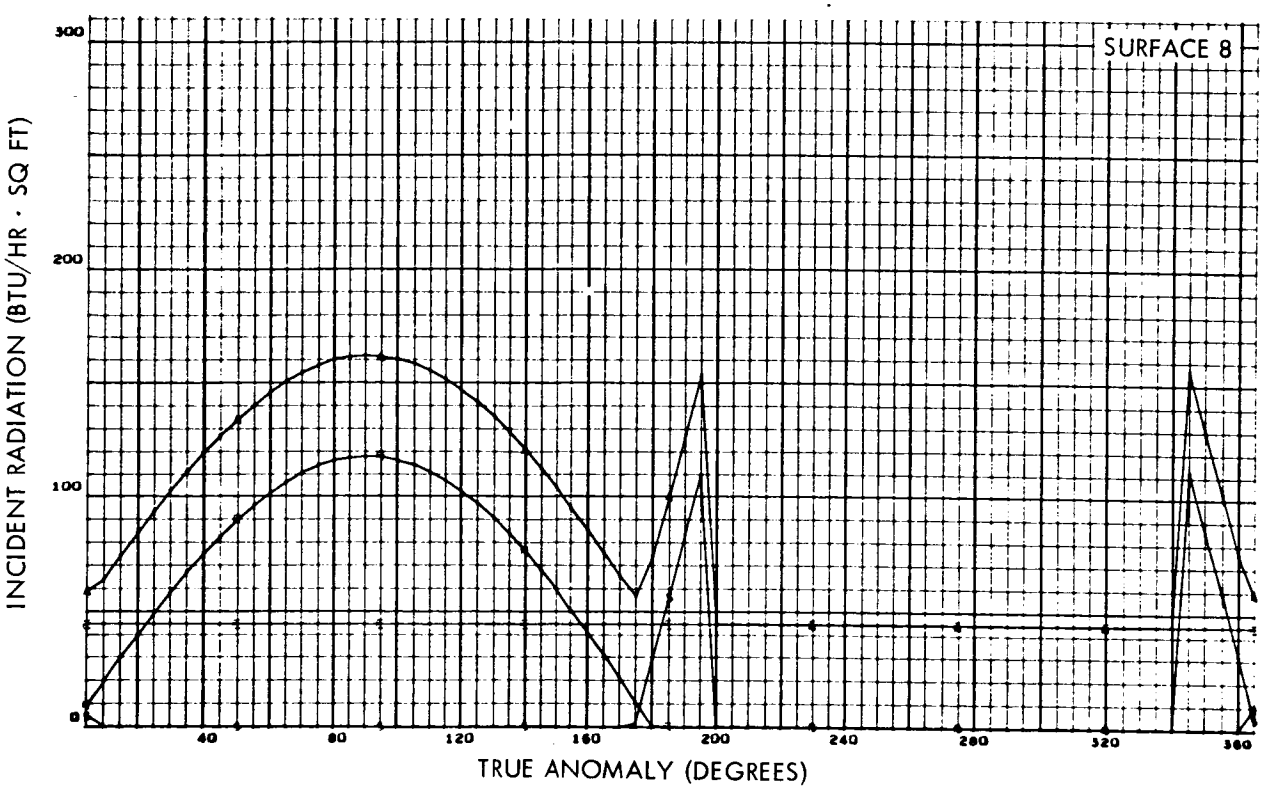
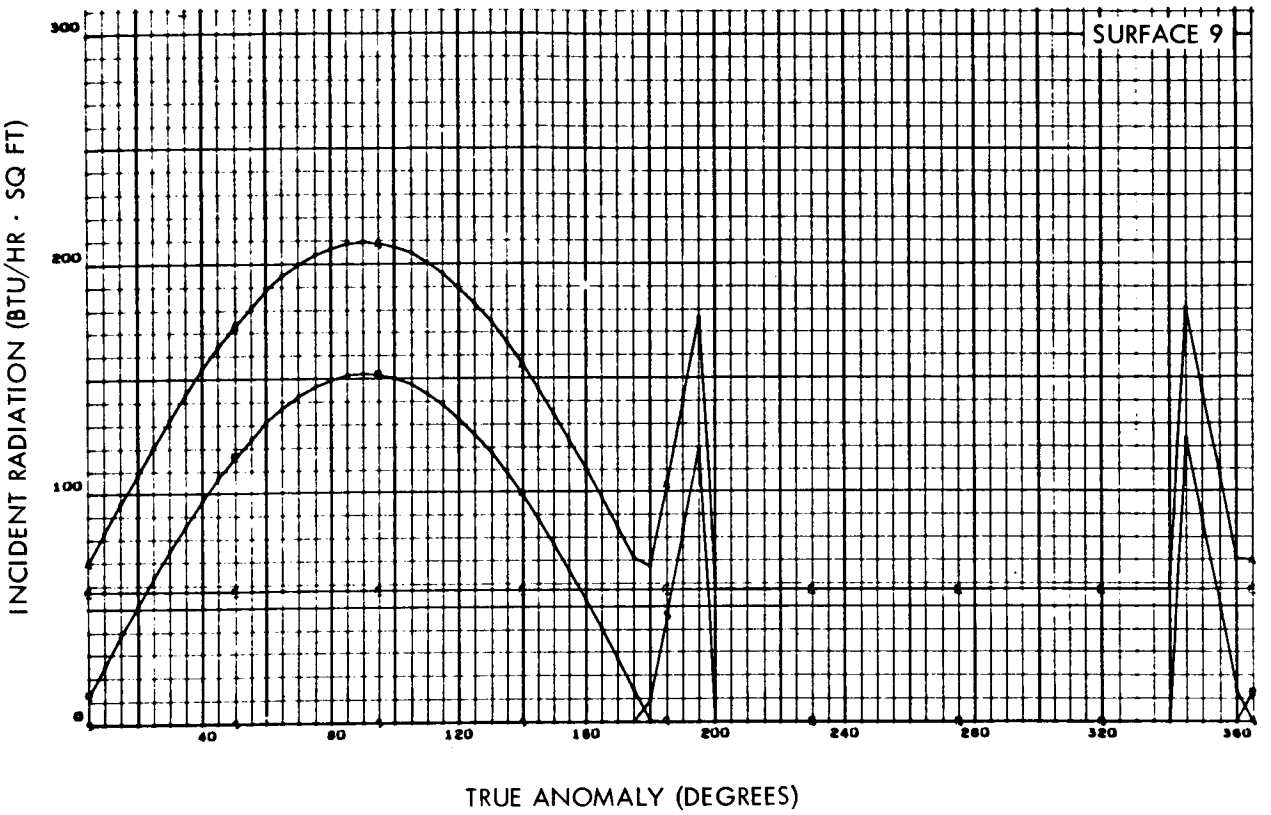


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 6 of 8)



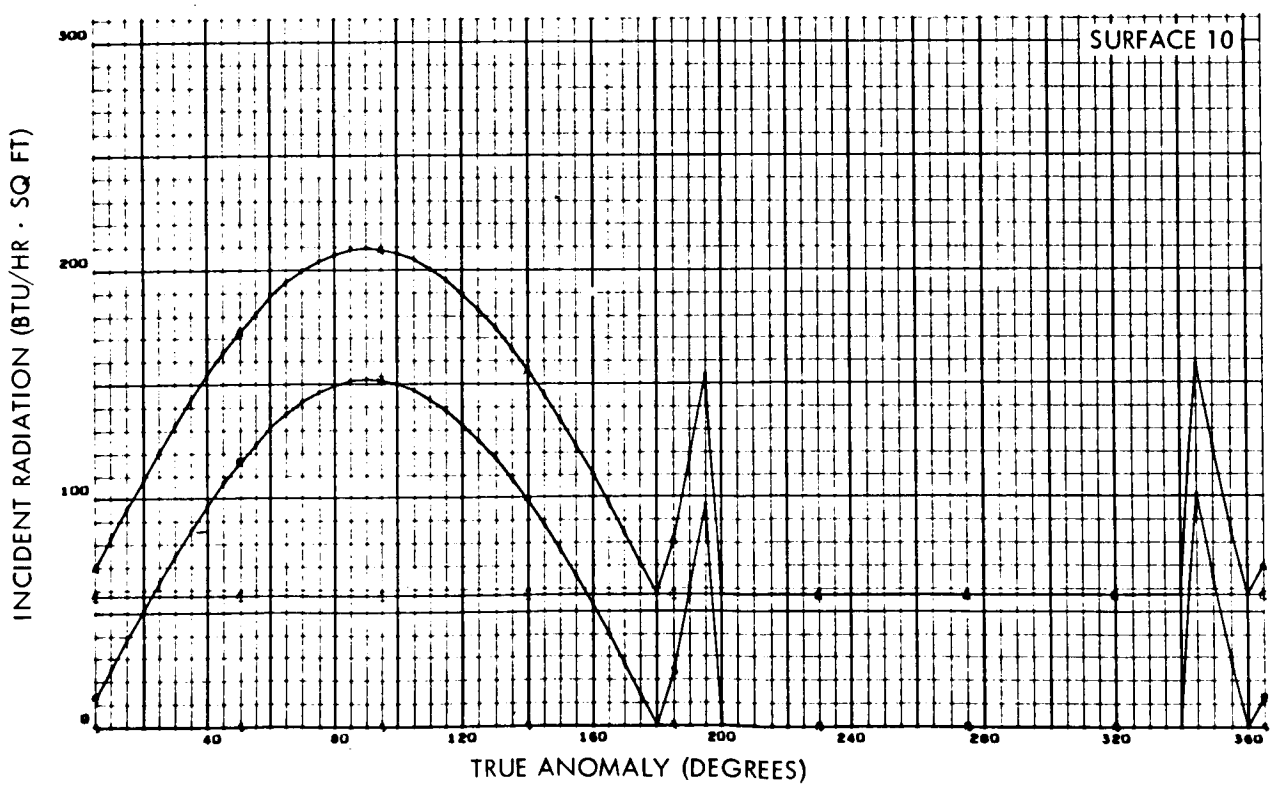
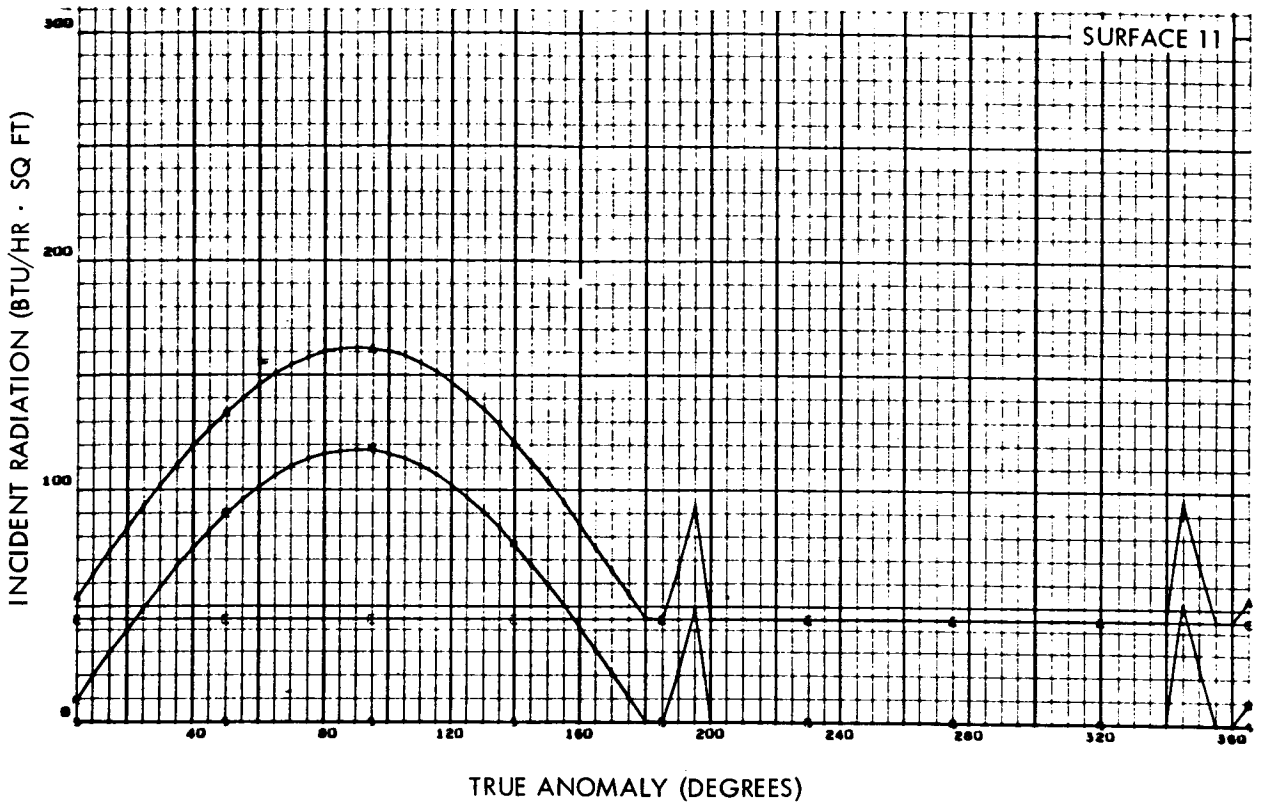


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 7 of 8)



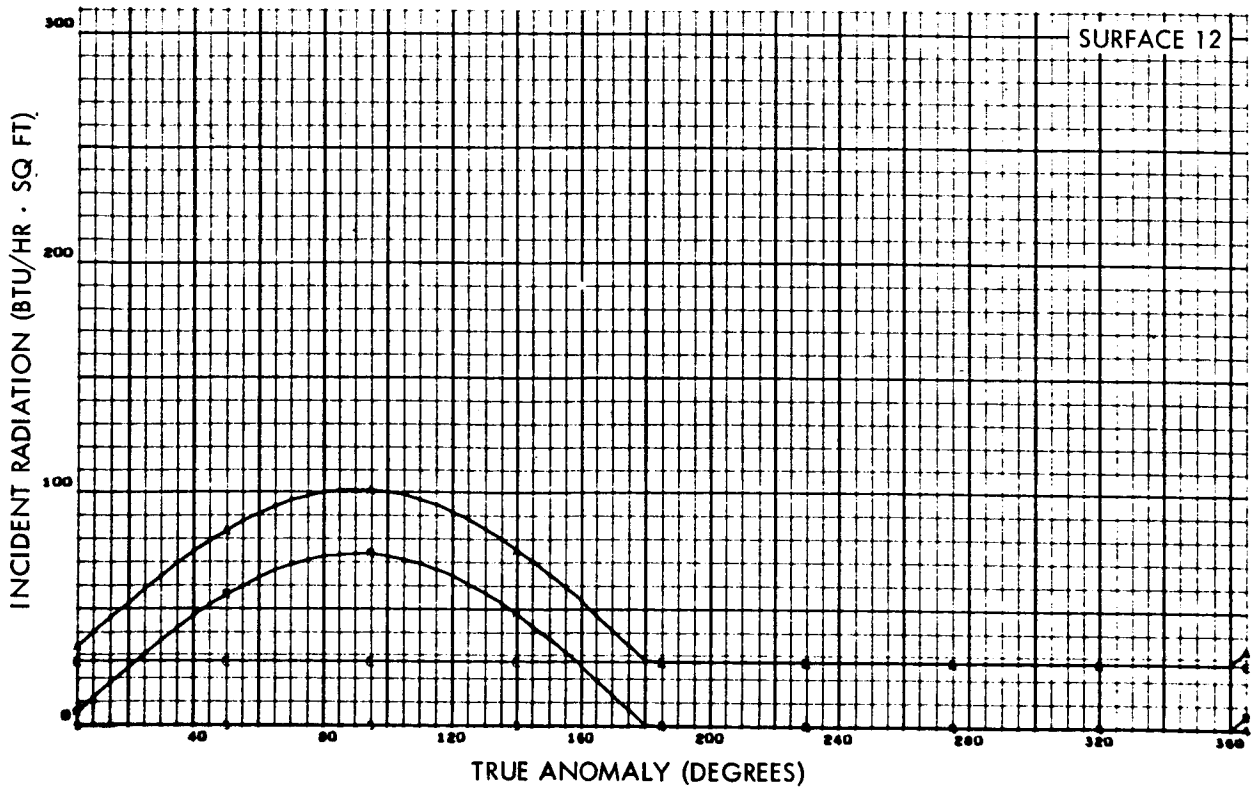
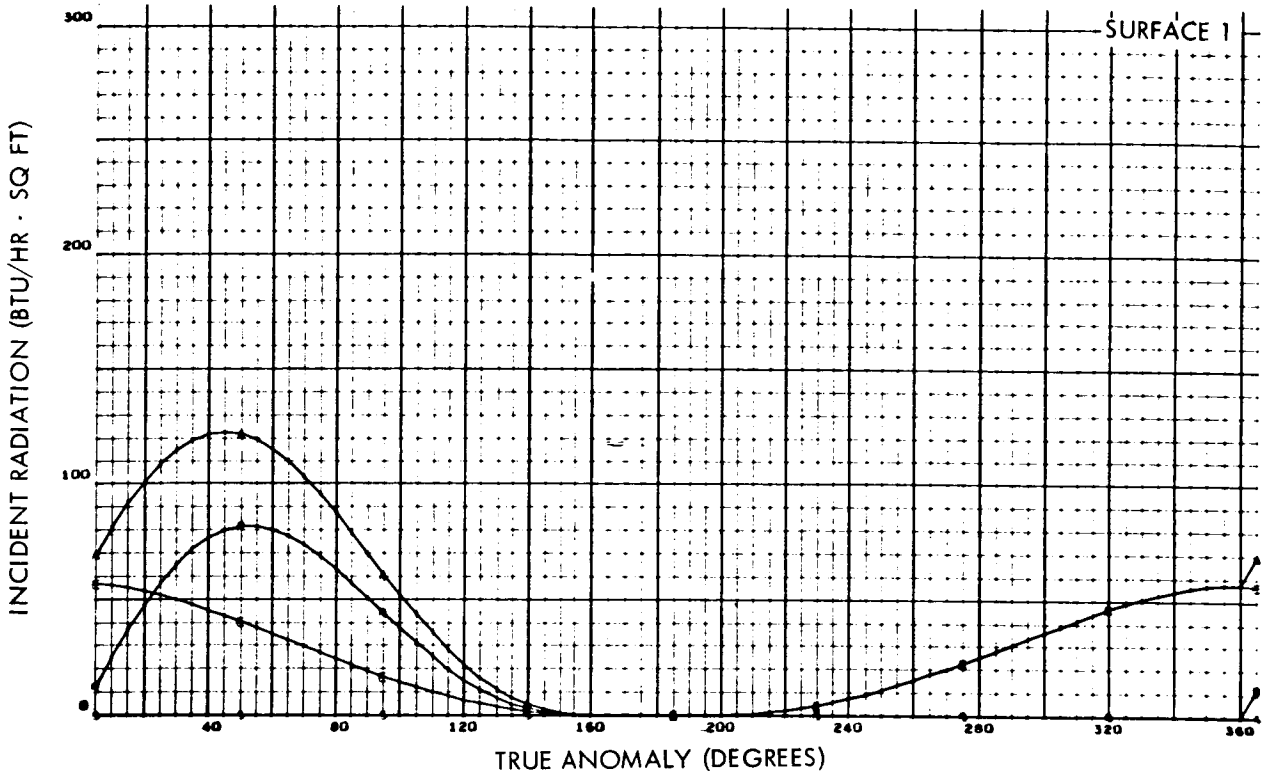


Figure IU-1a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 8 of 8)



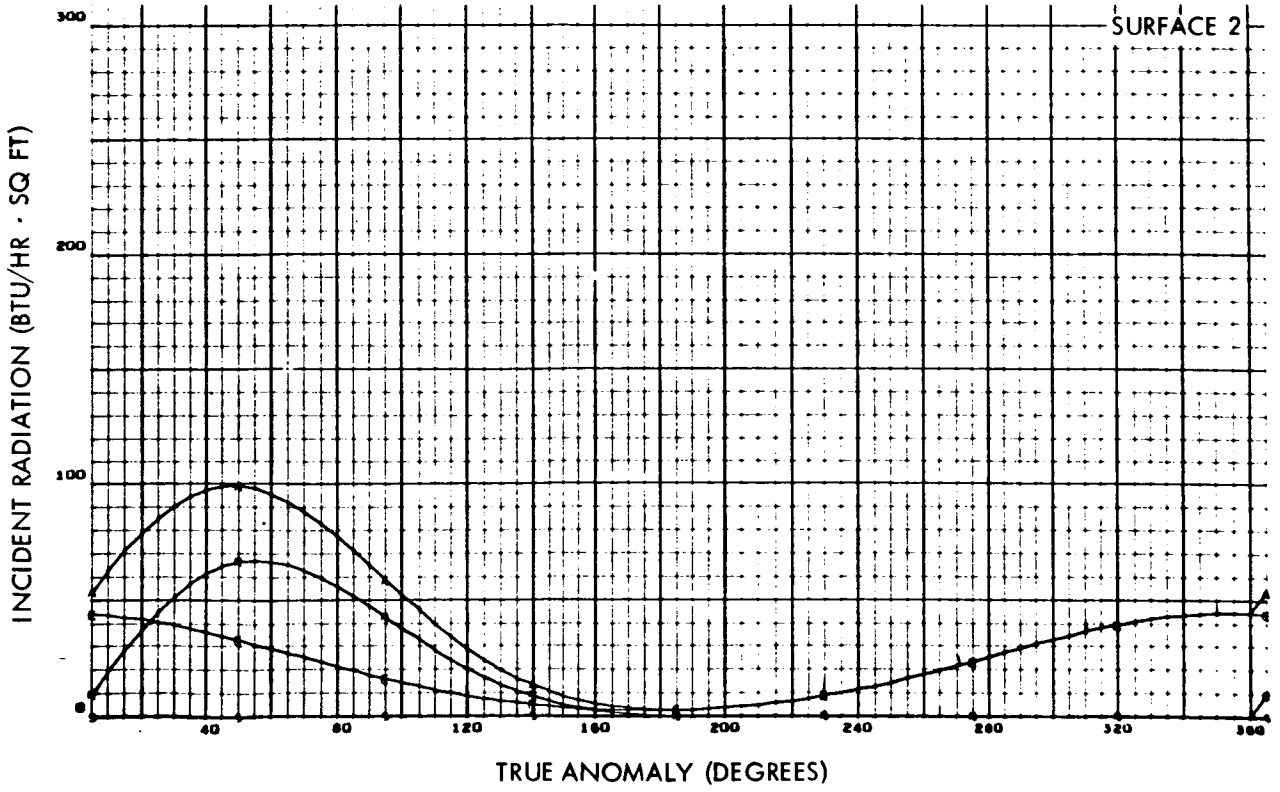
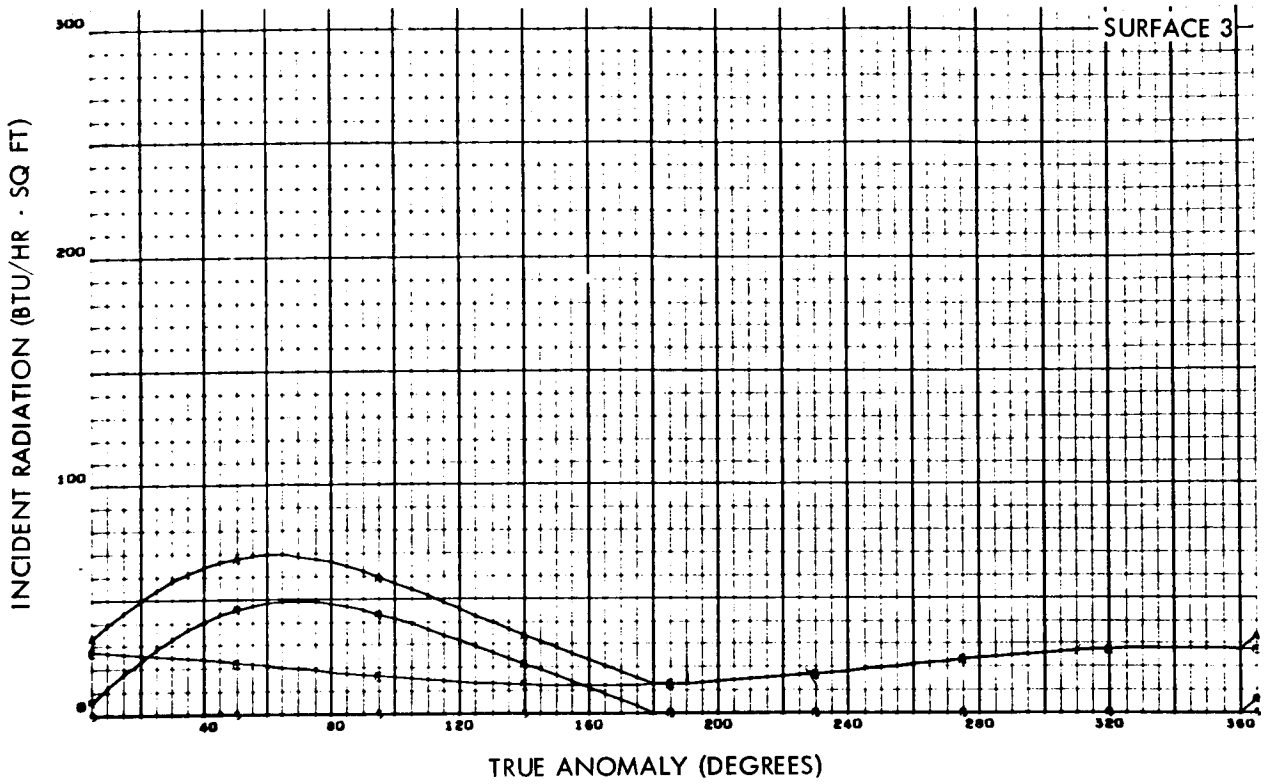


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 1 of 6)



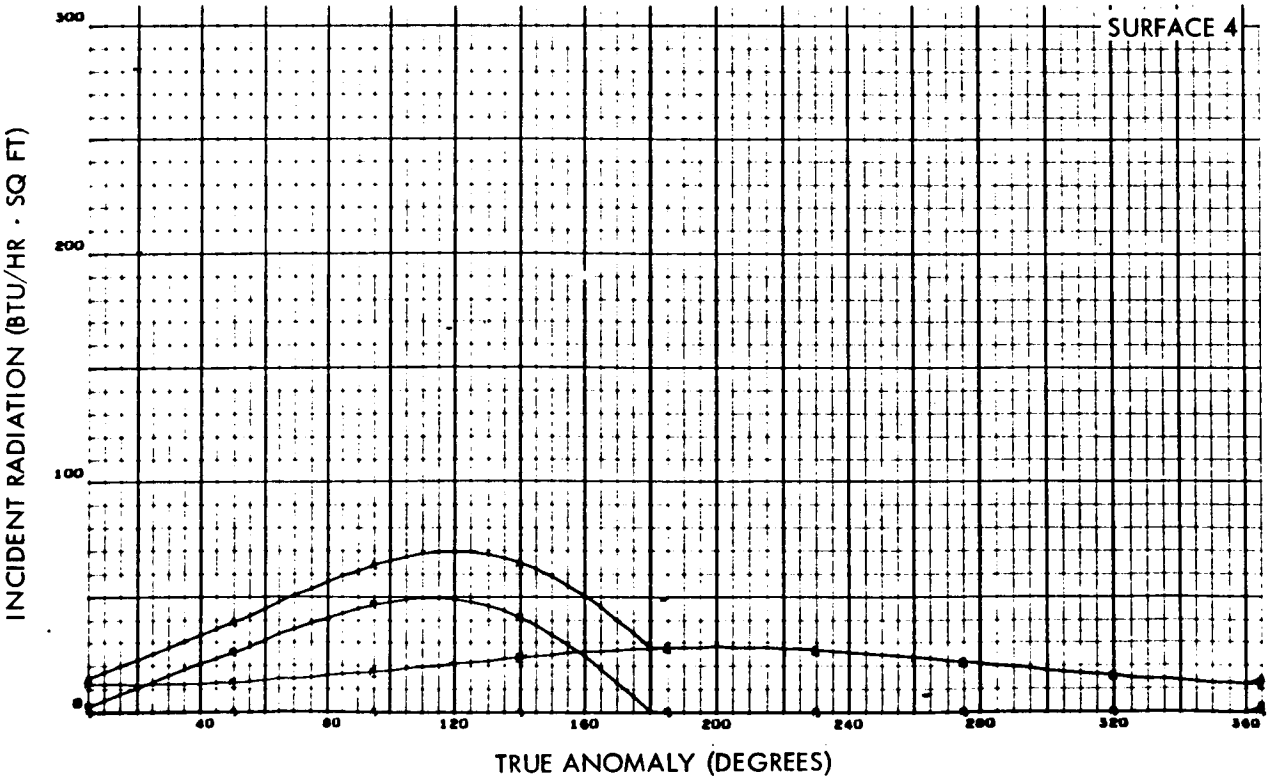
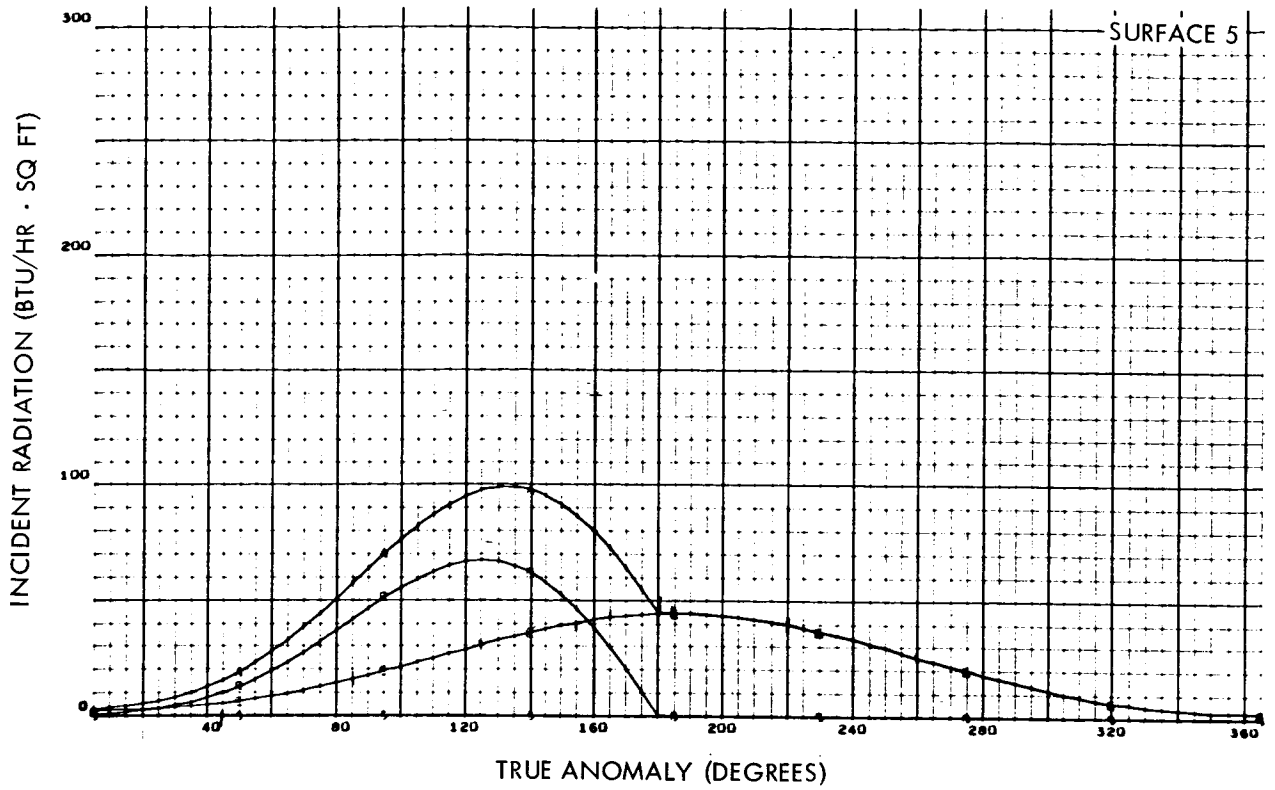


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 2 of 6)



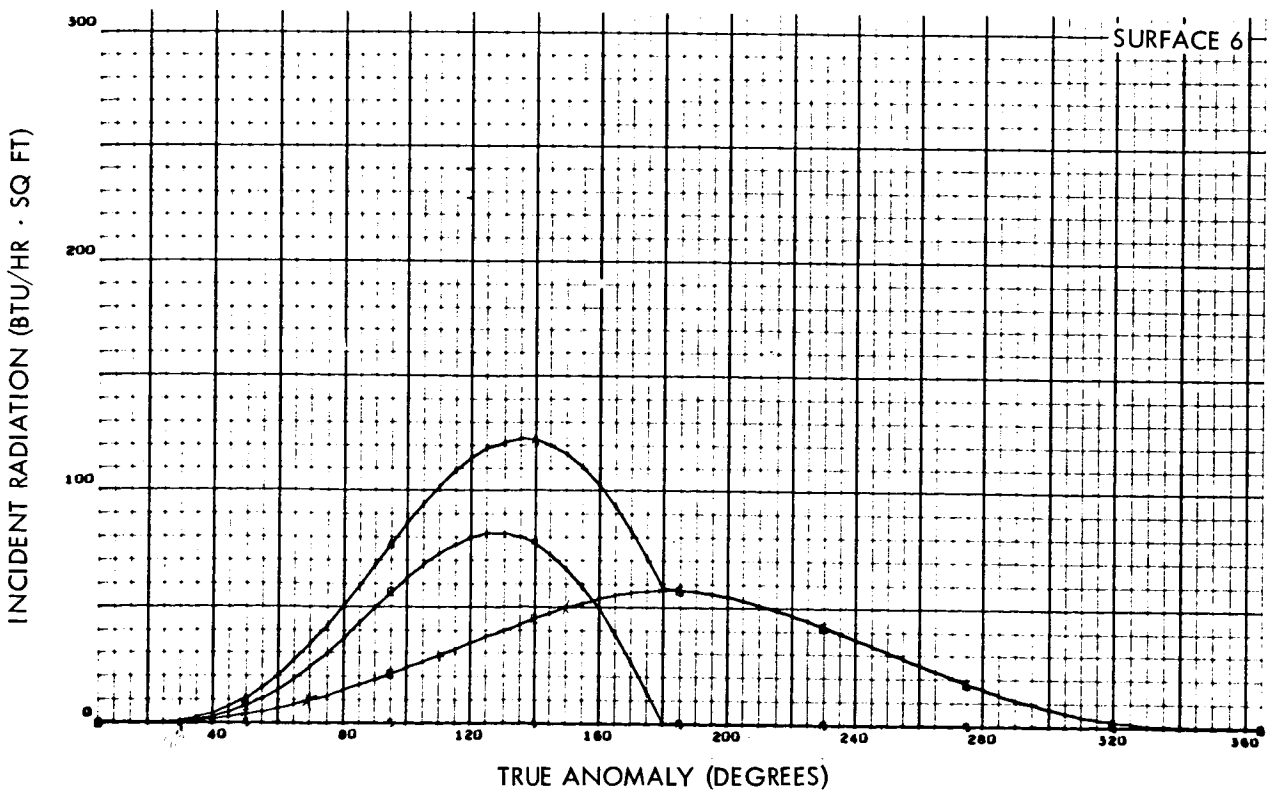
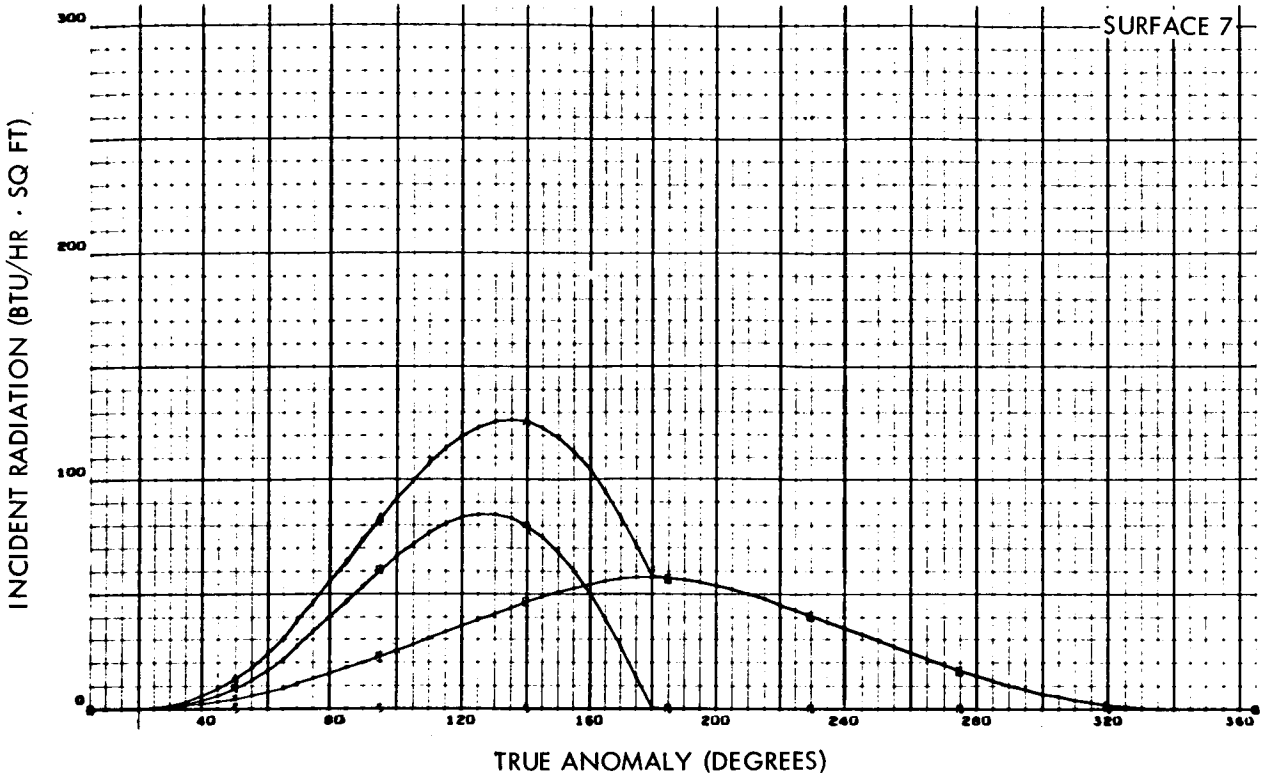


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 3 of 6)



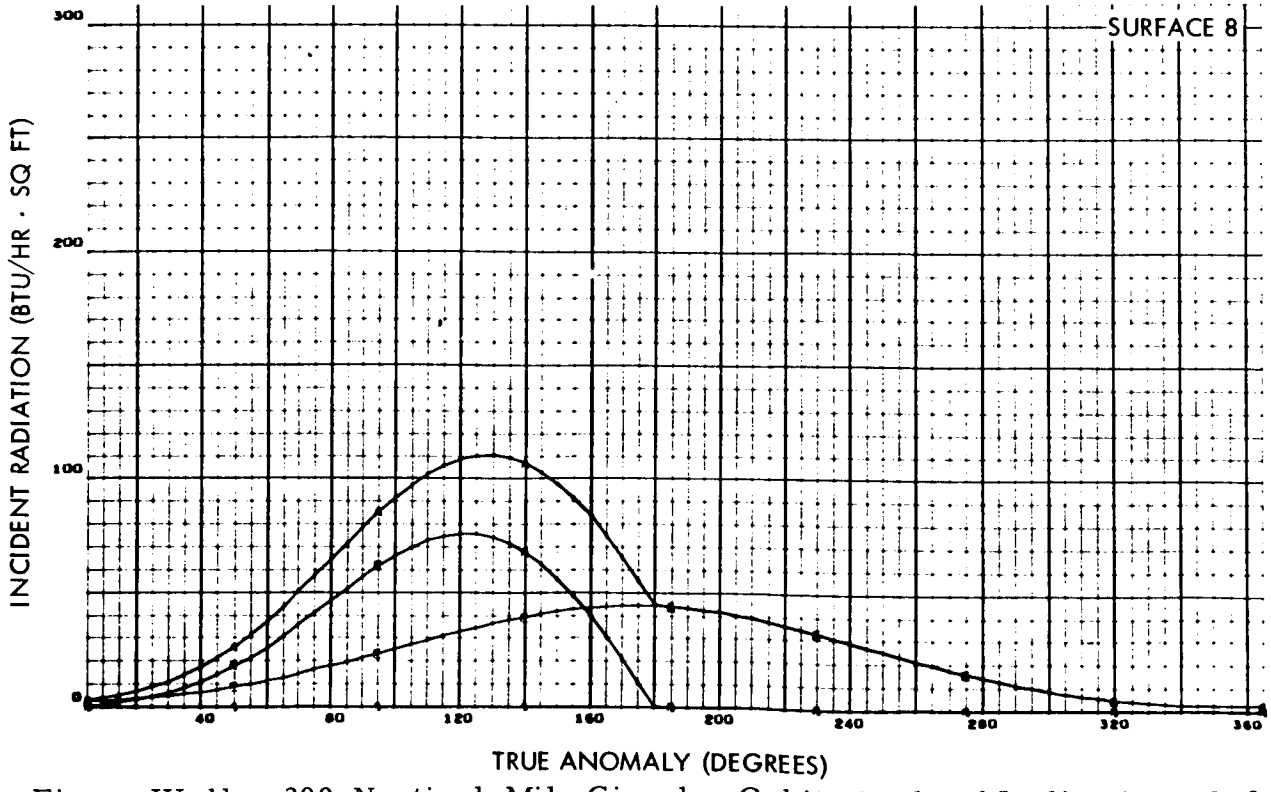
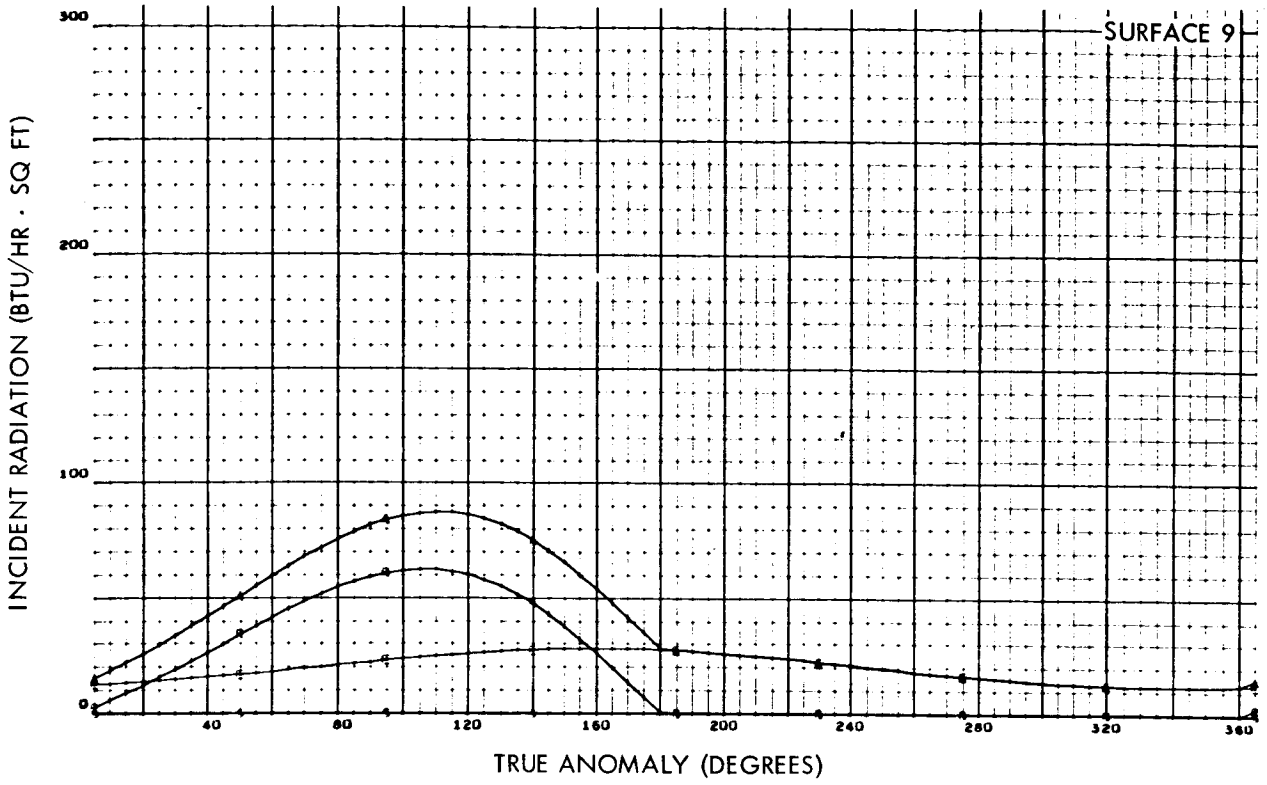


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 4 of 6)



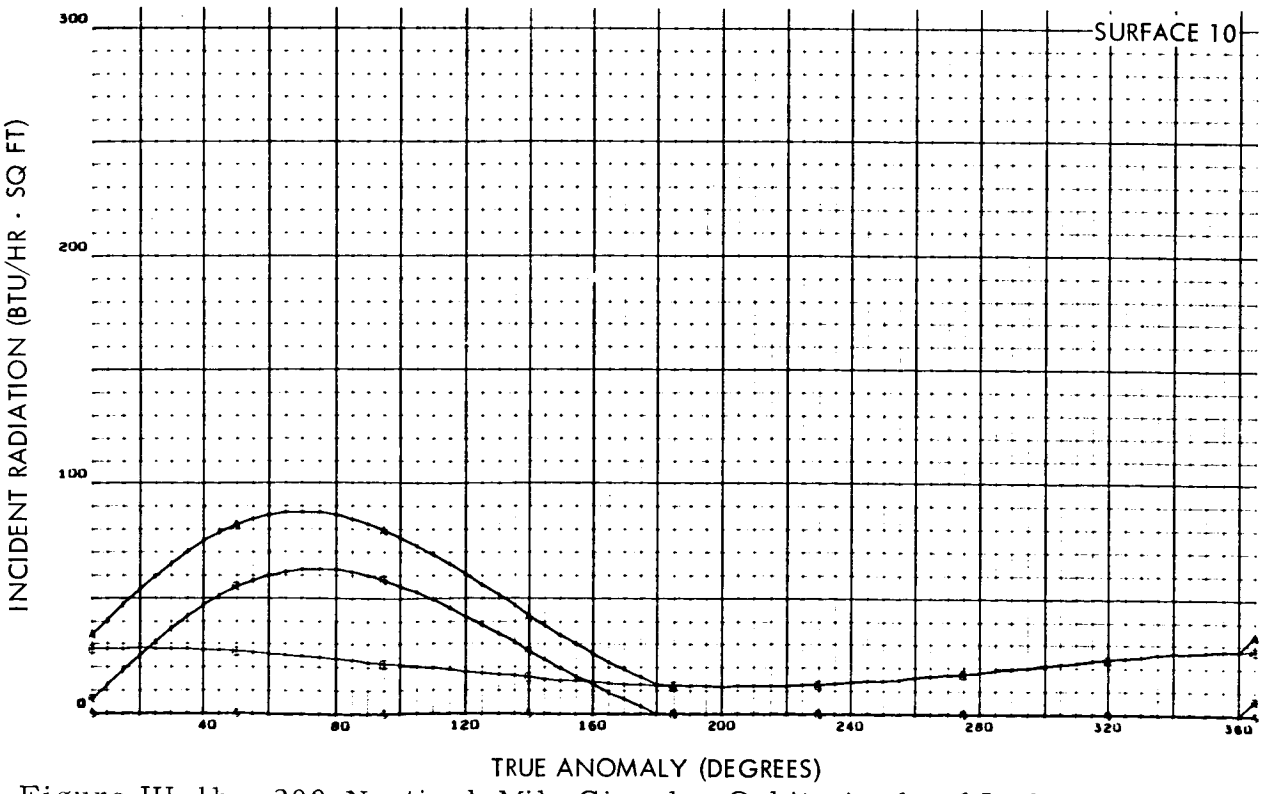
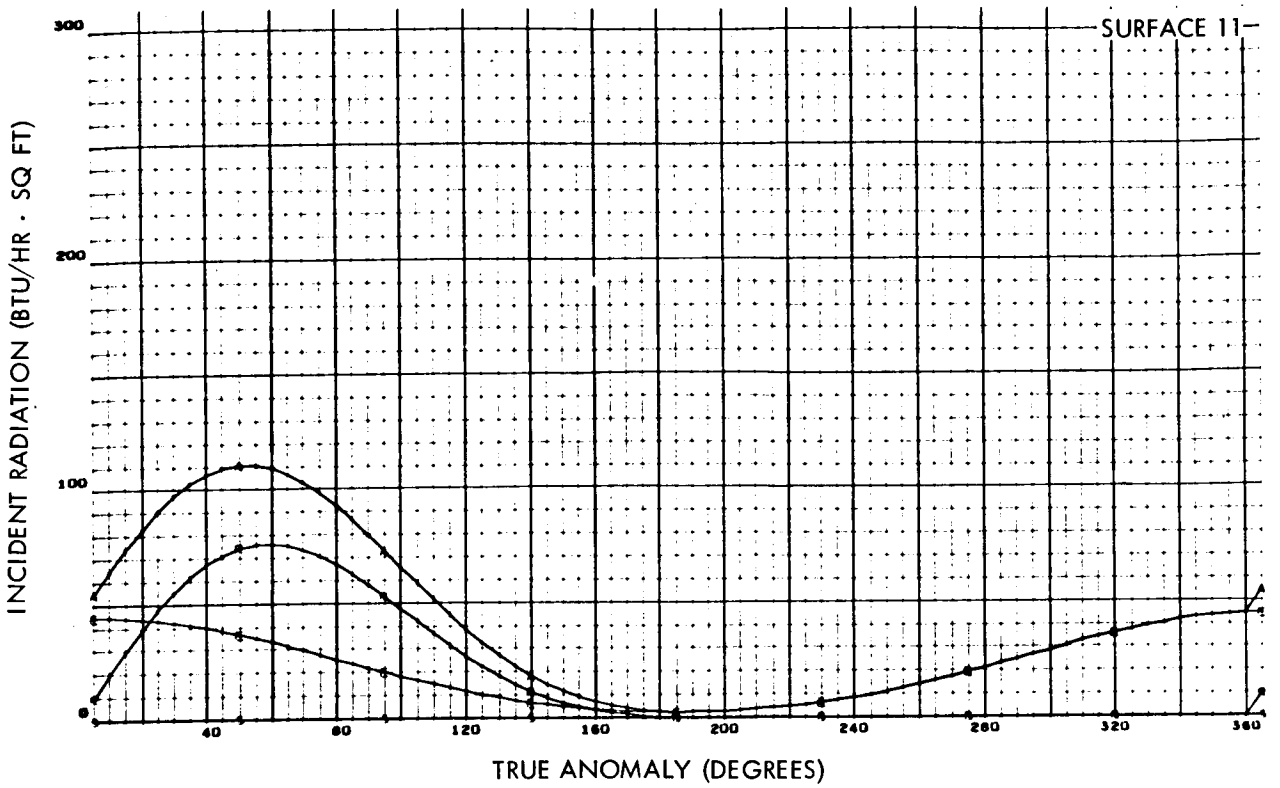


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 5 of 6)



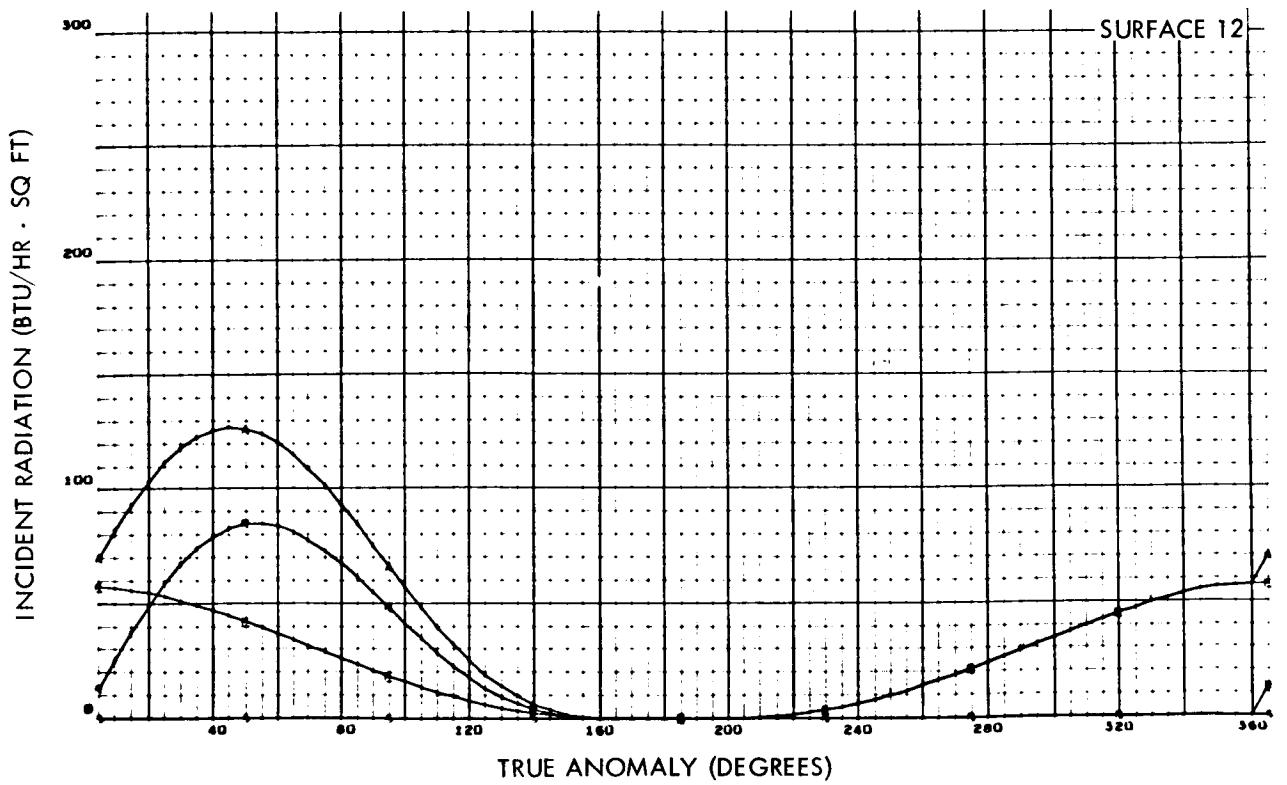


Figure IU-1b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 6 of 6)

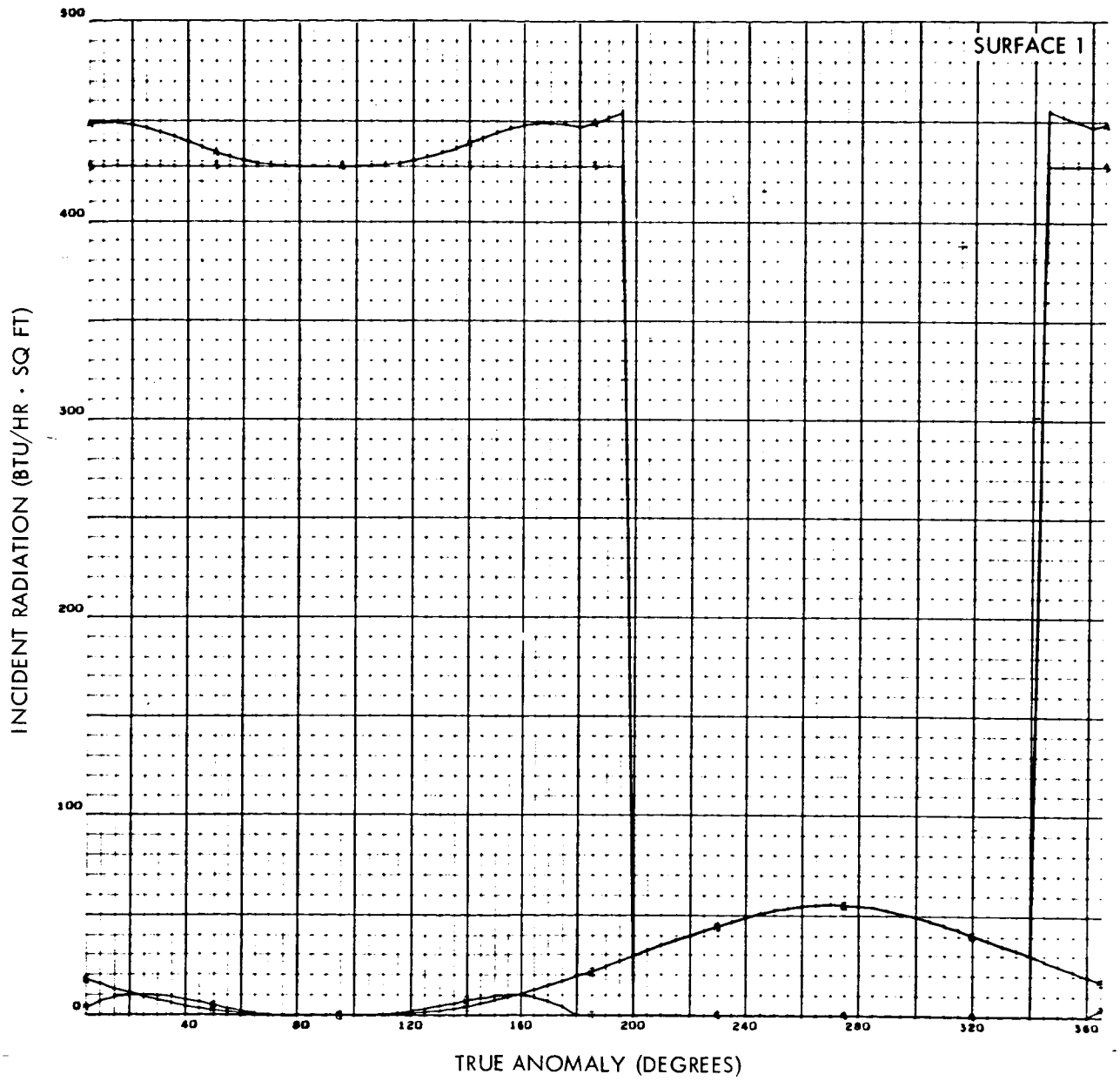


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 1 of 8)

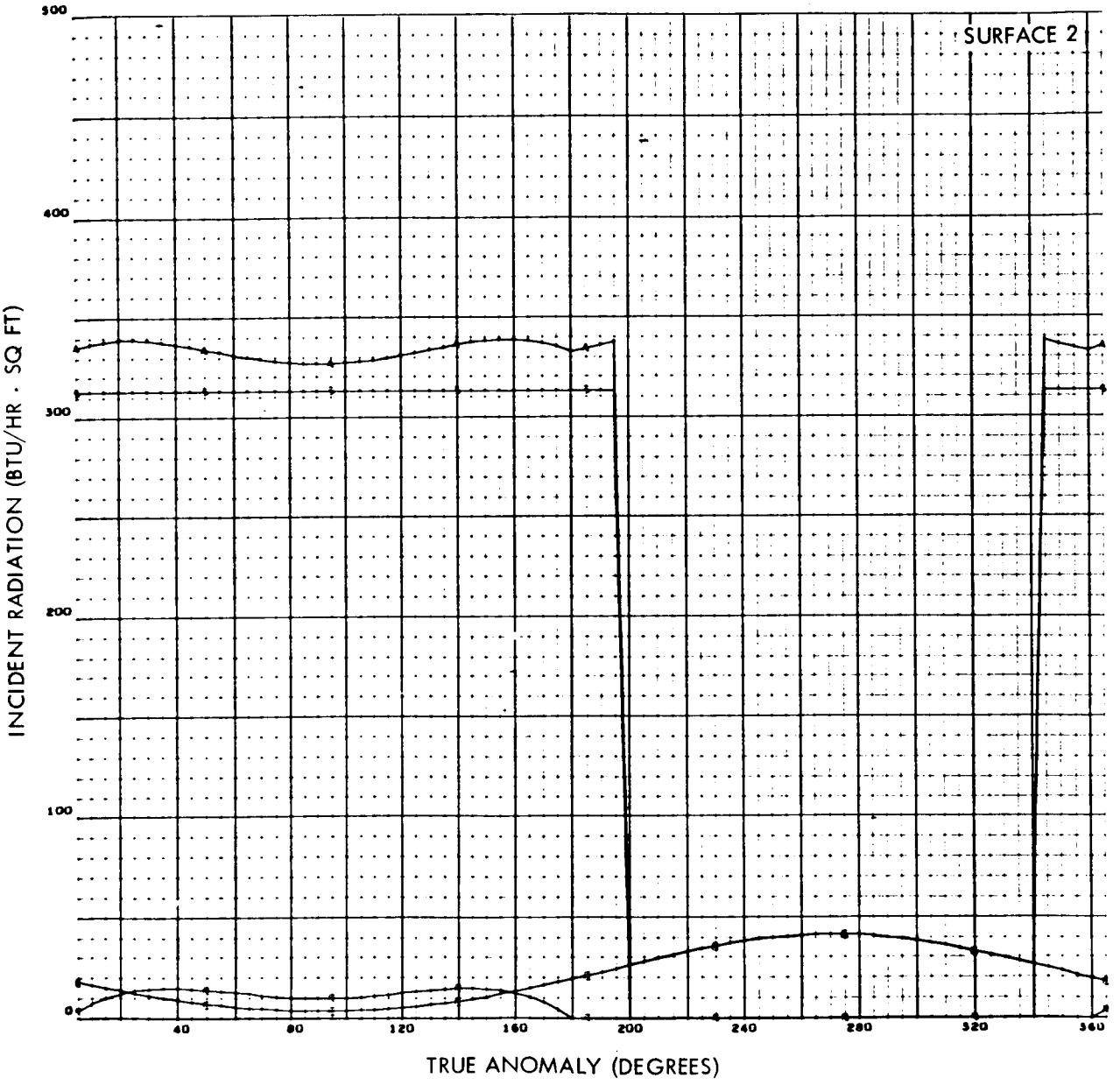
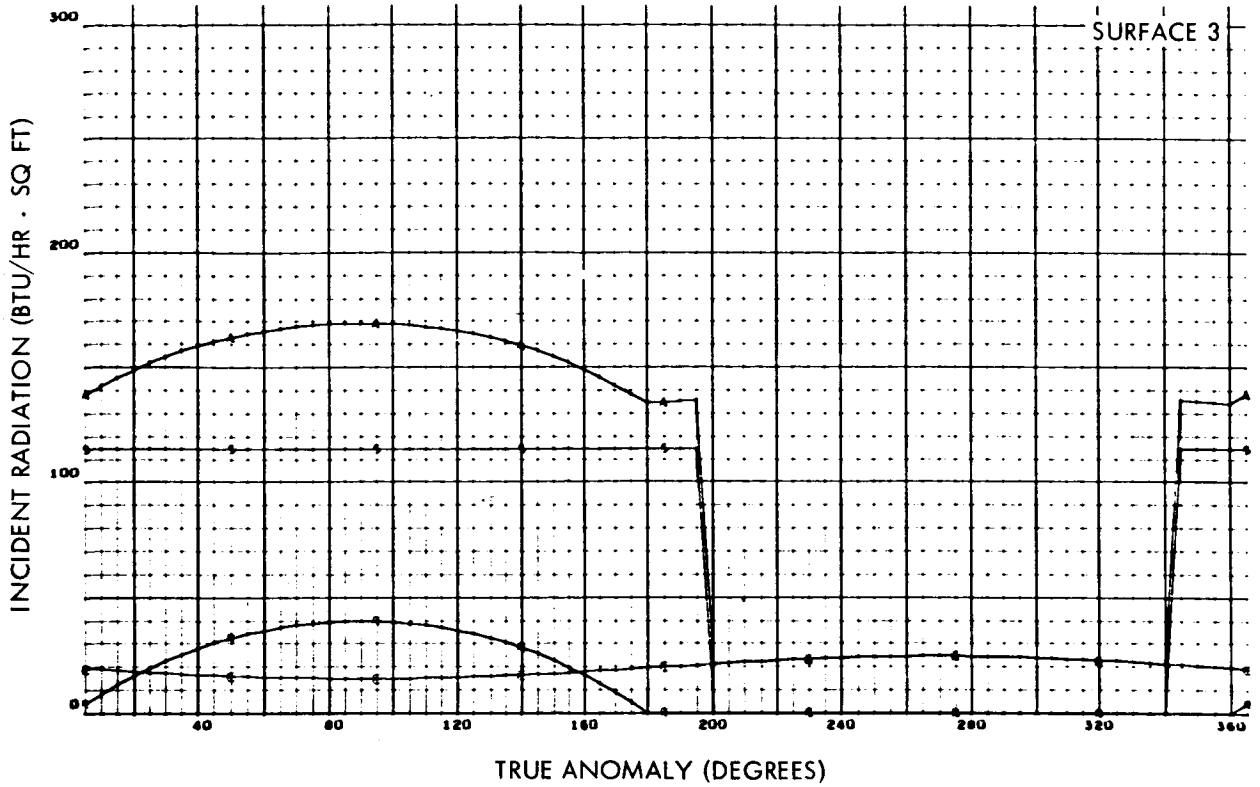


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 2 of 8)



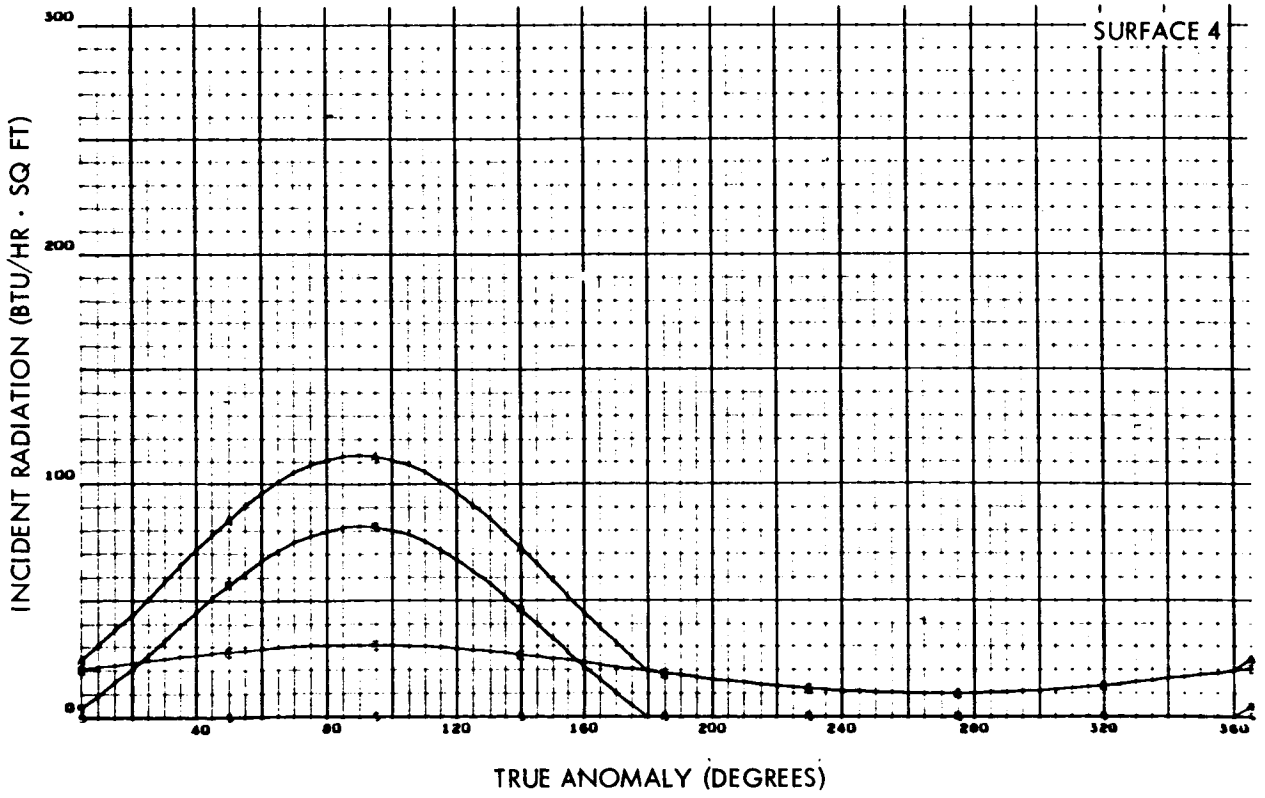
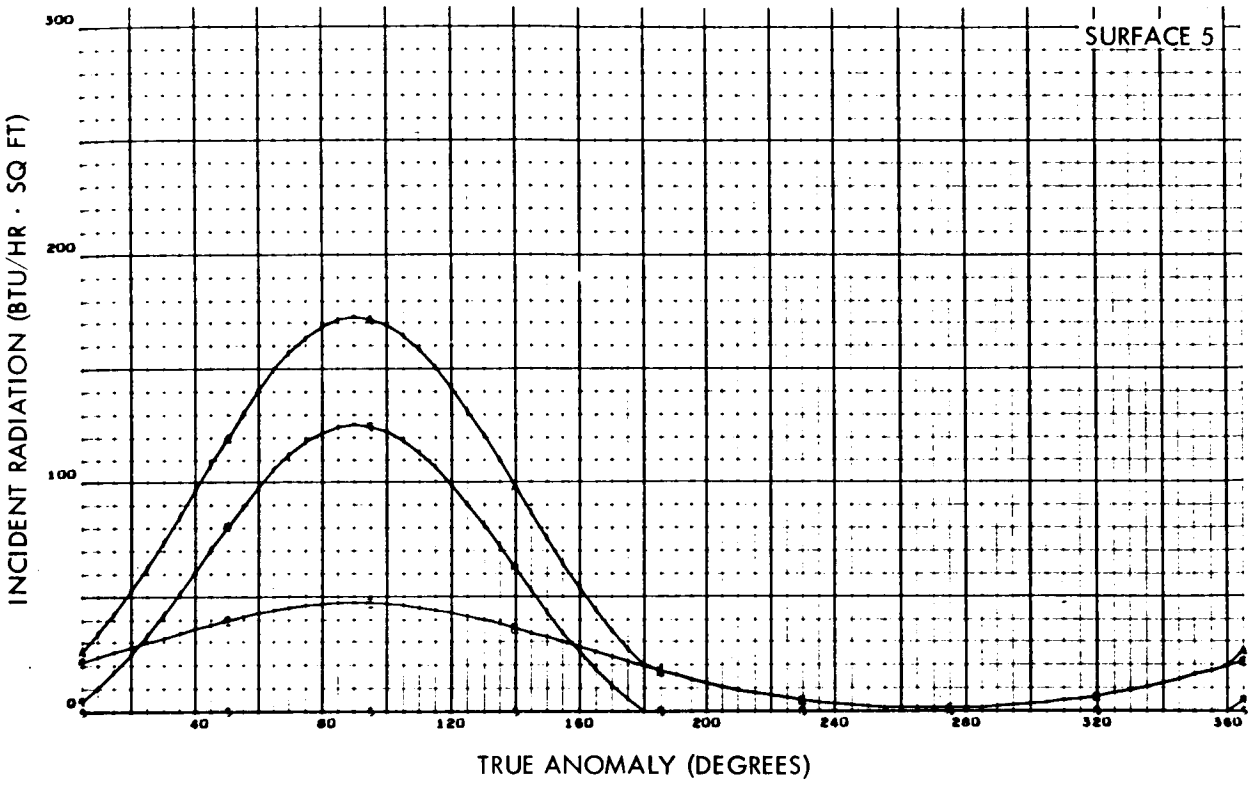


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 3 of 8)



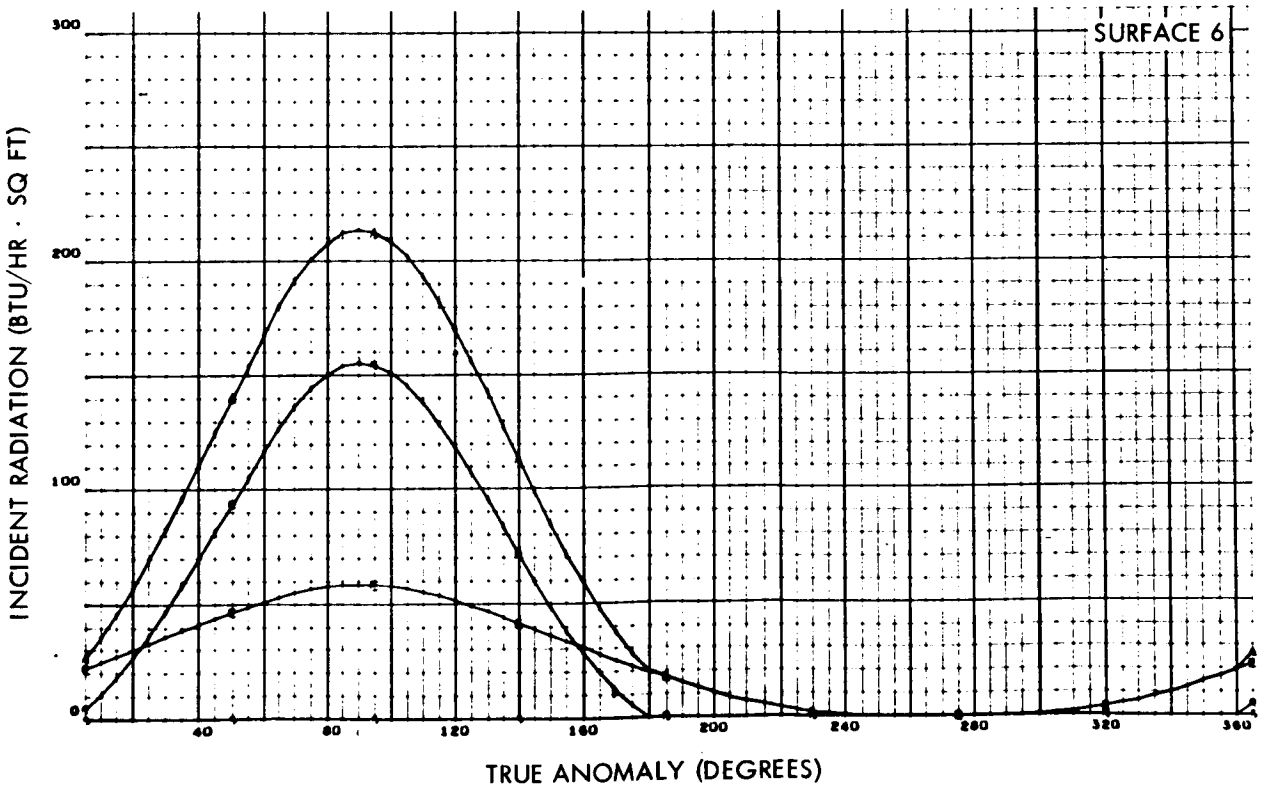
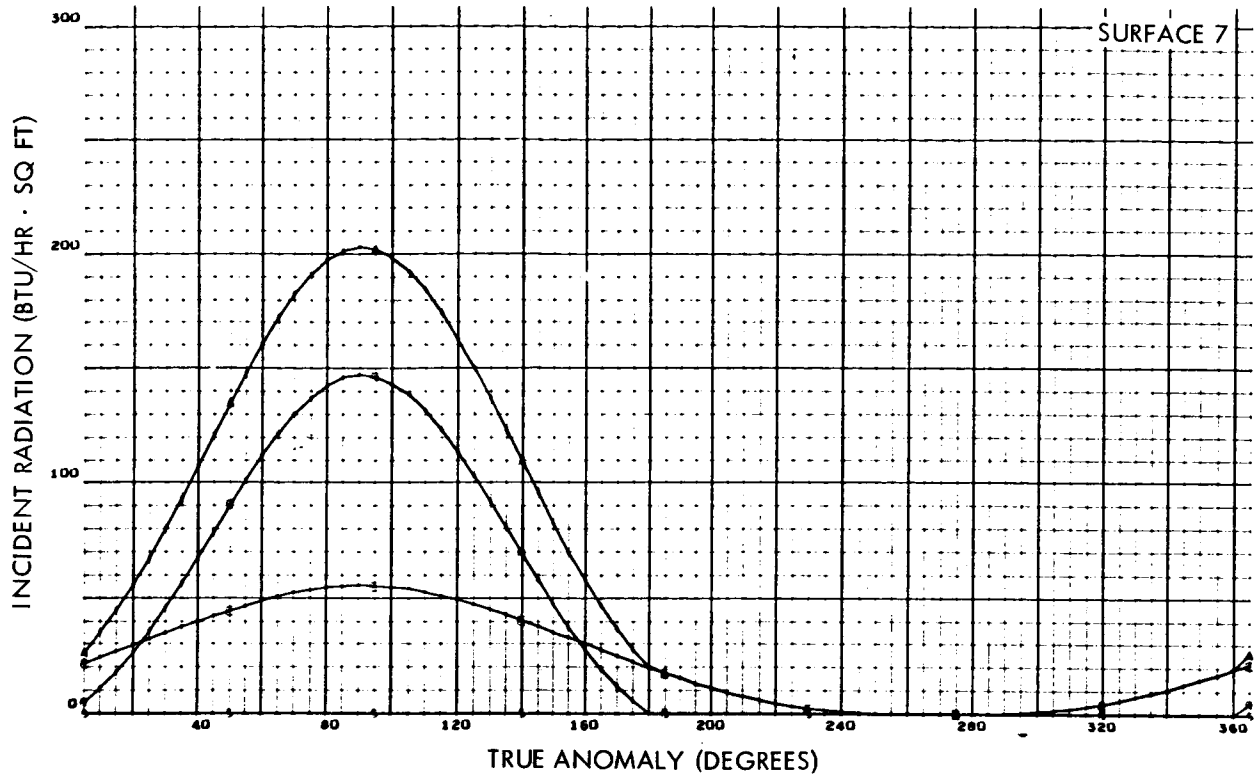


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 4 of 8)



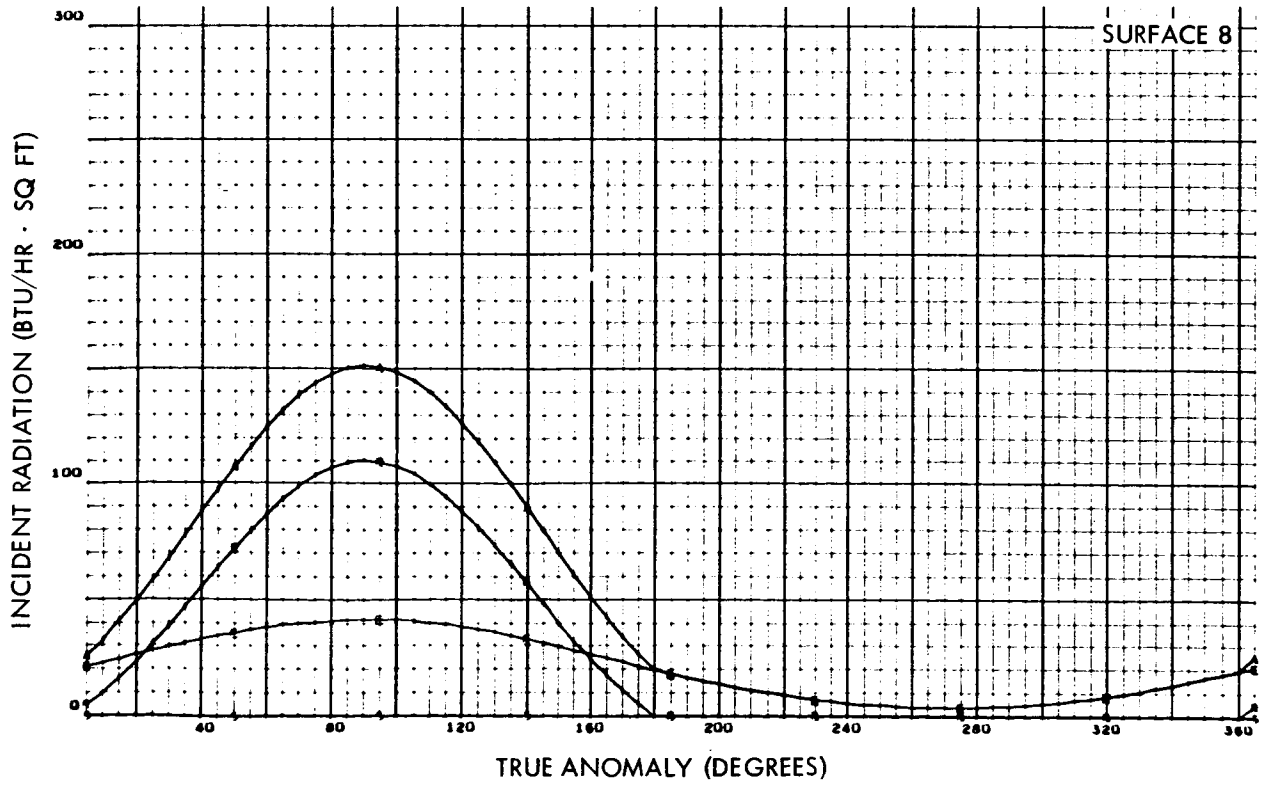
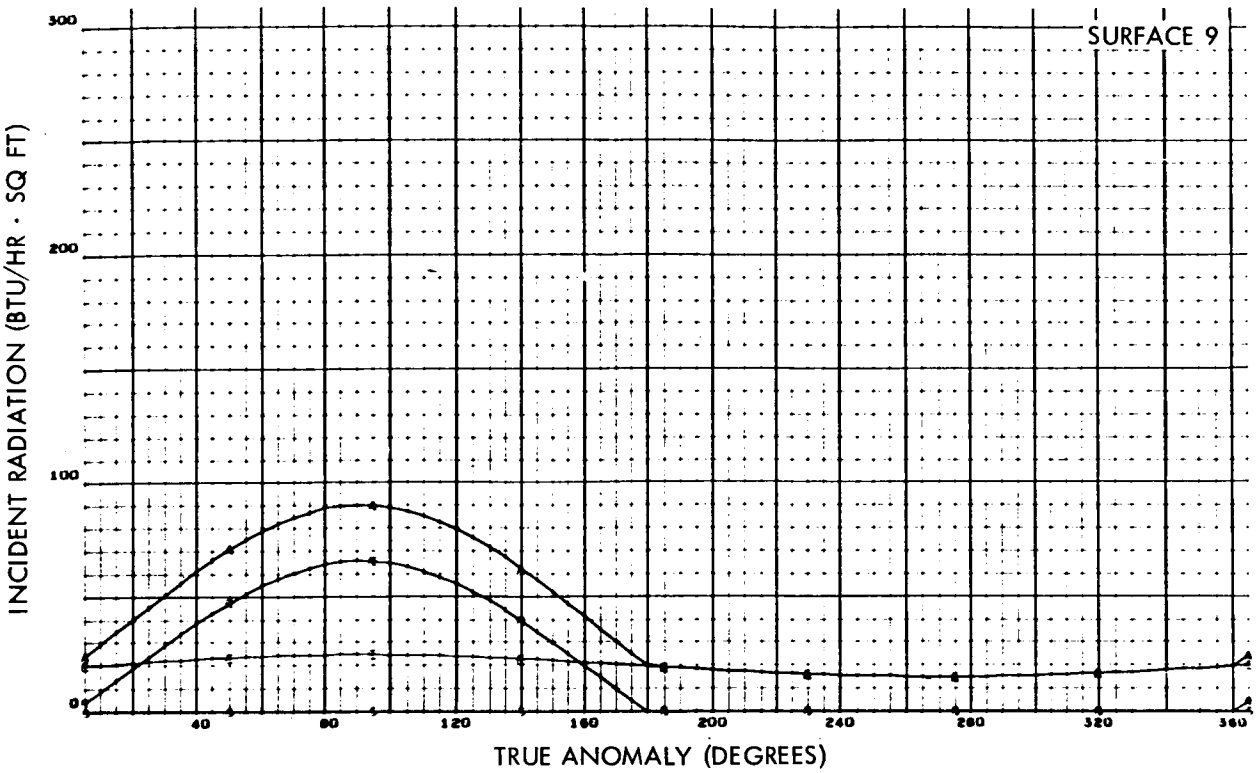


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 5 of 8)



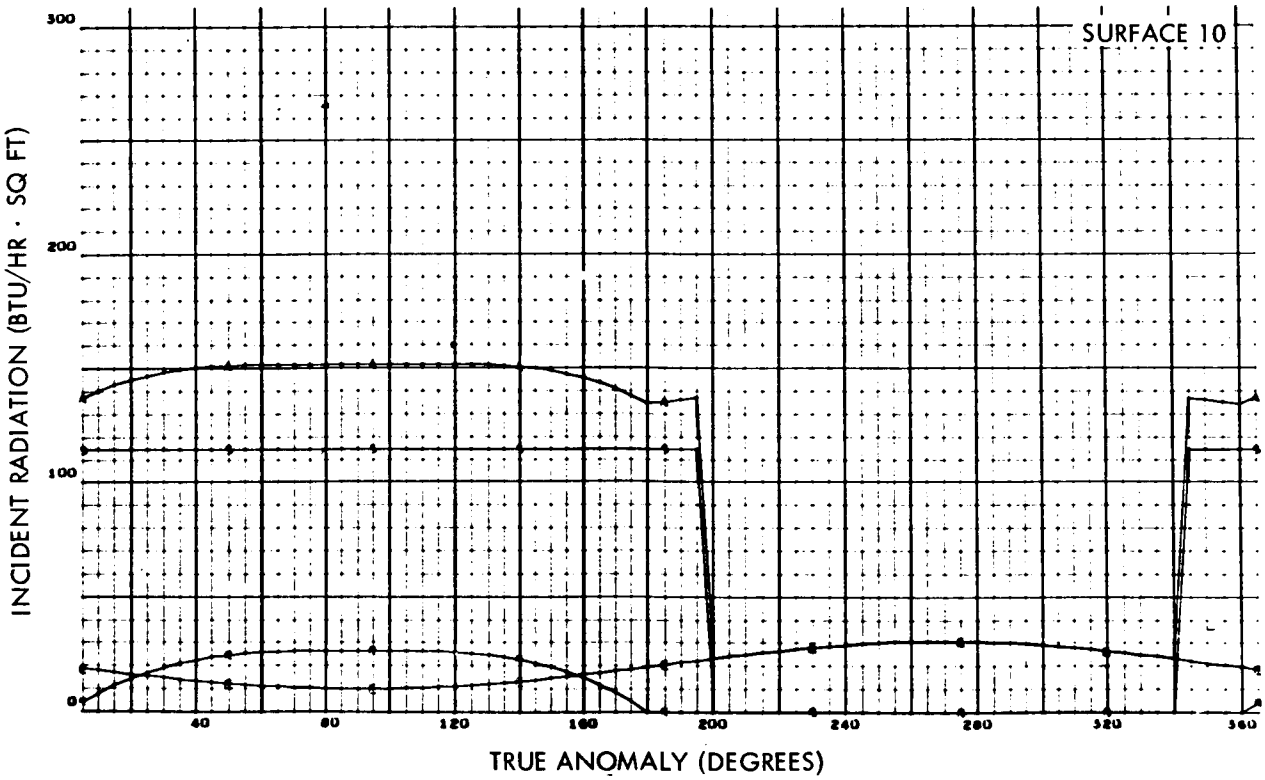


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 6 of 8)

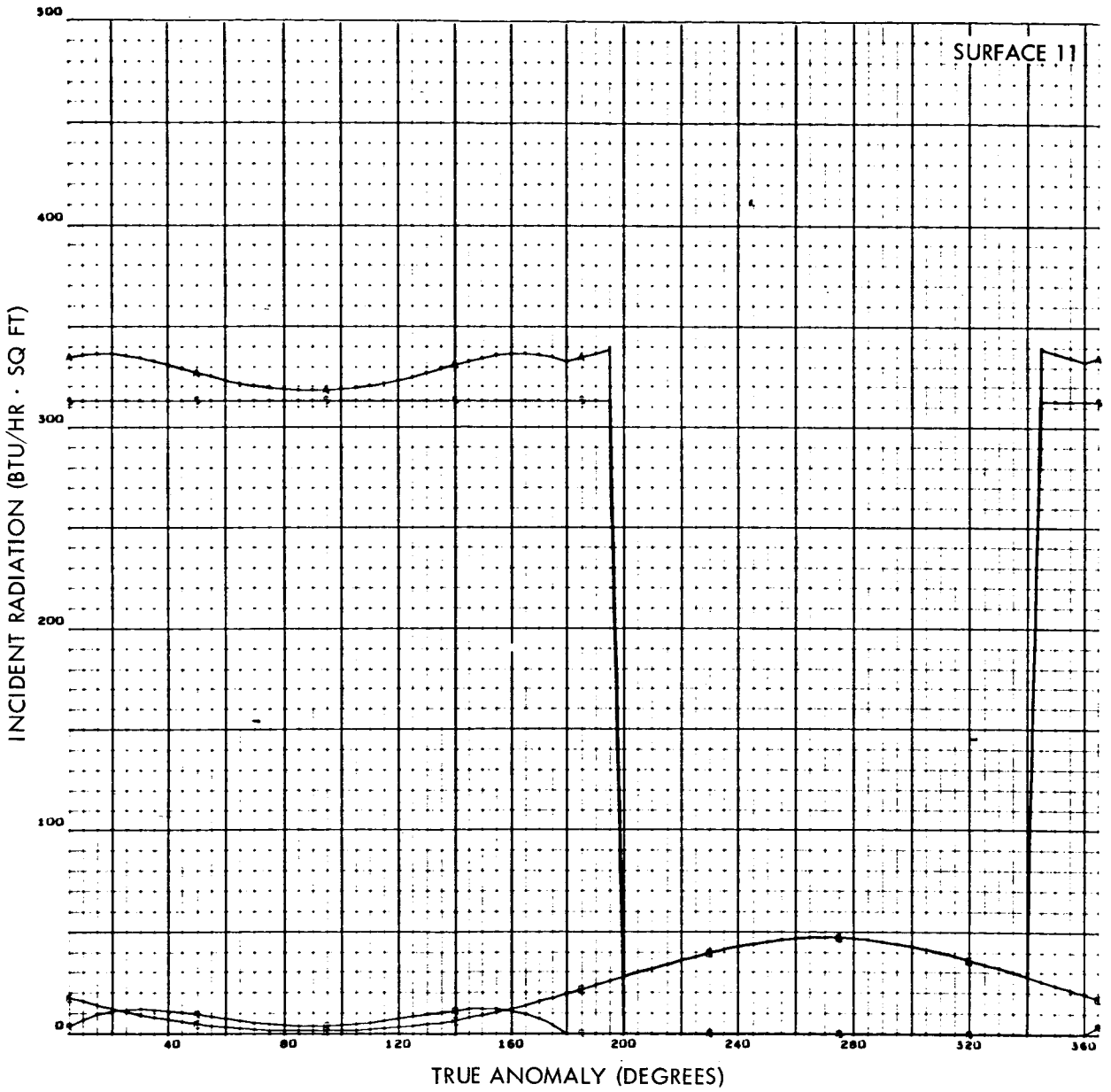


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 7 of 8)

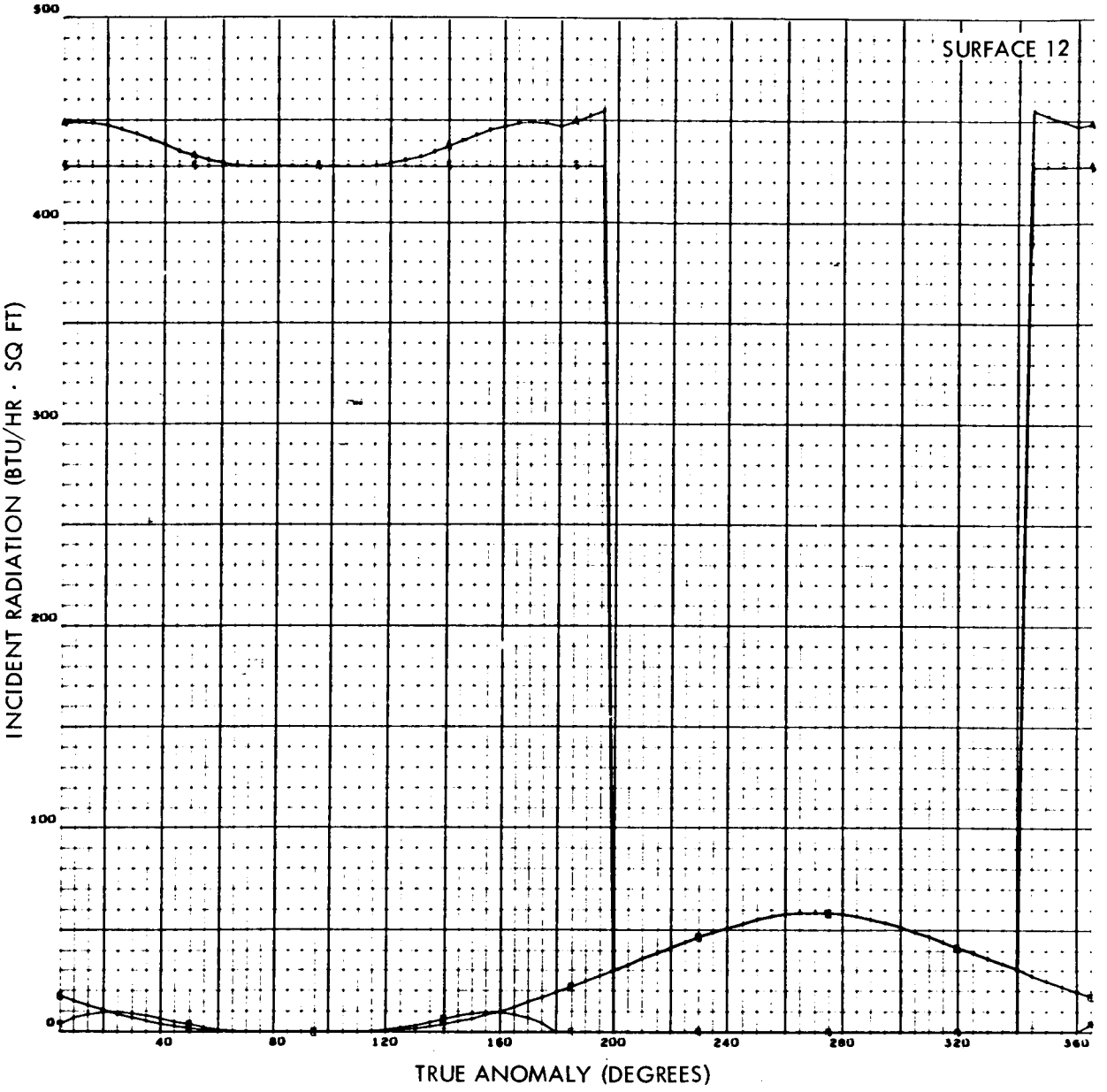


Figure IU-1c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 8 of 8)

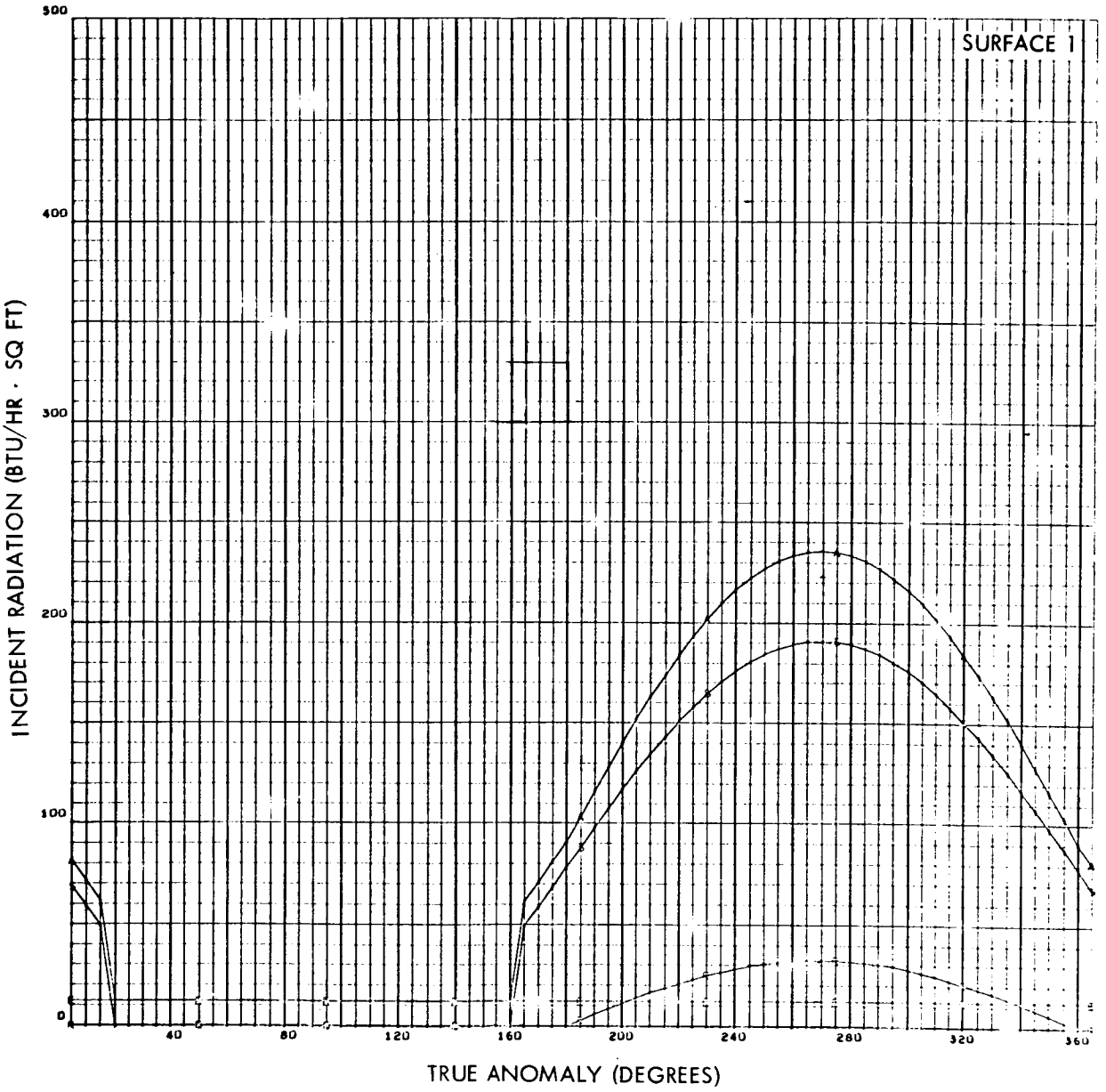


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 1 of 8)

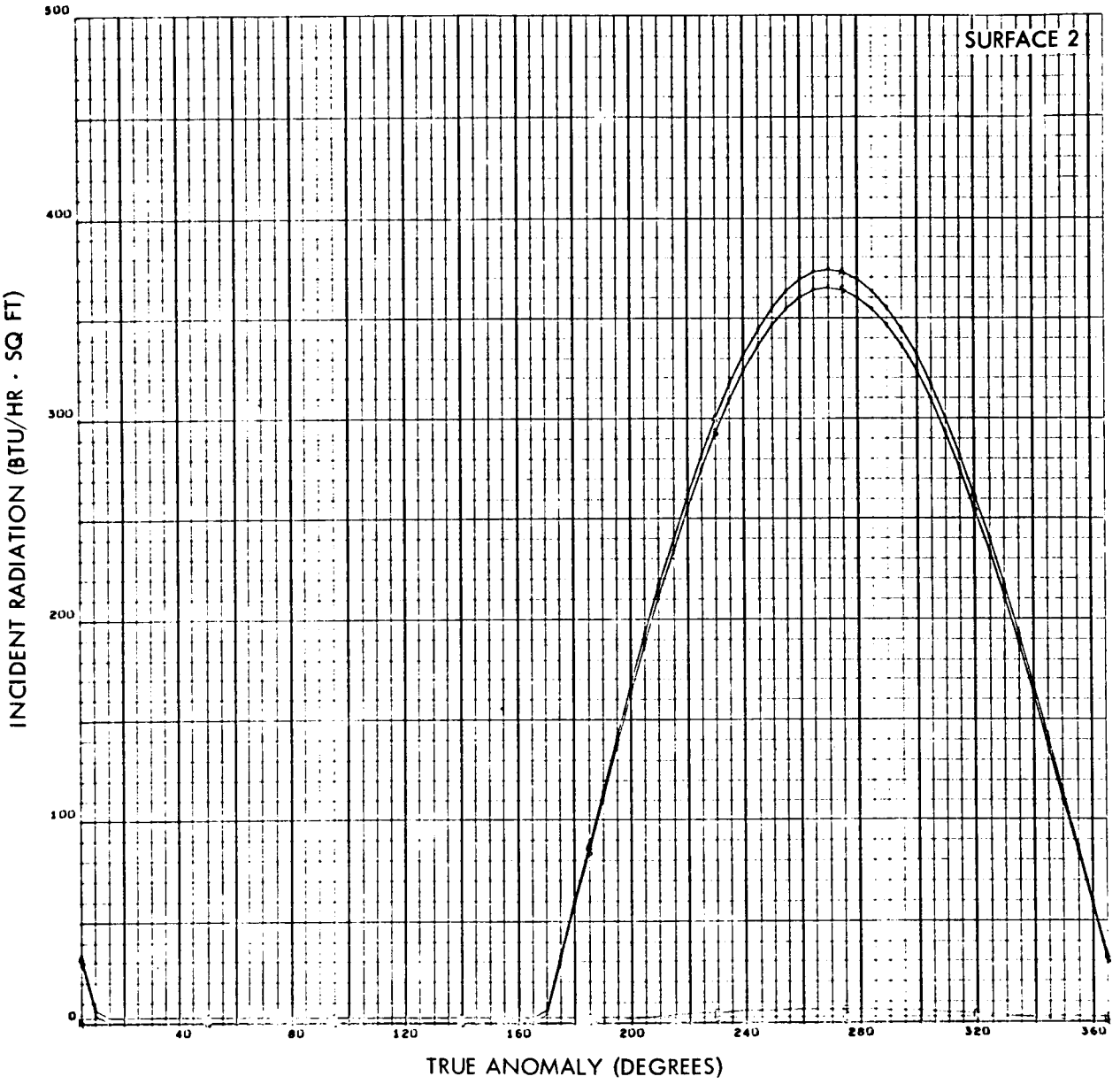


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 2 of 8)

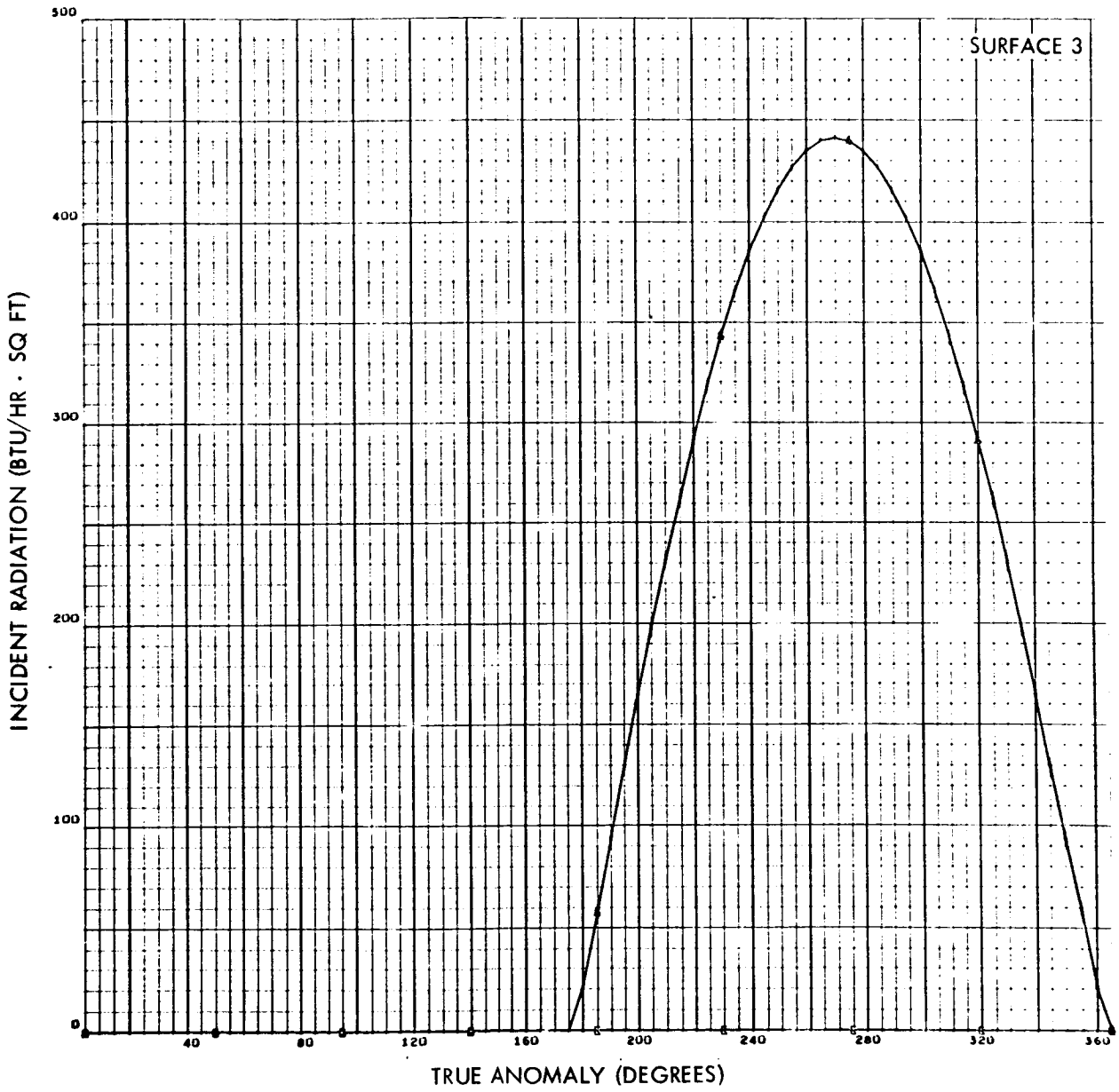


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 3 of 8)

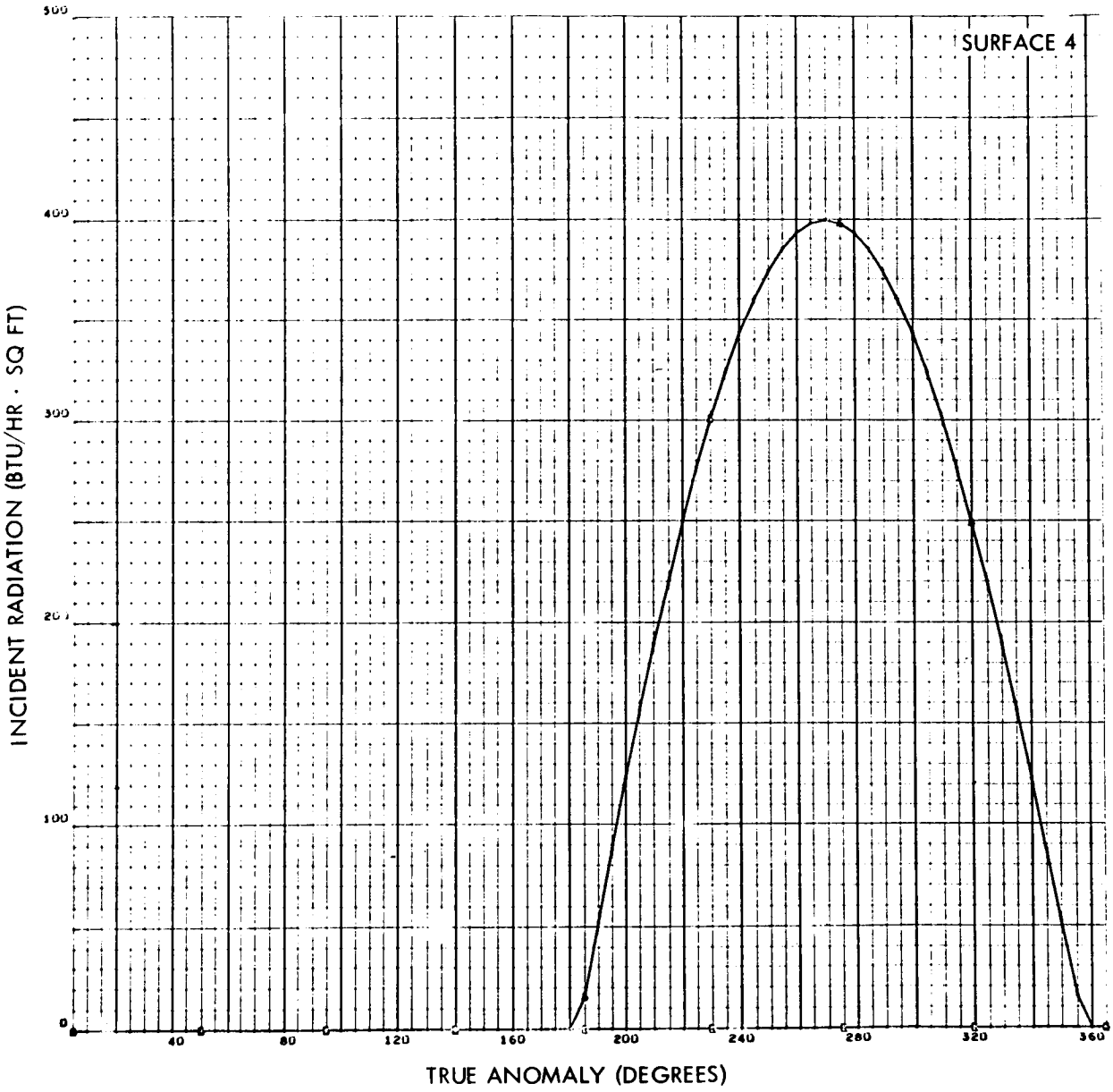
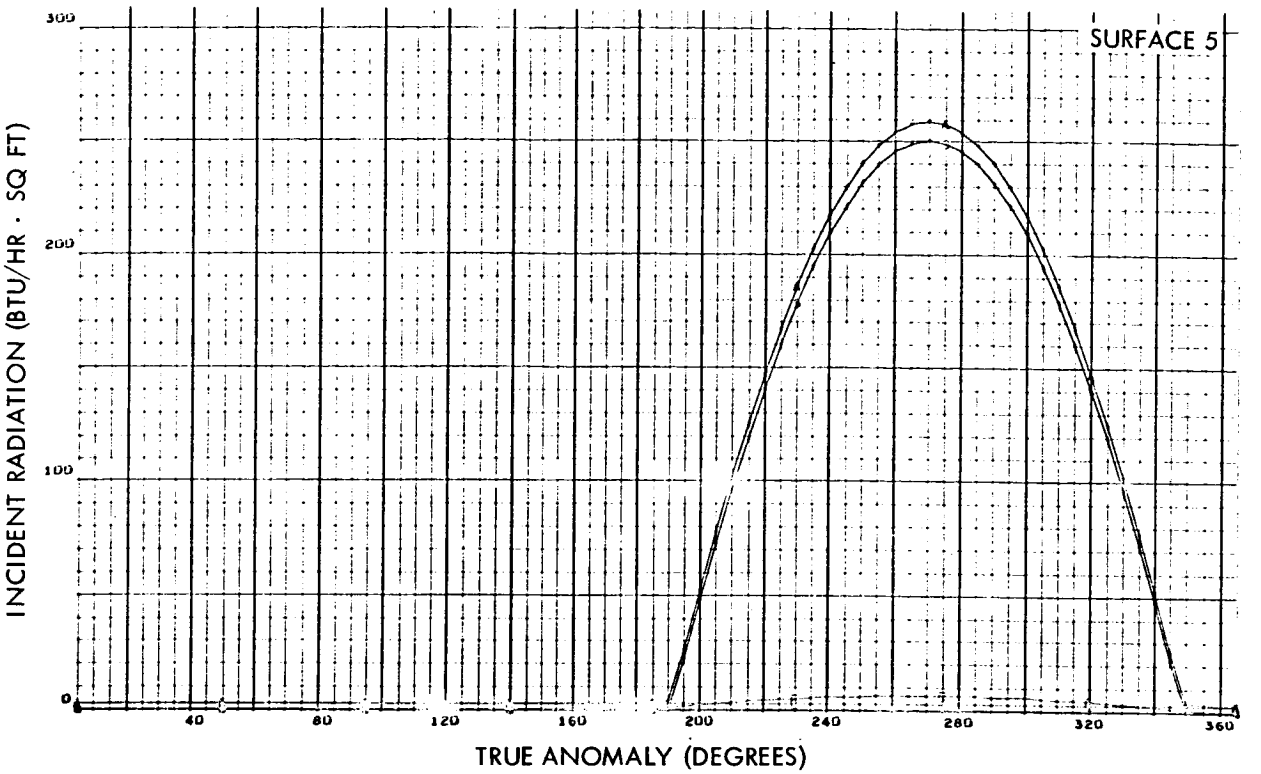


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 4 of 8)



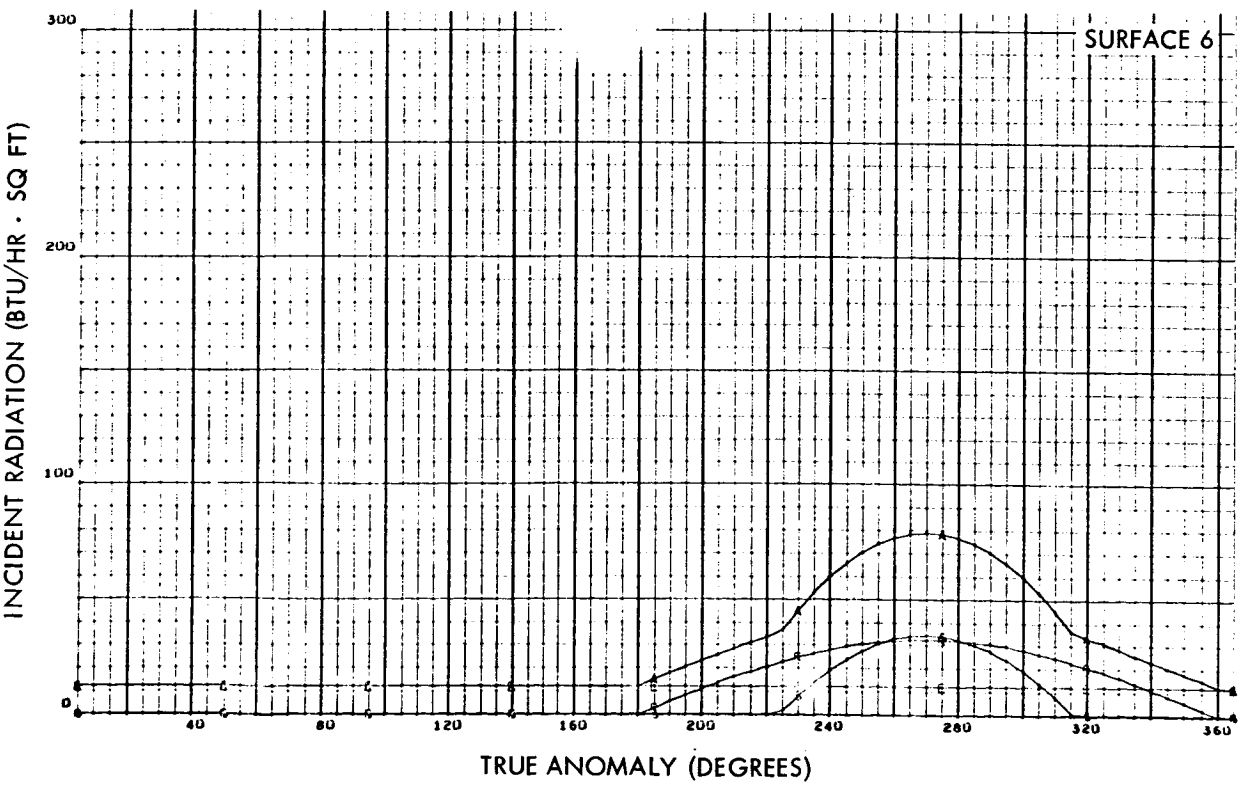
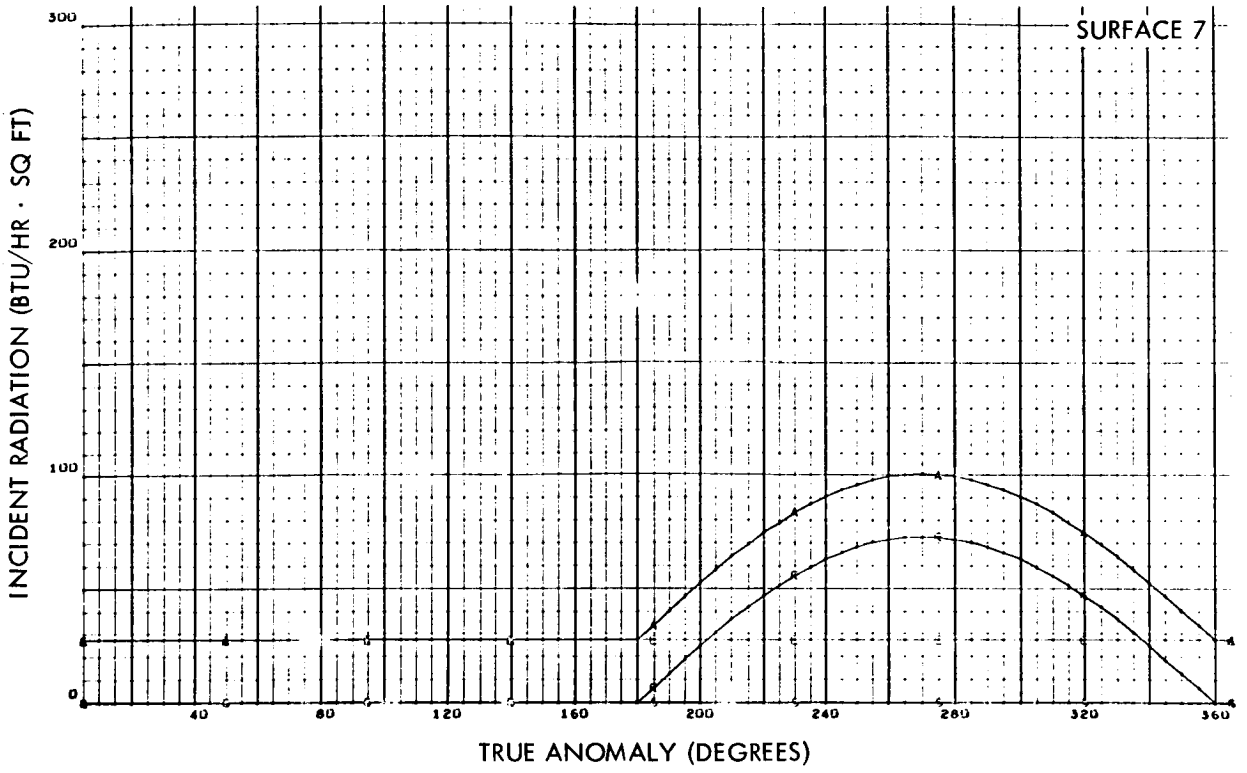


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 5 of 8)



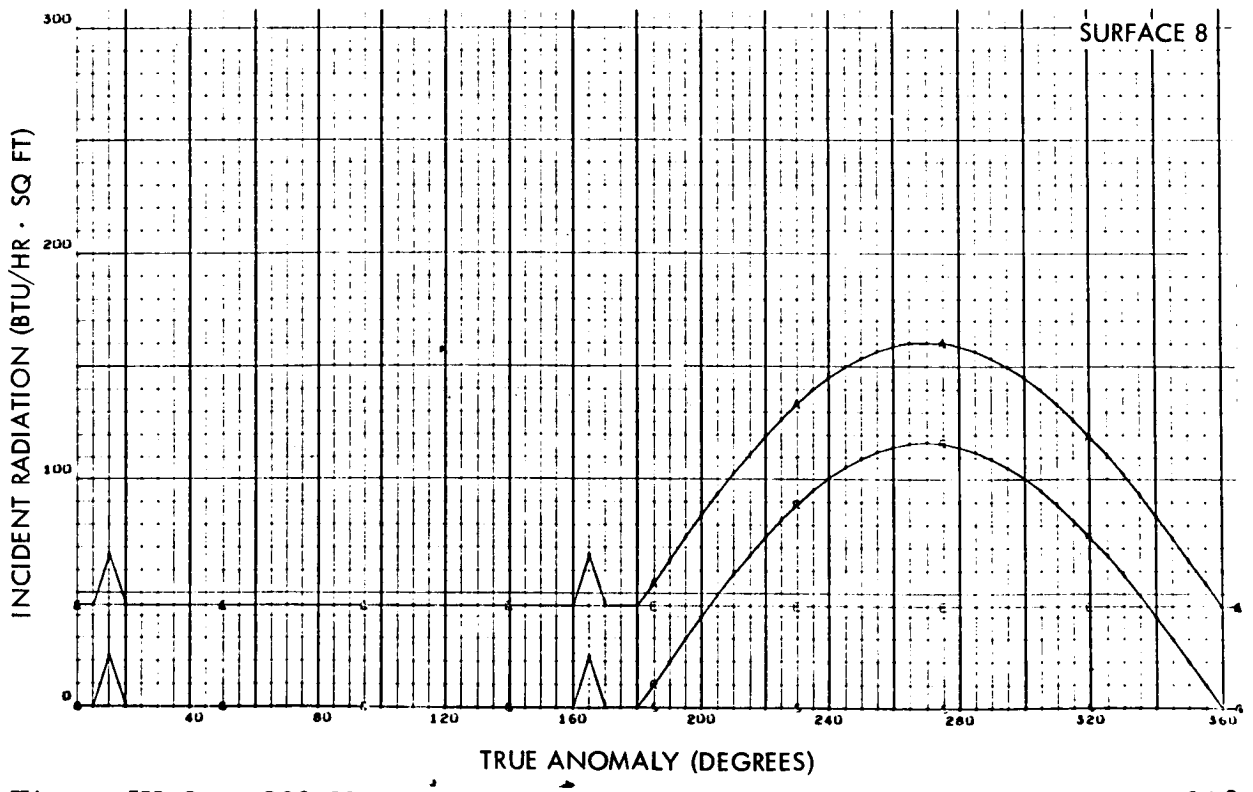
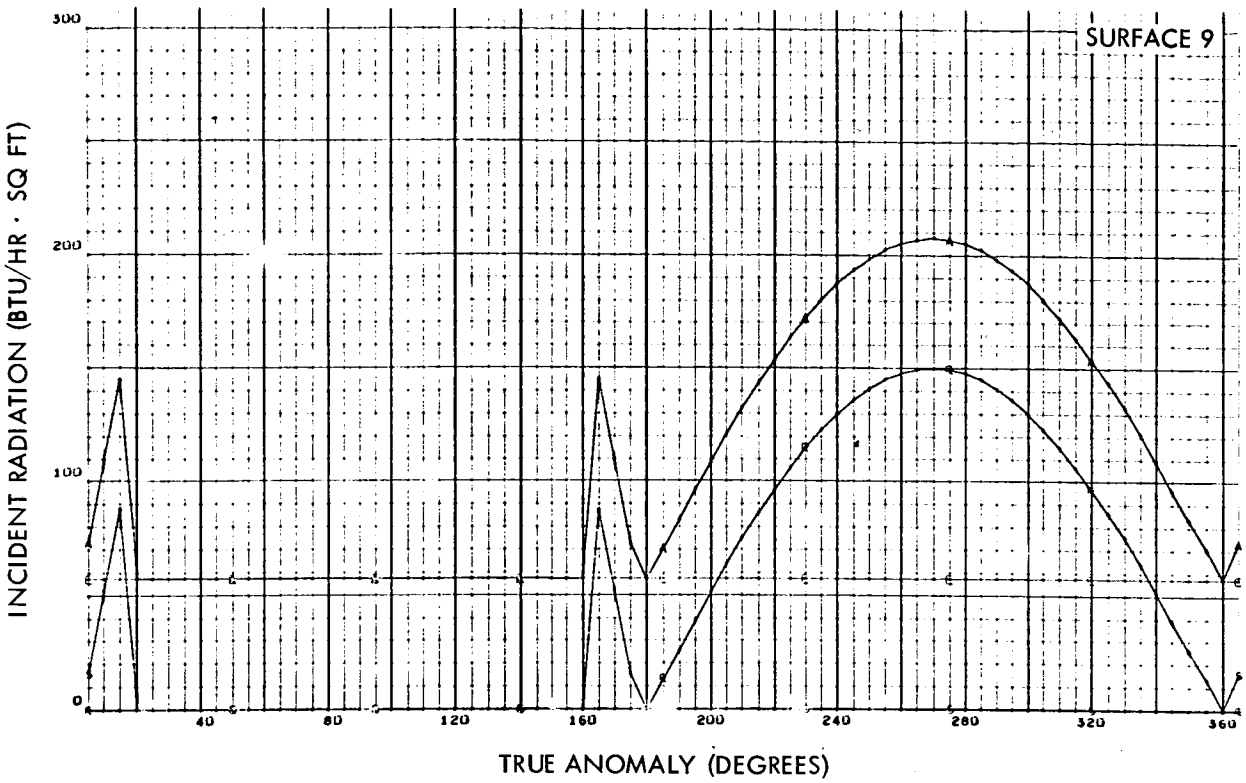


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 6 of 8)



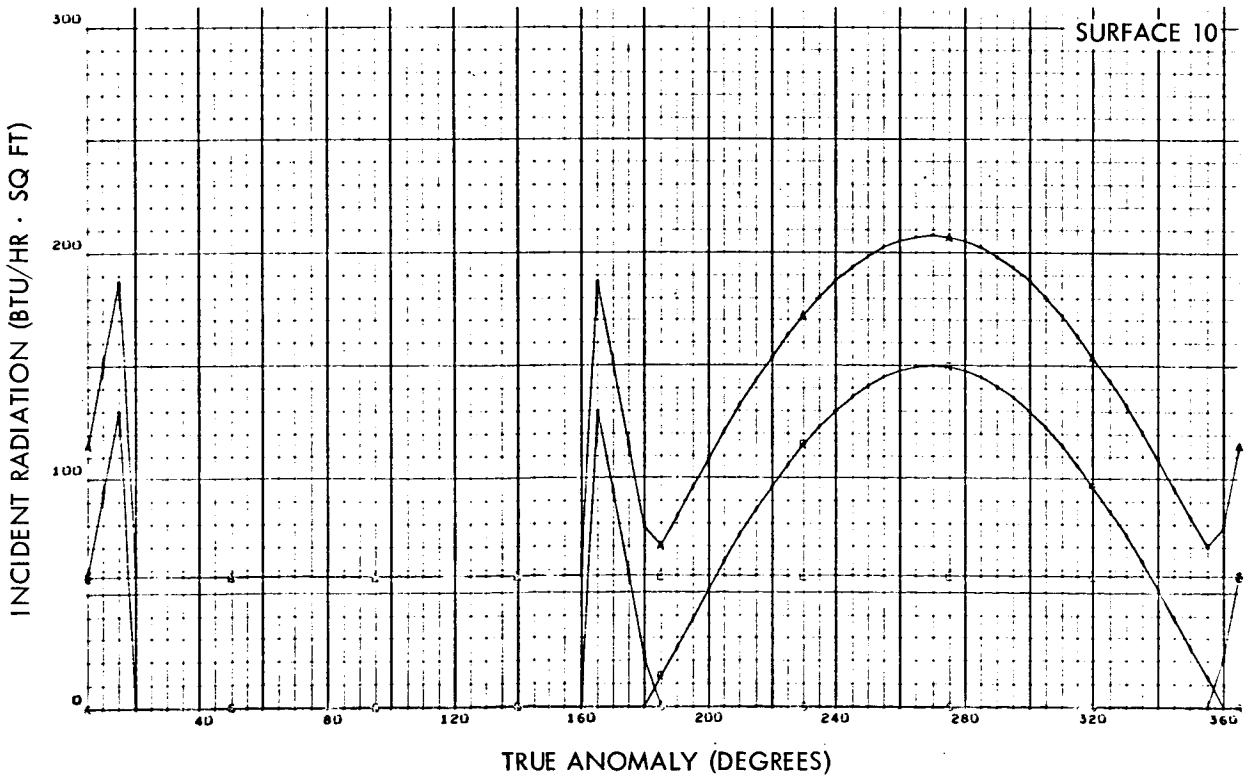
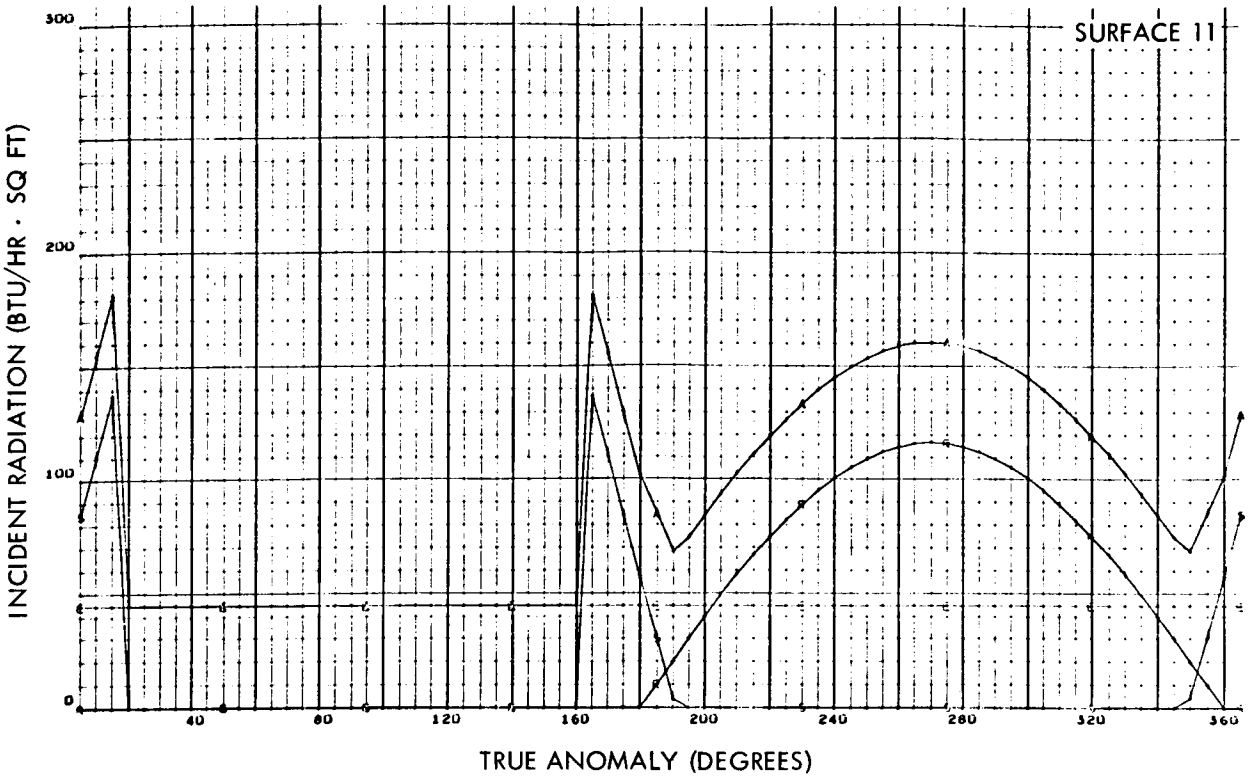


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 7 of 8)



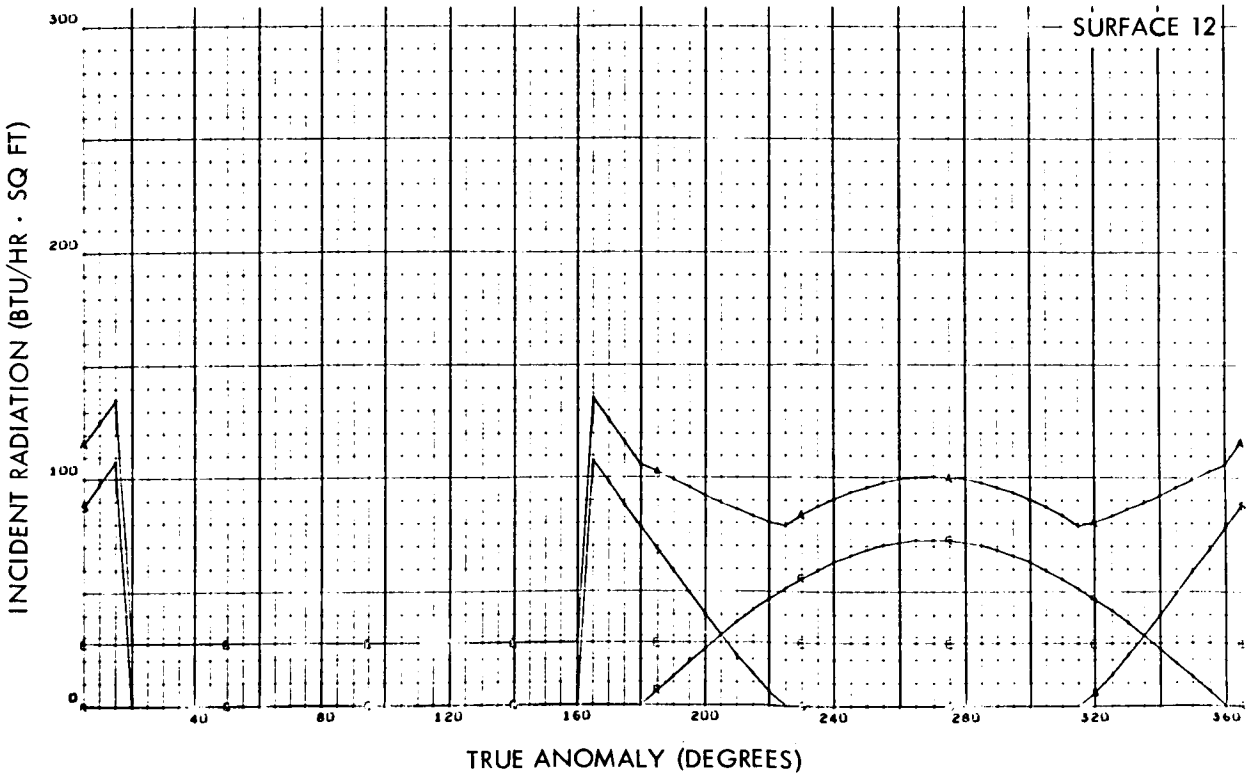


Figure IU-2a. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 8 of 8)

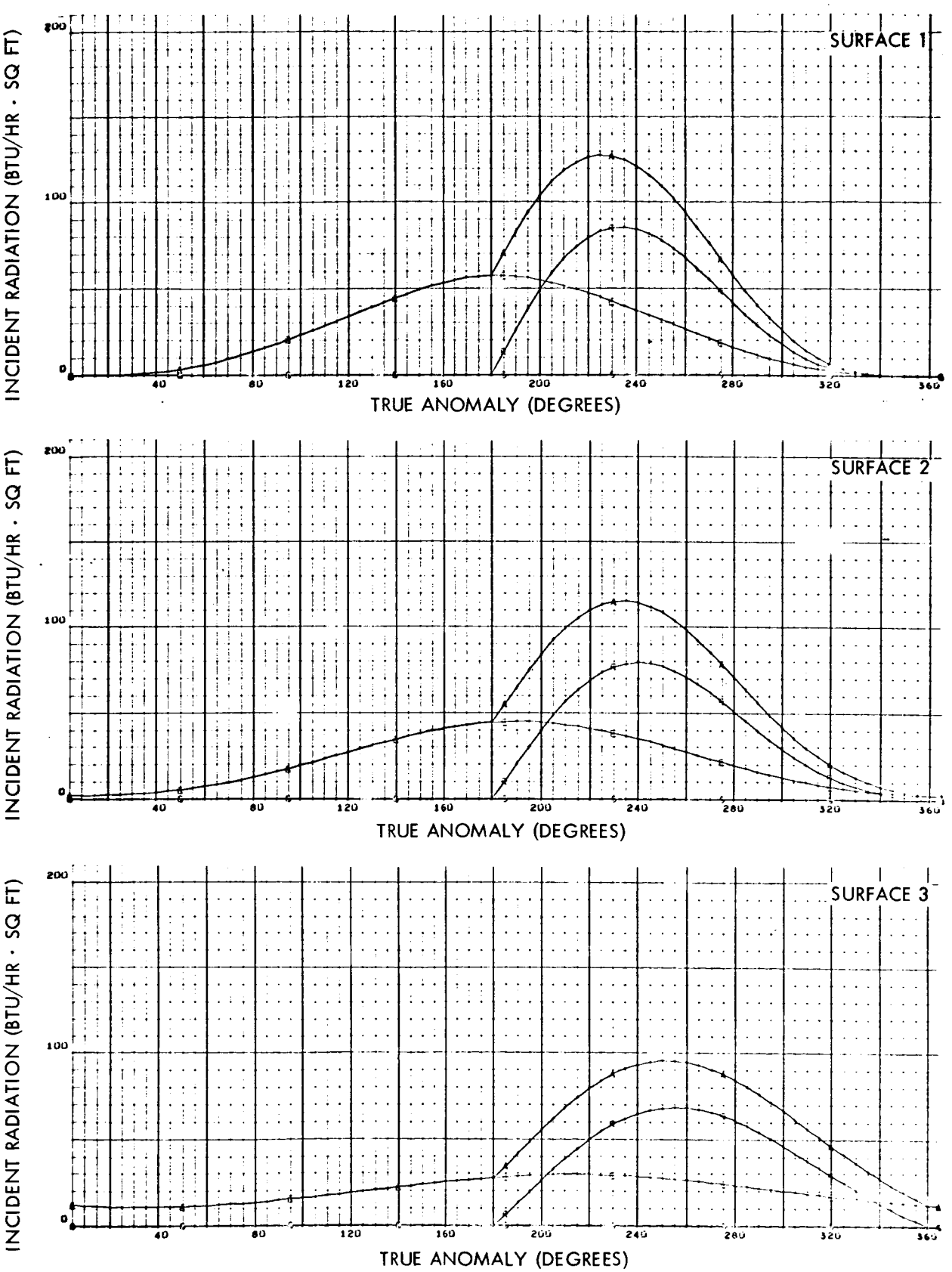


Figure IU-2b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 1 of 4)

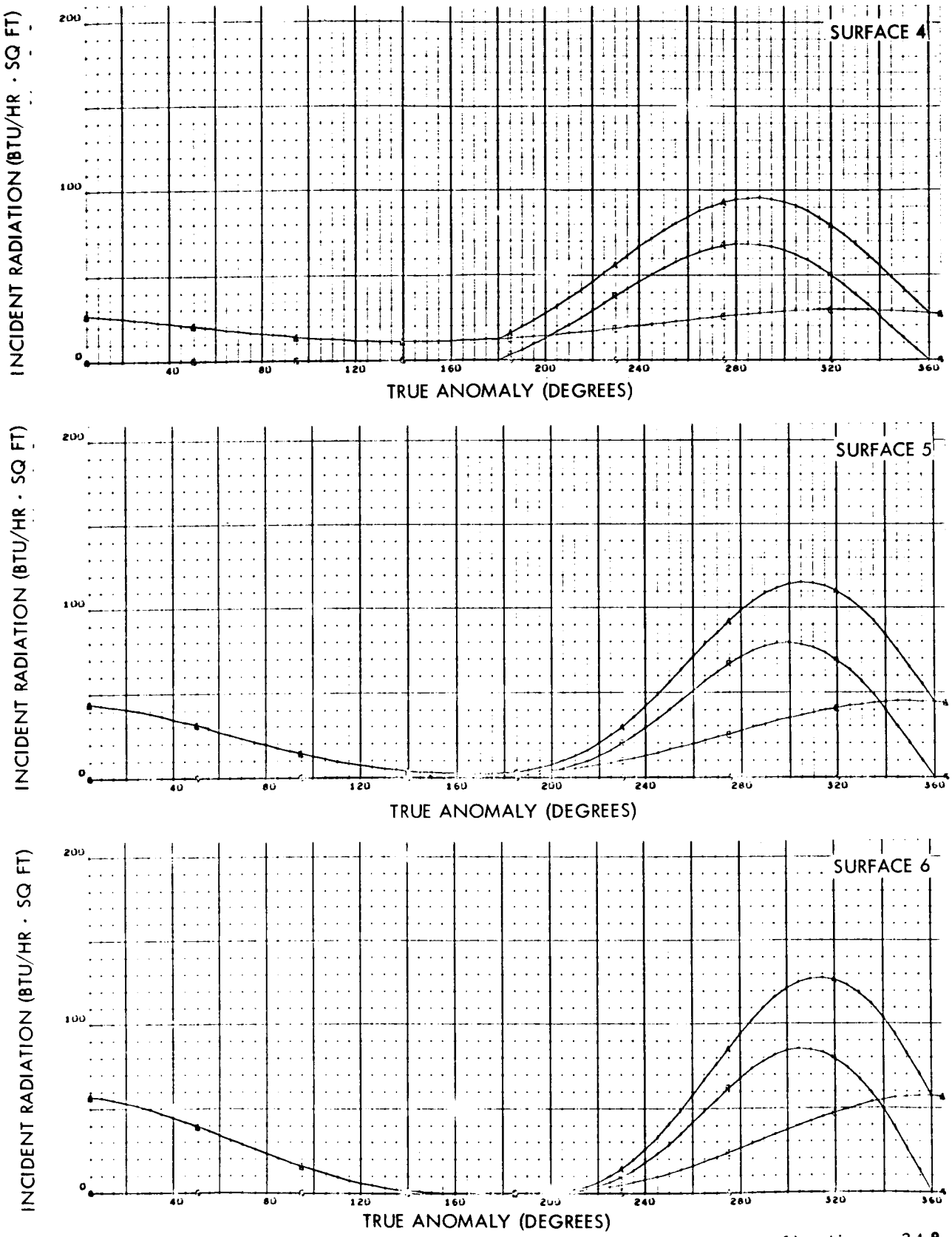


Figure IU-2b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 2 of 4)

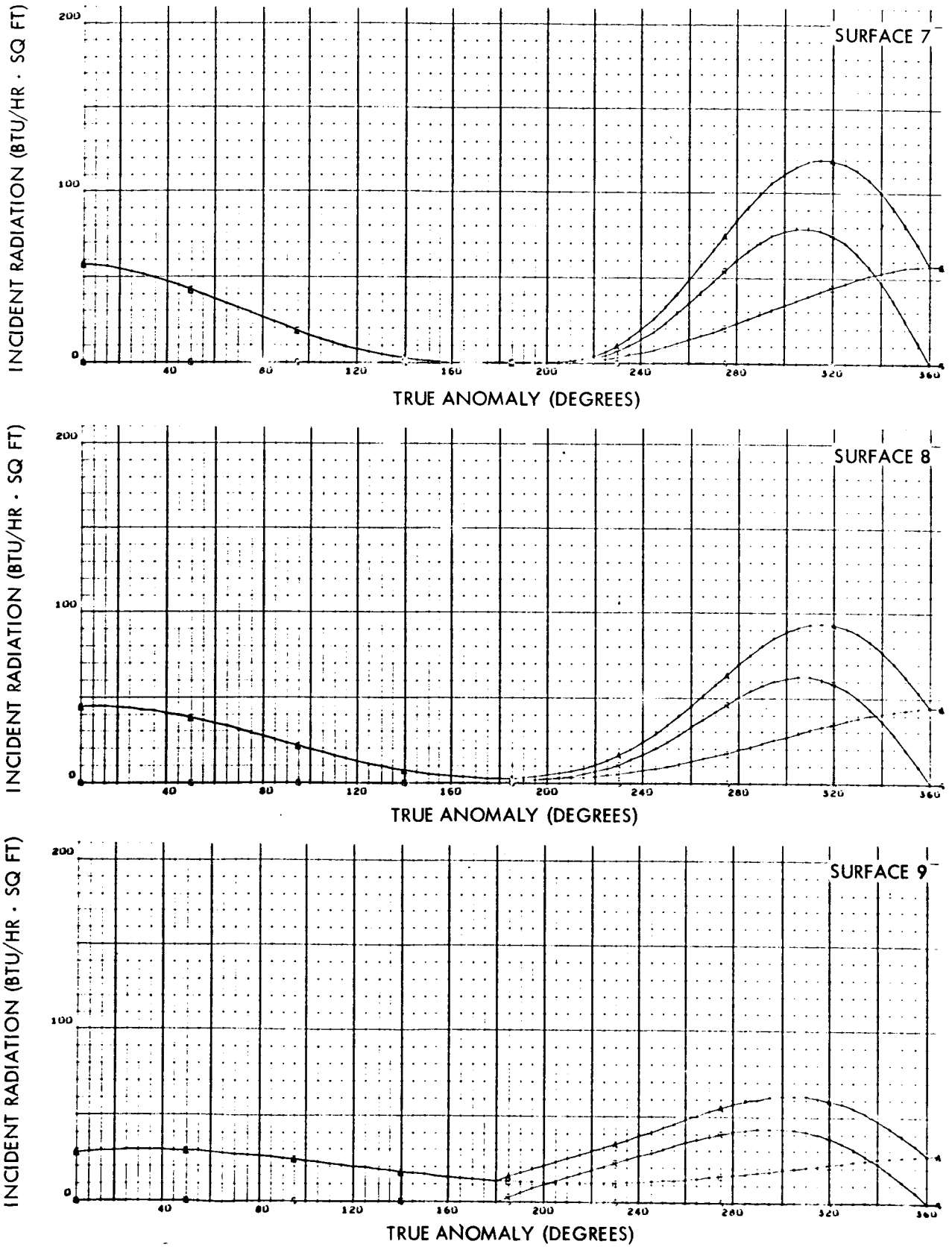


Figure IU-2b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 3 of 4)

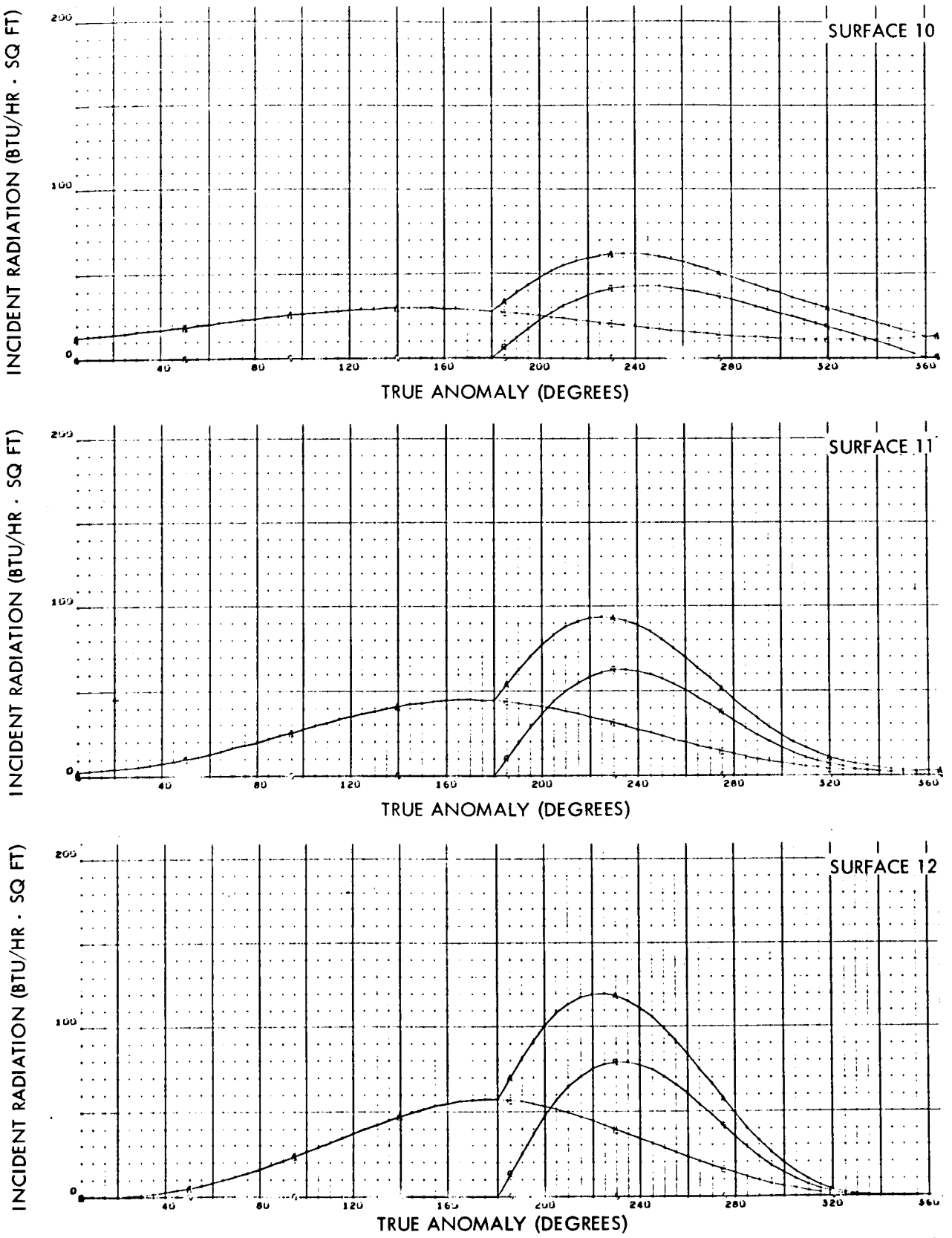


Figure IU-2b. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 4 of 4)

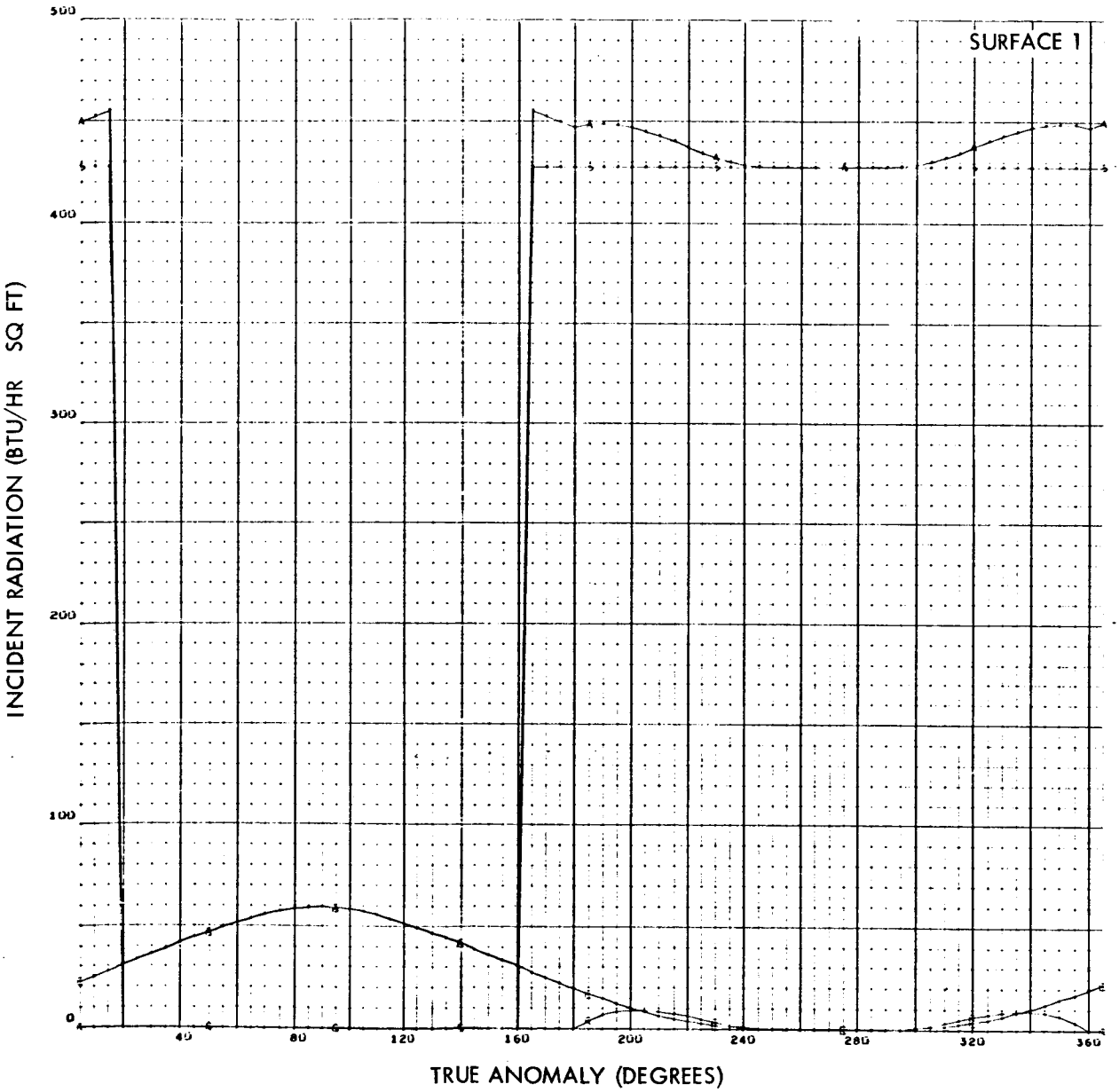


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 1 of 8)

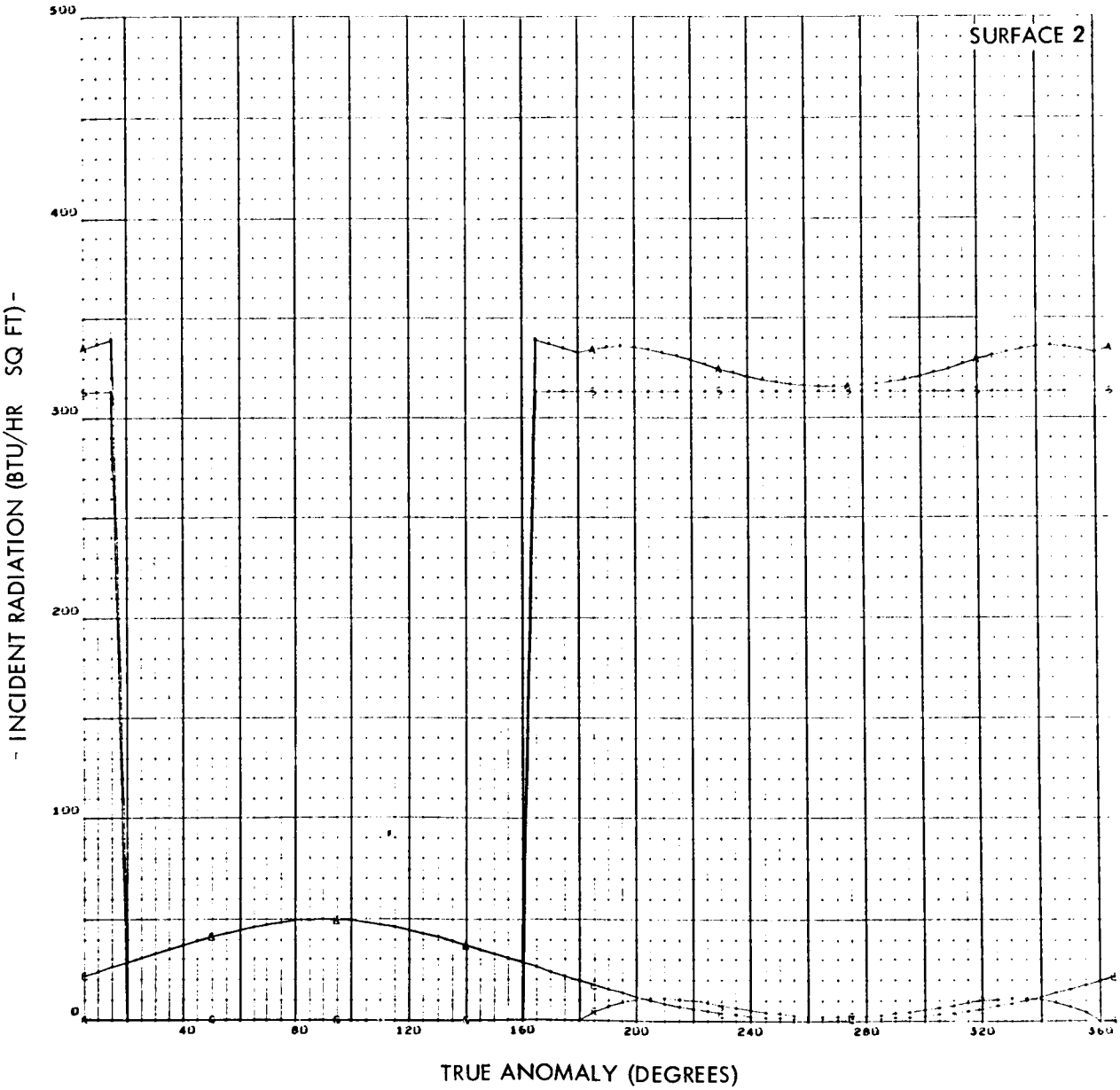
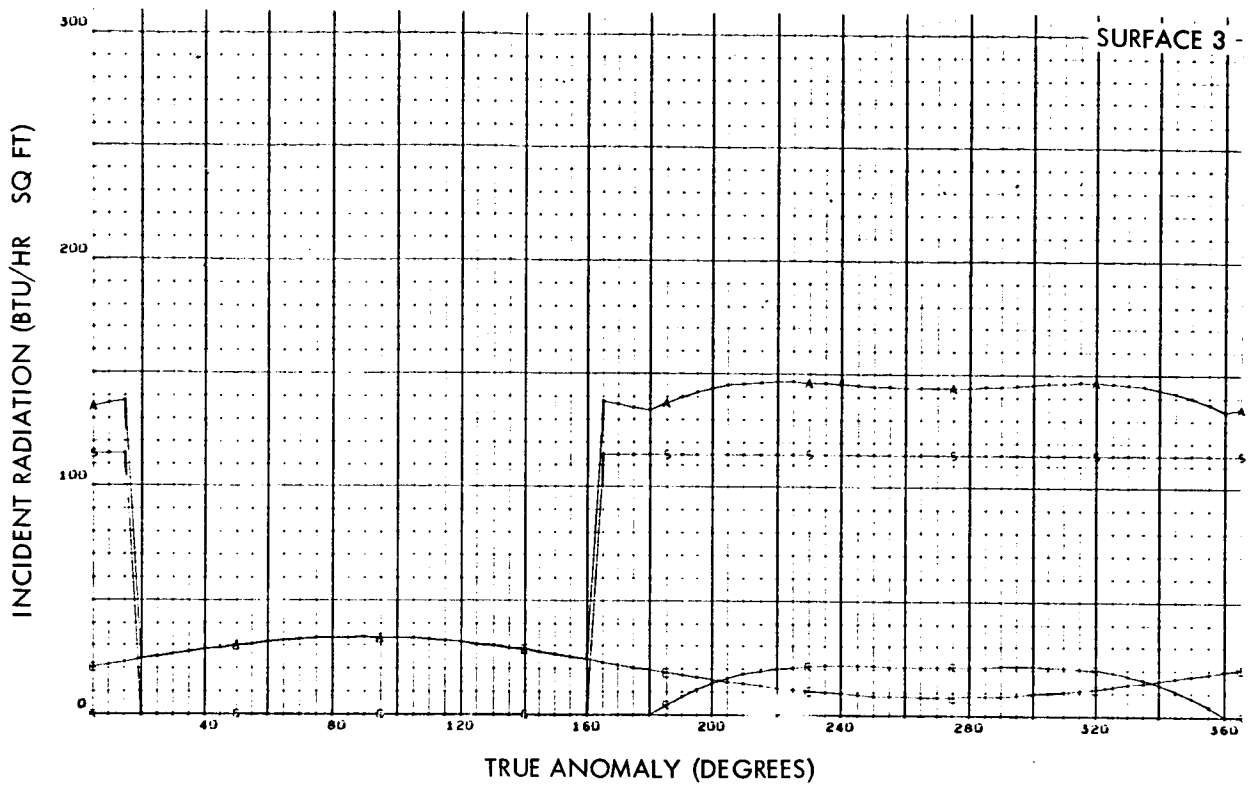


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 2 of 8)



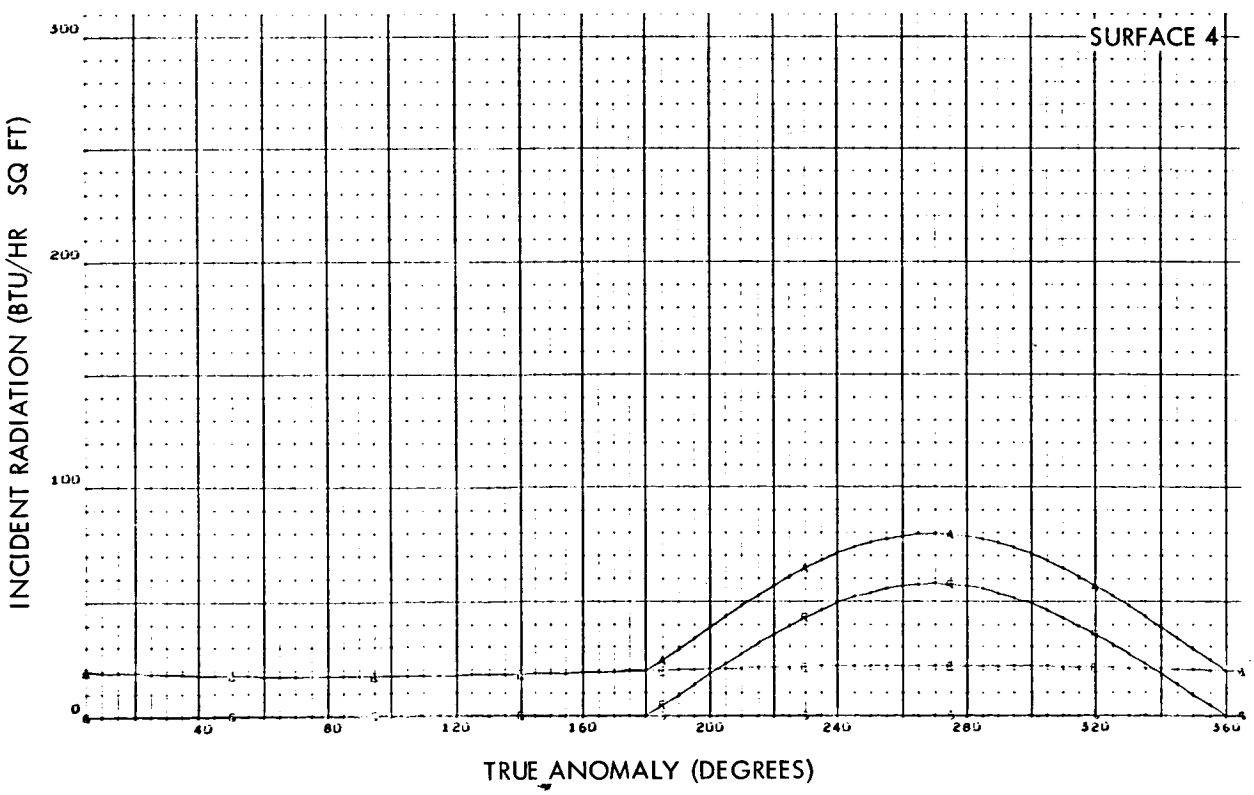
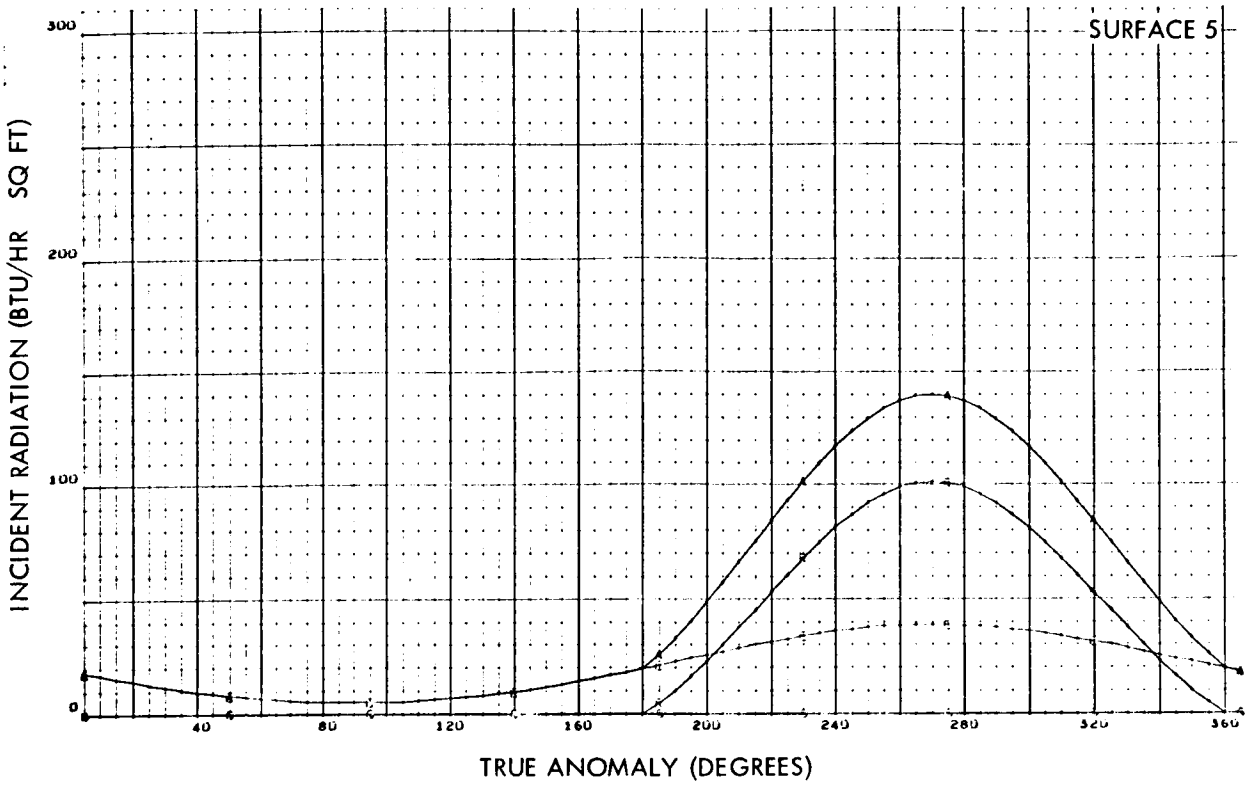


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 3 of 8)



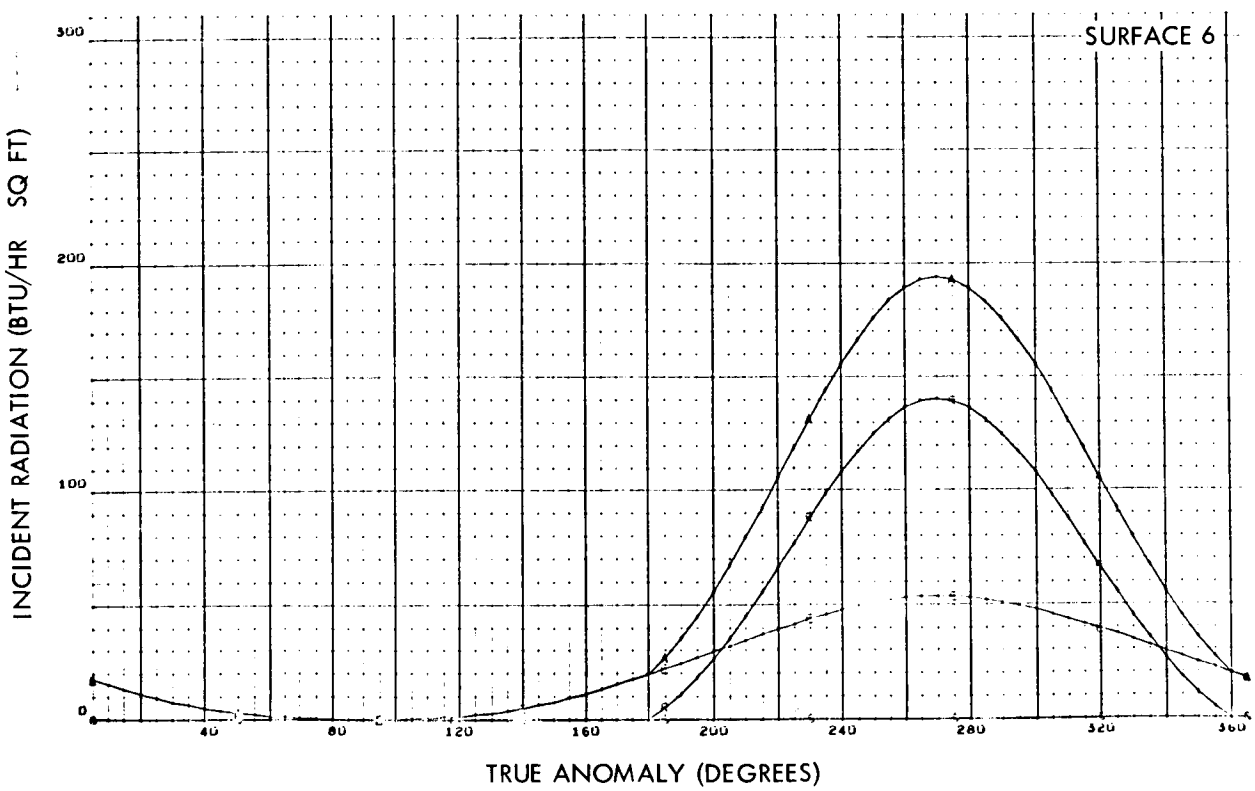
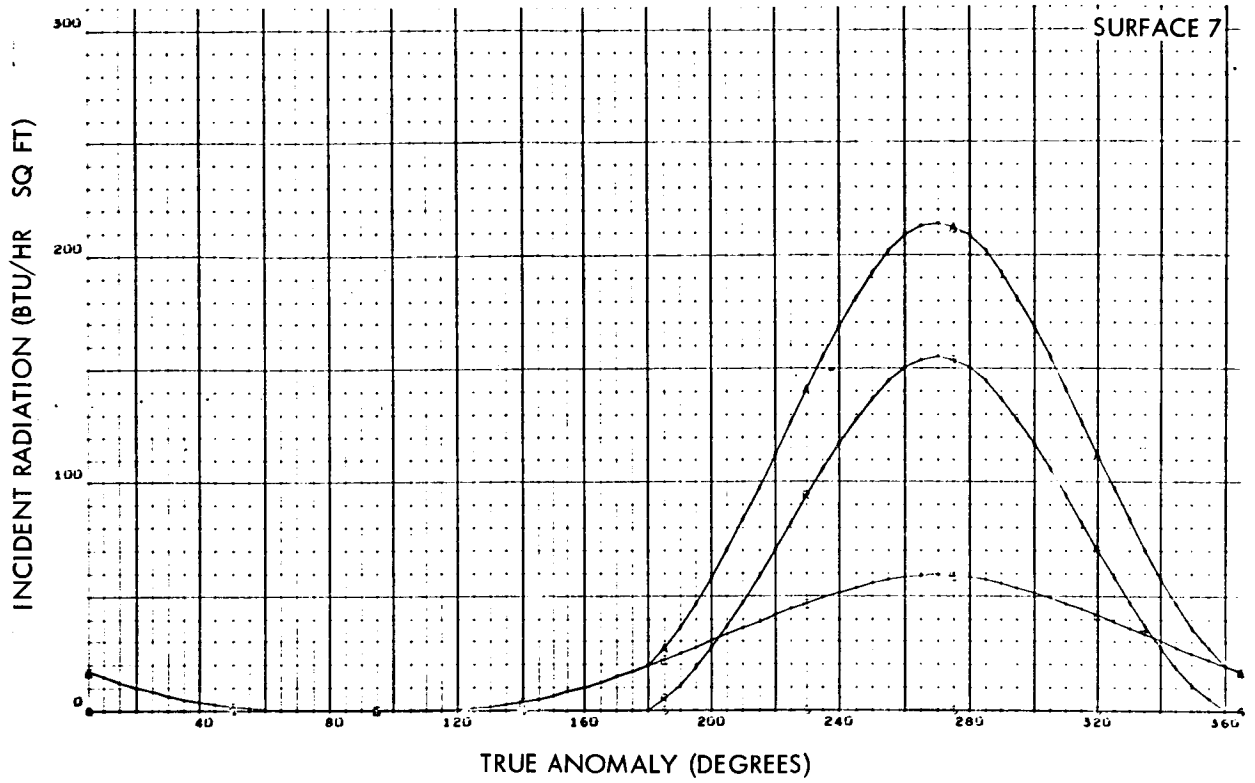


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 4 of 8)



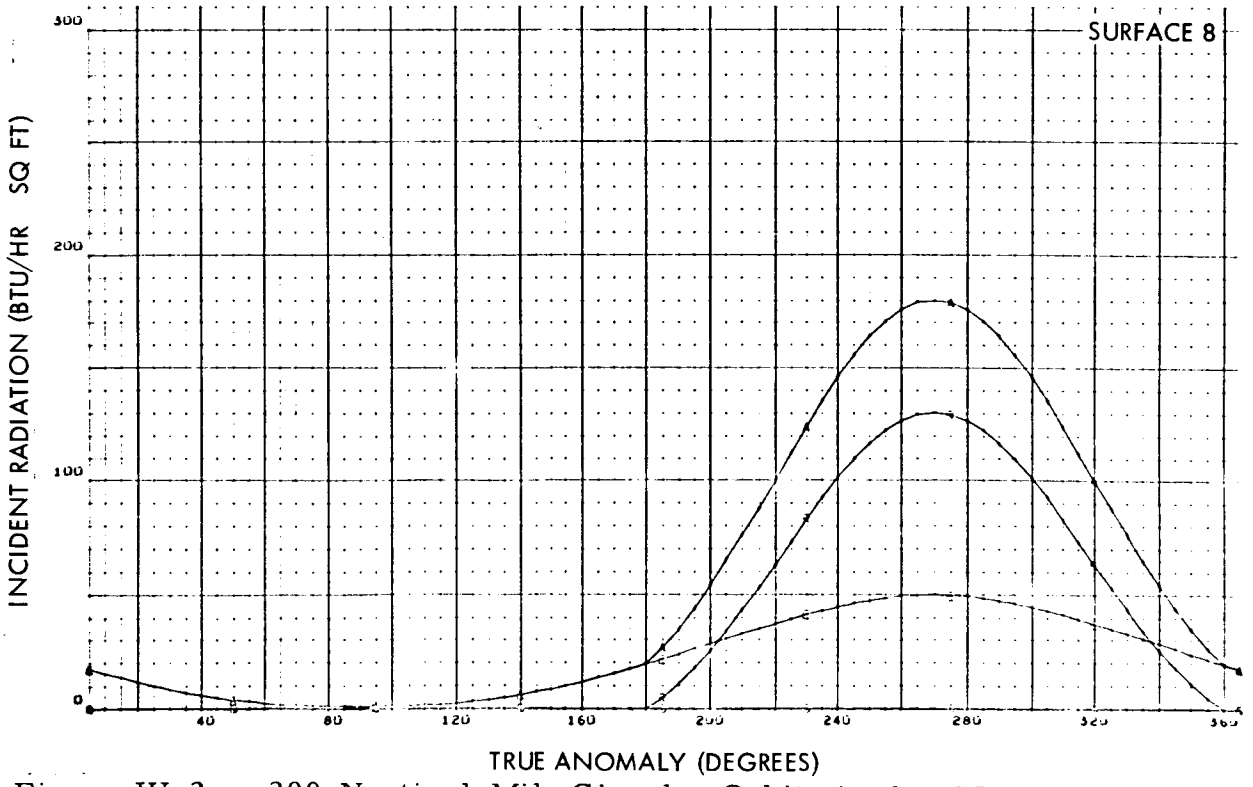
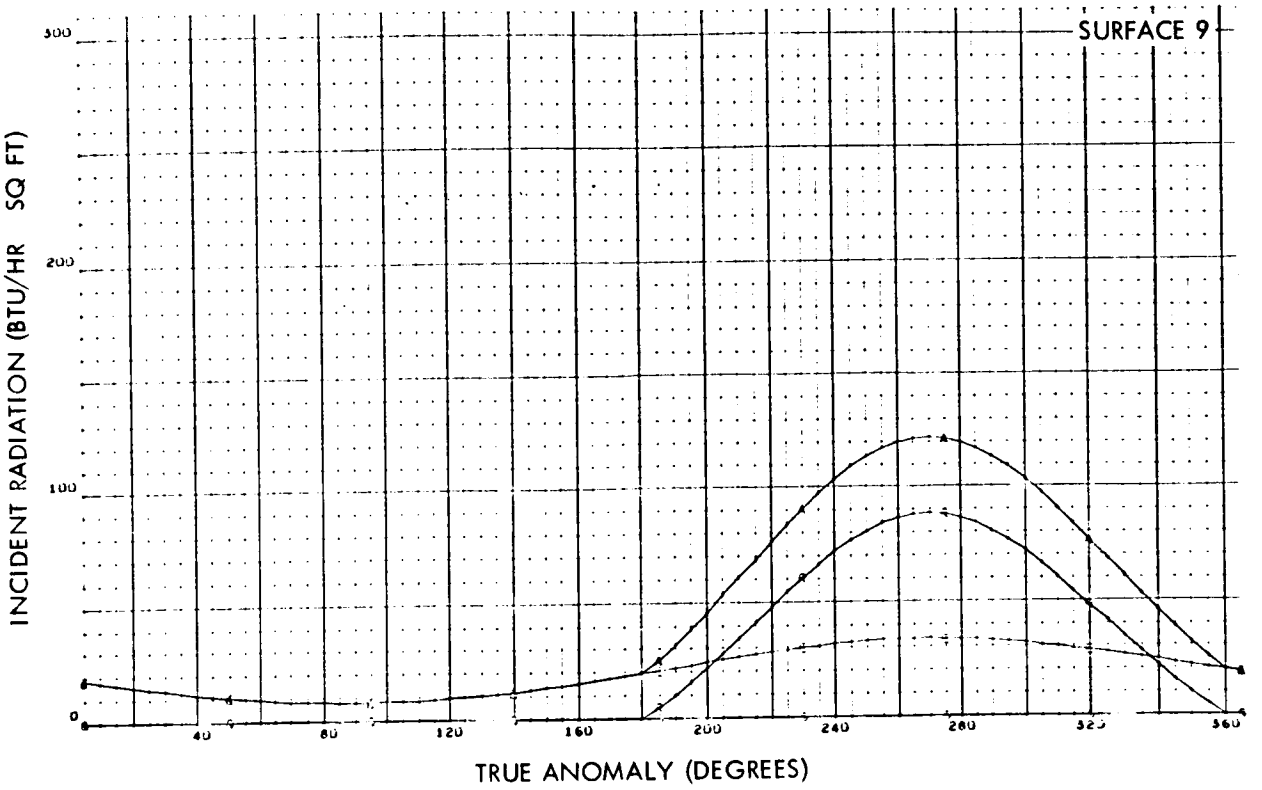


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 5 of 8)



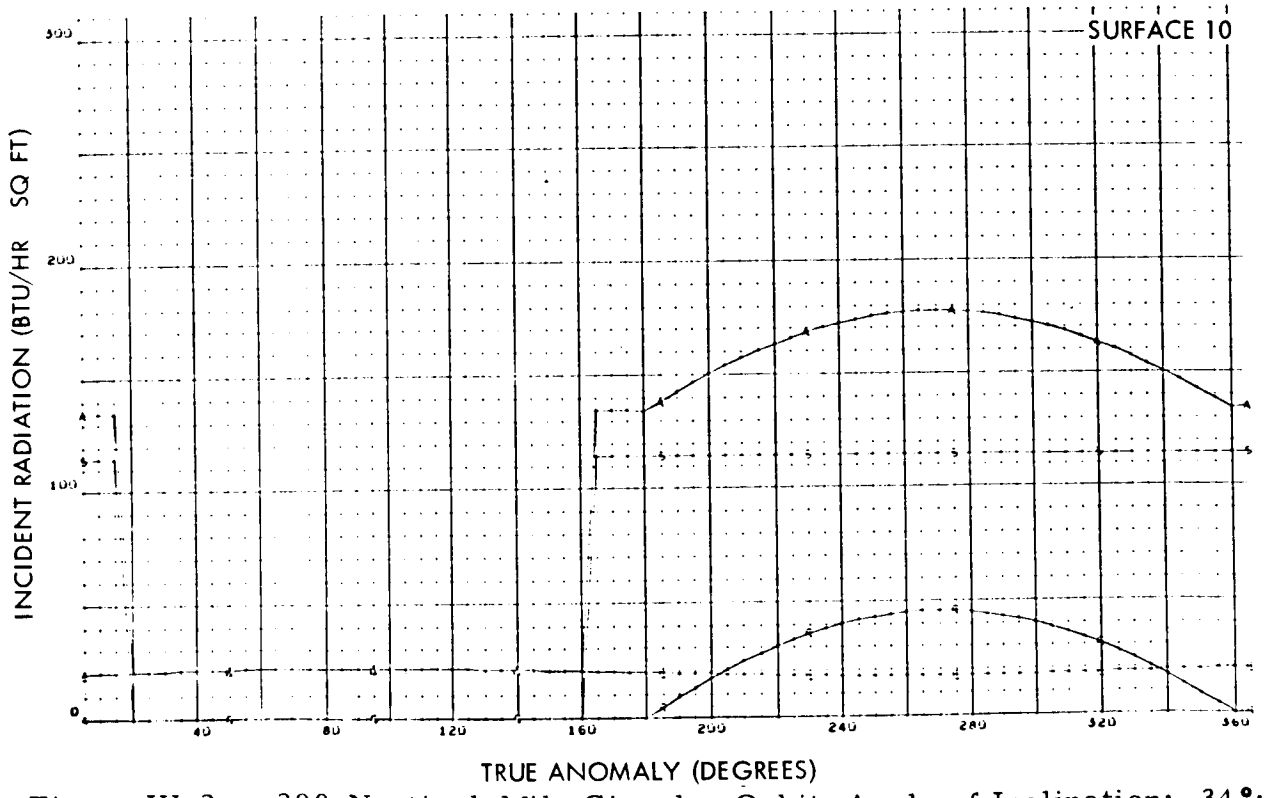


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 6 of 8)

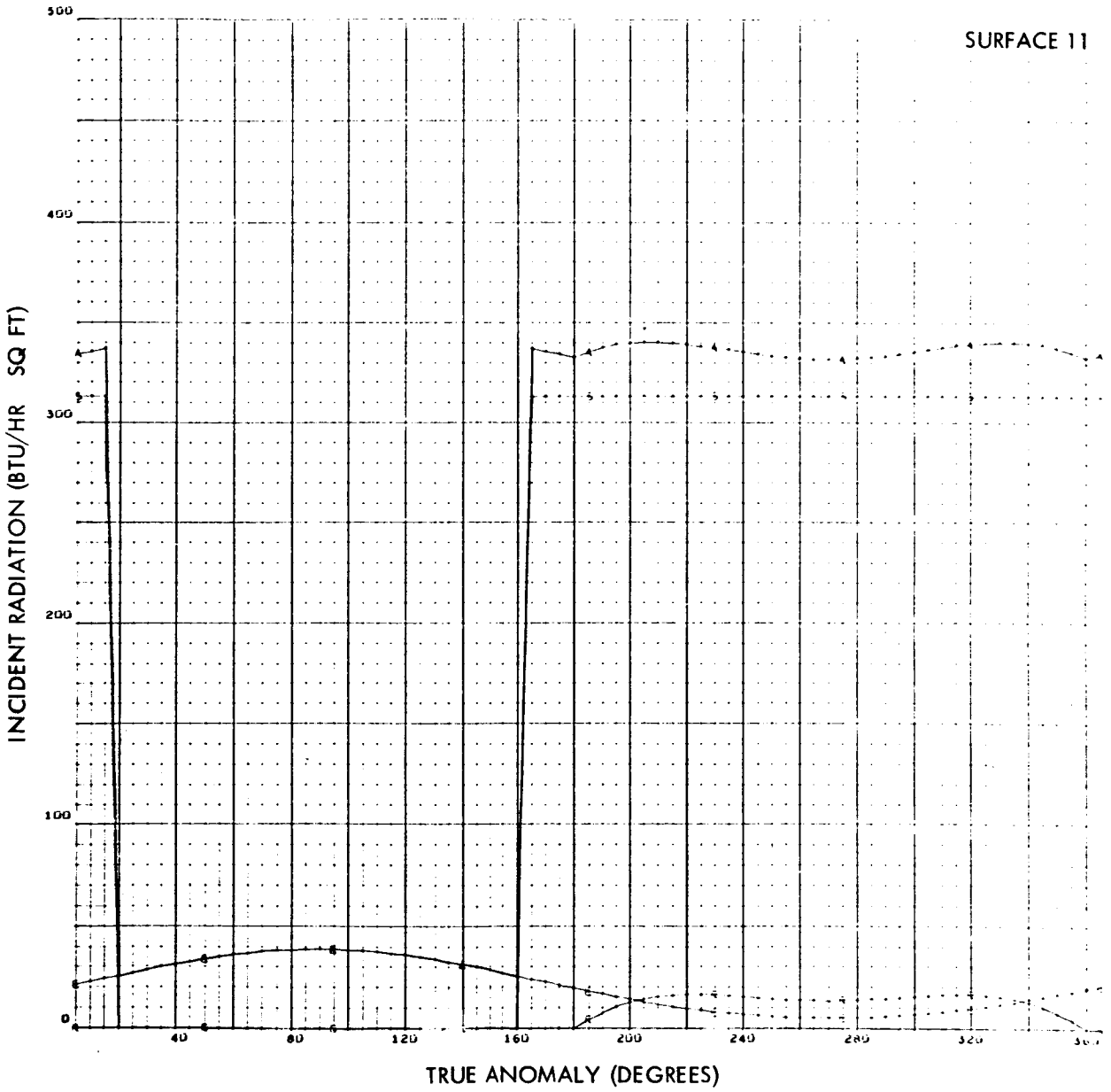


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 7 of 8)

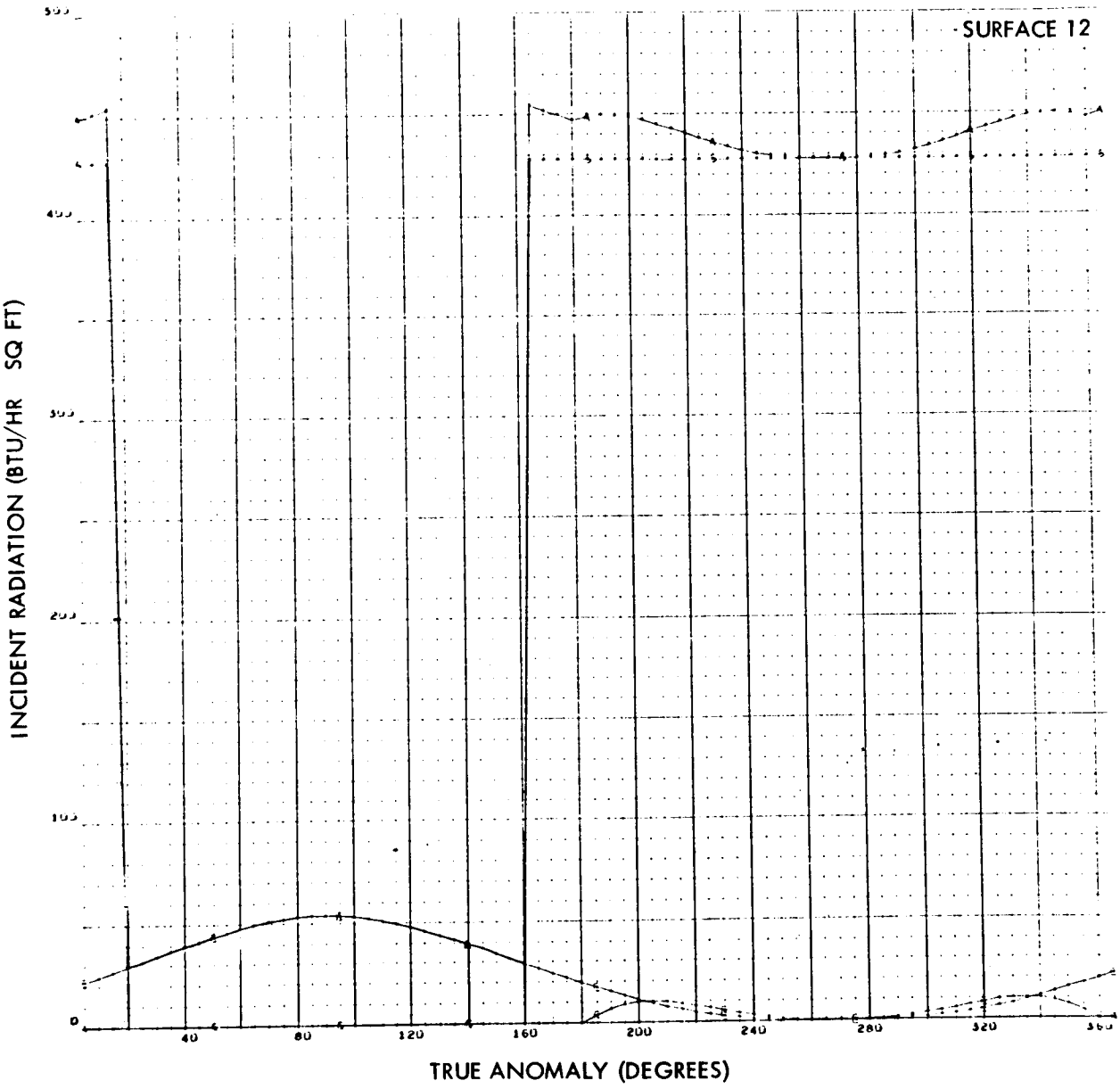


Figure IU-2c. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 8 of 8)

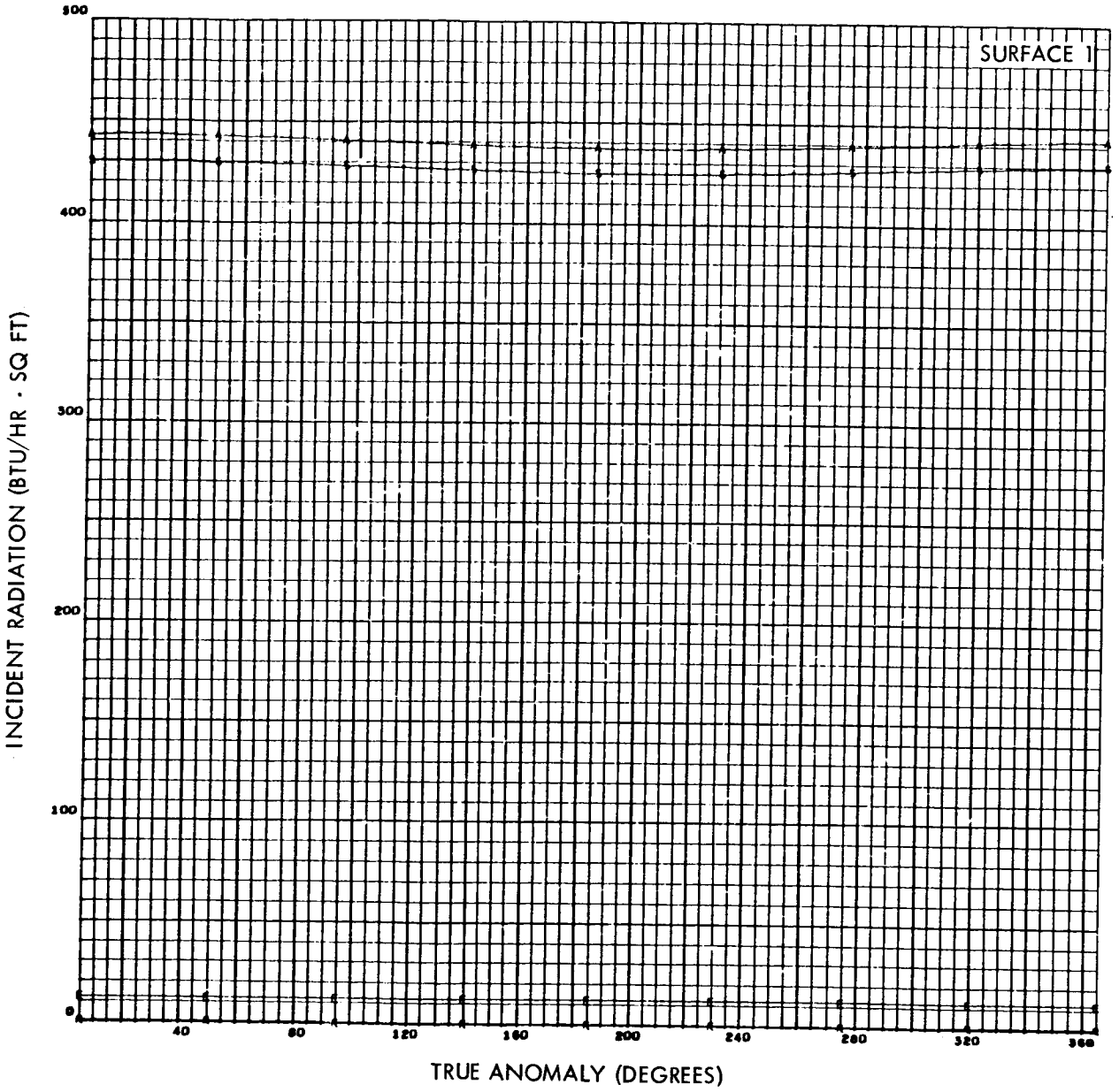


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 1 of 7)

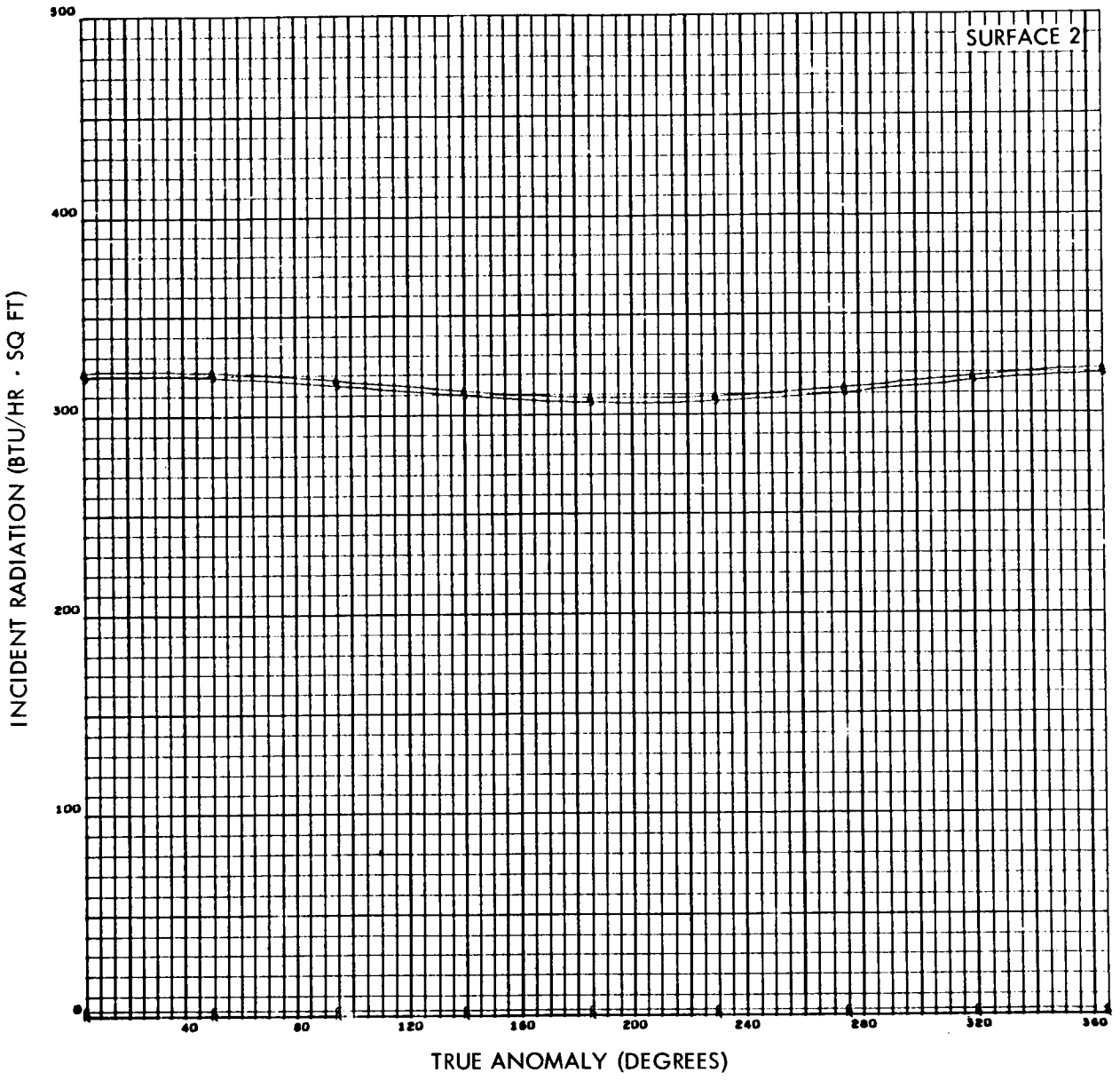


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 2 of 7)

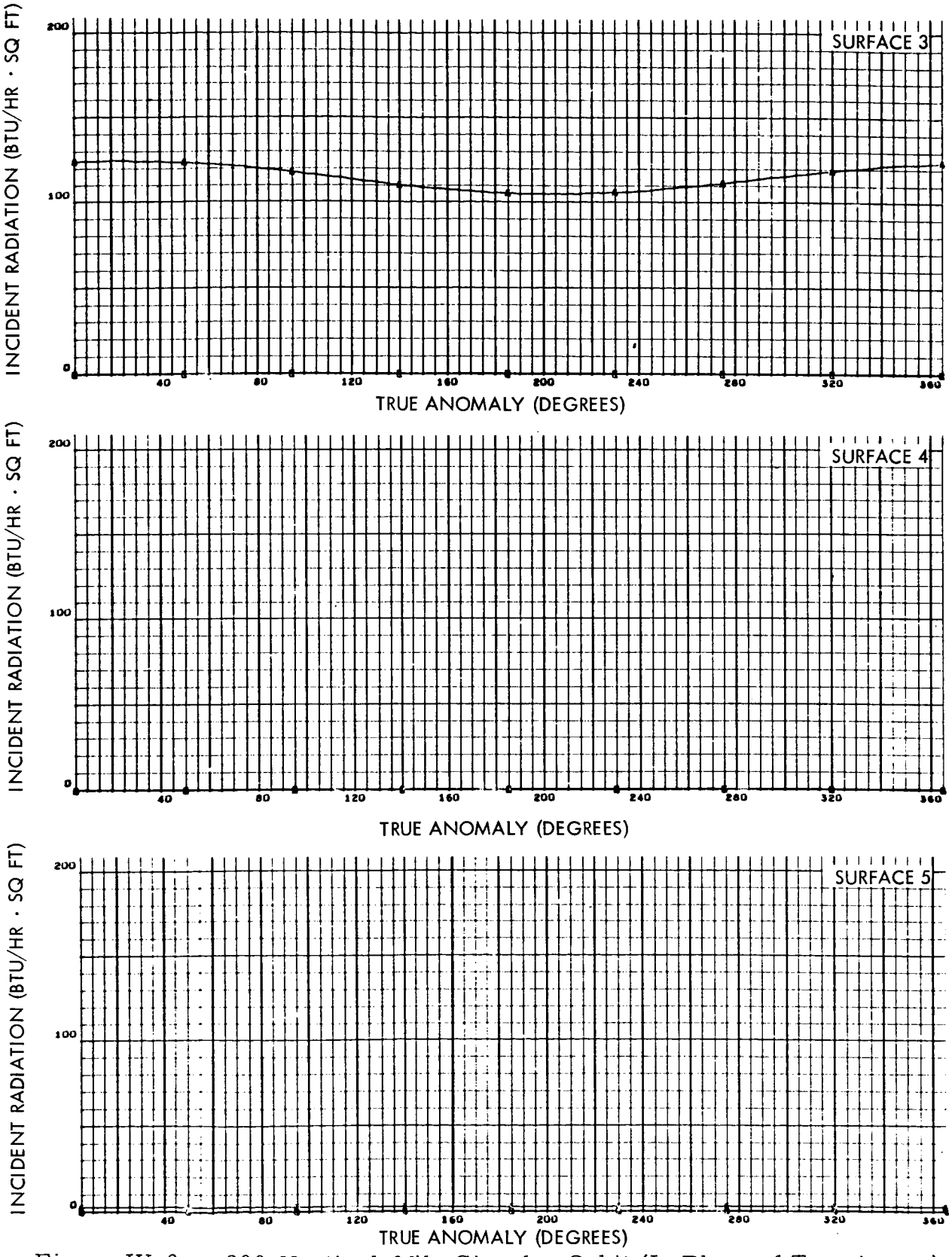


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 3 of 7)

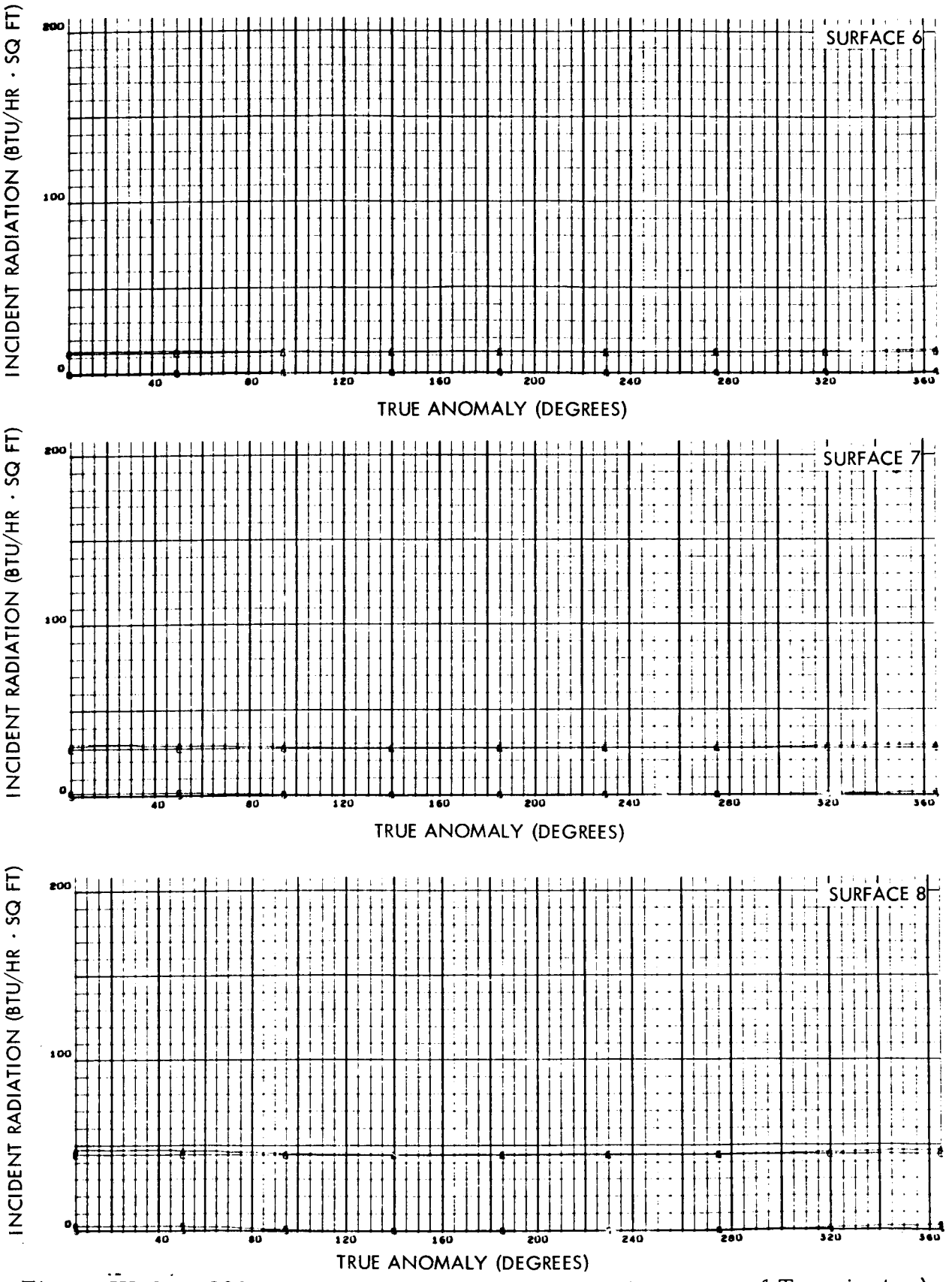
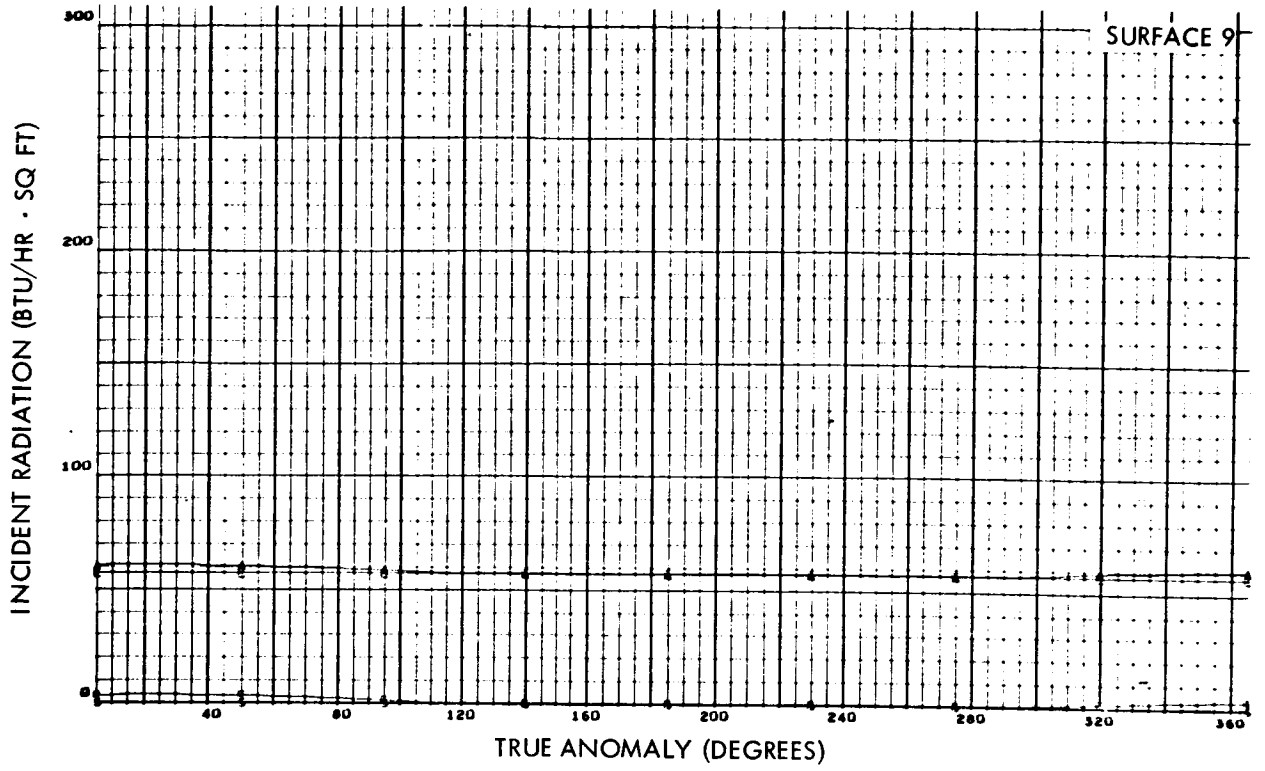


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 4 of 7)



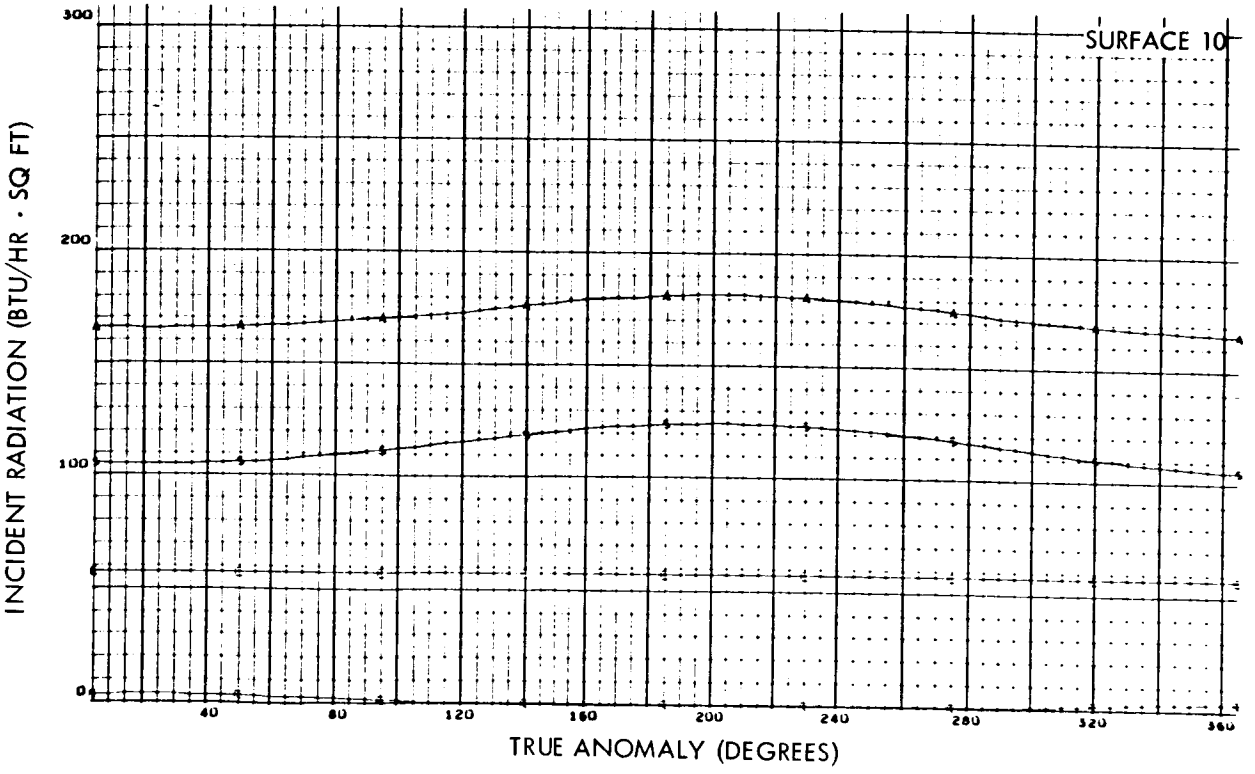


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 5 of 7)

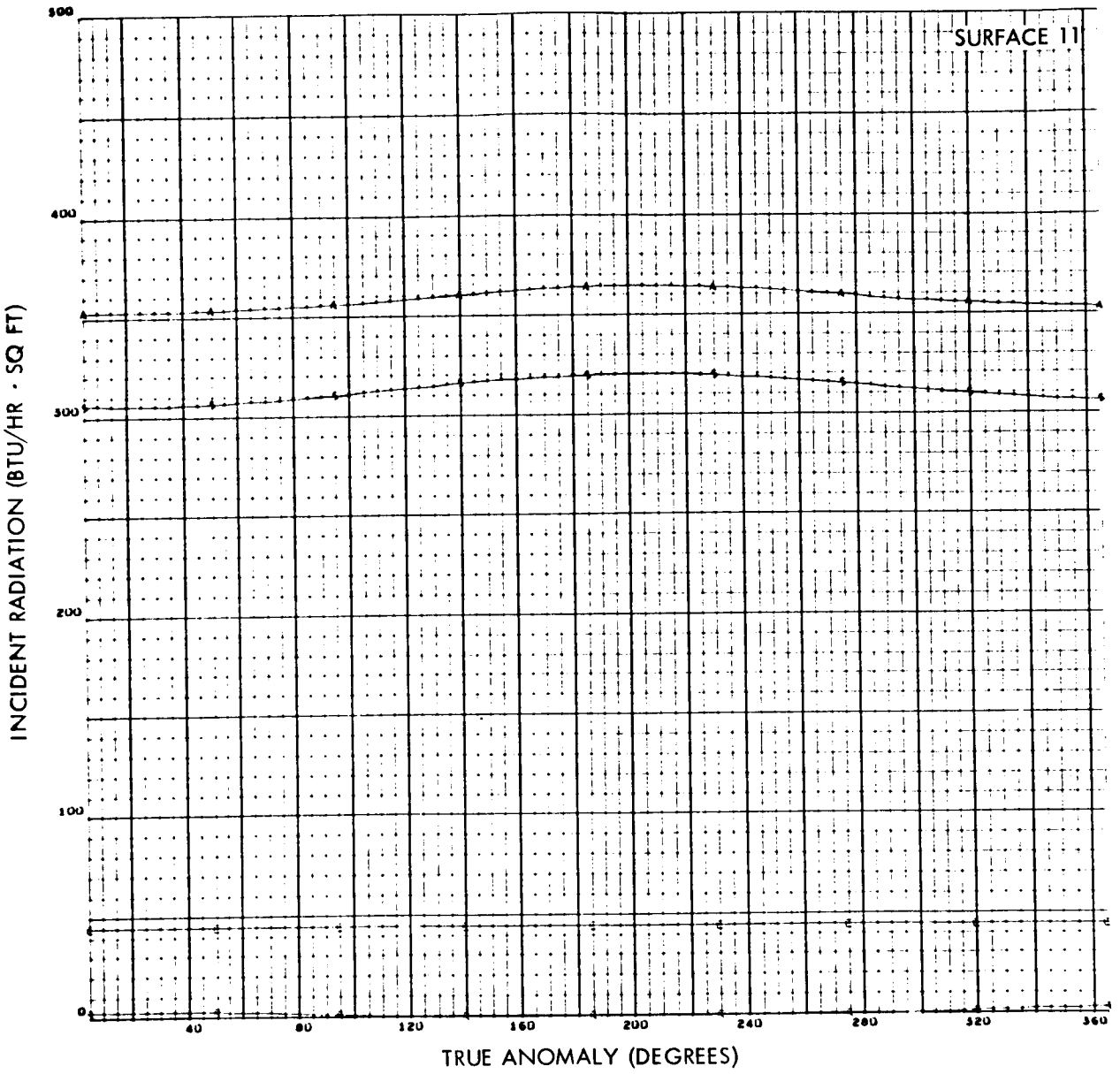


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 6 of 7)

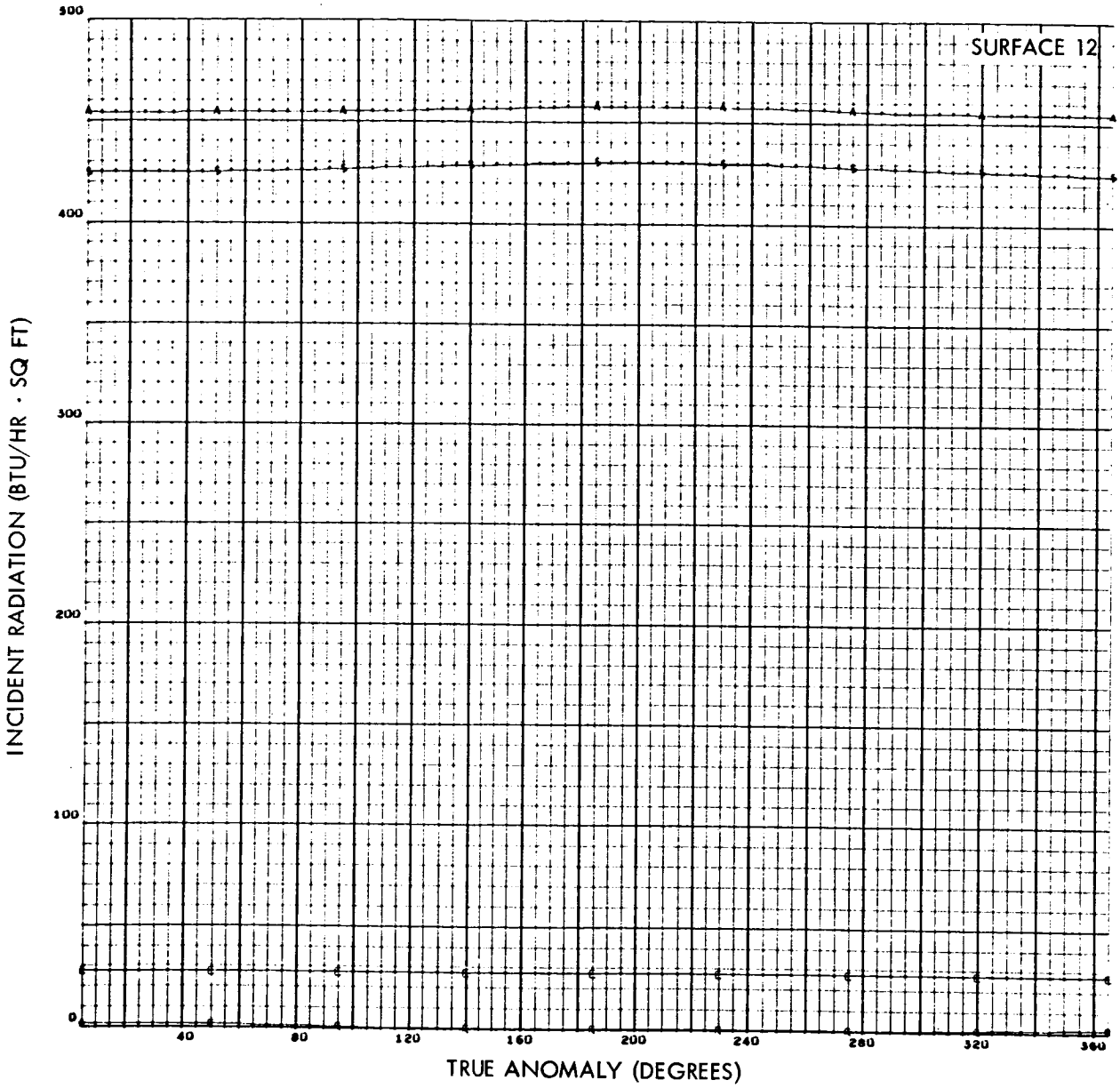


Figure IU-3a. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Tan (Sheet 7 of 7)

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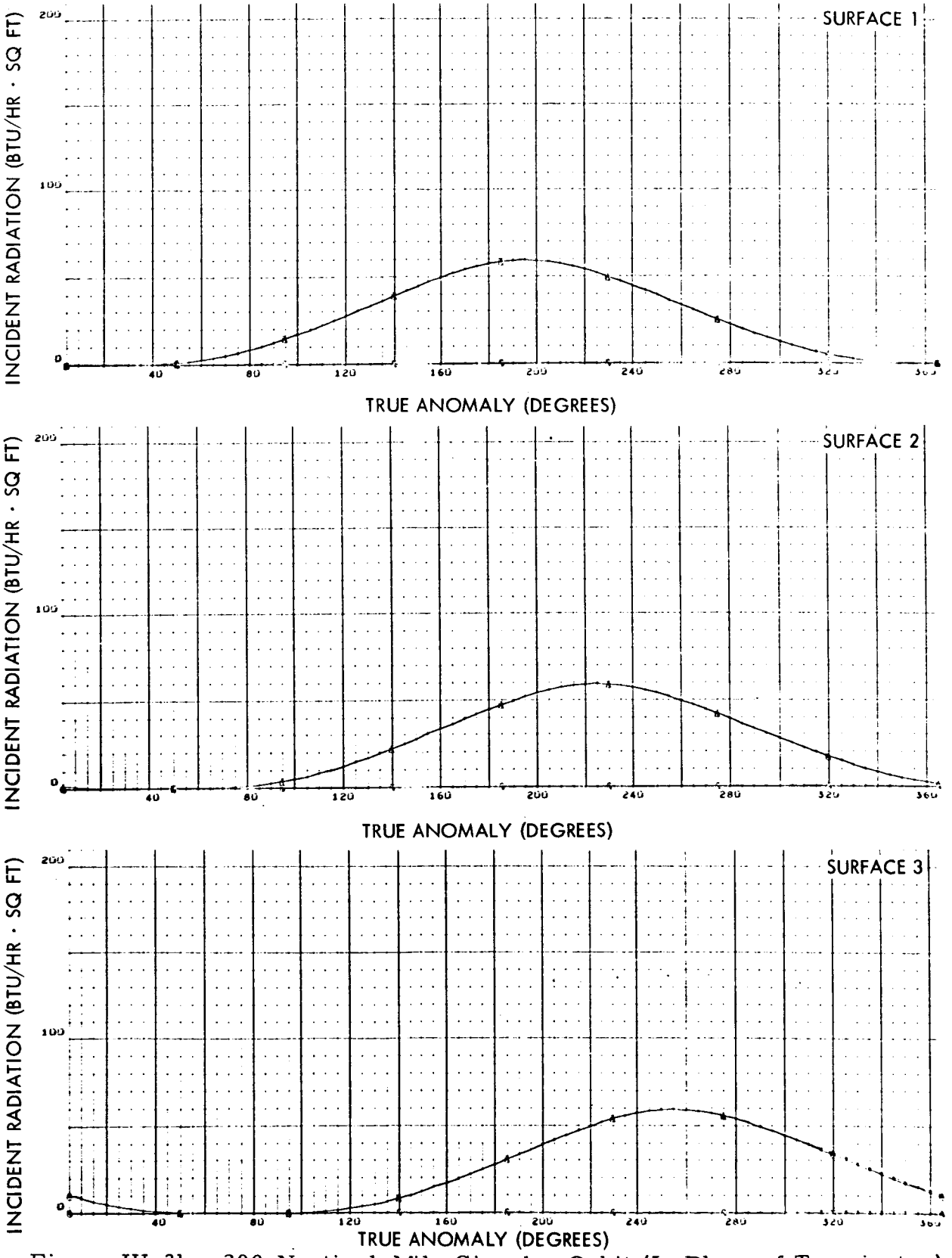

Figure IU-3b. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Sol (Sheet 1 of 4)

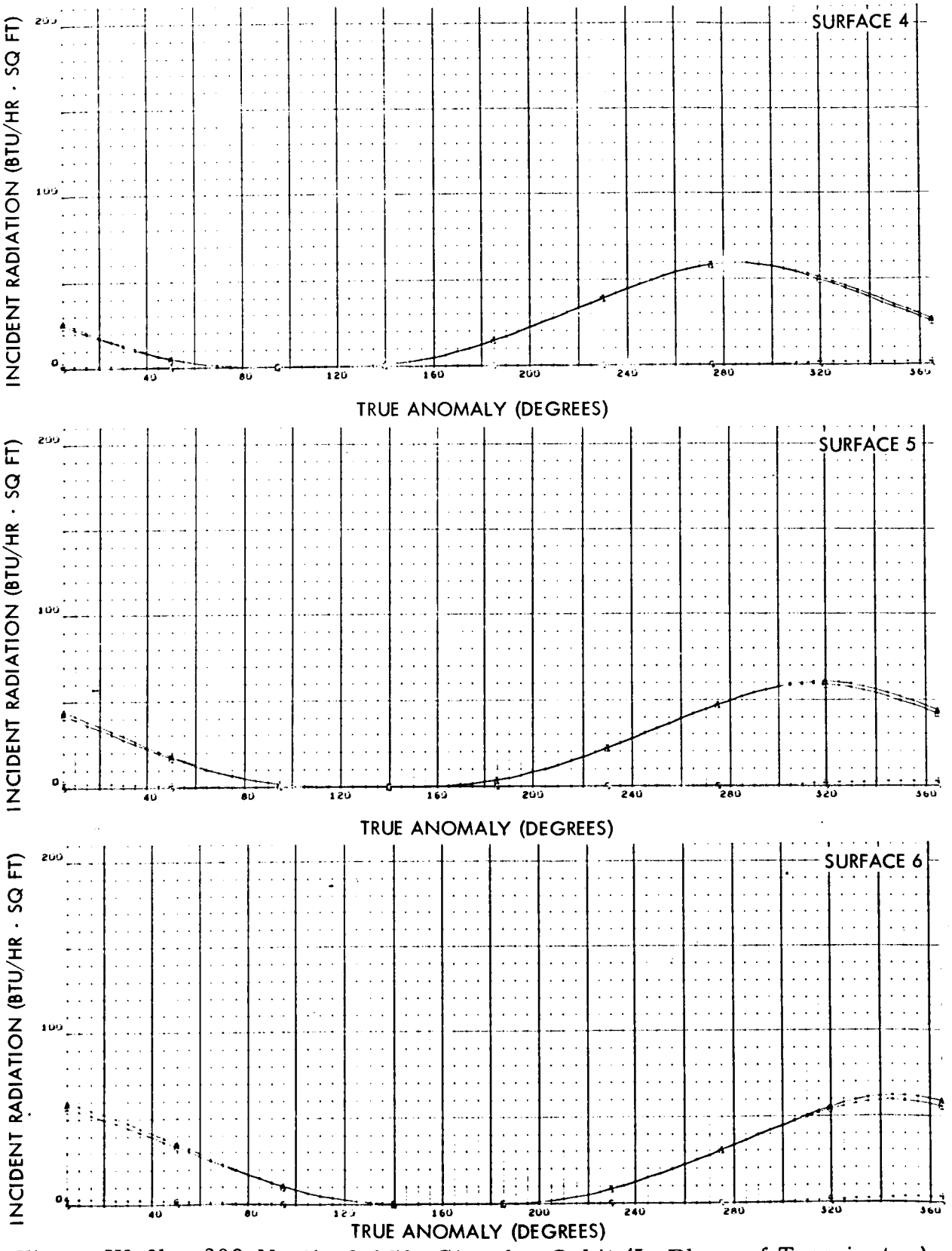

Figure IU-3b. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Sol (Sheet 2 of 4)

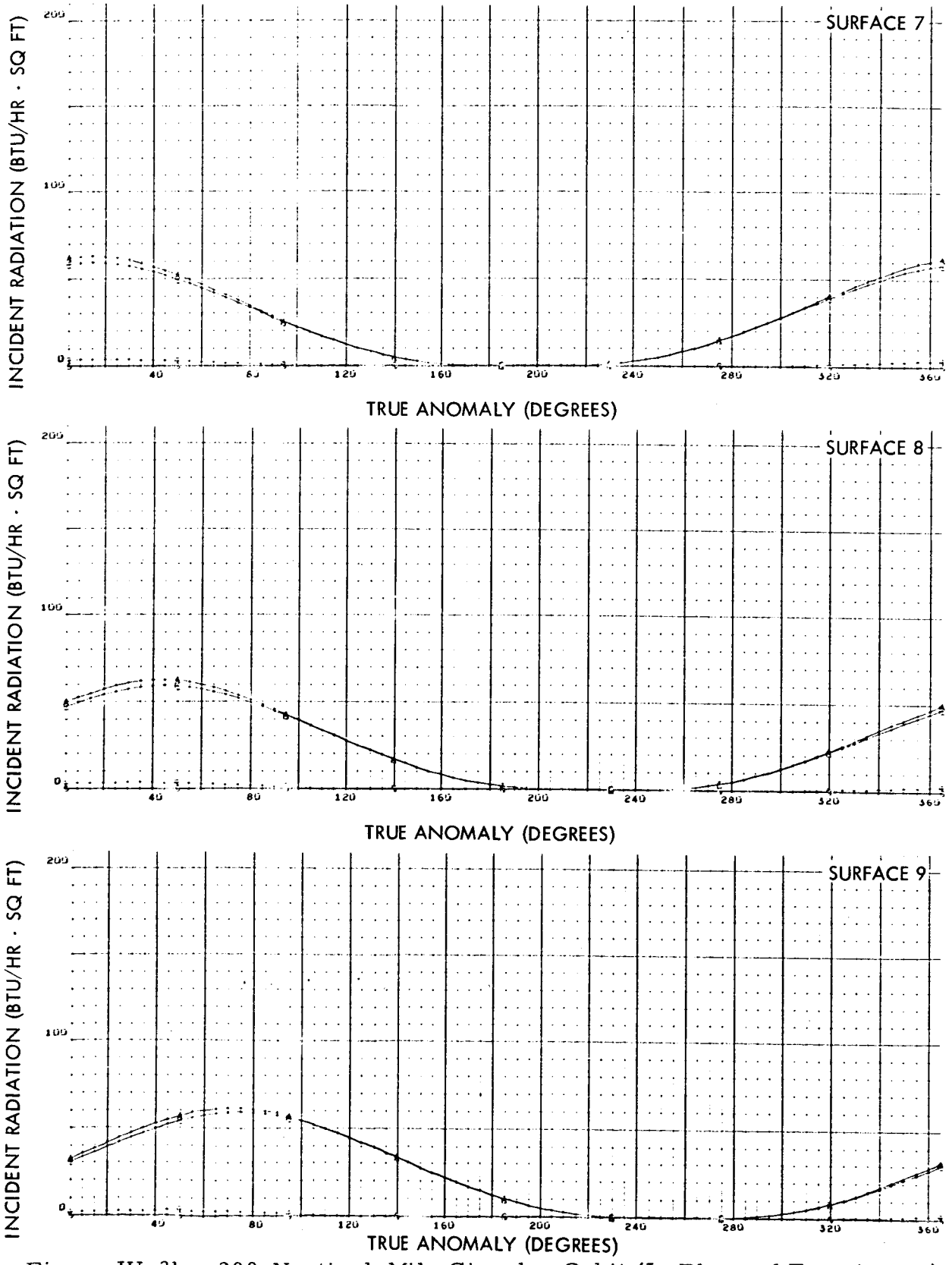

Figure IU-3b. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Sol (Sheet 3 of 4)

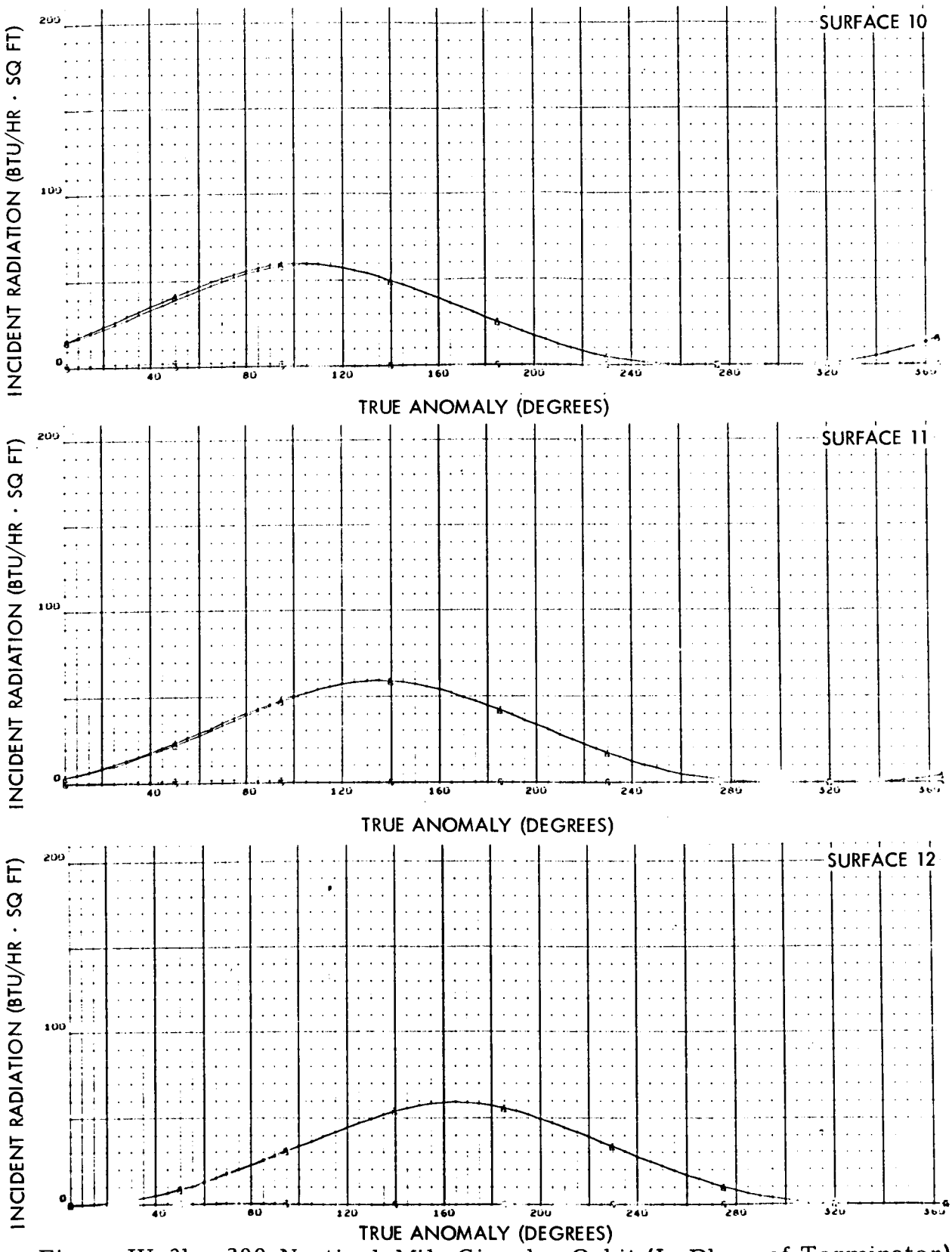

Figure IU-3b. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; X-Sol (Sheet 4 of 4)

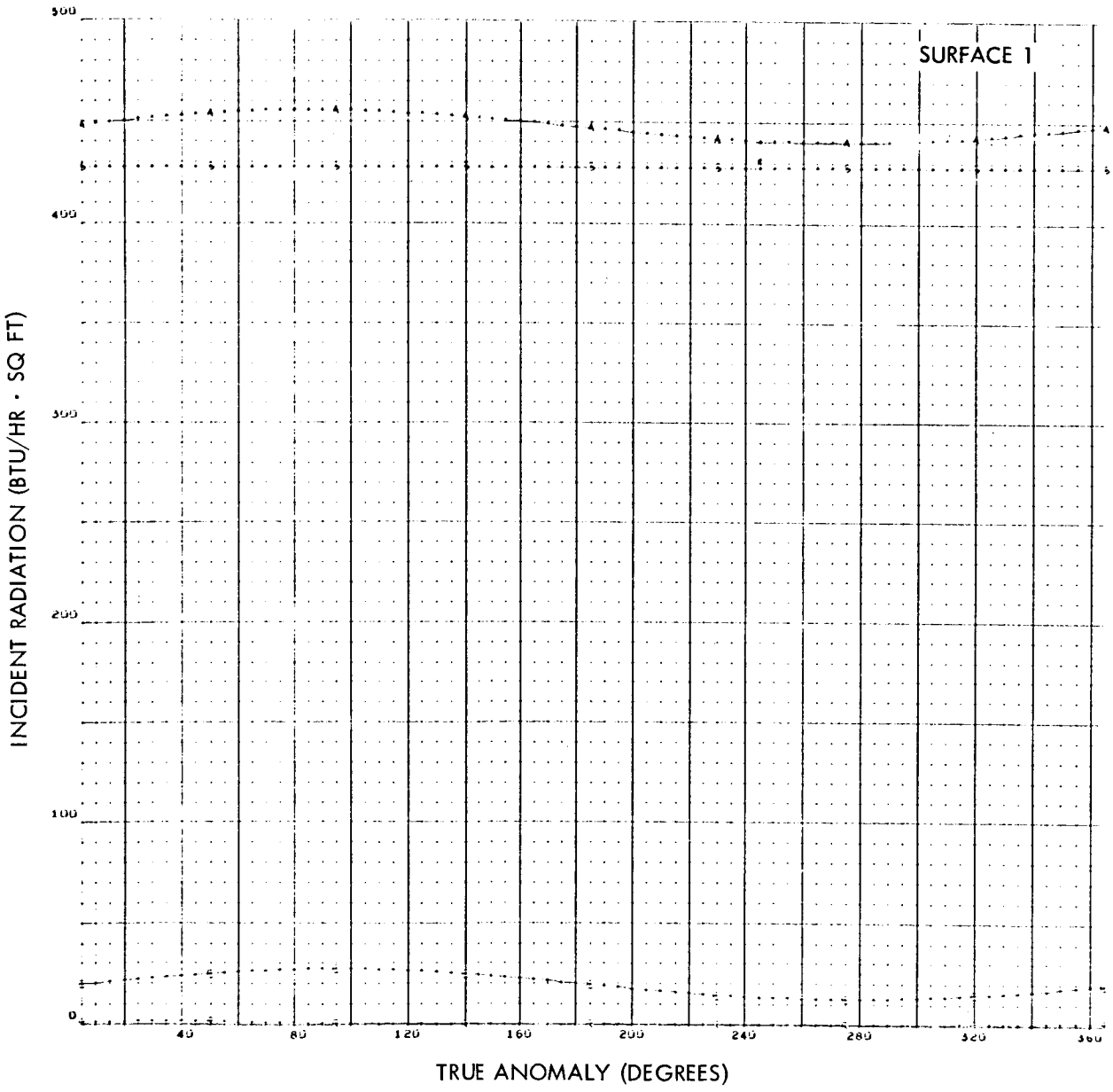

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 1 of 7)

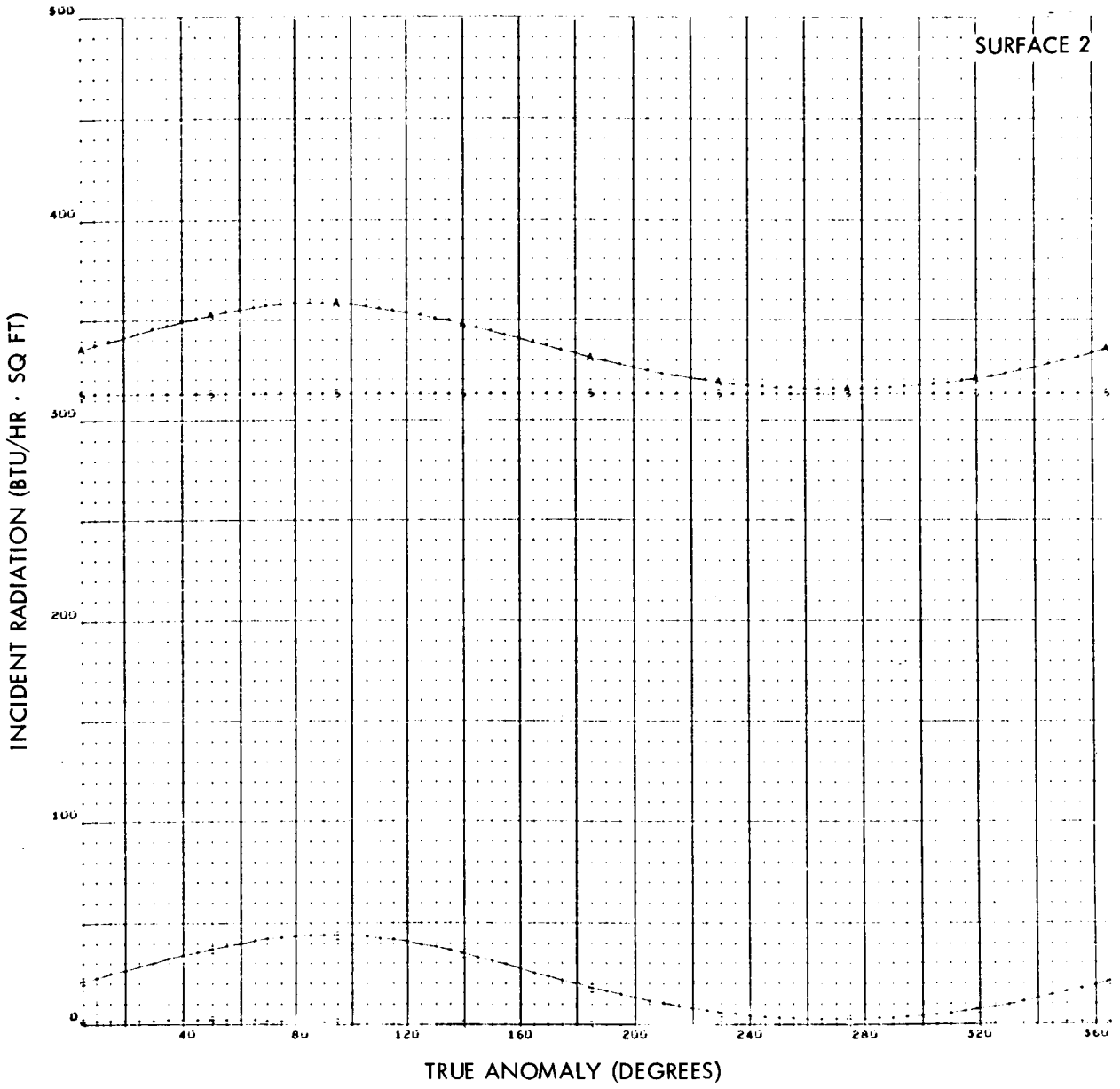

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 2 of 7)

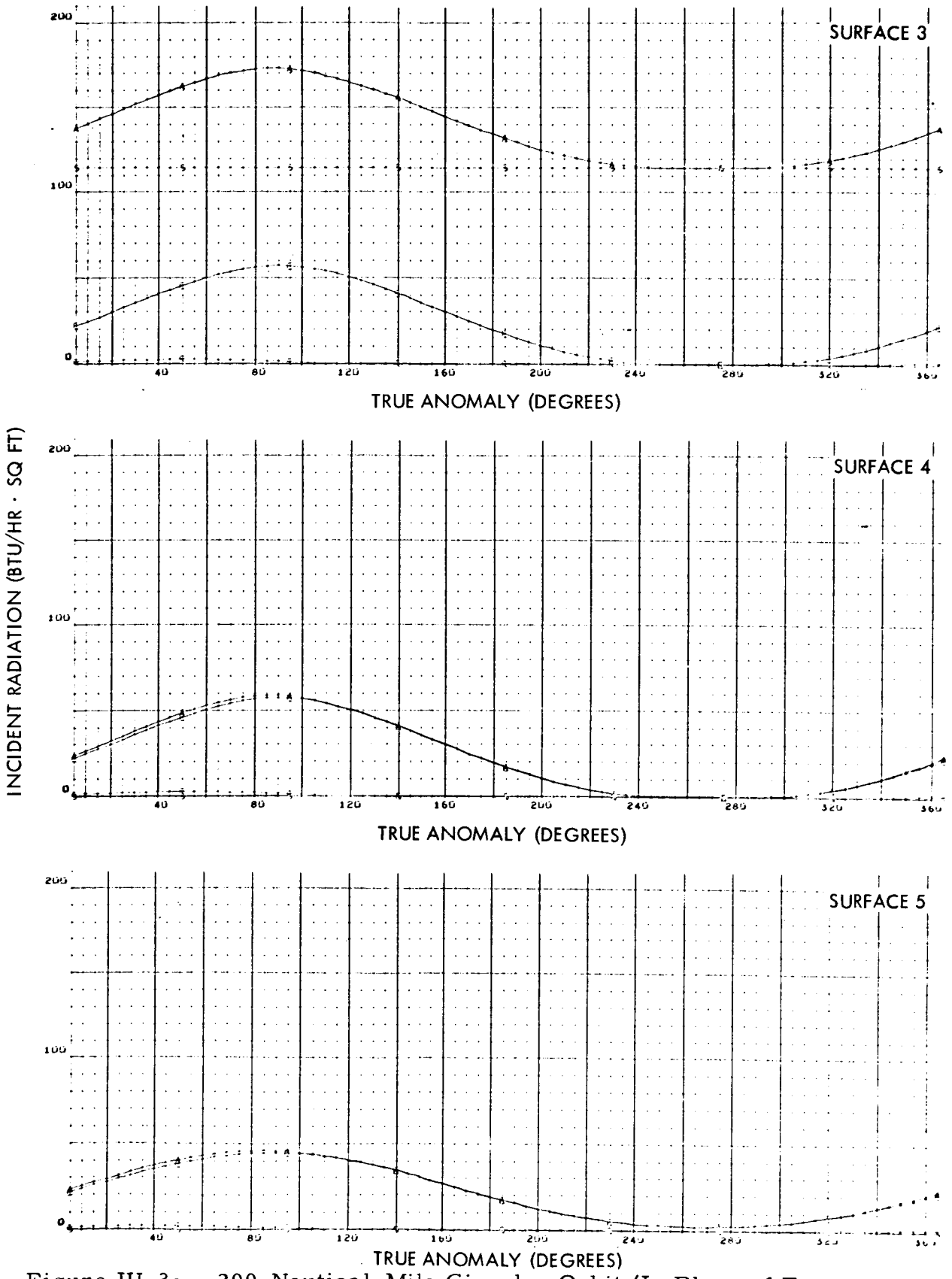

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 3 of 7)

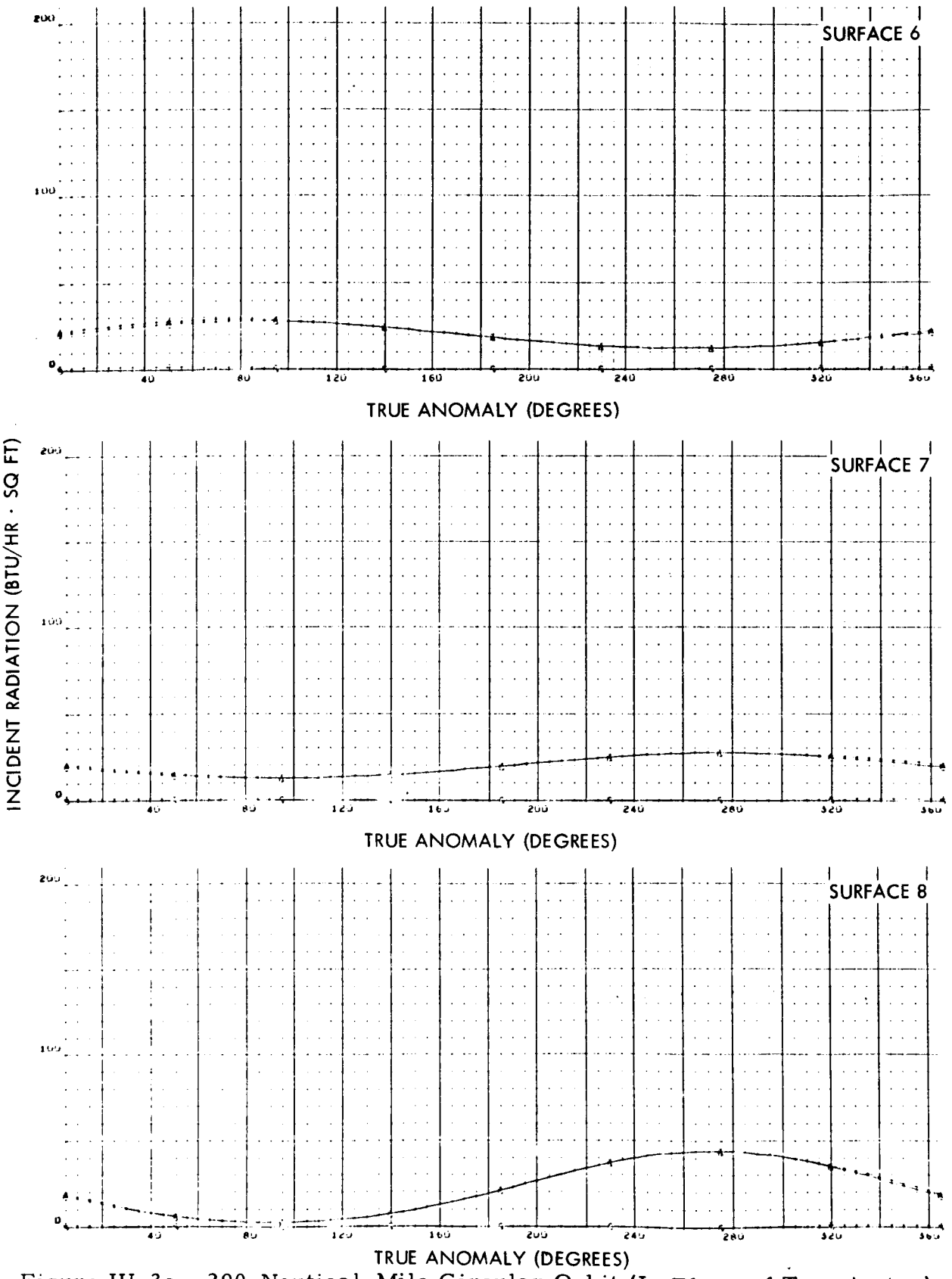

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 4 of 7)

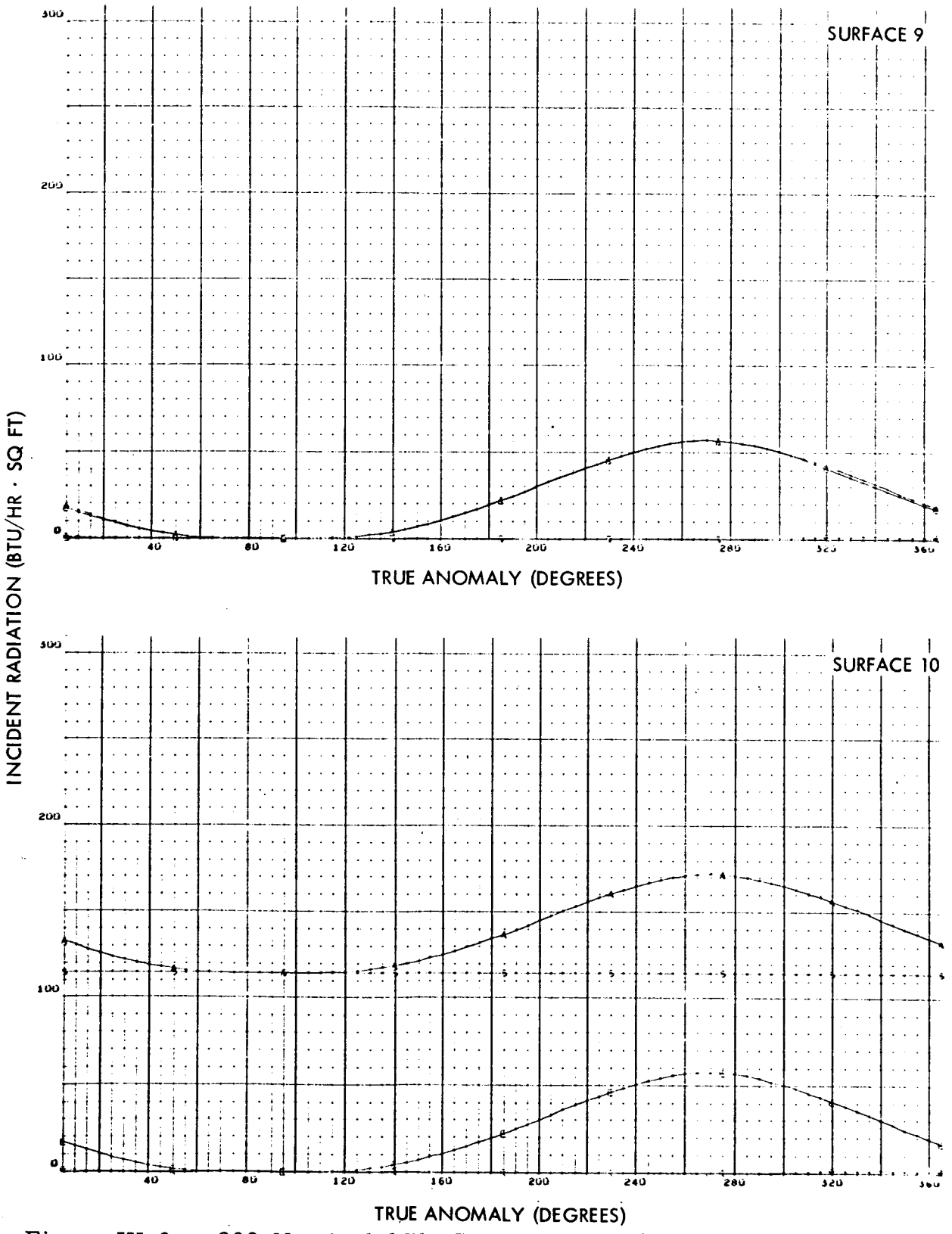

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 5 of 7)

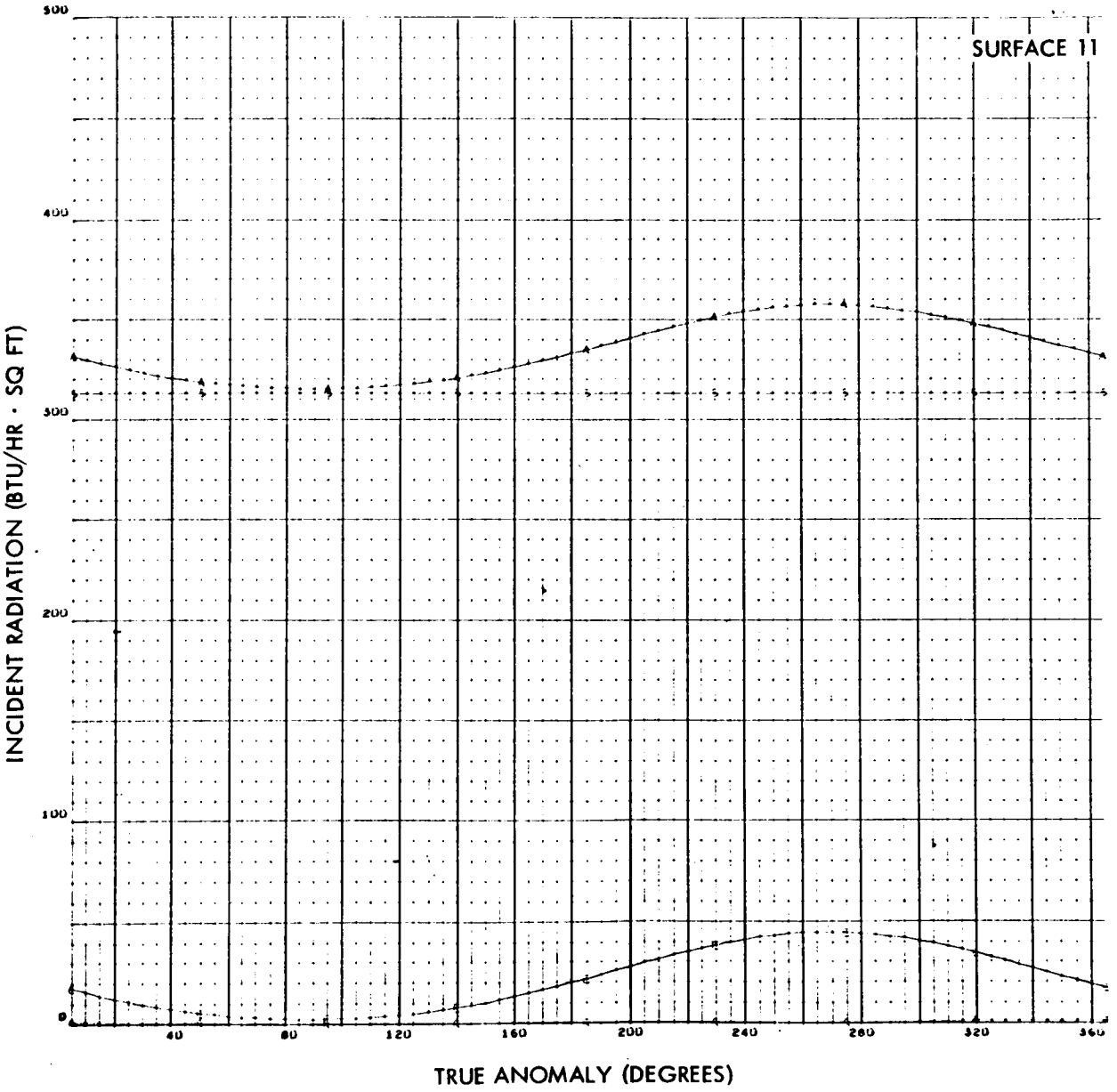

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 6 of 7)

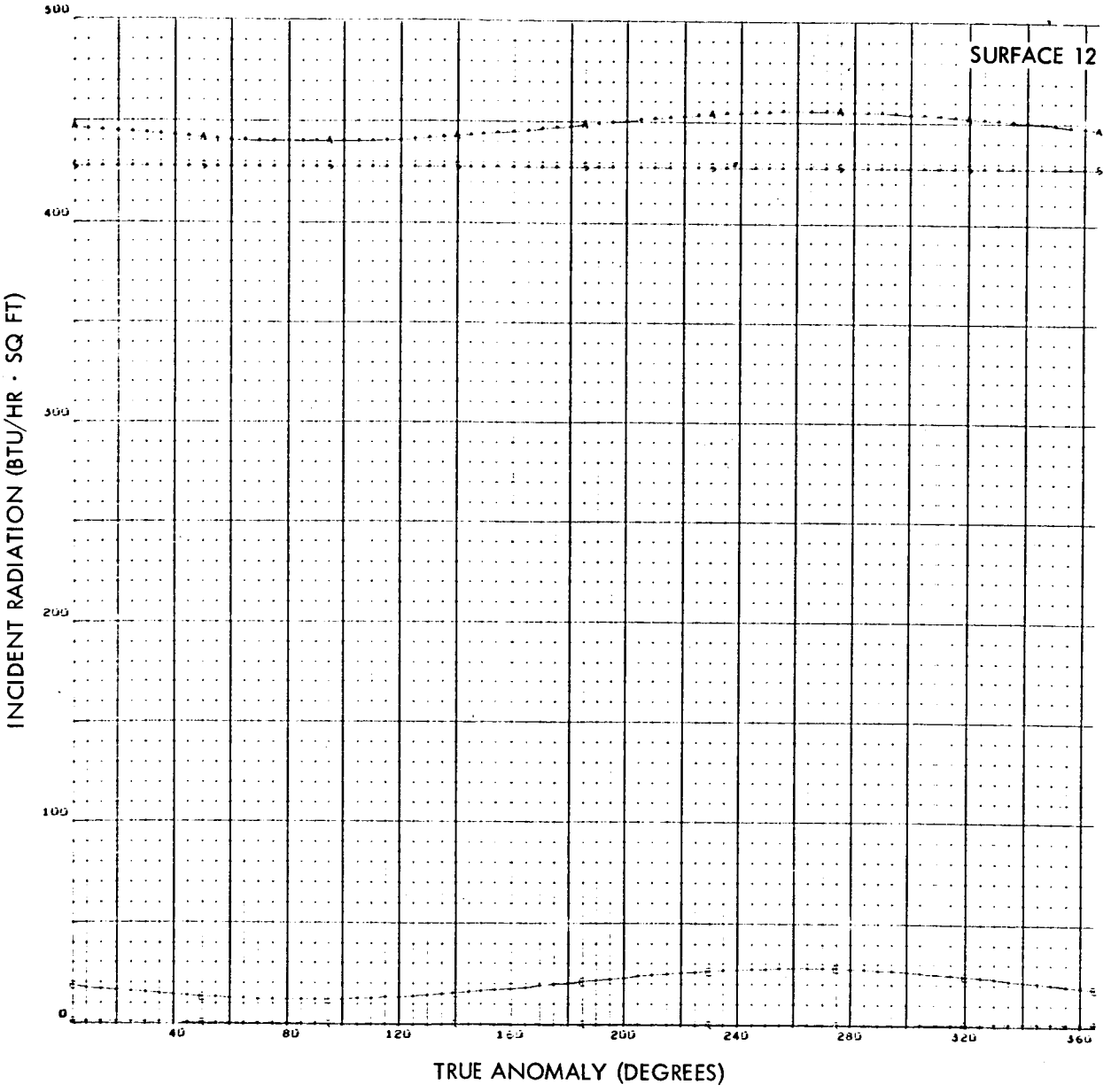

Figure IU-3c. 200-Nautical-Mile Circular Orbit (In Plane of Terminator); Angle of Inclination: 90°; Launch Date: March 21; Y-Sol (Sheet 7 of 7)

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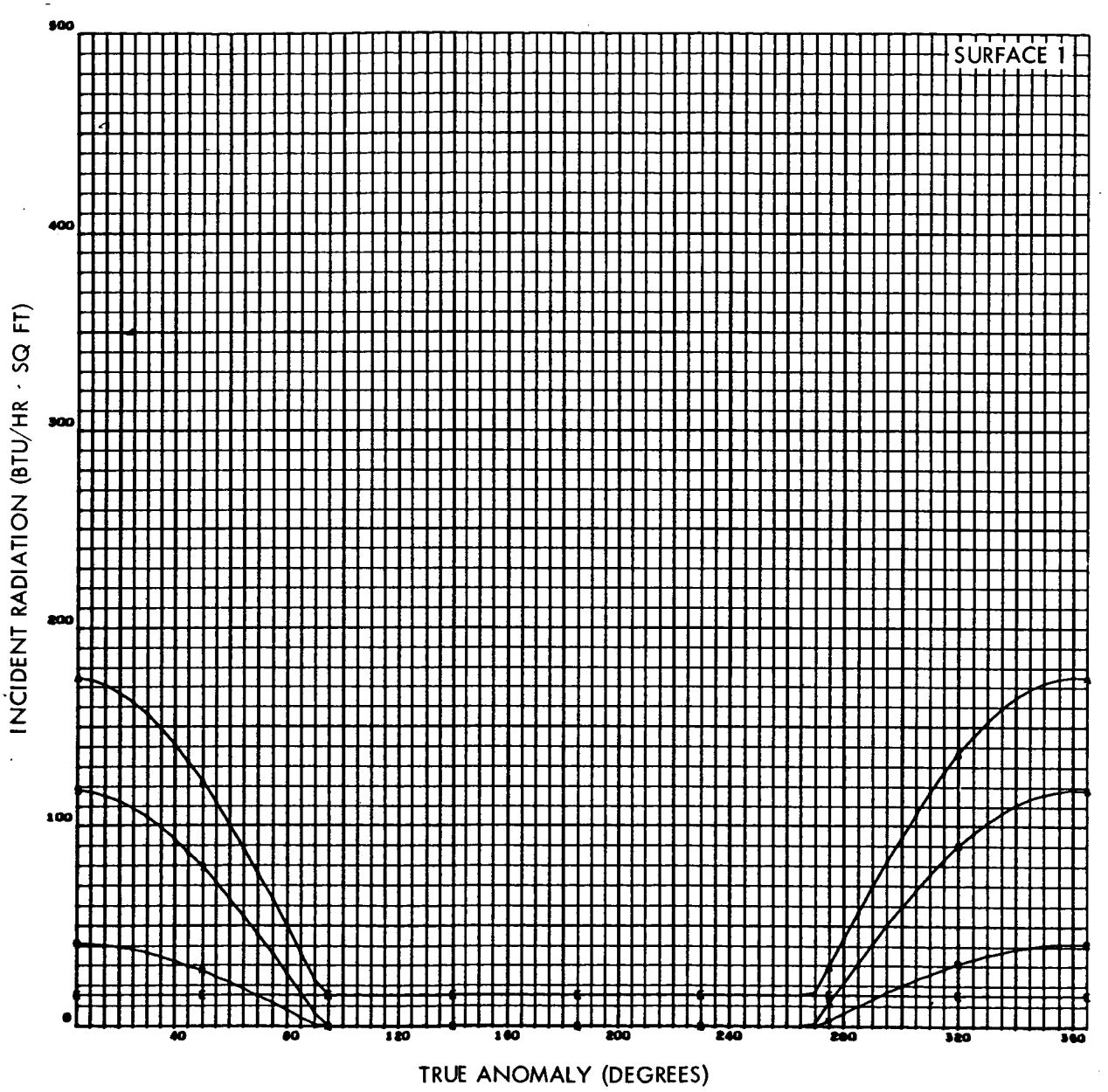


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 1 of 8)

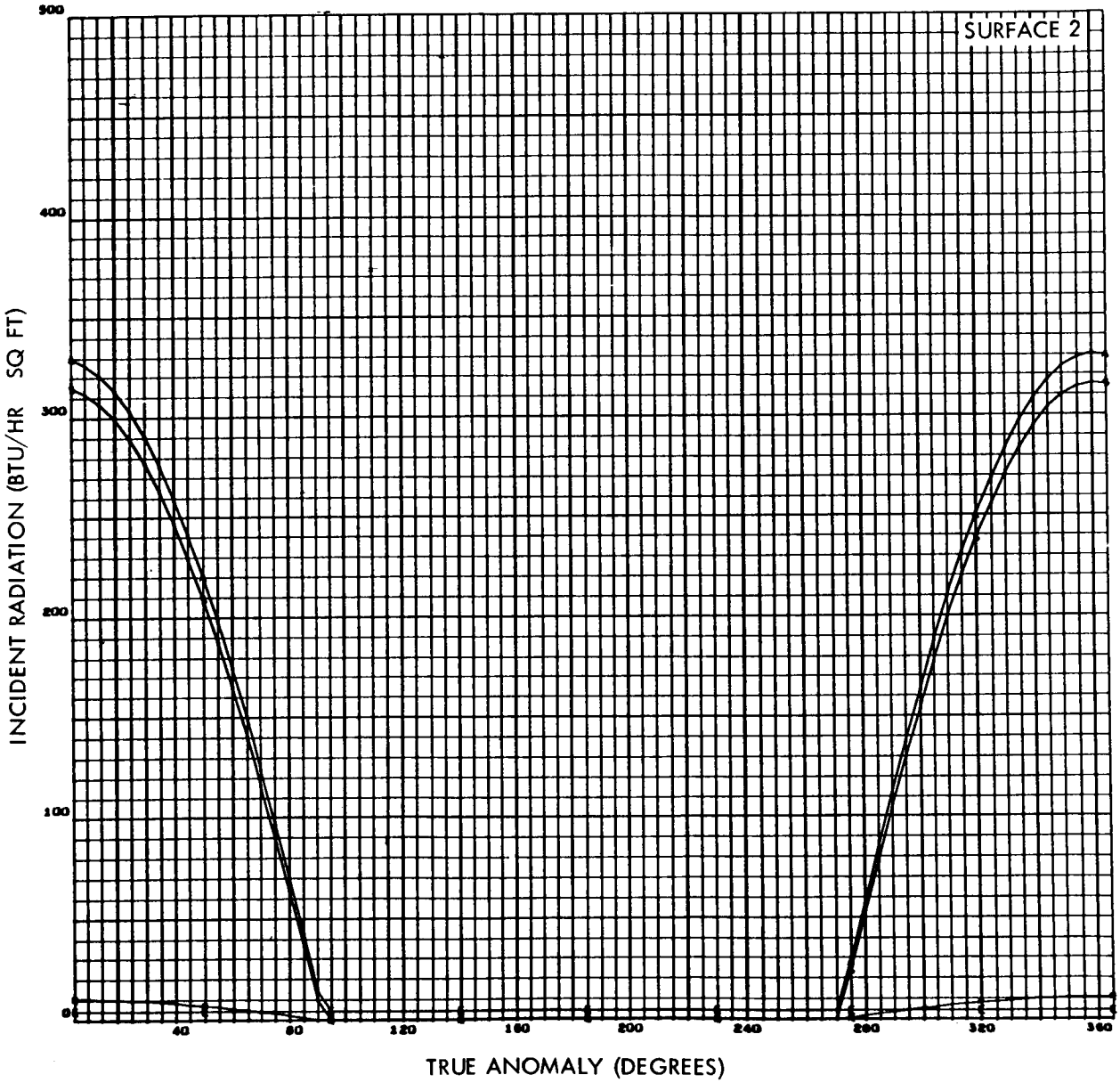


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 2 of 8)

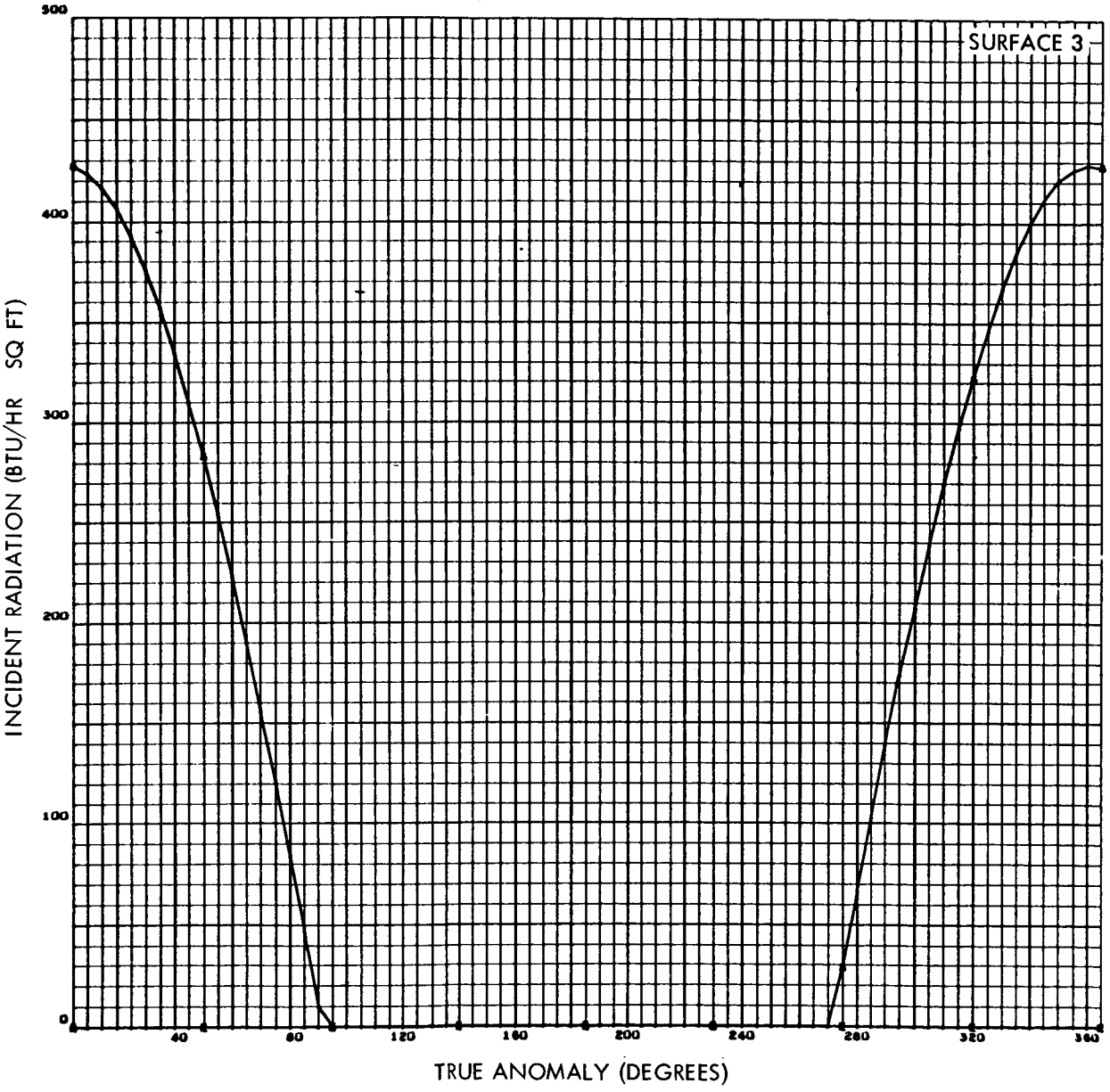


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 3 of 8)

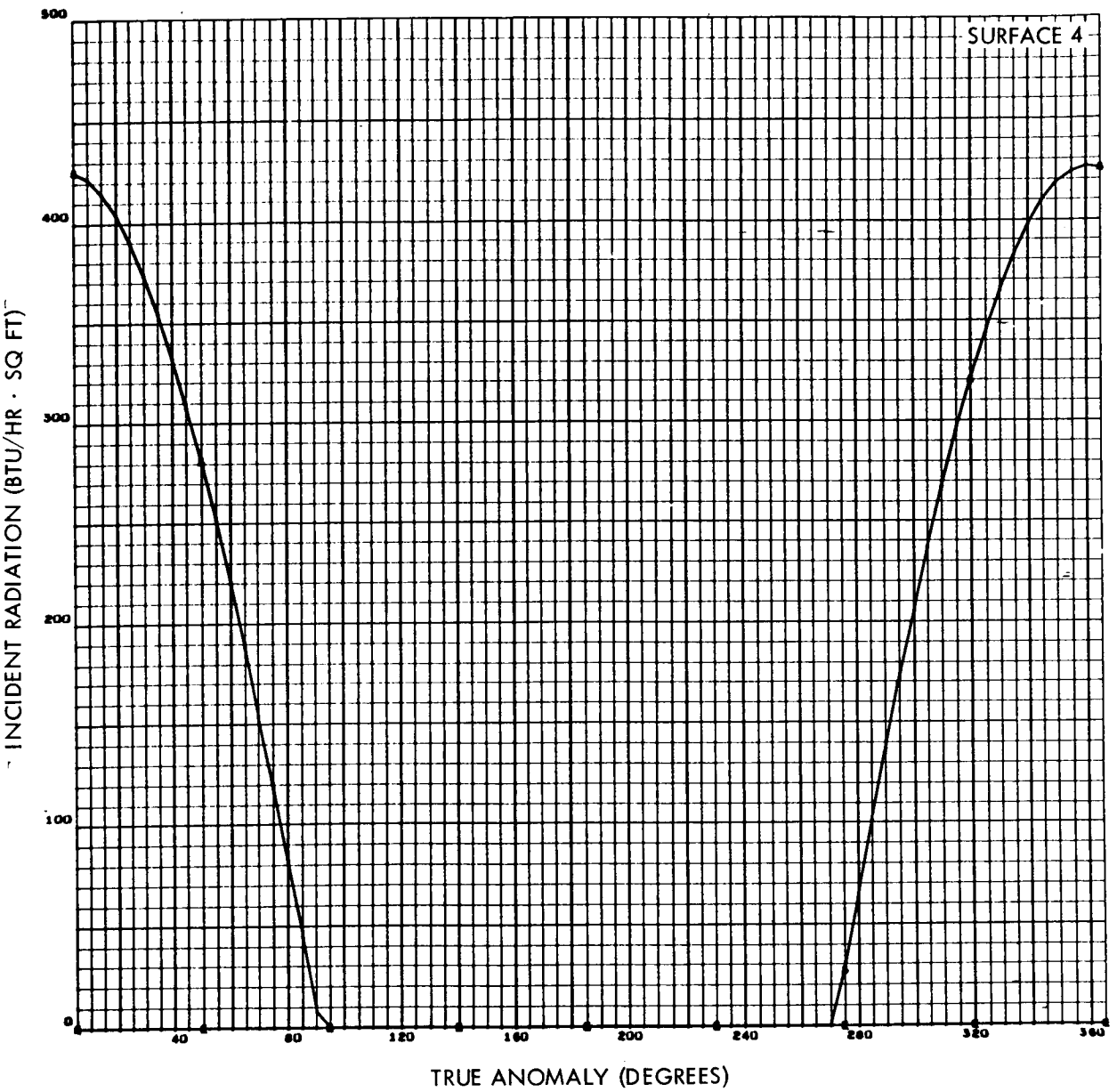


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 4 of 8)

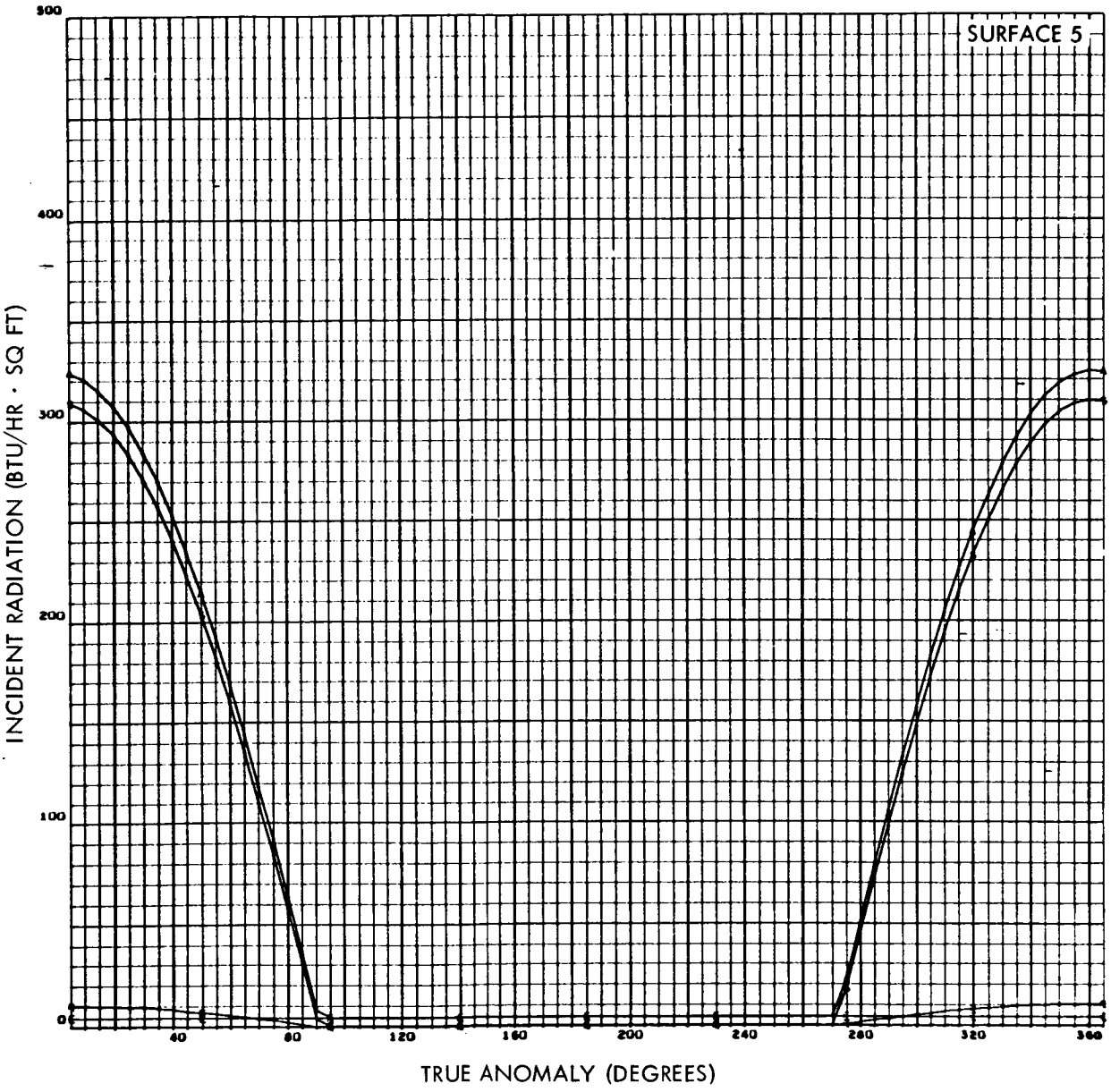
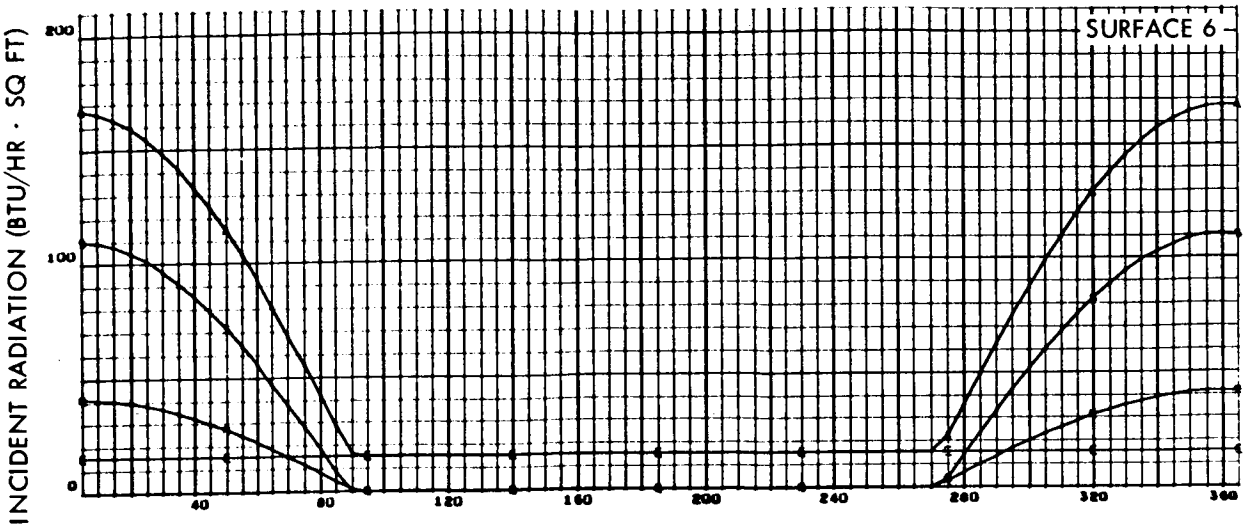
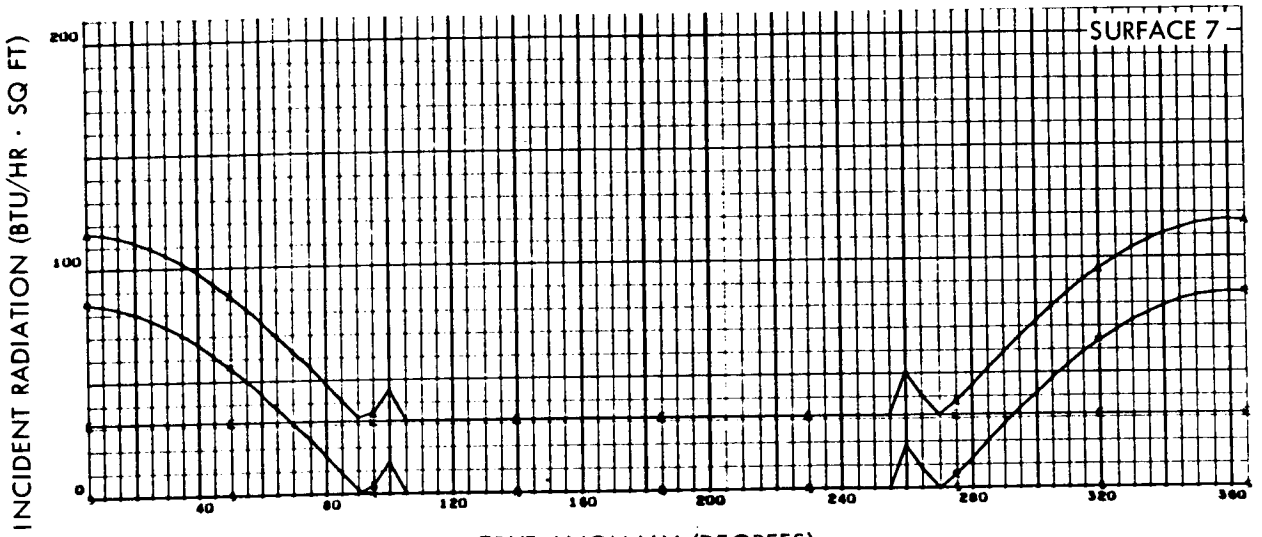


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 5 of 8)





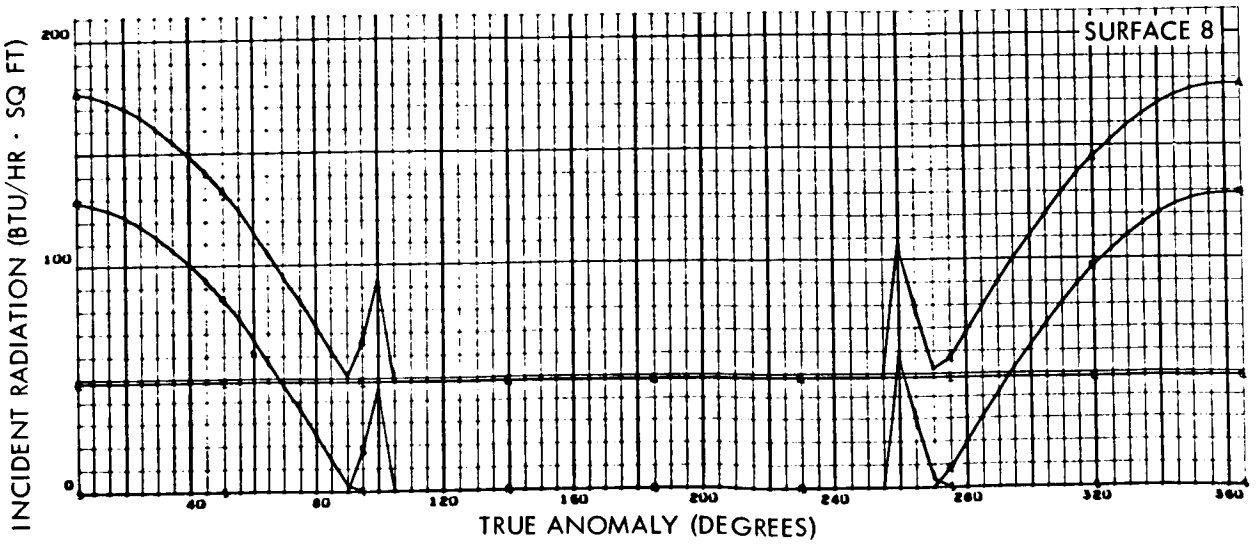
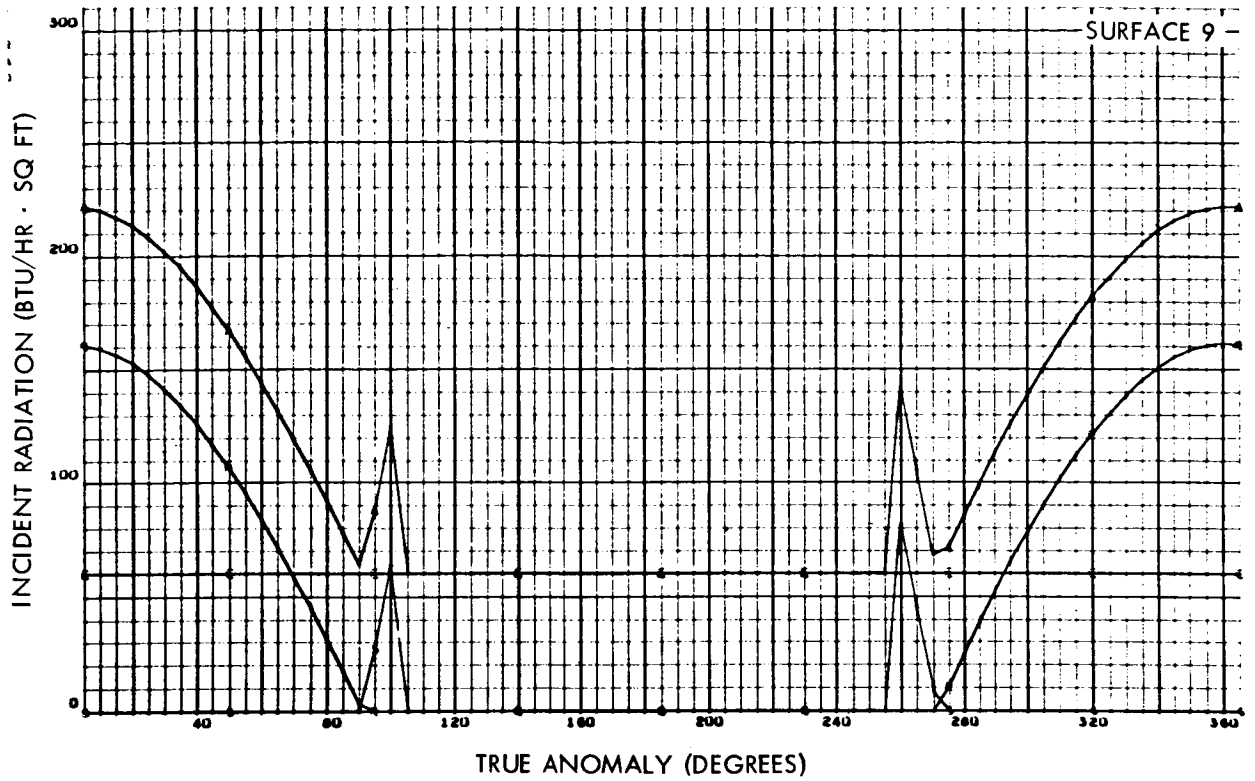


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 6 of 8)



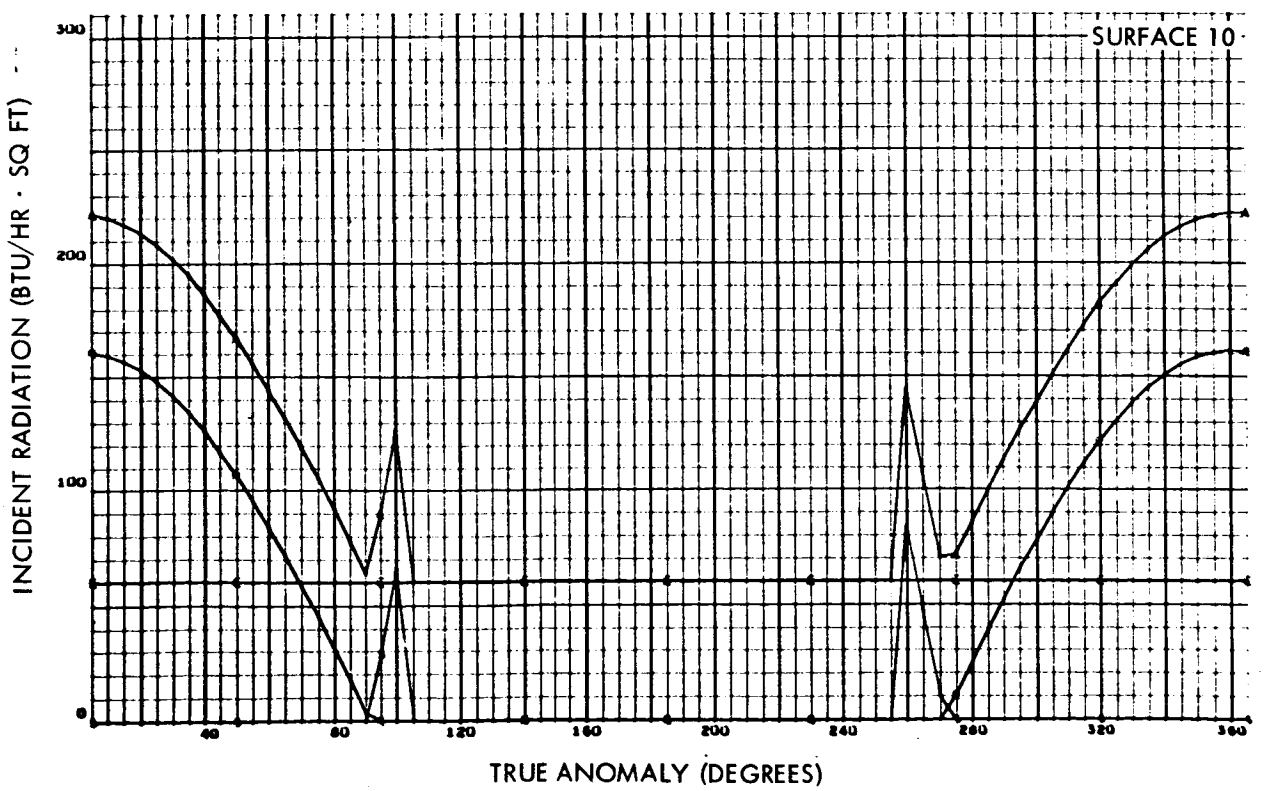
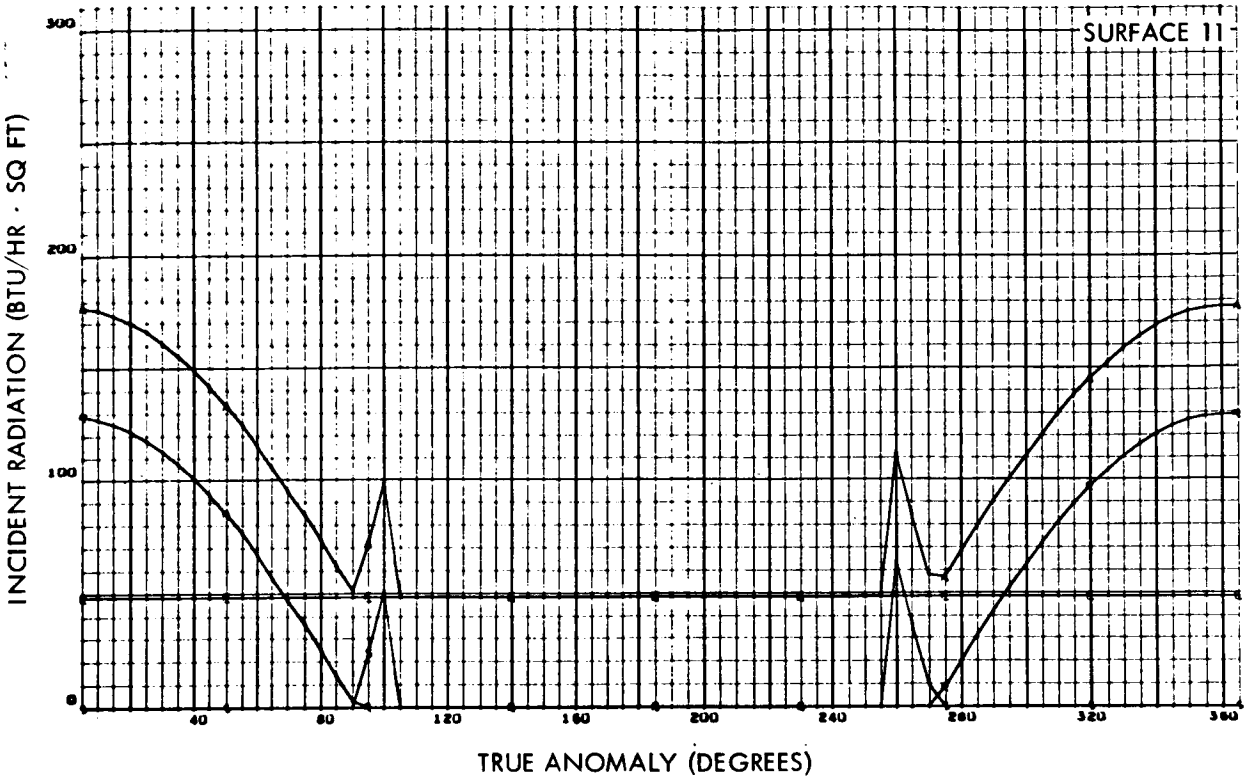


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 7 of 8)



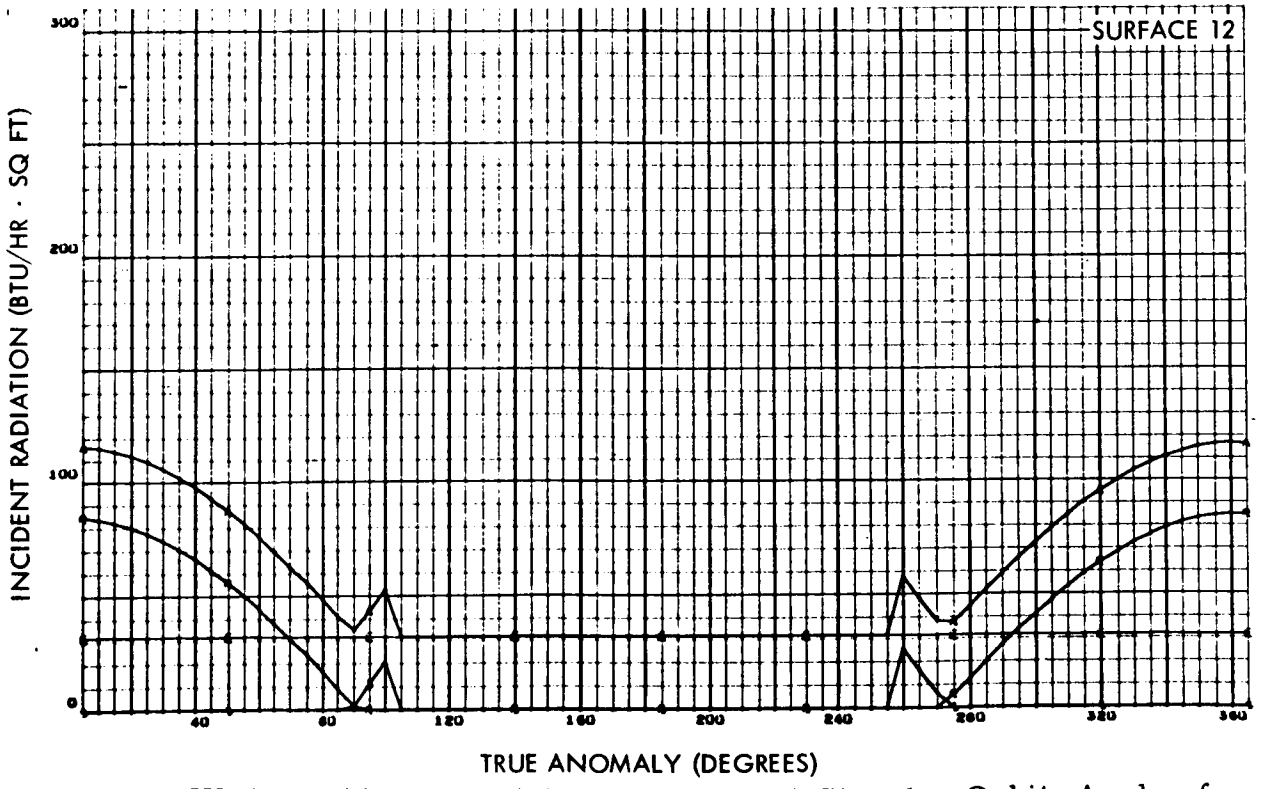


Figure IU-4a. 100-Nautical-Mile Equatorial Circular Orbit; Angle of Inclination: 0°; Launch Date: March 21; X-Tan (Sheet 8 of 8)

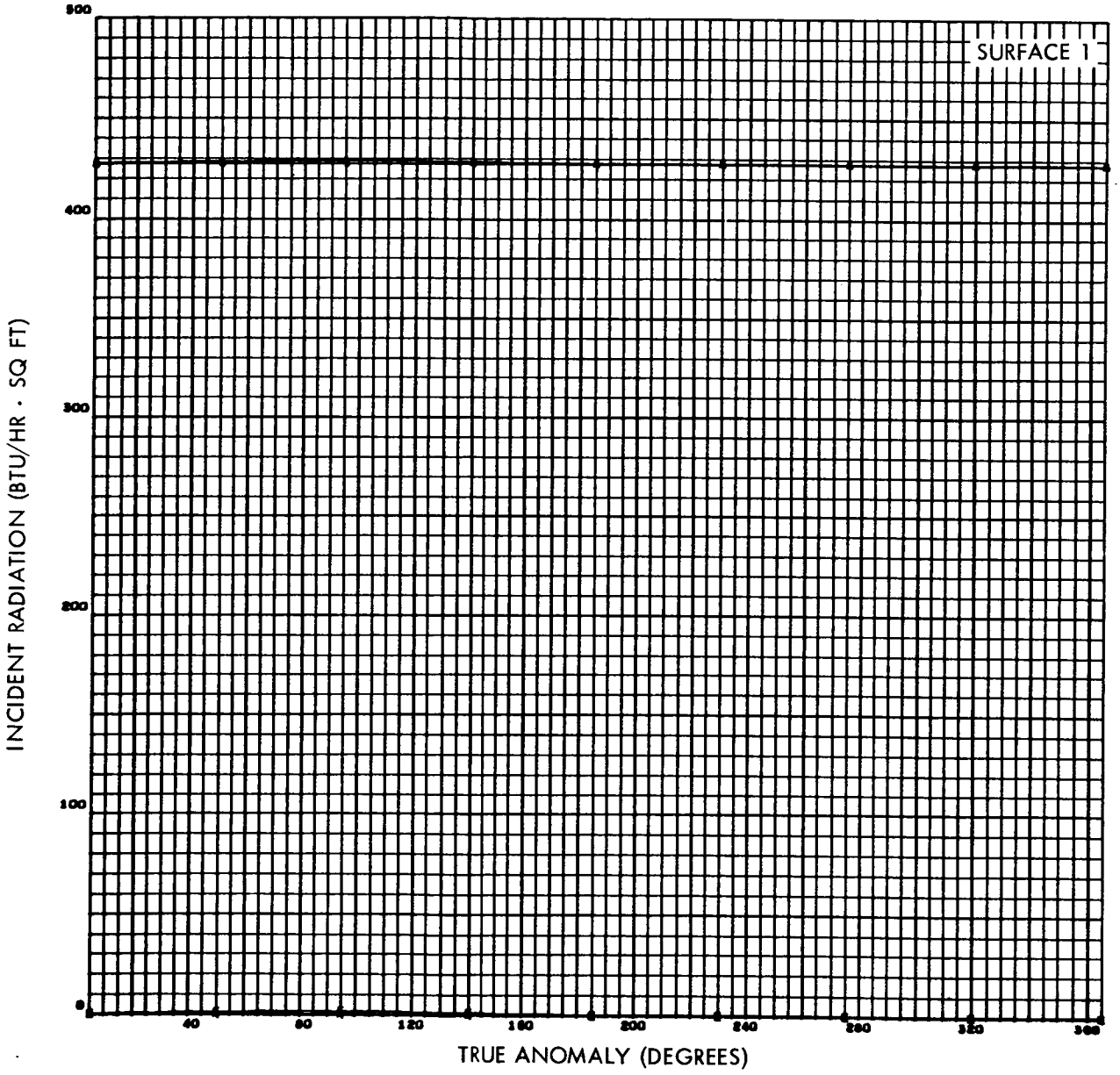


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 1 of 7)

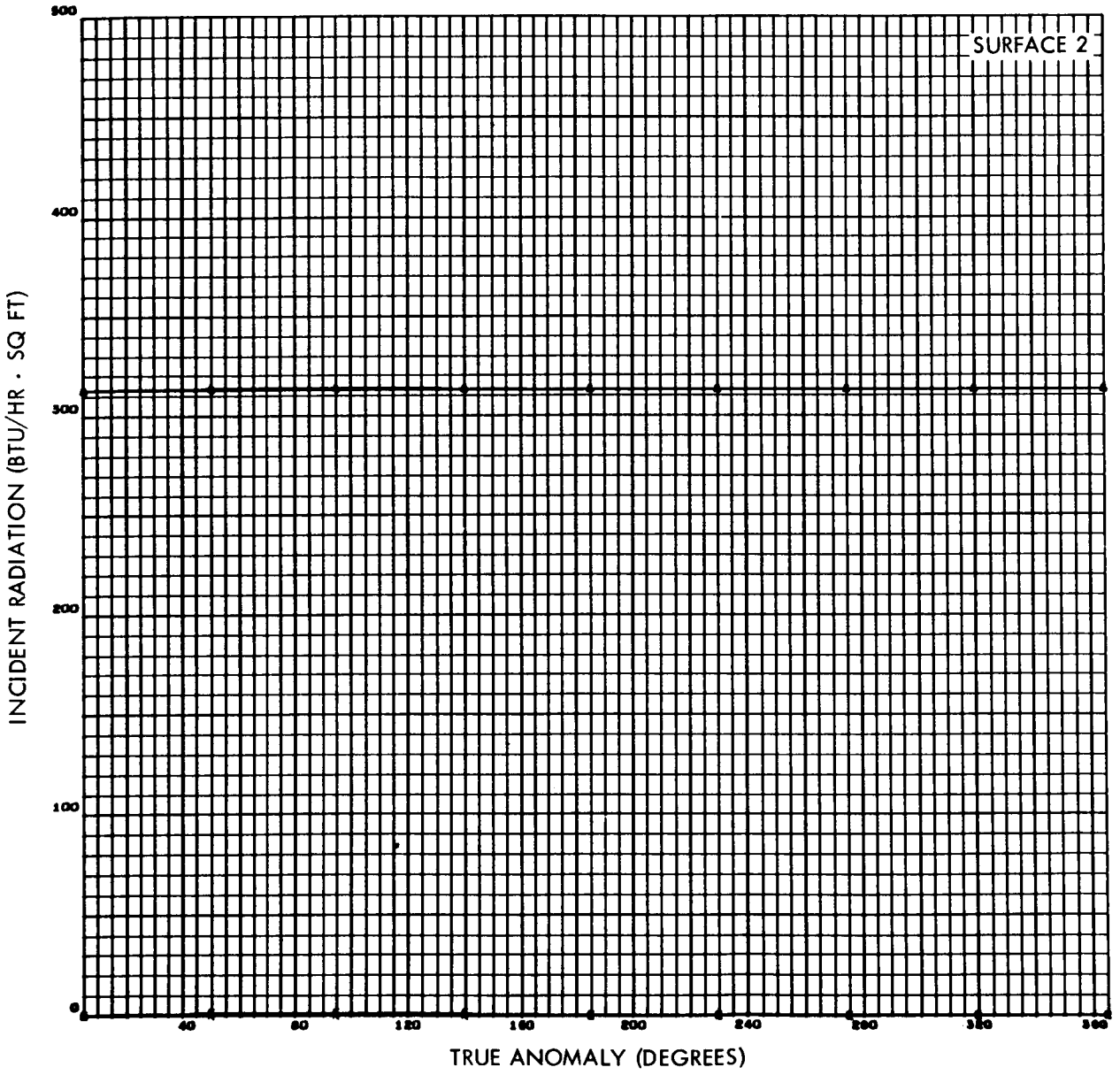


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 2 of 7)

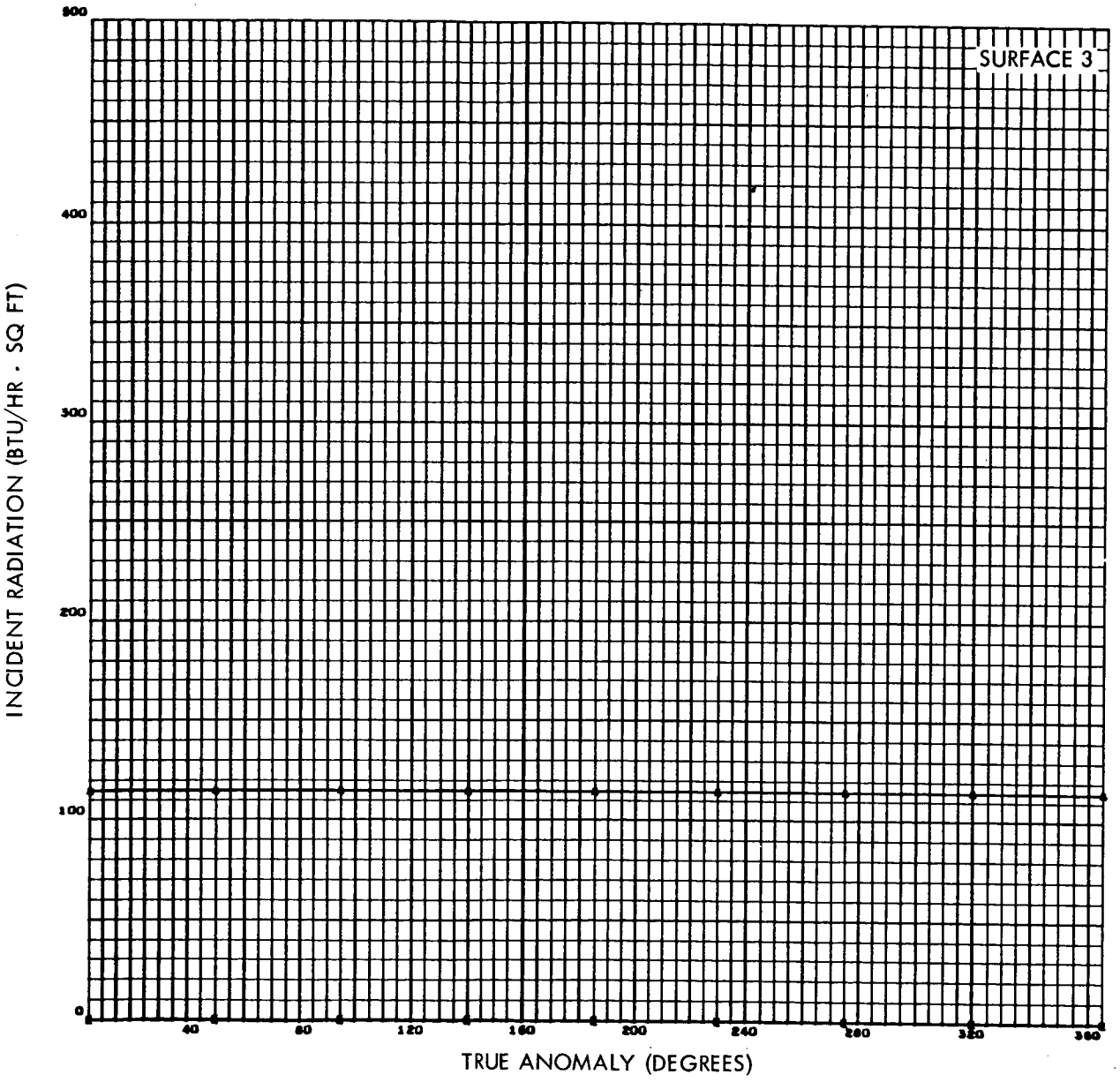


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 3 of 7)

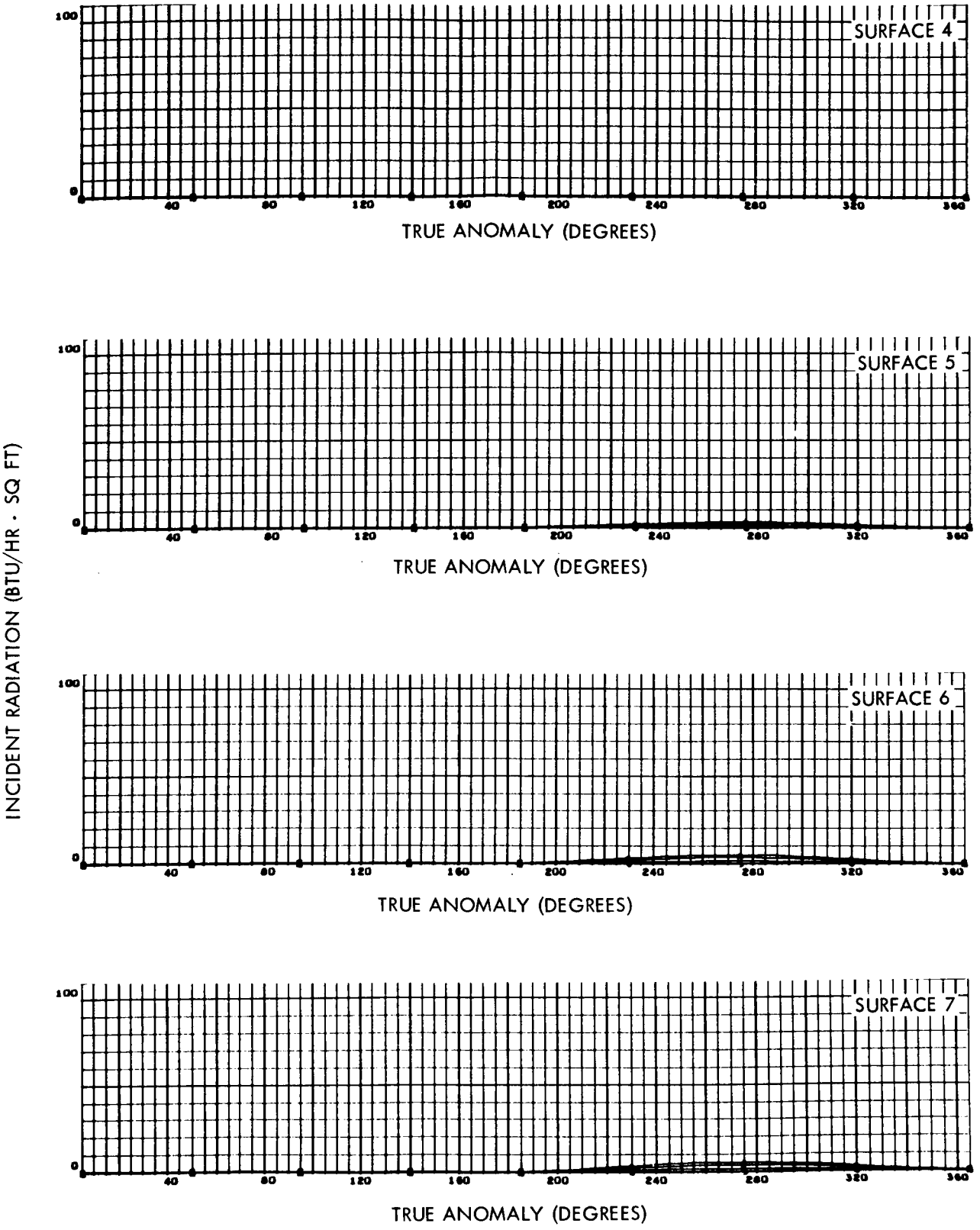


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 4 of 7)

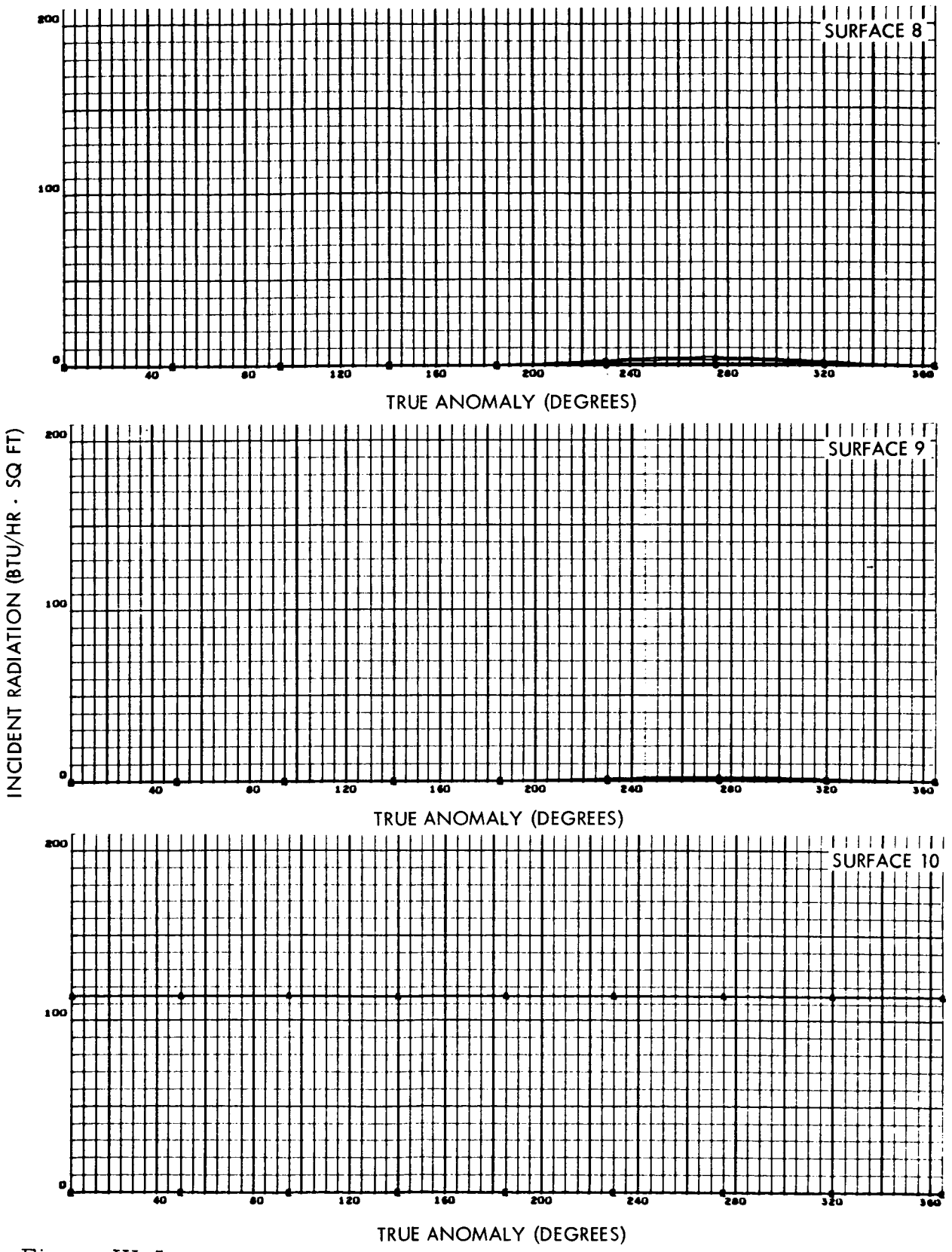


Figure IU-5a. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 5 of 7)

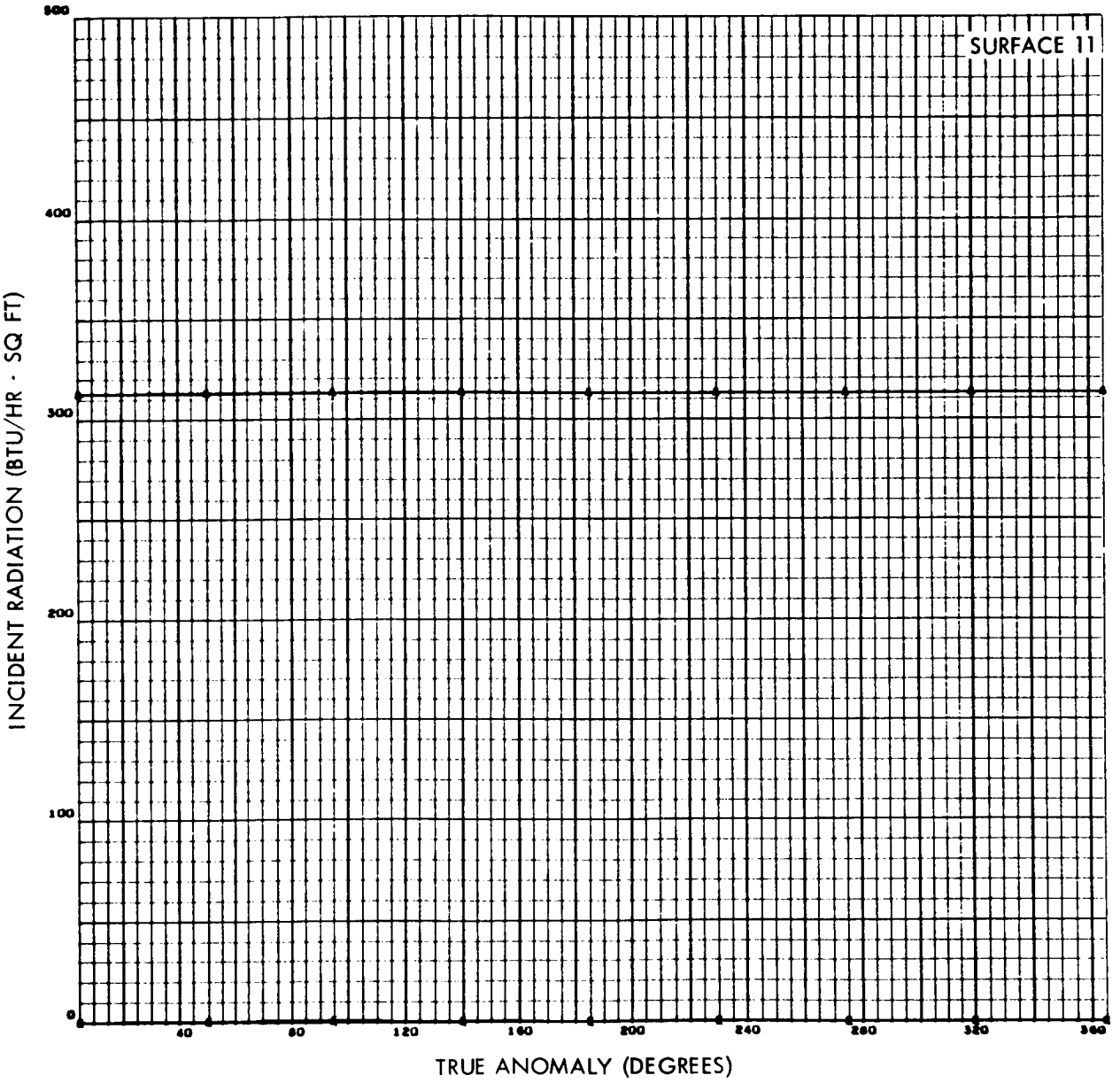


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 6 of 7)

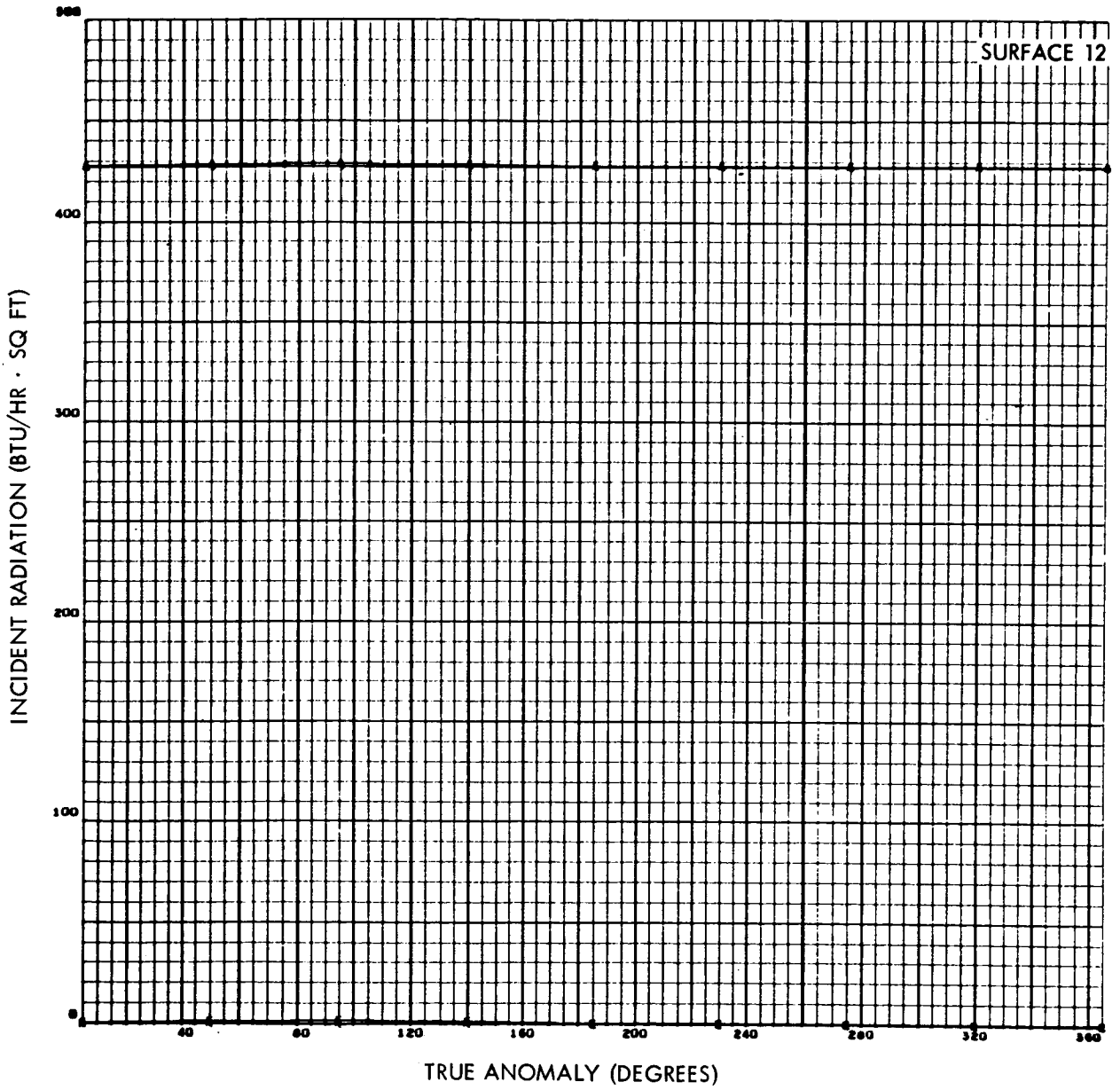


Figure IU-5a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; Y-Sol (Sheet 7 of 7)

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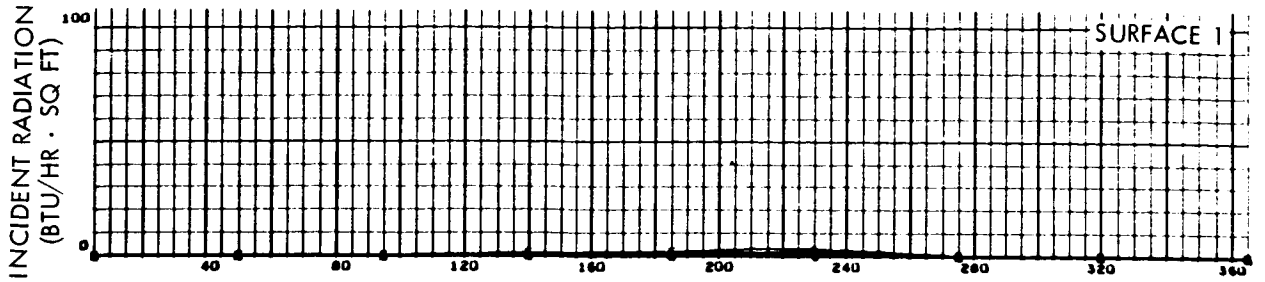
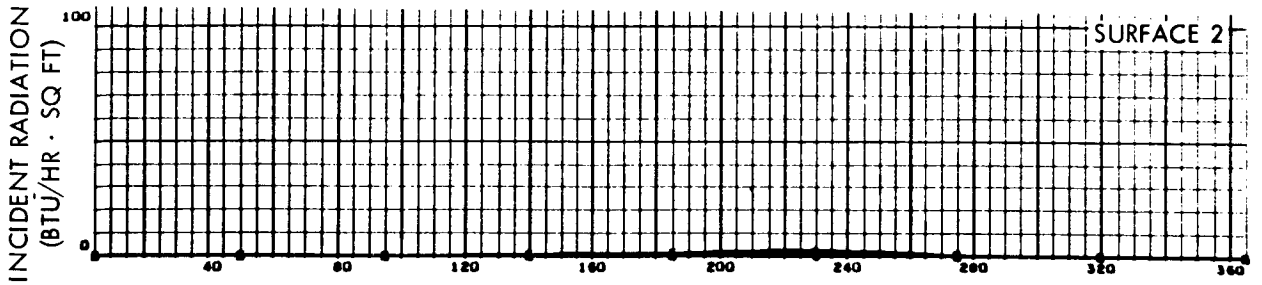


TRUE ANOMALY (DEGREES)



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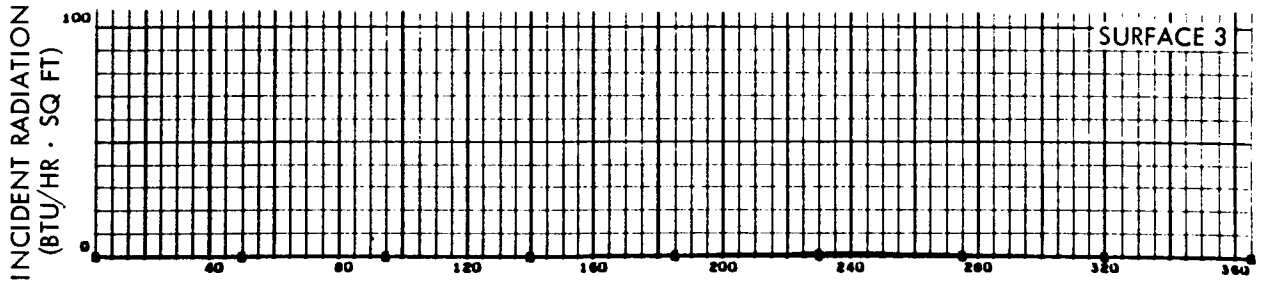

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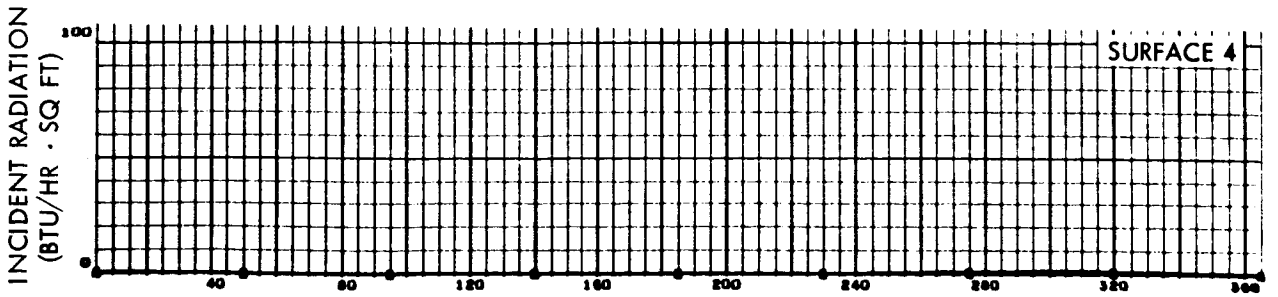
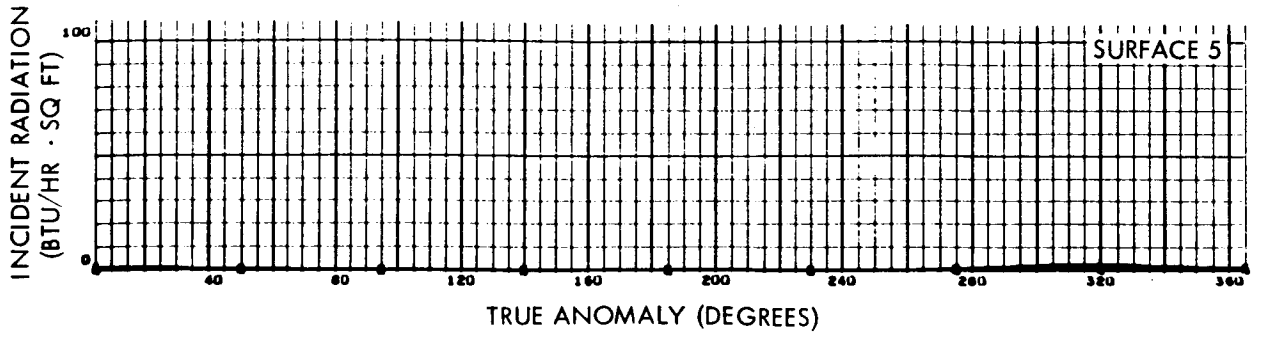
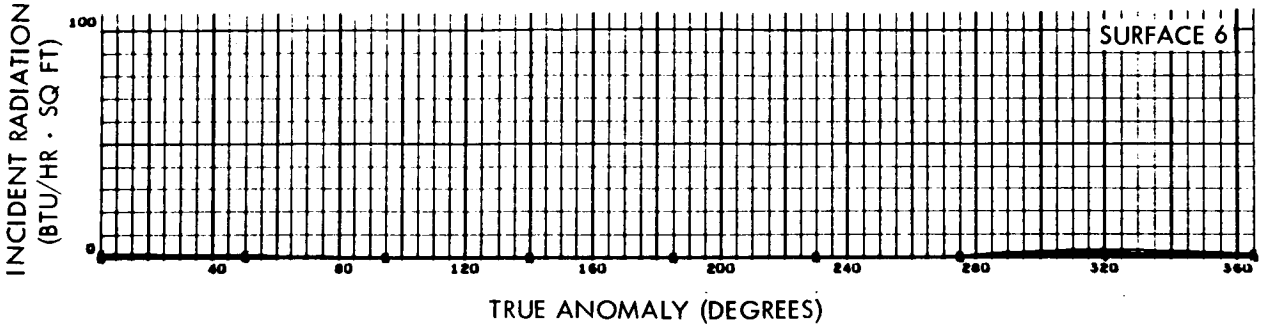
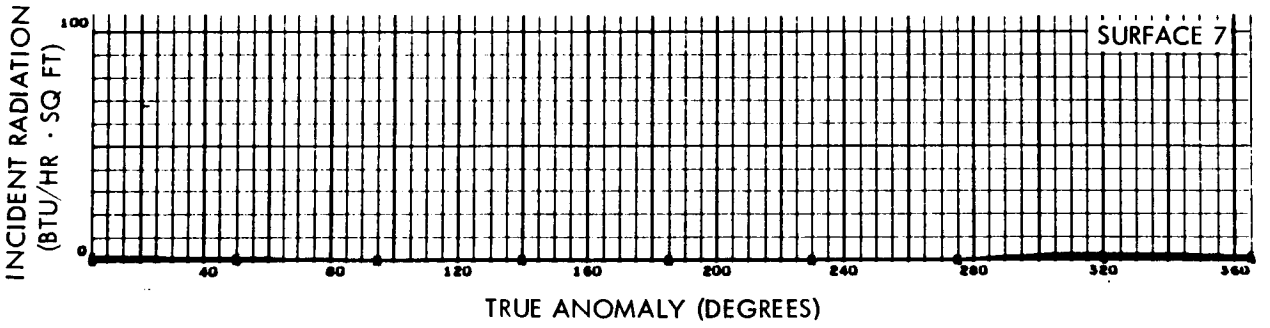


TRUE ANOMALY (DEGREES)

Figure IU-5b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Sol (Sheet 1 of 3)







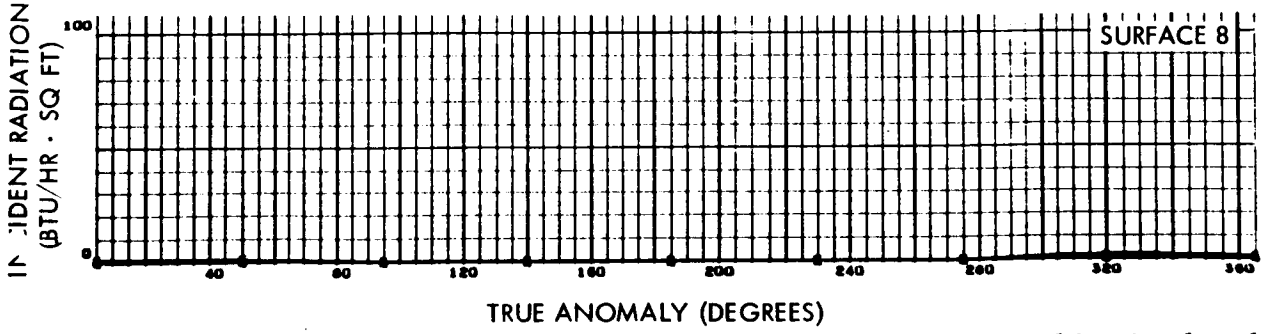


Figure IU-5b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Sol (Sheet 2 of 3)

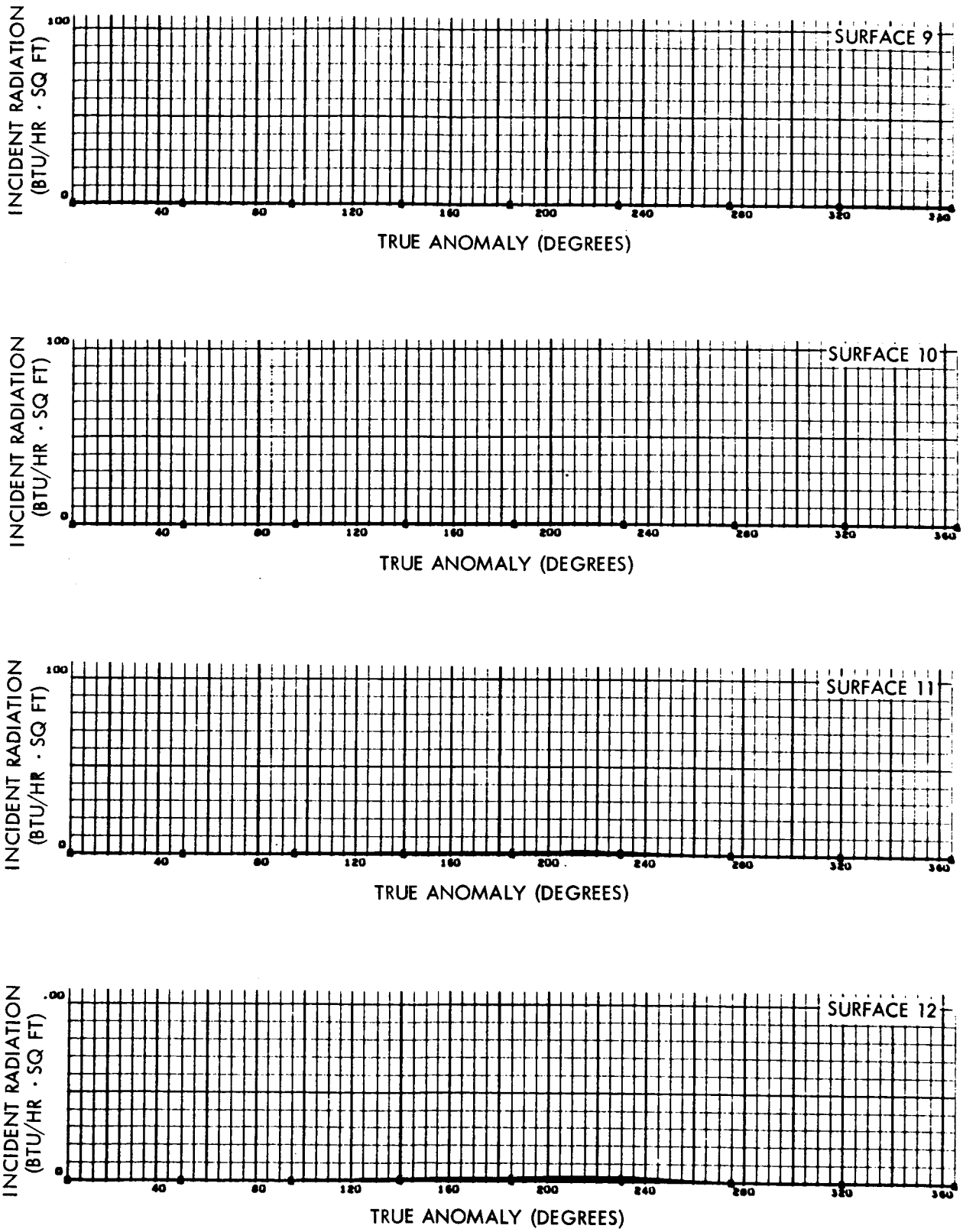


Figure IU-5b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Sol (Sheet 3 of 3)

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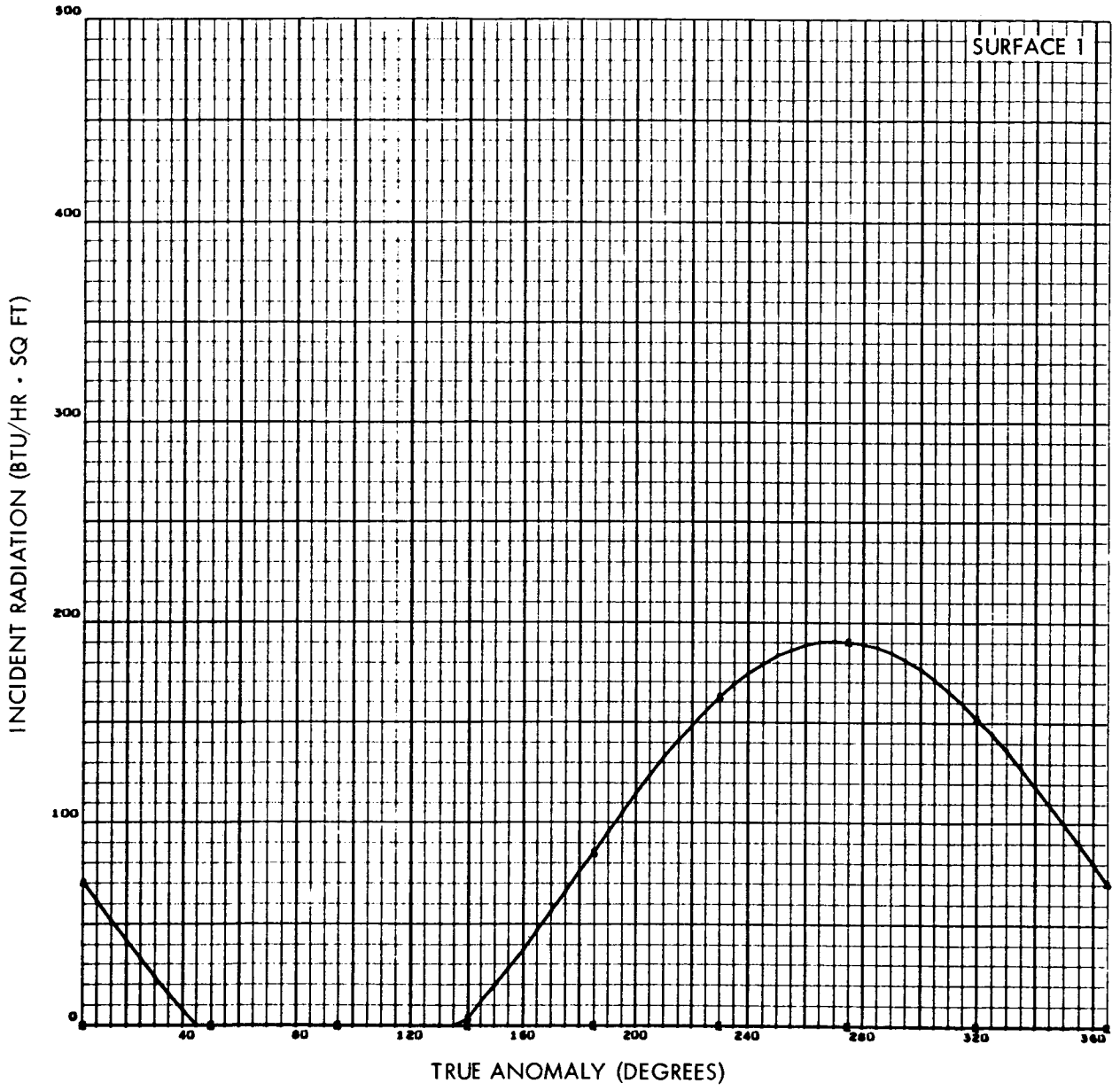


Figure IU-5c. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 1 of 10)

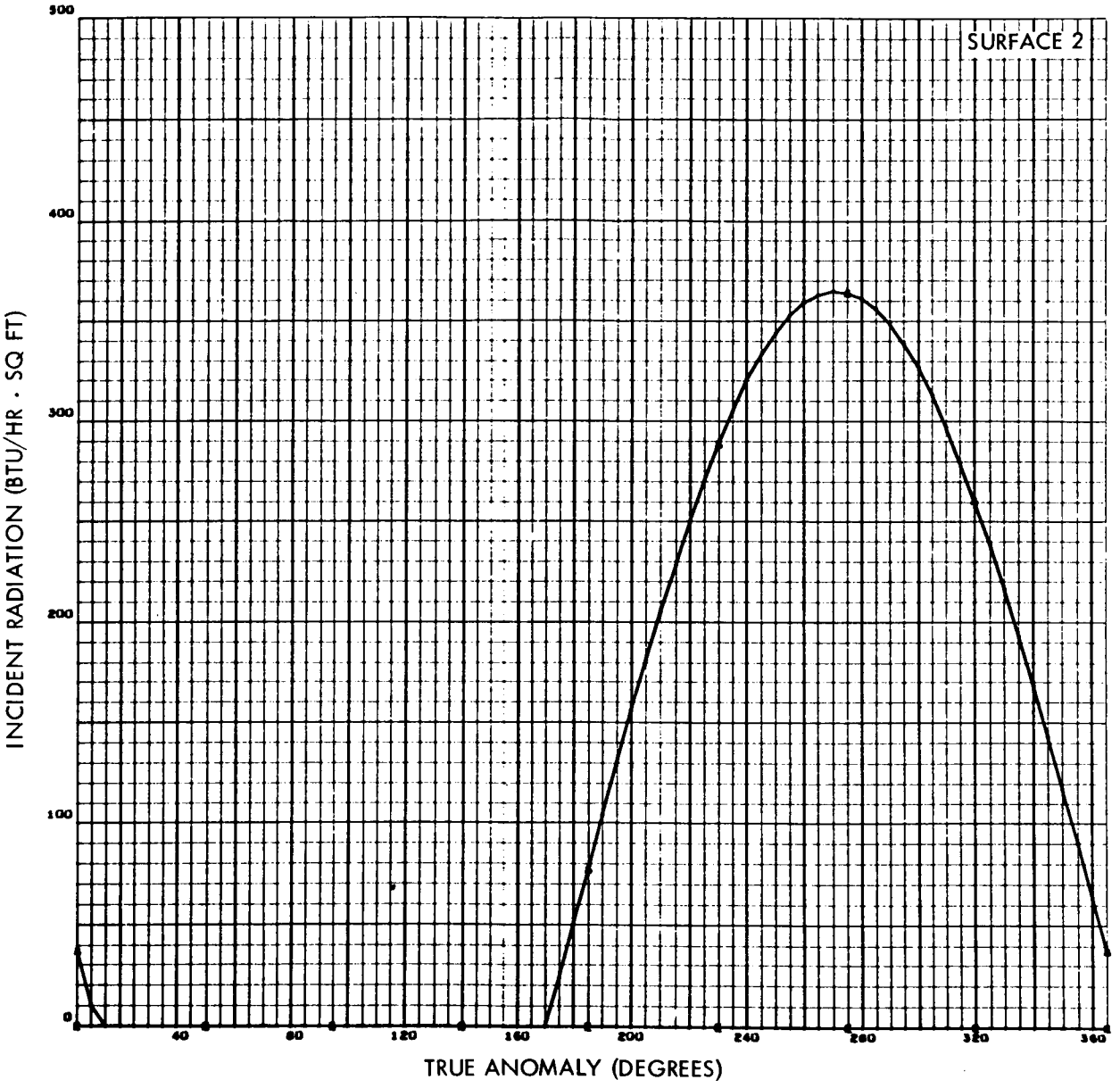


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 2 of 10)

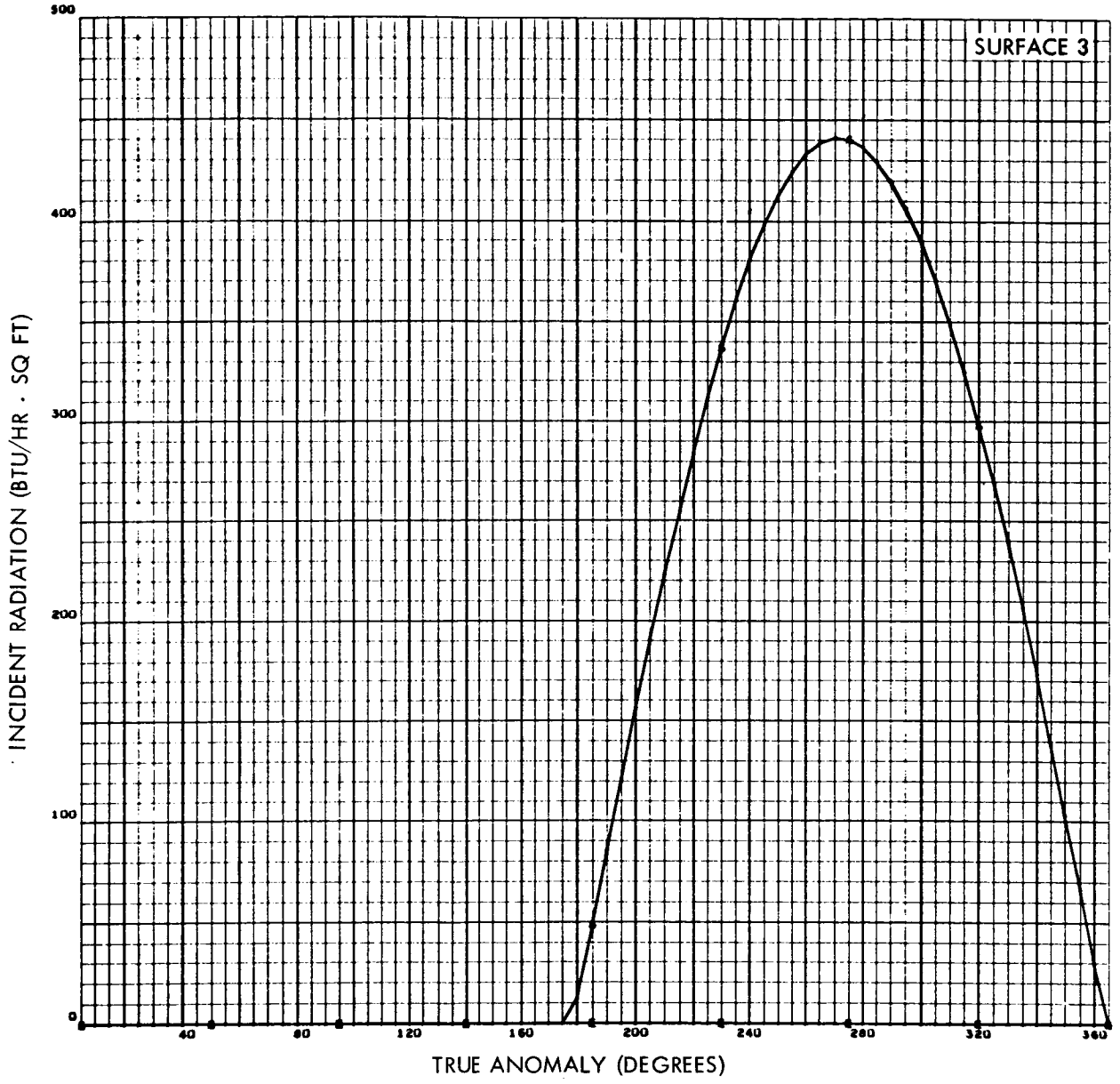


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 3 of 10)

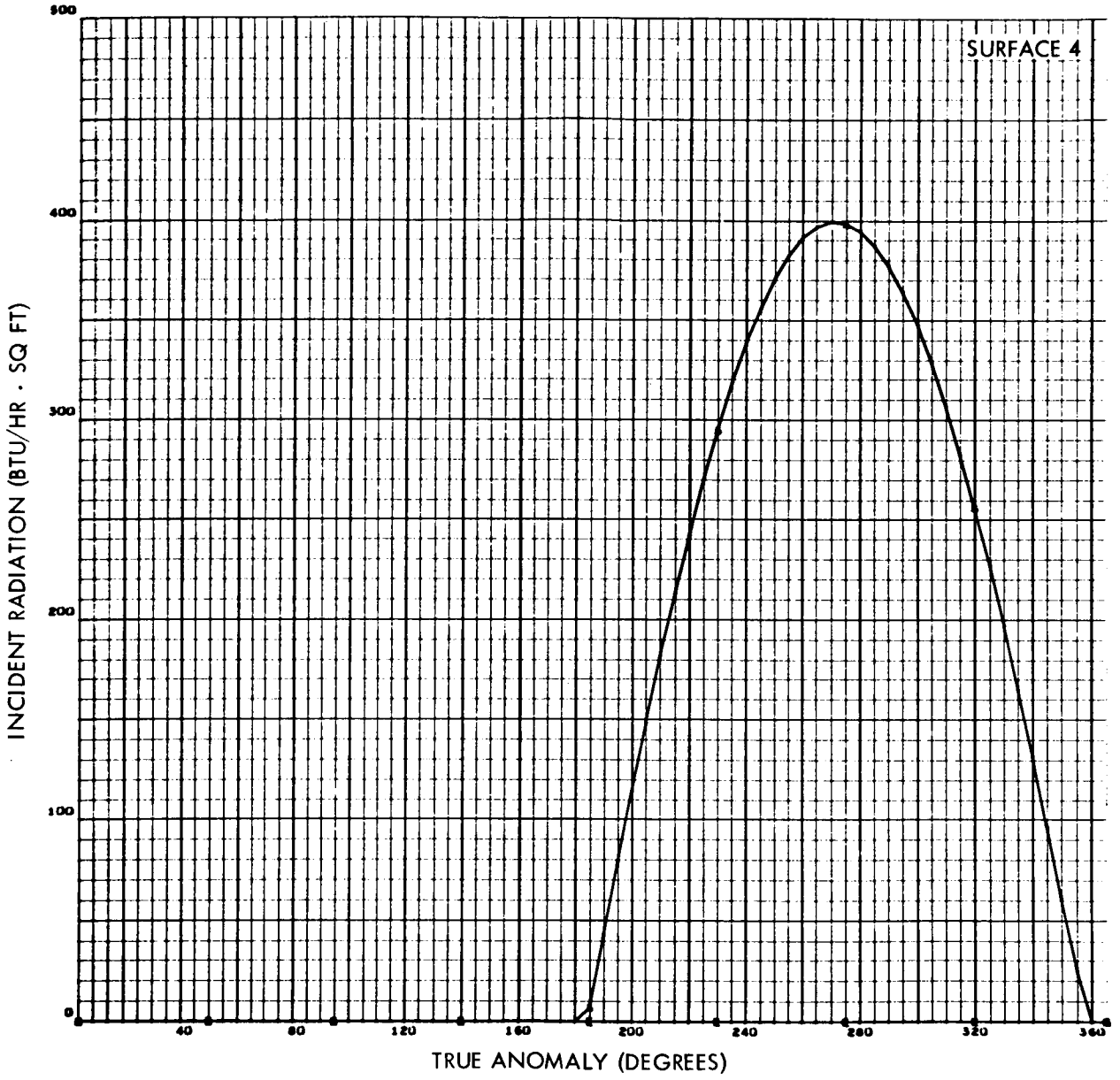
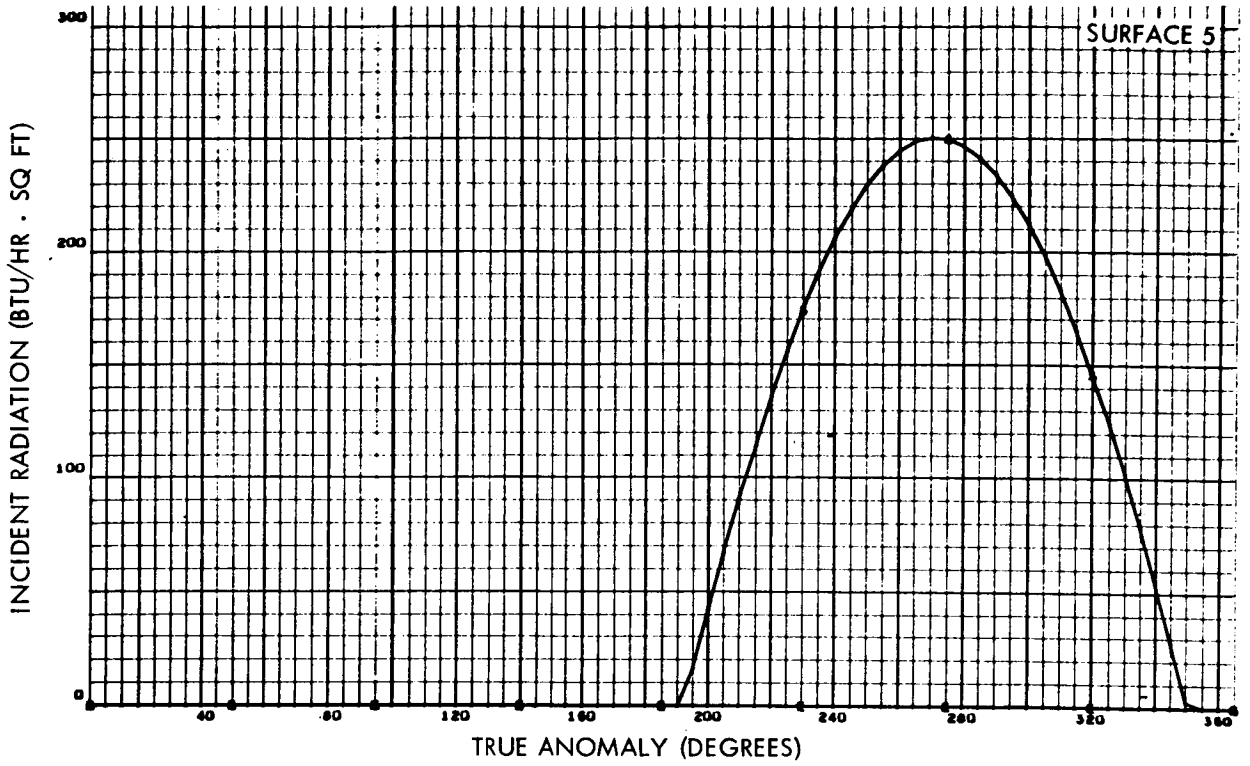


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 4 of 10)



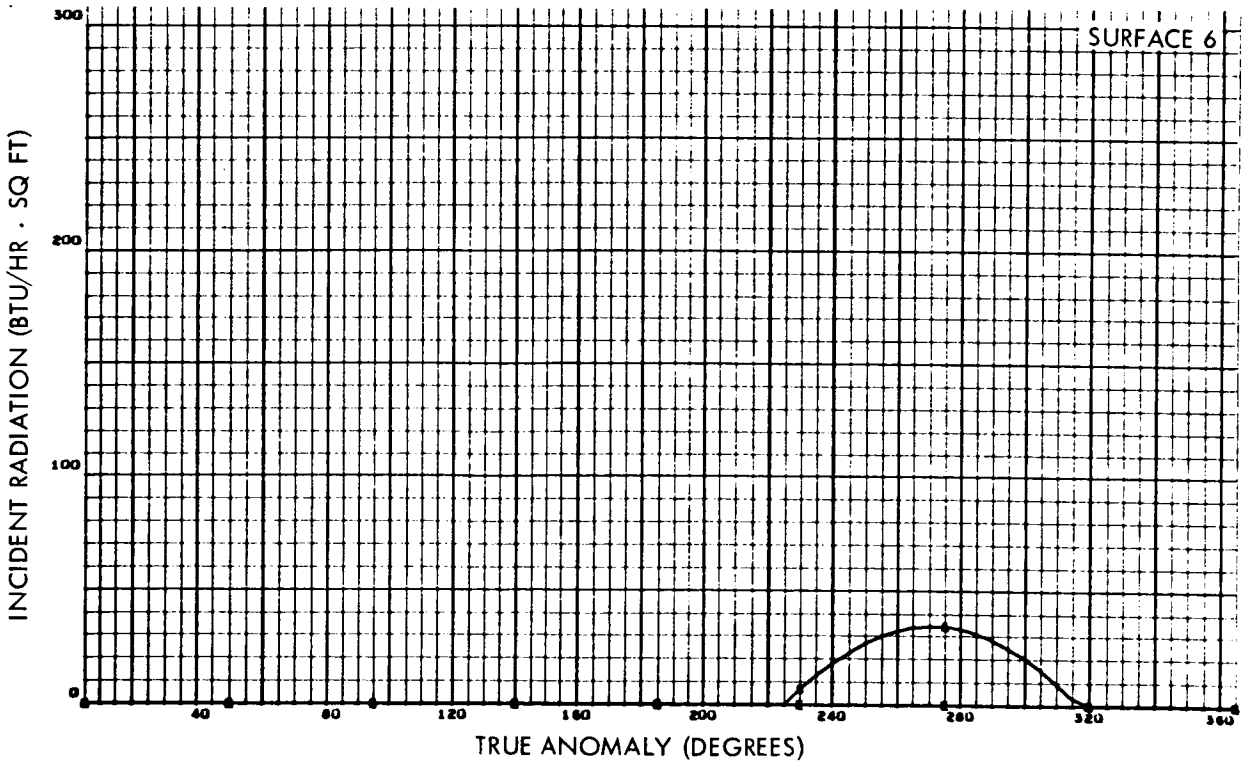
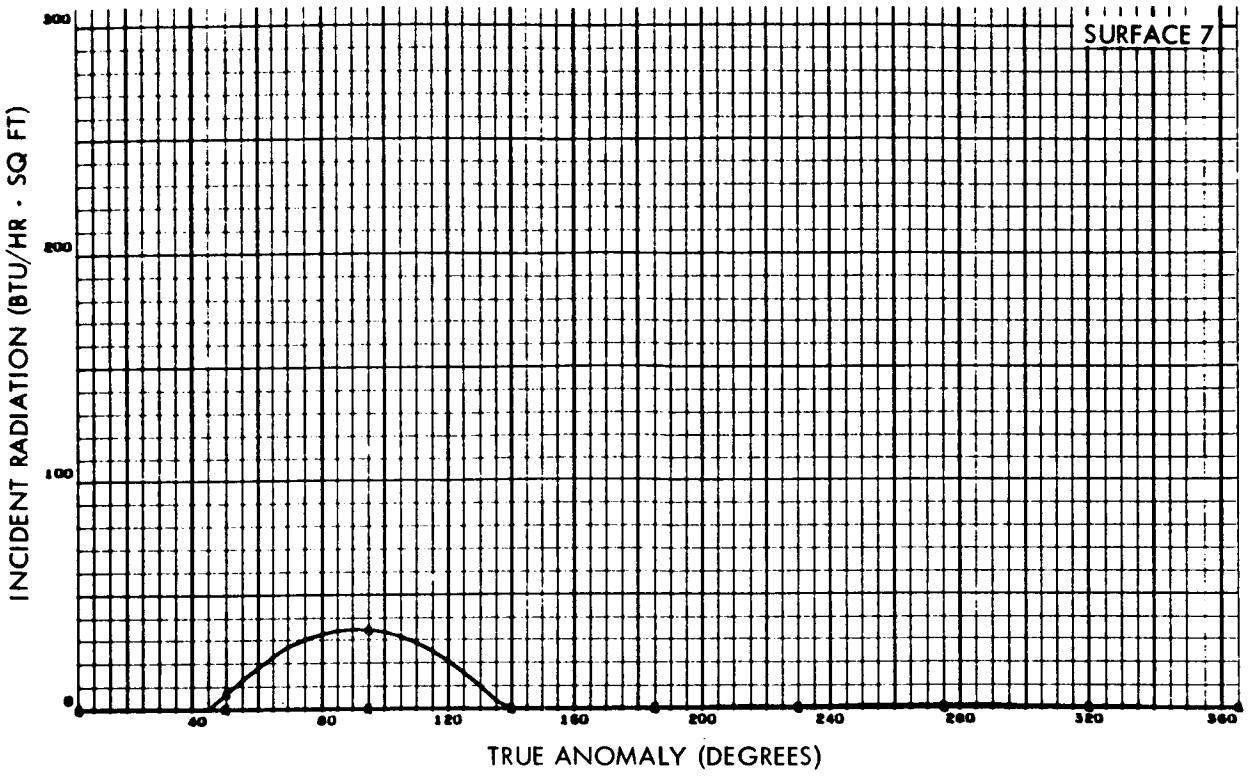


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 5 of 10)



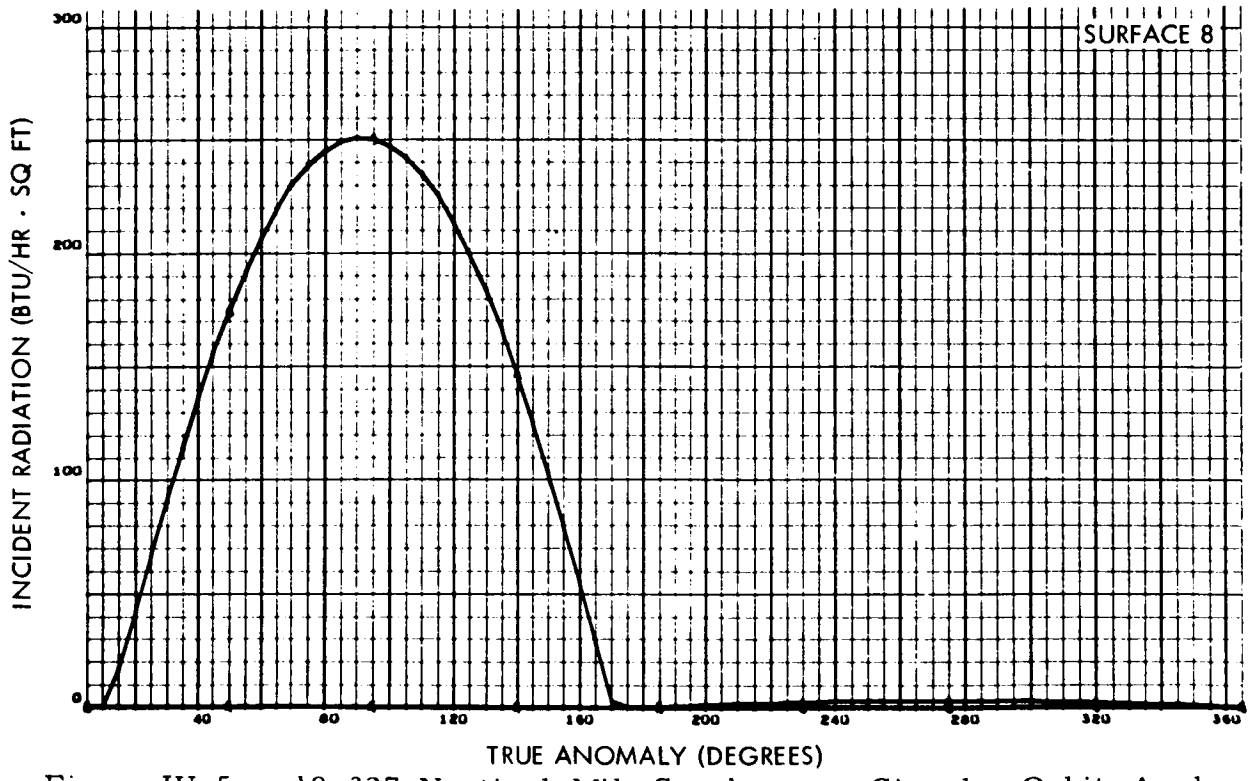


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 6 of 10)

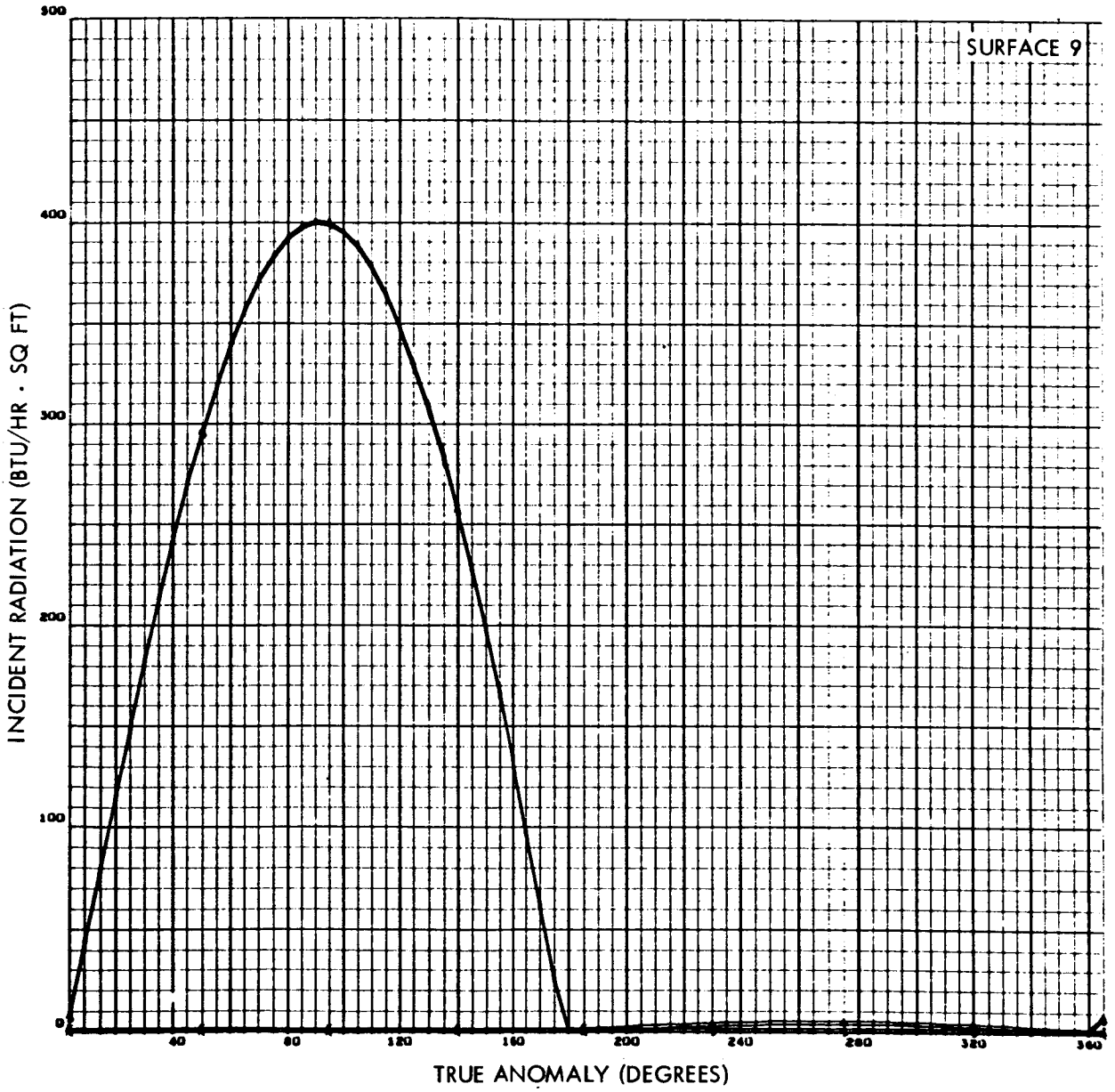


Figure IU-5c. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 7 of 10)

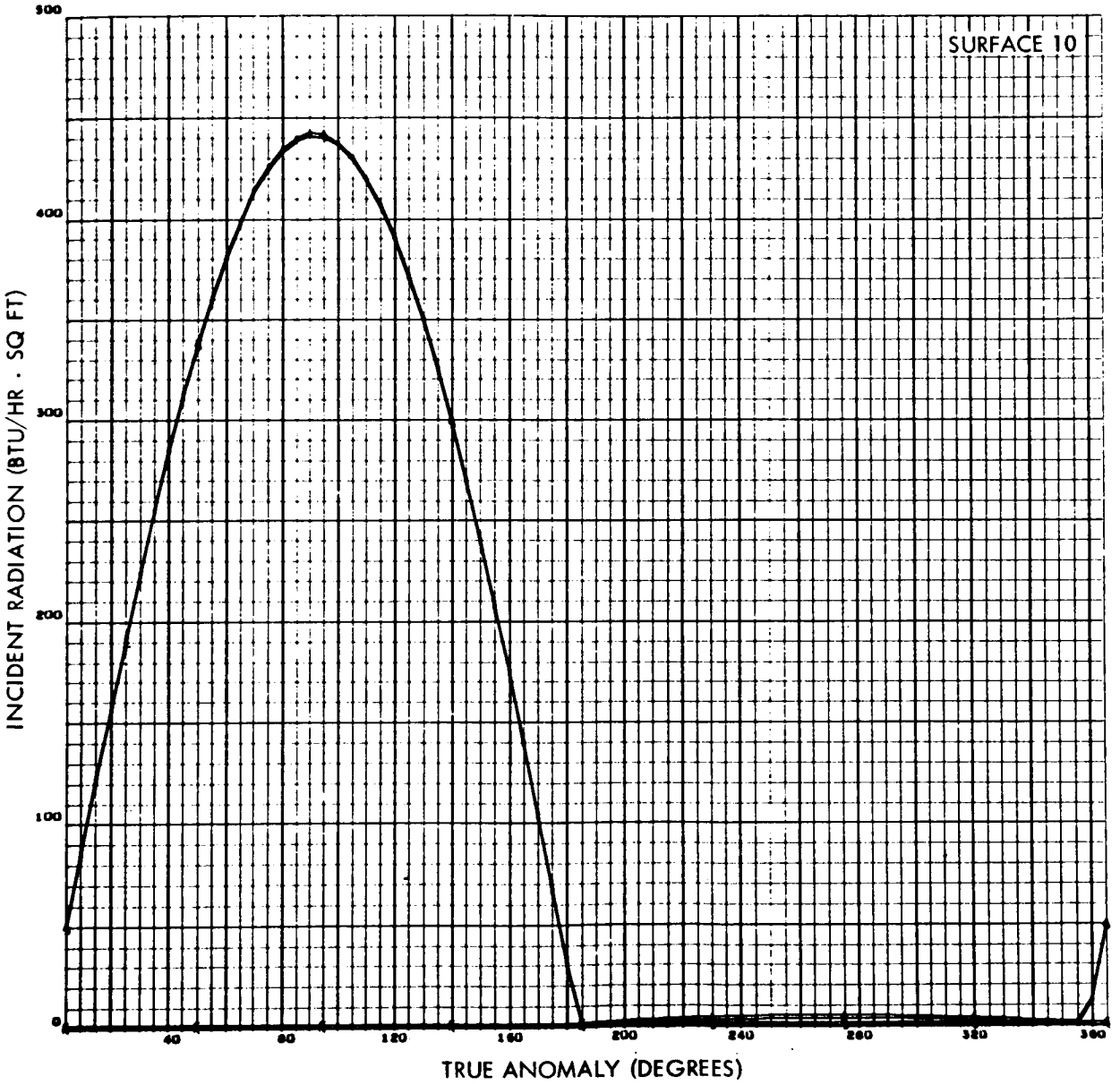


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 8 of 10)

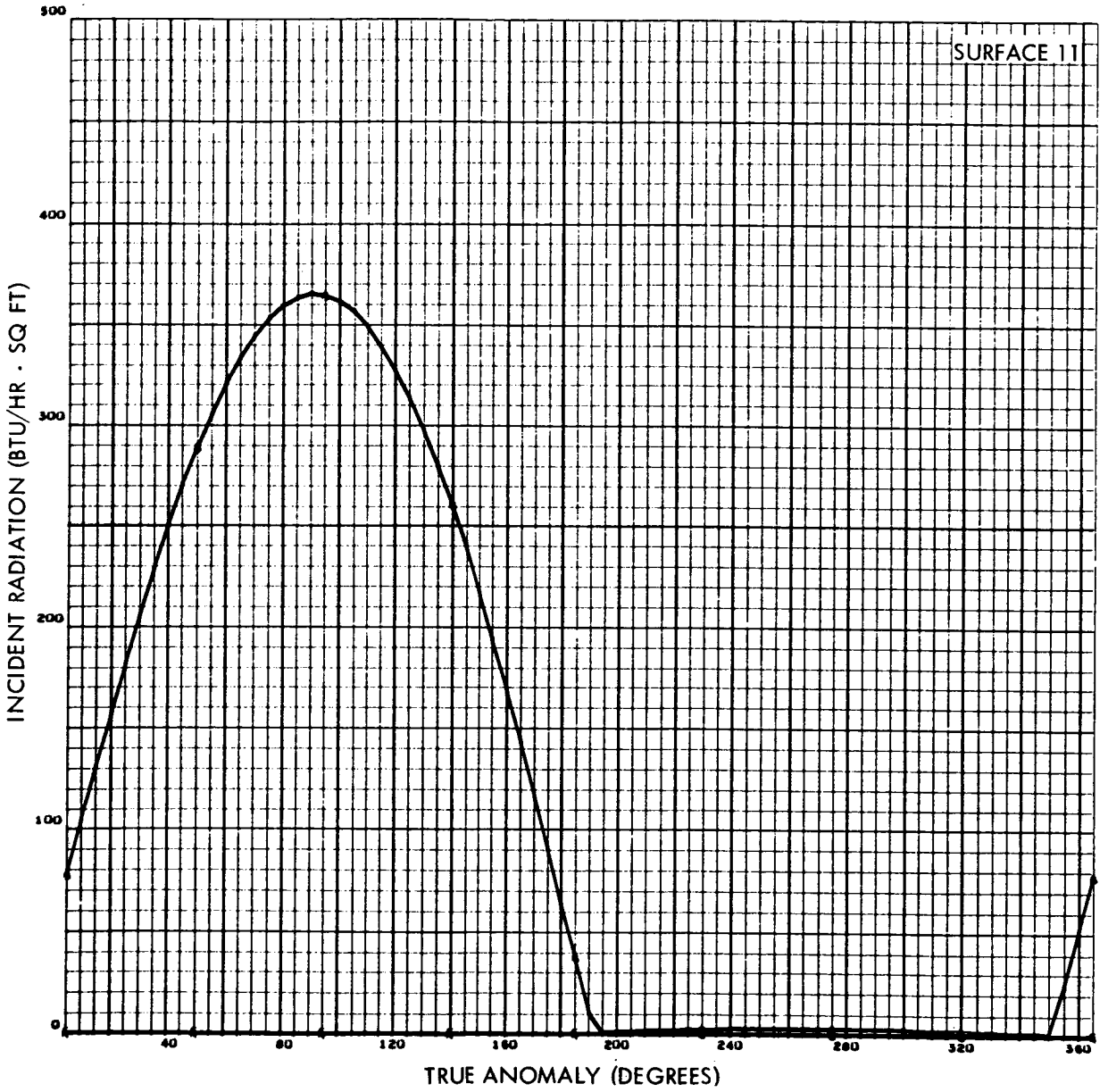


Figure IU-5c. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 9 of 10)

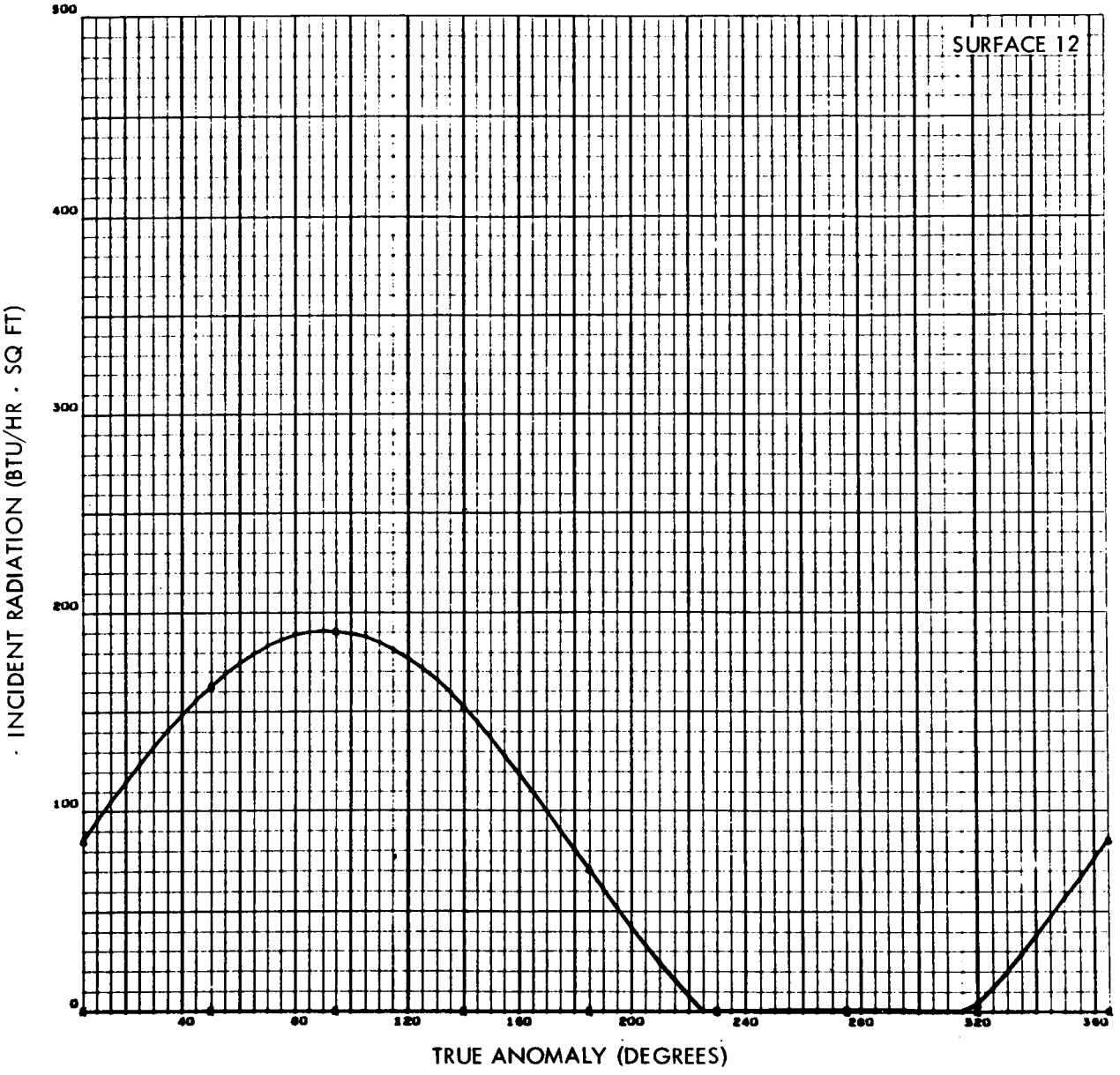


Figure IU-5c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 10° (Continuous Solar Exposure); Launch Date: March 21; X-Tan (Sheet 10 of 10)

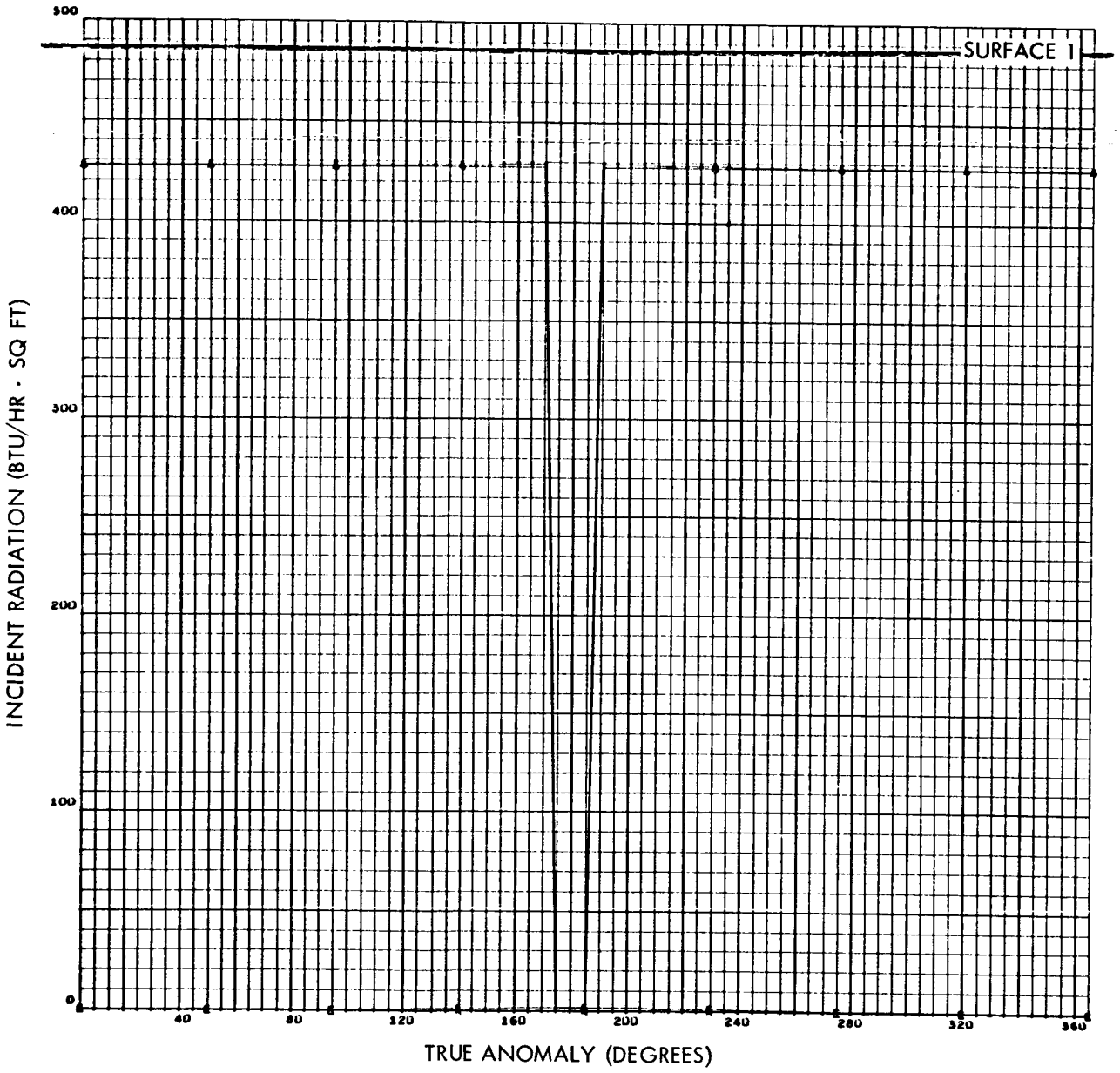


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 1 of 7)

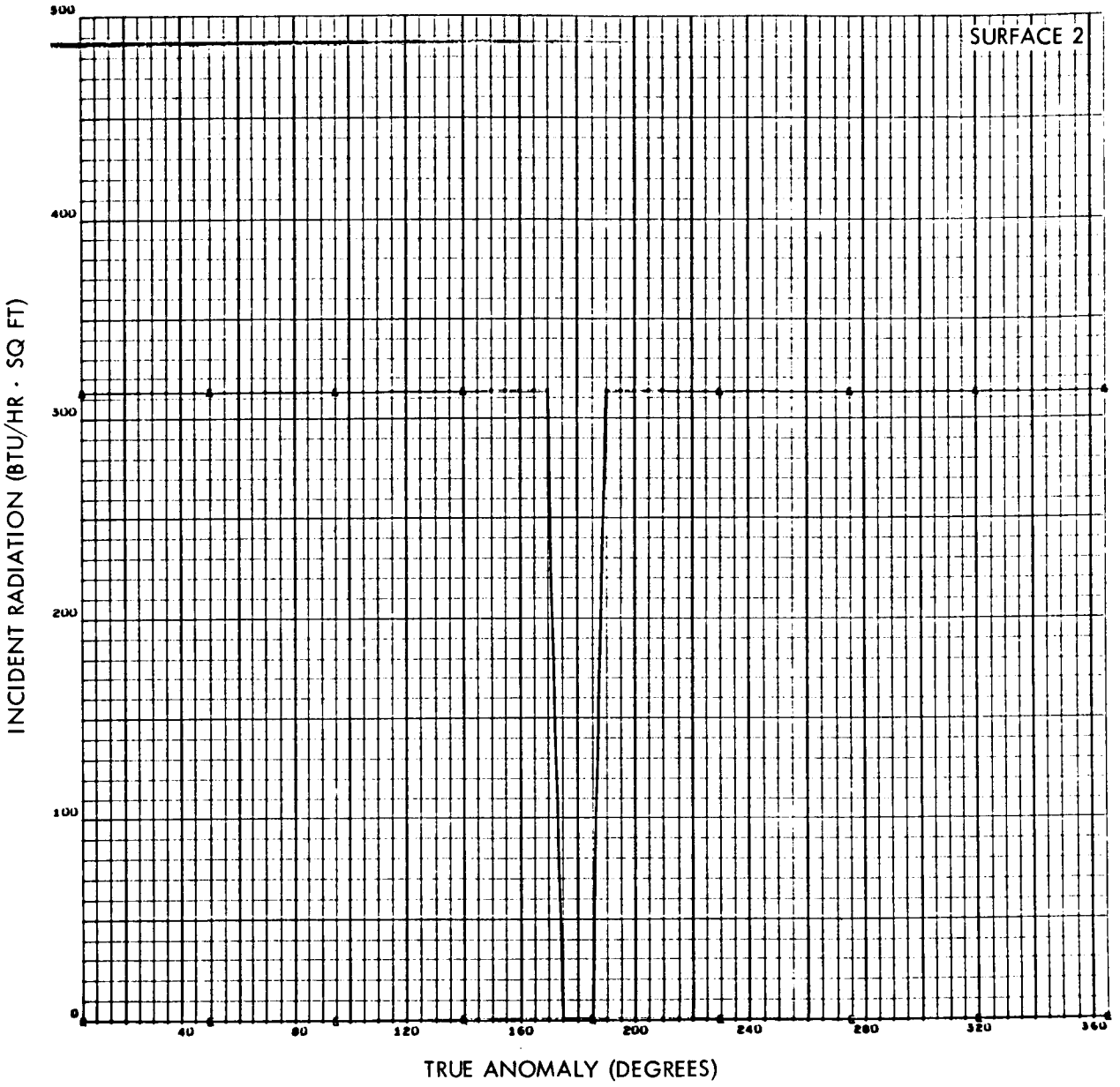


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 2 of 7)

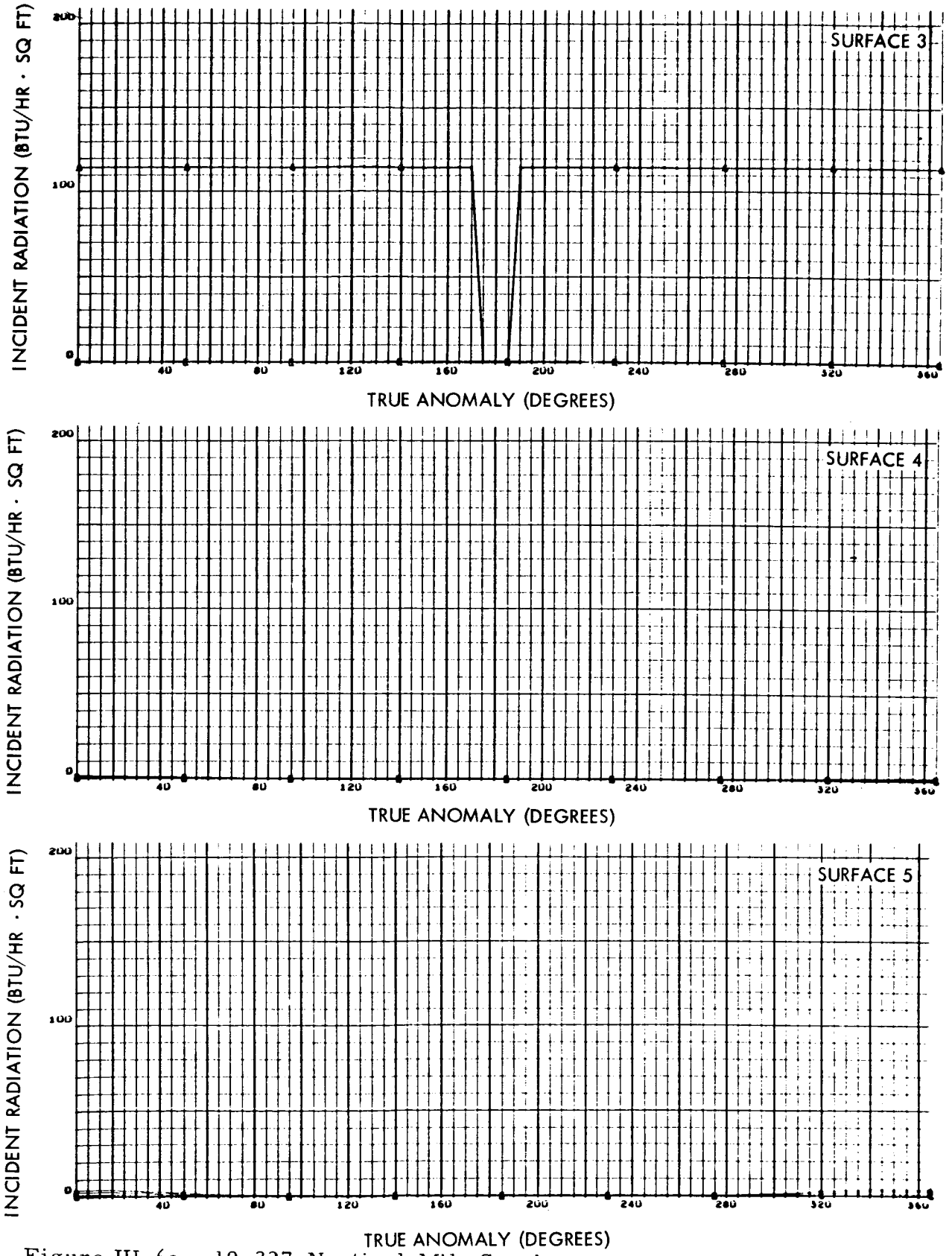


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 3 of 7)

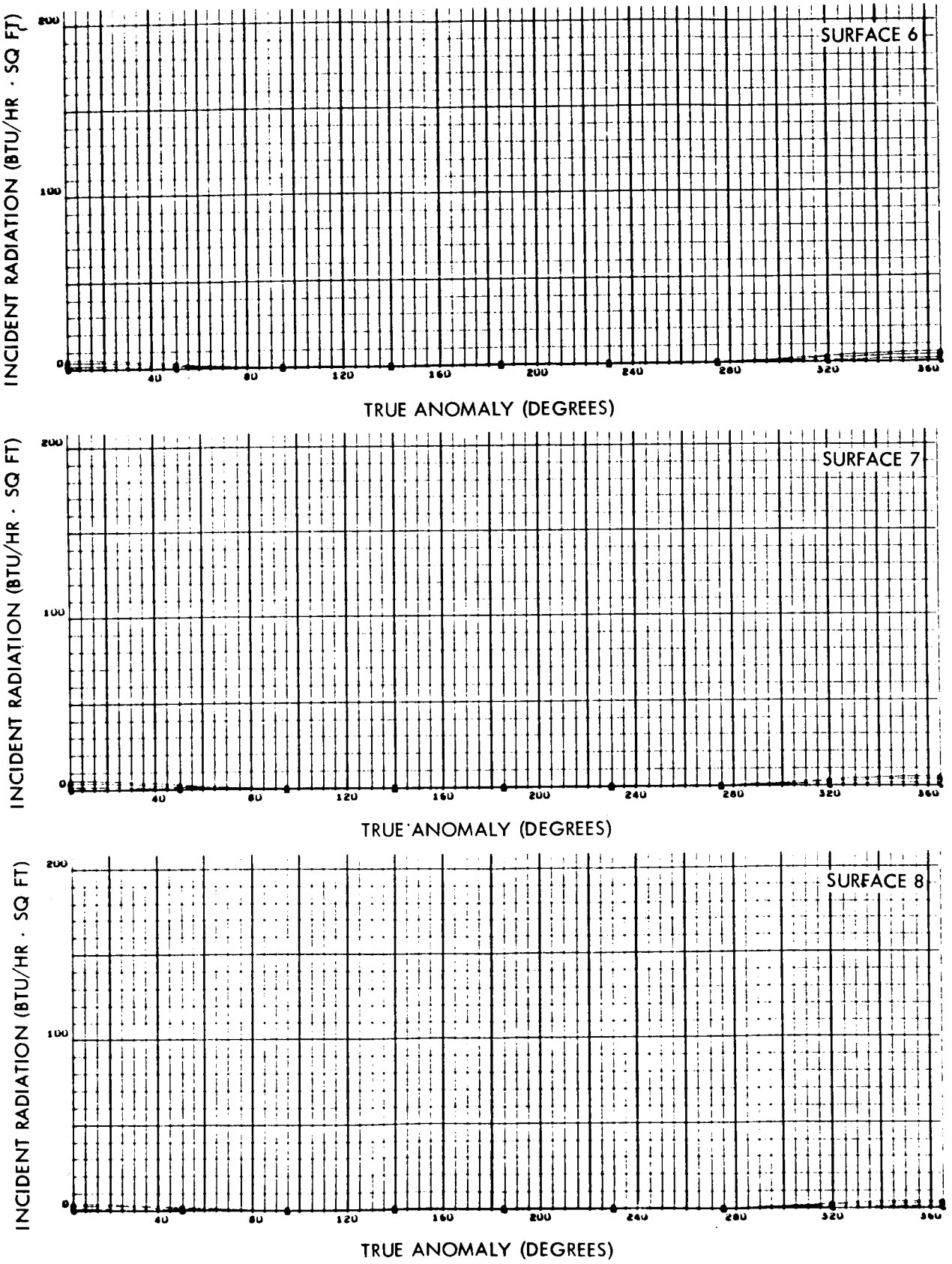
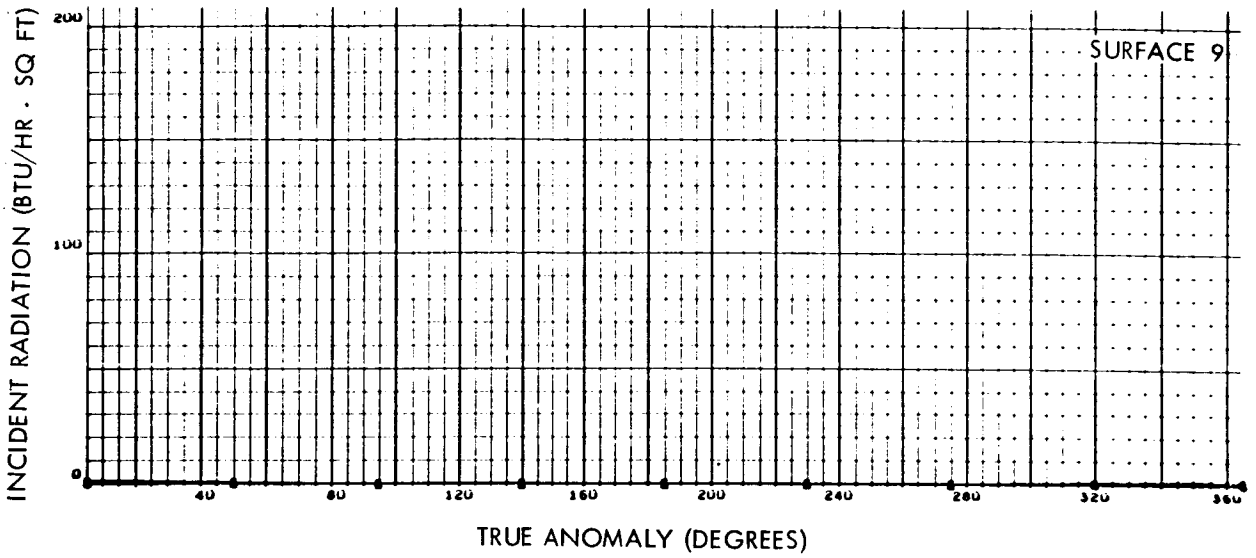


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 4 of 7)



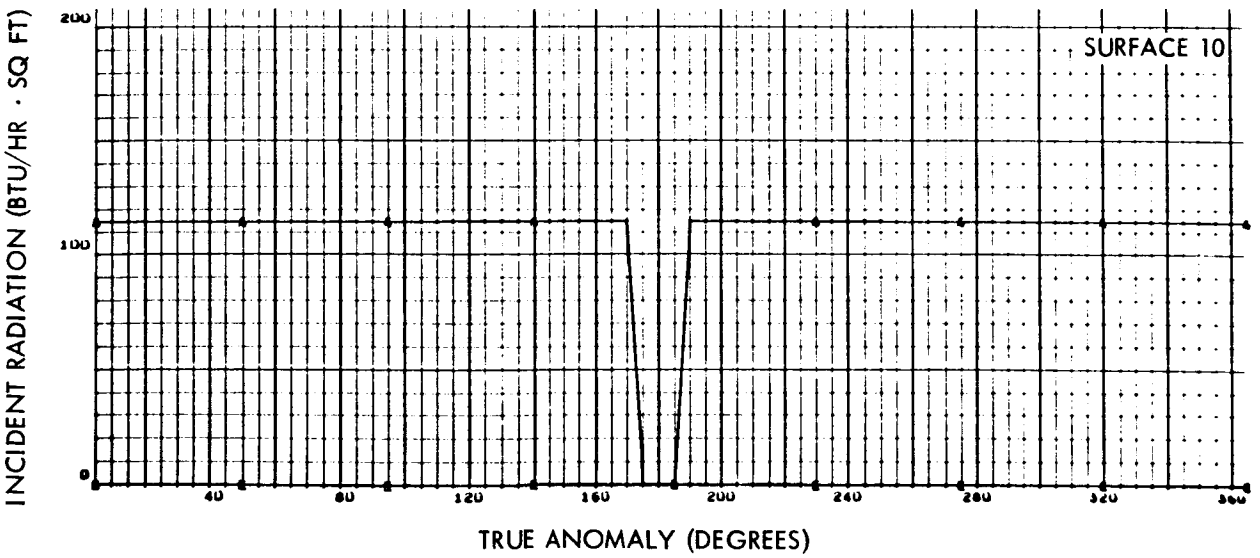


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 5 of 7)

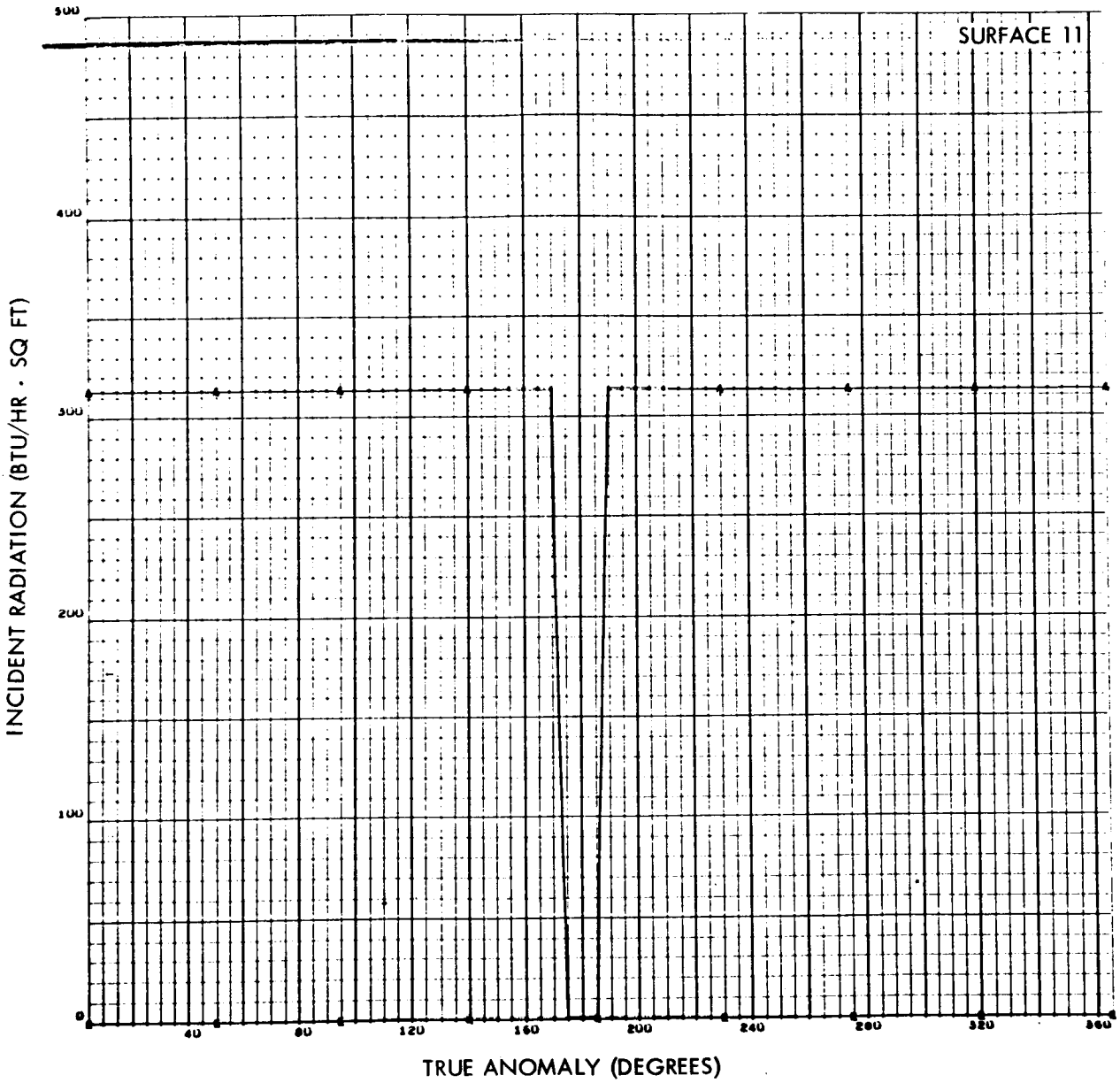


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 6 of 7)

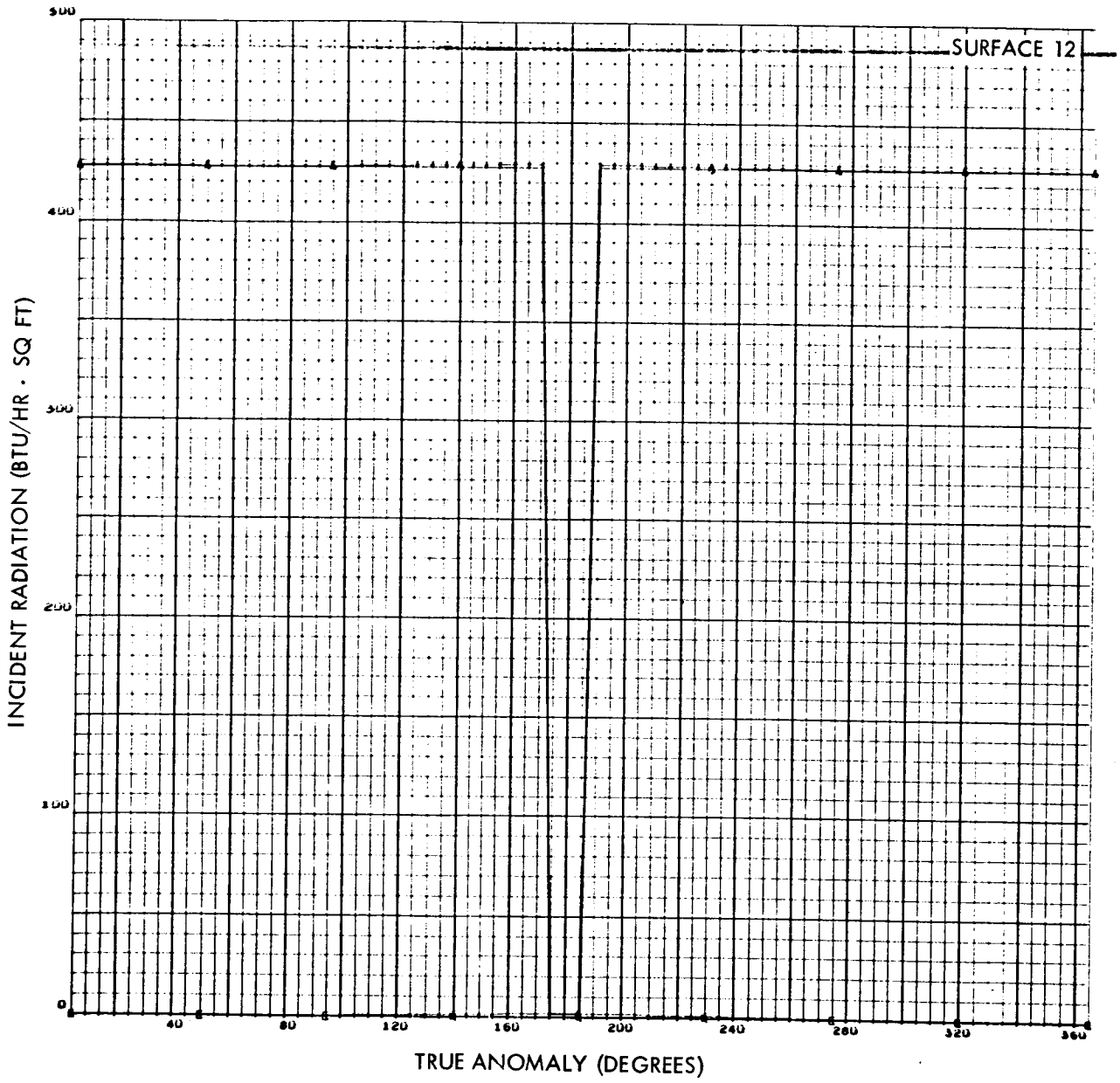


Figure IU-6a. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination; 0° (Maximum Shadow Period); Launch Date: March 21; Y-Sol (Sheet 7 of 7)

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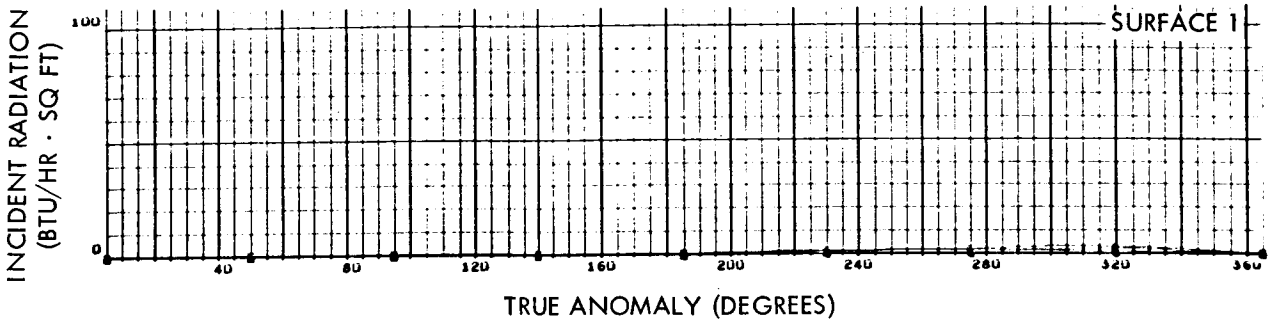

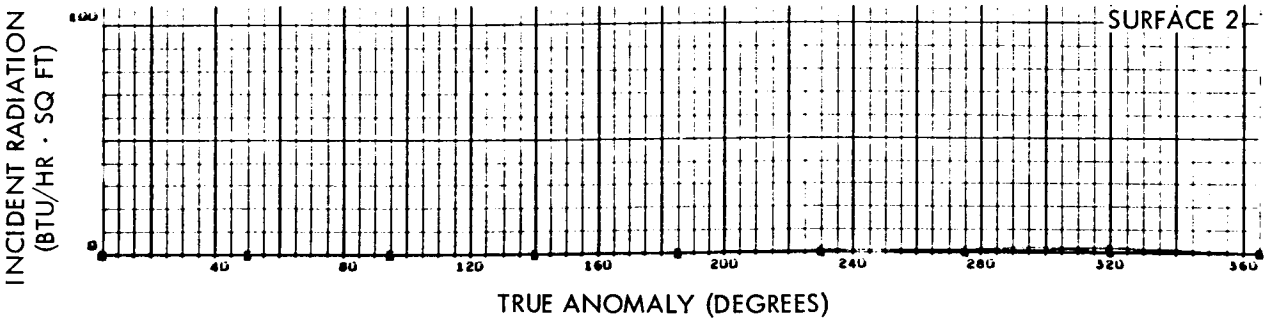

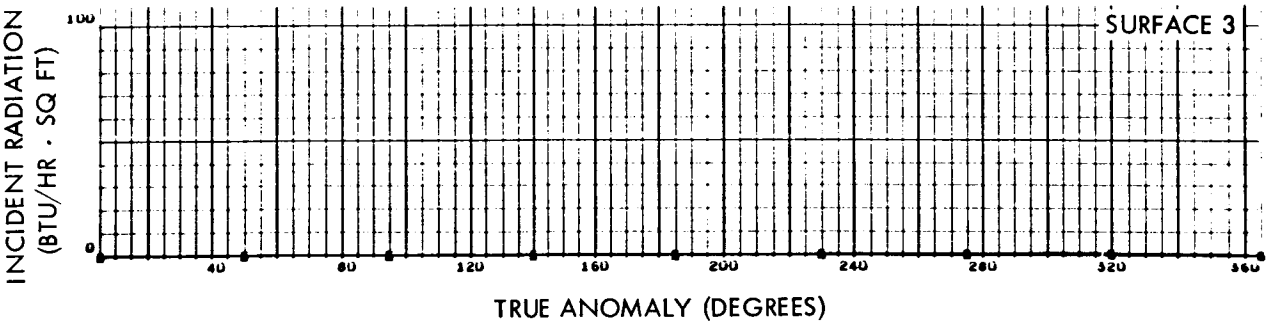

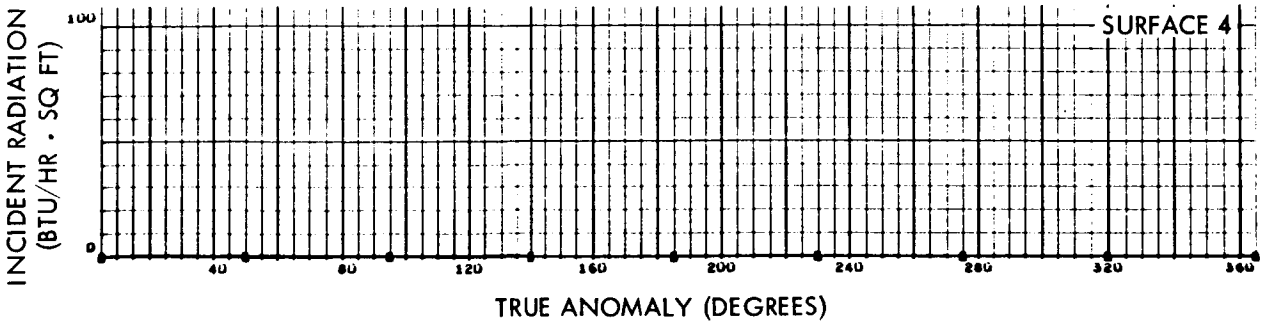

Figure IU-6b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Sol (Sheet 1 of 3)

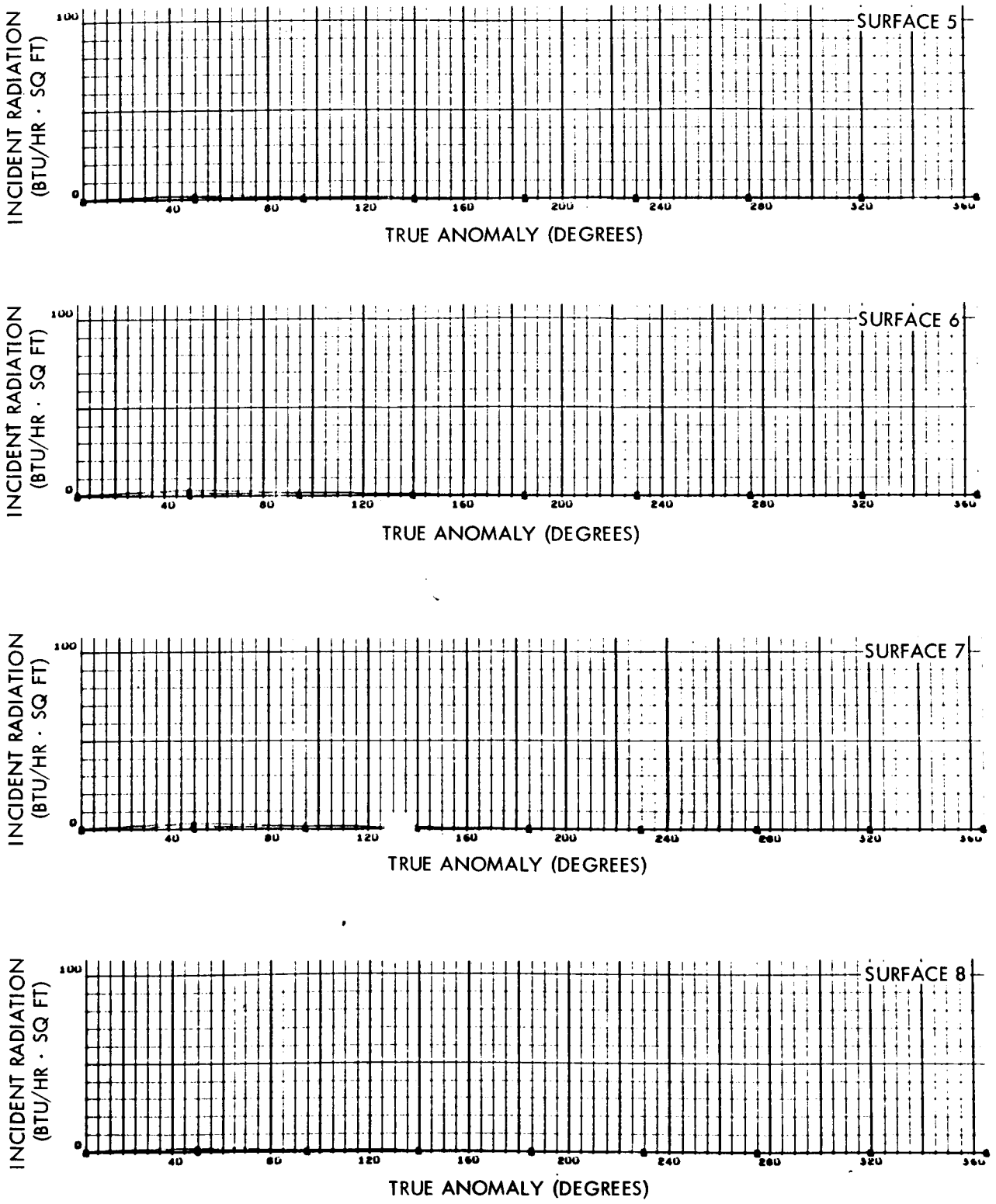

Figure IU-6b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Sol (Sheet 2 of 3)

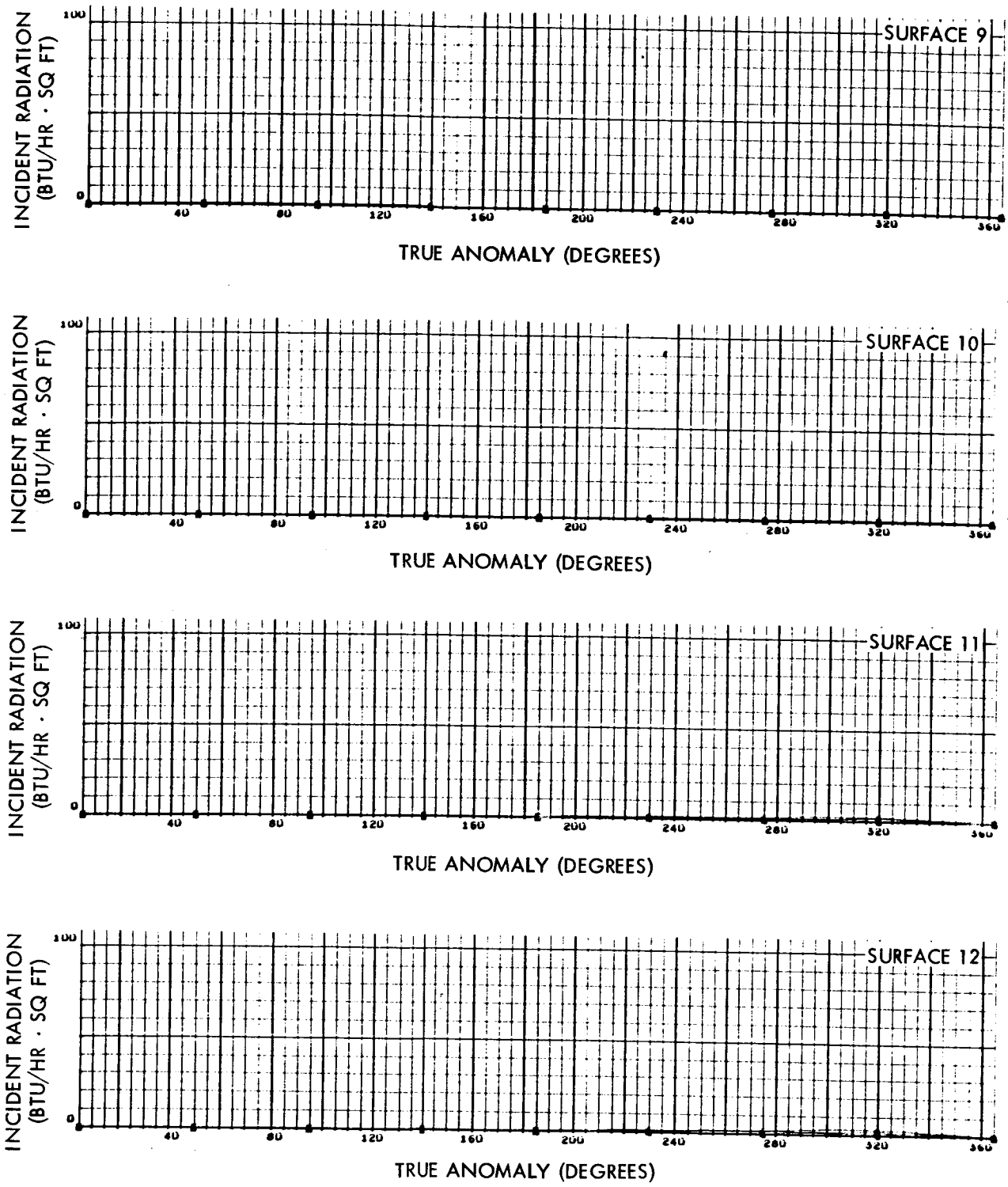

Figure IU-6b. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Sol (Sheet 3 of 3)

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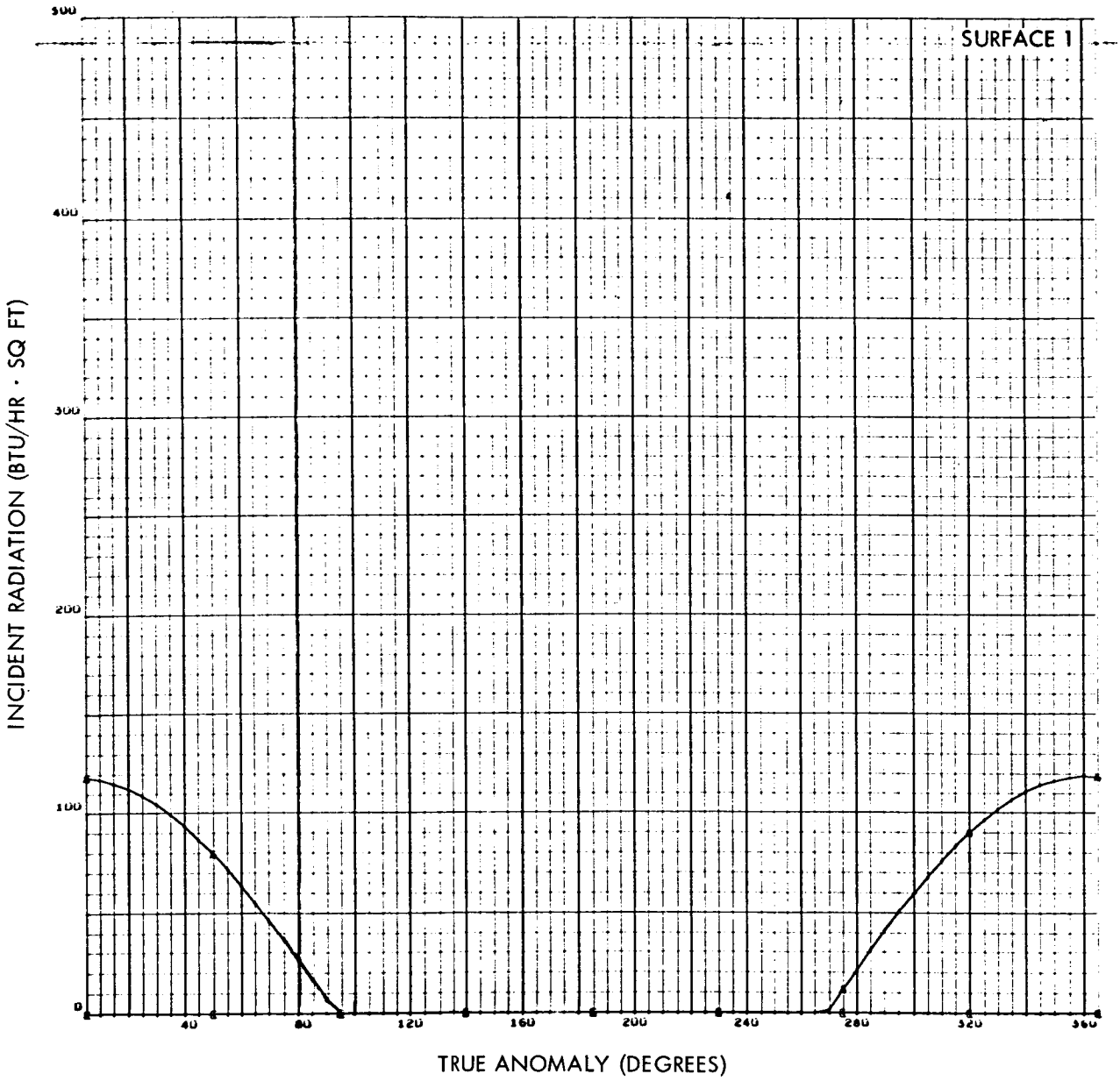


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 1 of 11)

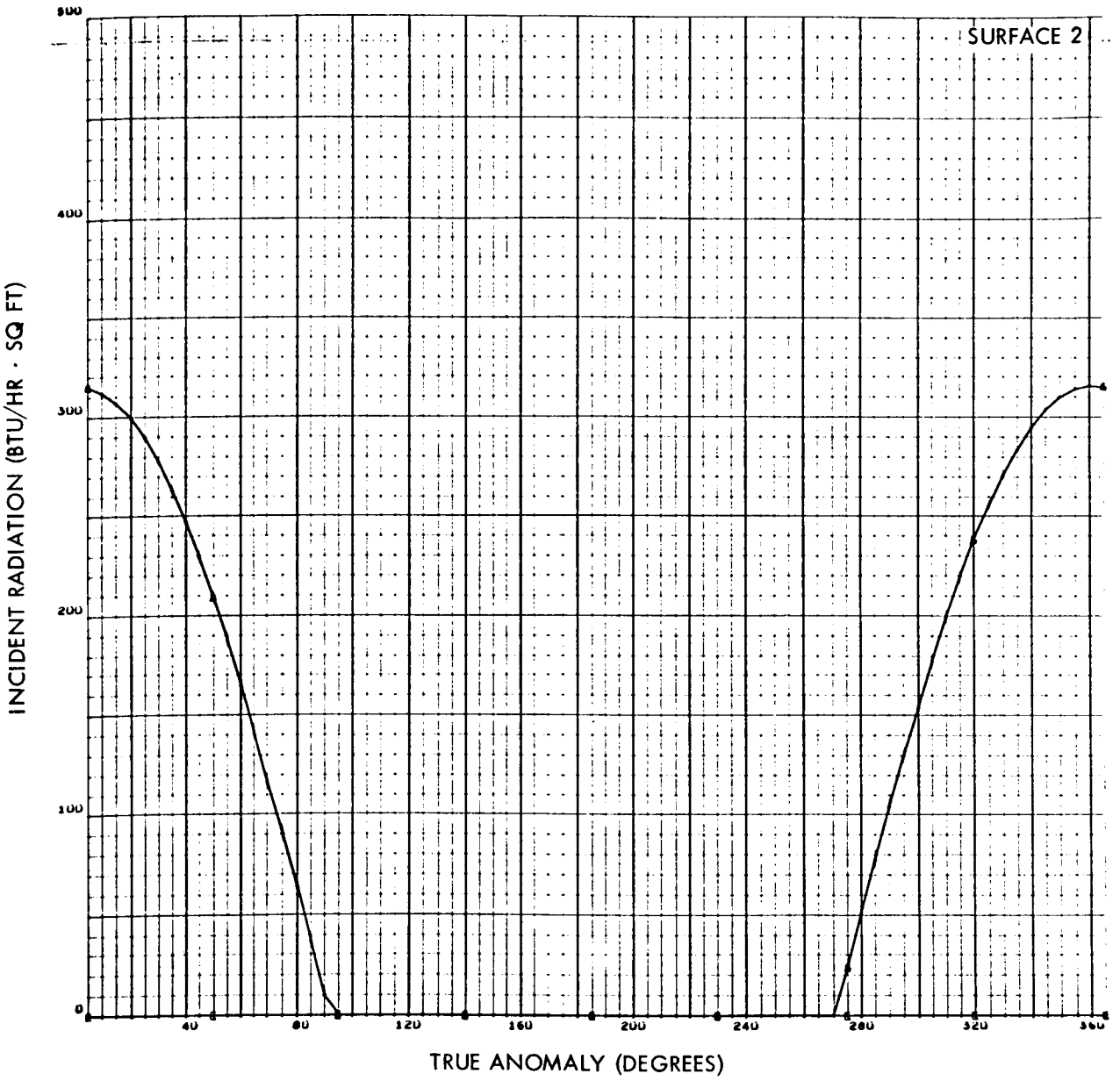


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 2 of 11)

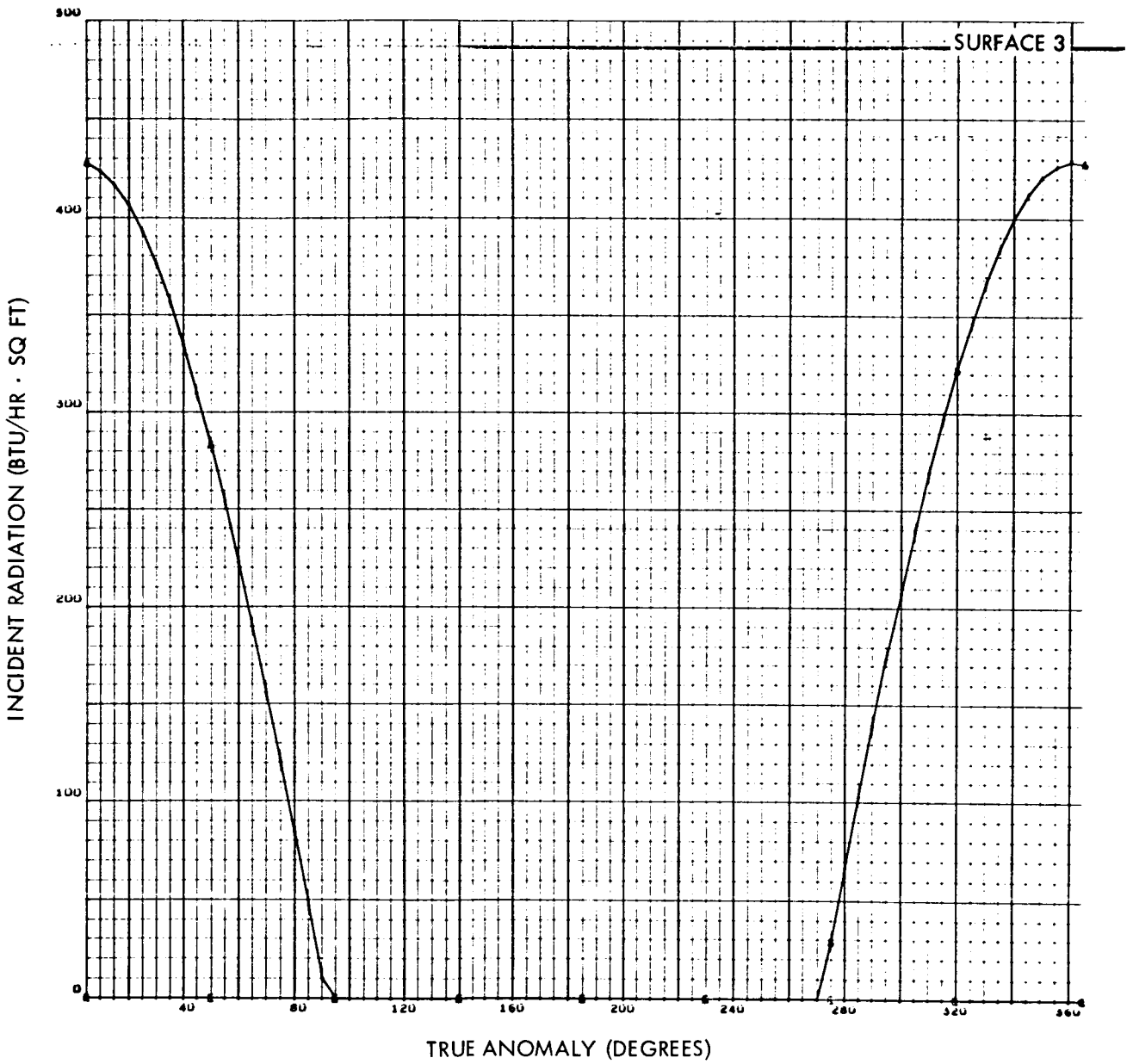


Figure IU-6c. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 3 of 11)

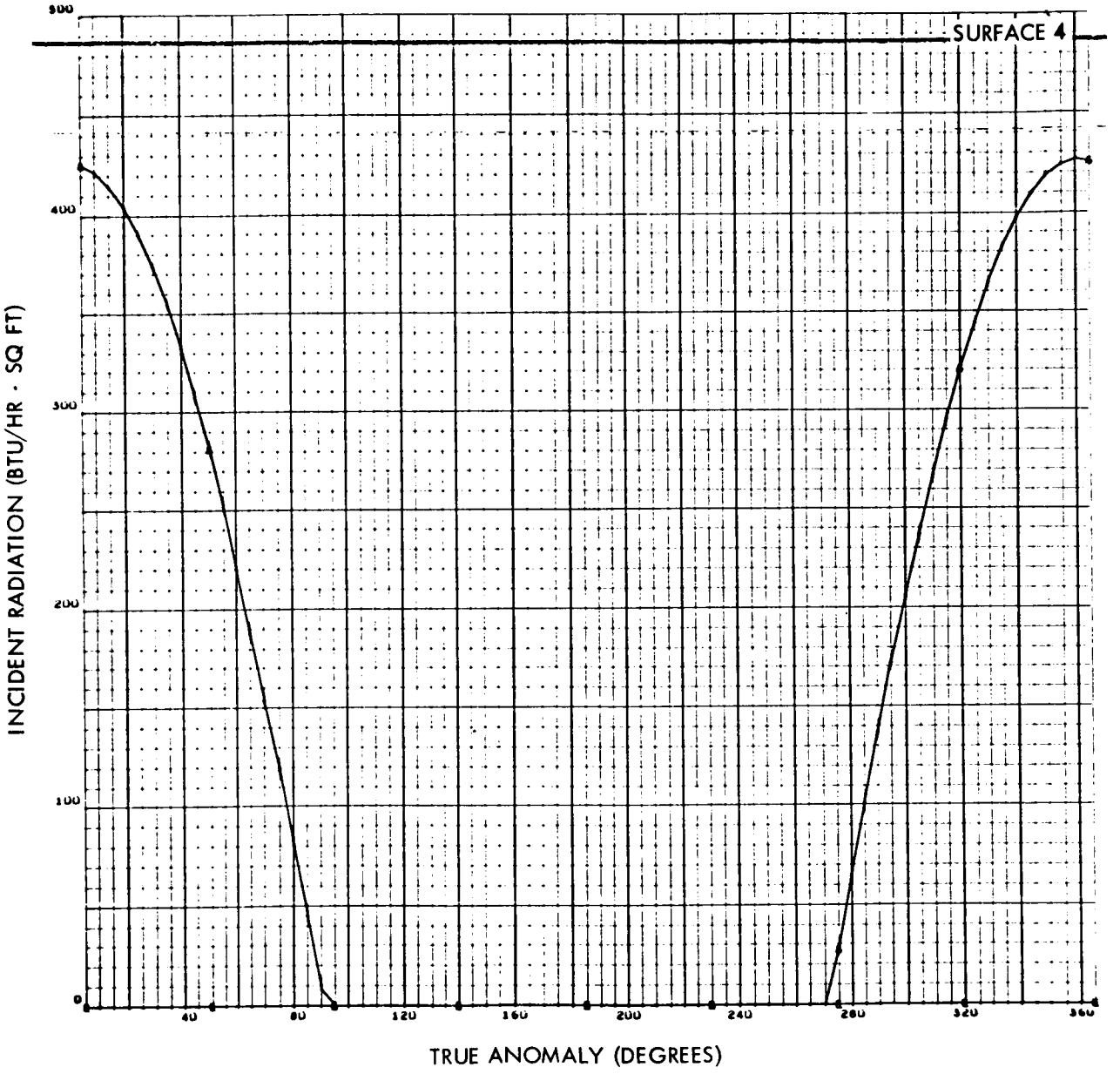


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 4 of 11)

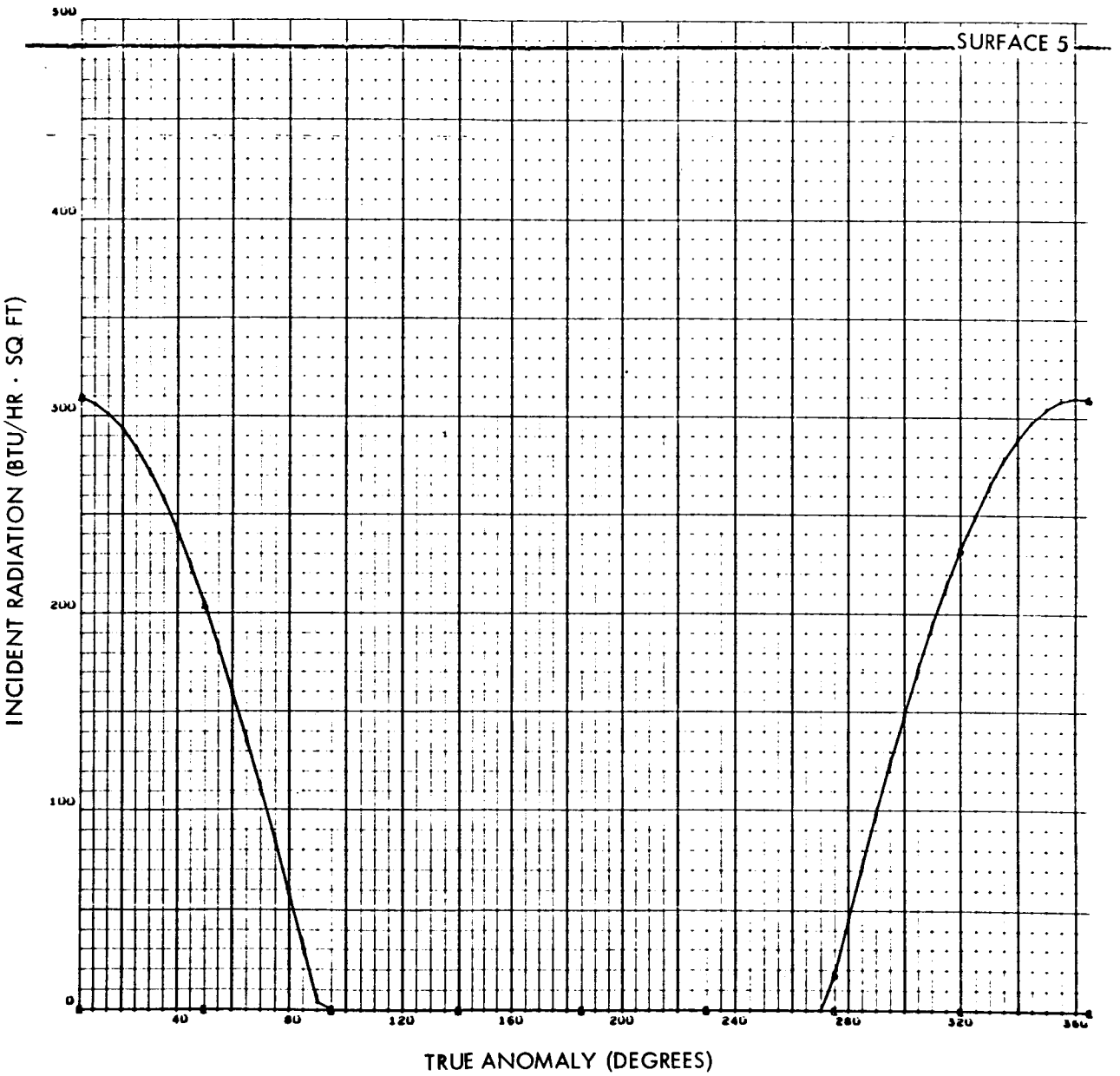
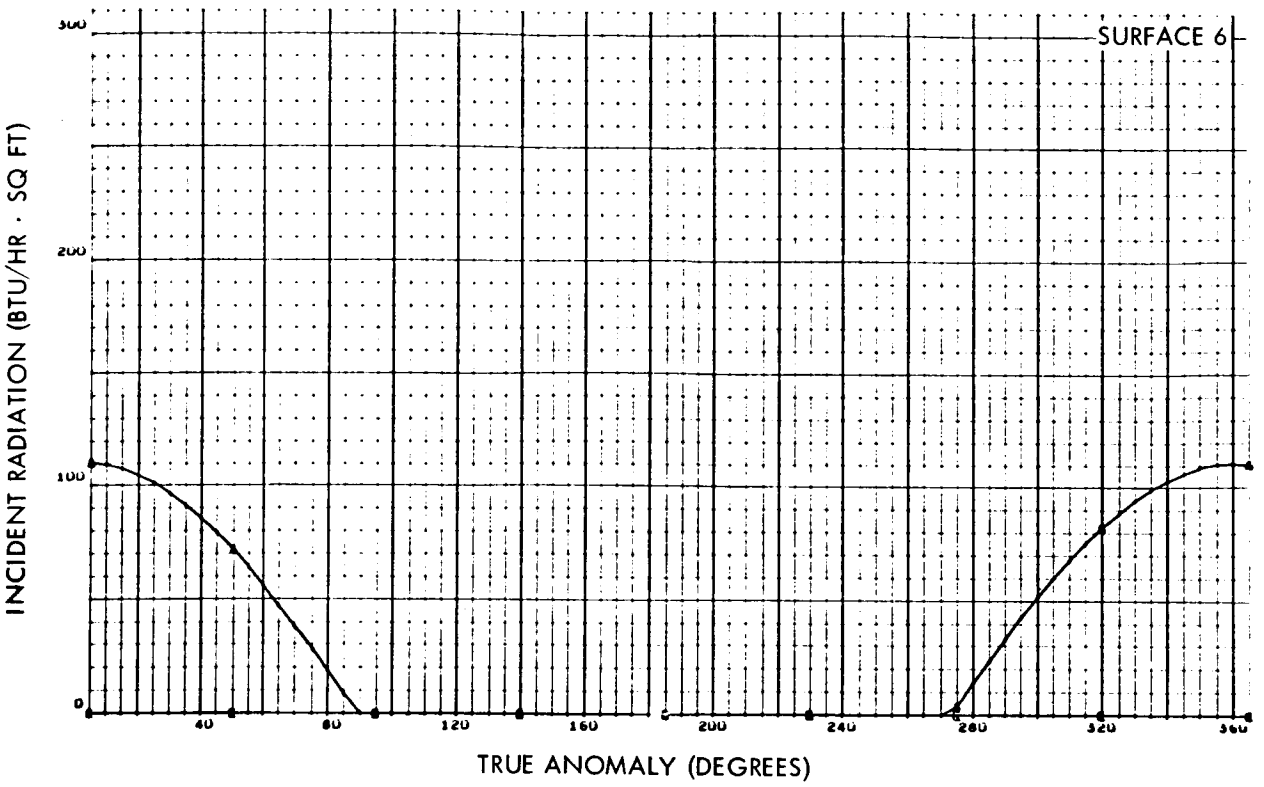


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 5 of 11)



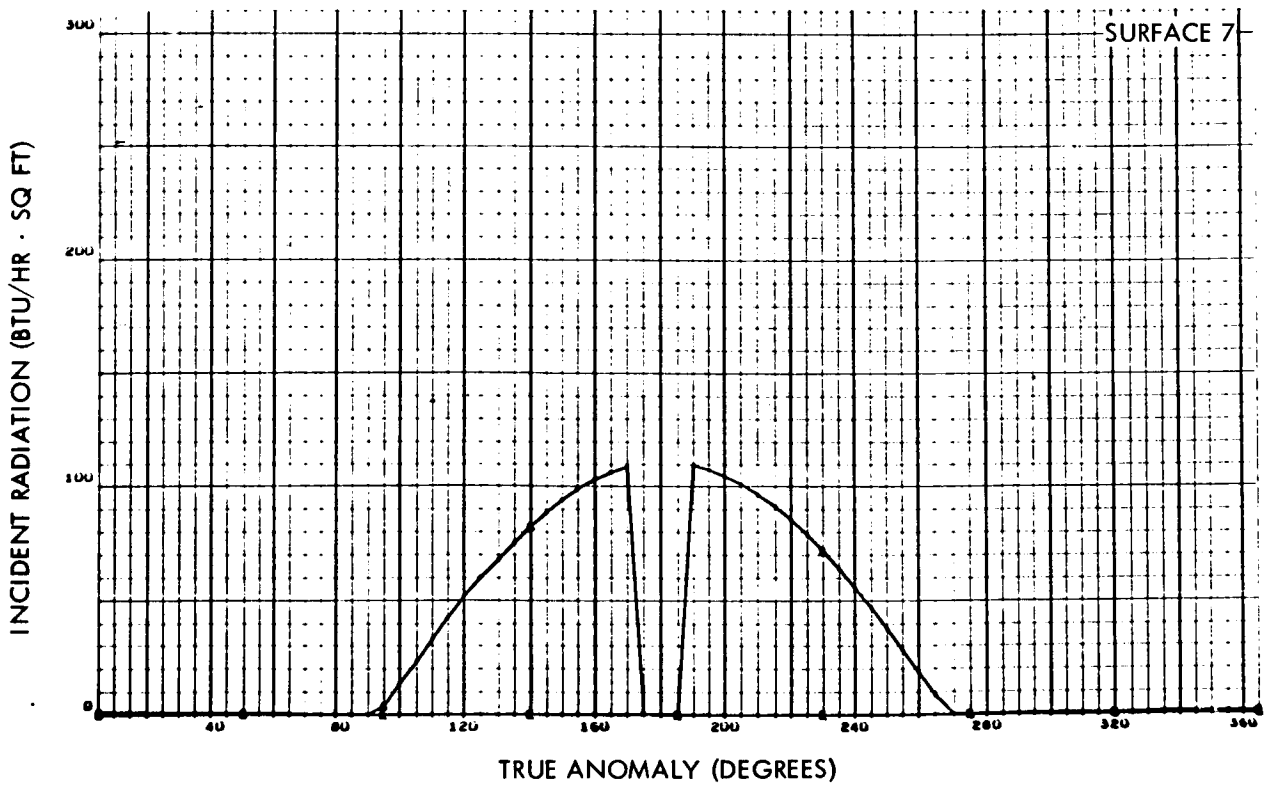


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 6 of 11)

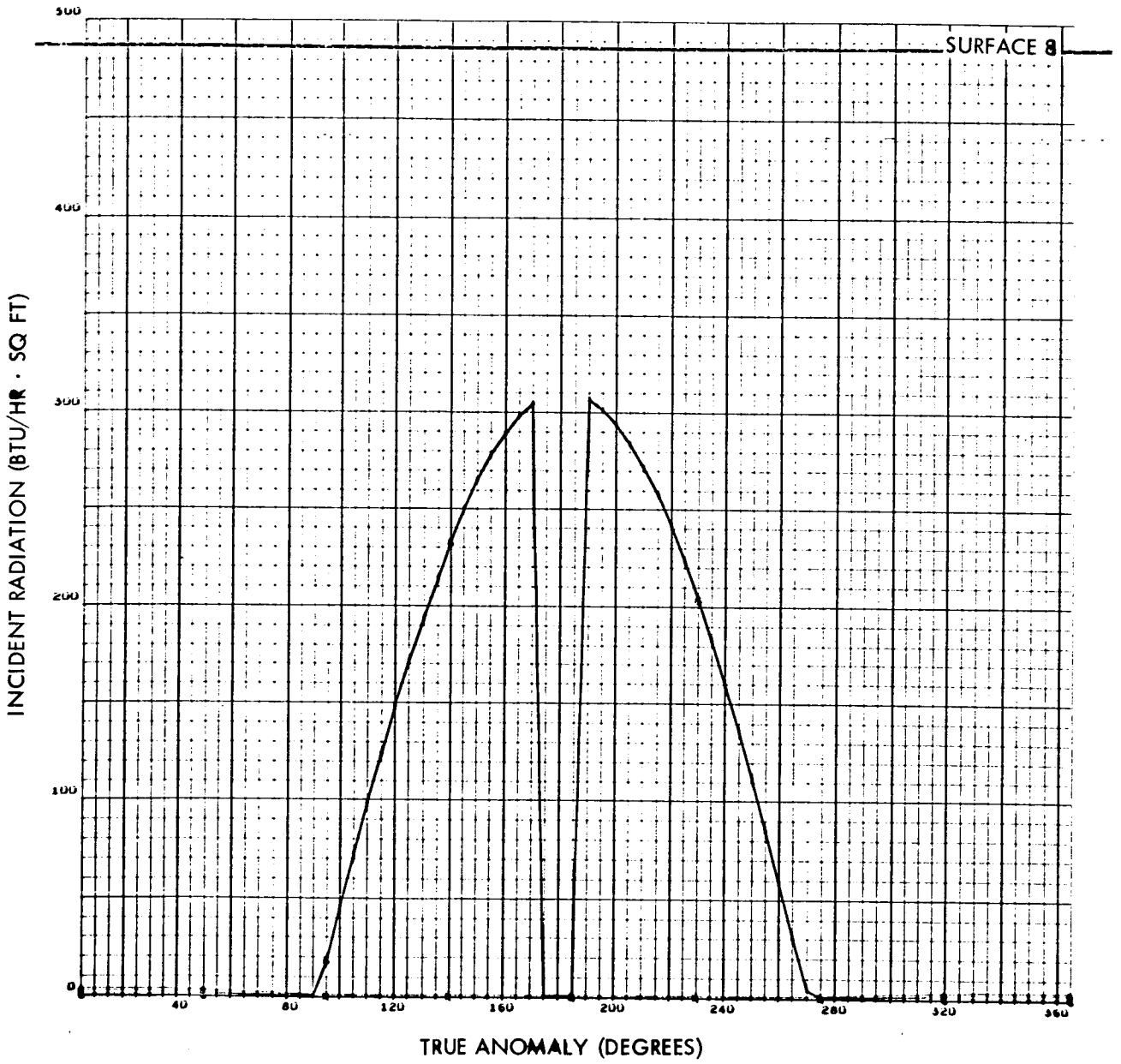


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 7 of 11)

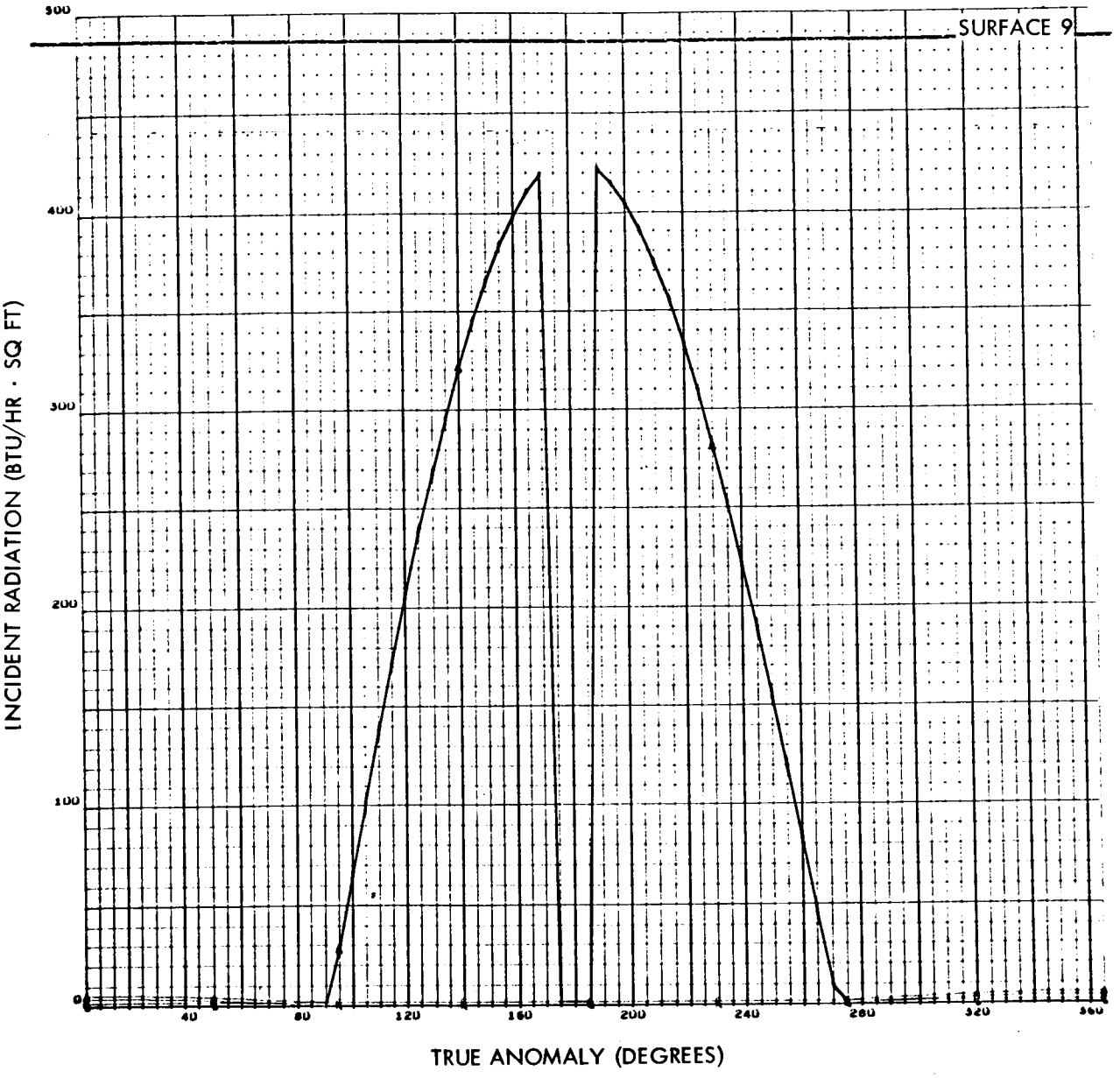


Figure IU-6c. 19, 327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 8 of 11)

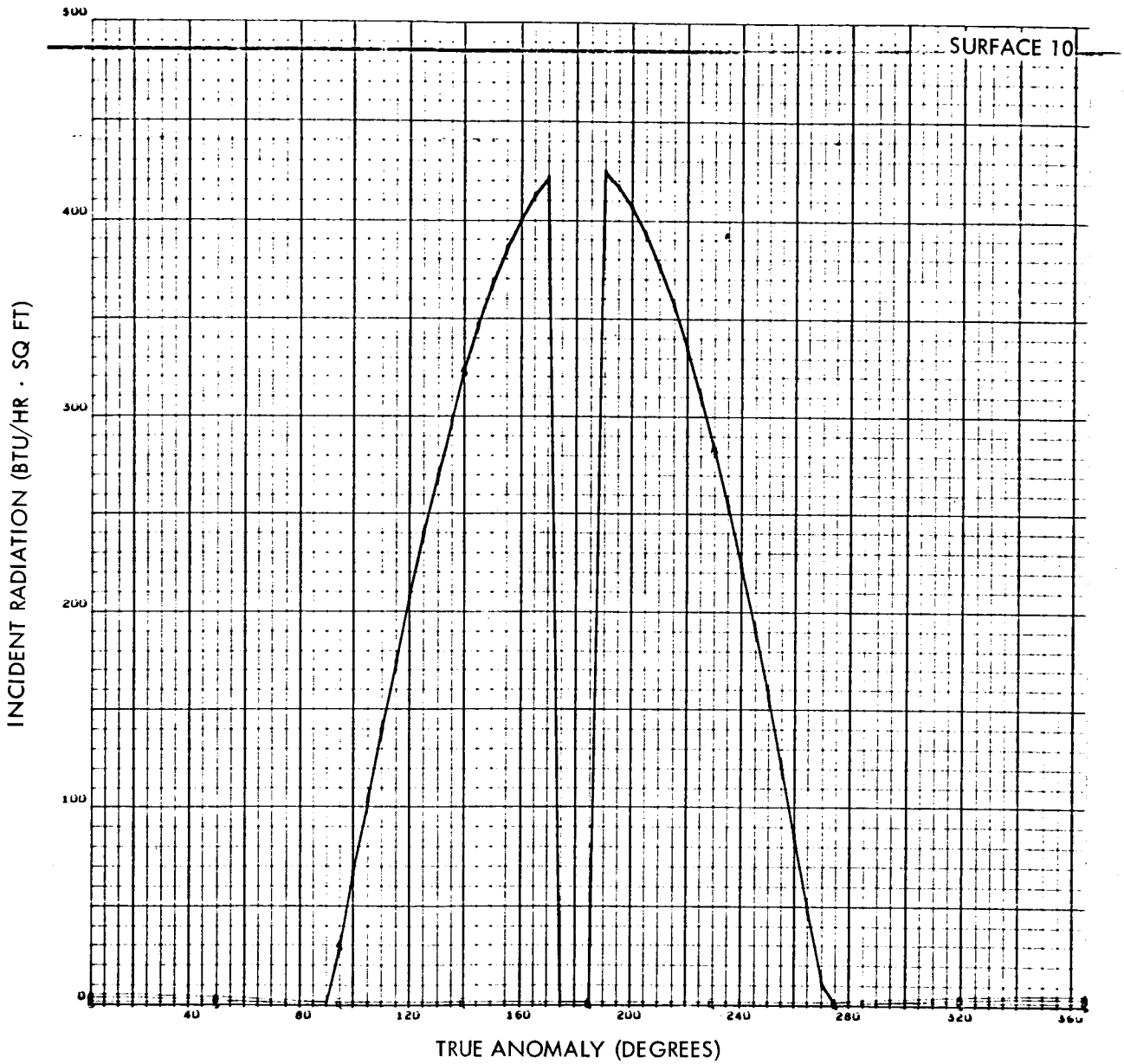


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 9 of 11)

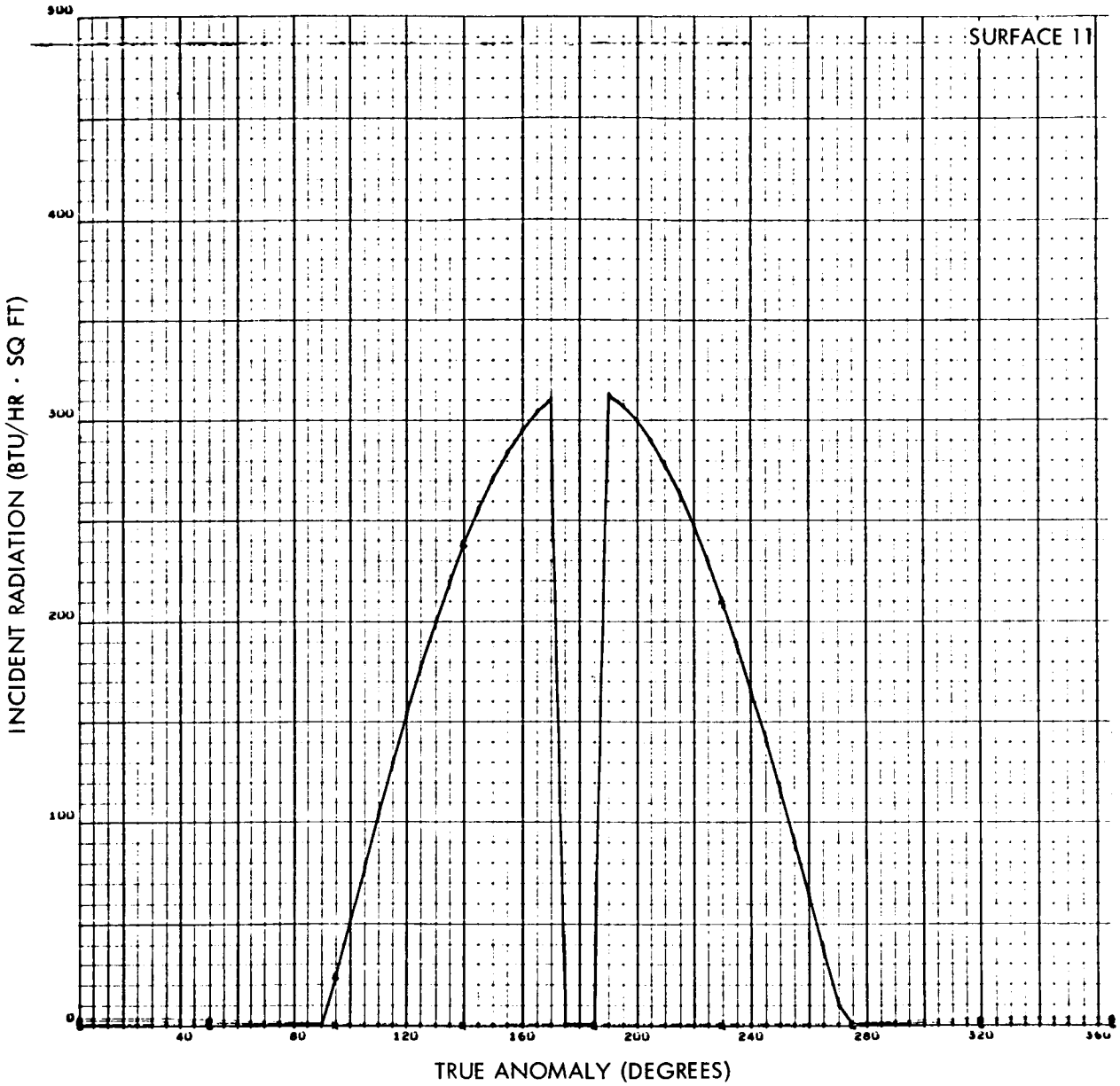


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 10 of 11)

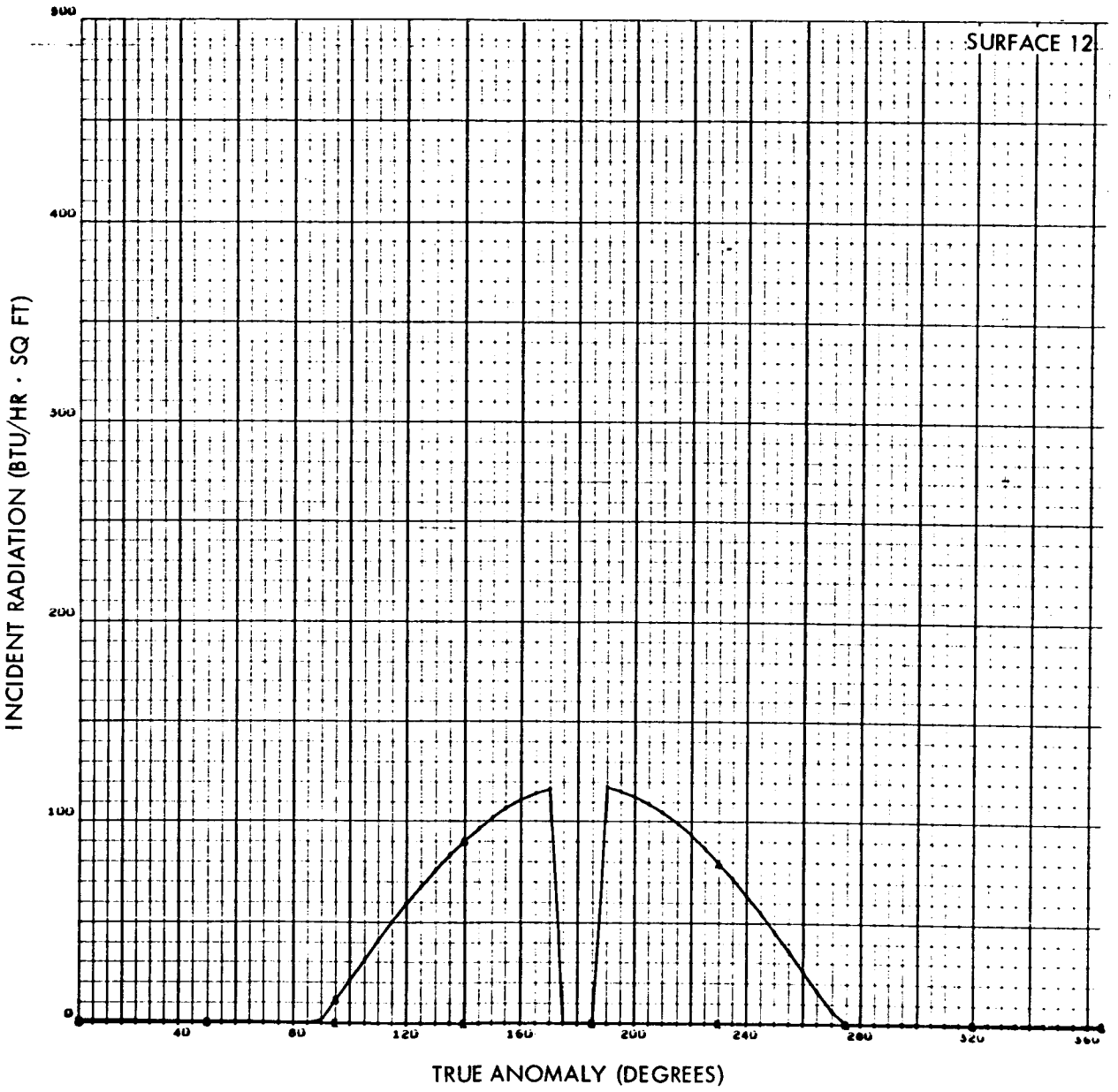


Figure IU-6c. 19,327-Nautical-Mile Synchronous Circular Orbit; Angle of Inclination: 0° (Maximum Shadow Period); Launch Date: March 21; X-Tan (Sheet 11 of 11)

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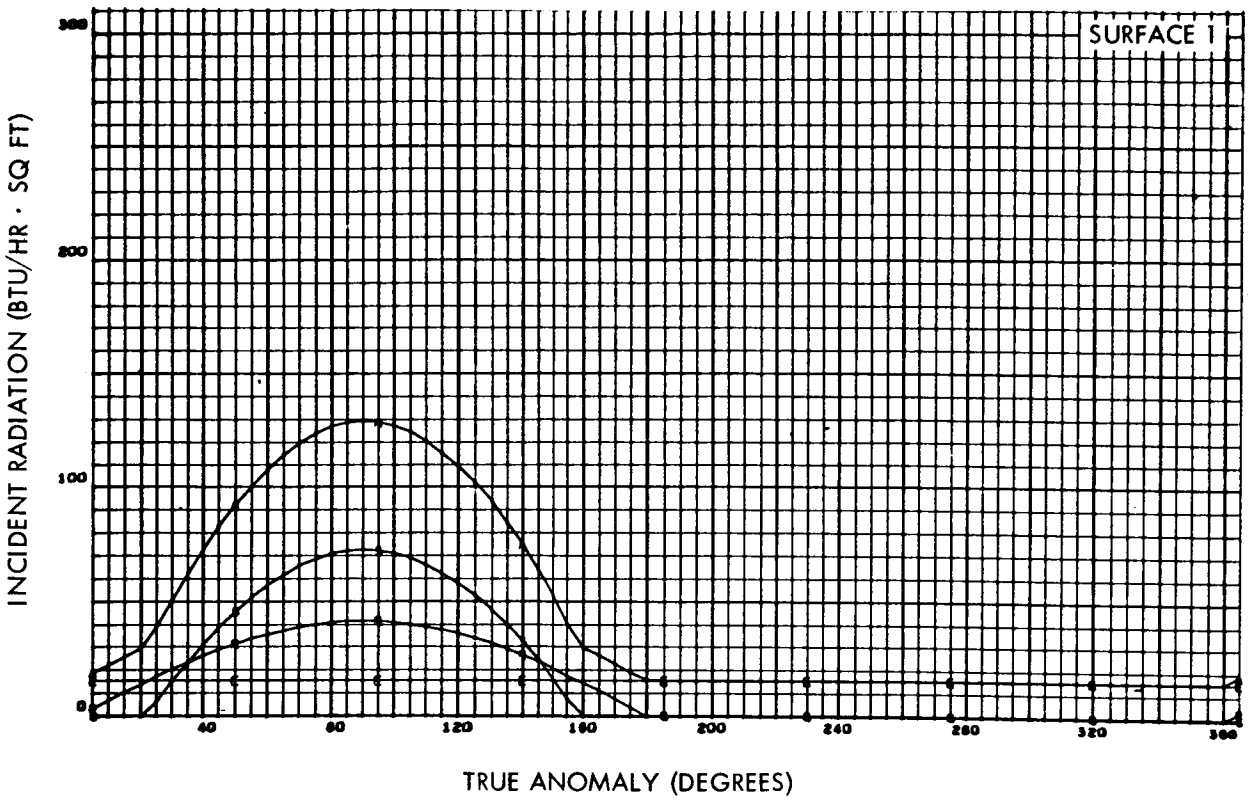


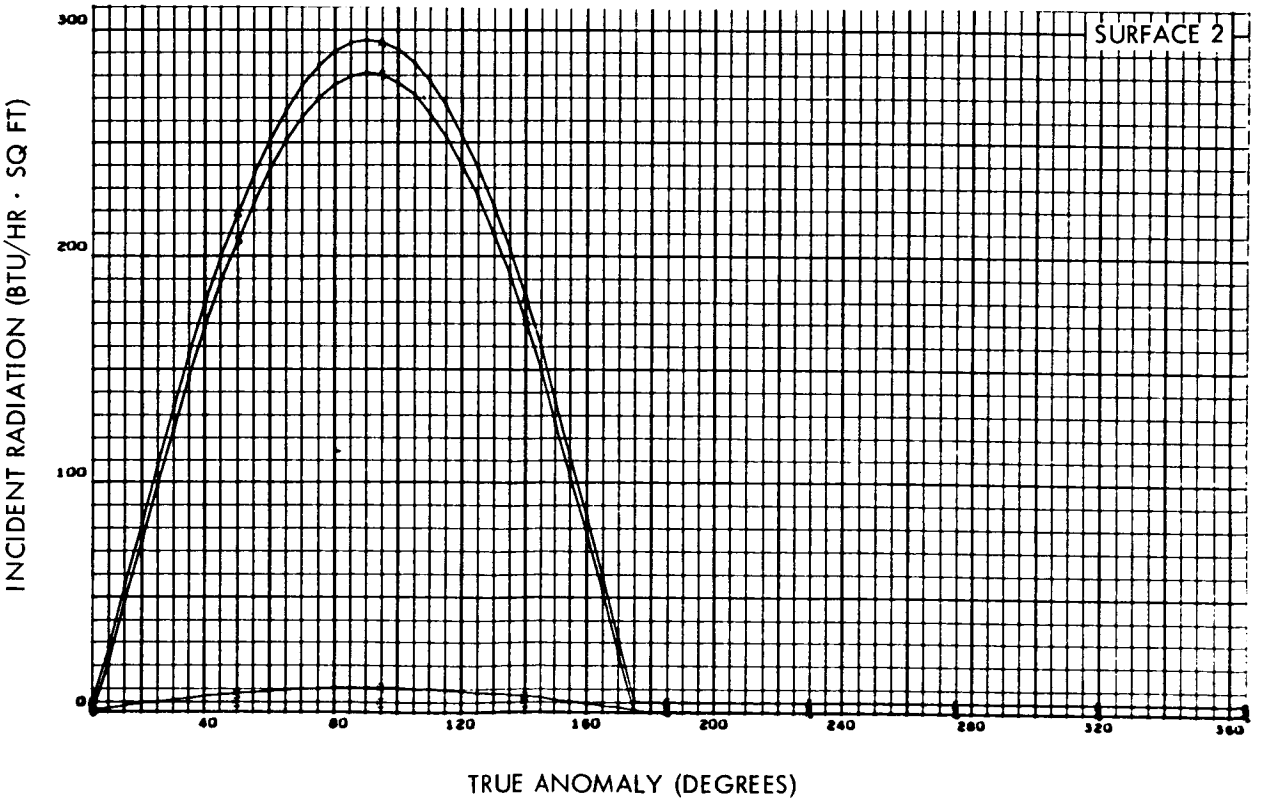


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 1 of 8)

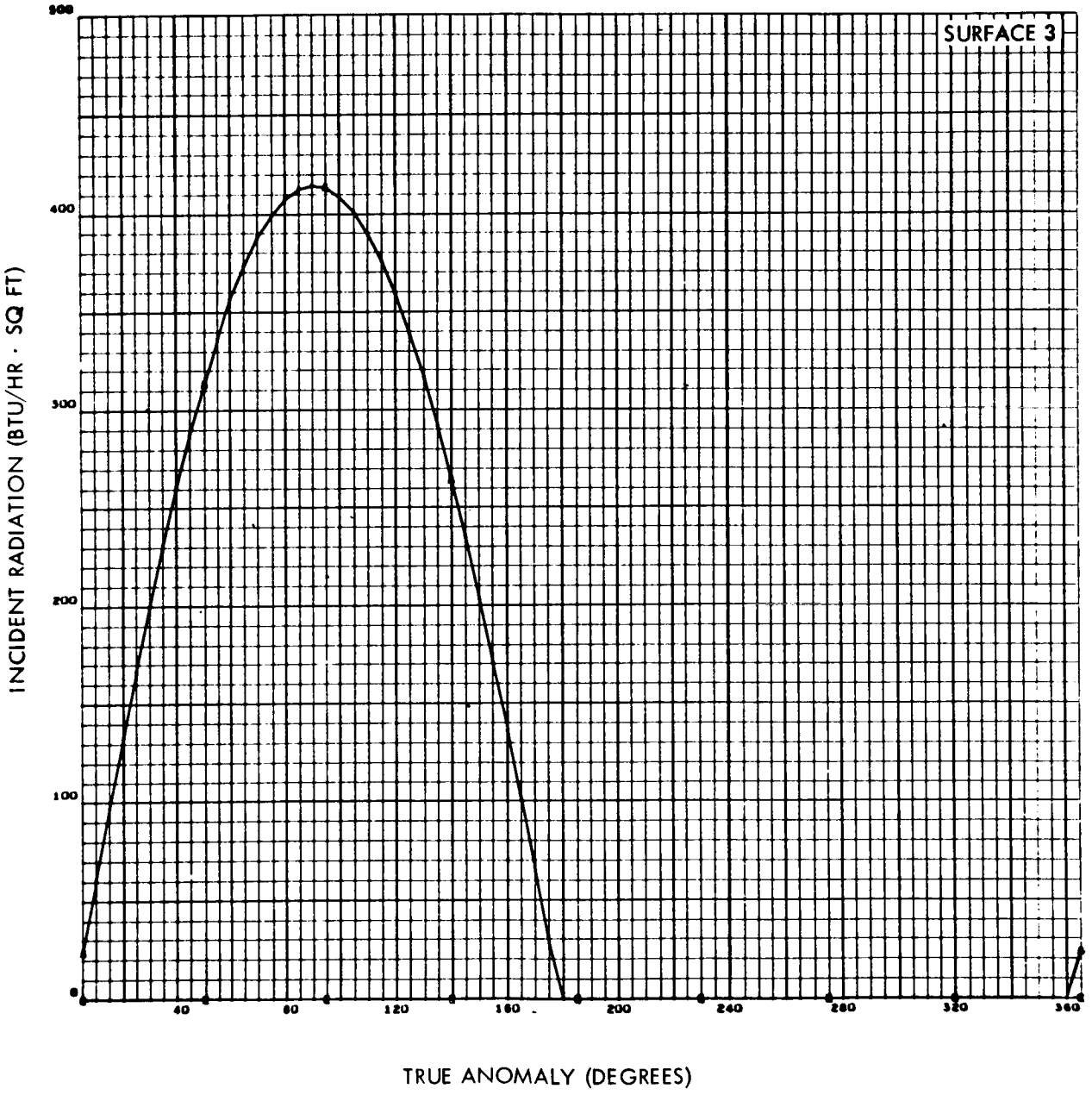


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 2 of 8)

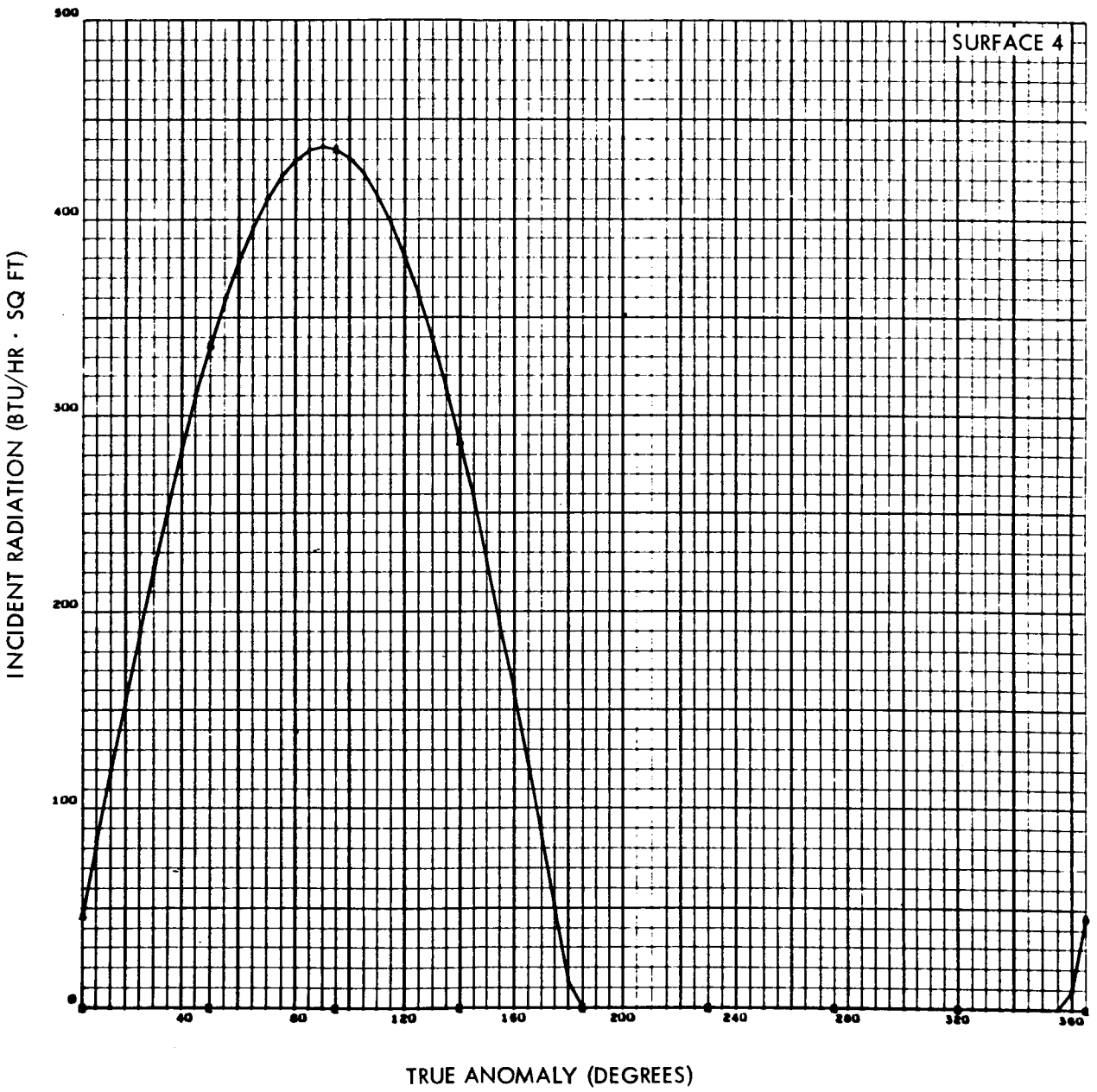


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 3 of 8)

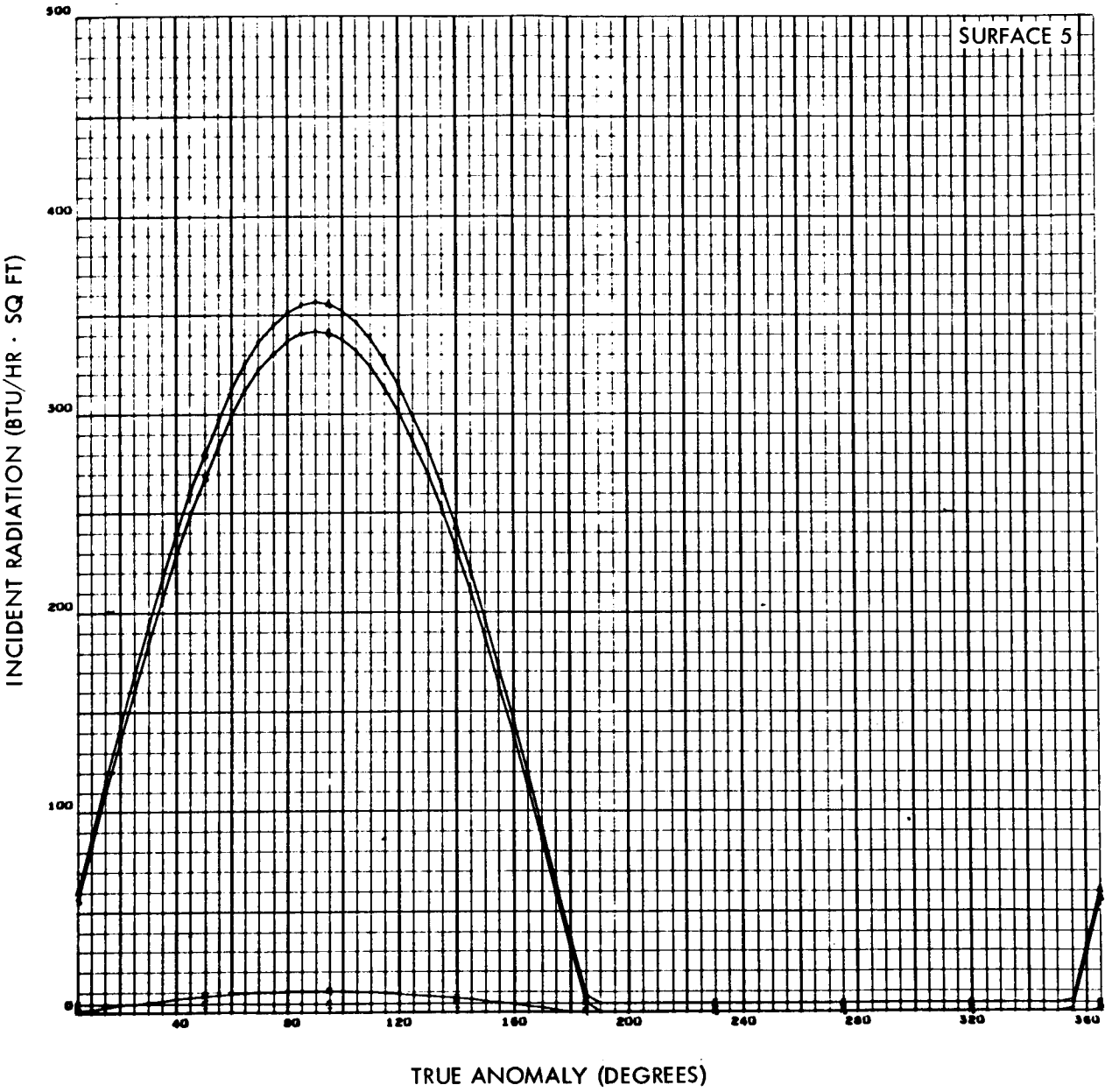
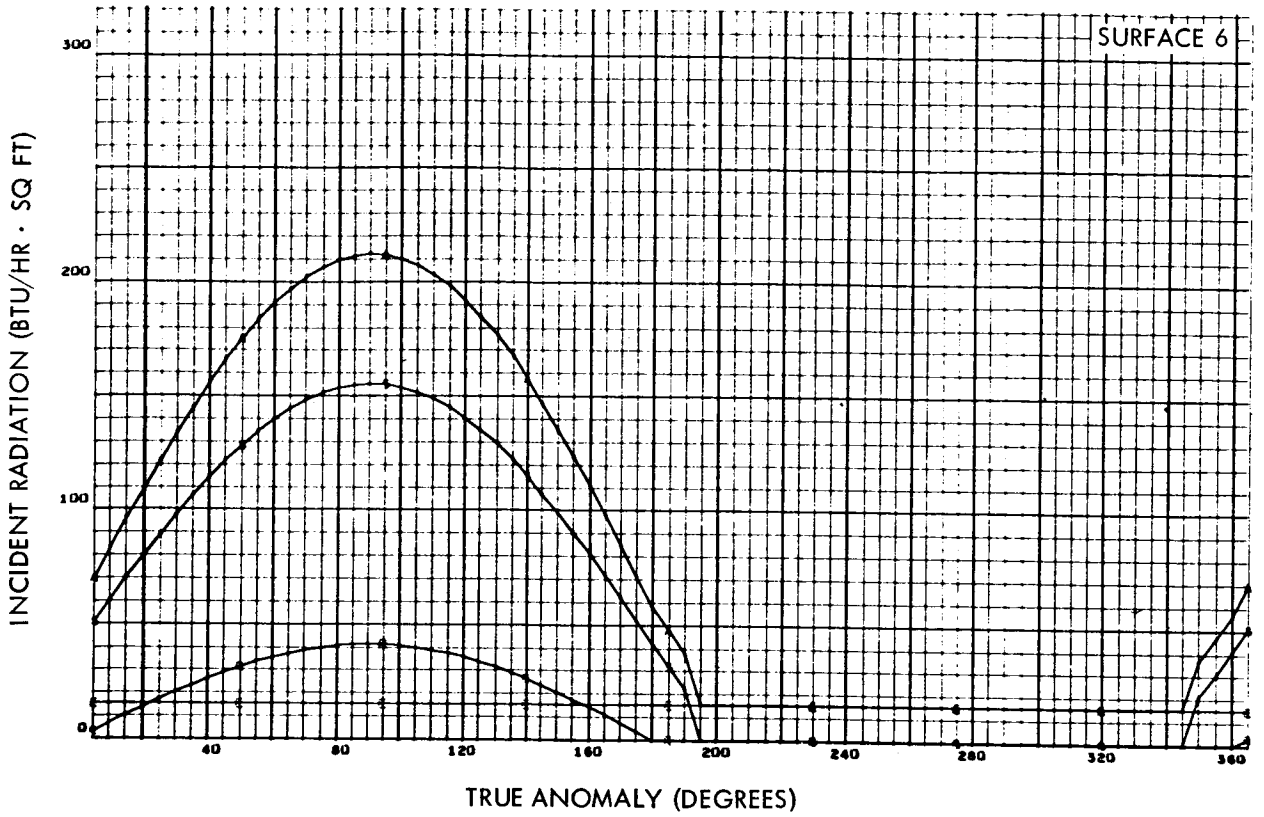


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 4 of 8)



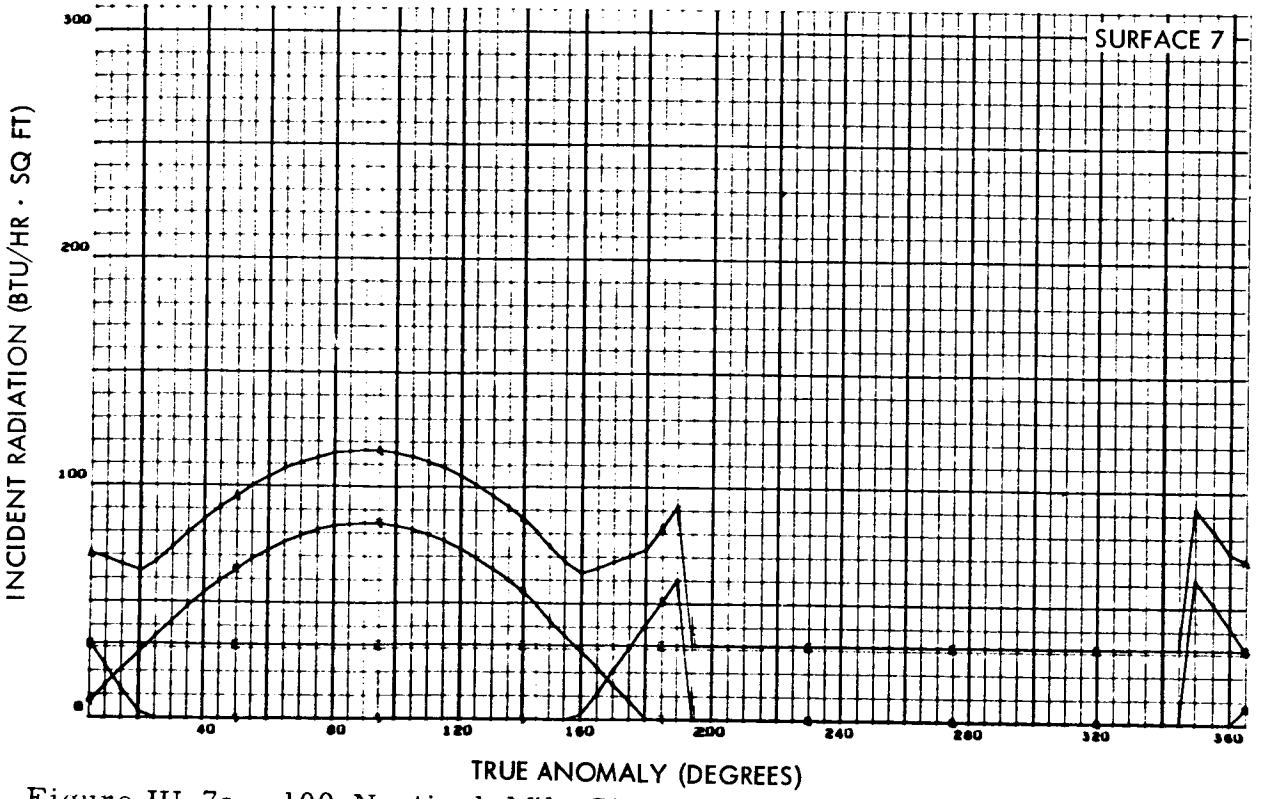
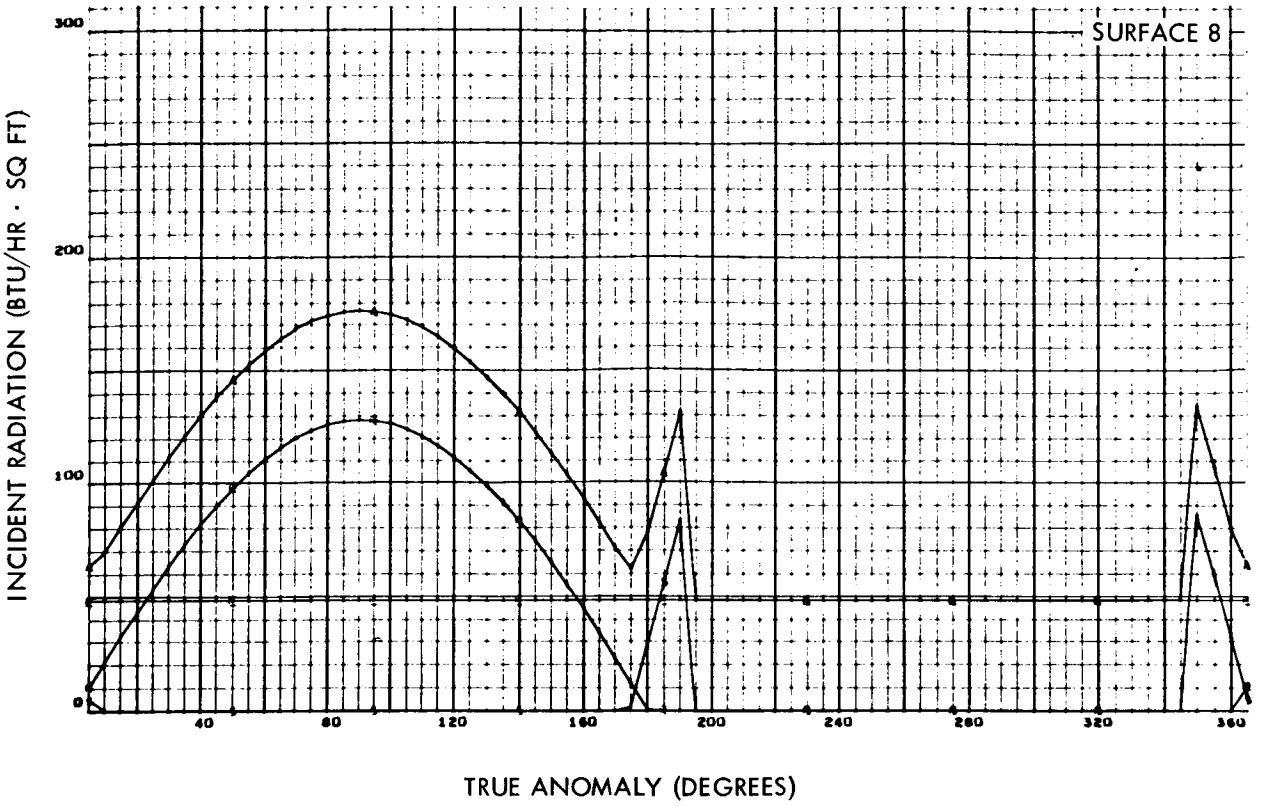


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 5 of 8)



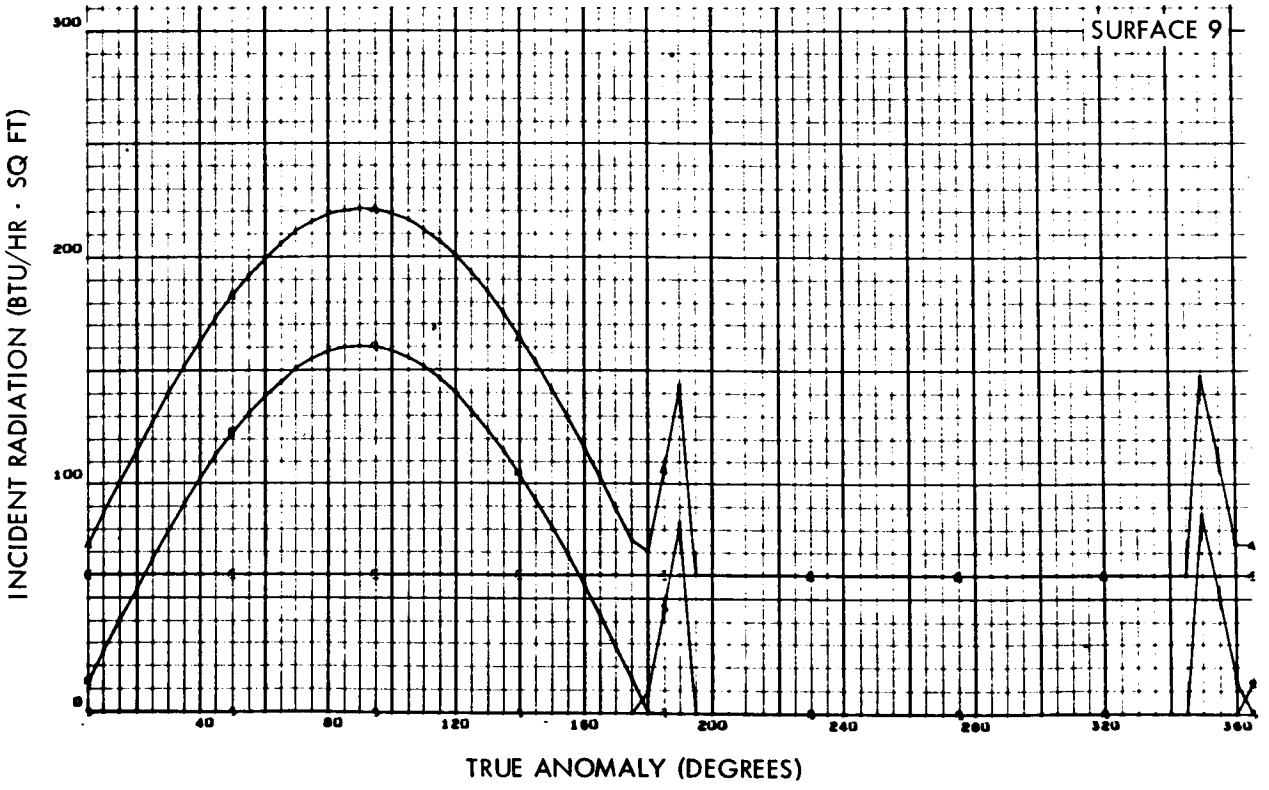
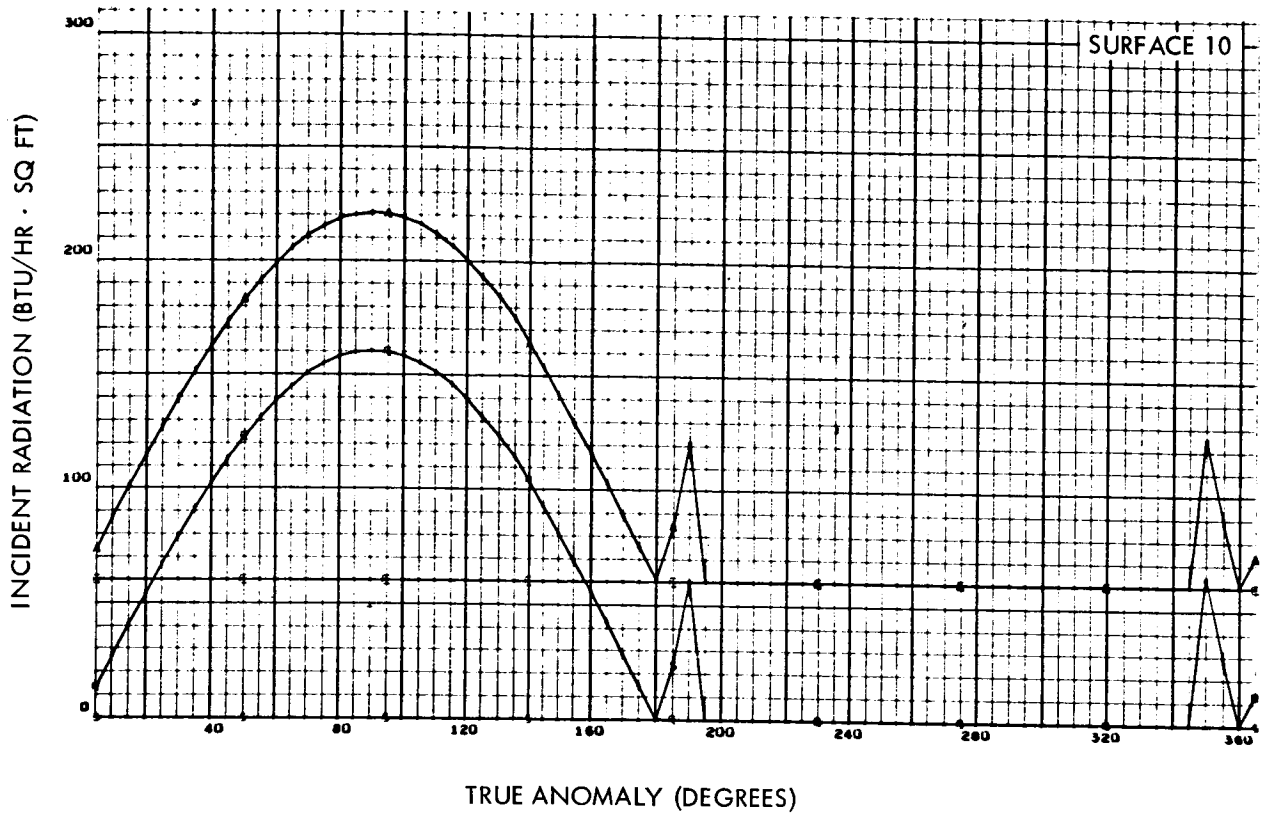


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 6 of 8)



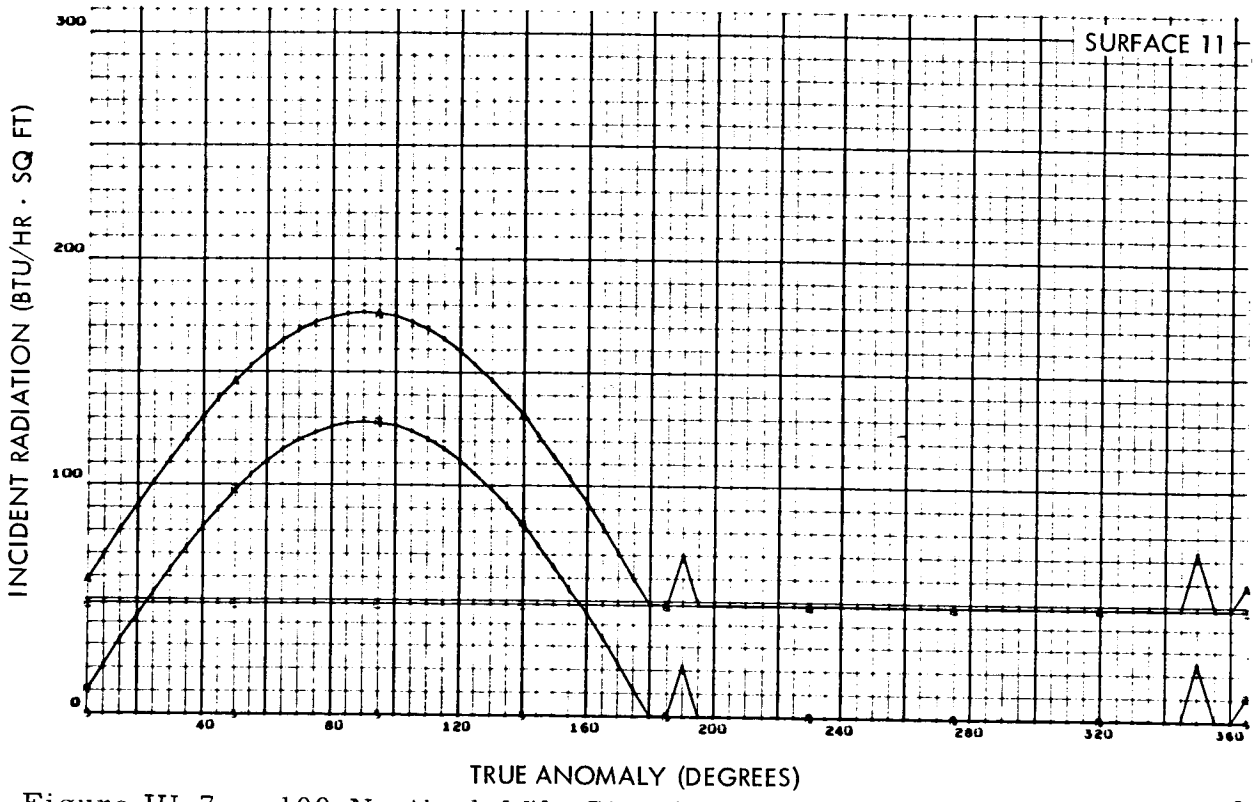


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 7 of 8)

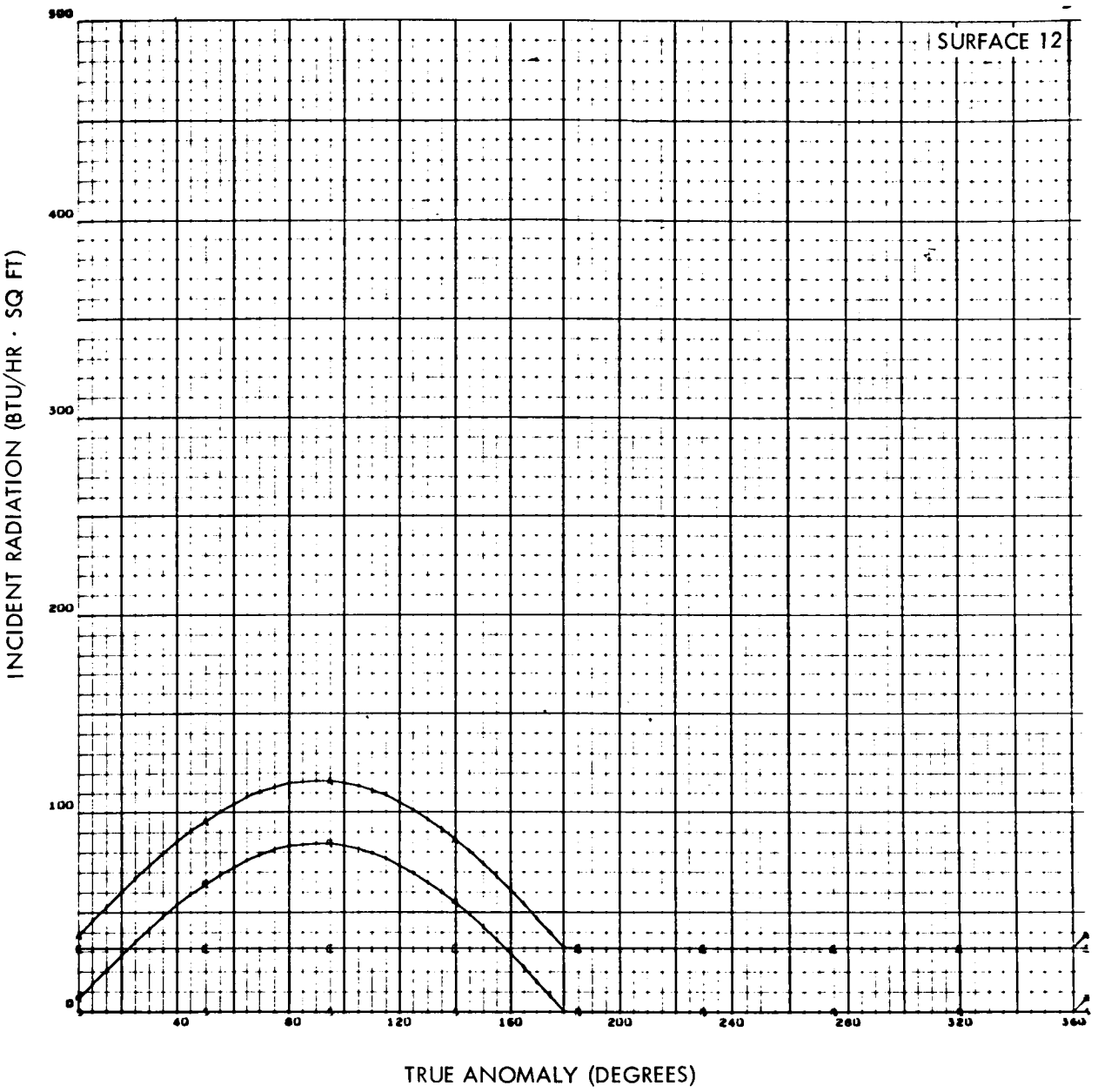


Figure IU-7a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Tan (Sheet 8 of 8)

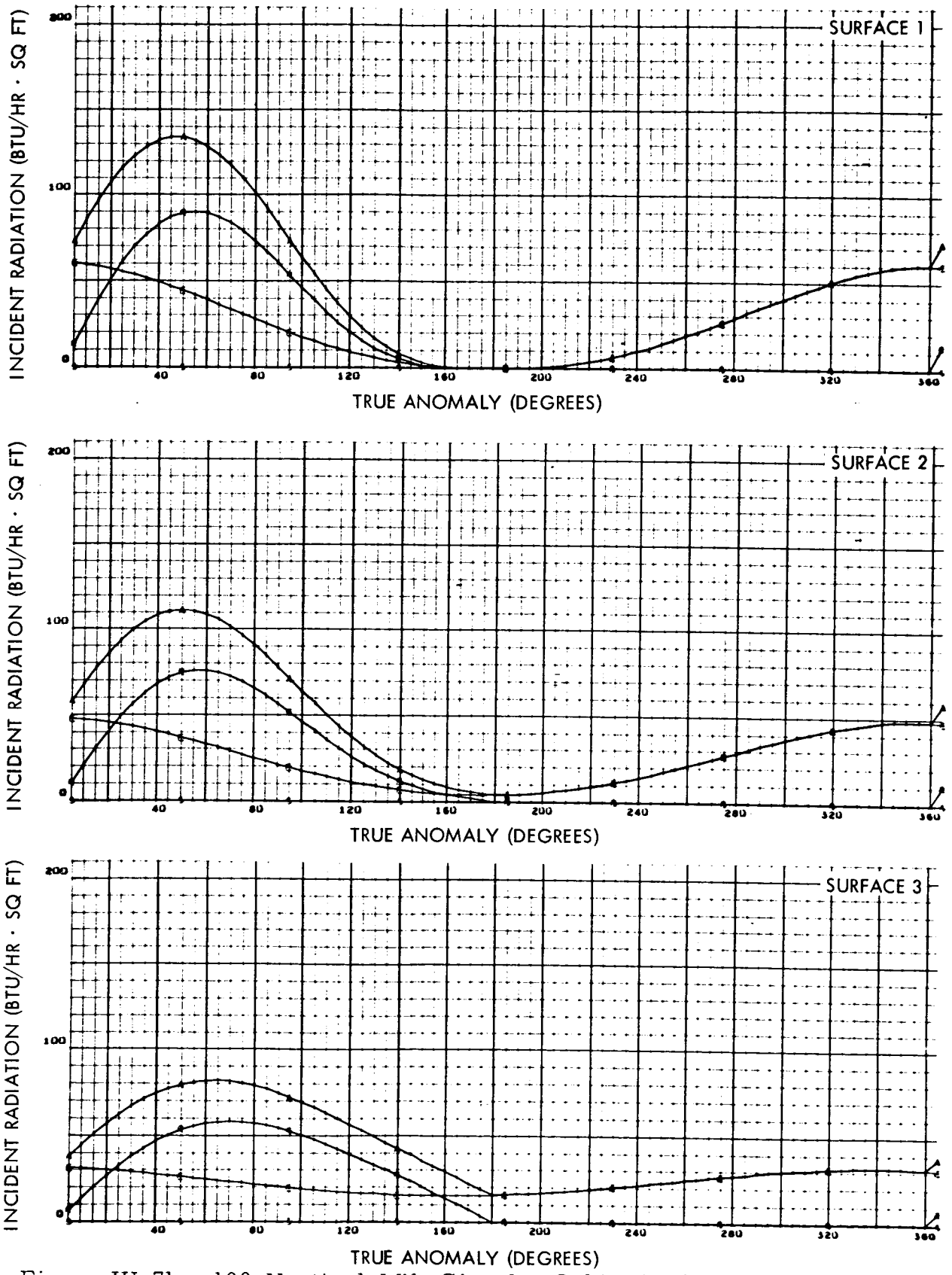


Figure IU-7b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 1 of 4)

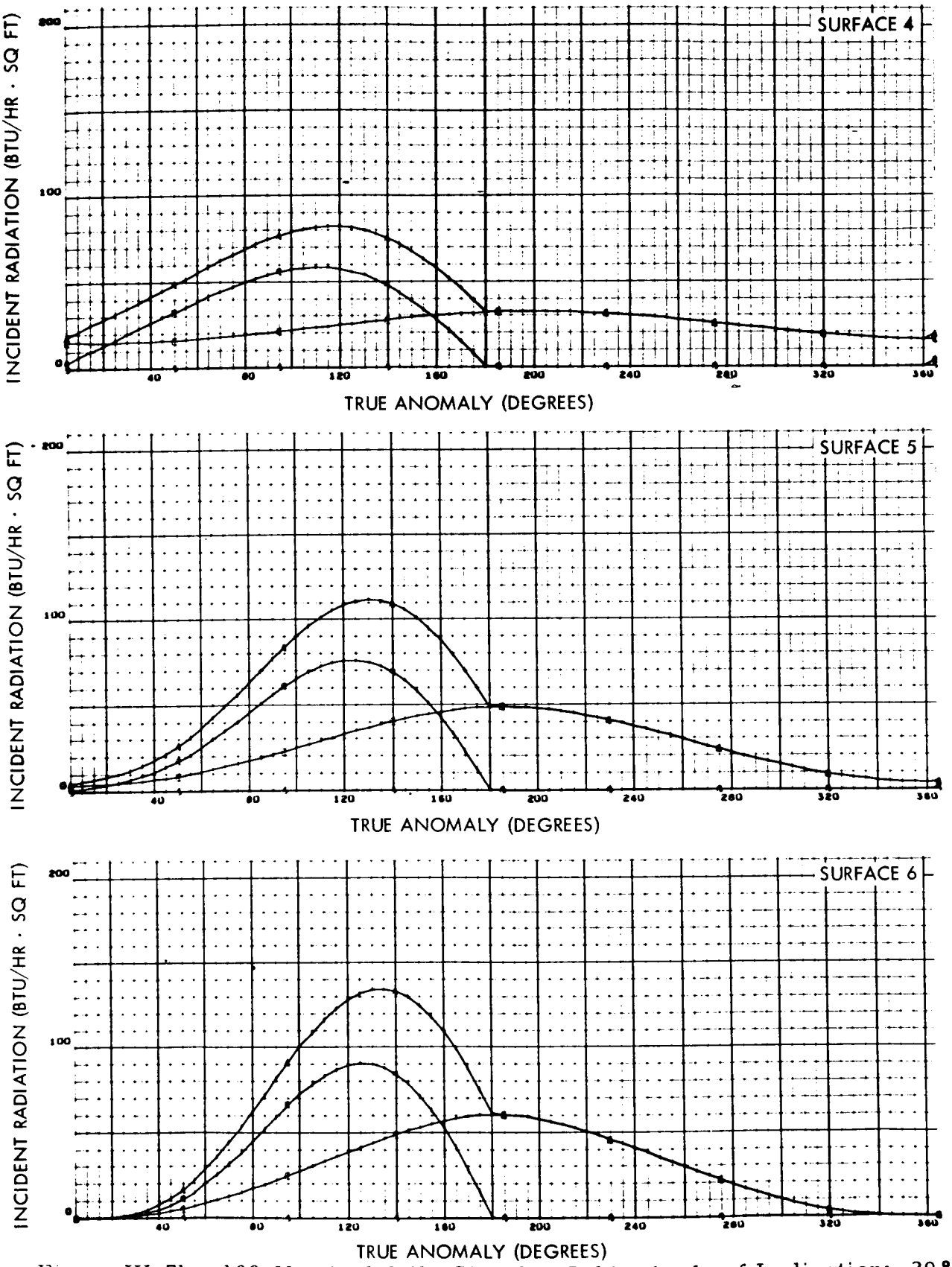


Figure IU-7b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 2 of 4)

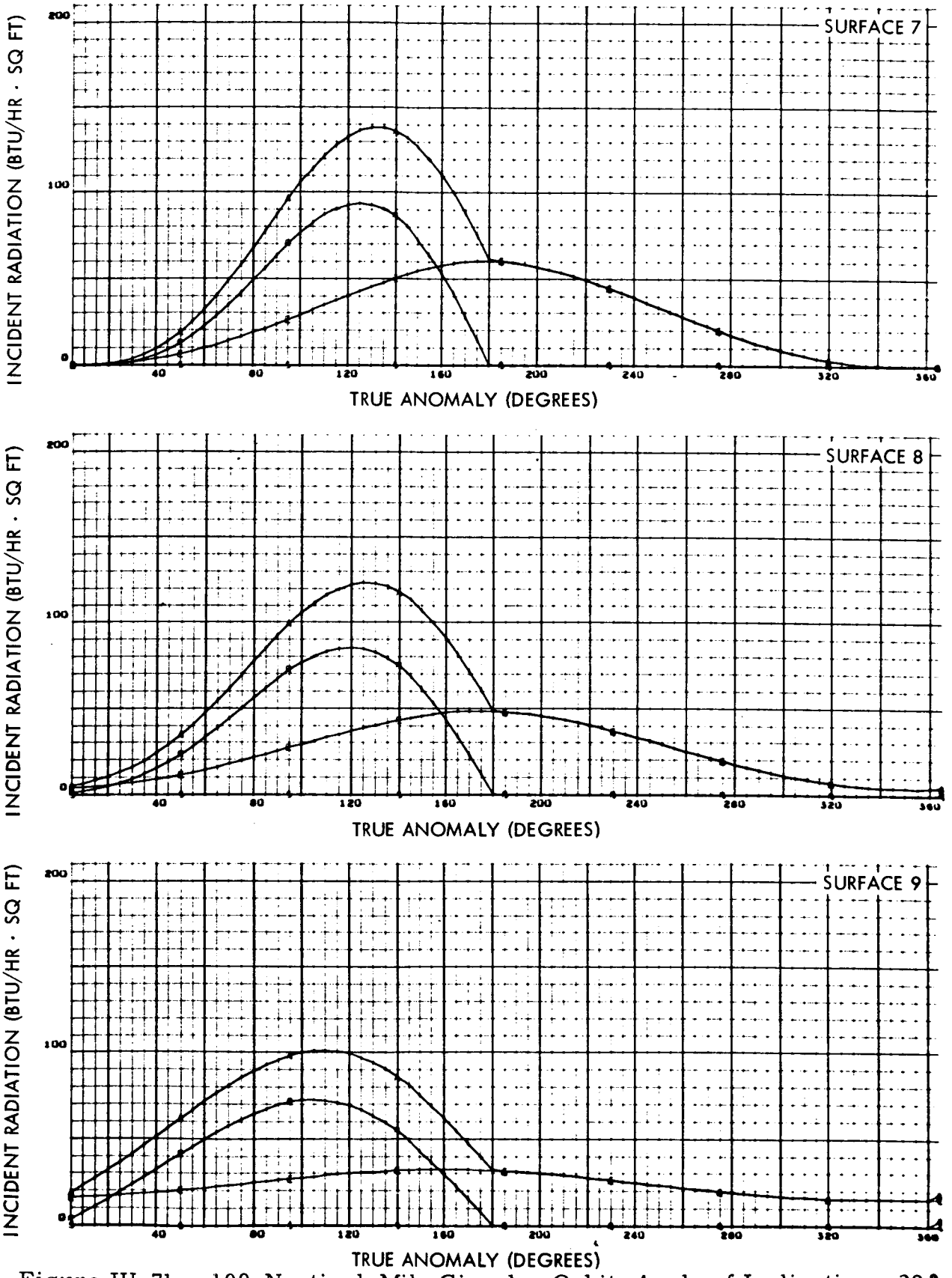


Figure IU-7b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 3 of 4)

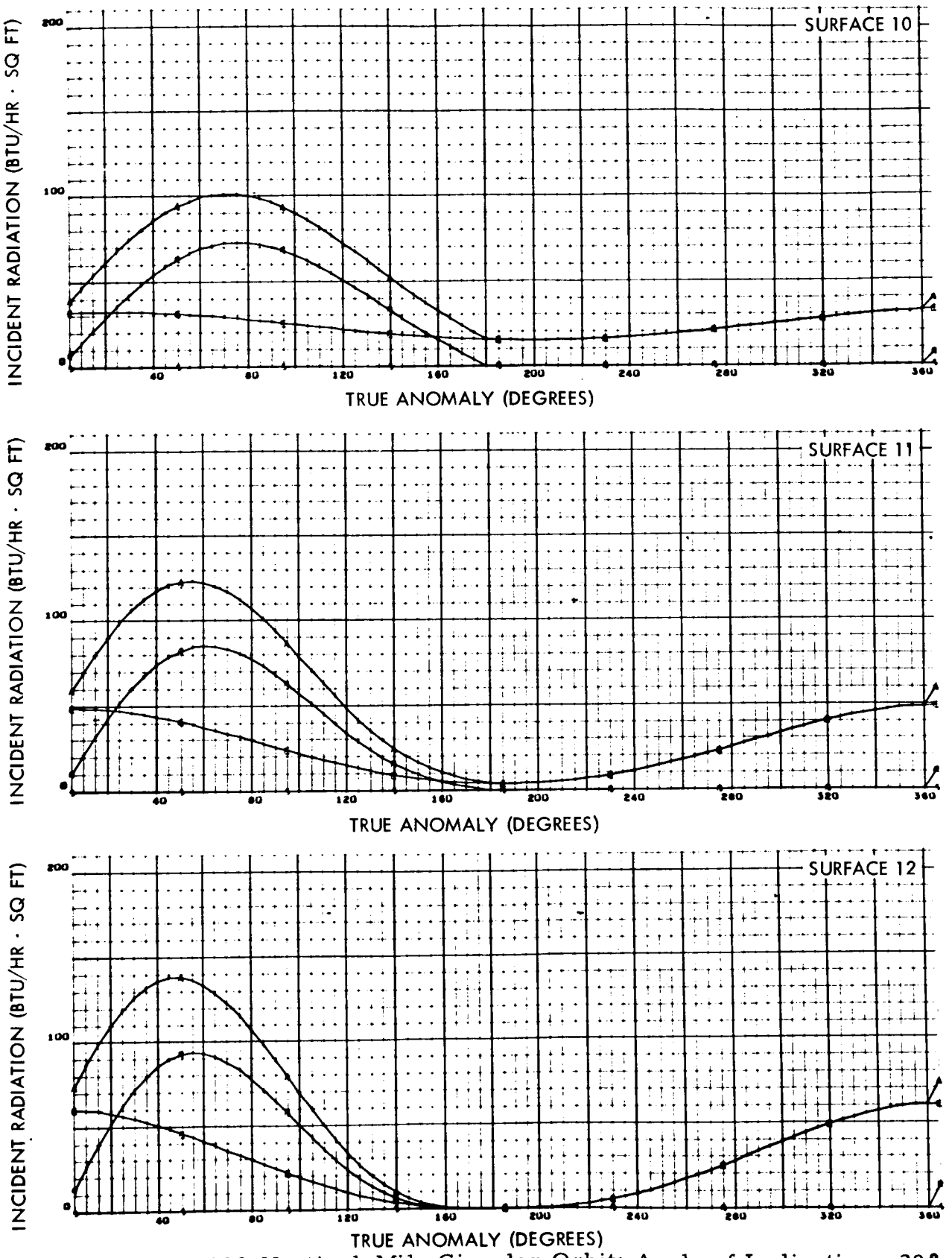


Figure IU-7b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; X-Sol (Sheet 4 of 4)

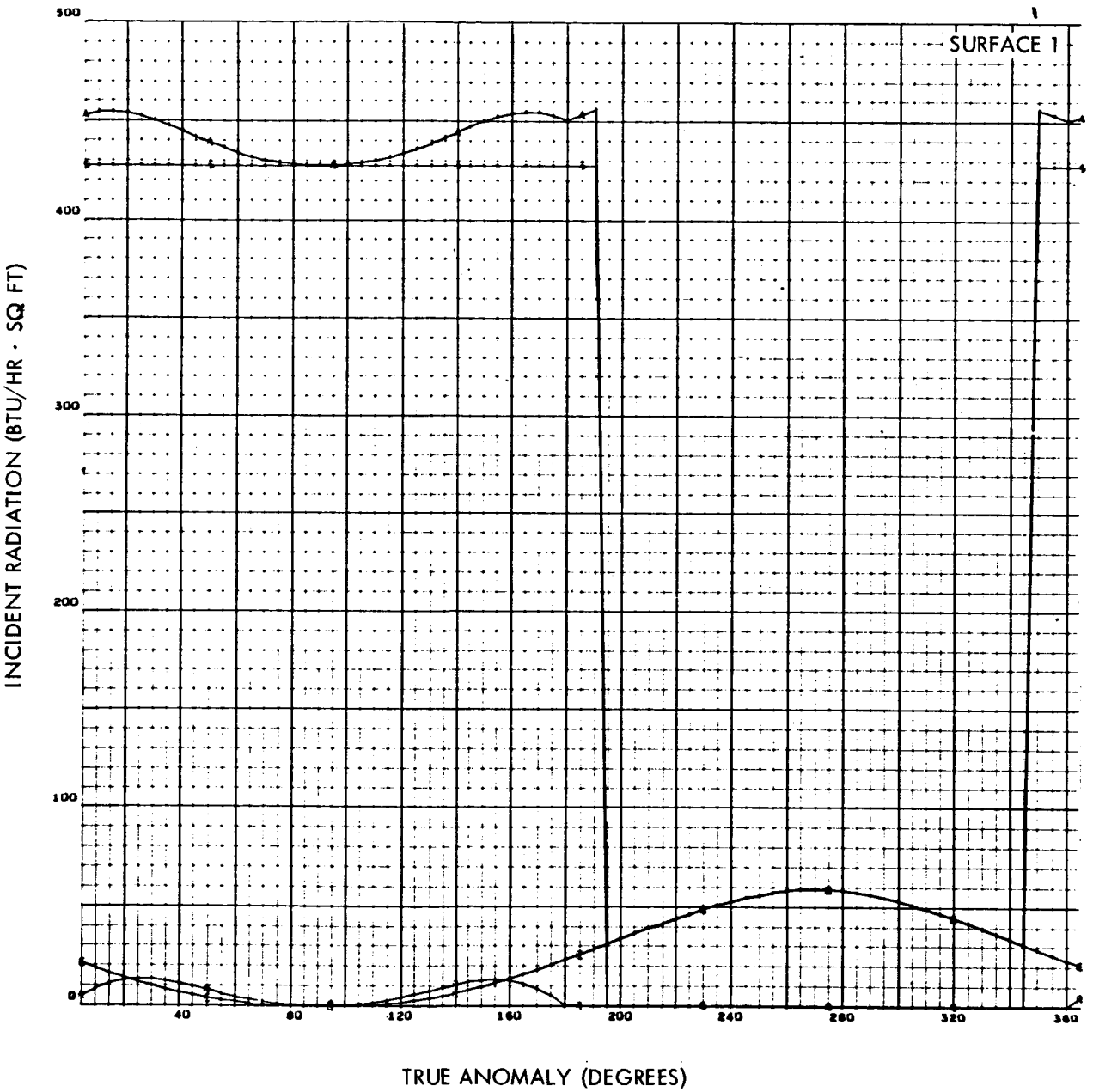


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 1 of 7)

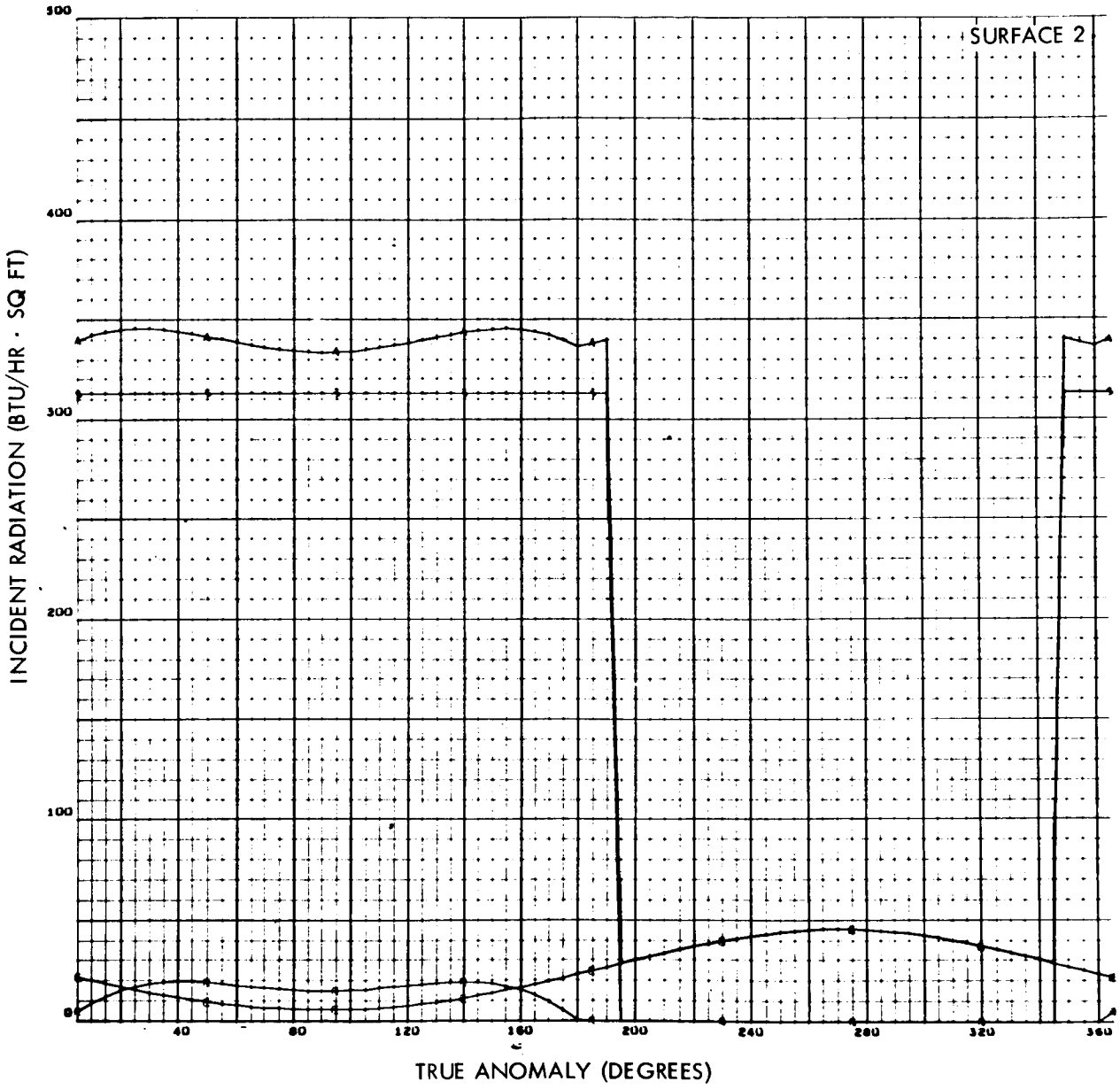


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 2 of 7)

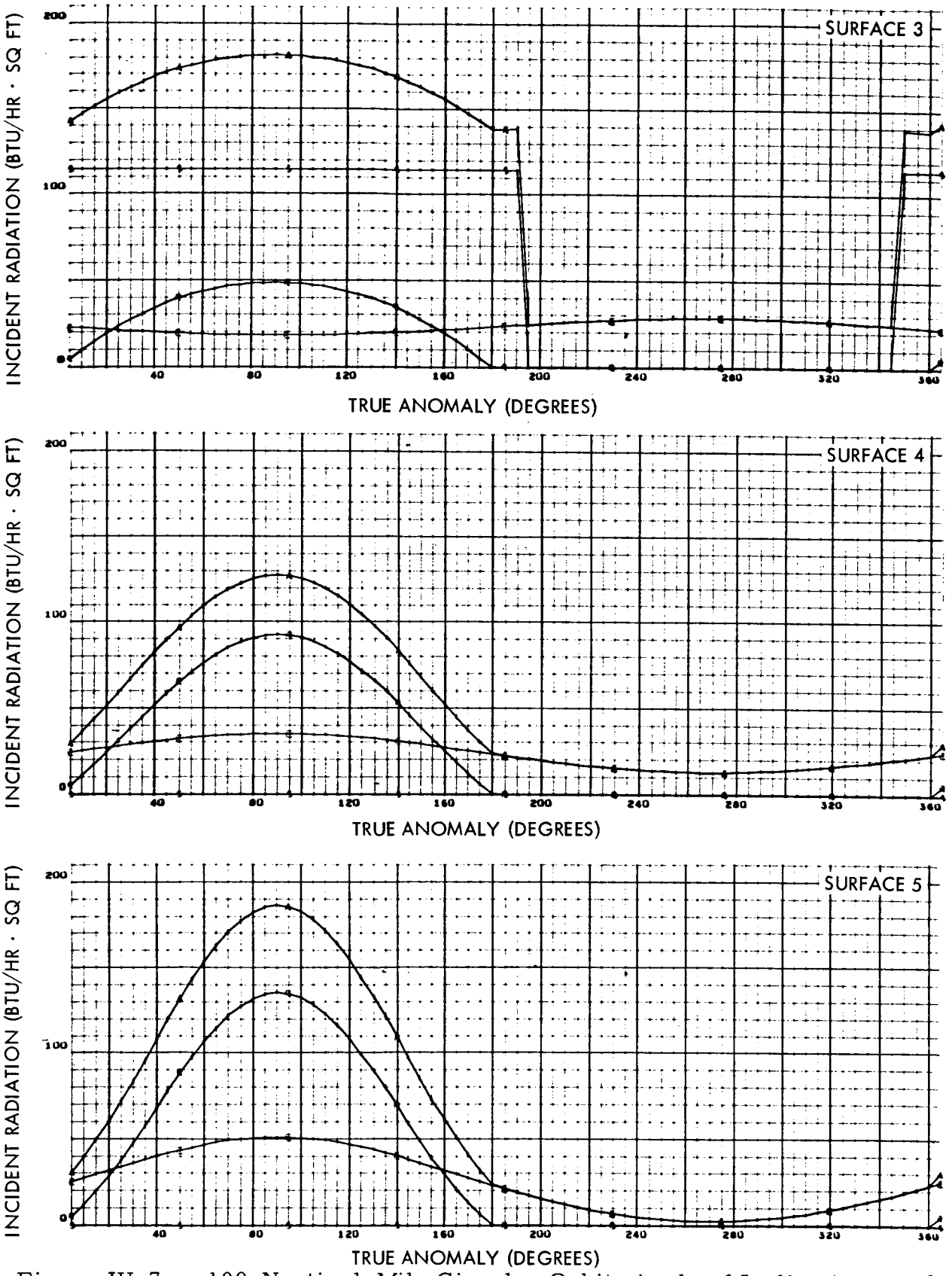
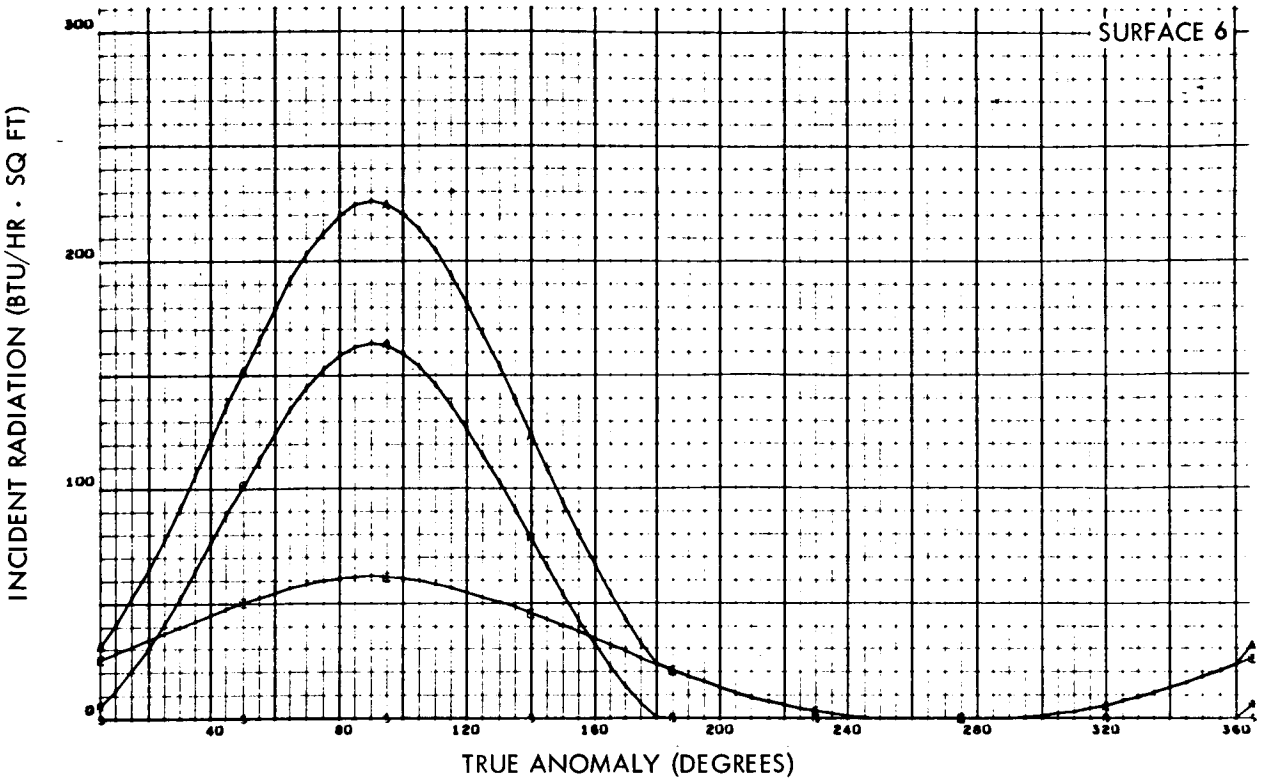


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 3 of 7)



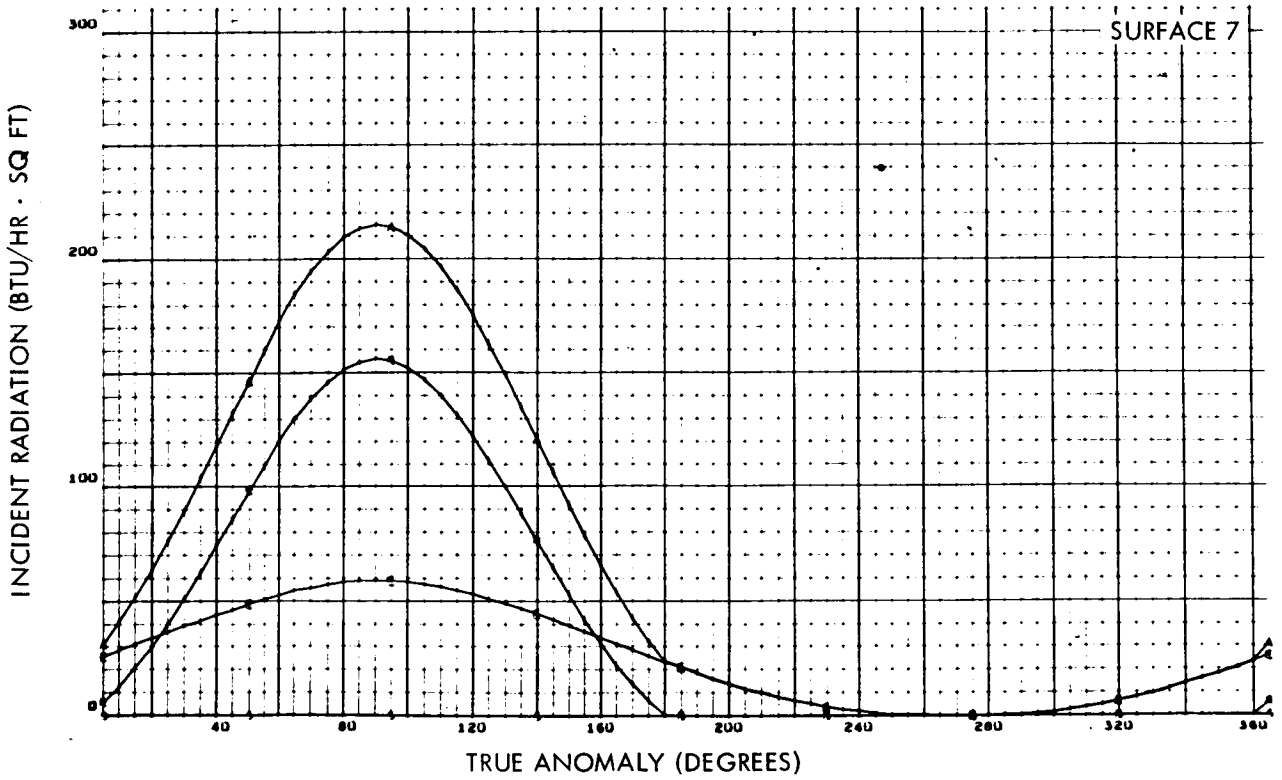


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 4 of 7)

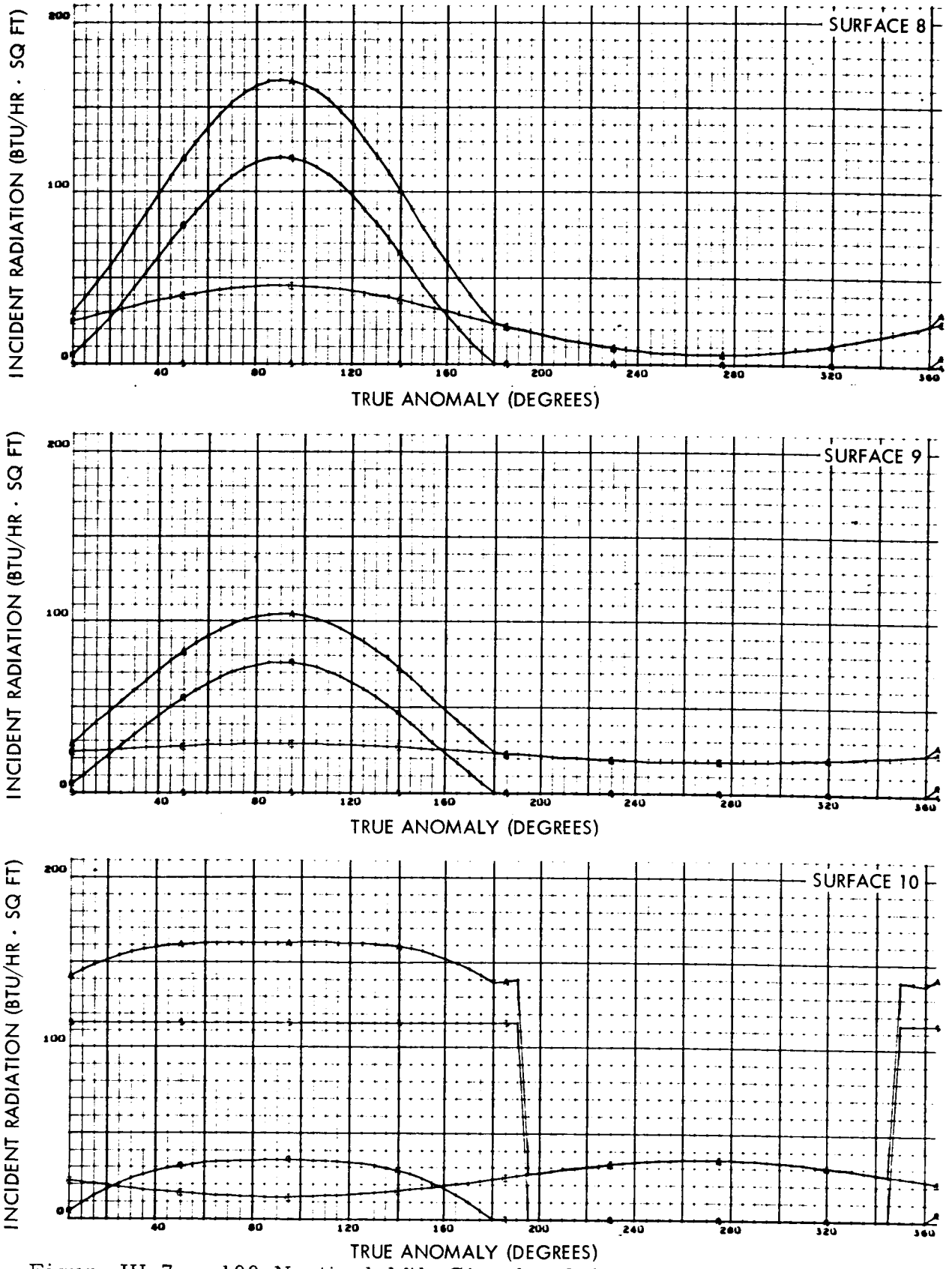


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 5 of 7)

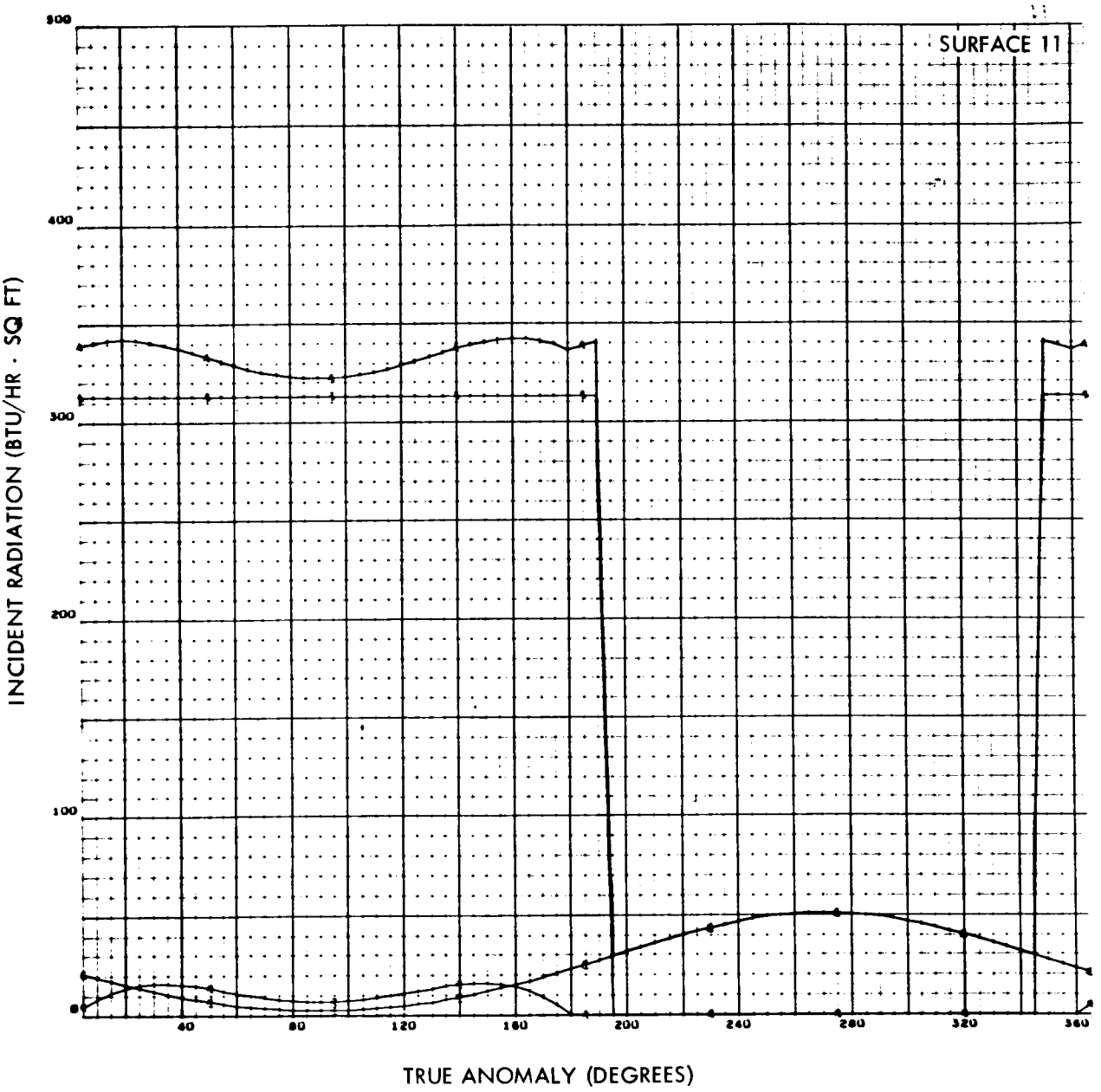


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 6 of 7)

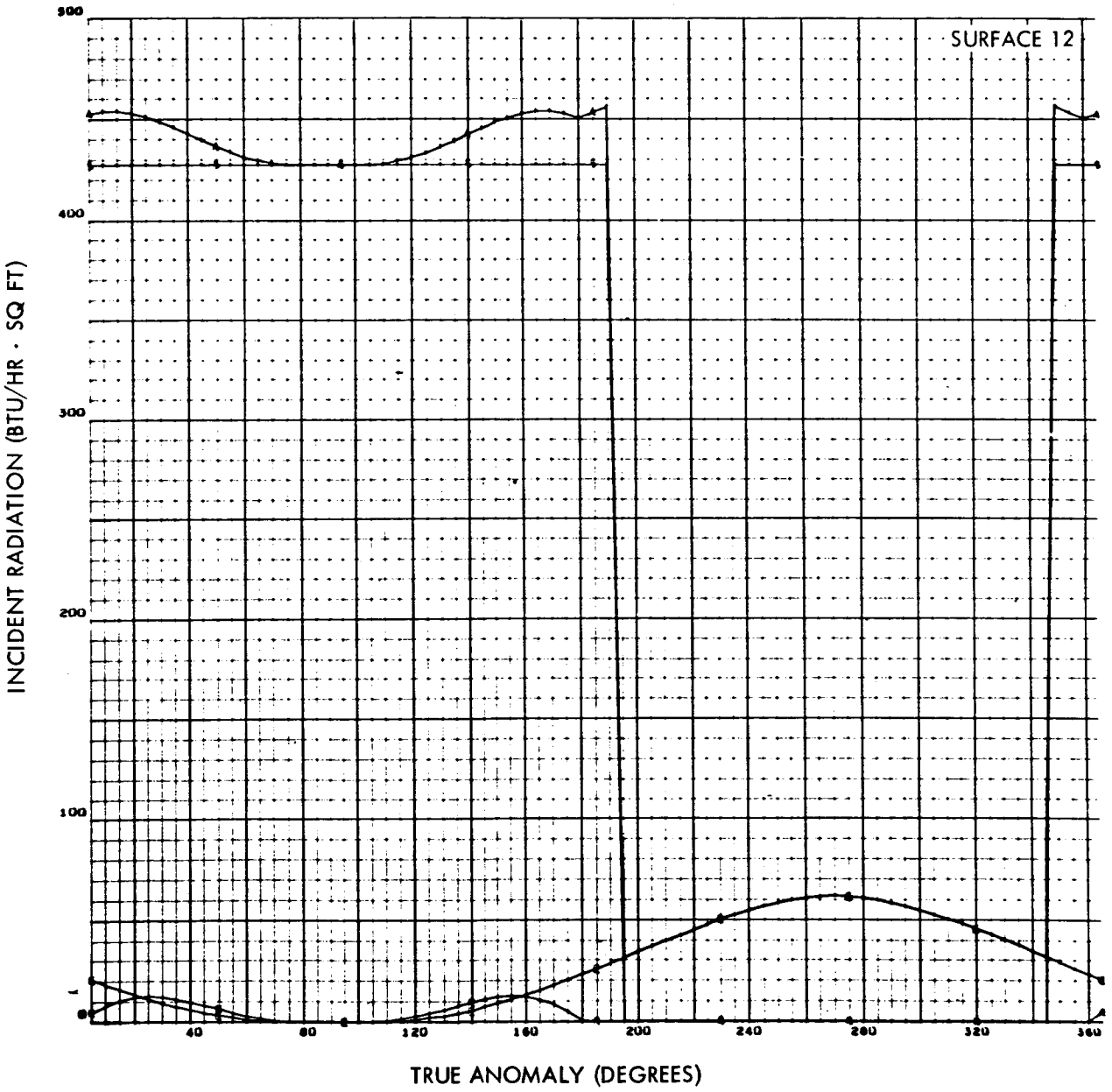


Figure IU-7c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 29°; Launch Date: June 21; Y-Sol (Sheet 7 of 7)

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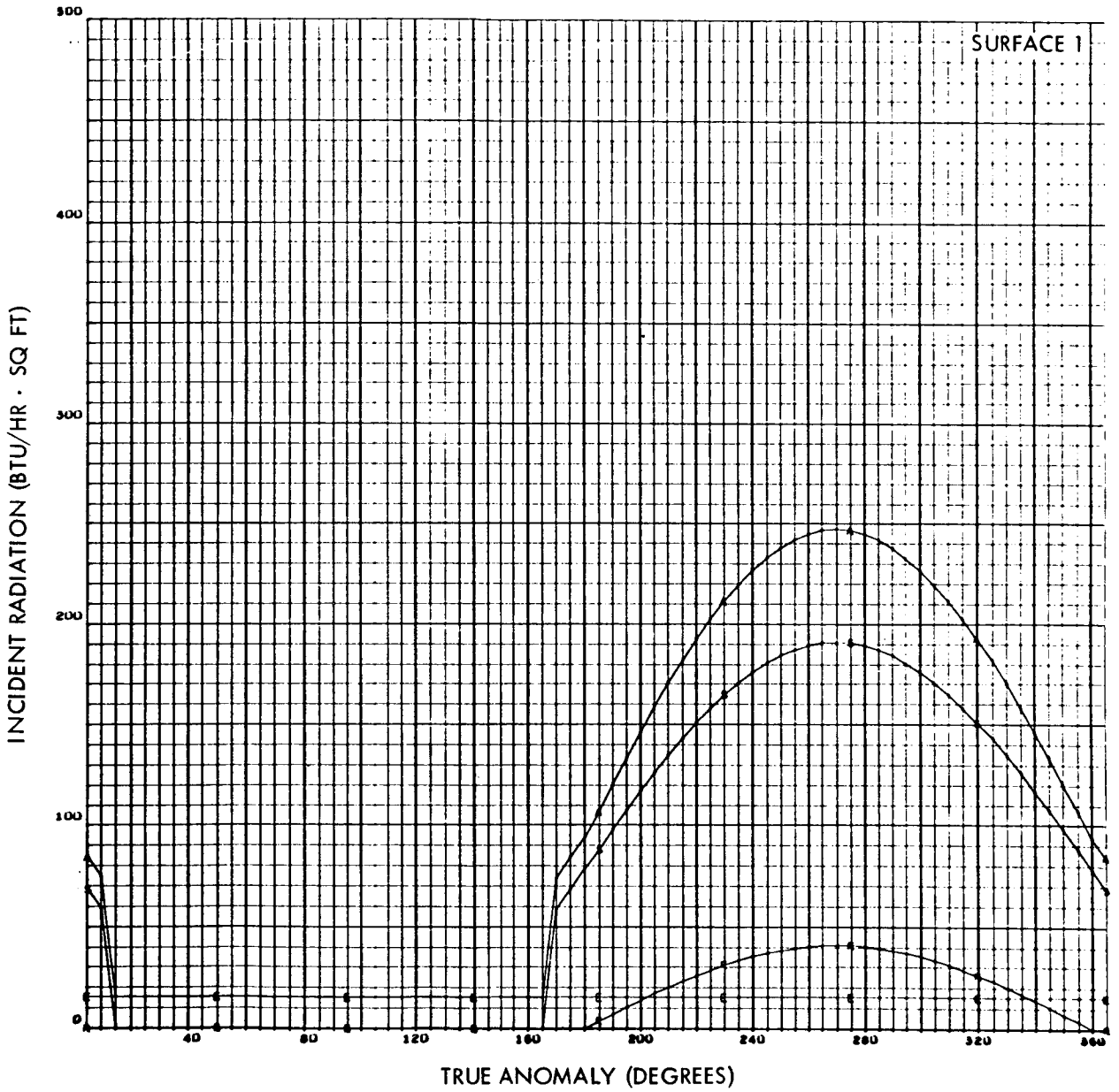


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 1 of 8)

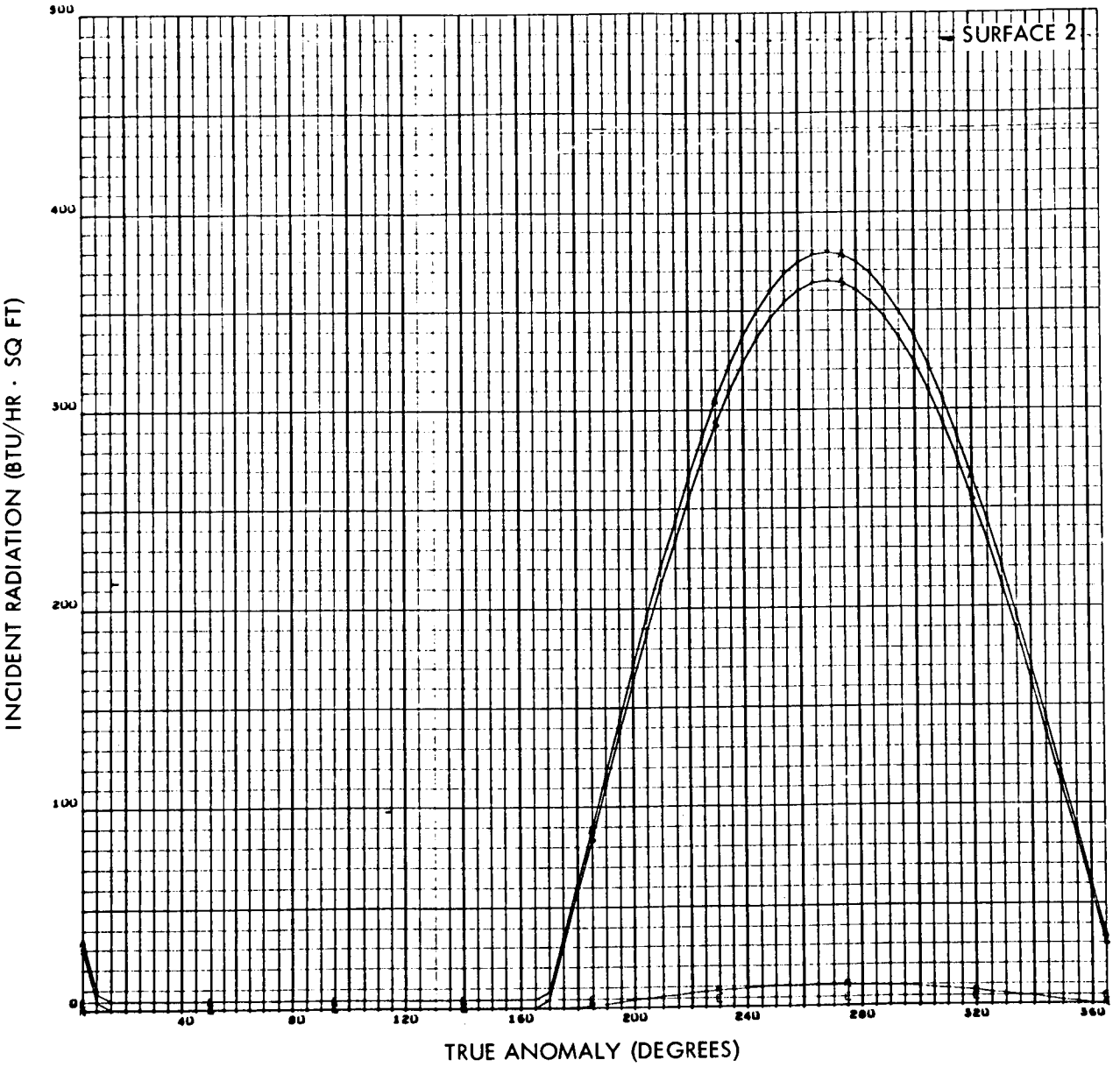


Figure IU-**8a**. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 2 of 8)

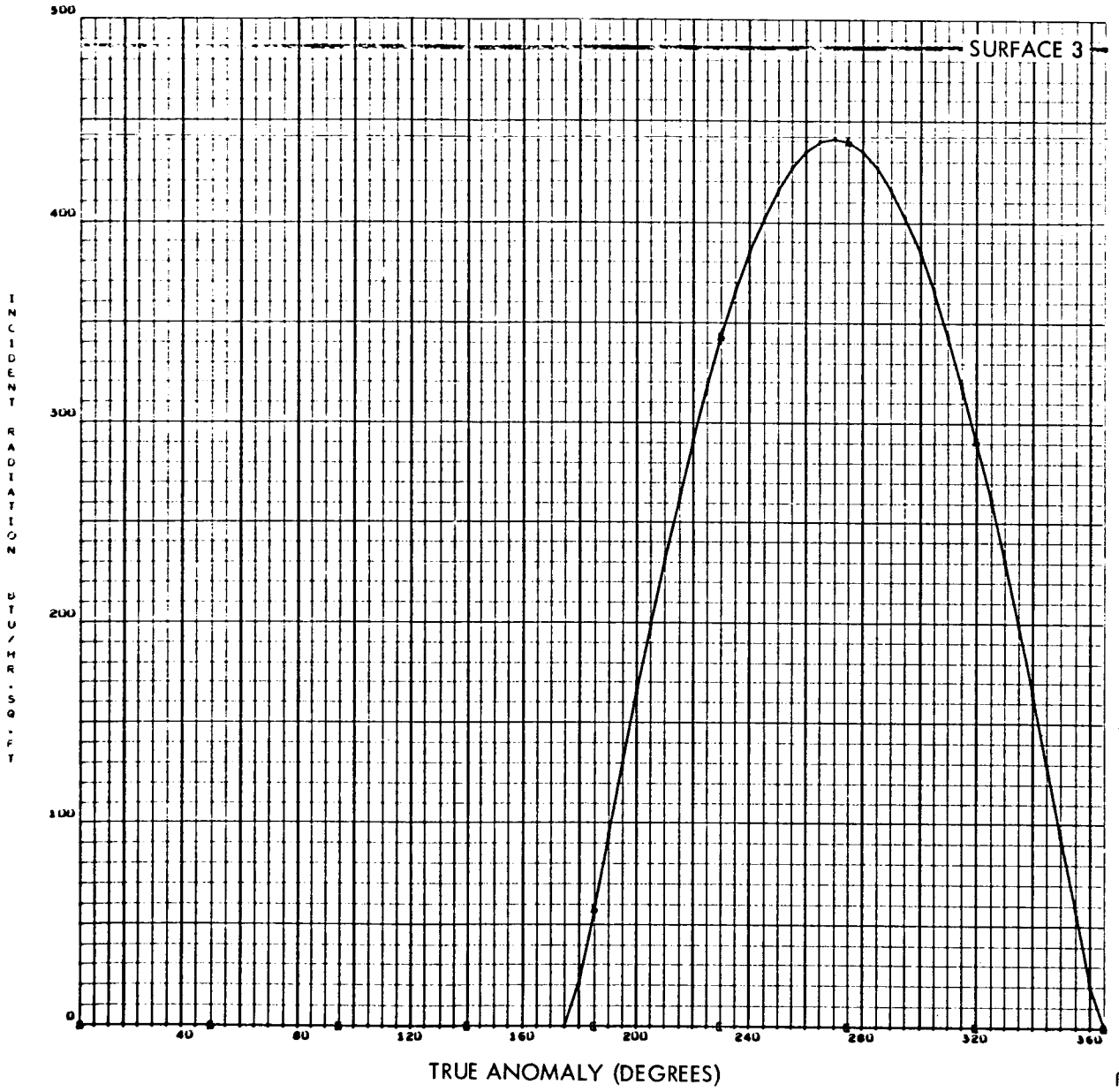


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 3 of 8)

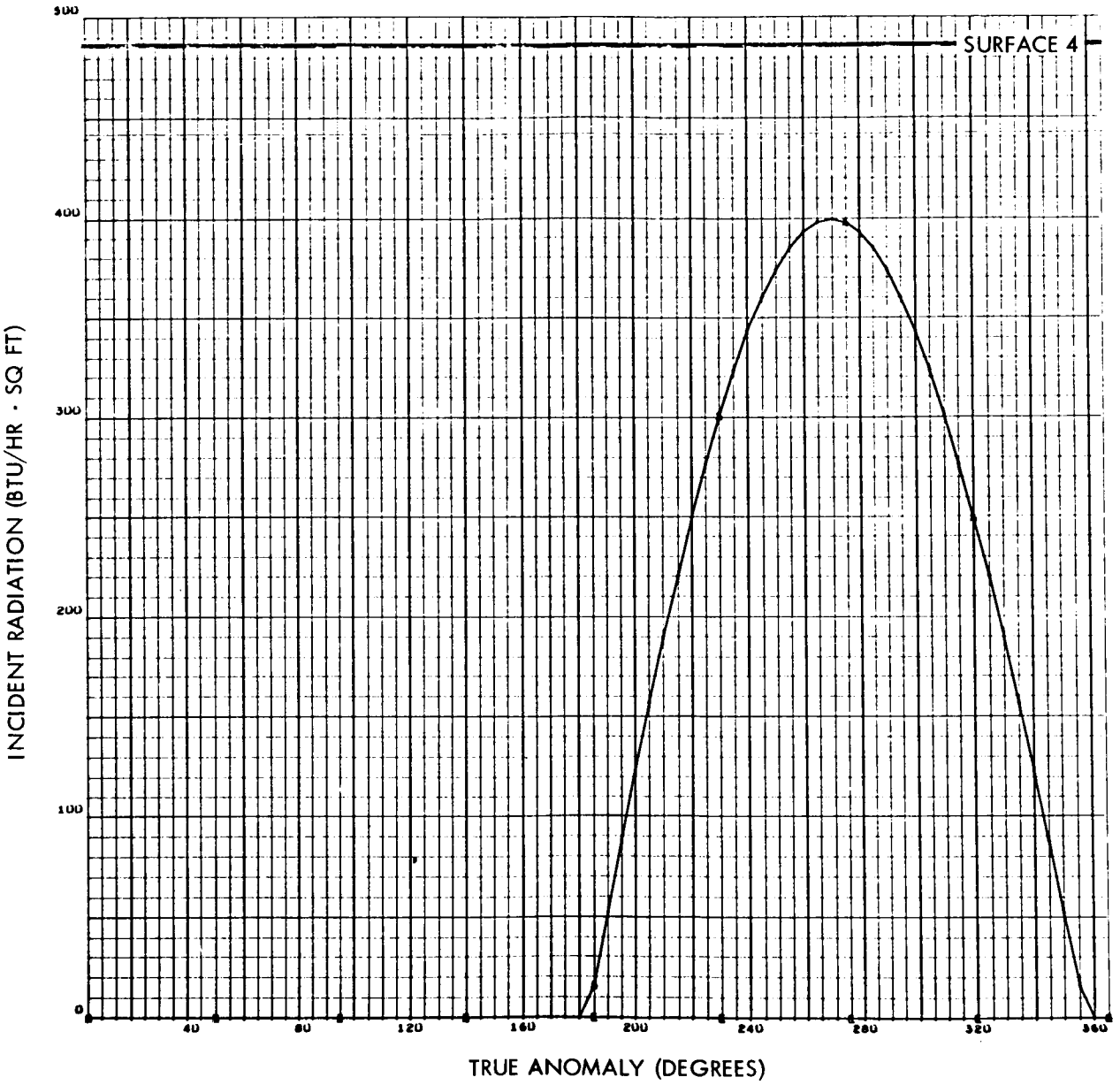


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 4 of 8)

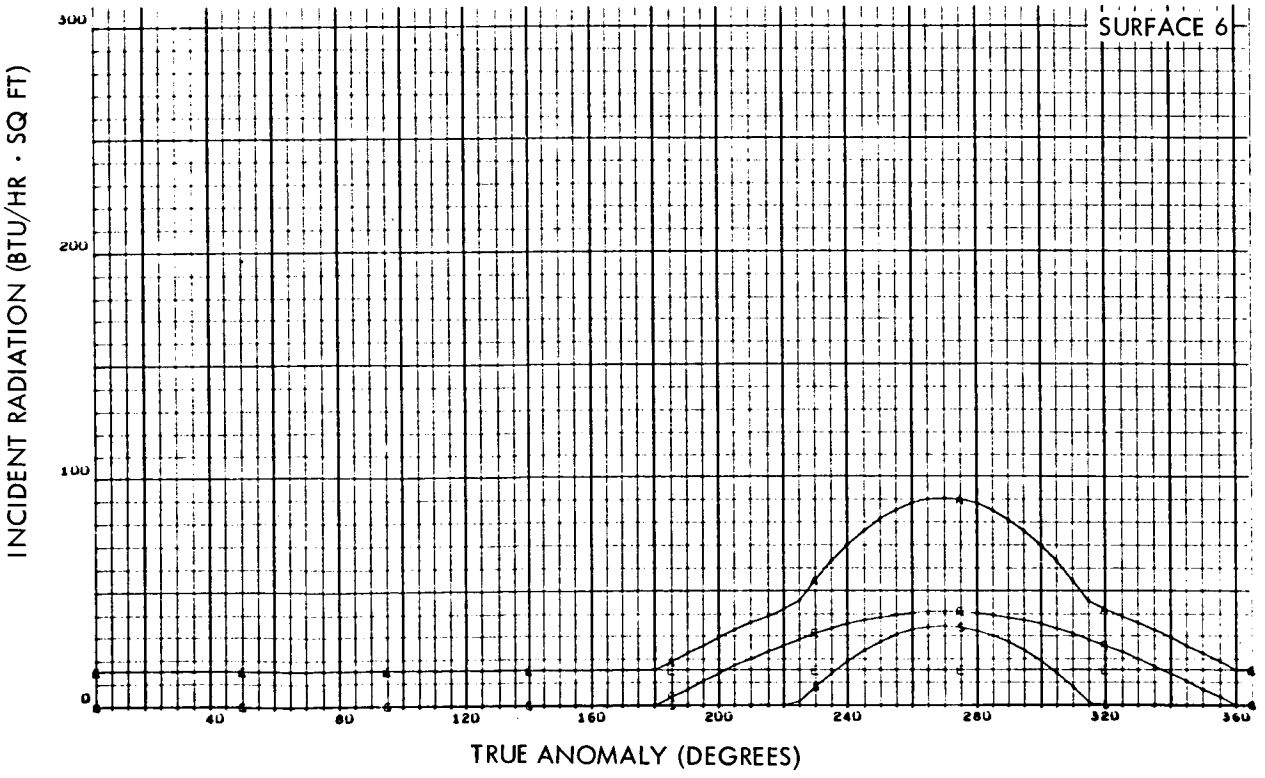
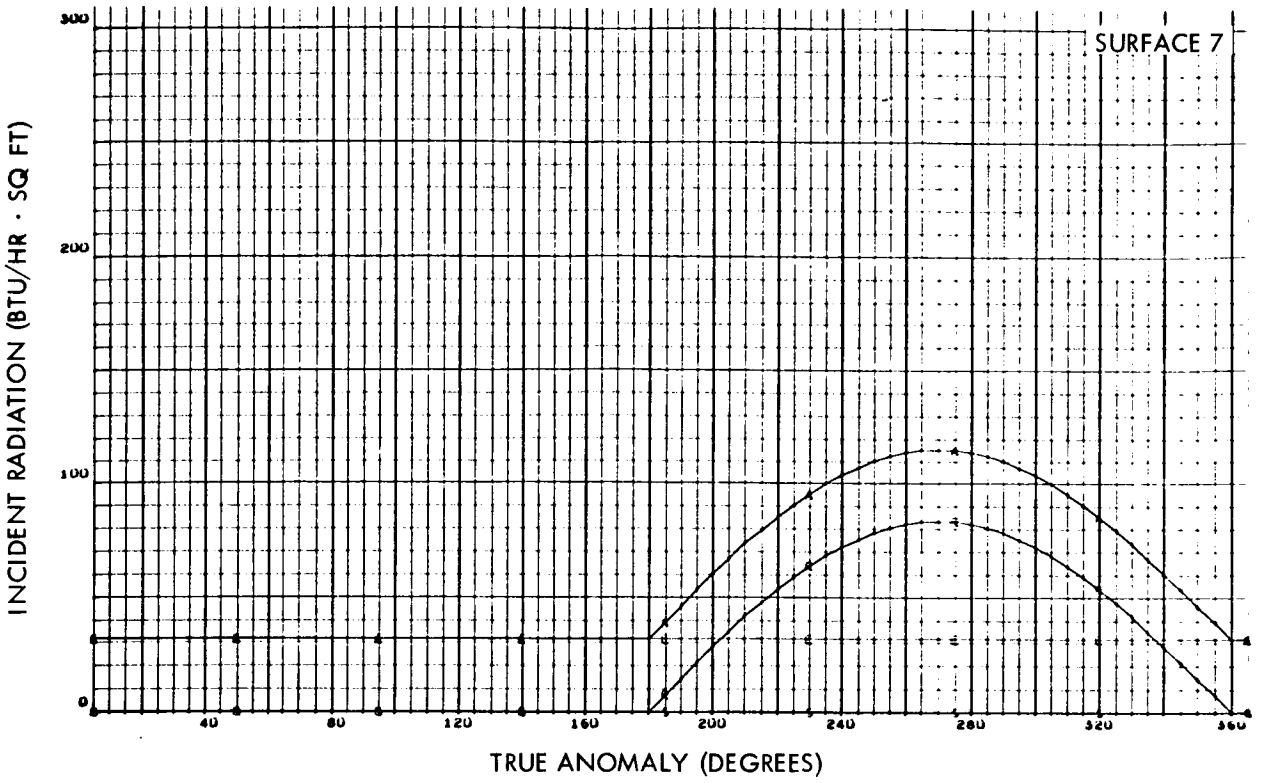


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 5 of 8)



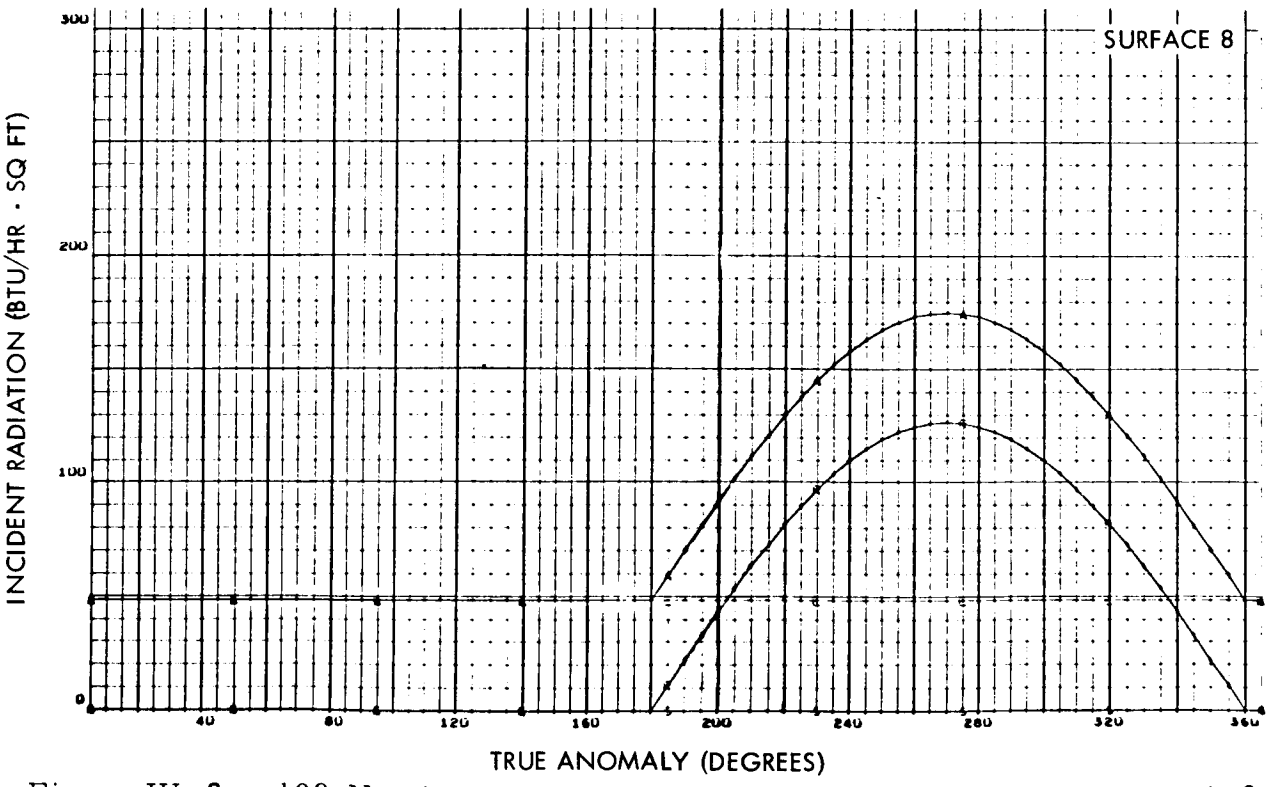
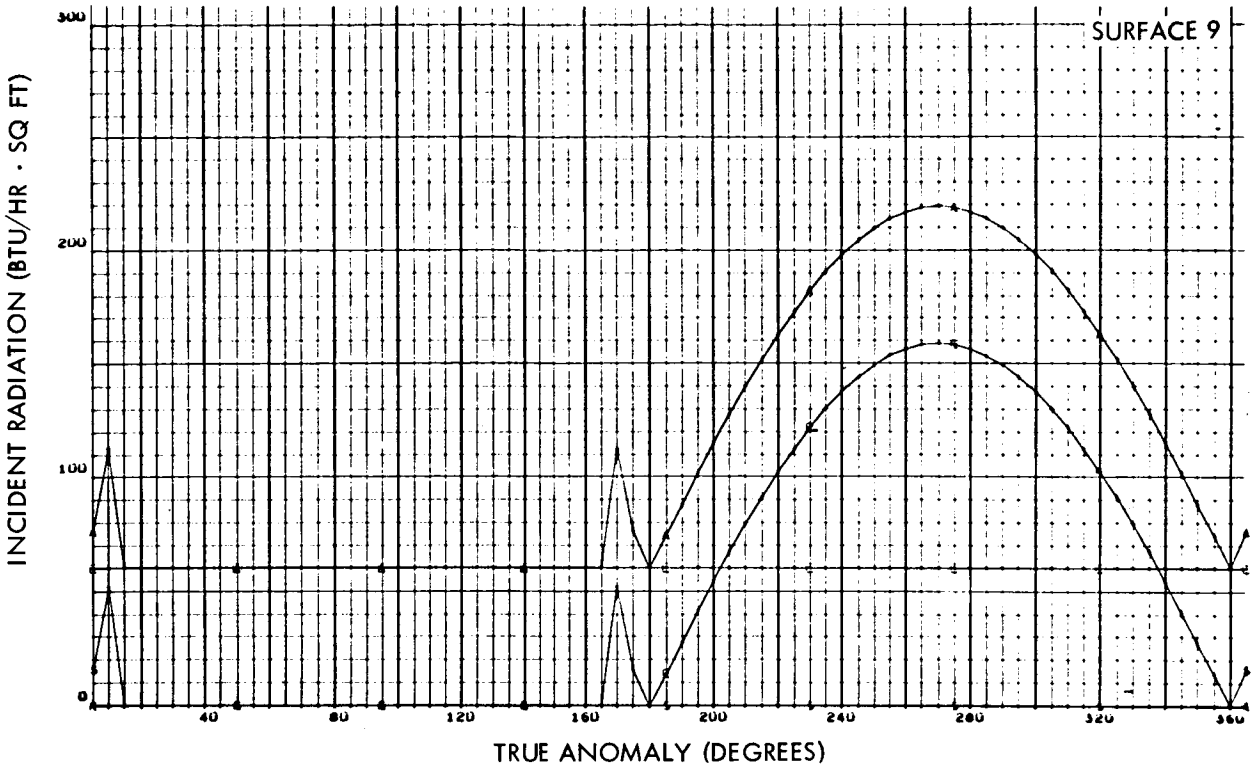


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 6 of 8)



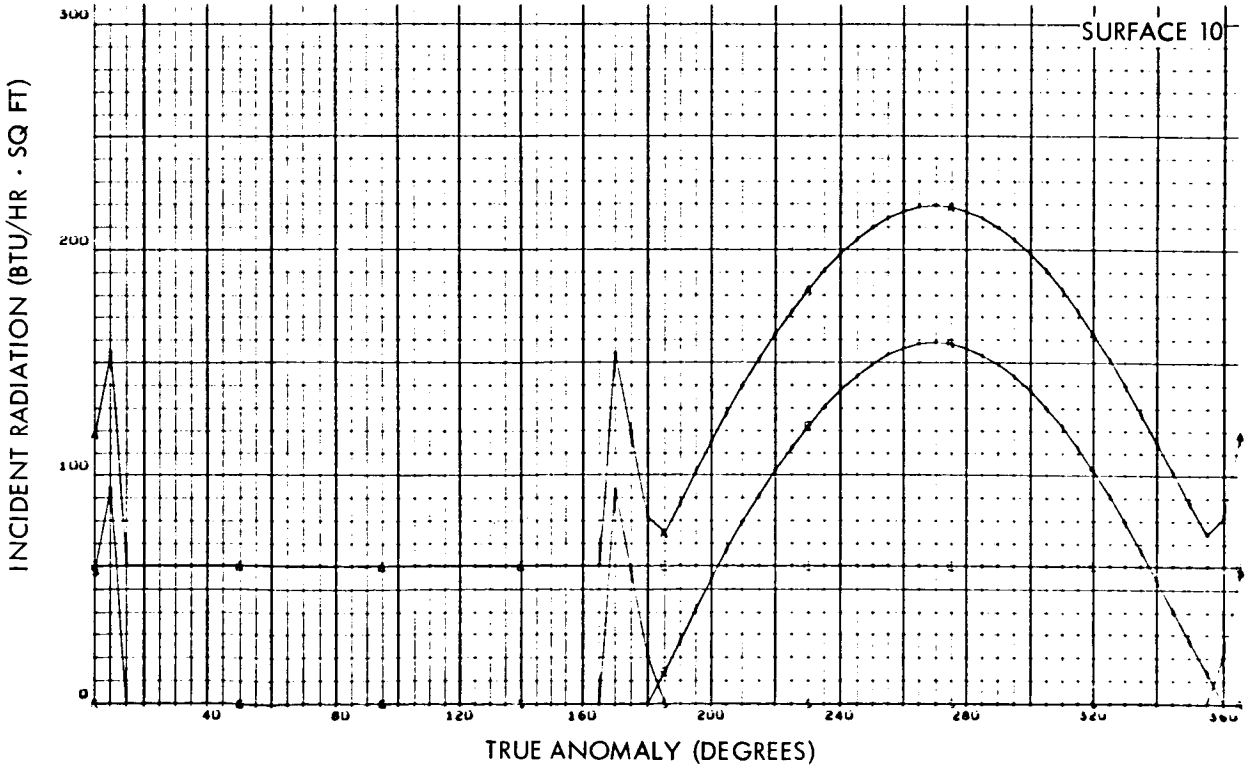
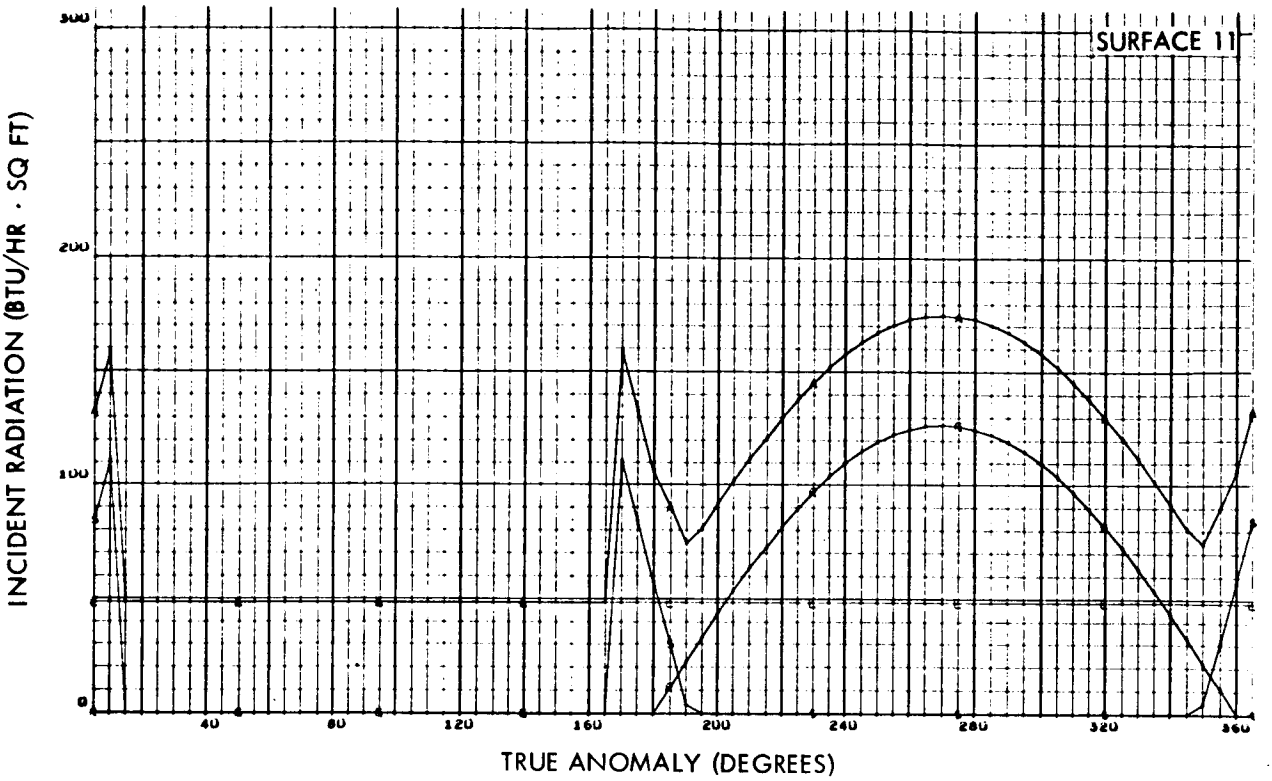


Figure IU-8a. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 7 of 8)



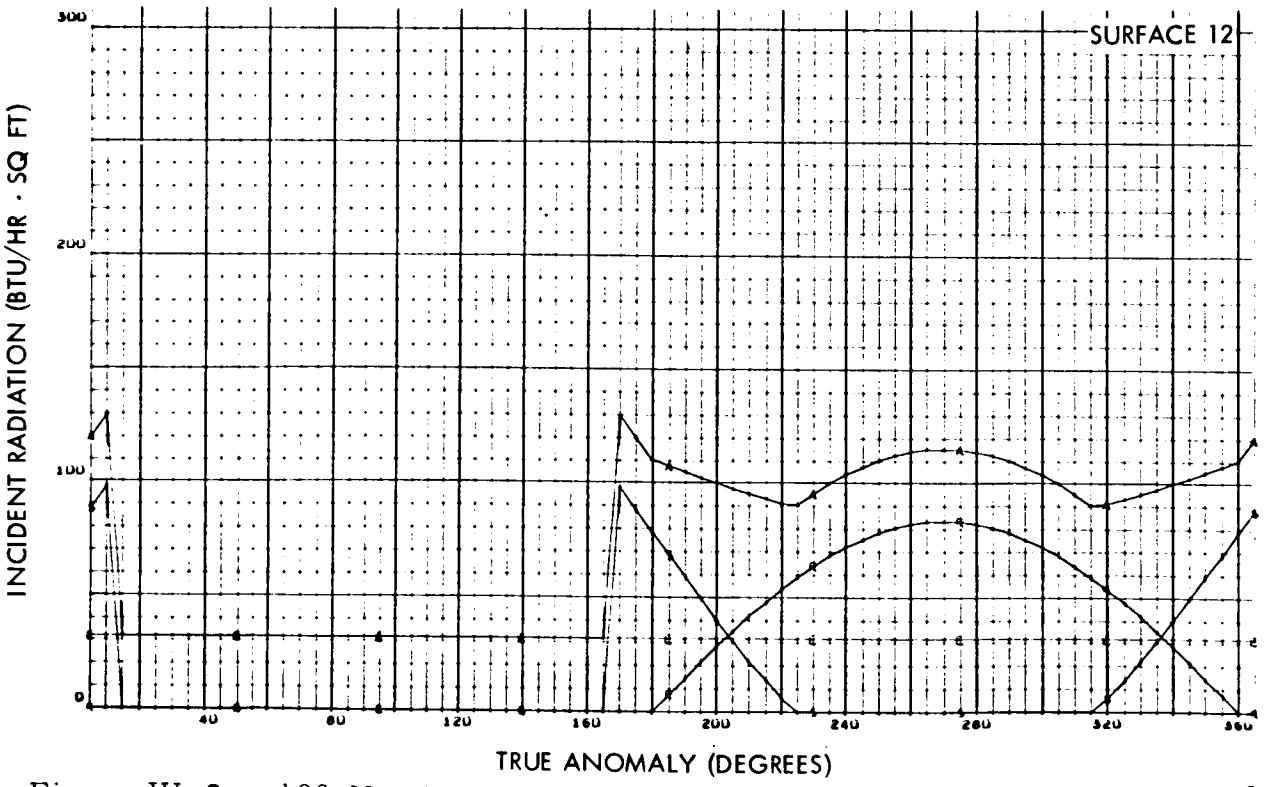


Figure IU-**8a**. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Sheet 8 of 8)

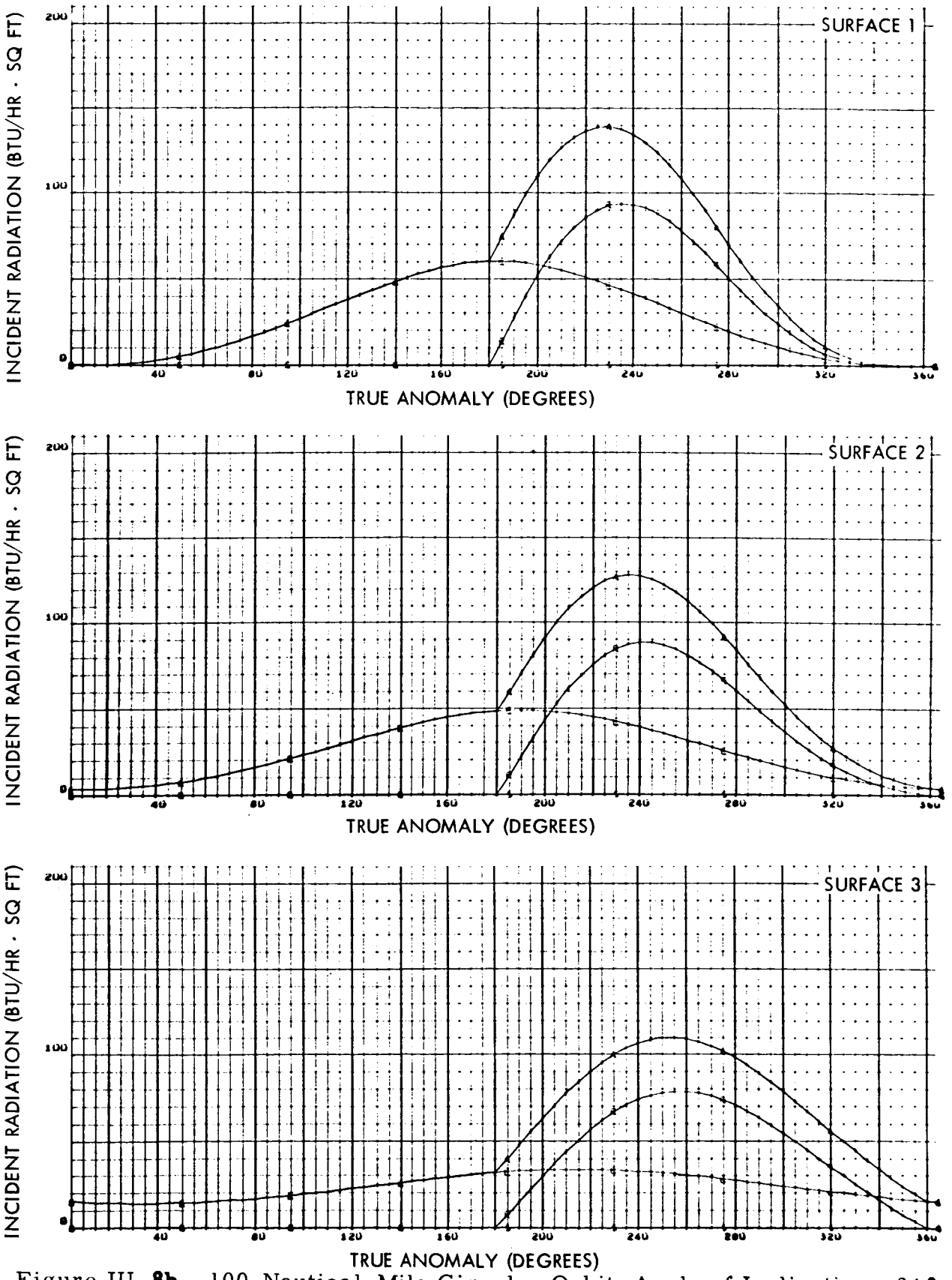


Figure IU-8b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 1 of 4)

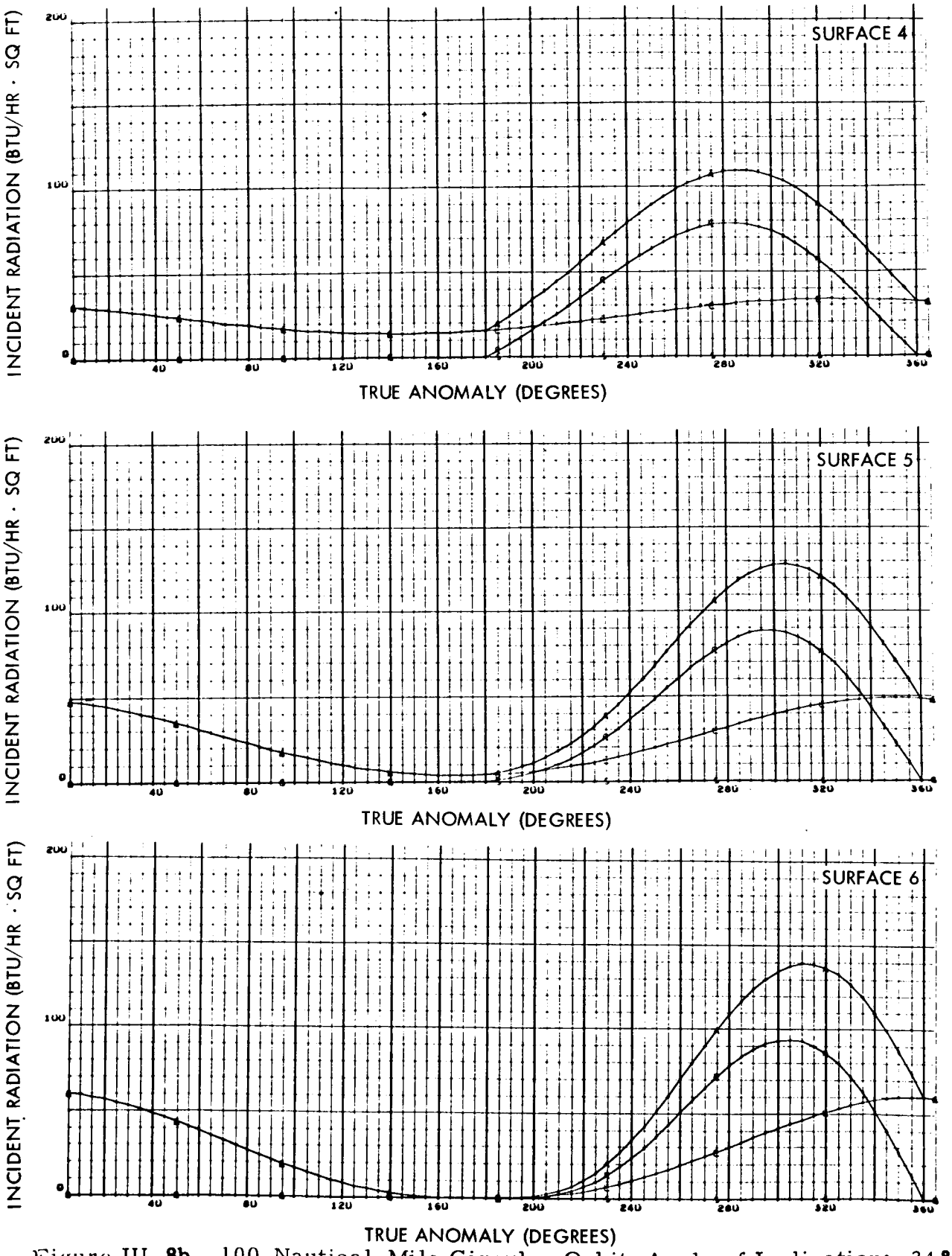


Figure IU-8b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 2 of 4)

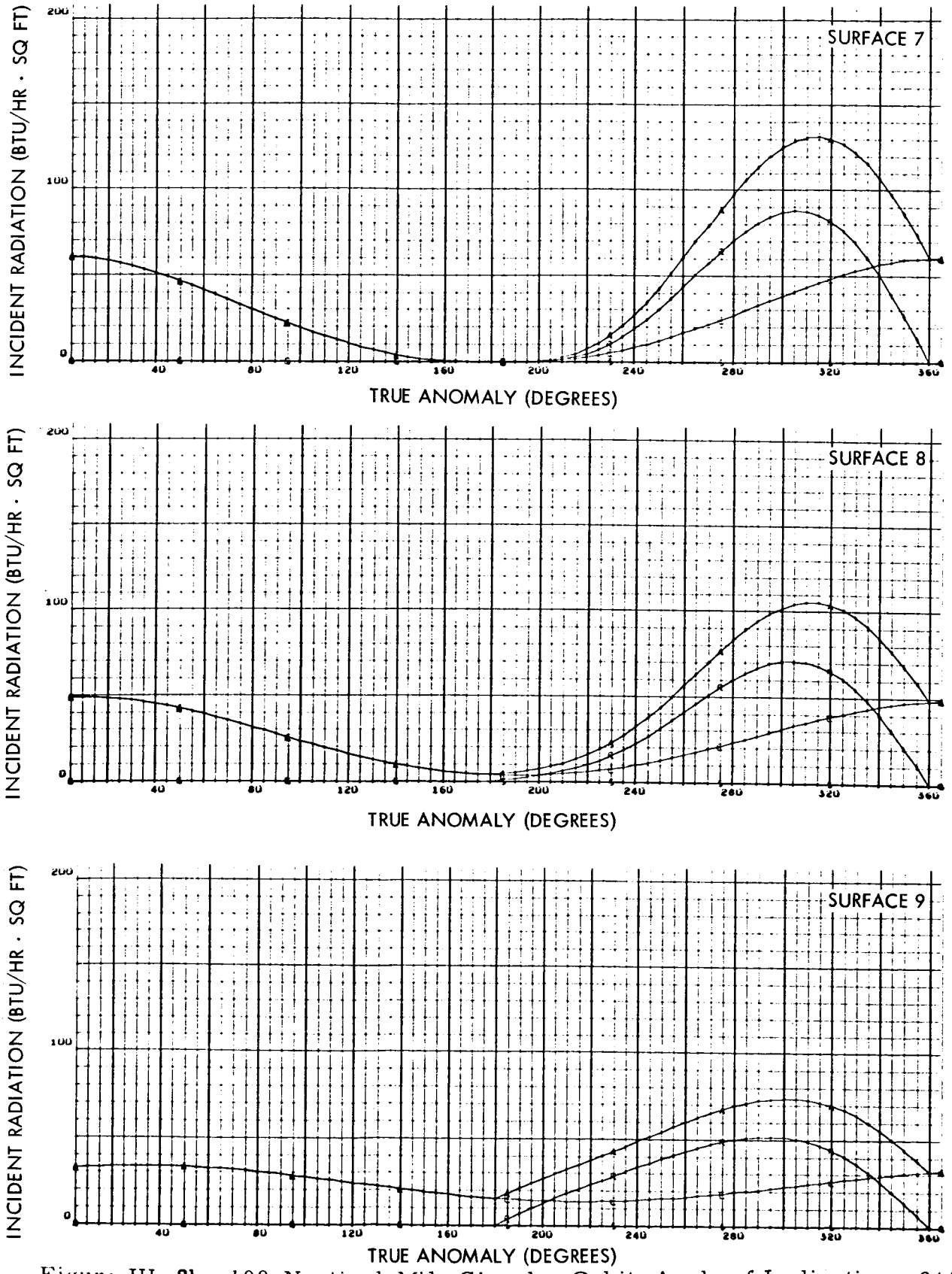


Figure IU-8b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 3 of 4)

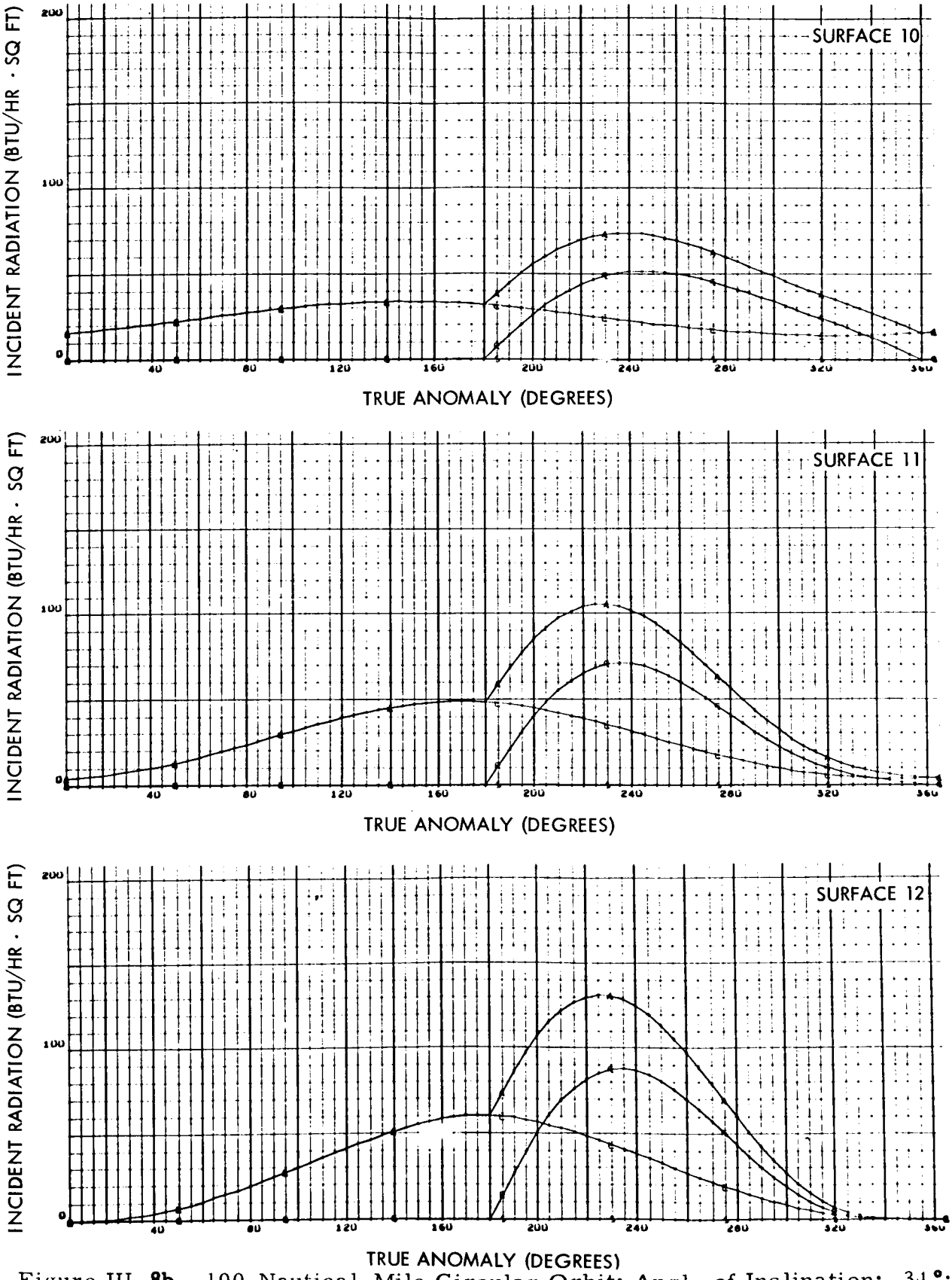


Figure IU-8b. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Sol (Sheet 4 of 4)

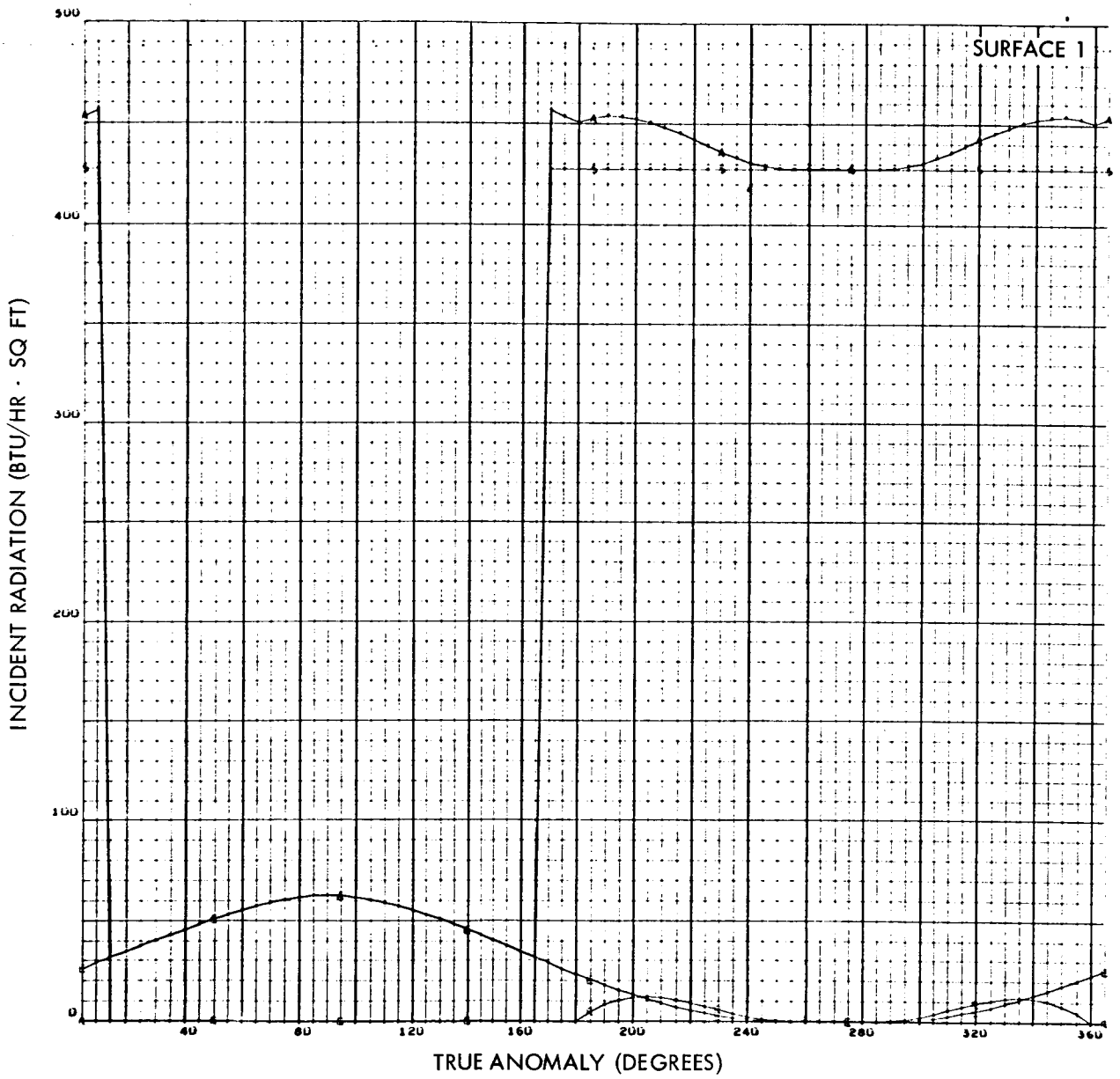


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 1 of 7)

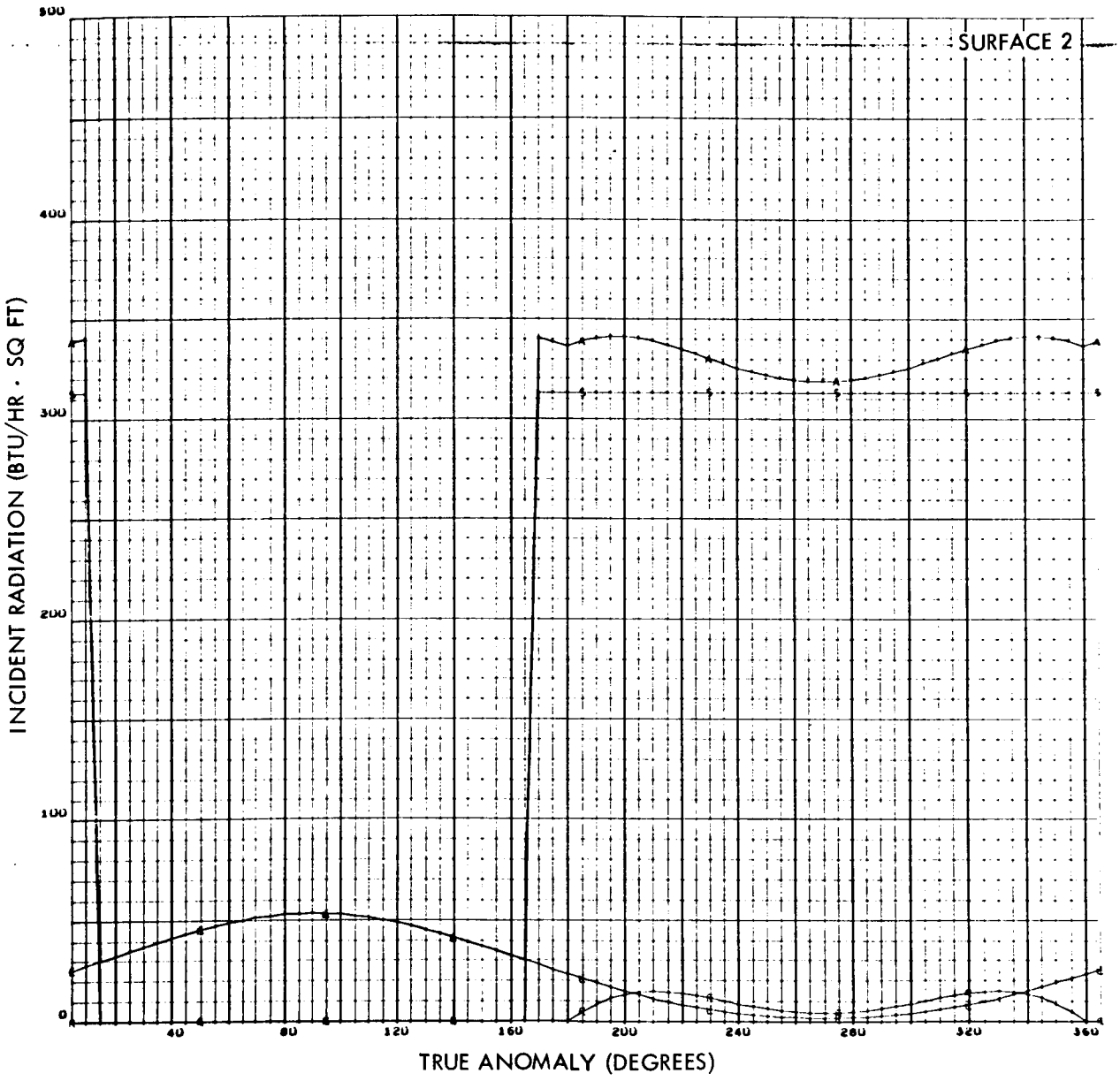


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 2 of 7)

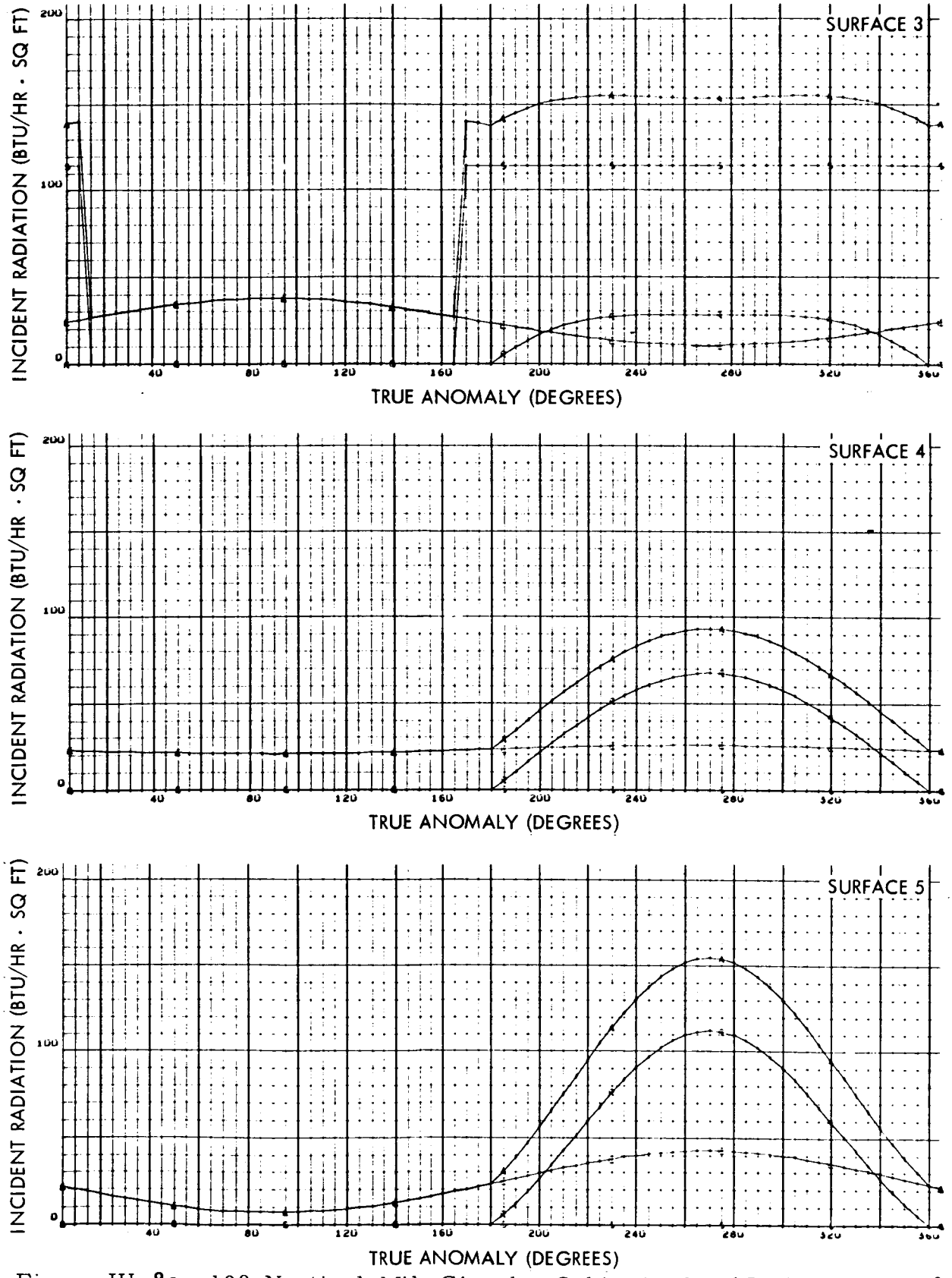
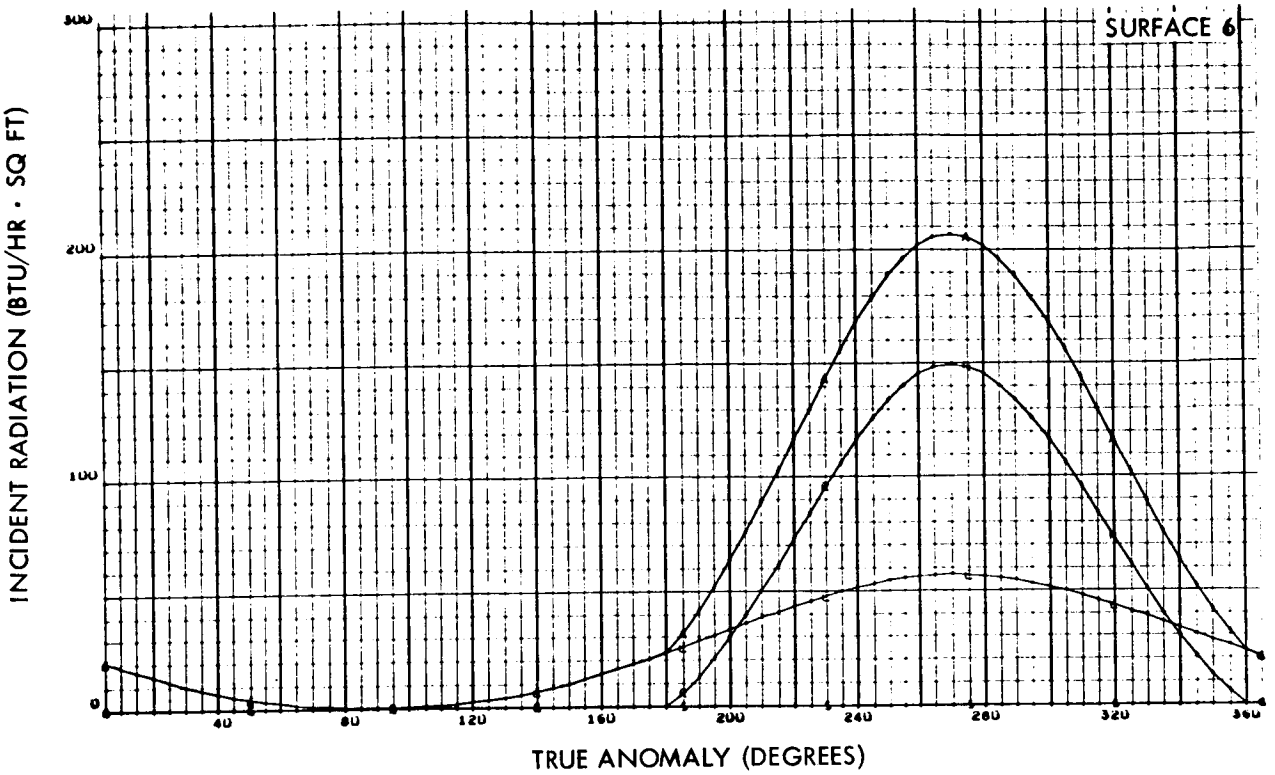


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 3 of 7)



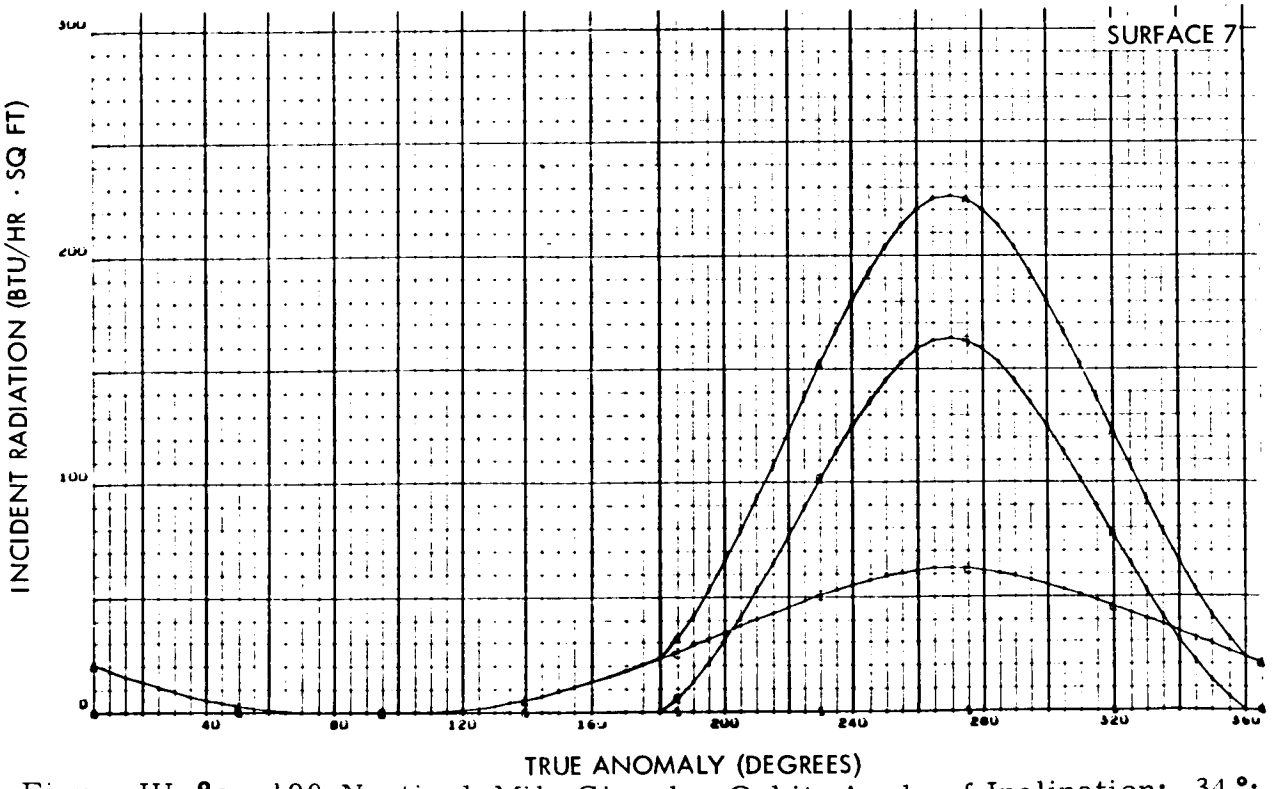


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 4 of 7)

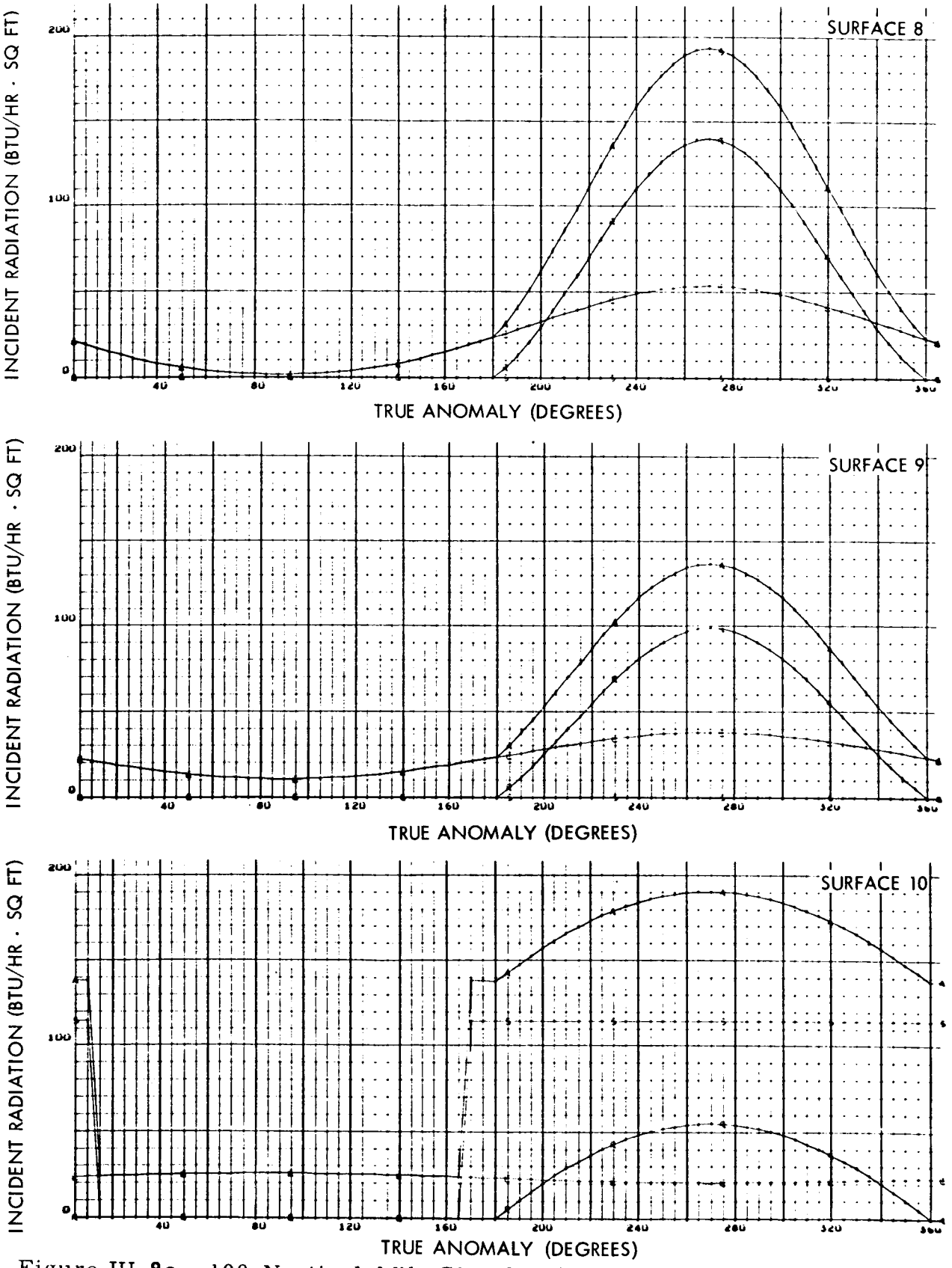


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 5 of 7)

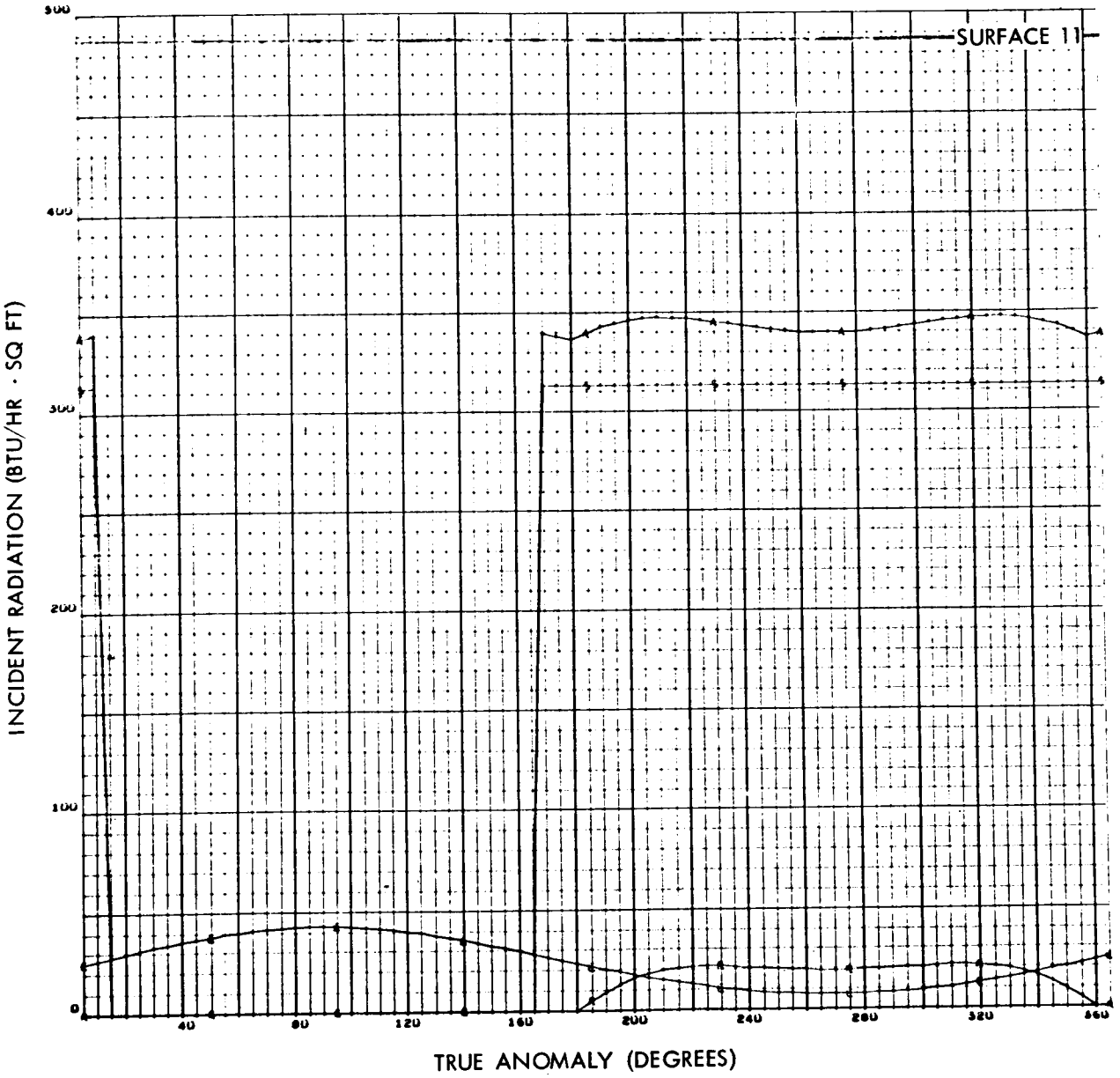


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 6 of 7)

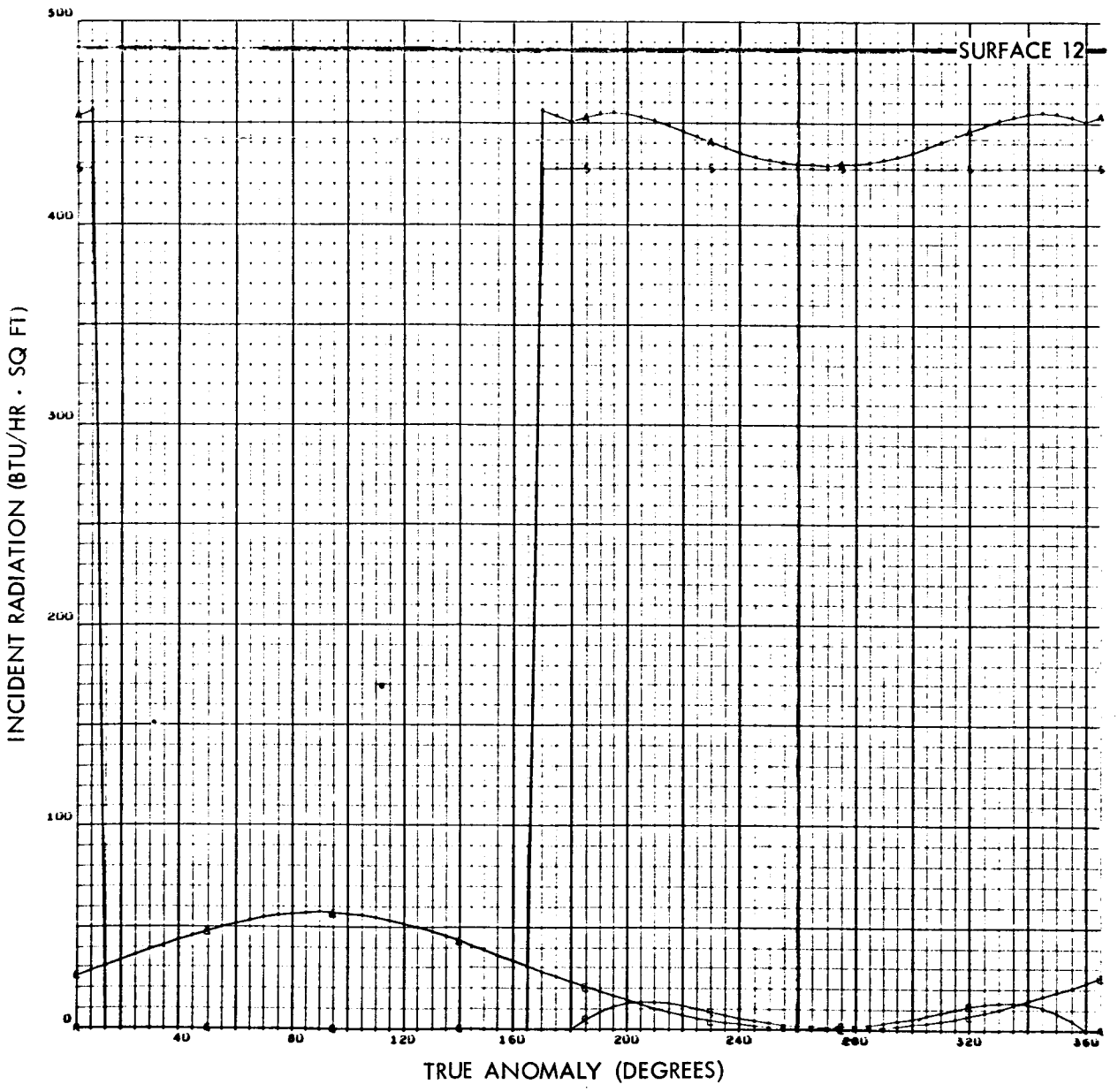


Figure IU-8c. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; Y-Sol (Sheet 7 of 7)

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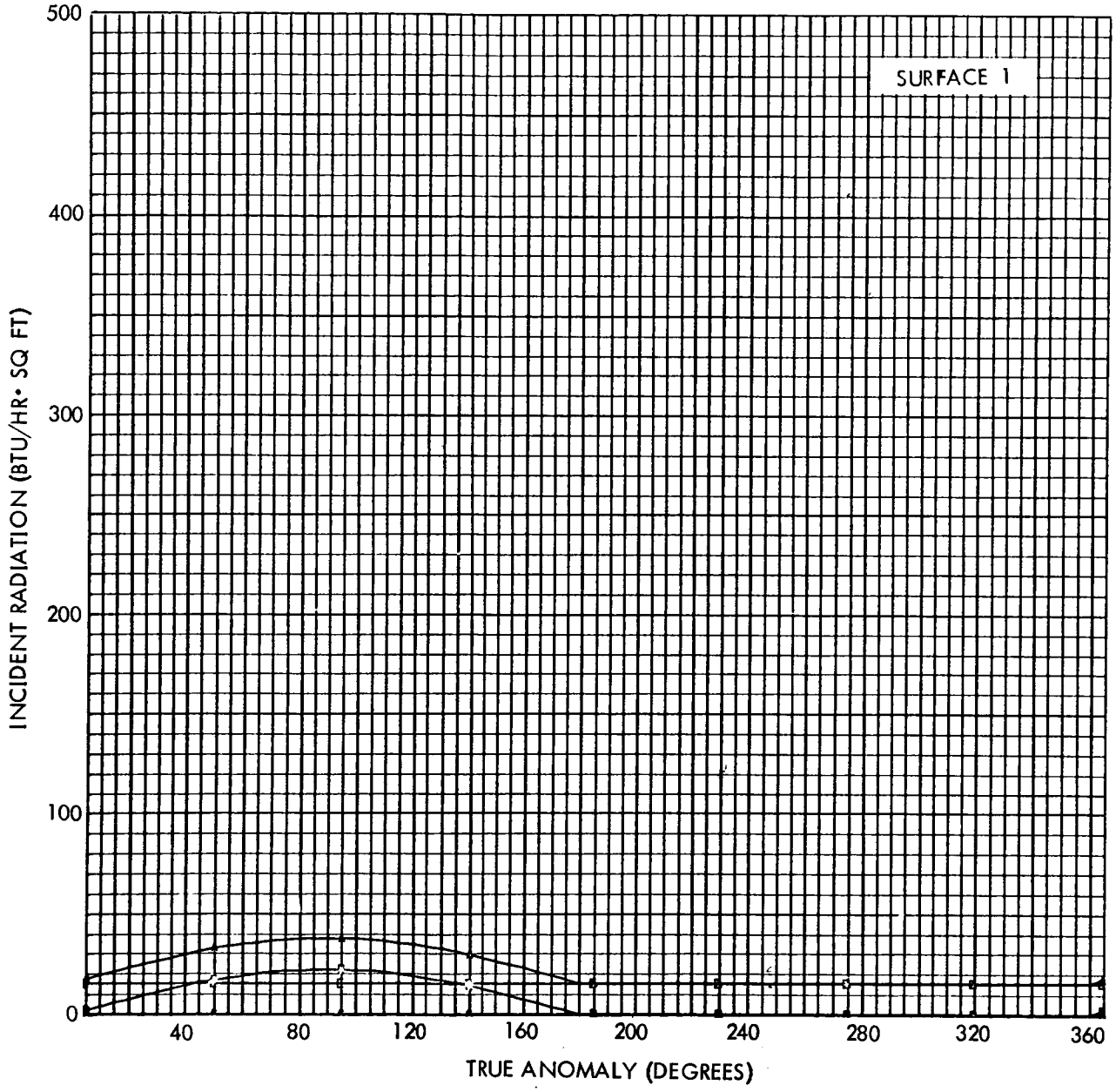


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 1 of 12)

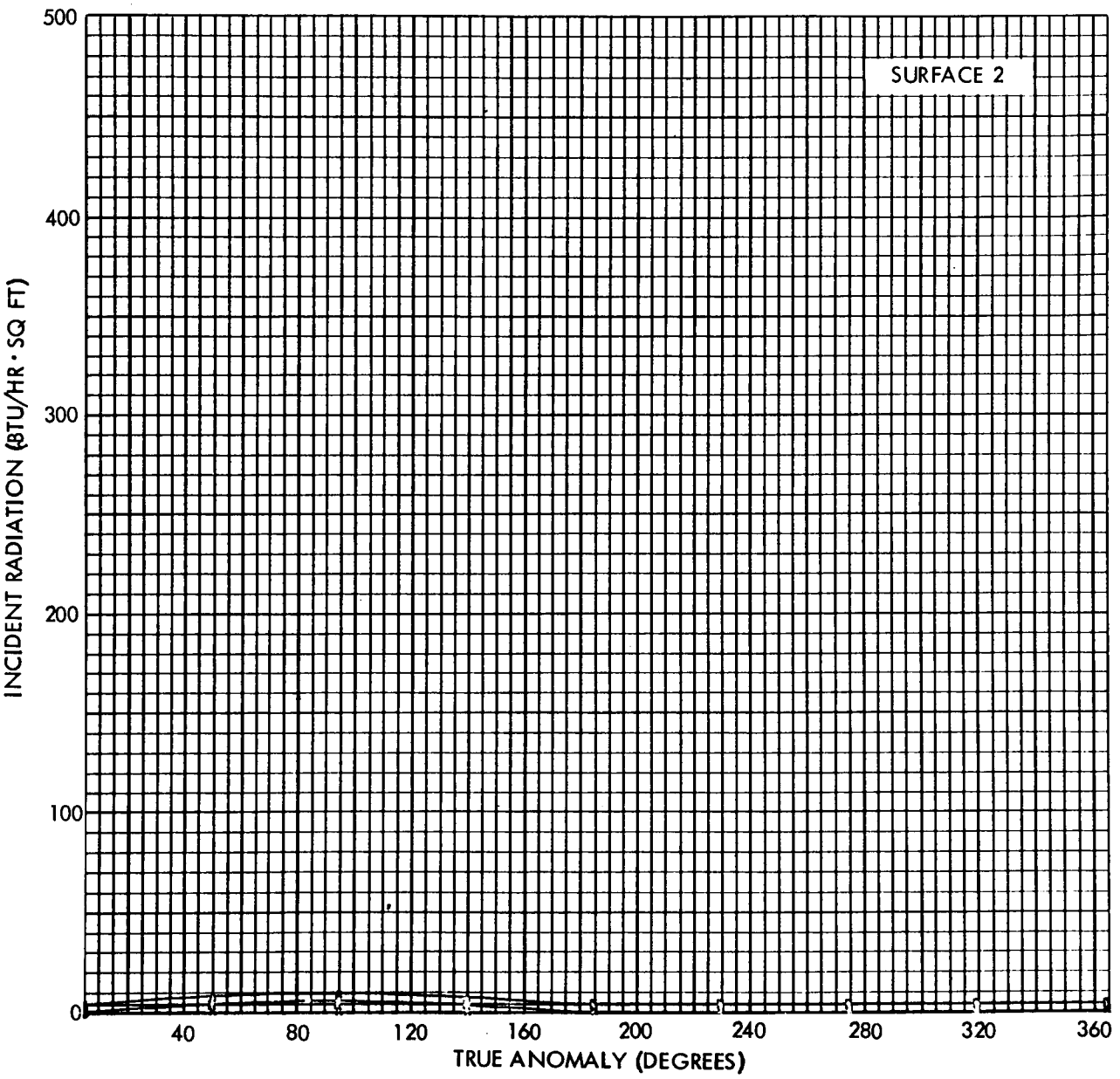


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 2 of 12)

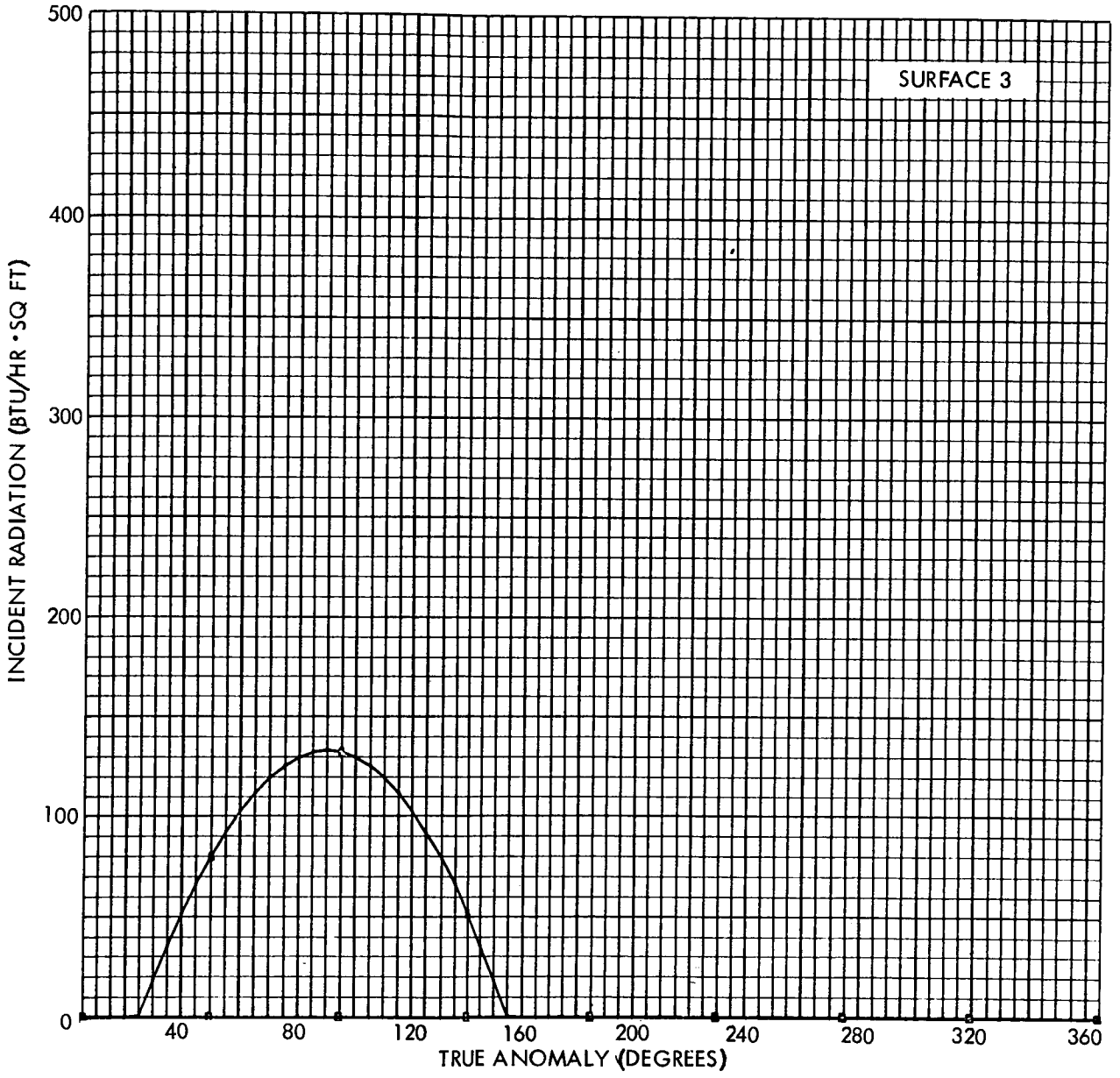


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 3 of 12)

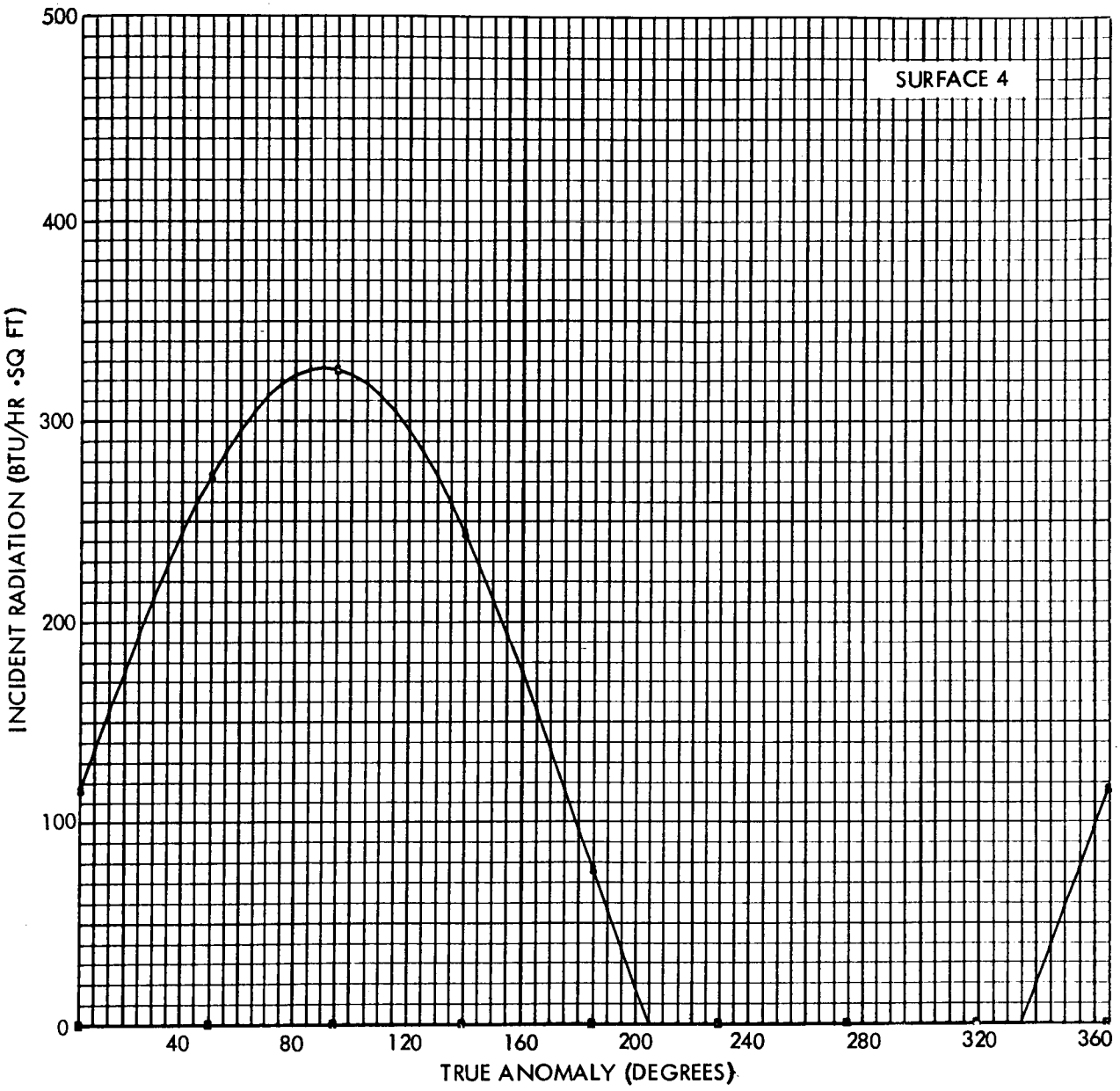


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 4 of 12)

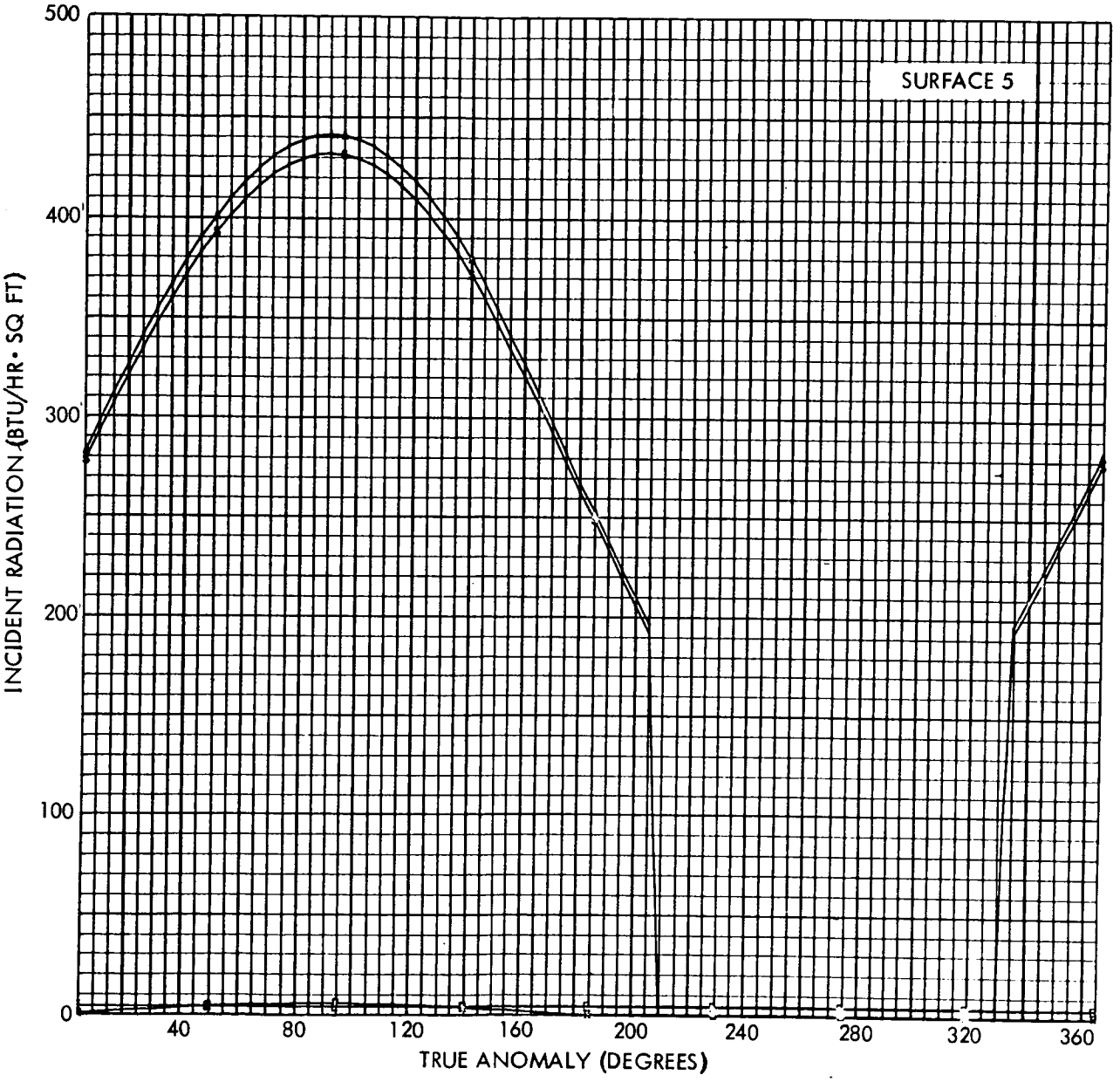


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 5 of 12)

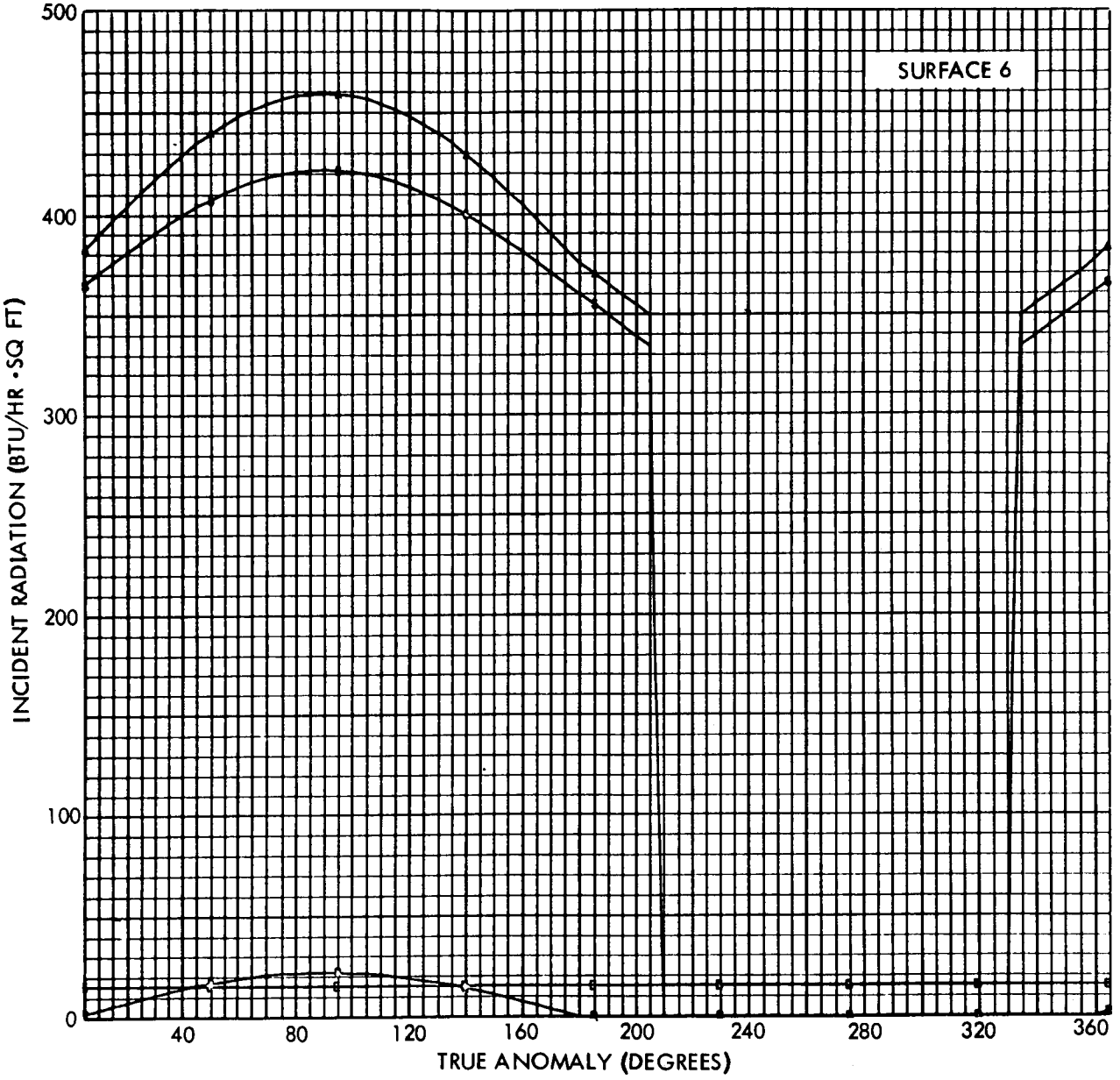


Figure IU-10. 100-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 6 of 12)

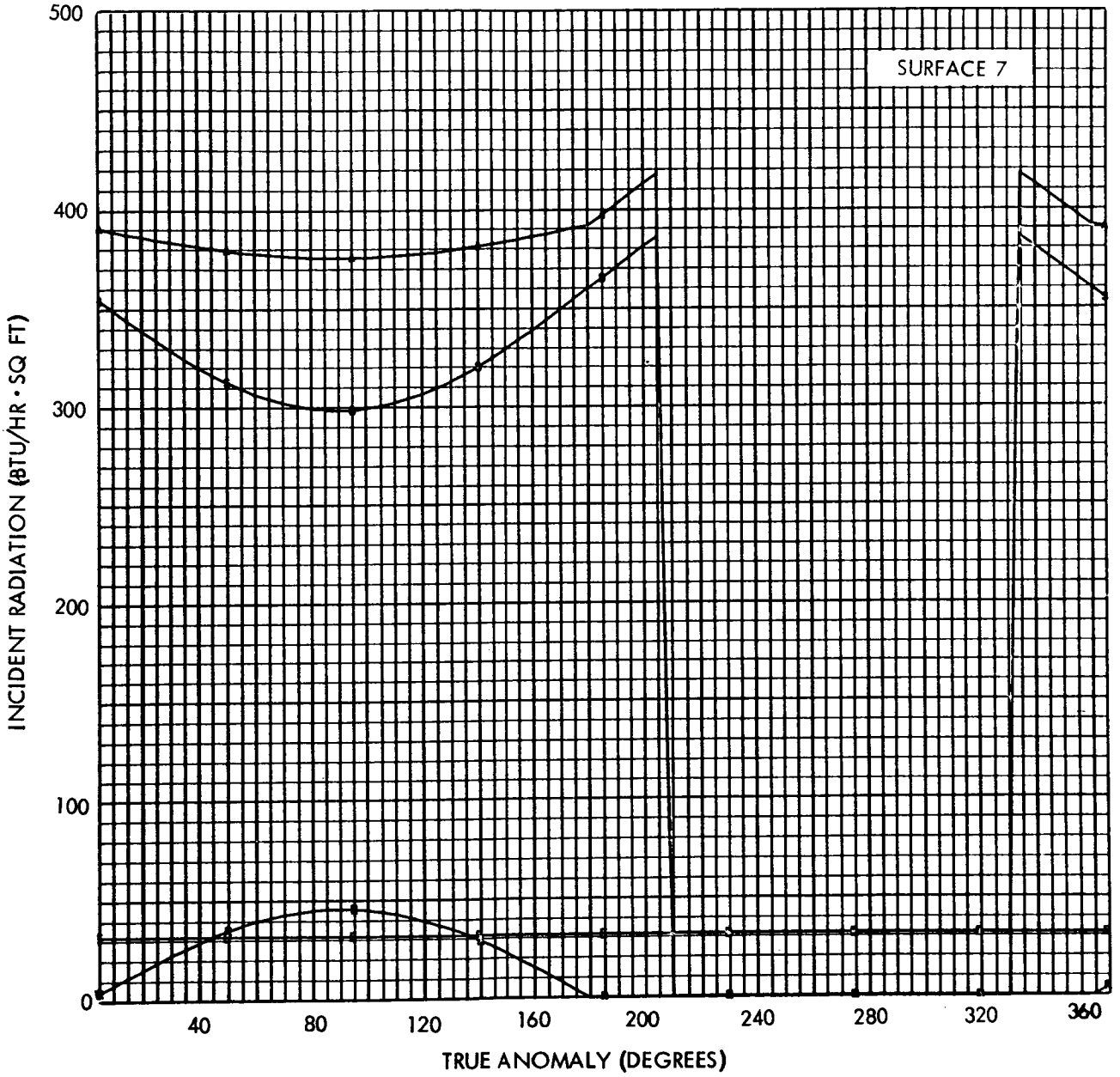


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 7 of 12)

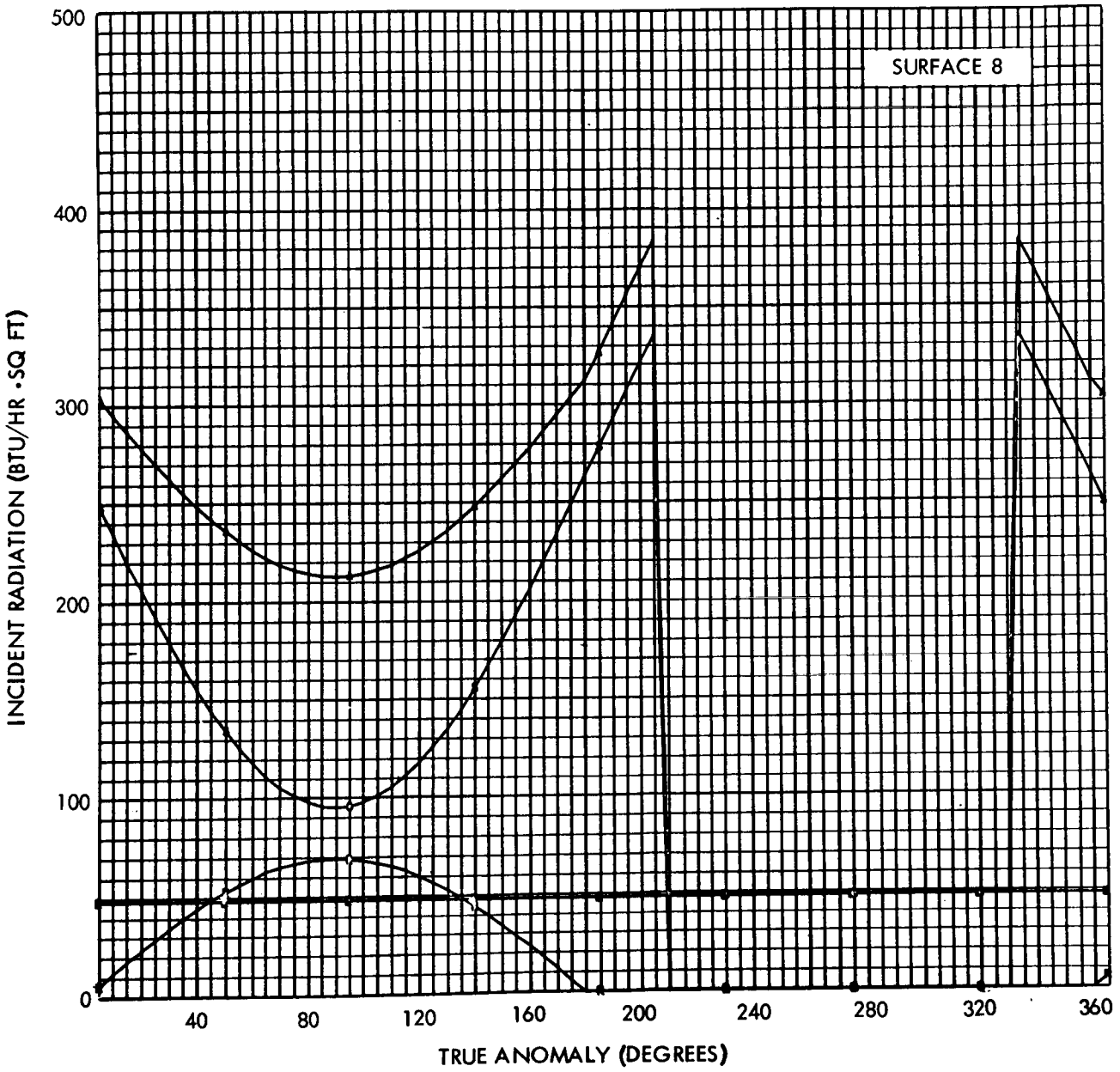


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 8 of 12)

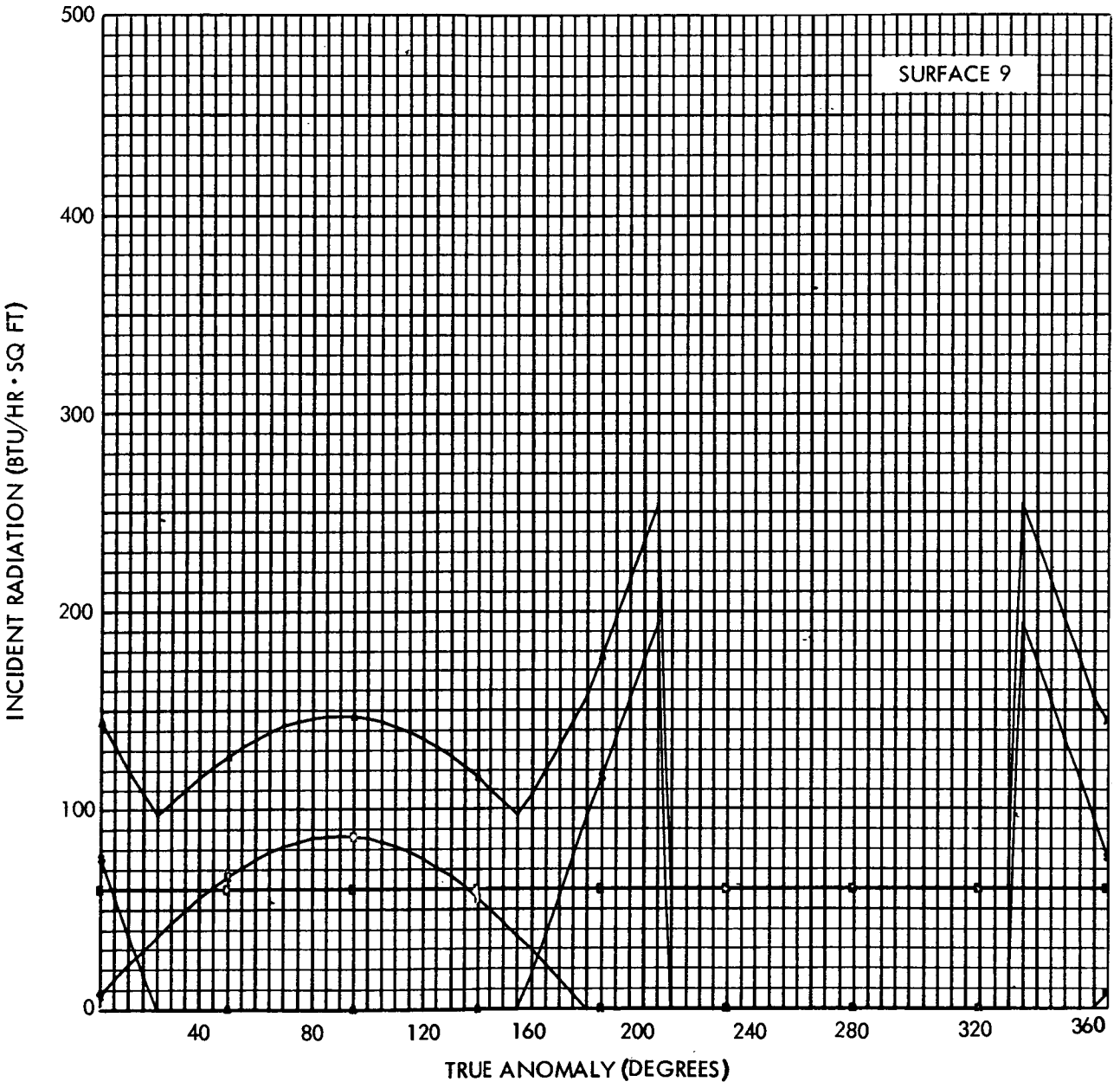


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 9 of 12)

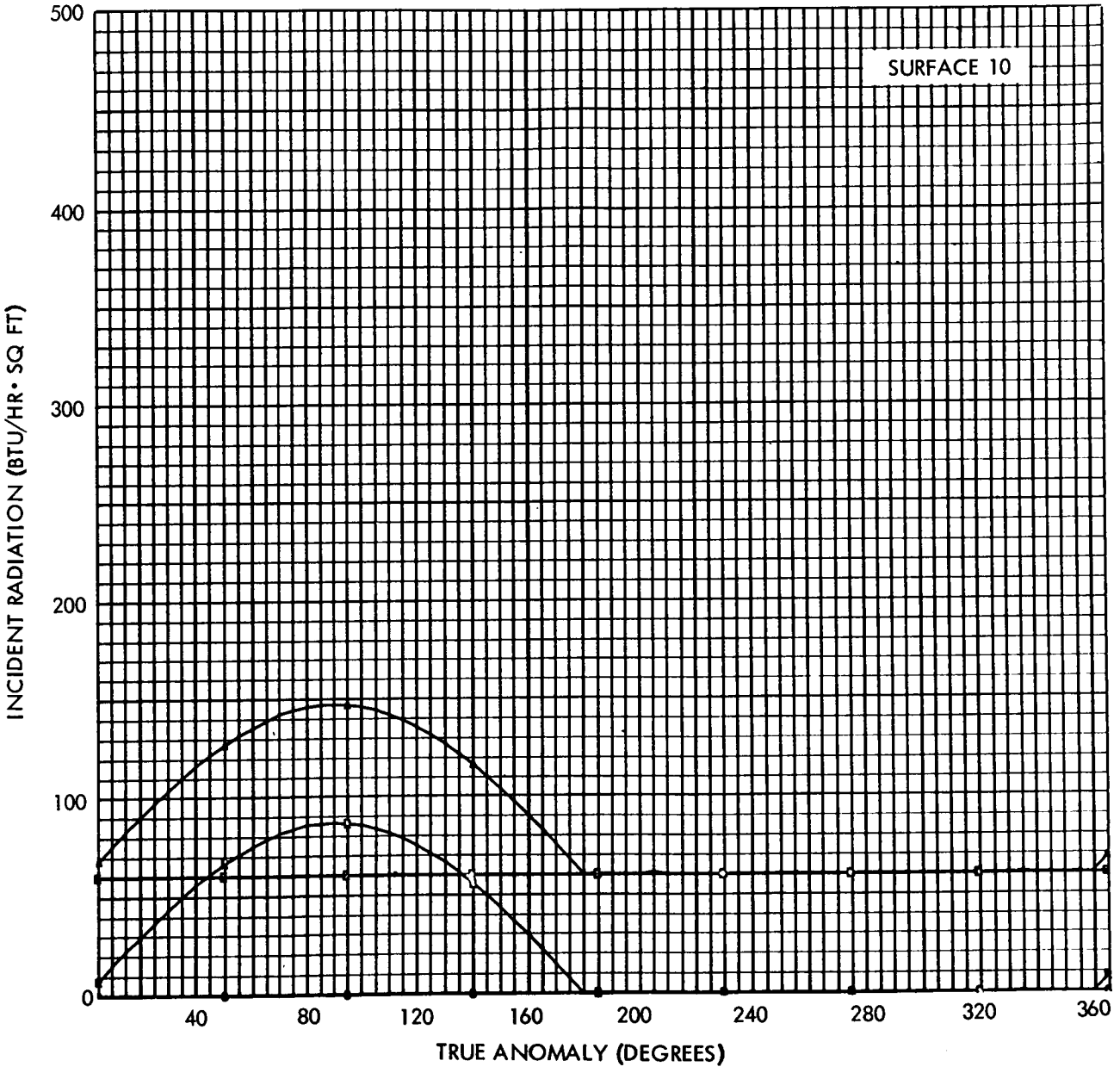


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 10 of 12)

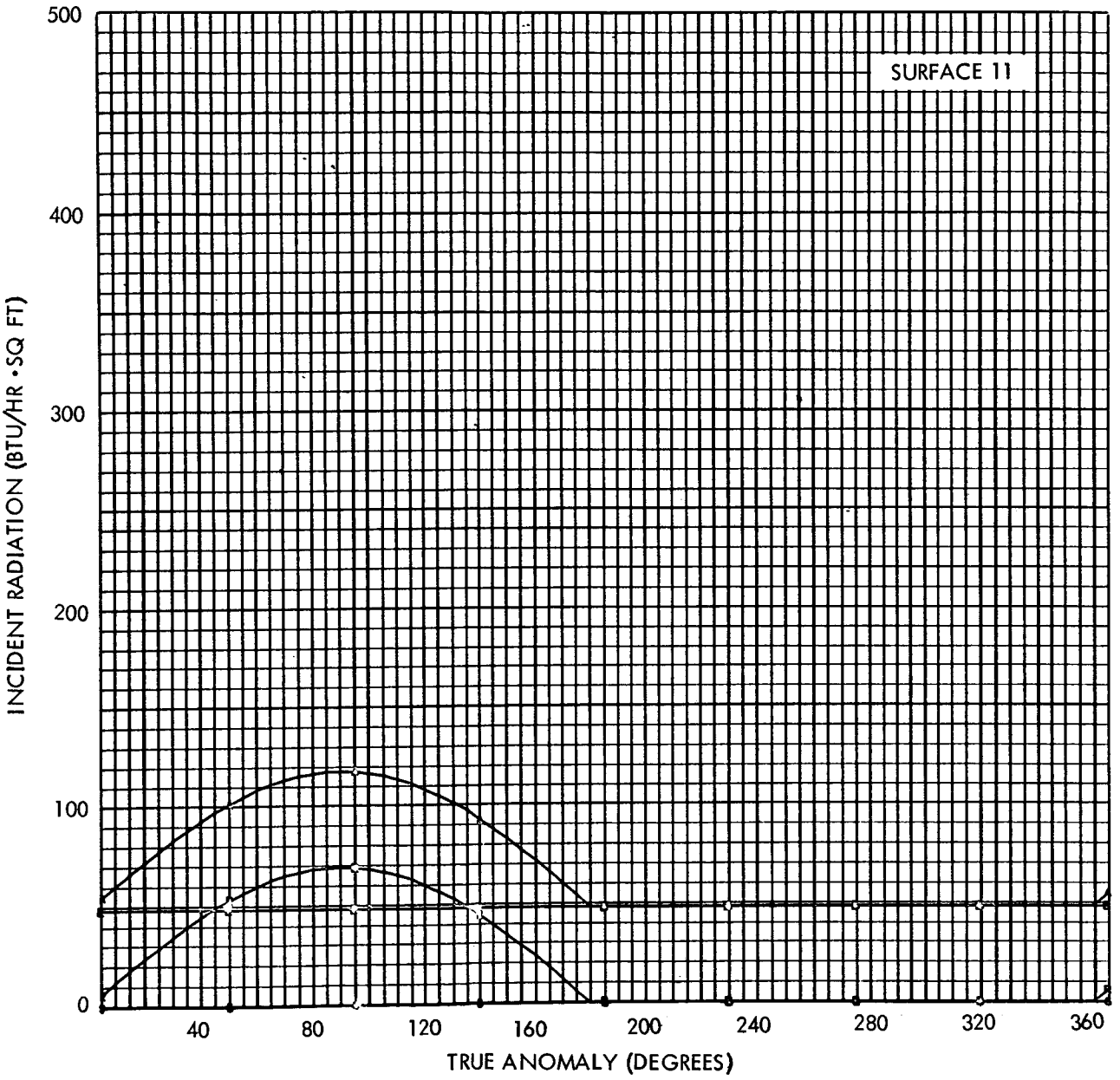


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 11 of 12)

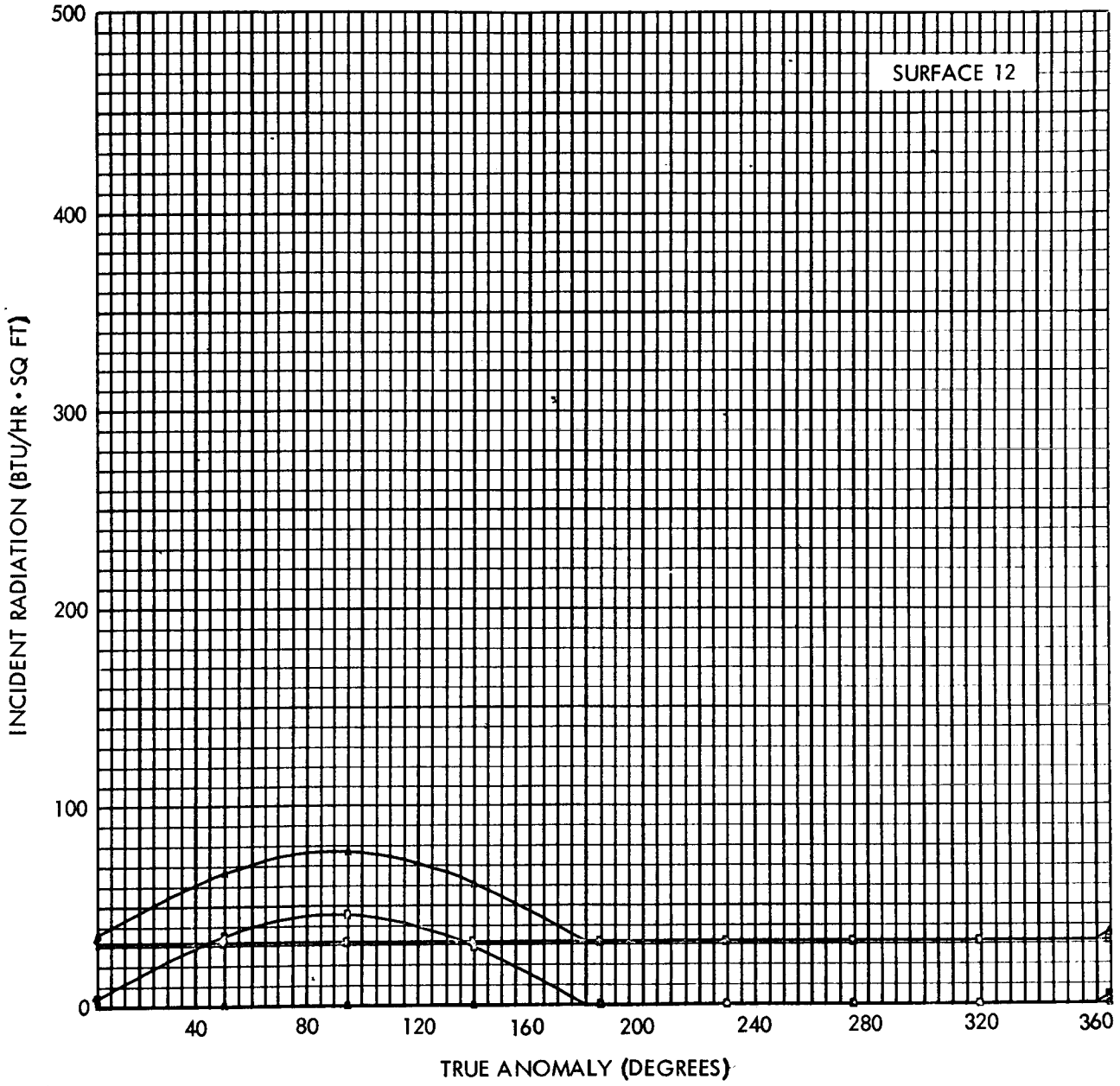
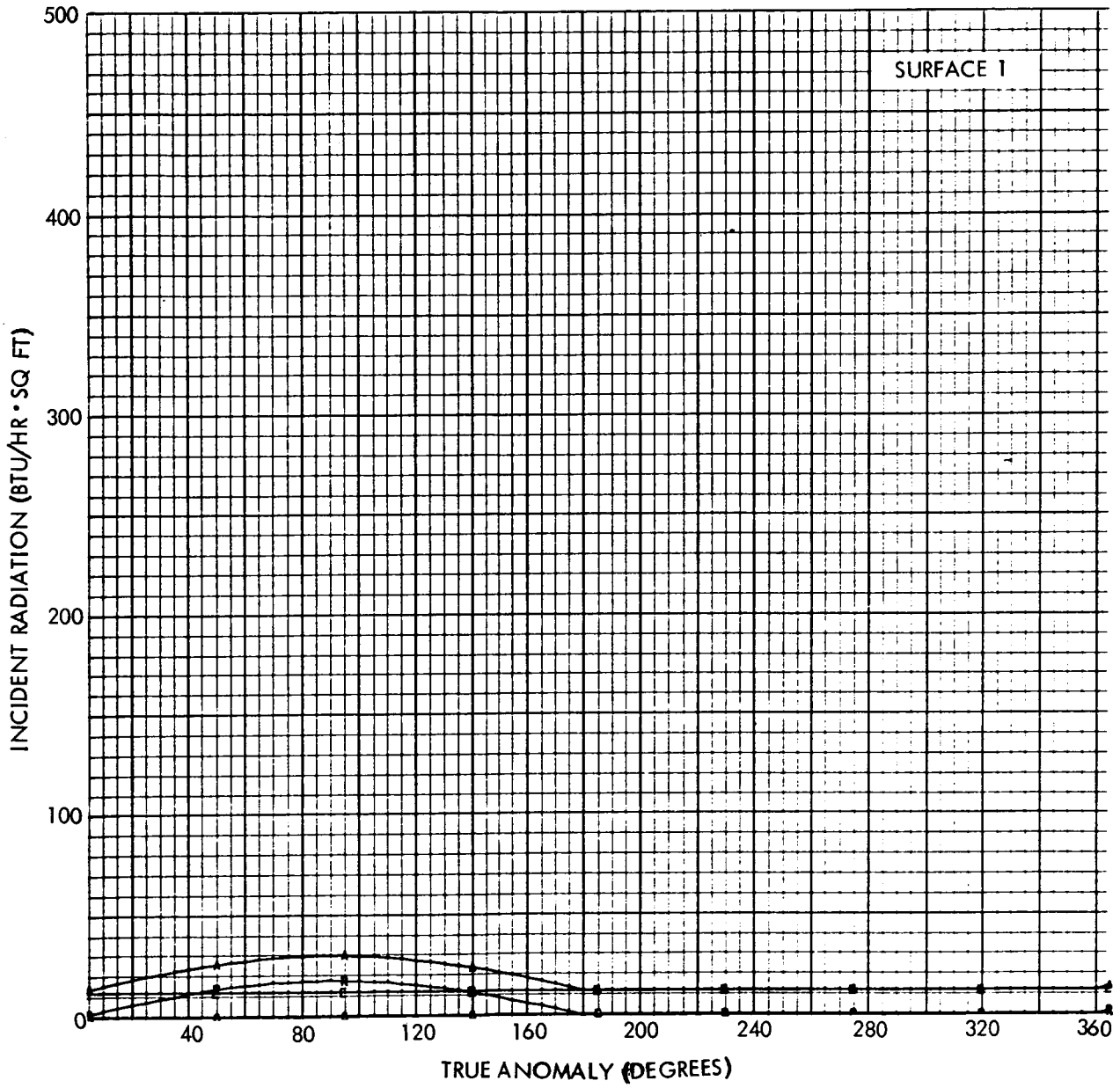


Figure IU-10. 100-Nautical-Mile Circular Orbit: Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 12 of 12)



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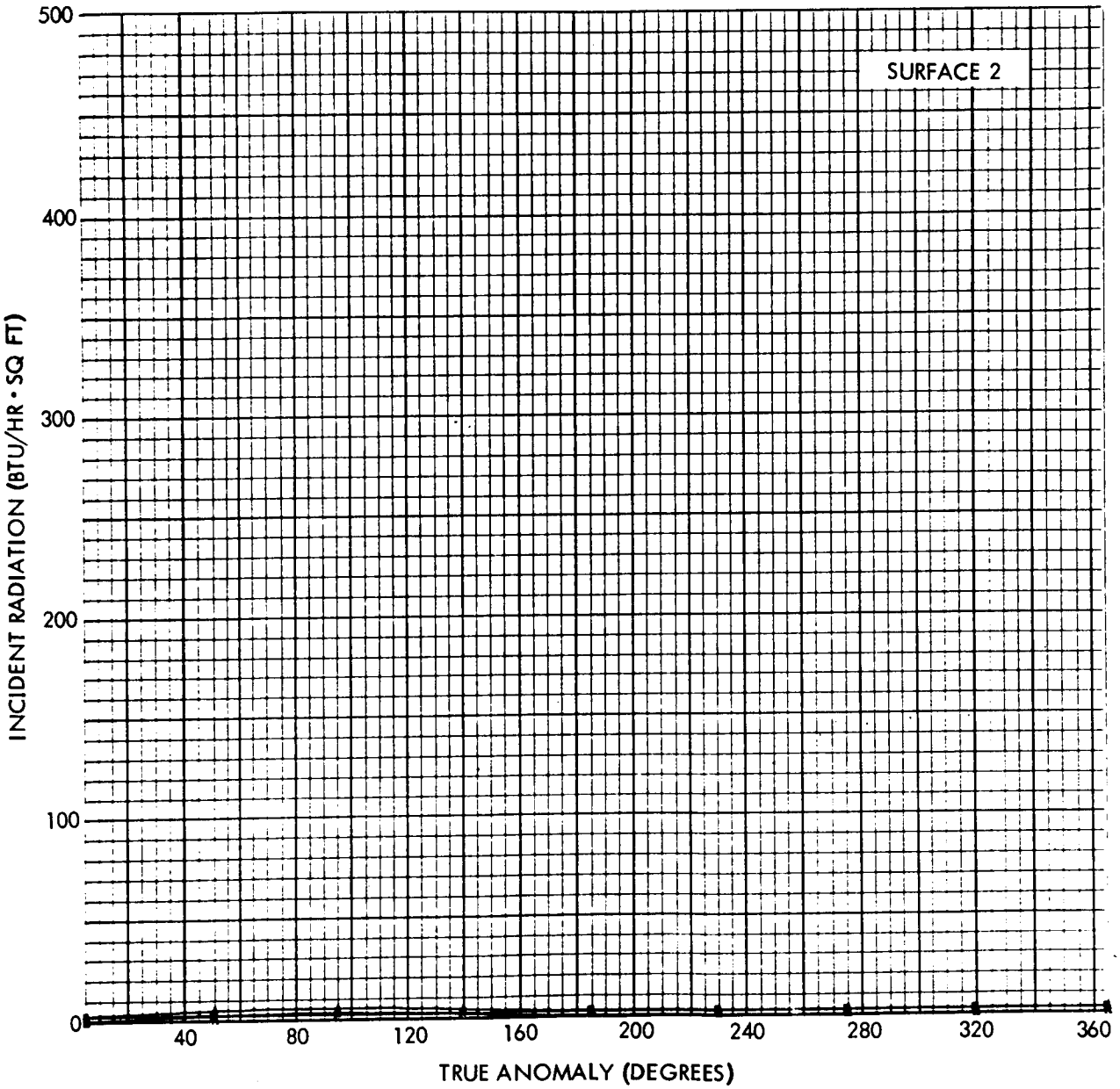

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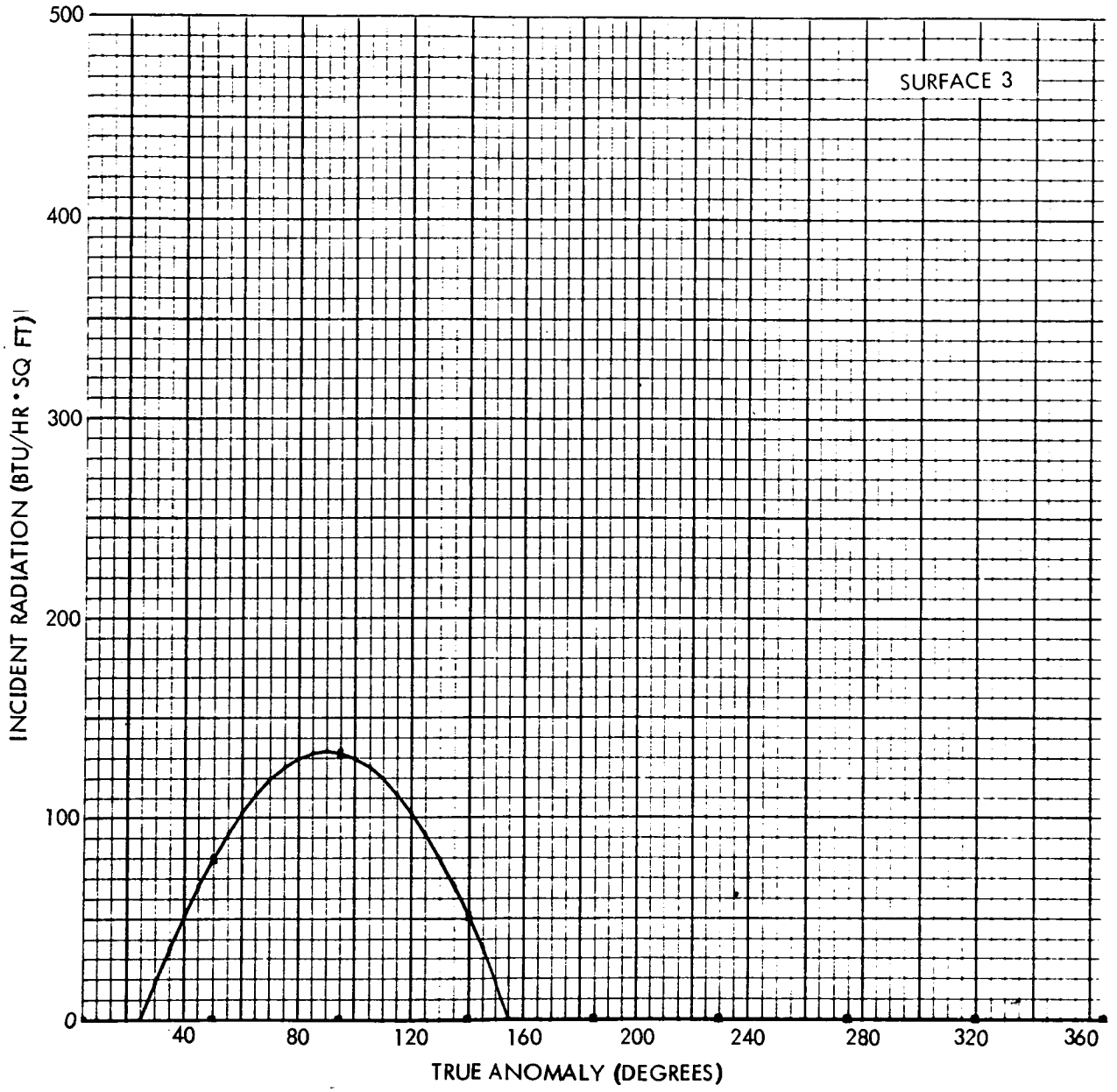

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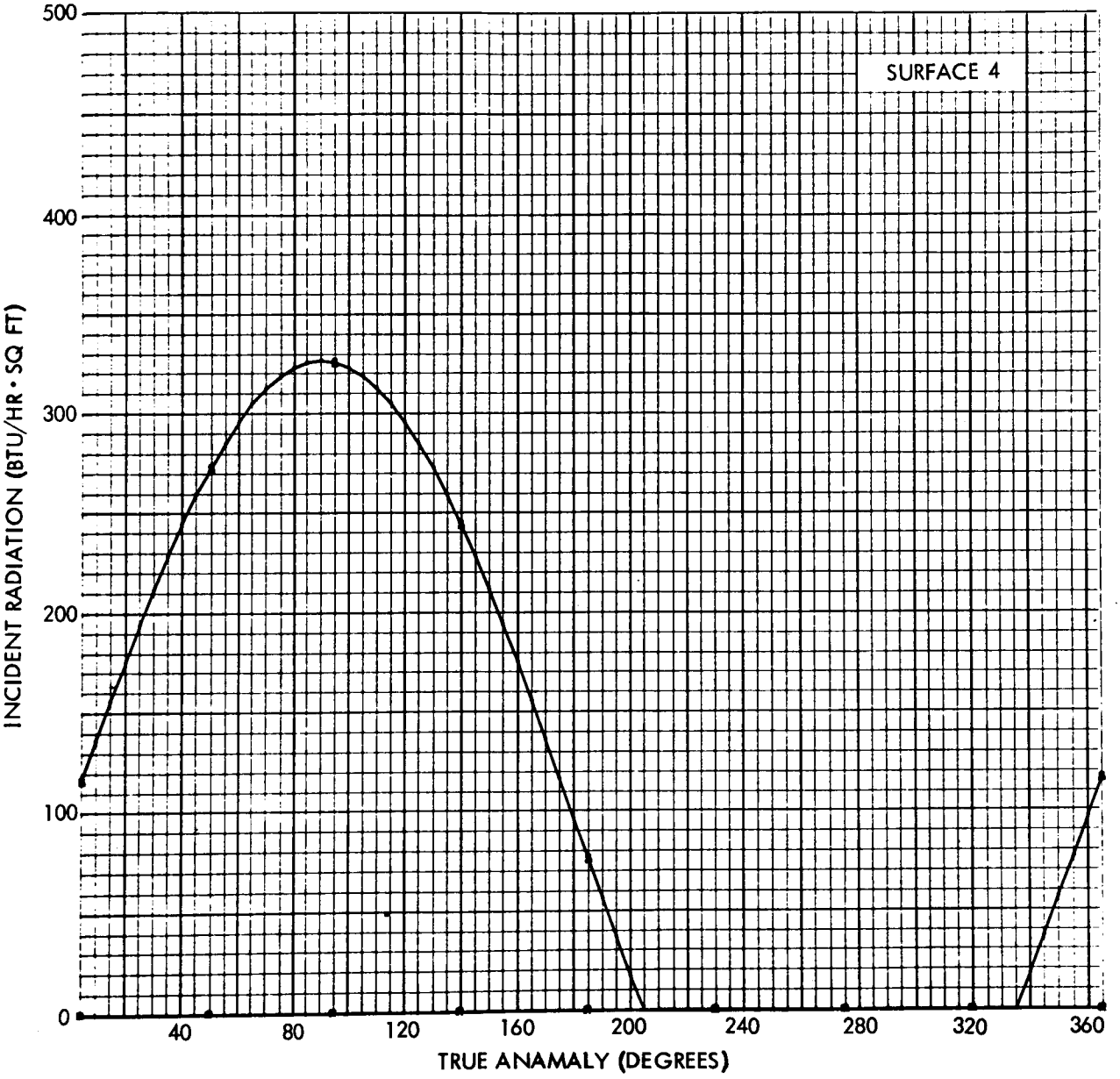

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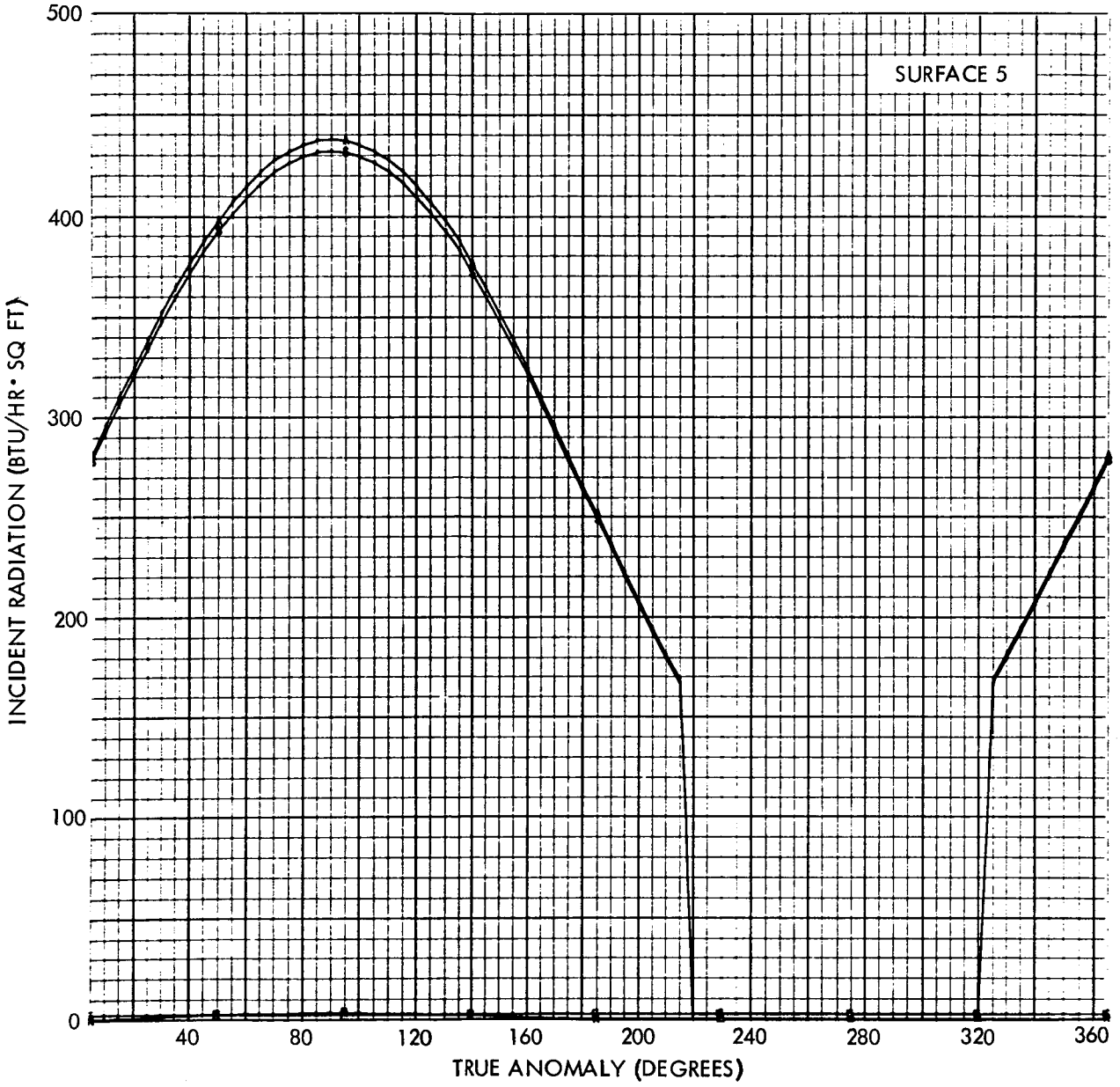

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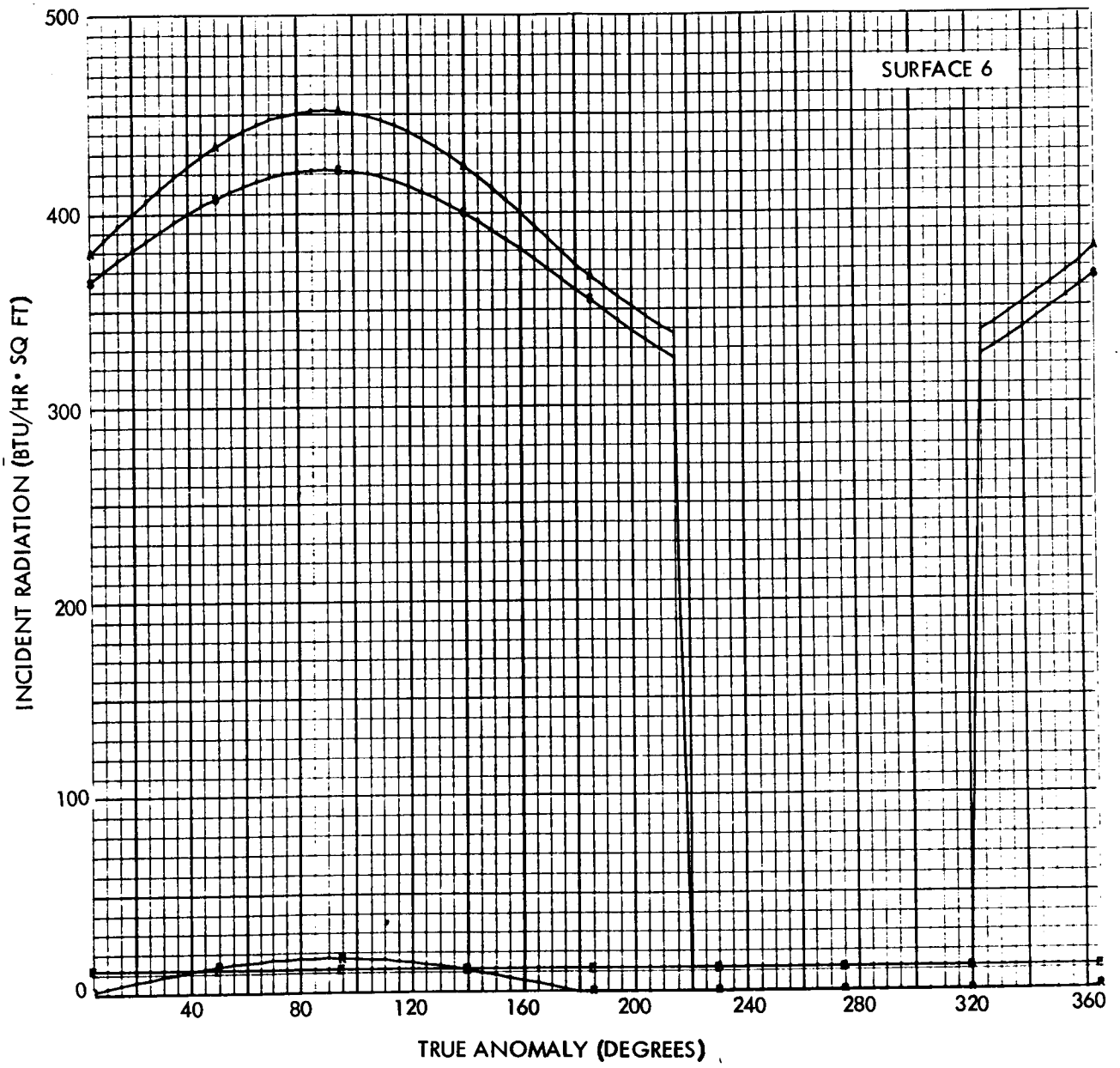
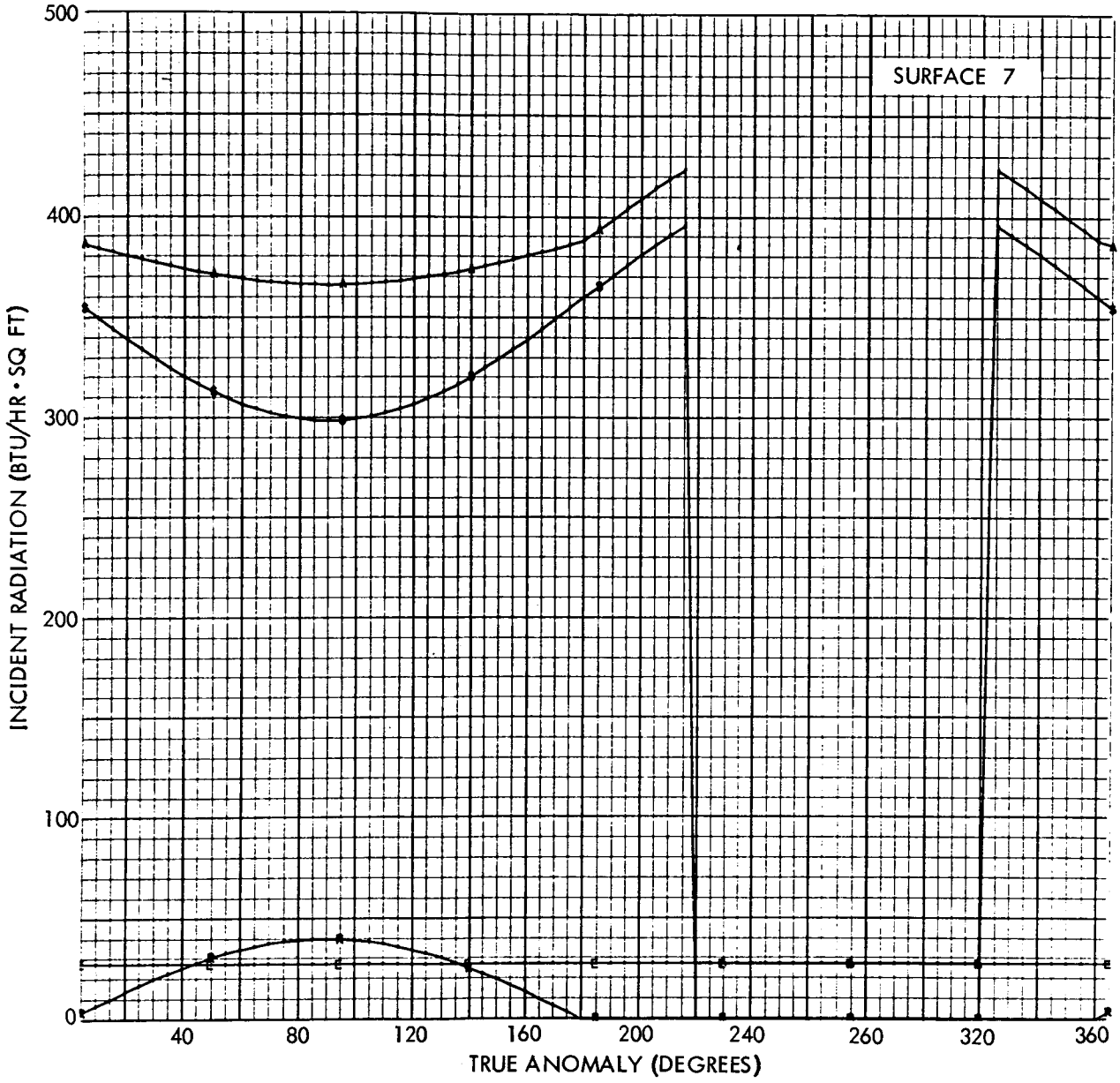


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 6 of 12)



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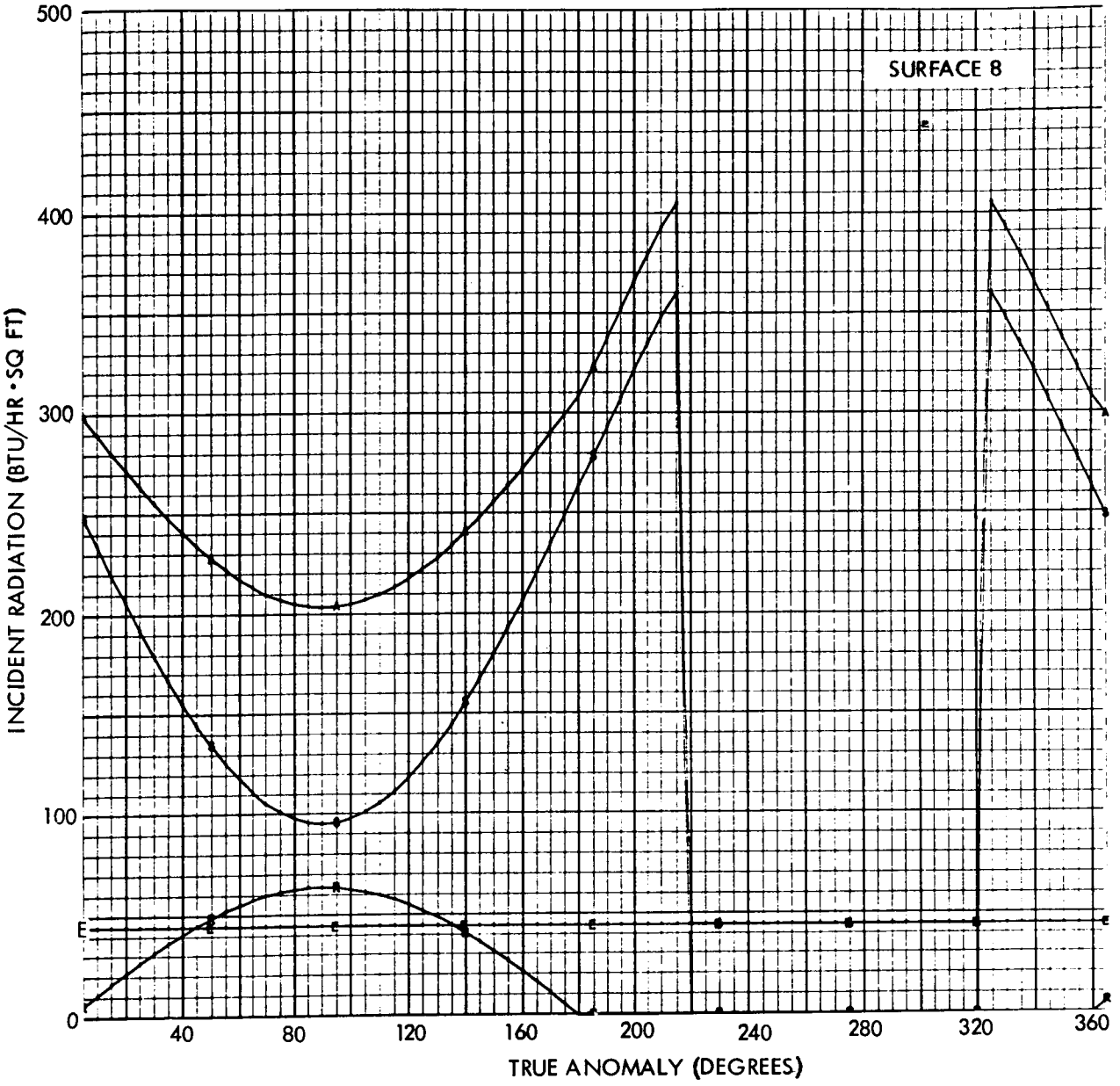


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 8 of 12)

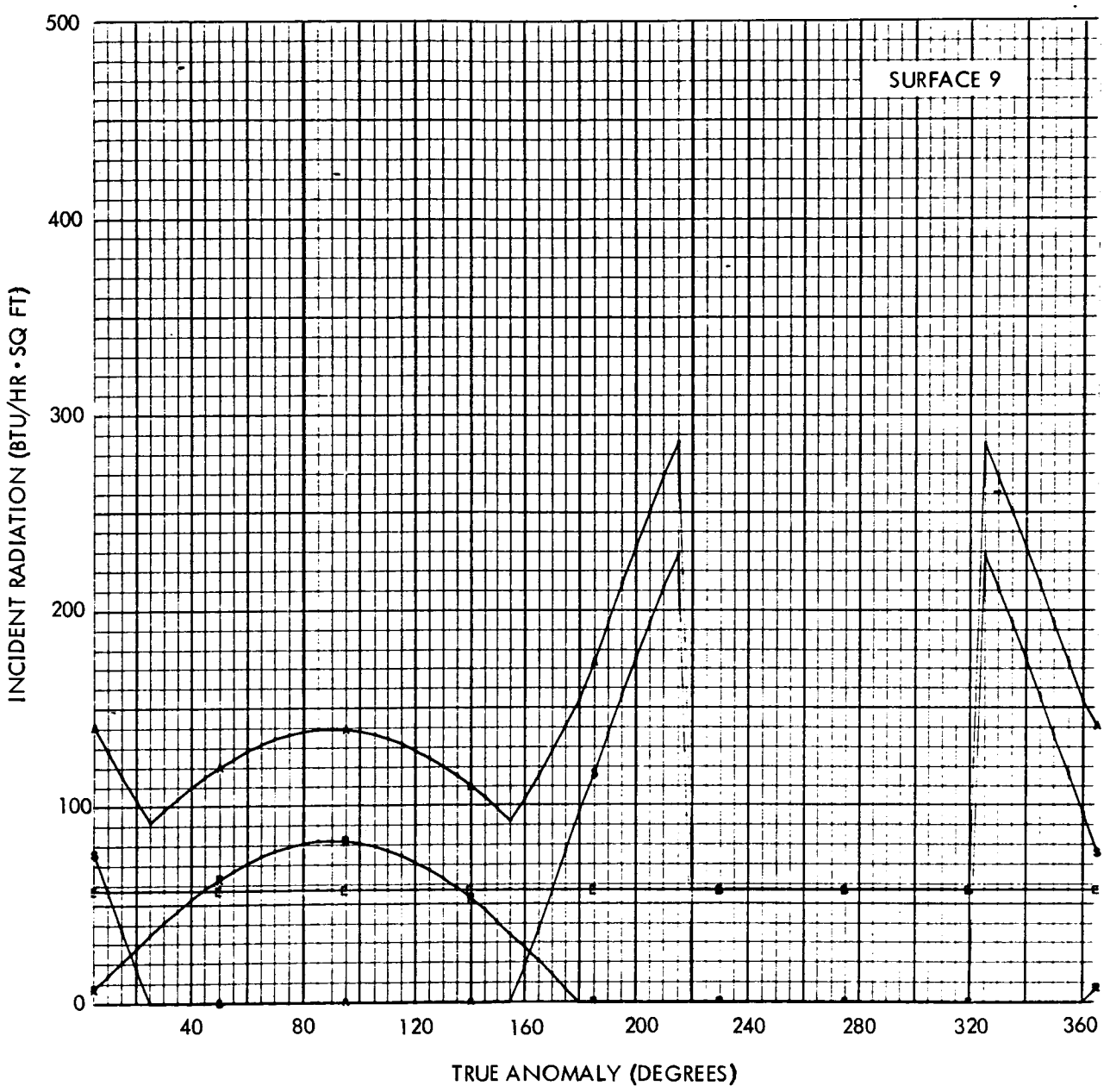


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 9 of 12)

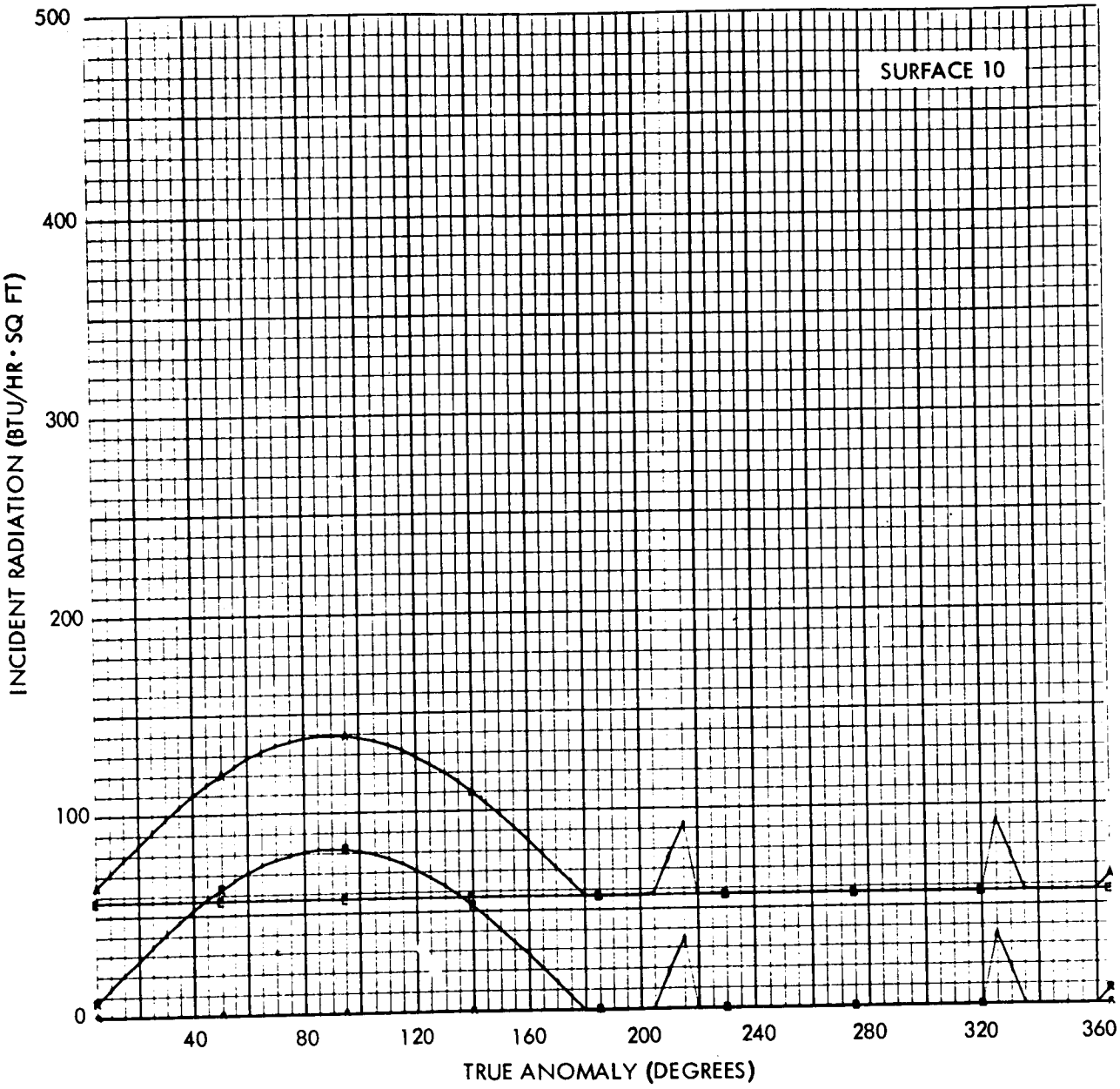


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 10 of 12)

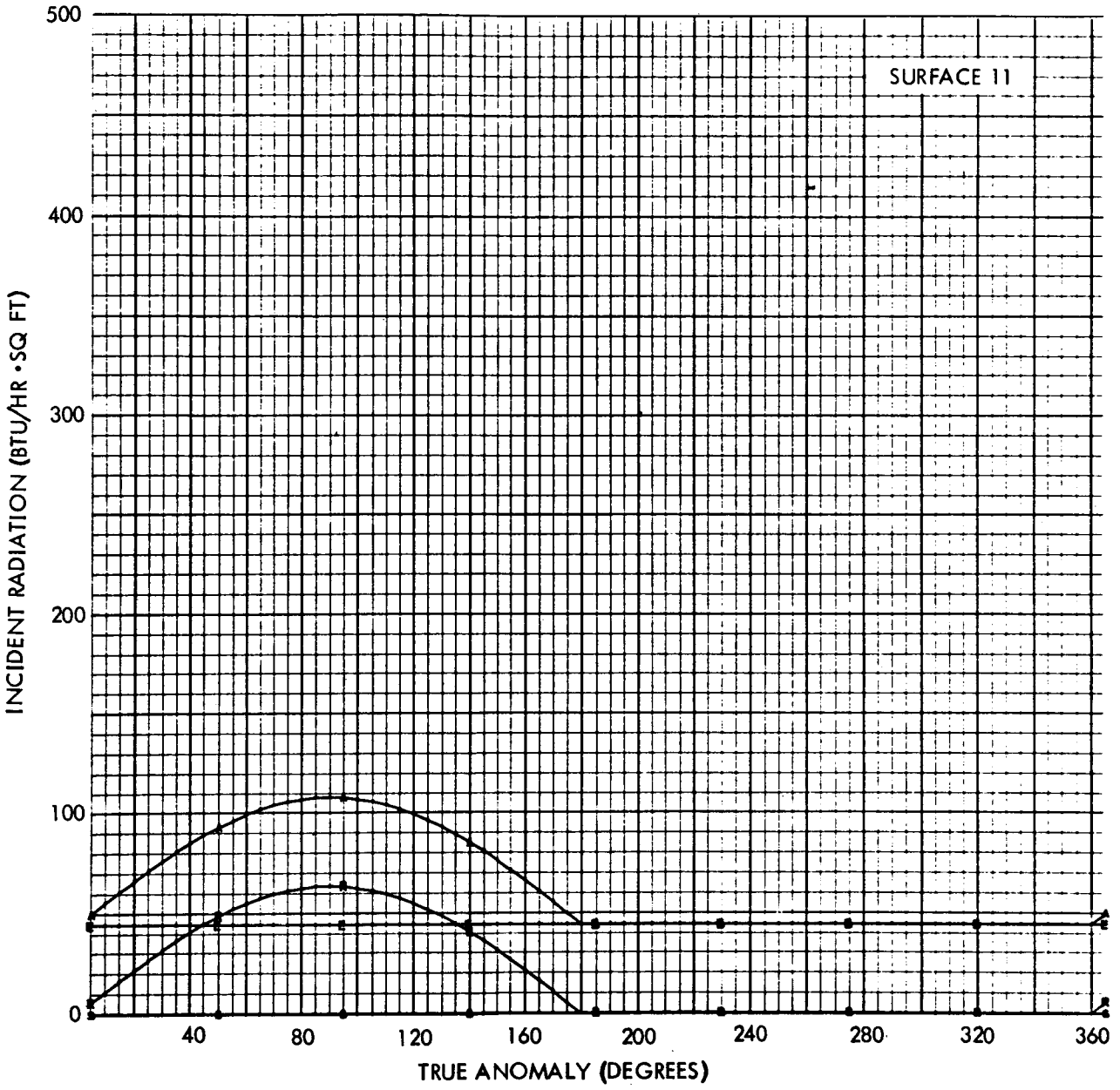


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 11 of 12)

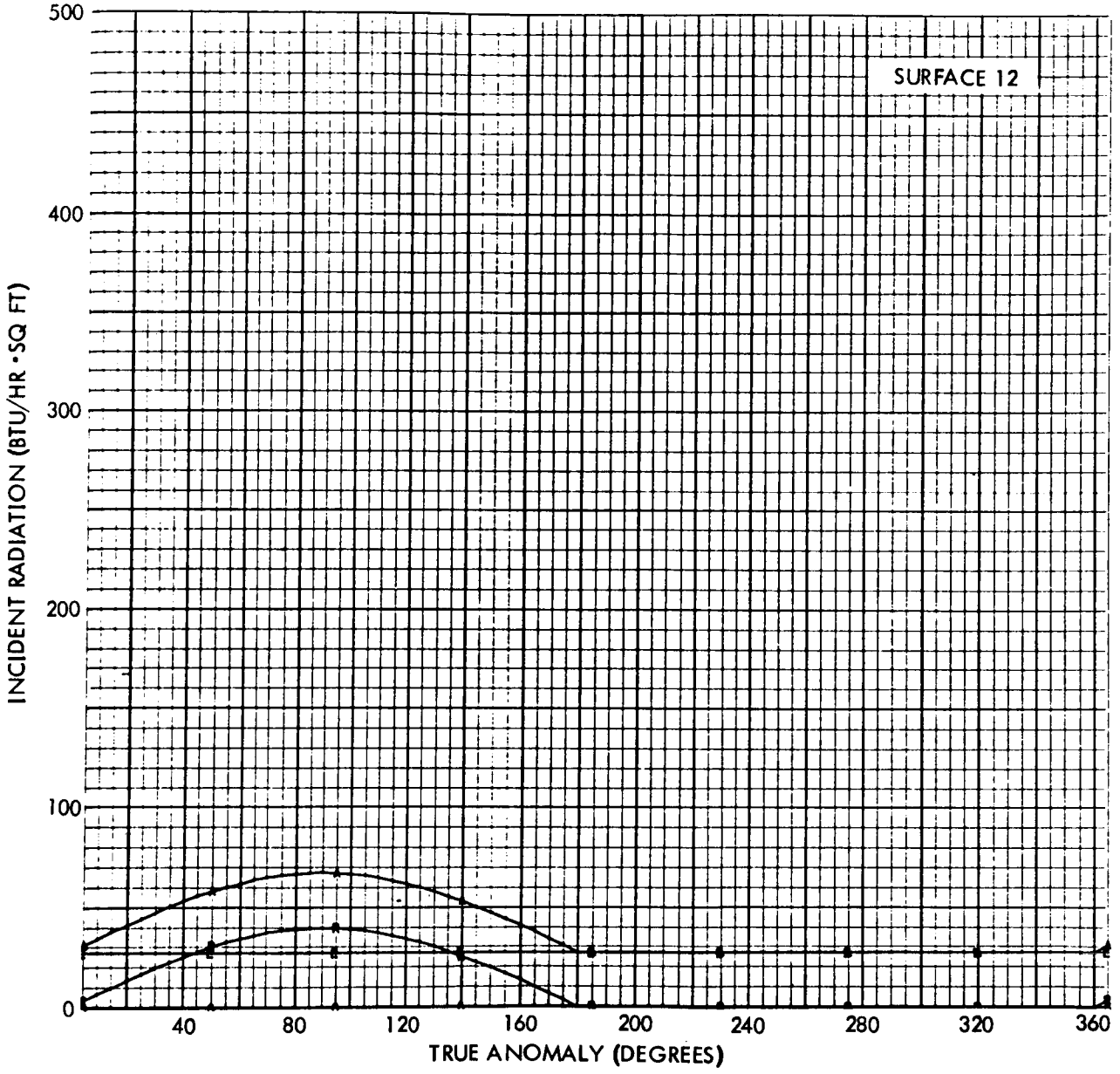


Figure IU-11. 200-Nautical-Mile Circular Orbit; Angle of Inclination: 34°; Launch Date: December 21; X-Tan (Right Ascension - 180°) (Sheet 12 of 12)

APPENDIX 2B. ELECTRONIC EQUIPMENT CHARACTERISTICS

Two aspects of electronic equipment characteristics that influence the vehicle thermal system are the effects of microelectronics and electronic equipment internal thermal design.

Microminiaturization Trends and Effects

To assist in a recognition of the requirements and constraints imposed by astrionics and the overall vehicle on each other, this appendix discusses the rapid changes taking place in the electronics industry. The primary instrument considerations with regard to thermal conditioning and thermal integration with the vehicle are the individual and total package heat loads and the degree of package internal temperature regulations required. The first consideration is intimately involved in the state of the art of microminiaturization; the second is related to the inherent maximum and minimum temperature limits of circuit or equipment components. These limits are essentially a matter of reliability, which again is influenced strongly by microelectronics.

Electronics is involved in a microminiaturization evolution. The functional complexity of space vehicles demands smaller, lighter-weight, more reliable, and lower power system implementation. In all respects, microelectronics is unrivaled for this task.

Microminiaturization, as the name implies, was initially an attempt to reduce size. It is generally recognized that the fallout from this size reduction realizes far greater benefits and has more significant impact than the initial goal. (Therefore, the term "microelectronics" is more appropriate.) Paramount in the fallout is increased reliability. Almost as important for space applications is the low power requirement, which, in turn, proportionately reduces the weight and size of both the power supply (such as a battery) and the vehicle ECS. These reduced weights and sizes, along with the reduced size and weight of the astrionic equipment, increases payloads, permits more complex missions, and/or allows even higher reliability such as through redundancy techniques or "built-in test" capability for prelaunch and manned inflight maintenance.

Despite the rapid changes taking place, microelectronics is perhaps more evolutionary than revolutionary, as illustrated by Figure 2B-1. The first miniaturization was " miniature" vacuum tubes in the early 1940's, then

"subminiature" tubes. The first major step in the miniaturization process was the discovery of the semiconductor devices, the germanium and silicon diodes, followed by the transistor in the late 1940's. Today the transistor replaces all but the highest power or special purpose vacuum tubes. It is much smaller than the smallest tube and requires no heater (filament) power. The use of transistors advanced significantly with the development of the printed or etched circuit techniques. First generation microelectronics reached its ultimate form when integrated circuits (IC's) replaced groups of transistors, resistors, capacitors, diodes, etc. The year 1962 represents perhaps the birth of microelectronics, when an entire production weapon system (the Minuteman II) went completely to microelectronics. Its D-37 computer used integrated circuits exclusively and is largely responsible for the "arrival" of the IC's. The improvements obtained with IC's are illustrated in Figure 2B-2.

Figure 2B-3 shows examples of the four important microelectronic approaches that have been advanced in recent years. (The 3D packaging technique is one of a number of compact packaging approaches.) These techniques were based on miniature verions of more or less conventional discrete circuits elements - often with a disciplined geometry to facilitate the compact packaging. With such an approach, each component provides only one circuit element, and, therefore, the number of parts is not reduced, and the economics of the system and heat reduction is not significantly affected.

With the thin film approach, some of the circuit elements (in this case, the resistors) are batch-fabricated as a single component. The limitations of this technology require that many of the circuit elements be produced as separate parts and assembled onto the thin film substrate. However, to the extent that the batch-fabricated elements comprise the circuit, the number of components is reduced.

With the silicon integrated circuit technology, a sufficient assortment of active and passive elements can be provided so that a complete circuit function can be batch-fabricated. With this technique, virtually all digital functions and a great many linear functions can be integrated. Thus, one part can replace many parts. This marks the beginning of significant improvements in reliability, size, cost, and heat dissipation.

In the metal oxide semiconductor (MOS) integrated circuit, a further step in batch fabrication is accomplished. In the example shown, 800 MOS transistors are formed in a single piece of silicon and are intraconnected to form a complex multifunction. The circuit illustrated is a complete digital differential analyzer incorporating all the necessary memory logic and register functions. MOS represents the second generation in microelectronics, the second large step in size, weight, power, cost, and reliability improvement.

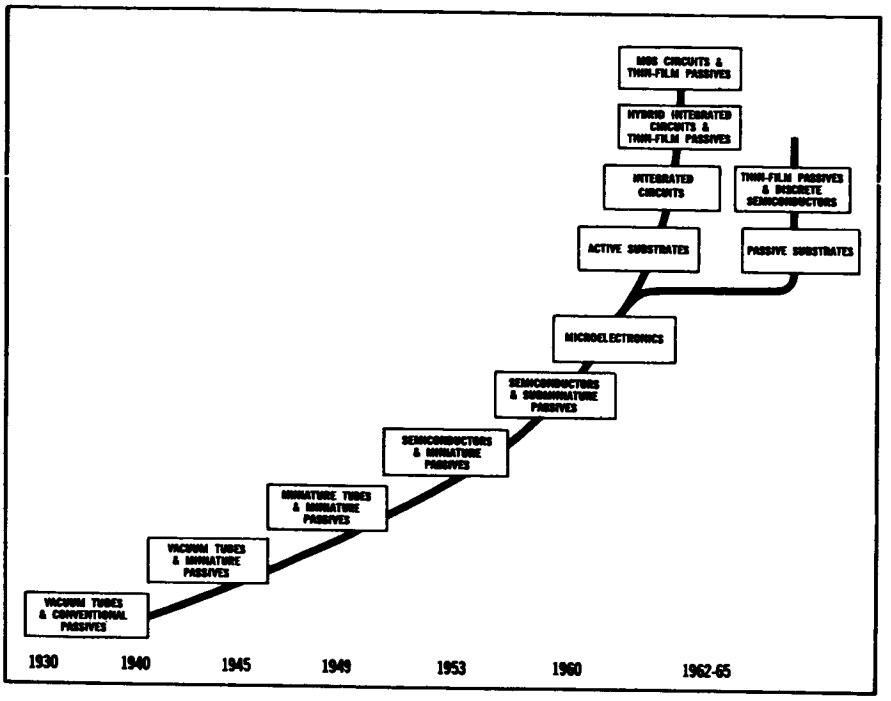
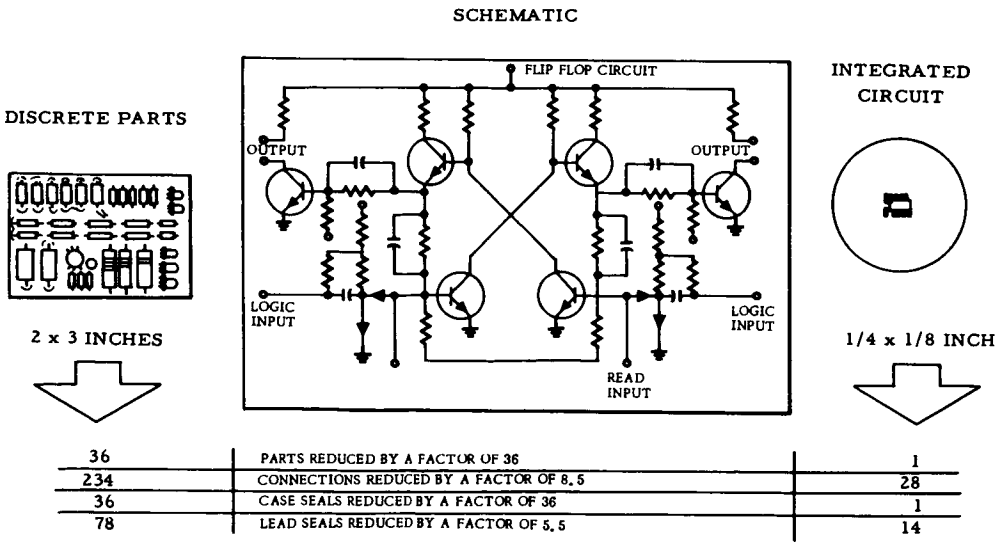
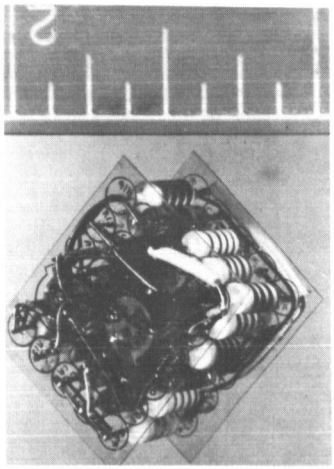


Figure 2B-1. Evolution of Parts - Electronic Systems

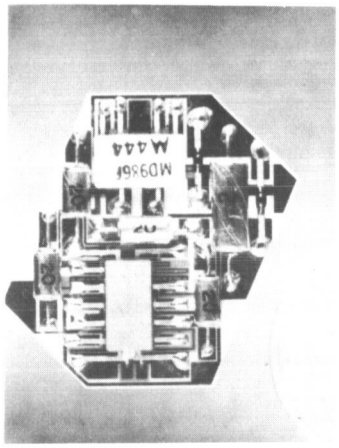


36	PARTS REDUCED BY A FACTOR OF 36	1
234	CONNECTIONS REDUCED BY A FACTOR OF 8.5	28
36	CASE SEALS REDUCED BY A FACTOR OF 36	1
78	LEAD SEALS REDUCED BY A FACTOR OF 5.5	14

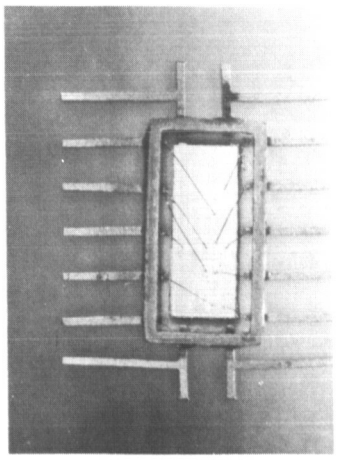
Figure 2B-2. Reduction Obtained With Integrated Circuits



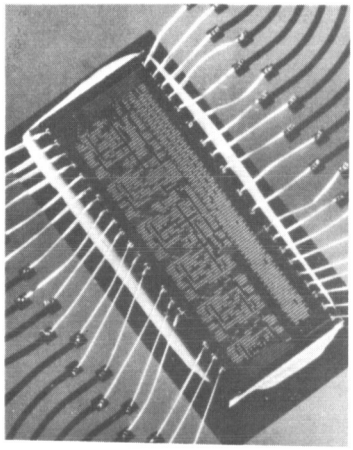
3D Packaging



Thin Film Hybrid



Silicon Integrated Circuit



Metal Oxide Semiconductor Integrated Circuit

Figure 2B-3. Microelectronic Techniques

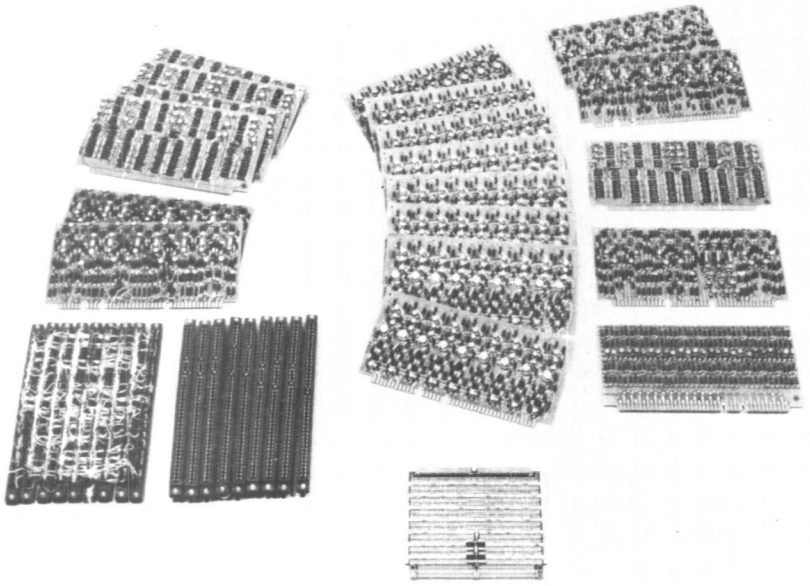
The reduction in parts count effected by use of first-generation silicon integrated circuits (not MOS) is illustrated in Figure 2B-4. Here, 19 circuit boards with approximately 2000 discrete element parts are replaced by one circuit board with 196 integrated circuit parts — a 10-to-1 reduction in parts count. Each of the 19 discrete element circuit boards carries an 82-pin connector. The integrated circuit board connector has 192 pins, a reduction of almost 8 to 1 in total connector pins. Comparable power reductions are obtained.

With the large scale metal oxide semiconductor array technology (Figure 2B-5), a very large circuit function can be provided in one part. To perform the function of this one MOS circuit, 100 conventional integrated circuits would be required. The reduction in device leads (a measure of reliability) is 1000 to 40, a ratio of 25 to 1. Heat dissipation on the functional basis is reduced in a smaller ratio. These examples are drawn from digital circuitry, but the same considerations apply to linear circuits.

The future, or third generation, is already beyond embryonic stages in the laboratories. At Autonetics alone, research and development are being pursued in many areas, such as solid-state devices for microwave applications, solid-state micromemories and displays, deposited waveguides and high-resolution conductors, microlayer boards compatible in size with the integrated circuitry they will carry, and new micropackaging techniques.

A particularly significant development has been silicon on sapphire (SOS), a controllable, repeatable process of expitaxially "growing" high-quality silicon crystals on a sapphire substrate. This Autonetics development is resulting in a variety of new microelectronic devices, unattainable by any other technique. For example, SOS makes it possible to fabricate extremely small areas (about 1 square micron) p-n junctions. These junctions, as diodes, have storage times of less than 0.5 nanosecond (5×10^{-10} seconds) and show great promise in large diode arrays for high-speed, high-bit-density memories. SOS also permits fabrication of insulated-gate, field effect transistors employing single-crystal materials. The insulating properties of sapphire fabrication and the operation of complementary MOS devices on a common sapphire substrate, which can be in close proximity without parametric electrical paths, form extremely low-power digital circuit combinations when cascaded or paralleled. In addition to excellent dielectric and strength properties, sapphire offers improved thermal properties compared to silicon.

Another Autonetics development has been the planar annular varactor, which permits solid-state invasion into the microwave field. The planar annular varactor has a conduction path of only three microns, less than 100 times less than conventional devices, and is therefore not susceptible to "skin effects".



1 integrated circuit multilayer board replaces

19 discrete component etched circuit boards plus associated connectors, wires, & chassis

Reduces

- Parts count
- Weight
- Size
- Power
- Cost

Increases

- Reliability
- Maintainability
- Producibility

Figure 2B-4. Microelectronics

Function

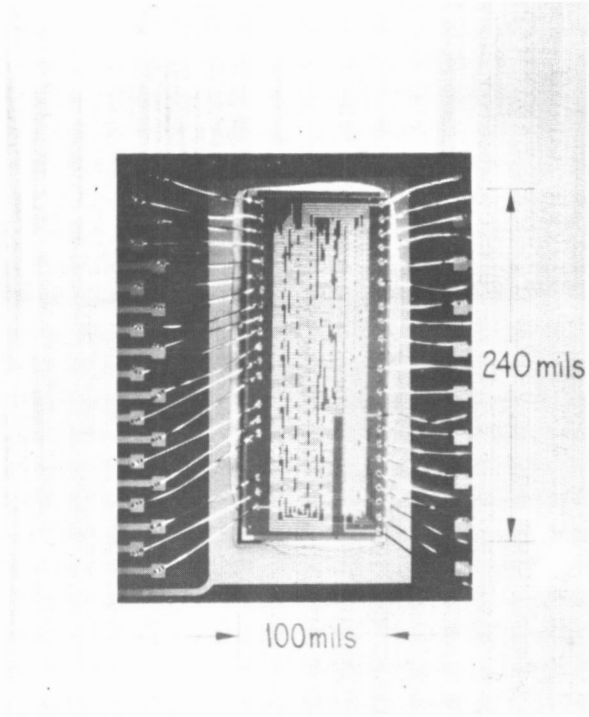
- 28-Bit Digital Integrator - Contains 800 MOS FET's Connected in 220 Gates
- 50 to 500 KC Clock Rate

Replaces

- 100 Conventional IC Flat Packs
- 1 Multilayer Board
- 1 Board Connector

Advantages

- Low Cost
- Low Power
- Size



Digital Differential Analyzer

Figure 2B-5. Large Scale Multifunctional Arrays

The degree or sophistication of microelectronics that should be used today depends on its application. There are three categories of microelectronics: digital, radio frequency (RF), and linear (analog). Digital systems include computers, signal converters, and other data processors. Circuit functions in these systems are pulse-driven, on-off (switching) operations and are largely repetitive and low-power. Few capacitors are used and their electrical and physical size is small. Semiconductor IC's are ideal for these digital applications at the present time.

In RF applications (radios, televisions, radar systems, etc.), capacitors are still small, but relatively larger numbers are needed. Also, in contrast to digital applications, RF microelectronics requires transformers, inductors, and high-precision resistors (e.g., for gain adjustment of amplifier-type circuits common to RF applications). Distributed and stray capacitances must be minimum. Currently, thin films offer the best solution. IC technology has not progressed as rapidly in the RF field as in the digital field because of the difficulty of fabricating high-speed transistors. However, second-generation semiconductor devices, novel isolation techniques, and new economical batch-produced field-effect devices are rapidly solving this problem, and future RF systems will be able to exploit integrated circuitry to almost the extent that digital systems have been able.

Linear circuits are used in electromechanical control systems (e.g., inertial navigation and flight altitude control) that interface with transducers such as gyro pick-offs, accelerometers, velocity meters (vm), servo motors, torquing coils, and voice coils. However, digital gyro pick-offs, vm outputs, etc., are coming into greater use. The circuitry often consists of amplifiers in the dc to 100 kilocycle frequency range, with 5 kilocycles typically the highest common frequency.

Because of the low frequency range of linear electronics, the value and size of capacitors are large, generally greater than 1000 picofarads. Further, a large number is required for coupling and bypassing functions. Interface with transducers requires relatively high power levels. Therefore, the microelectronic packaging techniques must be compatible with mounting and heat removing methods of power-dissipating discrete transistors and resistors.

Despite these problems, IC's have been applied effectively currently to about 70 percent of the circuit requirements in typical electromechanical control systems. Standardized semiconductor IC's have been designed for use with adapting circuits employing discrete and thin film components, a hybrid approach. Through revised system techniques of grounding, power supplies, impedance levels, and information format the size and number of large capacitors and inductors have been reduced, thereby reducing power requirements. The heat-dissipation problem is further mitigated by operating power amplifiers in highly efficient switching modes.

Applications of microelectronics (both digital and linear) to computers, communications, radar systems, etc., are described in many references, such as Reference 2B-1. Figure 2B-6 shows the projected weight reduction per channel of telemetry, which is indicative of the size, power, and heat load reductions achievable in the future. (Further information on microelectronics may be obtained from the Autonetics Division of NAA.)

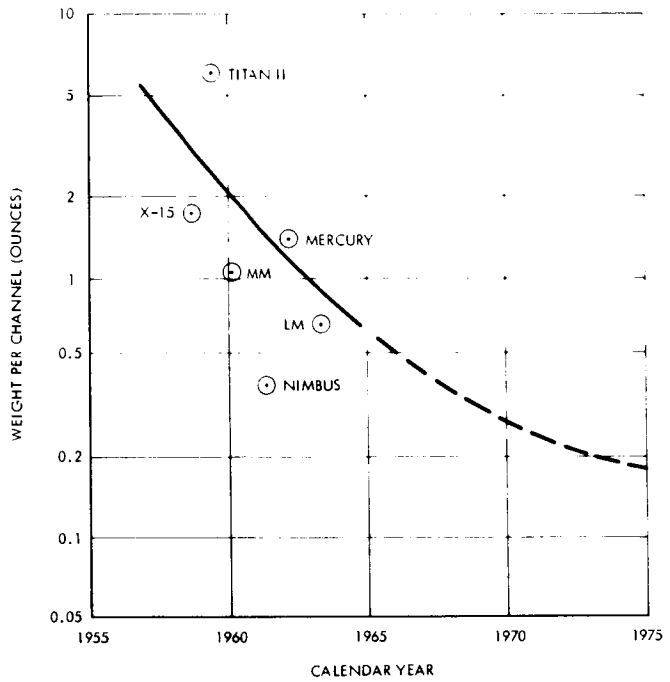


Figure 2B-6. Telemetry Weight Reduction Per Channel

Internal Components Temperature Constraints on Package Design

The reduction in power obtained by microelectronics is seldom as great as the reduction in volume, and the resultant higher heat density tends to increase the operating temperature. Typically, a size reduction in equipment design by a factor of 5 to 10 is associated with a heat reduction of 2. Thus, the problem of thermal management within a subsystem package becomes quite severe and is often the limiting factor in the degree of microelectronic sophistication used in a given design. For example, although it is technically possible to fabricate useful power circuitry in integrated form, there are severe disadvantages in cost, size incompatibilities, and electrical and thermal incompatibilities in the location of the collector where heat is dissipated. Under these circumstances, it is obviously better to distribute the heat dissipation among individually packaged elements than to concentrate the heat in one device package. (However, when power circuits are operated in the switching mode, the heat dissipation problem is greatly reduced. The

circuitry necessary to accomplish the pulsewidth or other time base modulation is quite amenable to IC techniques.)

For first-generation microelectronic circuitry, a fairly narrow temperature operating range is required (about 0 C to 50 C at the device case). It is possible, however, to trade off wider temperature ranges with additional circuitry complexity, weight, power, size, cost, etc., to some extent.

Thus, the operating temperature limits (or of the allowable temperature range of coolant supplied from the vehicle ECS) are flexible and are more significantly dictated by requirements of other specific equipment, including batteries, inertial platforms, and gyros. This electromechanical and chemical equipment usually has both high and low temperature limitations for proper performance; for example, batteries are generally limited to a temperature range of 0 C to 40 C. These limits usually depend upon some temperature-dependent physical property such as thermal expansion or vapor pressure.

Table 2B-1 shows the thermal characteristics of various active components that comprise astrionic packages. The values of the component characteristics are typical and, in actual design, are determined to a large extent by the manner of their usage in the particular application.

High temperatures result in performance degradation and accelerate failure rates for parts and components. As noted in Table 2B-1, the maximum operating temperature of most components used in astrionic equipment is dictated by reliability considerations because of the large number of active electronics and devices used, each of which invariably exhibits an increasing failure rate with higher temperatures. Figure 2B-7 shows the failure rate acceleration factor with operating temperature (junction) for an integrated circuit. Many such circuits are used in present-day computers and space electronics. Failure rates versus operating temperatures of other typical components are given in Figures 2B-8 through 2B-11. Additional failure rate data for thin film chips, ceramic printed circuits, and integrated circuits are given in Tables 2B-2 and 2B-3, which illustrate that reduction in upper temperatures (down to about 20 C) is reflected in significantly lower failure rate. Since these failure rates are additive in computing the circuit and the package failure rate, it should be apparent that the reliability depends almost entirely on the existing thermal environment, the thermal environmental controls provided, and the package internal thermal design.

Table 2B-1. Astrionic Equipment Component Typical Thermal Characteristics

Component	Typical Design Maximum Temperature (deg F)	Tolerable Maximum Operating Temperature (deg F)	Tolerable Minimum Operating Temperature (deg F)	Reference Temperature Location	Reason for Temperature Limit	Temperature Regulation Requirements
Typical circuitry	+ 80	+130	- 65	Ambient	Rel, performance	N/A
Power transistor	+200	+275	- 65	Junction	Reliability	N/A
Signal transistors	+160	+180	- 65	Case	Reliability	N/A
Integrated circuits	+190	+265	- 40	Junction	Reliability	N/A
	+100	+180	- 40	Case		
TWT, low power	+140	+160	- 65	Mtg surface	Reliability	N/A
TWT, high power	+180	+200	- 65	Mtg surface	Reliability	N/A
Gyros (IMU)	+180	+200	- 65	Case	Performance	±1 F
Gyros (sensor)	+180	+200	- 65	Case	Performance	±10 F
Battery cells	+ 80	+110	- 50	Cell	Regulation	±20 F
Accelerometer (dry)	+200	+250	- 65	Internal	Performance	±10 F
Silicon diodes & SCR	+ 80	+130	- 65	Case	Reliability	N/A
IR detectors	-100	0	-150	Det surface	Signal to noise	±20 F
Optics	+160	+160	- 65	Optic Bulk	Distortion, focus	±20 F
Photomultiplier	+100	+120	- 65	Surface	Reliability	N/A
	- 40	+130	-110	Ambient	Signal to noise	N/A
Vidicon tube	+100	+160	- 65	Optic surface	Signal to noise	N/A
	+ 80	+105	+ 40	Face plate		
Capacitors (tantalums)	+140	+200	- 65	Case	Reliability	N/A
Resistor	+250	+300	- 65	Case	Reliability	N/A
Motors	+250	+300	- 65	Linings	Reliability	N/A
CRT	+160	+200	0	Tube body	Reliability	N/A
Crystal oscillator	+160	+180	- 65	Crystal	Stability	±.01 F
Lasers	+220	+250	- 40	Laser surface	Reliability	N/A

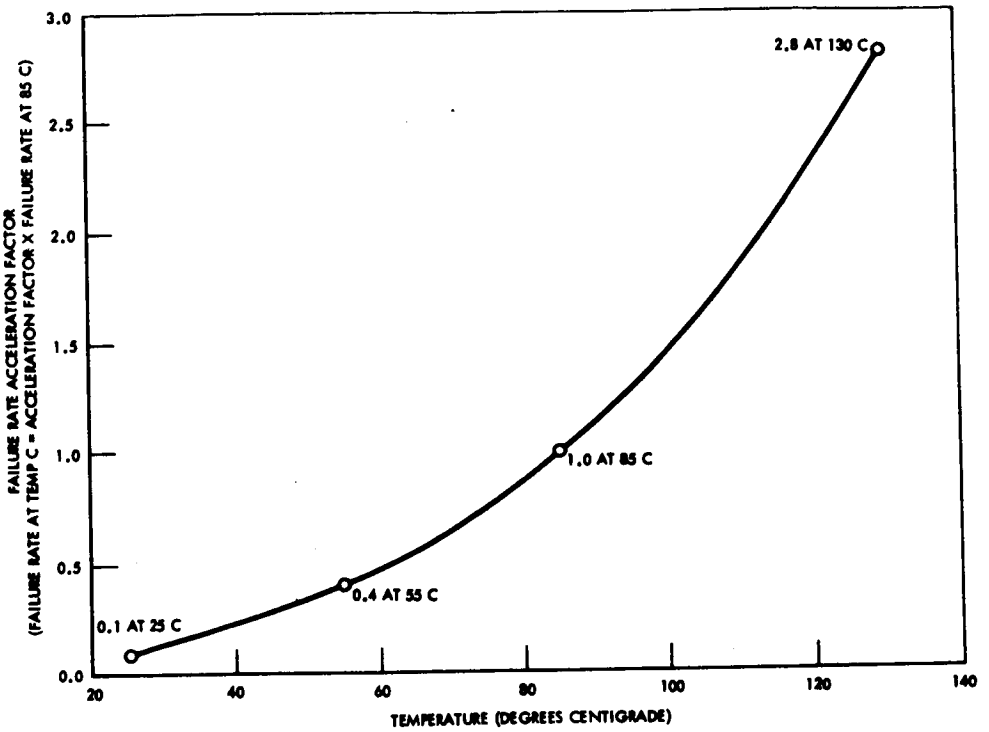


Figure 2B-7. Integrated Circuit Performance Versus Temperature

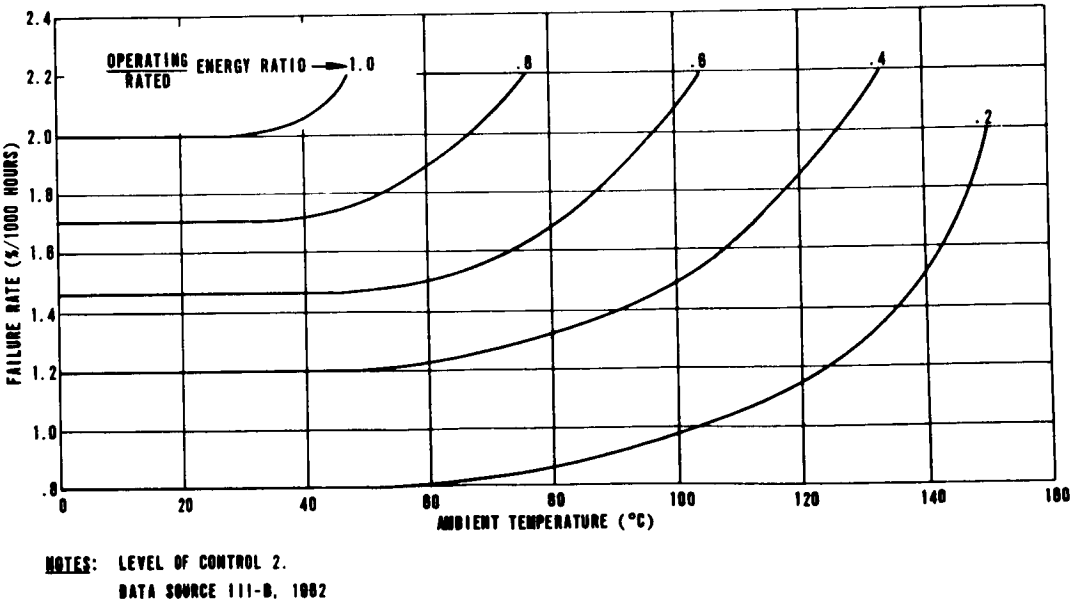


Figure 2B-8. Failure Rates for Microwave Diodes, Mixer Application

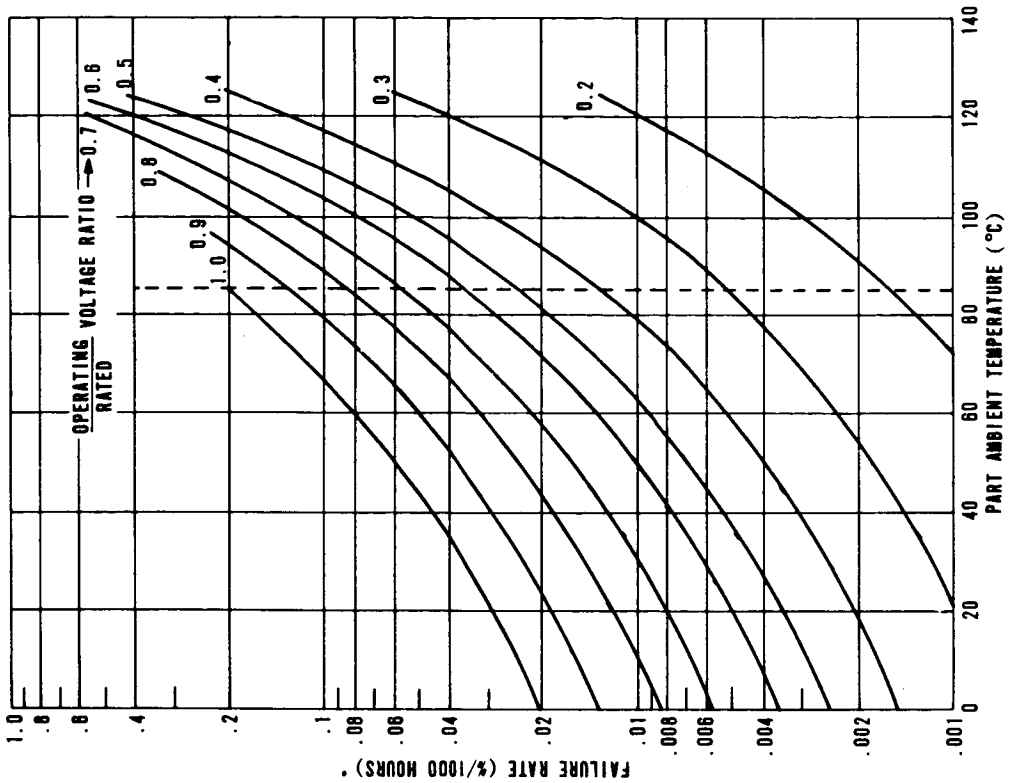


Figure 2B-10. Failure Rates for MIL-C-39658 Slug Tantalum Capacitor

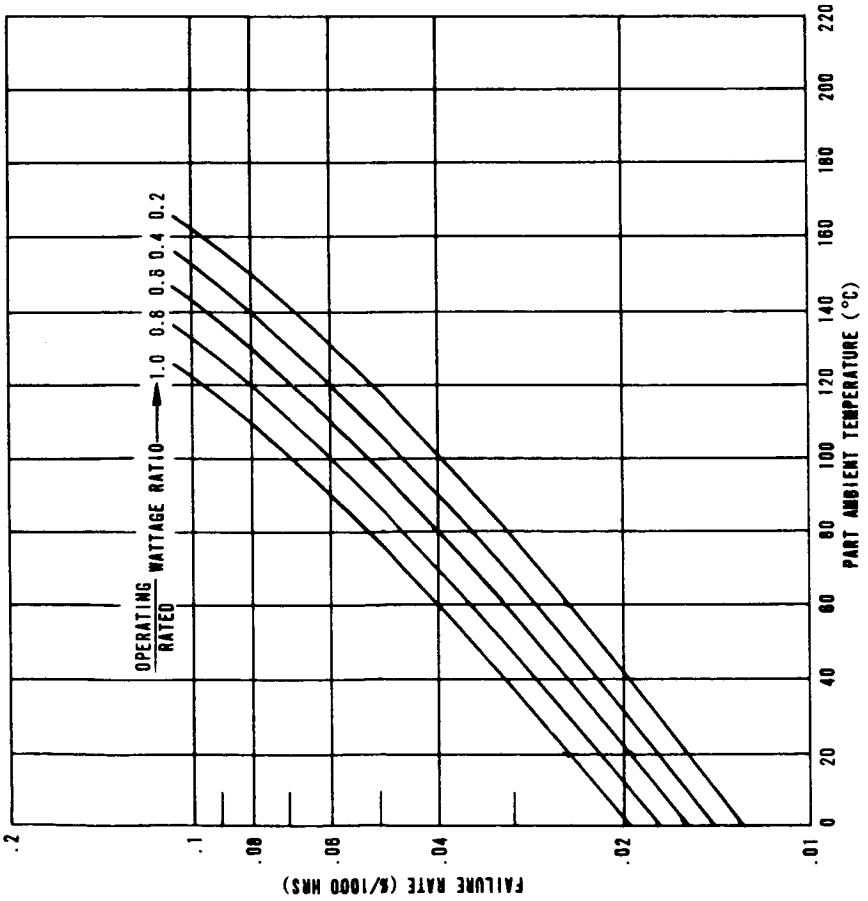


Figure 2B-9. Failure Rates for MIL-R-10509D Film Resistors

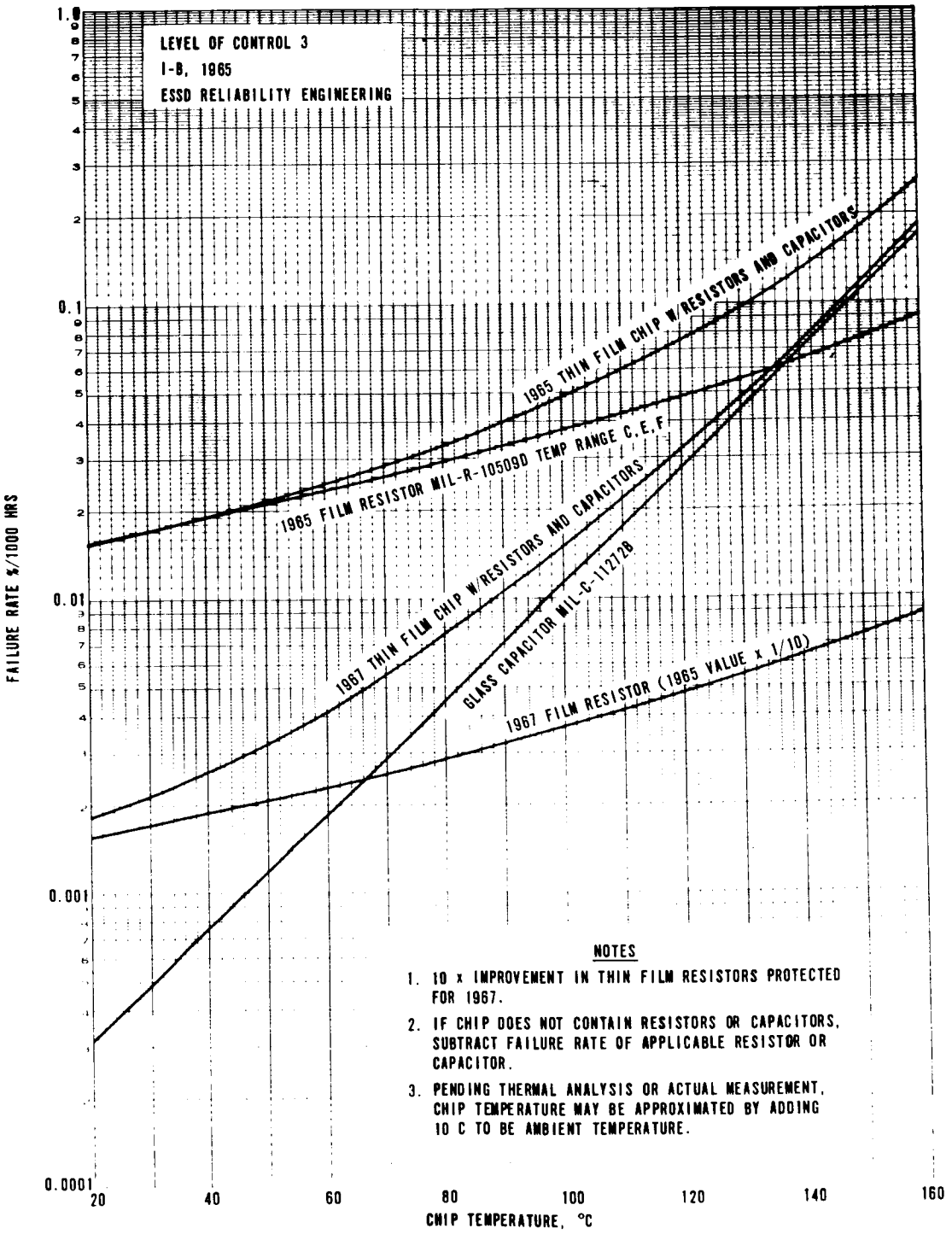


Figure 2B-11. Thin Film Chip Failure Rates

Table 2B-2. Failure Rates for Thin Film Chips and Ceramic Printed Circuits

Type Circuit	Stress	Level of Control	Failure Rate	Data Source and Year
Thin film chip with both resistors and capacitors *	50 C	3	0.022	Autonetics, 1964 (ESSD)
Thin film chip with capacitors only *	50 C	3	0.0012	Autonetics, 1964 (ESSD)
Thin film chip with resistors only *	50 C	3	0.021	Autonetics, 1964 (ESSD)
Ceramic printed circuits with screened conductors	D	3	0.0001	Autonetics, 1964 (NSD)
Each screened resistor			0.005	
*See Figure 2B-11				

From an astrionic equipment internal design state-of-the-art survey conducted during the second quarter of the present study (Reference 2B-2), the following conclusions were arrived at with regard to equipment internal component temperatures. Most equipment supplier's designs are governed by reliability; the lower the device or component temperature, the higher the reliability. The most frequently mentioned temperature limit was the junction temperature of silicon semiconductor devices (transistors, diodes, integrated circuits). Table 2B-4 gives the maximum temperature used as a design criterion by a number of organizations contacted. Gyros operate fairly hot (about 170 to 180 F), but require the closest temperature regulation. Batteries have the narrowest operating temperature range and are the weakest link in the overall vehicle thermal design.

Table 2B-3. Failure Rates for Silicon Integrated Circuits

IID Number	Type Circuit	Stress °C Ambient	Failure Rate
447-0010	Flip flop	25	0.001
447-0011	Triple nand gate	25	0.00075
447-0012	Clocked input nand	25	0.00075
447-0013	Clocked dual nand	25	0.0009
447-0014	Input network	25	0.001
447-0015	Output driver	25	0.0011
447-0017	Write switch	25	0.0009
447-0018	Matrix switch	25	0.0014
447-0019	Low-level switch	25	0.0007
447-0020	Read preamplifier	25	0.001
447-0021	Level detector	25	0.001
447-0024	Gen purpose amplifier	25	0.001
447-0025	Gen purpose amplifier	25	0.001
447-0026	Gen purpose amplifier	25	0.001
447-0028	Demod chopper	25	0.0008
447-0029	Driver switch	25	0.0012
447-0030	Power switch	25	0.002
447-0034	GPA-2A	25	0.001
447-0035	Unclocked dual nand	25	0.001
447-0040	Triple nand nonresistive	25	0.008
447-0043	Input network	25	0.001
447-0056	Gen purpose amplifier	25	0.001
447-0072	05 MV	25	0.0008
447-0096	Level detector	25	0.0011
447-0097	Write switch	25	0.0007

*Criteria of failure assume:

1. Parts have met all electrical, mechanical and qualification requirements excluding burn-in.

2. System design utilizes the three year end points.

Source of Data: Estimates of Inherent Failure Rates for WS133B Electronic Component Parts. Autonetics Document T4-1732.1/33 (Jan.1965).

Table 2B-4. Silicon Devices Maximum Temperature Design Criteria

Organization	Criteria Temperature (deg C)	Temperature Reference Location	Remarks
Autonetics	125	Junction	Minuteman criteria
Honeywell	125	Junction	
IBM	125	Junction	Normal; 100 C desired; 75 C very conservative
ITT-FL	125	Junction	Rated; 100 C used
Litton - DSD	80	Case	Low power devices
MIT Inst Lab	105	Junction	Used for conservative design
RCA - Space	150	Junction	
Sylvania	100	Junction	Design objective; 175 C absolute maximum
TI	250	Junction	Possible with proper thermal design
Westinghouse	125	Junction	Normal; 85 C very conservative

Astrionic Equipment Package Thermal Design

Heat is transferred from and within astrionic packages by convection, conduction, radiation, or a combination of these modes; however, one mode usually predominates. Convection may be natural (free), forced, or accompanied by a change of phase such as boiling. Figure 2B-12 shows all feasible instrument cooling concepts, categorized by the predominant heat transfer mode within and external to the package. Figure 2B-12 also indicates the approximate heat densities that can be removed by a temperature difference of 40 C. In general, more efficient heat removal can be accomplished at the penalty of increased weight and complexity, e.g., forced convection with the requirement of pressure-tight enclosures. Free convection is not applicable at zero-g condition or in the vacuum of space; however, this mode is shown on Figure 2B-12 for purposes of comparison.

As heat density increases, a more effective means is required for transferring the heat from its point of dissipation to the package enclosure or integral coldplate. Presently, this heat transfer is effected predominantly passively by conducting heat along definite thermal (metallic) paths. In some cases, it is done actively by recirculation of a gas within a sealed enclosure. If heat density increases further, possible improved package-internal heat transfer methods include thermoelectric heat pumps distributed within the

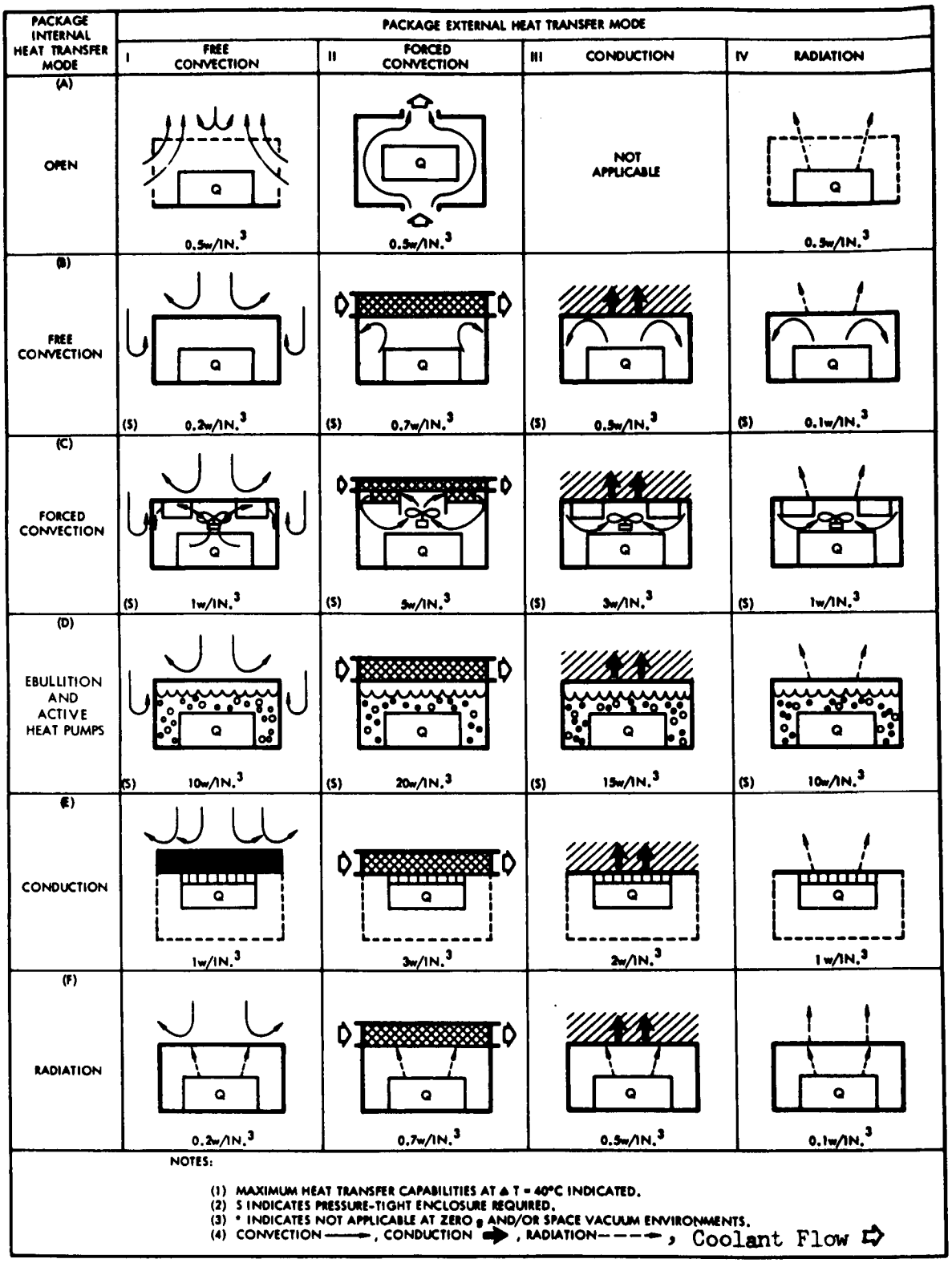


Figure 2B-12. Electronic Instrument Cooling Concepts

package (see H. Kamei, et al., Applications of Thermoelectric Cooling to Avionic System LRU's, NEPCON, 21 June 1966) and direct exposure of active circuit elements to the vehicle supplied liquid coolant.

Internal Heat Transfer Devices/Techniques

The following various heat transfer techniques are used within astrionic packages:

1. Conductive Materials

Conduction has become the most important method of internal electronic package heat transfer and will become increasingly dominant as microminiaturization continues because (1) heat transfer by conduction is the most predictable and reliable method (meaningful tests can be conducted at laboratory conditions); (2) miniaturization in size has shortened conduction paths; (3) significantly smaller package heat loads with higher heat densities exist; (4) heat conduction paths can be tailored to the heat source temperature and wattage; and (5) the pronounced trend to package integral coldplates is evident. It is expected that this method will be used in nearly all electronic equipment in the near future, particularly for predominantly digital circuitry equipment.

To the extent practical, conduction is relied upon through well-defined, high heat conductive (metallic) paths. Steady-state heat transfer by conduction is governed by $q = kA(\Delta T)/l$. Since maximum heat transfer is desired at minimum ΔT, it is obvious that a large k (high-conductivity materials), a large A (cross-sectional area), and a small l (conduction length) are desired. Tables for the conductivities of various materials commonly used in manufacture of astrionic equipment are readily available in reference handbooks and design guides. Metals such as copper, aluminum, and silver have highest conductivity, followed by alloys, such as those for aluminum and magnesium. Since weight is of great concern to astrionic equipment, lightweight metals such as magnesium, beryllium, aluminum, and maglithium are commonly used. Most nonmetals are poor conductors; beryllia (BeO) and alumina (Al_2O_3) are significant exceptions that are used where their properties of electrical insulation are required.

2. Encapsulants

Much electronic equipment, primarily that fabricated by the "welded module" approach, is encapsulated or "potted" for environmental protection. No ideal encapsulant is available, and a compromise exists with potted electronics among weight, repairability, and heat transfer (conductivity). Where thermal requirements are negligible and weight is the main factor, potting is accomplished by semirigid foams, or by encapsultants that have low

density fillers such as microballoons. Where heat transfer is required, fillers for encapsultants are usually high-conductivity materials, such as anodized aluminum particles and alumina or beryllia granules. A recent innovation has been the use of dry alumina granules in hermetically sealed cans without the plastic binder. Commonly used binders include epoxies and silicone rubber compounds.

3. Component Fins

Commercially available component fins (erroneously called heat sinks) promote convective heat transfer from devices such as transistors by acting as extended surfaces.

4. Module Retainers

The primary problem associated with conduction inside (as well as outside) the packages is contact thermal resistance. If internal package modules, such as the heat-conducting etched-circuit-board assemblies, are permanently or semipermanently cemented into place, contact resistance can be minimized. This approach, however, would make repairs impractical and throw-away costs excessive. A unique solution is offered by the module-lock concept used successfully in the Minuteman program (Figure 2B-13). Metal spring-type module retainers are also depicted in Figure 2B-13. These are commercially available, fabricated in beryllium copper, phosphor bronze, or danalloy, a silver heat-treatable alloy of very high thermal conductivity. The function of the module lock and spring module retainers is to apply pressure between the module and the coldplate to promote heat transfer, i.e., reduce contact thermal resistance. Usually the contact areas are wiped with silicone grease to reduce not only contact thermal resistance but also sliding friction.

5. Module Heat Shunts

Modules that use epoxy glass circuit boards, glass substrates, and other low heat conducting materials are frequently severely limited in heat density without some form of heat shunting. One common method is metal backup or a metal sandwich construction. Aluminum and magnesium are commonly used. The metal backup concept is illustrated, as applied to CPC's (ceramic printed circuits), in Figure 2B-14. Another method is the "copper rail," where a copper or aluminum bar is cemented onto the circuit board, and heat-dissipating active components such as integrated circuits are cemented to the rail. Another technique often used is to leave, wherever possible, the copper-clad material in circuit boards to act as thermal conduction paths. The clad is often thickened by dip-soldering.

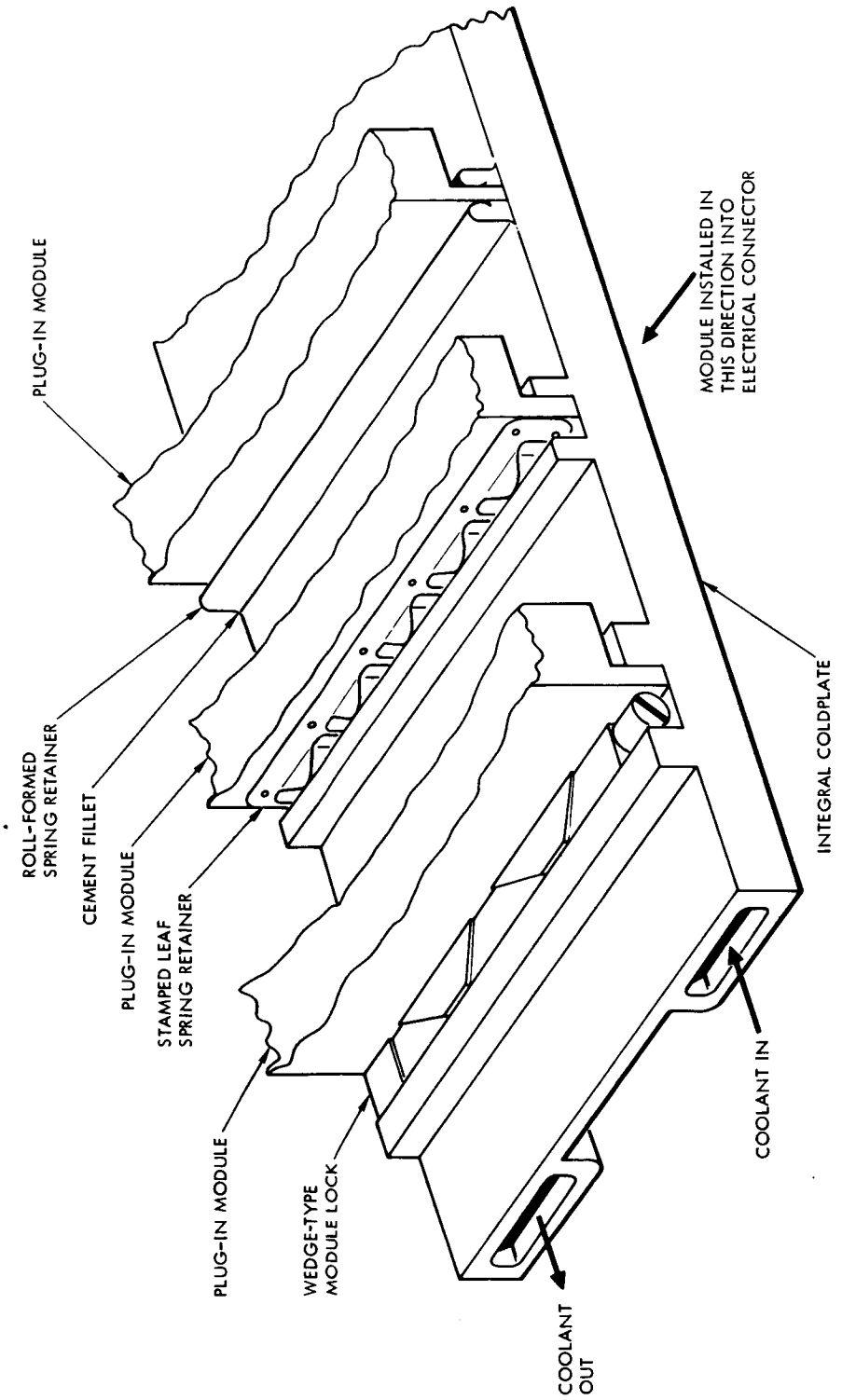
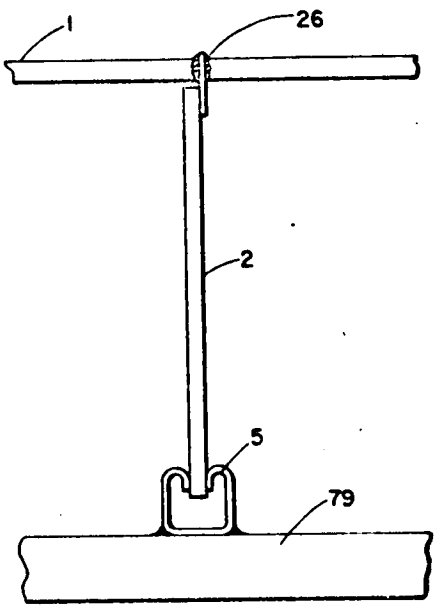
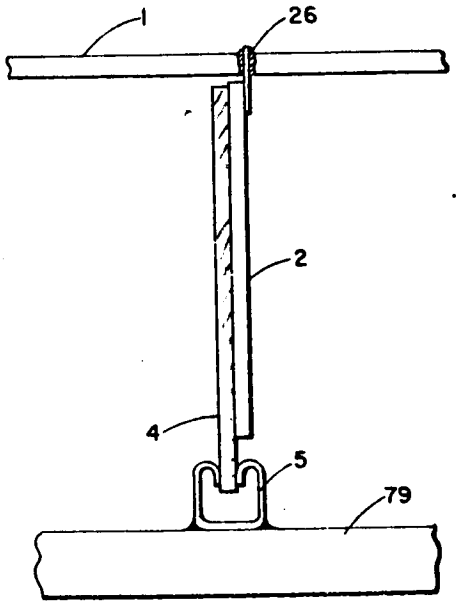
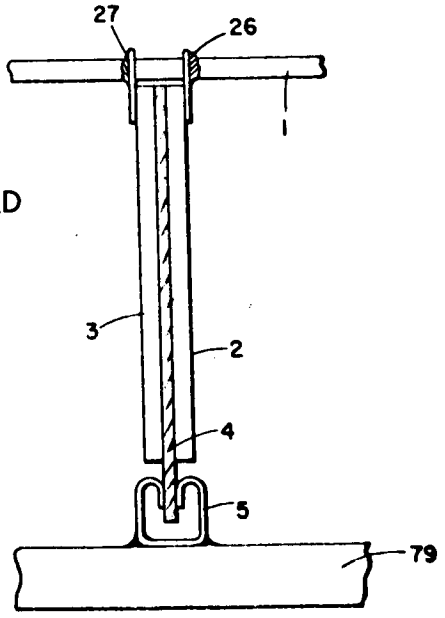


Figure 2B-13. Typical Module Retainers







1 - INTERCONNECTING MULTILAYER BOARD
2,3 - CERAMIC OR GLASS EPOXY CIRCUIT BOARD
4 - METAL BACKUP PLATE (HEAT SHUNT)
5 - MODULE RETAINER - SPRING TYPE
26, 27 - ELECTRICAL CONNECTION LEAD
79 - COLDPLATE OR PACKAGE WALL

NOTE: SEE U.S. PATENT 3,268,772
HIROSHI KAMEI, ET AL.
AUGUST 23, 1966

Figure 2B-14. Metal Backup Plate-Type Heat Shunts

6. Convection Techniques

Convection techniques involve either forced or natural circulation of a fluid in a sealed container. For orbiting space vehicle applications, natural convection is ineffective; therefore, a fan or pump is required. Because of the need for the fan or pump and for the hermetic or semihermetic sealed enclosure, convection techniques are not commonly used. However, there is limited use with complex, precise electromechanic devices, such as a gimbaled stable platform, in which case the internal coolant loop is required primarily for ease in precise temperature control.

With increased heat densities resulting from microminiaturization trends, the forced convection method will become more important for cooling application, perhaps as a supplement or backup for conduction cooling. Usually, the internal coolant is the initial charge of an inert dry gas. A leakproof package seal and a long-life blower are two major concerns.

The best seal is a hermetic seal, consisting of metal-to-metal or metal-to-glass fusions. However, for accessibility, semihermetic seals, which include various gaskets such as the O-ring and commercial molded seals, are required. Both the hermetic and semihermetic seals, if used, must be tested for their integrity. For example, the Minuteman I guidance and control equipment, which is hermetically sealed in a one-sixteenth-inch-thick magnesium wall enclosure containing about 10 cubic feet of helium at nominally 18 psia, is factory-tested to assure that leakage will not result in a pressure loss of 2 psi over 8 years. A mass spectrograph-type helium leak detector is normally used. If helium is not the inert gas used, helium can be added as a tracer; 5 or 10 percent by volume is commonly used.

Compact, lightweight blowers are necessarily high-speed, high-power, and low-life devices. Typical life of high-speed ball-bearing blowers is 3000 hours; however, high-speed blowers can last over 15,000 hours with special grease-pack and quality control. Longer duration would necessitate hydrodynamic gas-bearing blowers. Self-lubricating gas-bearing blowers are used in the Minuteman I guidance package and in the Minuteman II stable platform package, which have a three-year operating life requirement.

7. Ebullient Cooling

Ebullient or direct liquid cooling is accomplished by submerging the hot components in an inert fluorochemical liquid. Heat is transferred from the hot component to the liquid by conduction and vaporization and from the liquid to the package walls by convection and condensation. High heat dissipation factors are obtained; therefore, this cooling method may have application for future compact electronic equipment. Studies and tests of a computer power supply cooling application are reported in Reference 2B-3.

Major disadvantages of this method are as follows:

1. Effectiveness is limited in a zero-g environment.

2. Sealed and pressure-tight enclosure is required.

3. Fluid has high thermal expansion requiring expansion chambers, e.g., rubber diaphragm, metal bellows, and hollow balls.

4. Repair and servicing is limited to facilities having fill capabilities.

5. Increased weight due to 2, 3, and the fluid itself.

8. Heat Pumps

Heat pumps may be effectively used to pump heat from its point of origin at the active components to the walls of the package. The application of thermoelectric refrigeration for this purpose was described in References 2B-2 and 2B-4. The major disadvantage of the thermoelectric heat pump is the requirement for electrical power.

A heat pump method that does not require electrical power is the heat pipe (Reference 2B-5) concept. The heat pipe is a unique heat transfer device that is applicable where a large quantity of heat must be moved effectively and at low penalty. The physical processes involved are vapor heat transfer and liquid capillary action. The pipe consists of a tube closed on both ends, with a capillary structure (wick) along its inside surface. The pipe is evacuated and a small amount of fluid is introduced, which saturates the capillaries and has a significant vapor pressure at the desired operating temperature. The fluid is evaporated at the heat input end, condensed at the heat output end, and returned to the evaporator (heat input end) by capillary attraction. The heat pipe has an effective conductivity many times higher than a metal conduction bar of the same size and would obviously have much less weight.

9. Radiation

Radiation heat transfer of astrionic packages is presently used in some low heat dissipation equipment that is not amenable to conduction such as the Apollo flight director display. Unless high temperature components become universally available, radiation heat transfer within the equipment packages will become decreasingly important.

Temperature Control Devices/Techniques

Astrionic equipment packages containing high temperature sensitivity modules and components require sophisticated control systems. The degree of temperature regulation required is a function of the required equipment performance and reliability. In general, equipment provides better performance and reliability with closer temperature regulation. Performance dependence on temperature regulation is most clearly illustrated by inertial stable platforms whose performance is directly related to performances of their inertial instruments (gyros and accelerometers). These inertial instruments have temperature sensitive drift (error) coefficients that require temperature control from ±0.01 F to ±10 F, depending on the application and the type of instrument.

Temperature regulation requirements are expected to remain unchanged in future astrionic equipment from current equipment requirements. For example, the reduced temperature coefficients of improved inertial instruments such as the case rotated, gas-bearing free rotor gyros and dry electromechanical accelerometers will be balanced by demands for improved system performance because of longer operating duration. Also, in the case of semiconductor devices in future microelectronics, the complex integrated circuits will demand temperature regulation similar to present-day integrated circuits and discrete transistors. This is expected since all three—the transistor, the integrated circuit, and the complex integrated circuits—are silicon devices manufactured by basically the same techniques and processes.

Temperature regulation methods applicable within packages are not basically different from methods applicable outside packages. They include heater control systems, heating and cooling control systems, coolant flow control systems, and storage systems.

1. Heater Control Systems

The heater control system is the most common means of maintaining close temperature control. The essential elements of this system are the sensor, the electronic controller, and the heater. In the simplest form, the sensor and controller is a thermostat (good for plus or minus a few degrees F) or a thermostat with a solid state or mechanical relay (good to plus or minus a 1/4 degree F). Precise temperature control (better than ±0.1 F) requires an electronic controller. The method is versatile in that various modules can be controlled to their individually desired control point.

In a heater system, the equipment is over-cooled, and makeup or bias heat is applied to maintain a constant heat load. In more complex systems, an internal coolant loop is provided to facilitate temperature control where the heater rejects heat to the circulating coolant.

2. Reversible Heating/Cooling Control Systems

Reversible heating/cooling control systems are frequently employed where electrical power is at a premium. Such a system is typified by the thermoelectric temperature controller described elsewhere in this report. These systems have the advantages of (1) minimizing peak heater power, (2) operating at lower control temperature, (3) allowing higher reliability of the equipment, and (4) decreasing reaction time from a cold start condition. The first two advantages are illustrated in Figure 2B-15. The equipment temperature variation without temperature control could be due to changing equipment heat load, changing environment, and changing heat sink (e.g., coolant from the vehicle ECS) temperatures, or their combinations. The temperature control tolerance can be made as small as for the heater system; a tolerance of ±0.01 F is possible with an electronic controller and thermistor bridge sensor.

As an alternative to operating at lower control temperature, the reversible heating/cooling method can be used as a means of tolerating a wider heat sink temperature range. For example, a vehicle may have a number of electronic packages that can tolerate liquid coolant from the vehicle ECS in the range of -50 F to +150 F, and a few packages that require coolant in the range of 0 F to 100 F. Instead of providing coolant at the narrower temperature range to all the packages, the wider range can be provided to all the packages. Packages requiring the narrower temperature range will have incorporated within them the provisions for reversible heating/cooling. In effect, this is a coarse temperature control method where the control band is the narrower temperature range; that is, heating is provided when the coolant drops below 0 F, and cooling (local refrigeration) is provided when the supplied coolant exceeds 100 F.

3. Coolant Flow Control Systems

Thermally actuated coolant system flow control valves—i.e., thermovalves—can provide a non-electrical means of attaining proportional temperature control of equipment packages. Proportional temperature control can be maintained by varying the flow of coolant to the package coldplate by means of a mechanical valve in the coolant line. The valve position is varied by the action of a thermal actuator that senses the temperature of the electronic package or that of the coolant at the discharge end of the coldplate. The motion of the thermal actuator is translated into a corresponding valve motion through a mechanical linking device. This means of flow variation produces electronic package temperature control through control of the available fluid cooling capacity.

The thermal actuator usually consists of a cylinder of temperature-sensitive wax with a high coefficient of expansion. The wax is impregnated

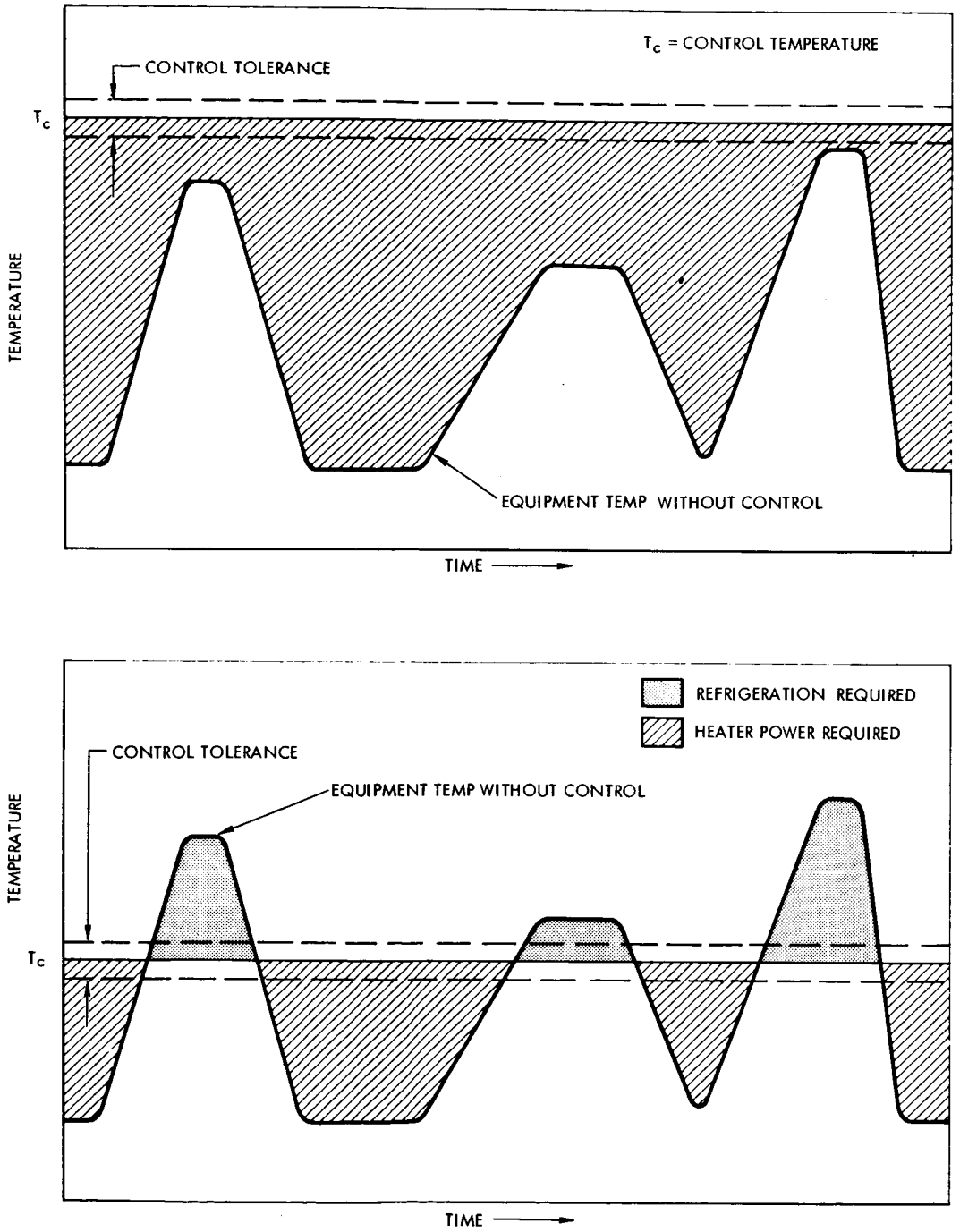


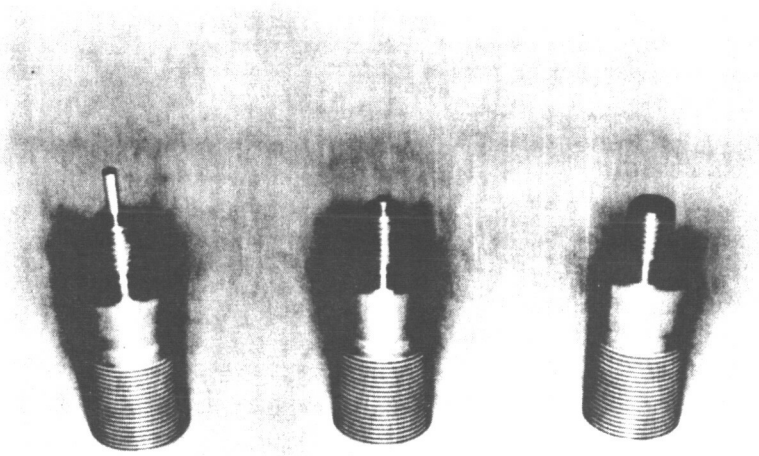
Figure 2B-15. Comparison of Heater Control System With Heater/ Refrigeration Control System

with metal particles of high thermal conductivity that serve to minimize the thermal lag in the control circuit. Thus, a closer regulation of the control temperature is possible without too much overshoot. Figure 2B-16 shows a commercially available thermal actuator in three different stages of operation. The design criteria are included to show the capabilities of this type of actuator.

Valve actuation can also be produced by means of a bimetallic element, a bulb containing a two-phase fluid, or an electric motor controlled by an electronic position servo. In the event that a bimetallic element is used, advantage is taken of the difference in the coefficients of expansion for the two metals involved. This difference produces a change in shape of the element with variation in temperature, and this change in shape is used to actuate the flow control valve. In the case of a bulb containing a two-phase fluid, this fluid is chosen on the basis of a relatively large change in vapor pressure with change in temperature. The vapor pressure is used to provide a force against one side of a spring-loaded diaphragm. When the vapor pressure in the bulb increases as a result of an increase in control temperature, it deflects the diaphragm and actuates a piston that rests against the diaphragm. The piston motion, in turn, changes the effective opening in a poppet valve, or it may be used to actuate a butterfly valve through a mechanical linkage.

A more complicated means of obtaining flow control is through the use of an electric motor drive. In this instance, a thermistor can be employed for sensing electronic package or coolant temperature. Since the electrical resistance of the thermistor varies as a function of temperature, the output of the electronic amplifier circuit containing the thermistor will also change as a function of temperature. This change in amplifier output signal is used to control the supply of power to an electric motor, which repositions the coolant flow control valve. One obvious disadvantage of this last control method, compared with the first three alternatives, is the decreased reliability due to the use of a rotating device (the electric motor) and the added complexity of the electronic amplifier control. A problem common to all four methods is prevention of coolant leakage past the valve stem and through the additional joints created by the insertion of the flow control valve into the coolant circuit. In the use of a bulb containing a two-phase fluid, one characteristic that must be considered is the possible variation in operating point with change in ambient pressure. This characteristic is present if the ambient pressure is used as a reference on one side of the diaphragm in the valve. One means of eliminating this potential problem is to use the coolant circuit pressure as a reference.

Thermally actuated control valves are recommended to prevent overcooling of critical electronic packages for which the minimum permissible coolant temperature is above that for the major portion of the IU equipment



TYPICAL THERMAL ACTUATOR CHARACTERISTICS

WEIGHT: - 1 OUNCE
OUTPUT FORCE: 20 POUNDS
AMBIENT TEMPERATURE RANGE: 65 F TO 250 F
TEMPERATURE CONTROL RANGE: 20 F TO 250 F
LINEAR BETWEEN 30 F AND 150 F
RATE OF TRAVEL: 0.015 INCH PER DEGREE F, OR LESS WHEN SPECIFIED
TIME CONSTANT (TYPICAL): STARTING AT 50 F, IMMERSE IN FLUID AT 100 F
TIME TO REACH 60% STROKE: 12 SECONDS

ACKNOWLEDGEMENT:
PYRODYNE, INC.
11876 WILSHIRE BLVD.
LOS ANGELES 25, CALIFORNIA

Figure 2B-16. Commercial Thermal Actuator Eutectic Wax Type

packages. This is accomplished by presetting the thermovalve, located in the coldplate coolant discharge line, at a temperature somewhat above the minimum permissible at coldplate inlet. When the coldplate coolant discharge temperature approaches the set point, the thermovalve starts to restrict the flow of coolant, thereby preventing a further drop in electronic package temperature. This process of progressive flow restriction continues over the temperature range required to move the thermovalve from the wide open to the fully closed position.

The thermovalve can be used in various configurations of environmental control systems. Figure 2B-17 is a typical application of the device. In this application the thermovalve is used to regulate the coolant flow rate by sensing the temperature of recirculated gas as it leaves the heat exchanger inside the equipment package. The thermovalve is pre-set at the proper control temperature at installation under simulated operating conditions. The thermal actuator exhibits no deterioration with age and thus allows long term temperature control stability which makes it ideal for space systems. A small amount of hysteresis is encountered in the operation of the thermovalve because of friction and tolerances inherent in such mechanical devices. Temperature control of the recirculated gas can be maintained with a ±2 F range about the set point without difficulty for ambient temperature in the range from -65 to +160 F. Finer temperature control requires a heater type local temperature controller that can operate within the coarse temperature control provided by the flow control system.

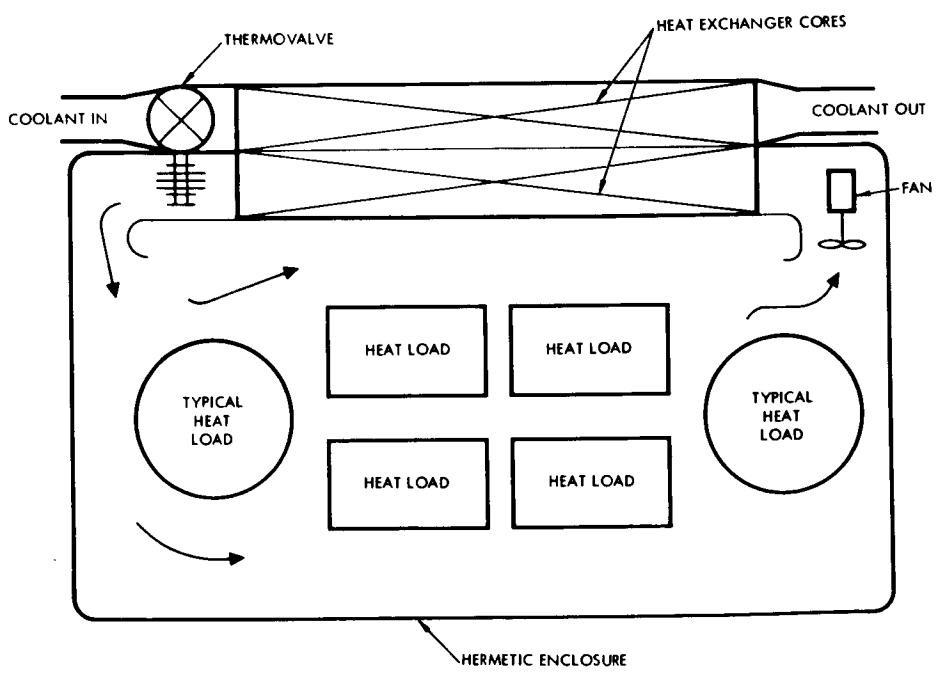


Figure 2B-17. Schematic of Typical Flow Control Temperature Regulation System

Another form of flow control temperature regulation is internal circulating blower (or pump) speed control. Temperature of heat-generating components is controlled by blower speed control because convective heat transfer is a function of the flow (velocity) of the recirculating coolant relative to the heat-dissipating component.

4. Storage Systems

Storage systems can be used inside packages to provide thermal control in the same manner that they can be used for spacecraft thermal controls. Temperature control is obtained by utilizing the heat of fusion of various materials to absorb the excess heat. Change of state storage systems are described in References 2B-6 and 2B-7.

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3.0 SYSTEM INTEGRATION

The discussion in the previous section indicates continuing improvements in the design of electronic equipment, but a radical change for the instrument unit as a result of these improvements may not be necessary. For near-term application, some electronic packages may be redesigned to take advantage of current technology, which may increase the temperature tolerance as indicated in Figure 2-7. In addition, the reliability requirement for longer-duration missions may necessitate the use of redundant components or parts, for which improved components or parts would be incorporated without increasing either the power requirement (or heat load) or the size of the electronic packages. A downward trend in equipment heat loads, smaller package dimensions, and the increased use of integrally or internally cooled thermal design is indicated for the future, as is a relaxation in the temperature tolerance. These trends lessen the requirements on the thermal conditioning system (TCS); thus, the system should tend toward a simpler design. One example is the possible change in the design of the inertial platform, which would eliminate the need for a thermally conditioned nitrogen gas supply for the gas bearings. This is particularly significant for the long-duration missions.

Gradual changes in the power system can be expected. As the mission time increases, the batteries will be replaced by other, more efficient power to serve as the primary supply; in all cases, however, batteries appear necessary to accommodate the peak loads. The change from batteries to fuel cells, for example, necessitates both a change in the thermal conditioning requirements and consideration of the possibility of utilizing the by-product (water) of the fuel cell in the synthesis of the TCS.

In addition to an increase in mission time, a change in the functional utilization of the instrument unit may be possible, such as the addition of experimental or astrionic equipment. In the absence of more specific data, it has been assumed that the environmental conditioning requirements (primarily heat loads and temperature tolerances) would not differ significantly from the values indicated in the previous section. Furthermore, new items of equipment that may be added and that have a specific requirement(s) would be designed either with their own TCS or within the limitations of the overall TCS.

On the basis of trends indicated for the astrionic equipment and its requirements, the current TCS for the instrument unit has sufficient merit to be considered as an initial concept, even though its operational time is

limited. From a conceptual standpoint, the present arrangement of the thermal conditioning panels around the inner periphery of the instrument unit could, under certain conditions, maintain the astrionic equipment within its temperature tolerances, or at least minimize the need for additional heat rejection or addition.

Furthermore, the expendable heat sink, water and sublimator, is perhaps the only practical means for heat rejection during the initial powered flight period of the mission. With modifications, which would include replacing components or parts whose design life is limited and eliminating all or part of the dependency on expendable supplies, the current system could be used for extended periods.

Using the current design concept as the baseline, various modified baseline concepts have been synthesized, ranging from the minimum modified system for short missions to the more extensive modified system for longer missions. These concepts represent the major or basic features required to meet the functional requirements of the TCS. The concepts discussed in Paragraph 3.2, and the system analysis presented in Section 4.0, form the basis for the selection of recommended TCS concepts.

3.1 BASELINE ECS

The current ECS has been reviewed to determine the significant design limitations for extending the operational time beyond the present six and one-half hours. A schematic of the current system is given in Figure 3-1 (from Reference 3-1), which illustrates the thermal conditioning and gaseous supply subsystems. The thermal conditioning subsystem consists of two closed liquid loops in parallel and an expendable heat sink, water and sublimator for heat rejection, located in the instrument unit. One closed liquid loop is located in the instrument unit and consists of 16 coldplates (or thermal conditioning panels) and 4 integrally cooled electronic packages. The second closed liquid loop is located in the forward skirt of the S-IVB stage and consists of 16 coldplates. The gaseous supply subsystem consists of several high-pressure gaseous nitrogen storage tanks and associated controls to provide the necessary pressurization to the methanol-water accumulator, the water supply tank, and gas supply to the gas bearings of the ST-124 inertial platform. This is a semiclosed system, which depends heavily upon stored or expendable supplies.

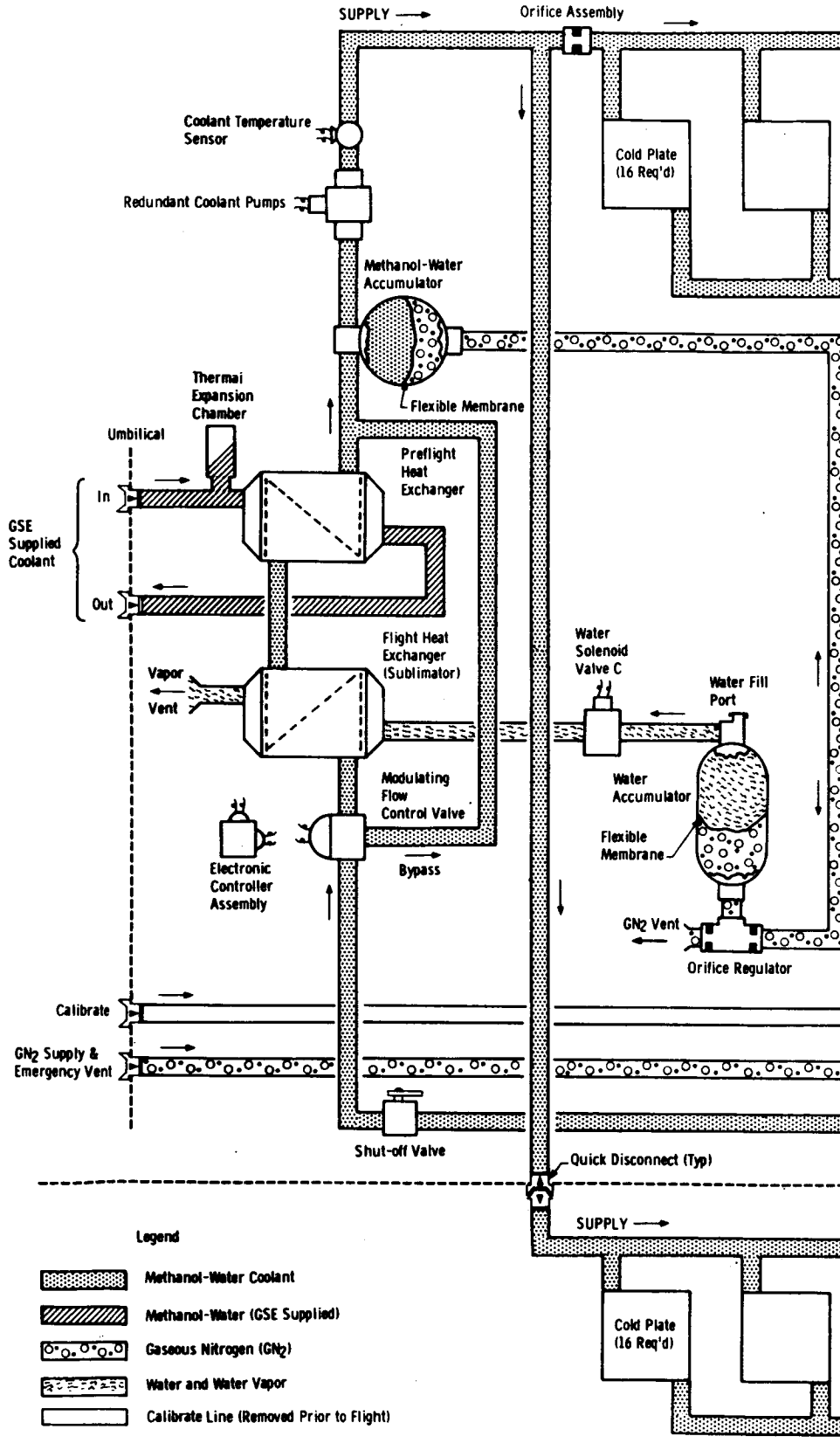
Assuming that the equipment heat load and environmental conditions remain the same as for the current design, component failure and the consumption of the expendable supplies are two general features limiting operational time. With regard to component failure, components that have rotating and/or moving parts (e.g., the centrifugal pump and the modulating flow control valve) can be assumed to be designed to a specific operating time limit and, thus, must be redesigned or replaced for longer periods. Components that have no moving parts could be used for an indefinite period, with the exception of the coldplates, which have a considerable area (100 square feet) vulnerable to meteoroid damage or puncture. The longer mission time and possible exposure of the forward end of the instrument unit to space environment increase the probability of such failure. A redesign of the coldplates or other means of protection from meteoroid damage should be considered.

The second significant feature that limits the operational time is the expendable supply, which includes methanol/water, gaseous nitrogen, and cooling water. The volume of the current methanol/water accumulator is 90 cubic inches. For an estimated leakage rate of 0.7 cubic inch per hour from the thermal conditioning loop, the capacity is limited to about 130 hours, or 5.2 days. The gaseous nitrogen is supplied by two separate sources for two different applications. The first source (a 165-cubic-inch sphere at 3000 psig) is used to pressurize the methanol/water accumulator and the water storage tank. Pressure regulation is maintained by continuously bleeding the

pressurant through an orifice. For the current tank size and orifice flow rate, the useful time is limited to about 15 hours. The second source (a two-cubic-foot sphere at 3000 psig) provides the gaseous nitrogen to support the gas bearings in the ST-124M stabilized platform. At the present use rate of 0.4 scfm, the current tank capacity limits operation to about 12 hours.

In the current design, the 148-pound sublimator water supply is provided to maintain the coolant at the design temperature of 59 F. The amount of heat rejection by the sublimator and the use rate of the water is dependent upon the heat rejection capability of the overall thermal conditioning loop. Thus, the mission time limit for the 148 pounds of water can vary from several hours to several days, depending upon the heat rejection rate. During the initial powered flight period, the heat load reaches a peak value, because of the combined ascent heating and equipment heat loads. On the basis of heat load data given in Reference 3-2, approximately 20 pounds of water is required during the first hour following launch, the major portion being required during the ascent period. For the orbits and vehicle orientations under consideration for this study, the lifetime limits imposed by the cooling water supply are listed in Table 3-1 for a coolant temperature of 50 F and two equipment power dissipation rates. The first of these rates, 3.0 kilowatts, represents the lower limit for equipment applicable to the 1966-1969 operational period, as indicated in Figure 2-9 under orbital checkout and orbit full-on conditions. The other power dissipation rate, 3.9 kilowatts, represents the total for the equipment on the present IU. It may be seen that, for the conditions selected, the minimum lifetime of the cooling water supply system is 41 hours. The last two columns in Table 3-1 show the required coolant temperatures such that no cooling water is necessary for temperature control. If these coolant temperatures were to be acceptable, the lifetime of the cooling water supply system would not be a limiting factor.

From this discussion, it appears that the current system could be used beyond the 6-1/2 hours to about 12 hours without design modifications. For longer periods, modifications such as the replacement of certain parts and an increase in expendables are necessary. These and other possible modifications, alongwith modified system concepts, are discussed in the following section.


SUPPLY
Orifice Assembly
Coolant Temperature Sensor
Redundant Coolant Pumps
Cold Plate (16 Req'd)
Methanol-Water Accumulator
Flexible Membrane
Thermal Expansion Chamber
Umbilical
Preflight Heat Exchanger
In
GSE Supplied Coolant
Out
Flight Heat Exchanger (Sublimator)
Vapor
Vent
Water Solenoid Valve C
Water Fill Port
Water Accumulator
Flexible Membrane
Modulating Flow Control Valve
Electronic Controller Assembly
Bypass
GN2 Vent
Orifice Regulator
Calibrate
GN2 Supply & Emergency Vent
Shut-off Valve
Quick Disconnect (Typ)
SUPPLY
Cold Plate (16 Req'd)
Legend
Methanol-Water Coolant
Methanol-Water (GSE Supplied)
Gaseous Nitrogen (GN2)
Water and Water Vapor
Calibrate Line (Removed Prior to Flight)

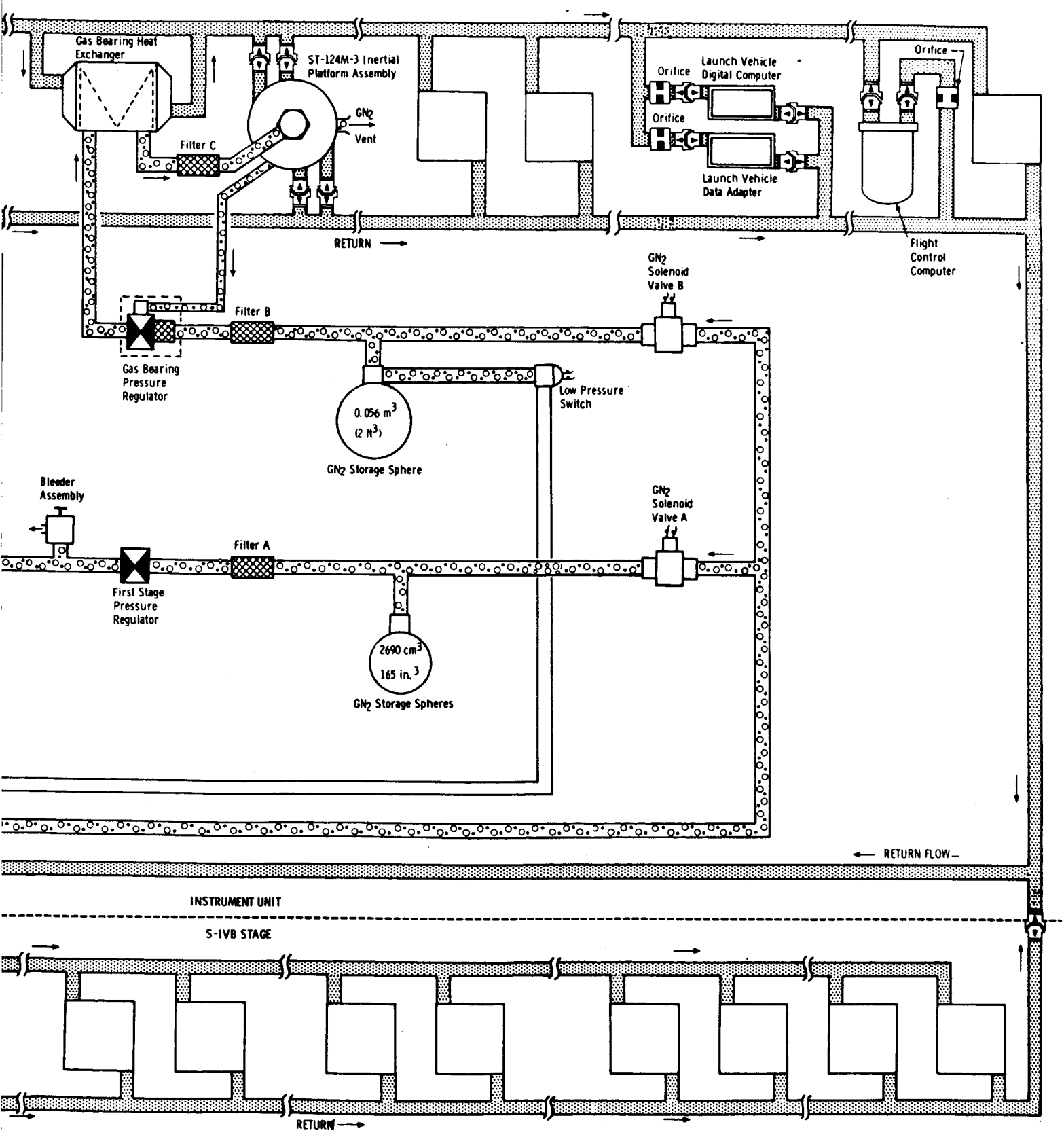


Figure 3-1. Environmental Control System Simplified Schematic

Table 3-1. Lifetime of Expendable Water System on Present IU Thermal Conditioning System

Orbit Designation	Altitude (n. mi.)	Angle of Inclination (deg)	Launch Date	Spacecraft Orientation	Cooling Water Supply Lifetime (hr) at 50 F Coolant Temp		Coolant Temperature (F) for Zero Water Requirement	
					Q_{el} = 3.0 kw	Q_{el} = 3.9 kw	Q_{el} = 3.0 kw	Q_{el} = 3.9 kw
IU-1b-2	200	29	June 21	X axis sun-oriented	296	67	54	68
IU-1c-3	200	29	June 21	Y axis sun-oriented	99	48	63	76
IU-3a-4	200	90	March 21	X axis along orbit path	74	41	67	81
IU-3b-5	200	90	March 21	X axis sun-oriented	296	67	54	68
IU-3c-6	200	90	March 21	Y axis sun-oriented	74	41	67	81
IU-4a-7	100	0	March 21	X axis along orbit path	99	48	63	76
IU-6a-8	19,327	0	March 21	Y axis sun-oriented	296	67	54	68
IU-6b-9	19,327	0	March 21	X axis sun-oriented	*	296	40	56

Q_{el} = Equipment power dissipation
*Requires heat addition to coolant

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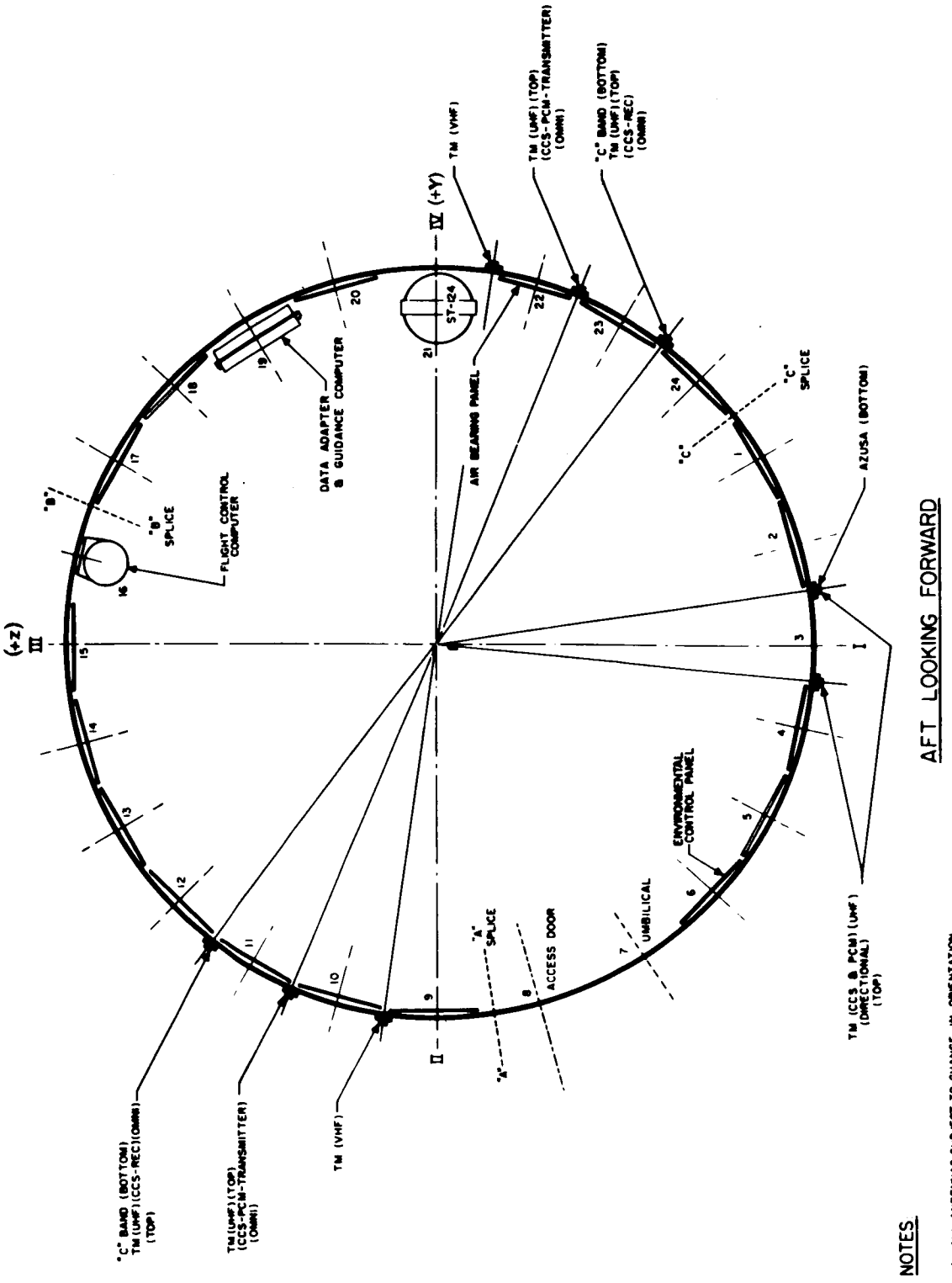
3.2 MODIFIED BASELINE CONCEPTS

Minimum modifications of the current design concept to extend the operational time were considered first; then, increasingly extensive changes or modifications were considered to satisfy the longer mission time and other system requirements. The underlying considerations of any modifications to the baseline system were weight and reliability, which are assumed to be the most significant criteria. The limitations of the present system, discussed in the previous paragraph, were based on these two criteria. Other considerations were the possible design improvements of astrionic equipment and the future trend of the design and development of electronic equipment. These considerations, as well as the requirements and constraints presented in Section 2.0, provide the basis for synthesizing the modified baseline concepts.

For the initial concepts, no changes in the basic design or location of the thermal conditioning panels were assumed, because these panels represent the major portion of the current system design and so any basic changes would constitute a major modification. Figures 3-2 and 3-3 (from Reference 3-1) illustrate the layout of baseline thermal conditioning panels and location of astrionic equipment. The system thermal conditioning panels (or coldplates) provide sufficient surface area (100 square feet) for mounting current and projected future astrionic equipment. Each of the 30-by-30-inch panels was designed to dissipate a maximum of 420 watts, with a 60-percent methanol-water cooling medium flowing at 200 pounds per hour and a 60 F panel inlet temperature. On the basis of equipment heat loads, the capacity of these panels appears adequate. However, since environmental heat loads must also be considered, the complete adequacy of the panels must be determined by a detailed thermal analysis or heat balance of the complete closed thermal loop. In addition to being equipment heat sinks, these thermal conditioning panels could serve as secondary radiators to reject heat by radiation and conduction to the outer structure. Also, they may become heat sources by absorbing the environmental heat, which, in some cases, could be beneficial in obtaining the necessary heat balance. Thus, the consideration of initial changes would be limited to coolant flow rate, coolant temperature, and surface coating. A range of values for these quantities was used in the thermal analysis of the closed coolant loop, discussed in the analysis section.

As discussed in Section 2.0, component failure was indicated as one of the limiting factors in extending the operational time. For the current system, it has been assumed that the components with rotating and/or moving parts have a design life of six and one-half hours and that, to meet the longer

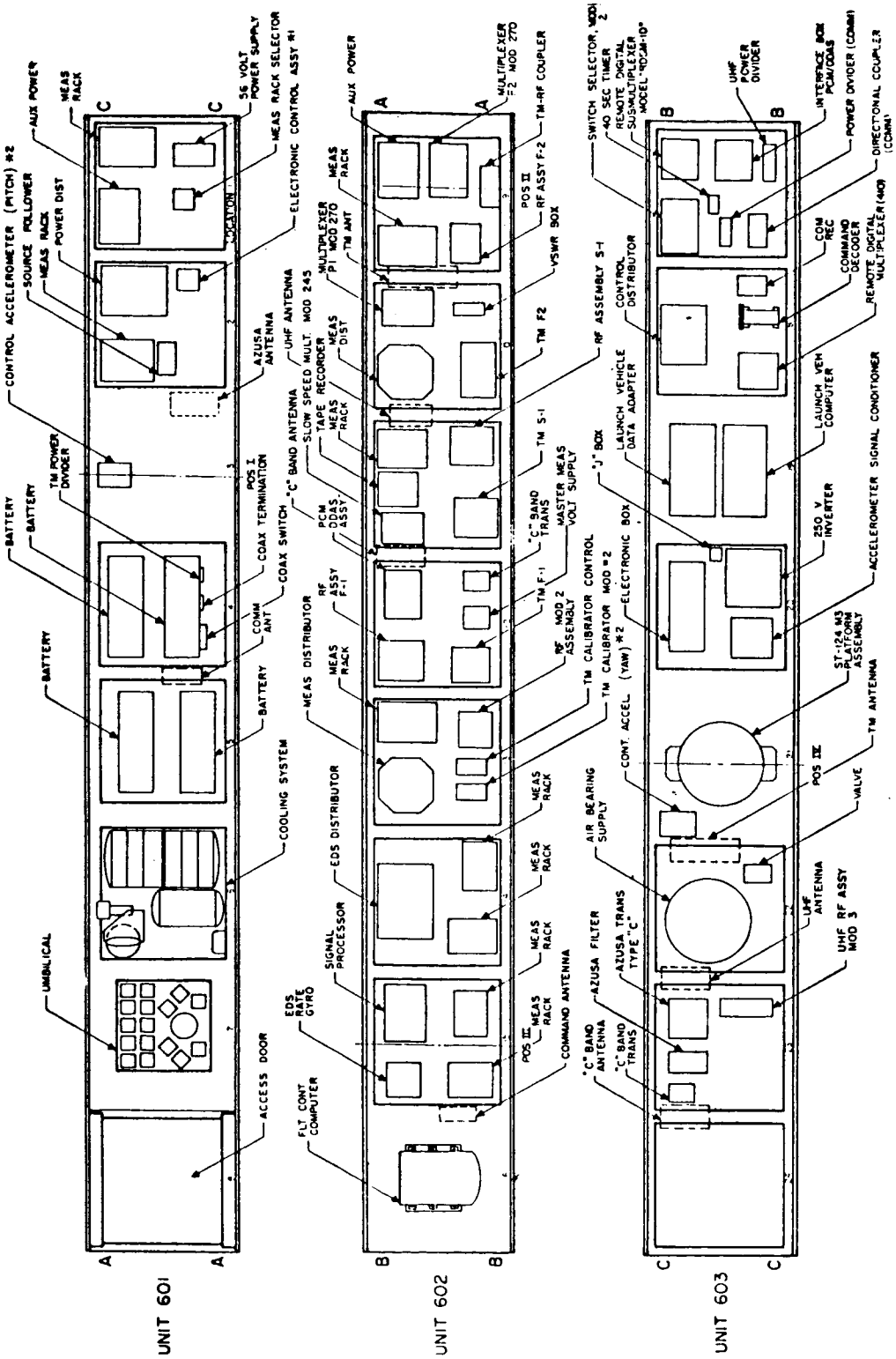


AFT LOOKING FORWARD

NOTES

1. ALL ANTENNAS SUBJECT TO CHANGE IN ORIENTATION AND ANTENNA TYPES DUE TO REQUIREMENTS ESTABLISHED BY THE VEHICLE TRAJECTORIES AND MISSION REQUIREMENTS.

Figure 3-2. Baseline Thermal Conditioning Panel Layout Relative to Vehicle Positions



*NOTES:
1 P&VE ENVR CONT COMP (601440), P&VE SUPPLIED
2 TO BE FLOWN ON SATURN IB ONLY

Figure 3-3. Baseline Instrument Unit Layout

operating time, these items would be redesigned, replaced, or used in redundant arrangement. Components with no moving parts have been assumed to have indefinite life. (The only exception is the thermal conditioning panels, which are possibly vulnerable to meteoroid damage or puncture.) Since no design changes to the panels have been assumed, the use of protective shields around the panels and any other vulnerable components would be a practical approach, because it would involve neither any significant design changes nor increase in the overall system weight.

No change in the present methanol-water coolant has been assumed since adequate measures can be taken to prevent corrosion of those surfaces that are in contact with the coolant over a long period of time.

In general, any changes necessitated by potential component failure can be accomplished quite readily and should not result in any appreciable increase in system weight.

The second major factor that limits the operating time is the stored supplies or expendables. Increasing the amount of expendables, reducing the usage rate, or eliminating all or part of the requirements for expendables are among the possible methods of increasing the system operating time. The simplest and most direct approach is to increase the amount of expendables. However, it is readily apparent that this is limited to relatively short operating times because of the increase in weight and volume. Thus, for longer operating times (up to 180 days), the other alternatives must be considered to satisfy the functional requirements and still achieve a minimum-weight, highly reliable system.

The various possible approaches for each of the three expendables (methanol-water, gaseous nitrogen, and water) are discussed in the following paragraphs.

In Paragraph 3.1, it was estimated that the capacity of the present methanol-water accumulator is sufficient for approximately 5.2 days. To increase the time duration, additional accumulators could be added without any appreciable increase in weight or volume. However, there is a practical limit because of the increased amount of pressurant required, as well as the added complexity of manifolding. Thus, for mission periods beyond 14 days, which may require more than three accumulators, the consideration of a new tank with enlarged capacity appears warranted. Furthermore, the butyl rubber bladder is another factor that may limit the useful life of the present accumulator.

In conjunction with the possibility of increasing the amount of methanol/water, the reduction in leakage rate must be considered. The present thermal conditioning loops have about 200 joints that are potential sources of leakage.

Improvement in the joint seals and reduction in the number of joints are the two obvious means of reducing the potential leakage. The number of joints could be reduced with the reduction in the number of coldplates used for thermal conditioning. This, of course, is dependent upon the thermal requirements and other considerations.

A further consideration with regard to the leakage problem is to consider the separation of the two thermal conditioning loops, which could be accomplished readily by providing shutoff valves in the lines to and from the S-IVB thermal loops, which would be closed at the end of S-IVB boost period. This assumes that the S-IVB electronic equipment would not be required for the remainder of the mission. For the longer-duration missions (perhaps beyond 14 days), and for the case of intermittent use of S-IV electronic equipment, the two thermal loops could be completely separated and possibly connected thermally by a common heat exchanger or by a closed liquid loop with heat exchangers. This arrangement warrants consideration because of the improved reliability by redundant environmental control and greater flexibility in the functional use of the electronic equipment.

Since the amount of leakage is relatively small and the leakage is uncontrolled, the combination of increasing the amount of methanol/water, improving the joint seals, and possibly reducing the number of joints is perhaps the best and only approach.

The present supply of gaseous nitrogen for pressurizing the methanol-water accumulator and the water storage tank has been estimated to be sufficient for about 15 hours, based on an orifice flow rate of 0.066 pounds per hour. It appears that the present flow rate of 0.066 to 0.074 pounds per hour could be reduced considerably without affecting the pressure regulation of the water storage tank by using a smaller orifice. This change, plus additional stored nitrogen, appears feasible for missions up to 14 days. For longer durations, the use of a pressure relief valve in place of the constant flow orifice to regulate the water storage tank pressure appears necessary to minimize the weight. Even with a pressure relief valve in place of the constant bleed orifice, additional stored nitrogen may be required for the long duration.

The present supply of gaseous nitrogen for ST-124M gas bearings has been estimated to be sufficient for about 12 hours of operation. At the present use rate of 0.4 scfm, the supply weight, including the tank, would be about 100 pounds for 48 hours of operation. Thus, additional supply can be considered for only a short duration. For an extended time, one approach would be to use a gaseous nitrogen recirculating system, as described in Reference 3-2. The alternate would be to use a new or modified stabilized platform that does not require gaseous nitrogen supply, as discussed in Paragraph 2.2. If the current ST-124 M stabilized platform is used for extended missions, the nitrogen recirculating system appears to be the best approach, at least from a standpoint of weight.

As discussed in Paragraph 3.1, the present supply of 148 pounds of water for cooling purposes may be adequate for a few hours up to several days, depending upon the heat rejection requirements. For longer operation, the addition of more stored water soon becomes prohibitive from a standpoint of weight and volume. Thus, the first consideration has been to examine a means of conserving the use of the water, which requires a reduction in the heat rejection requirements of the sublimator.

During the initial powered flight period, the expendable heat sink is the only means of heat rejection, and there is little that can be done to reduce the amount of cooling required. For the subsequent mission period, the sublimator heat rejection requirement is dependent upon the heat rejection capability of the overall thermal conditioning loop. Thus, if the thermal conditioning panels are capable of rejecting all or nearly all the waste heat during orbit, the requirements for the sublimator would be a minimum and, thus, the current water supply could be used for a longer period. This period could be further increased by intermittent use of the sublimator, which again depends on the heat rejection requirement. Thus, the extended use of present water supply depends upon the heat rejection capability of the thermal conditioning panels, and must be determined from a detailed thermal analysis or heat balance of the thermal conditioning loop, as discussed in Section 4.0.

Another possible approach to minimizing the requirement for stored water is to use hydrogen vent gas from the S-IVB stage. This source of cooling may be unpredictable in terms of cooling capacity and duration, but it warrants consideration because, in some cases, sufficient vent gas may be available to remove a substantial portion of the waste heat, and modification to the thermal conditioning loop and the hydrogen vent line may be minimal. A detailed discussion and analysis is presented in Appendix 3C.

For mission times exceeding 48 hours, the possible use of fuel cells as the primary power source (as indicated in Section 2.0) would provide water as a by-product, which could be used to augment the stored supply. An estimate of two to four pounds per hour of water output, depending upon the power demand, would provide cooling of approximately 2000 to 4000 Btu's per hour, which may be sufficient in certain cases. The only addition required to the ECS would be an accumulator and its associated ducting and controls.

For intermediate and long mission times, the space radiator would be the logical choice for rejecting waste heat. The expendable heat sink would be used during the initial powered flight period. For the remaining mission time, it could be used to augment the space radiator for heat rejection, such as during periods of peak heat load. The space radiator could be designed to eliminate completely the need for an expendable heat sink after the initial powered flight period.

These and other possible heat sinks are discussed in greater detail in Appendix 3A.

To use the present sublimator for an extended time, and particularly for intermittent operation for which the thermal load is zero or a very low value, the problems of possible freeze-up and start-up transient must be considered. The present sublimator is designed for a heat load range between 1.5 and 9.0 kilowatts, and so at zero or very low heat loads, provisions must be made to prevent freezing, which could mean the addition of some rather complex controls. Furthermore, since a sublimator is more suitable for continuous operation, the changing requirements for the extended time applications strongly suggest that a new and different type of evaporative cooler, such as the plate fin or wick-type water boiler, should be considered.

For the longer missions, the possibility of water freezing in the storage tank must be considered. Among the possible ways of eliminating the problem are insulating the storage tank, modifying the tank so that waste heat from the thermal loop could be utilized, and reducing the freezing point by additives to the water. The use of electrical heaters is also a possibility if adequate power is available. These alternatives can be readily incorporated, and so there appears to be no advantage in changing to a fluid whose freezing point is lower than that of water.

From the foregoing discussion of possible modifications to extend the operating time, four modified concepts in which the basic configuration of the present system is maintained were extracted. It was assumed for these initial concepts that the S-IVB electronic equipment would be used only to control the S-IVB stage and, thus, would not be used after restart to change from the checkout orbit to the final mission orbit. Thus, the addition of shutoff valves in the coolant lines to and from the S-IVB coolant loop, to be programmed to shut off automatically after the S-IVB stage has been completely spent, is indicated.

MODIFIED CONCEPT 1

The simplest minimum modification to extend the operating time beyond the present six and one-half hours is to replace the components that have limited design life and to increase the stored quantity of water and gaseous nitrogen for the ST-124M gas bearings by adding storage tanks. The amount of increase in the stored water and gaseous nitrogen is limited by mission and vehicle constraints, since the weight and volume of the stores could reach prohibitive values. This situation is shown in Table 3-2, which lists required weights or volumes of expendables as a function of mission duration. Quantities available in the present system are shown for comparison. These

latter quantities and the leakage rates used to calculate required amounts were obtained from Reference 3-2. It is apparent that the operating time of the present system is limited only by the amount of permissible increase in stored expendables.

Table 3-2. Weight of Required Expendables Versus Mission Duration

Mission Duration	GN_2 for ST-124M Gas Bearing System (lb)	GN_2 for Methanol/Water Accumulator (lb)	Methanol/Water Leakage (in.^{3})	Cooling Water for 3-kw Heat Load (lb)
10 hours	21.75	0.90	7.0	100
48 hours	104	4.32	33.6	480
10 days	544	21.6	168	2,400
30 days	1,630	64.8	504	7,200
90 days	4,890	195	1510	21,600
180 days	9,780	389	3,020	43,200
Capacity of present system	28	1.35	90	148

In addition, changes in the coolant flow rate and surface coatings of the thermal conditioning panels and surrounding structure may be required to utilize the thermal conditioning panels for heat rejection, or heat retention, to the fullest extent. Another change would be to use a smaller orifice size for the pressure regulation of the cooling water storage tank.

MODIFIED CONCEPT 2

This concept is similar to Concept 1, except that the stored gaseous nitrogen for the ST-124M gas bearing is replaced by a gaseous nitrogen recirculating system, and expendables from other sources are used in addition to the stored water. One alternative, which depends upon the use of a fuel cell, would be to use the water from the fuel cell to augment the stored water supply. For this alternative, only the addition of a water accumulator

would be required. A second possible alternative would be to utilize the hydrogen vent gas from the S-IVB stage, in the event such gas is available as a heat sink material during orbital coast. After final burn of the stage, the remaining quantity of hydrogen (173-701 pounds, according to Reference 3-3) may be available if utilization of the stage does not call for immediate dumping of the hydrogen. Use of cryogenic hydrogen gas would require the addition of a hydrogen-methanol cooler in the thermal conditioning loop.

Concept 2 is a step toward limiting the amount of stored supplies, thereby minimizing any weight increase for extending the operating time.

MODIFIED CONCEPT 3

This concept is similar to Concept 2, except that a space radiator is added to the thermal conditioning loop for heat rejection, and expendables from other sources are not used. The stored water is used for cooling during the ascent period and on a demand basis for the remainder of the mission time, primarily for periods of peak heat loads. An alternative would be to design the radiator to reject all heat during the orbital phase so that stored water would not be required. A radiator designed to meet both the peak and sustained heat loads could present radiator freezing problems.

Concept 3 introduces a new interface with the IU structure or the other adjacent structure for which modifications would be required.

MODIFIED CONCEPT 4

This concept is similar to Concept 3 except that it depends upon water from fuel cells to augment the stored water supply. In this concept, the radiator is designed for the steady heat load, and the stored and the fuel cell water is utilized for the peak heat load periods.

These four concepts represent a progressive increase in the degree of modification required to the baseline concept, as well as increased integration with other subsystems to meet the long duration operational time with minimum increase in system weight. In these initial modified concepts, to minimize the extent of modifications, no change in the configuration of the thermal conditioning loop was assumed. The next step was to consider various modifications to the thermal loop for better utilization and possible reduction in the heat loads to the thermal loop and the associated heat rejection device.

A review of current astrionic equipment that is coldplate-mounted (Section 2.0) indicates that, on the basis of the allowable case temperature tolerance, the equipment could be placed in the following three groups:

1. Group I, with the narrowest temperature tolerance range (50 F to 122 F), is assumed to require an active ECS consisting of a recirculating coolant loop with a means for heat rejection, in addition to the thermal conditioning panels.

2. Group II, with a greater temperature tolerance range (-4 F to 167 F), is assumed to require only a recirculating coolant loop, which would depend upon the thermal conditioning panels for heat rejection. By separating Groups I and II, the heat load to the heat rejection device, such as the expendable heat sink or space radiator, would be reduced. The Group I and Group II thermal loops could be connected thermally by a common heat exchanger with a bypass that would permit heat transfer from one loop to the other or no heat transfer, depending upon thermal requirements.

3. Group III, with the widest temperature tolerance range (-67 F to 185 F), is assumed to require only a passive means for thermal control. There are two possible alternate methods for mounting the equipment. One method is to mount the equipment directly to the IU inner structure so that the equipment heat would be transferred by the combination of conduction and radiation. Although this is a simple approach, it may not be feasible because of the ascent heating. The other alternative is to mount the equipment on the thermal conditioning panel and provide a thermally controlled shutoff valve at the coolant outlet of the panel. The panel(s) is located in the Group II thermal loop so that whenever passive cooling is not sufficient, the thermally controlled valve would allow the coolant to flow and remove the excess heat.

This approach of grouping and localizing the heat rejection is another means of reducing the heat rejection load on an expendable heat sink or space radiator, which could result in weight savings. However, any benefit would be partially offset by the increased complexity of the overall system.

Table 3-3 summarizes the alternate approaches to thermal control on the basis of astrionic equipment grouping and mission periods. The TCS concepts to be selected will be total concepts that encompass the three equipment groups and the various mission periods on an integral basis.

As indicated in Section 2.0, a review of future astrionic equipment design points to a trend toward integrally cooled equipment rather than packages that transfer power dissipation heat by conduction to a coldplate. The review also reveals trends toward lower package heat loads, little change in package temperature tolerance, and smaller package size. These trends result in a reduction in the number of thermal conditioning panels required for equipment cooling. One approach to this situation would be to maintain the present thermal conditioning configuration with no change in the number

Table 3-3. Alternative Approaches for Thermal Control

Astrionic Equipment	Thermal Control Approaches for Mission Periods		
	Prelaunch	Initial Powered Flight	Orbit
Group I	GSE HX	Active: Sublimator	Active: Sublimator and/or radiators, plus coldplates as secondary radiators
Group II	GSE HX	Closed liquid loop; (Active: sublimator)	Closed liquid loop with coldplates as secondary radiators (radiation only)
	GSE HX	Closed liquid loop with coldplates as secondary radiators (radiation only) S-IVB dome used as heat sink	(No cooling by sublimator or radiator) (Coolant circulating through coldplates)
Group III	Combined with Group II TCS	Combined with Group II TCS	Passive (radiation only); Coldplate mounted
	Passive; IU skin mounted	Passive; IU skin mounted	Passive (radiation only); IU skin mounted

of thermal conditioning panels. These panels would be used for mounting equipment, including that which is integrally cooled (flight control computer, launch vehicle digital computer, launch vehicle data adapter, and ST-124 inertial platform assembly); panels that are not used for equipment heat sink would be used for heat rejection and in conjunction with other heat rejection devices. Each of these panels would be equipped with a thermally controlled shutoff valve at the outlet from the panel to control the heat rejection. In some instances, some of the panels could serve as a heat source, by absorbing the environmental heat, to maintain the desired overall heat balance.

An alternate approach would be to remove the panels that are not required and rearrange the remaining panels for maximum utilization as both heat sinks and heat rejection devices. In addition to the expendable heat sink, a space radiator would be used for necessary heat rejection. The advantage of this approach would be the more efficient overall heat rejection capability since the space radiator is more efficient than the thermal conditioning panels for heat rejection.

On the basis of design changes projected for the future operation equipment (Table 2-7), the present 16 thermal conditioning panels could be reduced to about 8 panels for those electronic packages that require coldplates for heat sink. Other equipment would be integrally or internally thermal-conditioned. In addition to a reduction in weight that results from the reduction in the number of thermal conditioning panels, the operating conditions may change, such as a wider temperature range for the coolant, which may further minimize the need for heat rejection by expendable means or reduce the space radiator size.

These possible changes to the thermal-conditioned panels and, hence, to the system configuration can be combined with the four previous concepts in various combinations to arrive at additional concepts representing a greater degree of modifications.

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3-1. Astrionics System Handbook, Saturn Launch Vehicles (Revised 15 August 1966).

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3-3. Orbital S-IVB Spent Stage Study, Douglas MSSD Report, Contract No. NAS7-101 (17 May 1966).

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APPENDIX 3.0 RESIDUAL HYDROGEN UTILIZATION

APPENDIX 3A HEAT SINK CONCEPTS

Most of the energy used to operate electronic equipment ultimately appears as heat in the immediate environment of the equipment. The heat is removed either by active or passive methods, or both, and is disposed in a sink. There are a number of heat sinks that may be used with the various heat removal methods (active or passive). The selection of the heat sink(s) depends on the amount of heat to be rejected, the duration required for heat rejection, and minimum weight.

The various heat sinks and regions of applicability are illustrated in Figure 3A-1. The regions or boundaries have been established on the basis of providing a minimum weight heat sink. To develop these regions of applicability, a number of assumptions and estimated values have been used. For this reason, Figure 3A-1 represents an initial attempt to provide a useful means for selecting a heat sink to meet a particular requirement. Additional refinements in Figure 3A-1 and possibly several heat sink maps can be made for different assumptions and values for the numerous parameters or variables involved. A brief discussion of the various heat sinks follows.

Thermal Mass

The heat that results when electrical energy is dissipated causes the temperature of equipment mass to rise. This rise is directly proportional to the energy involved and inversely proportional to the heat capacitance (mass times specific heat). When the amount of heat is very small (in relation to the heat capacitance), the temperature rise is also small and no further thermal consideration is necessary. As the duration and heat loads increase, more energy must be absorbed. Additional mass can be used, but will result in considerable weight penalty. If a 20-degree F rise in temperature is permitted, even the best material will absorb only about 20 Btu's per pound of material (for example, aluminum will absorb only about 4 Btu's per pound, and steel only about 2 Btu's per pound). The thermal mass is applicable for extremely small power dissipations or short power spikes or where the material serves some other function. This type of heat sink can be regenerated (temperature reduced to original value) indefinitely; thus, the useful capacitance may be several times the actual heat capacitance.

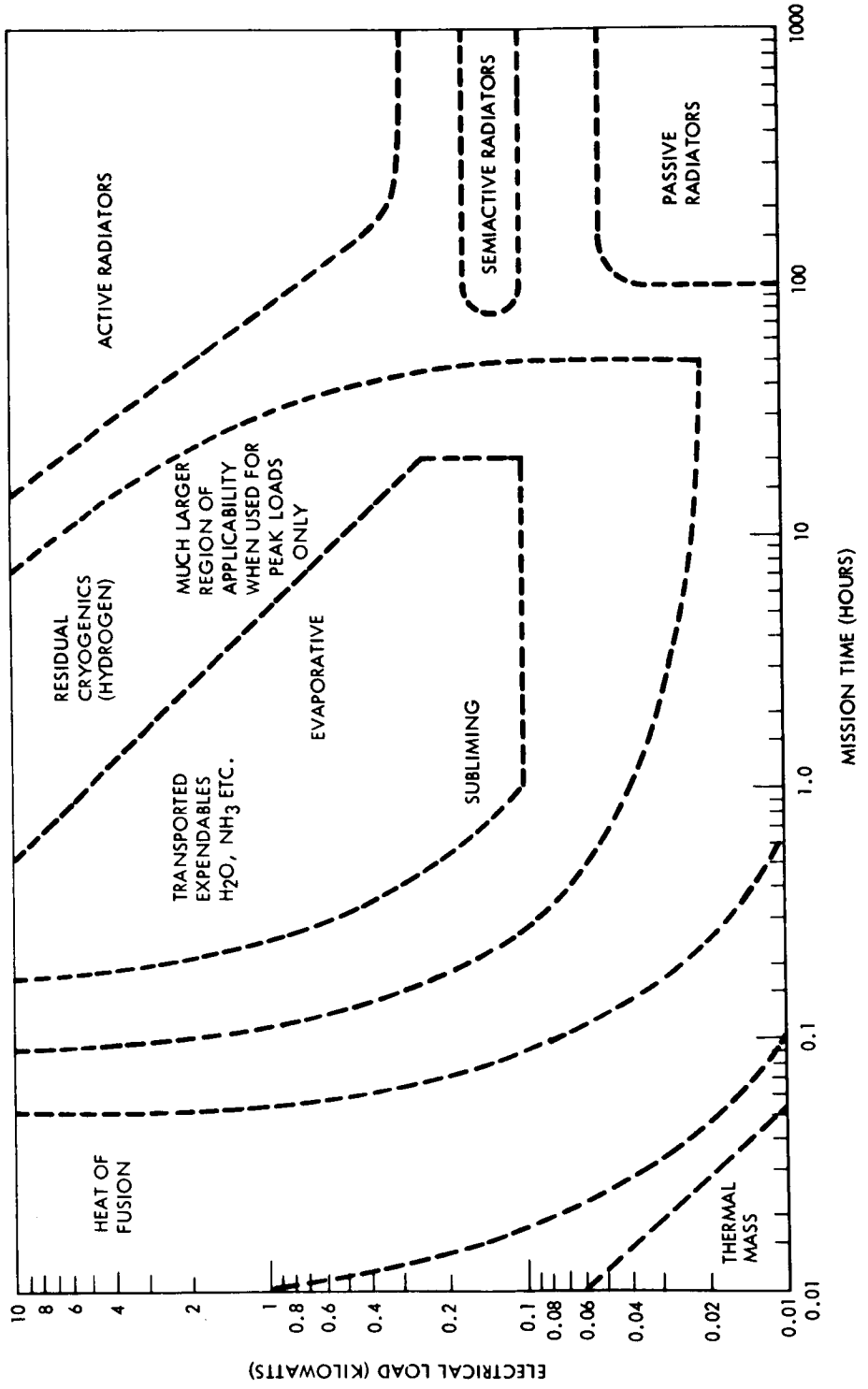

Figure 3A-1. Regions of Applicability for Heat Sinks

Heat of Fusion

When the total heat to be dissipated becomes appreciably larger, a more efficient heat sink is necessary. A number of materials that undergo a change from a solid to a liquid state may be used to absorb heat. As much as 138 Btu's per pound can be removed in this manner. The heat of fusion limits the temperature rise of the electronic equipment to a narrow temperature band. Heat is also absorbed below and above the change of state temperature by capacitance. The containment of the change of state material must be flexible enough to account for some change in volume. Since this heat sink can be regenerated, its useful heat capacitance may be several times the heat of fusion. Figure 3A-2 shows the heat of fusion for several different substances at the temperature at which the change of state occurs. Additional information can be obtained from Reference 3A-1.

Expendables

The use of expendables as a heat sink is discussed in detail in Appendix 3B and the utilization of residual hydrogen in Appendix 3C. The information provided in these appendixes was used to establish the regions of applicability in Figure 3A-1.

The weight penalty for utilization of expendables includes the associated lines, pressurization, coolers, connectors, valves, etc. In many instances, the use of available expendables will not be practical. However, the ability of expendables to be used on a demand basis makes their use particularly attractive for peak (spike) loads, since they reduce the size of radiators and make their load more uniform.

Radiation

The theory and application of radiating surfaces for heat rejection to space has been widely used in past and current space vehicle thermal systems. Since space can be considered an infinite heat sink, the radiating surface or radiator is perhaps the most efficient method for long-duration, low to high heat loads. The radiator may be classified as passive, semi-active, or active, depending upon the design.

In a passive radiator, the equipment to be cooled is attached directly to the radiating surface. This is a simple arrangement with no moving parts or power requirements. Since no fluids are involved, there is no problem of freezing or meteoroid puncture. Application of this type of radiator is limited to constant heat loads or to equipment with large temperature tolerances.

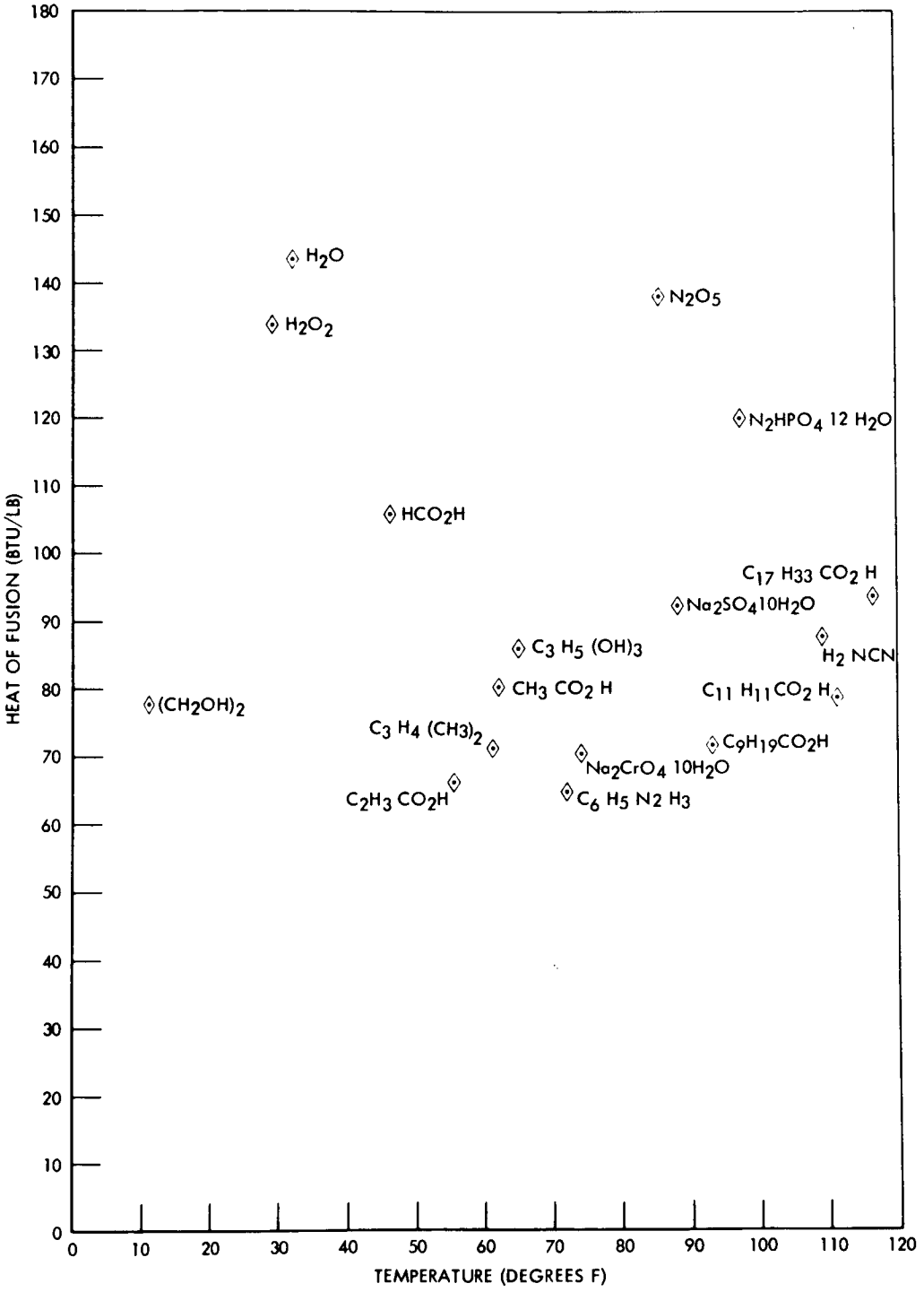

Figure 3A-2. Heat of Fusion Data

In a semiactive radiator, a heat pipe with fluid flow but no external power or moving parts is used to transfer heat from the equipment to the radiating surface. This method provides some self-regulation to accommodate variations in the heat rejection load and/or environmental heat load. A closer temperature tolerance may be maintained by the use of the heat pipe (as compared to the passive method). Relatively large passages required for the heat pipe poses a problem of meteoroid penetration if large areas or long-duration use is required.

In an active radiator, a circulating fluid is used to transfer heat from the equipment or source to the radiating surface. This method provides the maximum temperature regulation to accommodate variations in heat loads. The use of fluids creates the problem of freezing and possible radiator tube punctures by meteoroids. For long-term application, the meteoroid protection must be considered, and will have some influence on the radiator weight.

Reference

3A-1. Fixler, S. Z. "Satellite Thermal Control Using Phase-Change Materials," Journal of Spacecraft and Rockets, Vol. 3, No. 9 (Sept. 1966), pp. 1362-1368.

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APPENDIX 3B EXPENDABLE COOLING METHODS

For a relatively short duration cooling operation, the expendable heat sink provides a reasonably simple, lightweight system for continuous or intermittent operation, depending upon the application. The present design of the thermal control system for the instrument unit uses the expendable heat sink as the primary cooling method because of the short-duration operation. For a longer-duration operation, the expendable heat sink may be used in conjunction with a nonexpendable heat sink, such as a space radiator. For this type of application, the expendable heat sink may be designed to meet peak loads (spikes) and for other possible situations in which the nonexpendable heat sink is nonoperative. One possible situation would be an emergency due to failure of the primary heat sink, such as a space radiator. Another possible advantage in utilizing the expendable heat sink as an integral part of the thermal control system is the convenience of expanding the cooler capacity in terms of heat load and/or operating time without making major system changes or modifications.

There are a number of possible expendable cooling alternatives (Figure 3B-1). The selection of a particular method will depend upon the availability and source of coolant, the design requirements of the major components, and the overall weight, power, and volume savings. The stored or transported expendable (water) method is used in the present instrument unit thermal control system. An example of a possible utilization of generated fluid (boiloff) and the residual fuel is that of hydrogen from the Saturn S-IVB stage. This investigation is discussed in detail in Appendix 3C.

The general area of applicability of expendable cooling methods is discussed briefly in Appendix 3A.

Expendable Coolant Sources

Stored or Transported Expendables

Because of the weight and volume penalty, only those fluids or solids that have high heat of vaporization would be considered suitable as stored expendables. The design of the storage container expulsion method, and heat exchanger will also influence the selection of the coolant.

In Reference 3B-1 (pages 39 through 44), there is a list of possible expendable coolants and their thermal properties. Of the coolants listed,

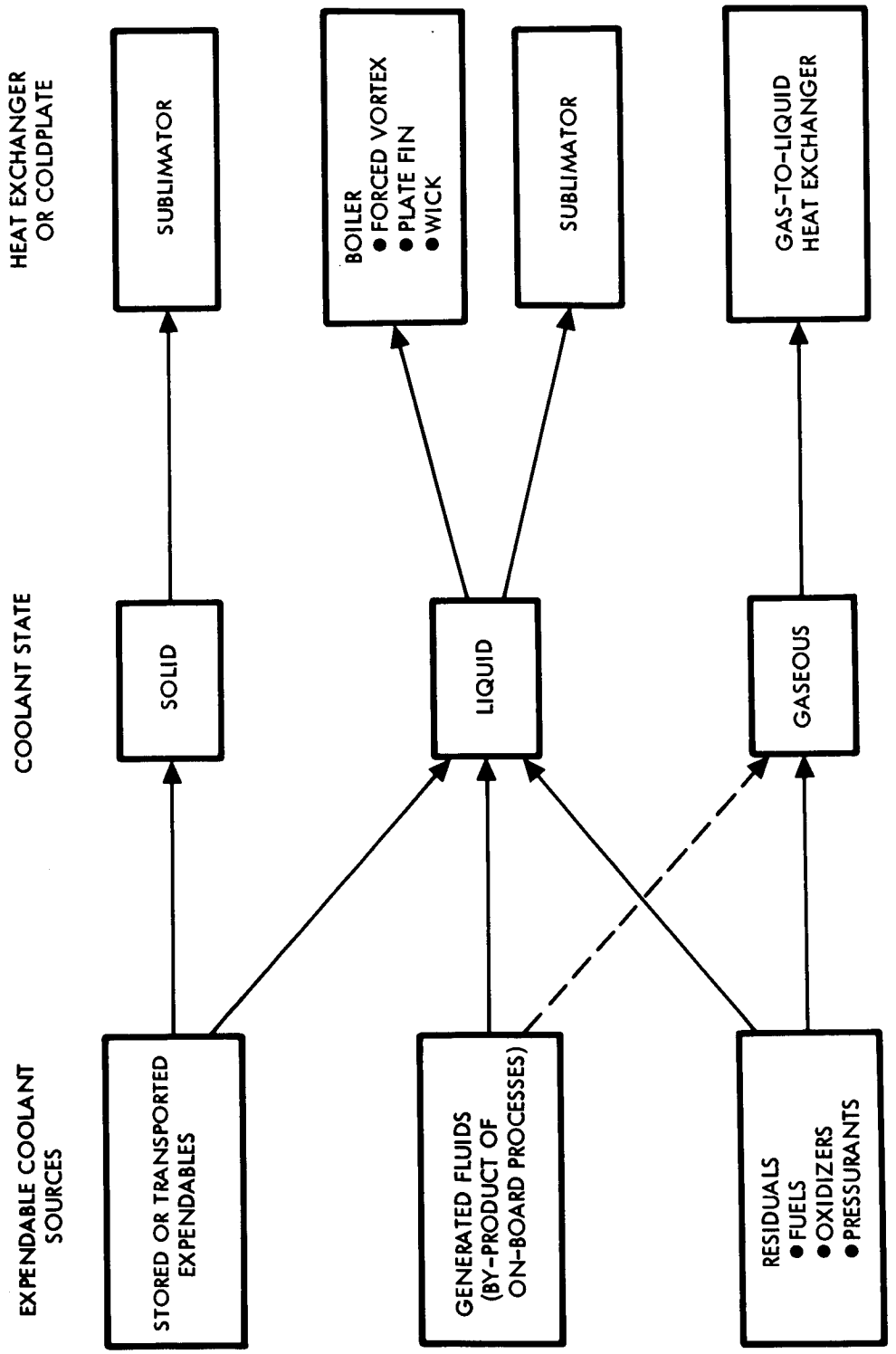


Figure 3B-1. Expendable Cooling Alternatives

only water (h_v = 1000 Btu/lb), ammonia (h_v = 570 Btu/lb), and ammonia-water solutions (h_v = 950 Btu/lb) have sufficient vaporization heat to be considered as liquid transportable expendables. Formic acid (h_v = 560 Btu/lb) and acetimide (h_v = 560 Btu/lb) are subliming solids that can be considered for special applications. Utilization of the evaporating liquids follows existing technology. To date, the handling of subliming solids has been neglected. Though no particular difficulties are expected, some experimental work on the interface between the source and the subliming solid is required to establish the interface temperature drop.

Generated Fluids

Equipment and personnel from other functioning units of a space vehicle may generate fluids useful for cooling. Water with various amounts of contaminants may come from fuel cells, humidity condensers, wash water, and urine. Carbon dioxide may also be produced in appreciable quantities, but the use of it in cooling is not practical.

The utilization of the generated fluid will depend upon a number of factors, including: (1) availability of the fluid (i.e., quantity and quality); (2) design modifications or design compromises of the source, and possible increased complexity; (3) overall reliability; (4) design requirements for the expendable cooling equipment; and (5) advantages over other approaches to cooling.

In general, the utilization of generated fluid should result in weight savings or design simplicity, or the combination of the two, over that of other possible means for achieving the desired temperature control.

Residuals

The use of residual fluids and boiloff from cryogenic tanks as expendable coolants may be practical if sufficient heat sink capacity (heat of vaporization plus temperature rise times capacitance) is available. Also, it will depend on the weight of a residual fluid cooler system to other systems.

Various physical characteristics, such as heat of vaporization and estimates of cooler weights (compared to equivalent water boiler), of residuals are presented in Table 3B-1. An examination of the cooler weight indicates that the weight and size do not change greatly with the residual fluid, because the circulating electronic coolant governs much of the design by available coefficient and wall temperature requirements. These estimates were based on a 60-percent glycol/-40-percent water solution, and could change if a coolant with different properties and freezing temperature were used. The closeness to existing water boiler sizes permits the selection of the most suitable type cooler for each residual.

Table 3B-1. Physical Properties of Residuals

Item	h_v	t_F	t_B	p_B	t_c	p_c	sg	c_p	k	μ	W_c/W_cH_2O
FUELS											
H_2	195	-434	-423	NA	-400	188	NA				0.7
NH_3	596	-107	-28	73.3	270	1636	0.64	1.10	0.200	11	0.7
N_2H_4	540	35	236	0.7	716	2131	1.02	0.73	0.21	82	1.25
MMH	377	-63	189	0.3	609	1195	0.88	0.69	0.146	85	1.4
B_5H_9	219	-54	140	1.6	435	557	0.64	0.53	0.10	25	1.3
50% N_2H_4 50% UDMH	426	18	170	0.65	635	1696	0.91	0.68	0.152	82	1.2
OXIDIZERS											
H_2O_2	596	31	302	0.077	855	3146	1.45	0.63	0.28	100+	1.6
NHO_3	216	-43	181	1.3	549	1240	1.55	0.423	0.20	73	1.4
ClF_3	128	-105	53	11.0	345	838	1.87	0.300	0.137	35	1.2
N_2O_4	178	12	70	7.0	316	1470	1.48	0.352	0.08	34	1.2
ClF_5	73	-153	8.4		289	771	1.9	0.32	0.13	1.3	1.2
NF_3	73	-341	-201	NA	-88	729	NA				0.7
O_2	92	-362	-297	NA	-182	731	NA				0.7
F_2	72	-365	-307	NA	-201	808	NA				0.7
85% HNO_3 15% NO_2	247	-56	148	0.9	520	1286	1.55	0.417	0.172	120	1.3
PRESSURANTS											
N_2	85.8	-345	-320	NA	-232	492	NA				0.7
He	10.5	-456	-452	NA	-450	32	NA				0.7

h_v = heat of vaporization, Btu/lb
t_F = freezing temperature, F
t_B = boiling temperature, F at 14.7 lb/sq in.
p_B = saturation pressure at 40 F, psia
t_c = critical temperature, F
p_c = critical pressure, psia
sg = specific gravity of liquid 40 F
c_p = specific heat of liquid at 40 B, Btu/(lb)(F)
k = thermal conductivity of liquid, Btu/(hr)(sq ft)(F)
μ = viscosity, (lb)(sec)/(sq ft)
W_c/W_cH_2O = estimate of weight of the cooler using this residual divided by the weight of a wick type water boiler cooling circulating fluid to 50 F at the same heat rejection

Fluids with freezing temperatures and vapor pressures approximating those of water probably would be used in a cooler similar to a sublimator. H_2O_2, N_2H_4, and possibly N_2O_4 or 50-50 N_2H_4-UDMH fall within this group. Fluids with lower freezing temperatures, lower vapor pressures and/or heats of vaporization would probably require a plate or wick-type boiler. MMH, B_5H_9, HNO_3, etc., fall within this group. Some improvement in boiling coefficient occurs as the vapor pressure rises. (Plate-type coolers or, possibly, a tubular forced vortex cooler would be superior here.) ClF_3 and ClF_5 fall within this group. When both the vapor pressure and boiling coefficients are high (such as NH_3), a tubular force vortex cooler would be the most practical. The cyrogenic fluids would be utilized in a gas-to-liquid heat exchanger, such as the concentric tube type.

An excellent example of the utilization of residual and boiloff liquid is given in Appendix 3C.

Design Concepts

Figure 3B-2 illustrates three general concepts that use solid or liquid expendable coolants and the general usefulness for each. The selection of the particular concept will depend mainly upon the cooling load and duration. The subliming solid concept has been included, but it may not be feasible for the mission durations considered in this study. The two concepts for liquid expendables indicate the possibility of using either stored or residual liquid, or a combination of the two.

Various heat exchanger designs for the expendable liquid coolant are illustrated in Figure 3B-3. All of them use standard heat transfer surfaces. Studies of evaporating water-glycol heat exchangers during a number of years by several different organizations have resulted in a considerable backlog of information. However, very little information is available on boiling with water that contains dissolved solids. Both the sublimator and wick type boilers, which have received the most attention, have small passageways that could be plugged by the solids in the water. Additional work on evaporating water cooling is being performed under Contract NAS8-11291 by AiResearch Manufacturing Company for NASA-Huntsville.

For design purposes, the following approximate weight equation for a water-glycol evaporative boiler may be used:

$$W_{WB} = 0.0006 + \frac{2}{h_v \, (\rho_v \text{ at } t_s) \, p_c}$$

where

W_{WB} = weight in pounds per Btu/hour heat dissipation

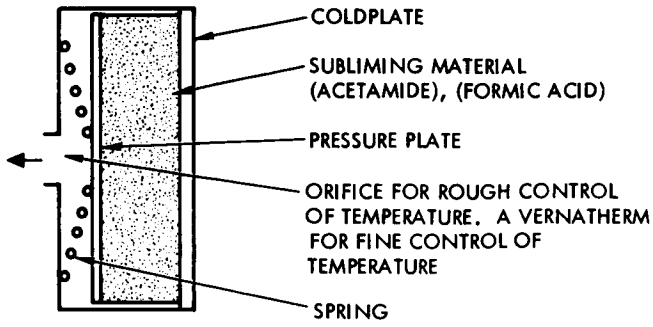
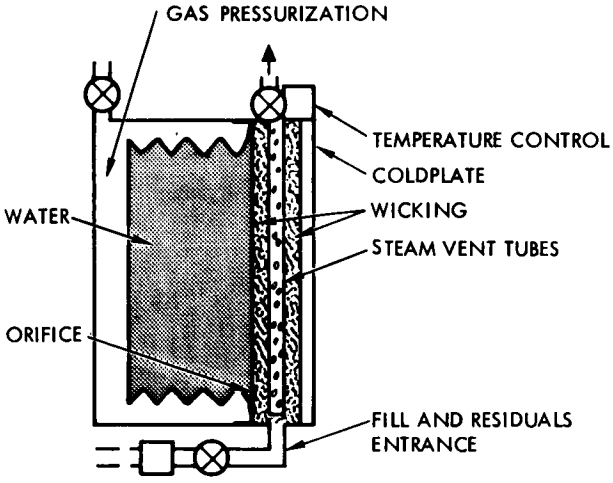
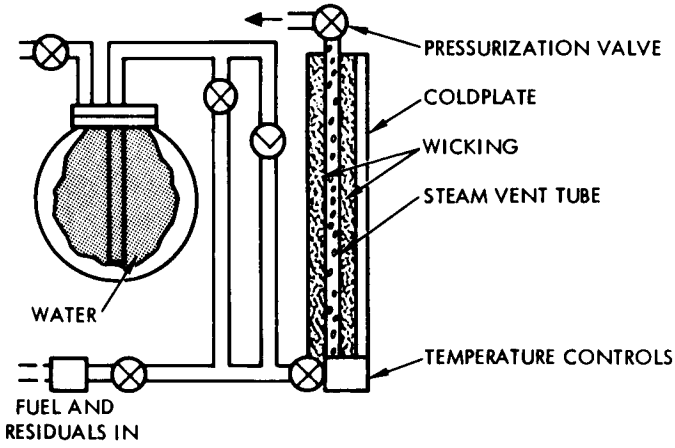
CONCEPT	REGION OF USEFULNESS
 SUBLIMING SOLID	MODERATE TO LOW HEAT DISSIPATION SHORT TIME ROUGH TEMPERATURE CONTROL RESTRICTED TEMPERATURE RANGE PREMIUM FOR EXTREME SIMPLICITY
 CONTAINED EXPENDABLE	MODERATE TO HIGH HEAT DISSIPATION FINE TEMPERATURE CONTROL EXTENDED TEMPERATURE RANGE TESTABILITY REQUIRED
 SEPARATE TANK EXPENDABLE	MODERATE TO HIGH HEAT DISSIPATION TESTABILITY REQUIRED MINIMUM COLDPLATE PACKAGE VOLUME

Figure 3B-2. Expendable Cooling Concepts

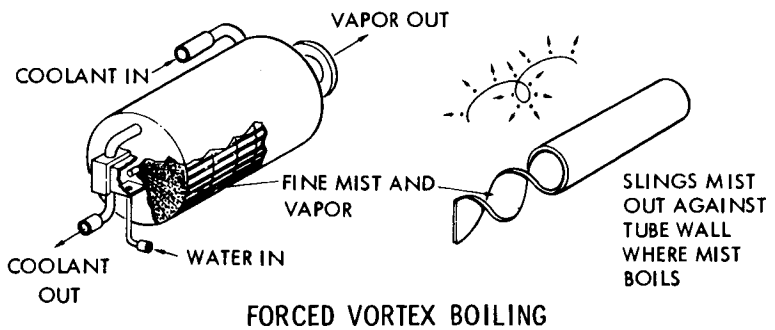
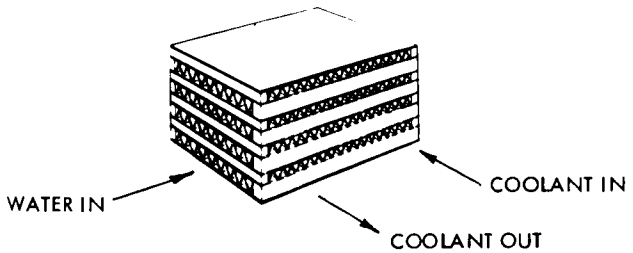
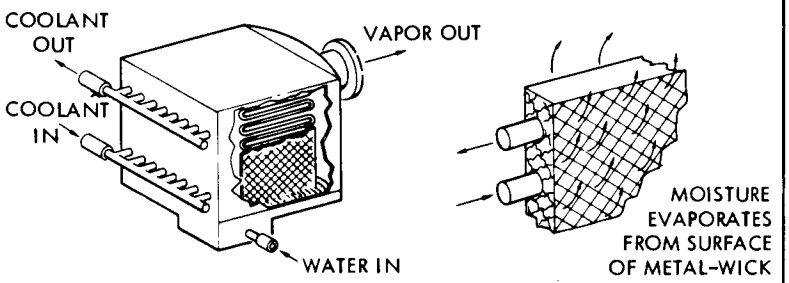
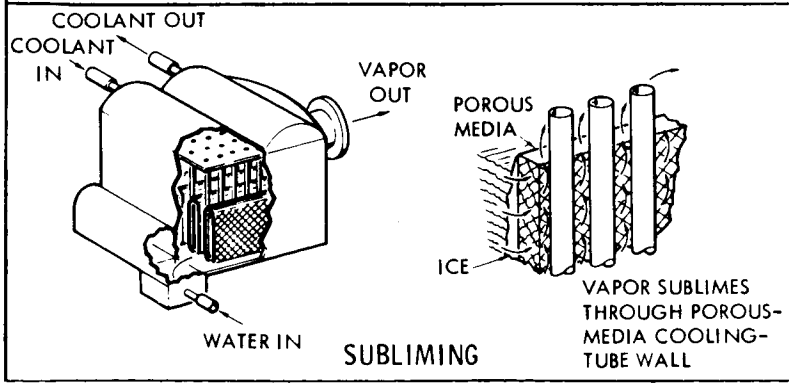
CONCEPT	REGION OF USEFULNESS
 FORCED VORTEX BOILING	HIGH BOILING COEFFICIENTS h_B MIN >100 h_B AVG >300 COOLANT ABOVE 125°F USING WATER COOLANT ABOVE 0°F USING AMMONIA
 PLATE FIN BOILING (ALTERNATE CORE FOR FORCED VORTEX BOILING CONCEPT)	MODERATE BOILING COEFFICIENTS h_B MIN > 30 h_B AVG >100 COOLANT ABOVE 60°F
 WICK BOILING	SAME AS PLATE FIN BOILING CONCEPT
 SUBLIMING	LOW BOILING COEFFICIENTS h_B MIN >50 h_B AVG >150 COOLANT BELOW 70°F USING WATER

Figure 3B-3. Expendable Coolant Equipment - Active Systems

ρ_v at t_s = density, lb/cu ft of the saturated evaporant vapor at the glycol temperature

h_v = heat of vaporization of fluid, Btu/lb

P_c = critical pressure of fluid, lb/sq in. absolute

Reference

3B-1. Bacha, C.P., F.I. Honea, and D. Watanabe. Temperature Control Systems for Space Vehicles. Aeronautical Systems Division, ASD-TDR 62-493, Part I (6 April 1962).

APPENDIX 3C UTILIZATION OF HYDROGEN BOILOFF

The possible proximity of the astrionic equipment to a Saturn upper stage, such as the S-IVB or S-II, suggests the possible use of residual cryogenic boiloff for equipment cooling. The example of hydrogen boiloff utilization is discussed in the following paragraphs.

For a booster stage in space that contains residual hydrogen, heat transferred from solar and other sources causes hydrogen boiloff and an increase in temperature and tank pressure. This process will continue until the tank design pressure is reached, at which point the pressure is controlled by venting hydrogen gas through the tank pressurization valve (curve A of Figure 3C-1). The vent gas flows from the tank at approximately saturation pressure (design tank pressure) and temperature (always less than -400 F). For an estimated initial liquid enthalpy of approximately 120 Btu's per pound, the enthalpy of saturated hydrogen vapor varies from about 306 Btu's per pound at 0.6 atmospheres (and at 8 atmospheres) to about 317 Btu's per pound at 3 atmospheres. Thus, heat removed by evaporation from the liquid hydrogen in the tank varies little with tank pressure (Figure 3C-2). Figure 3C-3 illustrates the case of $H_i = 108$, where H_i is the initial enthalpy of liquid hydrogen.

Based on these estimates for saturated hydrogen gas, approximately 1200 Btu's may be absorbed by one pound of hydrogen for a temperature rise from saturation conditions to 0 F, which indicates very effective heat sink for equipment cooling.

Before the tank design pressure is reached, the hydrogen boiloff may be vented in different ways, as indicated in Figure 3C-1. Curve A of Figure 3C-1 represents the case of no venting until the design pressure is reached and, thus, limits the utilization period. The other three approaches indicate the way in which the boiloff may be utilized, from the point of initial pressure buildup. There may be other uses for the hydrogen boiloff besides equipment cooling that will influence the approach to be used.

The desired approach for hydrogen utilization is the demand basis, as indicated in the following analysis. For a heat load profile such as Figure 3C-4, a hydrogen-fluid cooler designed to handle a uniform base load of 100 watts would reduce the heat load for a space radiator from 2000 to 1900 watts, which requires a radiator area of 130 square feet. If this same

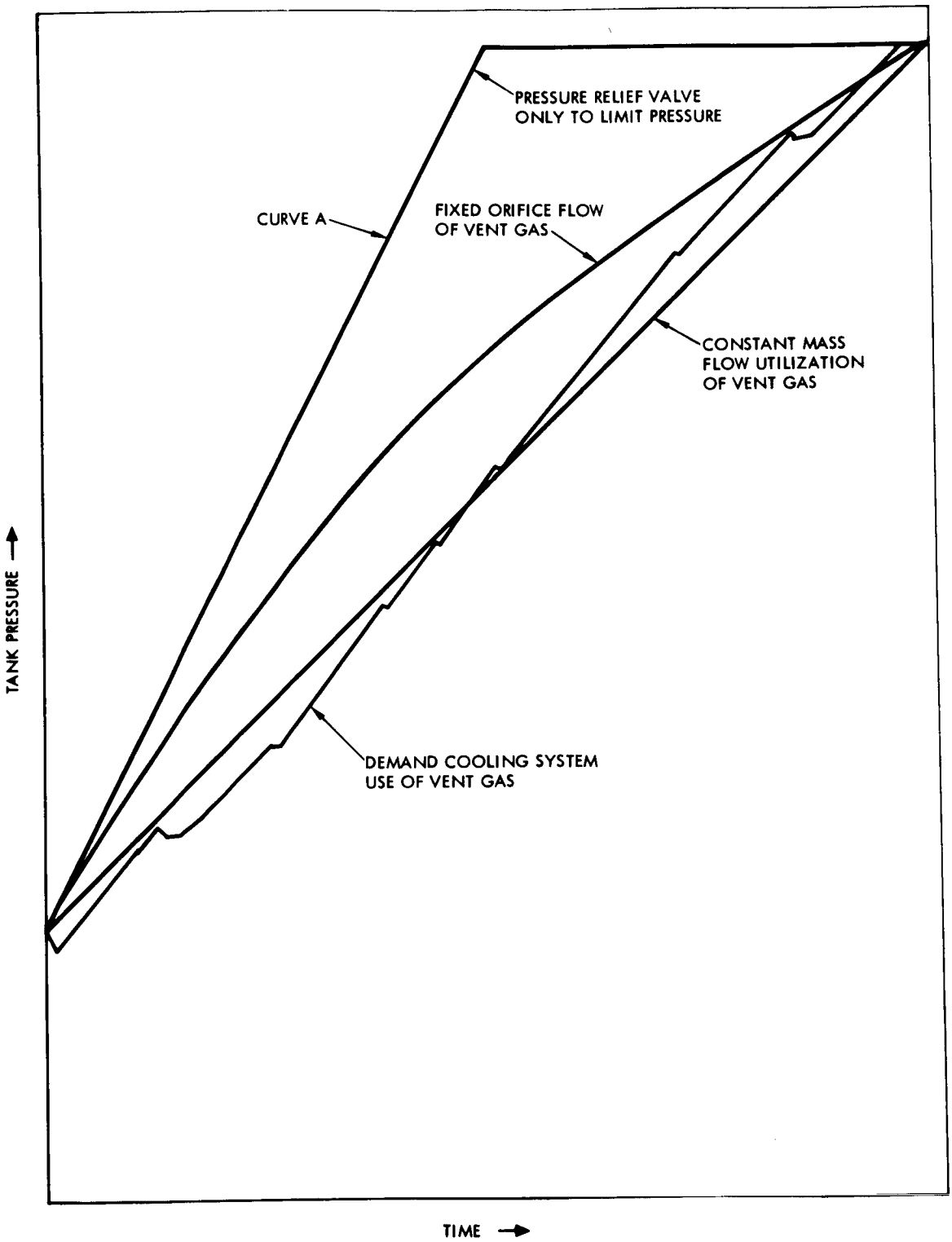


Figure 3C-1. Tank Pressure Versus Time

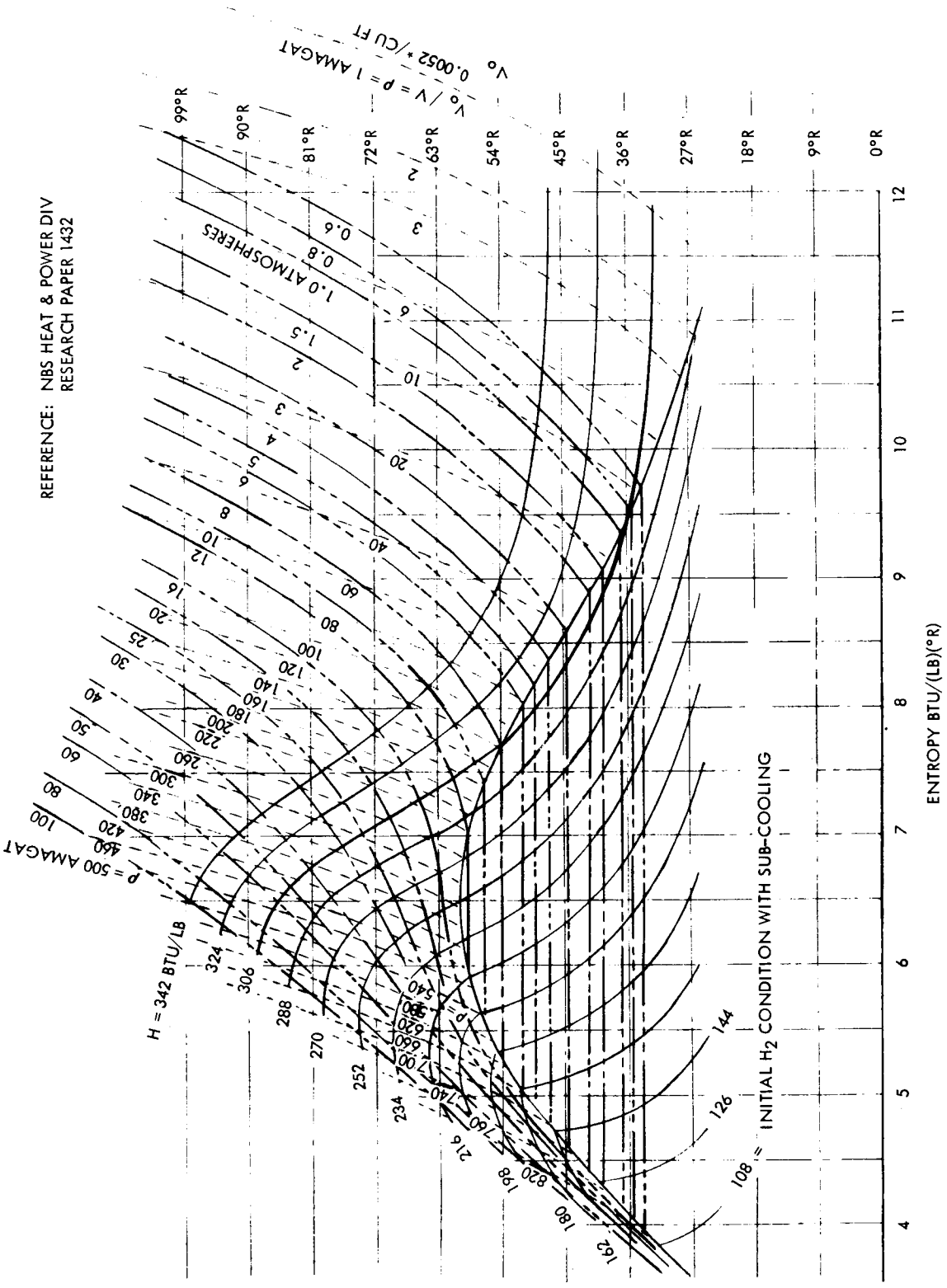


Figure 3C-2. Hydrogen T-S Plot

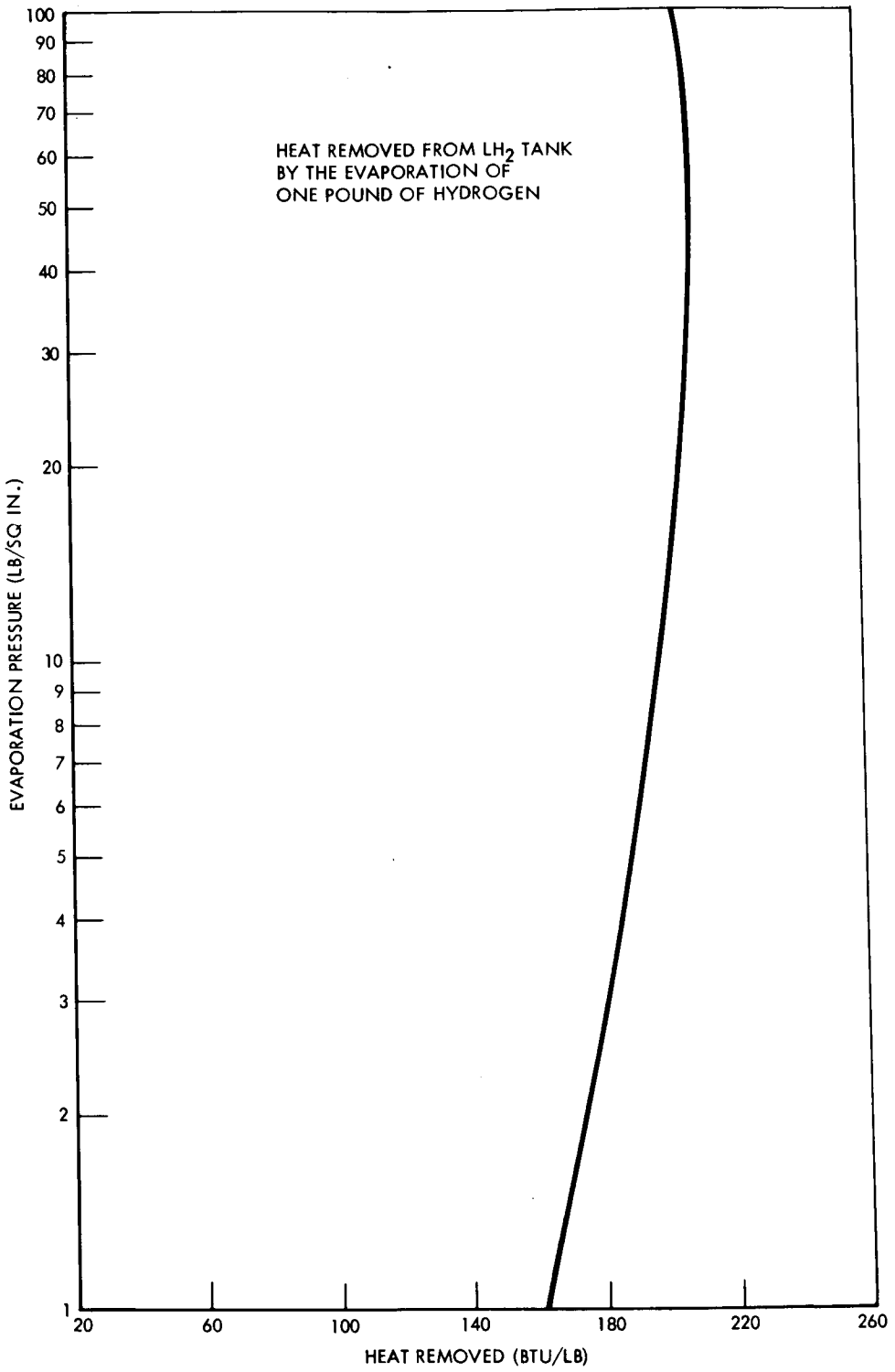


Figure 3C-3. Hydrogen Evaporation Pressure Versus Heat Removed

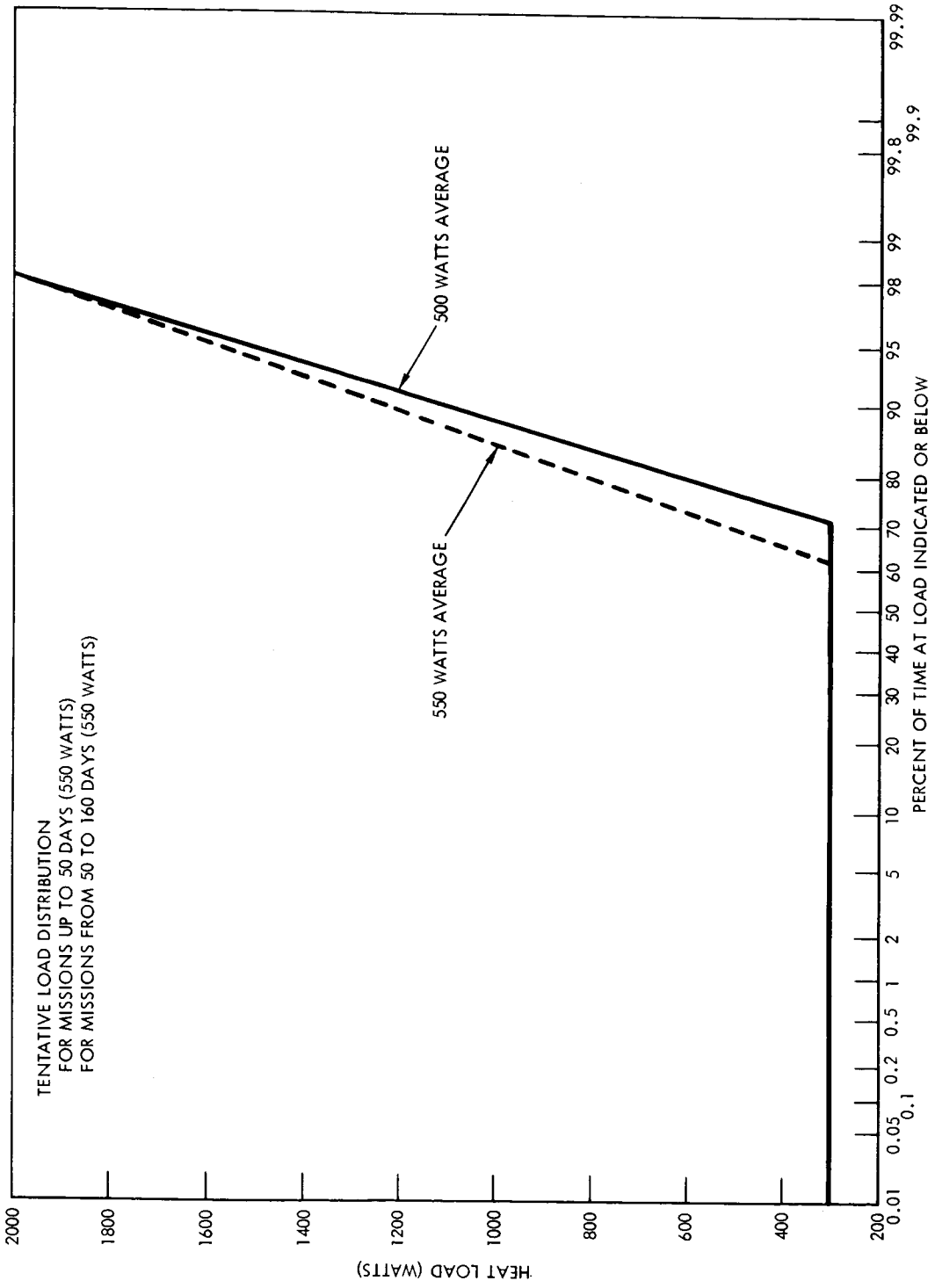


Figure 3C-4. Tentative Load Distribution

amount of hydrogen for cooling were available on a demand basis, half of the peak (or spike) loads could be handled by the hydrogen cooler, thus reducing the radiator (cylindrical normal to sun at one point) heat load requirements to approximately 750 watts and its area to 51 square feet, a sizable reduction. If there is sufficient hydrogen to handle a uniform base load of 200 watts, the radiator heat load would be reduced from 2000 to 1800 watts, which requires a radiator area of 124 square feet. If this same amount of hydrogen for cooling were available on a demand basis, the hydrogen cooler would be able to handle all the peak (or spike) loads and would reduce the radiator heat load to 300 watts and its area to 20.4 square feet, which clearly indicates the desirability of a demand basis for hydrogen utilization.

All systems utilizing hydrogen vent gas on a demand basis to take up part or all of the cooling load of the electronic equipment have potential system advantages over any type of cooling system. For example, the use of the vent gas continuously (though nonuniformly) would reduce the necessary size of the pressure relief valve and vent lines when they are sized by conditions in space. Another example is that the possible demand nature of the system may allow a considerable reduction in radiator area or elimination of radiators, since the peak loads are handled by the hydrogen-glycol cooler. The hydrogen could also supply the pumping power for a liquid coolant circuit.

A cursory examination shows that total venting is more than sufficient to handle cooling requirements. However, it may be necessary to carefully determine total energy dissipation by the electronic equipment. If this energy can be dissipated by the allowable boiloff, only a hydrogen-to-circulating fluid heat exchanger is necessary. This would be the simplest, lightest, and most reliable heat sink for equipment cooling.

In cases in which the hydrogen vent gas cannot meet the total cooling requirement, or a portion of the available gas is diverted for other purposes, the available cooling capacity may be used for peak heat load conditions. This is particularly ideal from the standpoint of using radiators for the sustained loads and the hydrogen circulating fluid cooler for peak loads, because each is utilized under its most suitable conditions.

If, for longer-duration missions, the energy of isentropic expansion of the hydrogen vent gas is also removed from the remaining hydrogen liquid, it will make little difference at what pressure the evaporation takes place (based on a fixed expansion ratio). Thus it is apparent that the time at which the venting takes place will not materially affect the quantity of gas vented. If used in an expander, the vent H_2 gas will be vented at very low pressure, which will severely restrict the use of vent hydrogen gas for cooling. Only low hydrogen pressure drop systems (Figure 3C-5, types 1

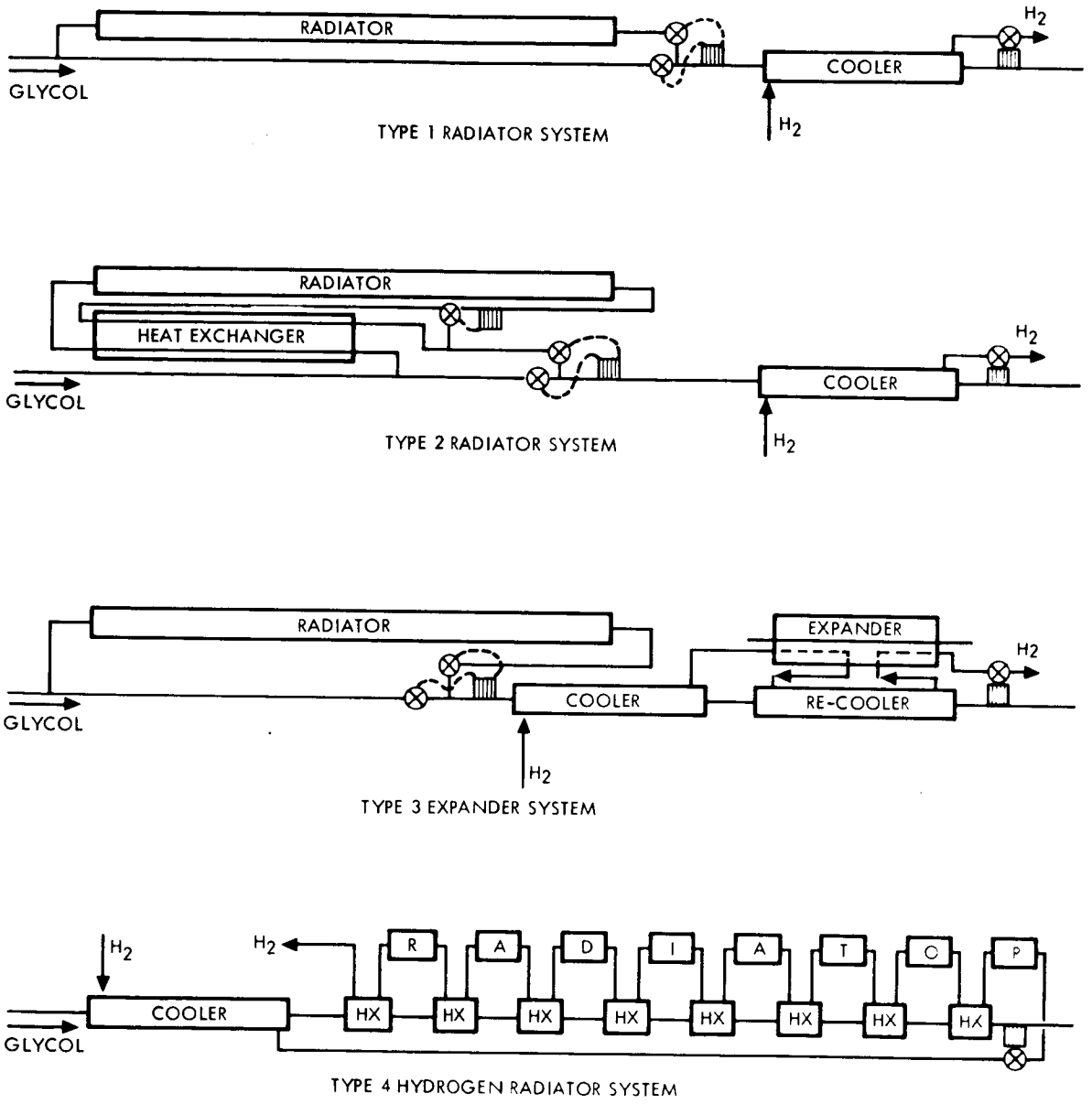


Figure 3C-5. Hydrogen Vent Gas Concepts for Cooling Electronic Equipment

and 2) could be used. An efficient expander whose flow is utilized for cooling on a demand basis would require a long developmental period.

One of the important design considerations for the utilization of hydrogen vent gas is the location of the hydrogen gas-to-liquid cooler in relation to the vent line and the equipment to be cooled. In general, the cooler should be located in close proximity to the vent line to minimize the length of the hydrogen gas duct. It will be simpler to have longer liquid coolant lines from the astrionic equipment to the cooler.

To control the flow of hydrogen, the hydrogen must be tapped off upstream of the vent pressurization valve as shown in Figure 3C-6.

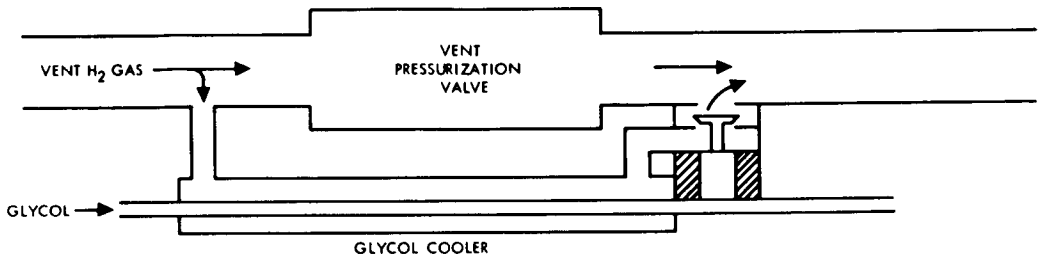


Figure 3C-6. Hydrogen Flow

System Concepts

Four possible combinations of the hydrogen gas-to-liquid cooler and the space radiator are illustrated in Figure 3C-5 and discussed in the following paragraphs.

The Type 1 radiator system is a simple by-pass system for the radiator, which uses a highly reliable wax controls element. For example, when the coolant temperature goes below 19 F, the by-pass around the radiator opens to control the temperature by adjusting flow through the radiator. When the coolant temperature exceeds 21 F at the cooler exit, the demand portion of the system (also a wax controls element) opens sufficiently to reduce the coolant temperature to the desired inlet temperature (20 F). By-passing the coolant around the radiator reduces the flow in the radiator, which, in turn, reduces the radiator exit fluid temperature and radiator cooling capacity. The minimum heat rejection (without other incident heat inputs) will maintain only a certain part of the area above the freezing (or congealing) temperature. As the radiator area increases (when the minimum heat rejection remains constant), the minimum radiator fluid outlet temperature decreases. Thus, the Type 1 system can be used only for missions of a limited number of days, unless some means of augmenting the heat supply at minimum load is provided or a coolant with lower freezing temperature is used. For mission lengths below a fixed number of days, a radiator may not be necessary.

The Type 2 radiator system is a modification of the Type 1 system to allow operation of the radiator at a more uniform temperature. A heat exchanger, which is by-passed until the radiator outlet temperature approaches the freezing temperature of the coolant, reduces the temperature of the coolant into the radiator. Since the outlet temperature is controlled, the inlet temperature can be reduced from possibly 40 F to 0 F, or lower, depending on the effectiveness of the heat exchanger. Since the average radiator temperature is lowered, the heat rejection per area unit is lowered and, for a fixed constant heat load, the area of the radiator that will not reduce the coolant below a fixed temperature is increased. The Type 2 radiator system would be used only for missions whose durations exceed the maximum mission length for Type 1. This system must compete with a Type 1 system using a coolant that will go to a lower freezing temperature (such as alcohol). The radiator temperature for gaseous heat dissipation versus radiator area is shown in Figure 3C-7.

The Type 3 expander system utilizes the hydrogen gas after it has been heated in the cooler and is still at a reasonable pressure. The gas is then allowed to do work that will lower its temperature, and is then passed through a re-cooler to extract additional heat from the circulating fluid. This system can be considered in two areas: (1) where length of mission slightly exceeds the Type 1 system without a radiator, and (2) where a radiator and heat exchanger are needed for the Type 3 system. The expander in this system is in direct competition with the radiator in the Type 1 system. It is doubtful whether the expander with moving parts and greater complexity would be sufficiently lighter to favor selection of the Type 3 system. Where the minimum fluid temperature in the radiator drops below the freezing point for longer-range missions, the expander reduces the required radiator area and permits operation of the radiator without danger of freezing. The expander competes with a heat exchanger in the Type 2 system for solving the freezing problem. The heat exchanger will probably be lighter and less complex. The use of both the heat exchanger and expander would extend the mission length beyond that which either alone could. A vortex tube expander, though very inefficient, does appear attractive when combined with a control valve, although it cannot be used if an expander is used to reduce H_2 boiloff.

In the Type 4 system, the glycol coolant radiator is replaced by a hydrogen gas radiator. The Type 4 hydrogen radiator system requires that the radiator be broken into separate elements, the number of which depends on the hydrogen flow rate and the amount of radiator area. The temperature difference between the hydrogen and circulating coolant fluid causes the radiator to operate at a lower temperature and, thus, reject less heat per area unit. Thus, greater radiator area is required. Since the radiator fluid is an expendable fluid, there is less meteoroid protection required, which helps to compensate for increased weight resulting from

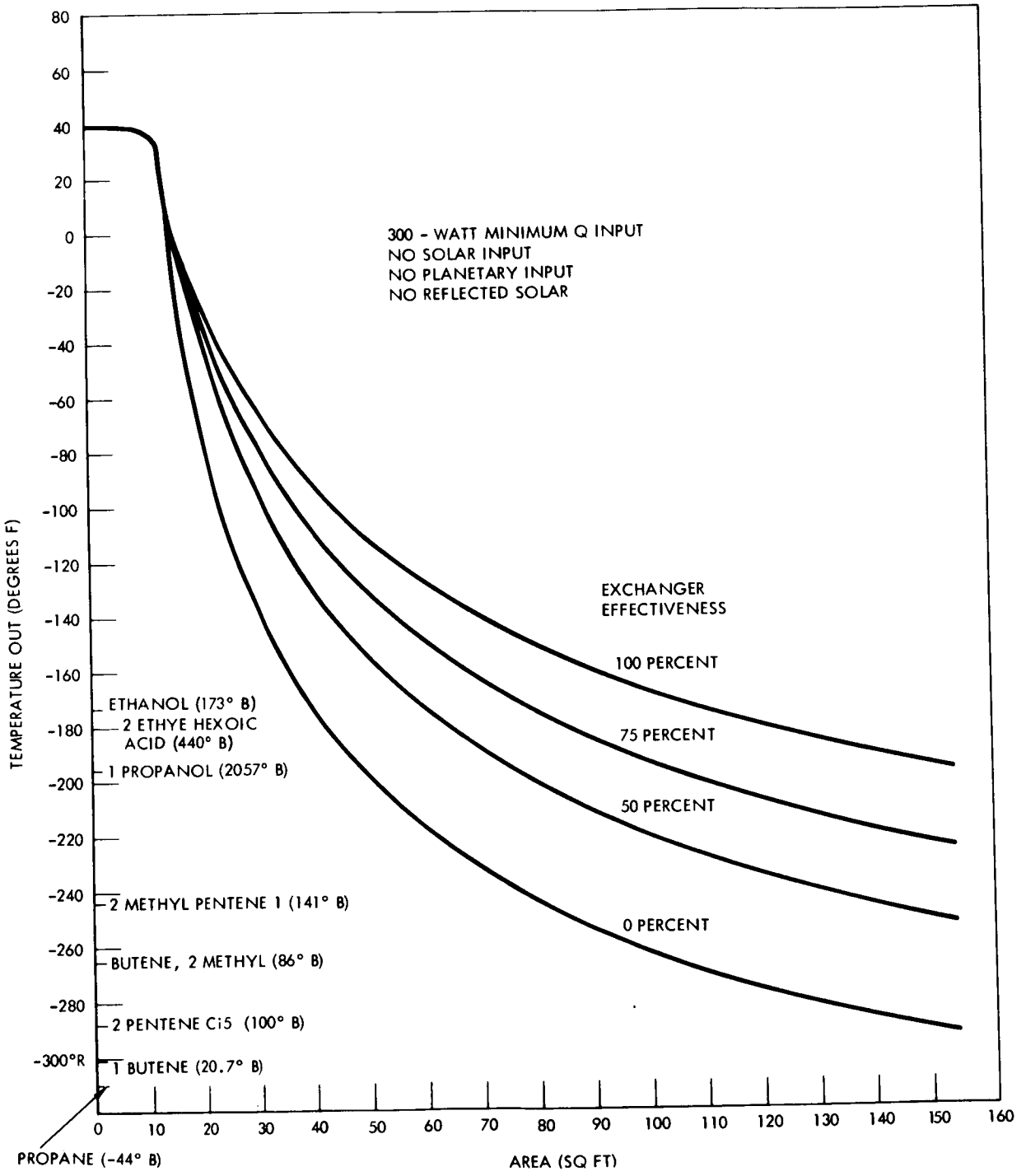


Figure 3C-7. Radiator Minimum Temperature, Type 2 System

the greater required area. The radiator has no freeze-up problems and has the simplest possible controls. It can be used for any mission length, and the heat exchangers very likely can replace existing manifolds. The pressure drop on the hydrogen side because of the series arrangement may cause the fluid passages to be considerably larger than equivalent glycol lines. However, there is no appreciable wet weight.

If the hydrogen circulating fluid cooler is long, relative to its diameter, it may be divided into more than one cooler, thus making it possible to locate the cooler where manifolding would be necessary. This would result in a savings of the wet weight of that portion of the manifolds. The vent hydrogen could be ducted to each of the multiple coolers, with each controlled separately, or first to one and then the other cooler. The latter, with only one control, would be more reliable and have higher coefficients, but it might also have more weight unless the coolers are close together.

It would be desirable to locate the cooler so that it would serve as part of the manifolding. Several possible schematic arrangements are shown in Figure 3C-8.

Two possible methods for utilizing hydrogen in a coldplate directly are illustrated in Figure 3C-9. The numerous problems associated with these methods make them impractical for further consideration.

Design Analysis

With the load distribution shown in Figure 3C-4 and two different average wattage heat dissipations, it was possible to calculate the hydrogen utilization of a circulating fluid cooler, as shown in Figures 3C-10 and 3C-11.

Figures 3C-12, 3C-13, and 3C-14 show the amount of radiator area that is required as a function of mission time and amount of hydrogen boiloff. These figures are based on a permissible or demand utilization of the hydrogen in a cooler with an effectiveness of 0.8 at maximum load.

The hydrogen boiloff permissible for a demand system may be limited by factors other than the heat input to the tank (i.e., total quantity of hydrogen). When utilized in space, the tank may have an available quantity in excess of the estimated boiloff that could become available by allowing utilization to reduce the tank pressure to the triple point and even to some freezing (slushing) of the hydrogen. If the actual boiloff were treated as the total boiloff, the radiator area could be calculated or estimated by interpolation between Figures 3C-12, 3C-13, and 3C-14.

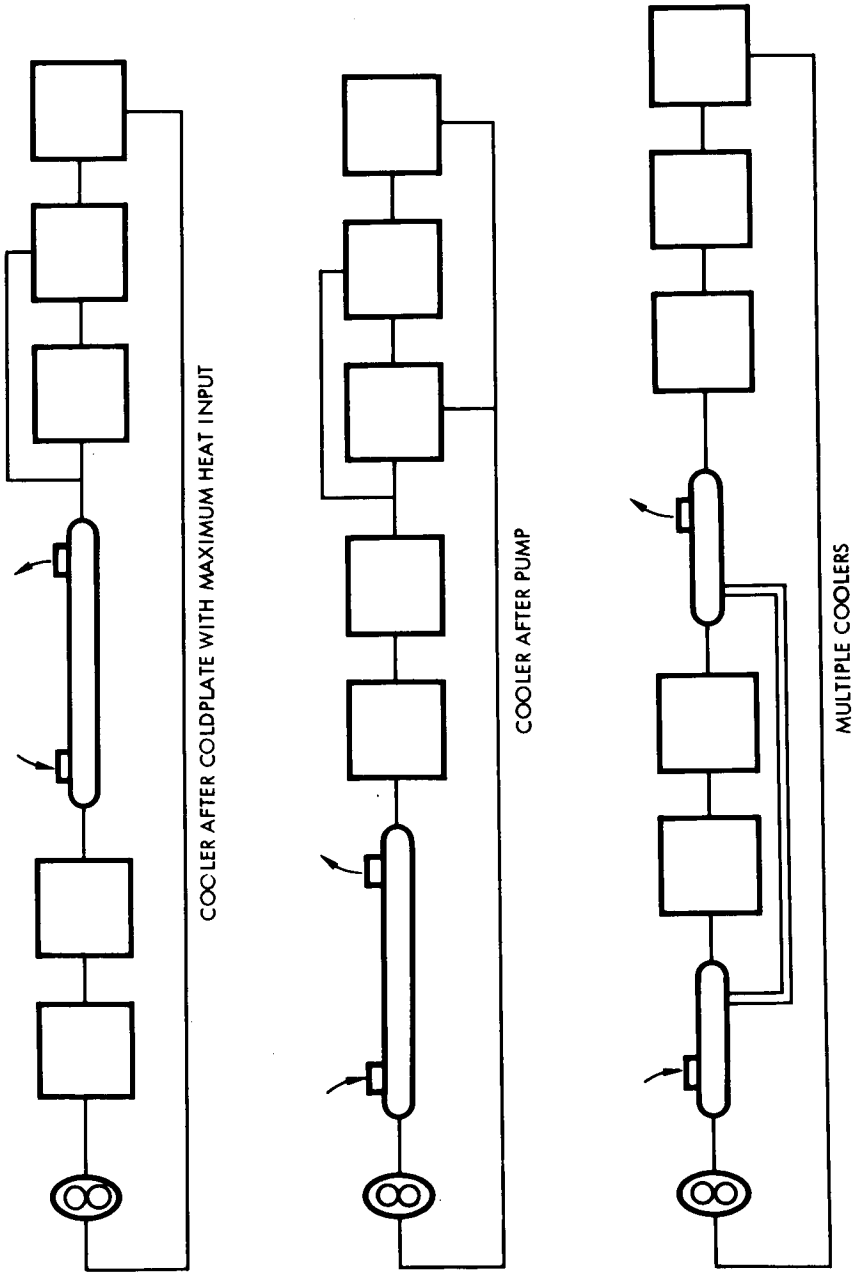


Figure 3C-8. Cooler Schematics

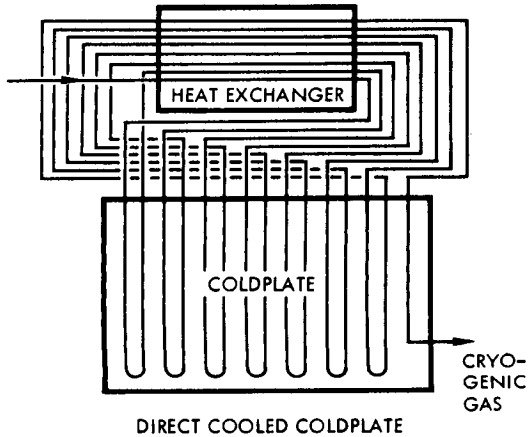
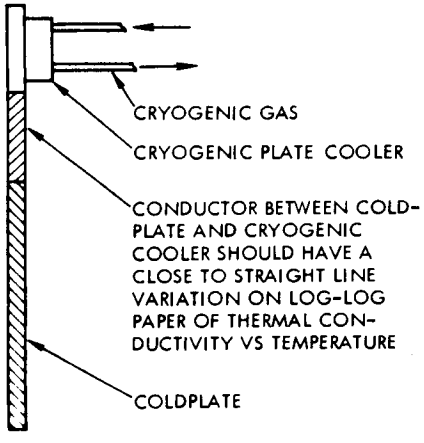
CONCEPT	DESCRIPTION	REGION OF USEFULNESS
 DIRECT COOLED COLDPLATE CRYOGENIC RESIDUAL GAS	THE USE OF CRYOGENIC GAS IN A COLDPLATE DIRECTLY REQUIRES THAT THE GAS BE AS CLOSE TO THE DESIRED COLDPLATE TEMPERATURE AS POSSIBLE. THIS REQUIRES A MULTIPASS HEAT EXCHANGER AND COLDPLATE AS SHOWN. IT CAN BE CONTROLLED.	COLDPLATE WITH BIG PEAK LOADS OF SHORT DURATION COLDPLATE AWAY FROM CIRCULATING COOLING FLUID
 CRYOGENIC EXPENDABLE CONCEPT	CONTROLS CAN BE INCORPORATED TO REGULATE FLOW OF GAS TO CONTROL THE COLDPLATE TEMPERATURE	USE OF CRYOGENIC RESIDUAL PREMIUM FOR EXTREME SIMPLICITY MINIMUM COLDPLATE PACKAGE VOLUME

Figure 3C-9. Concepts for Direct Utilization of Hydrogen in Coldplate

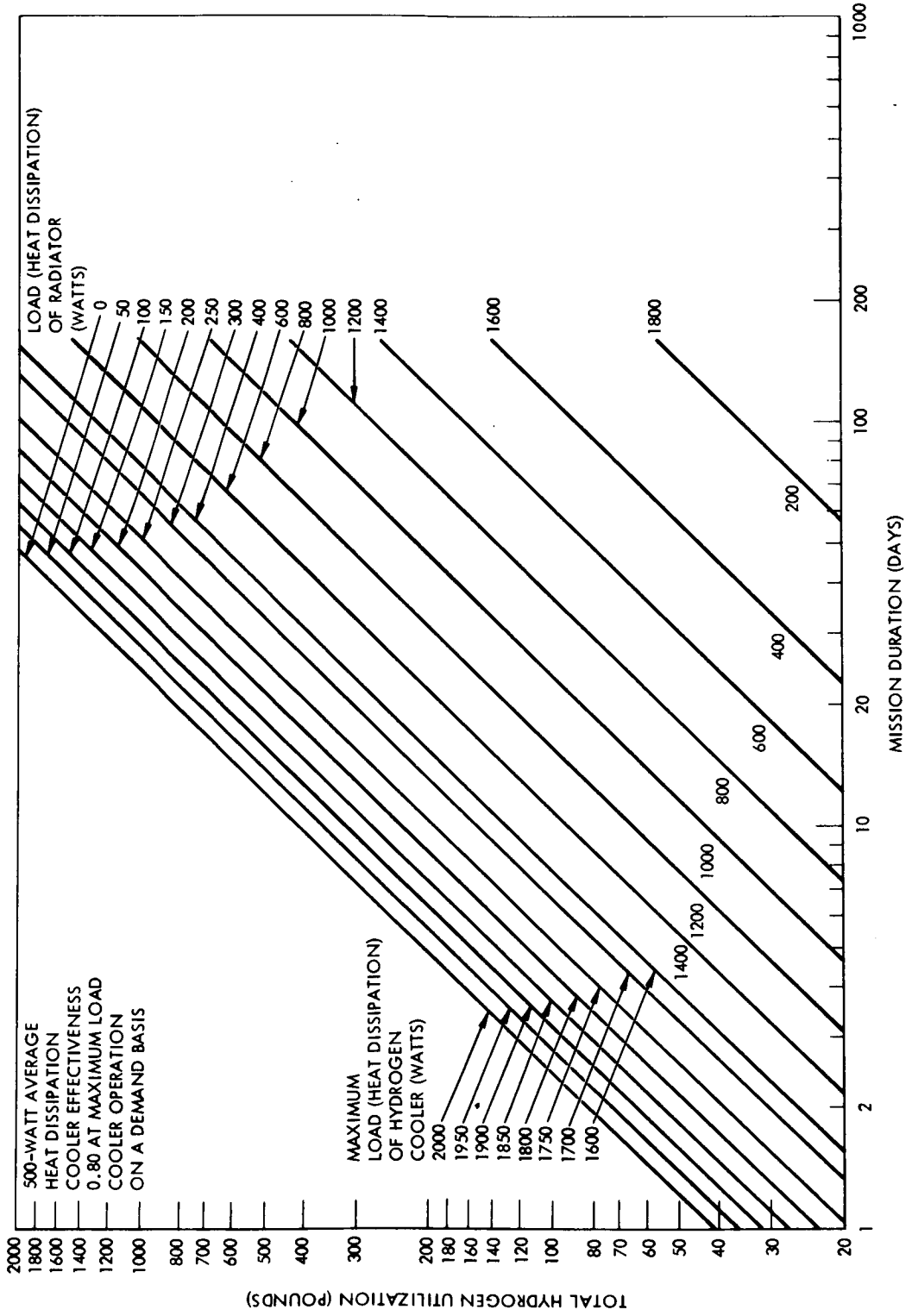


Figure 3C-10. Radiator and Cooler Size as a Function of Hydrogen Utilization, 500-Watt Load

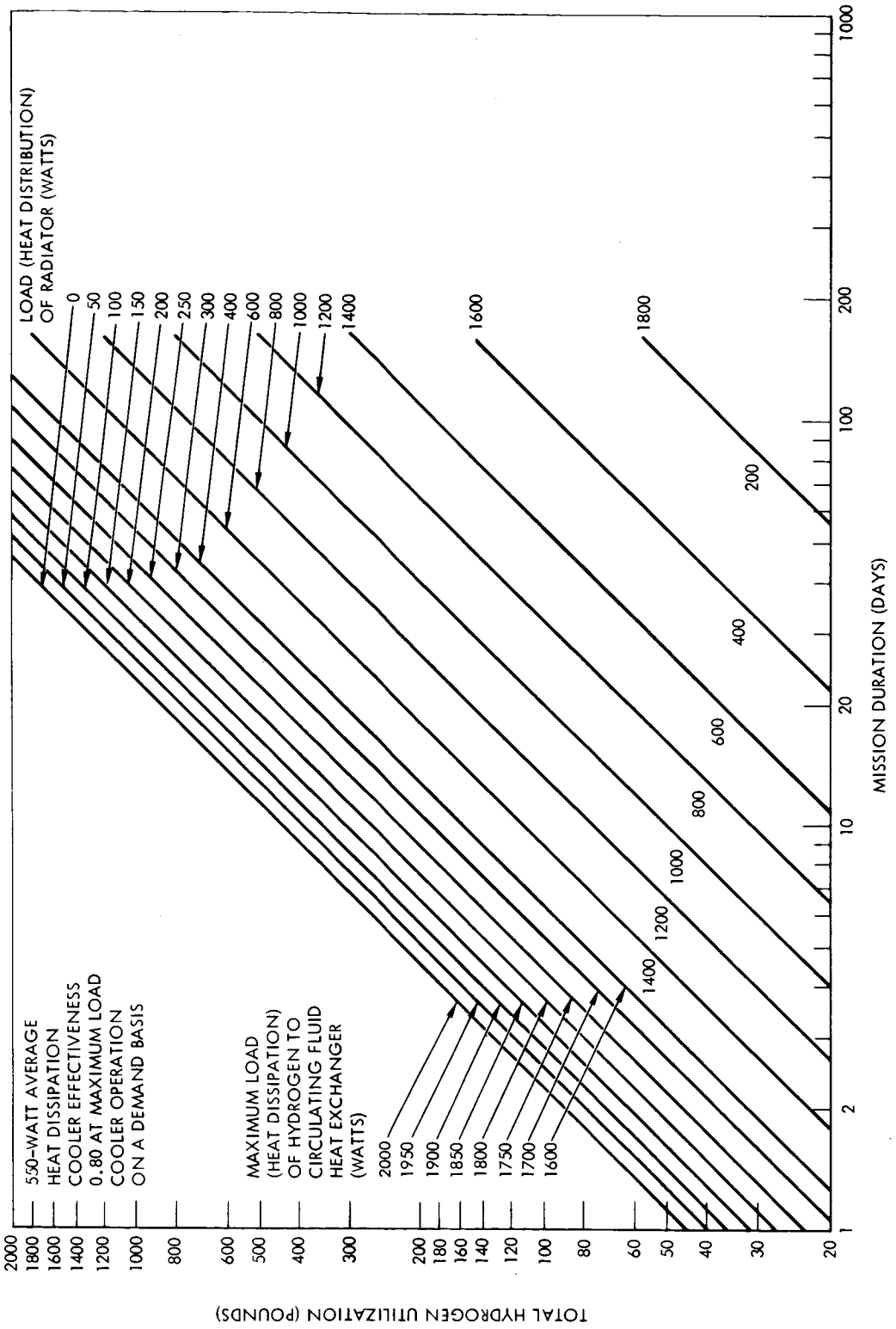


Figure 3C-11. Radiator and Cooler Size as a Function of Hydrogen Utilization, 550-Watt Load

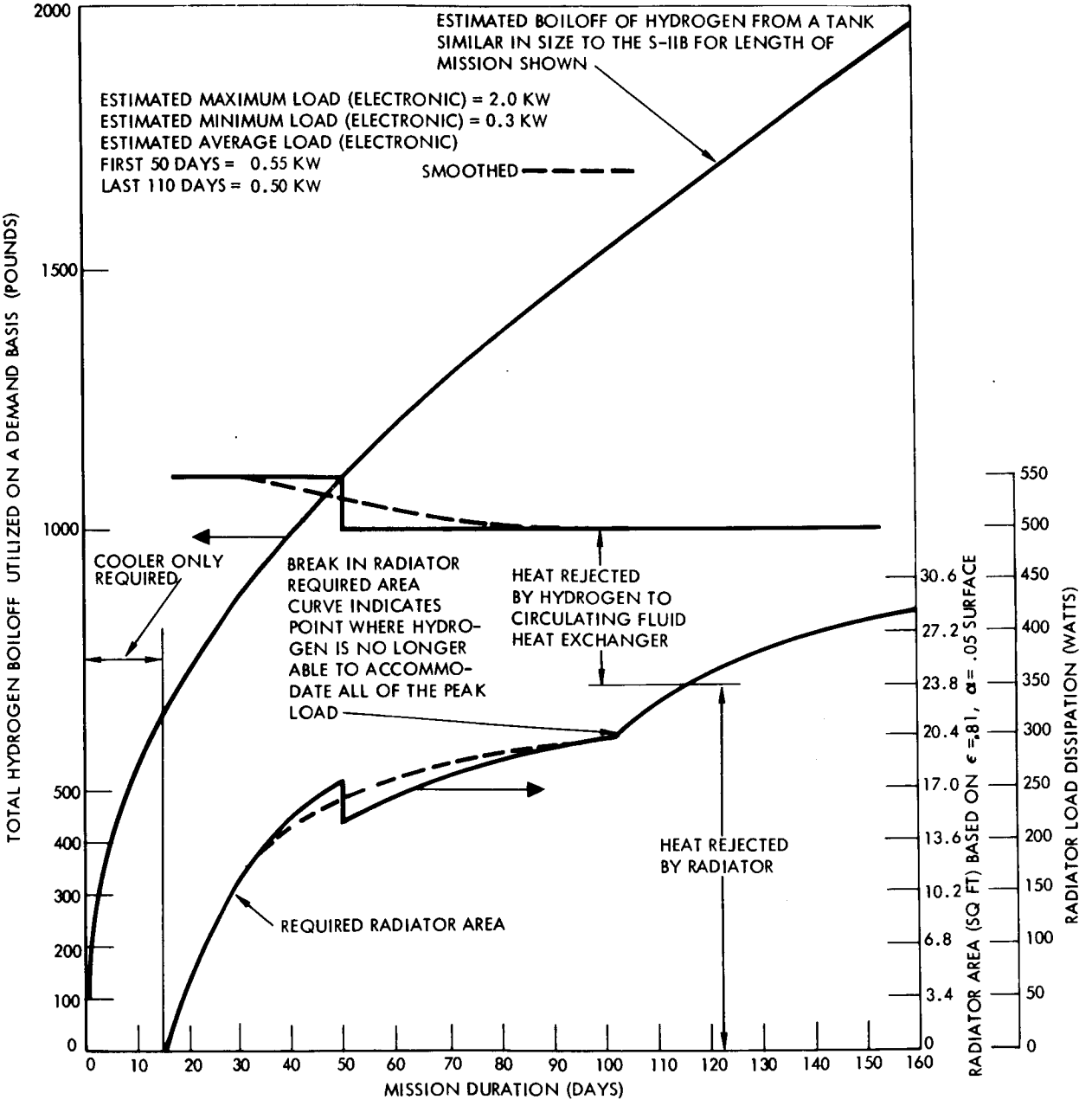


Figure 3C-12. Radiator Area Requirement Versus Mission Duration for Specified Hydrogen Boiloff

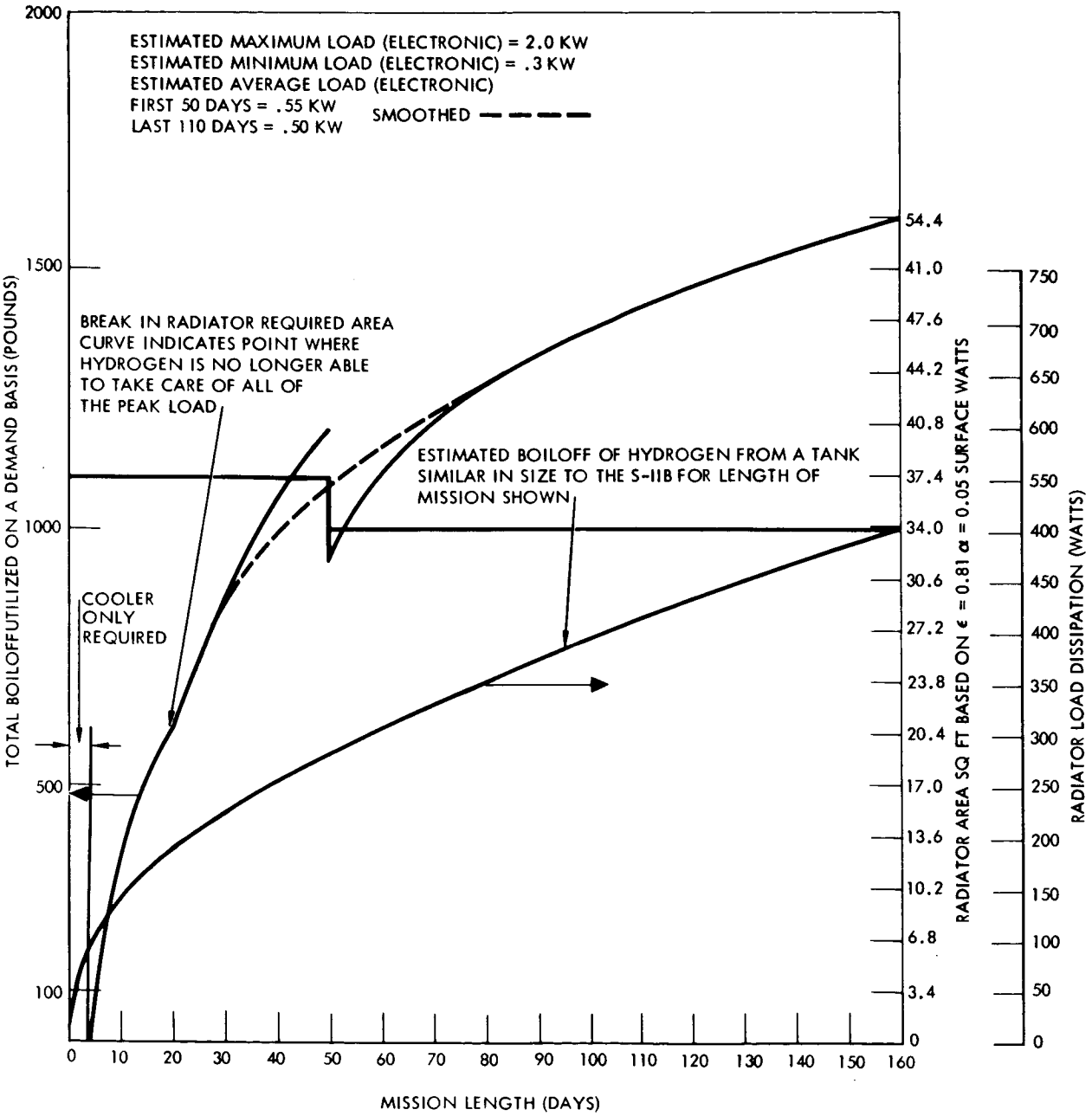


Figure 3C-14. Radiator Area Requirement Versus Mission Duration for Specified Hydrogen Boiloff

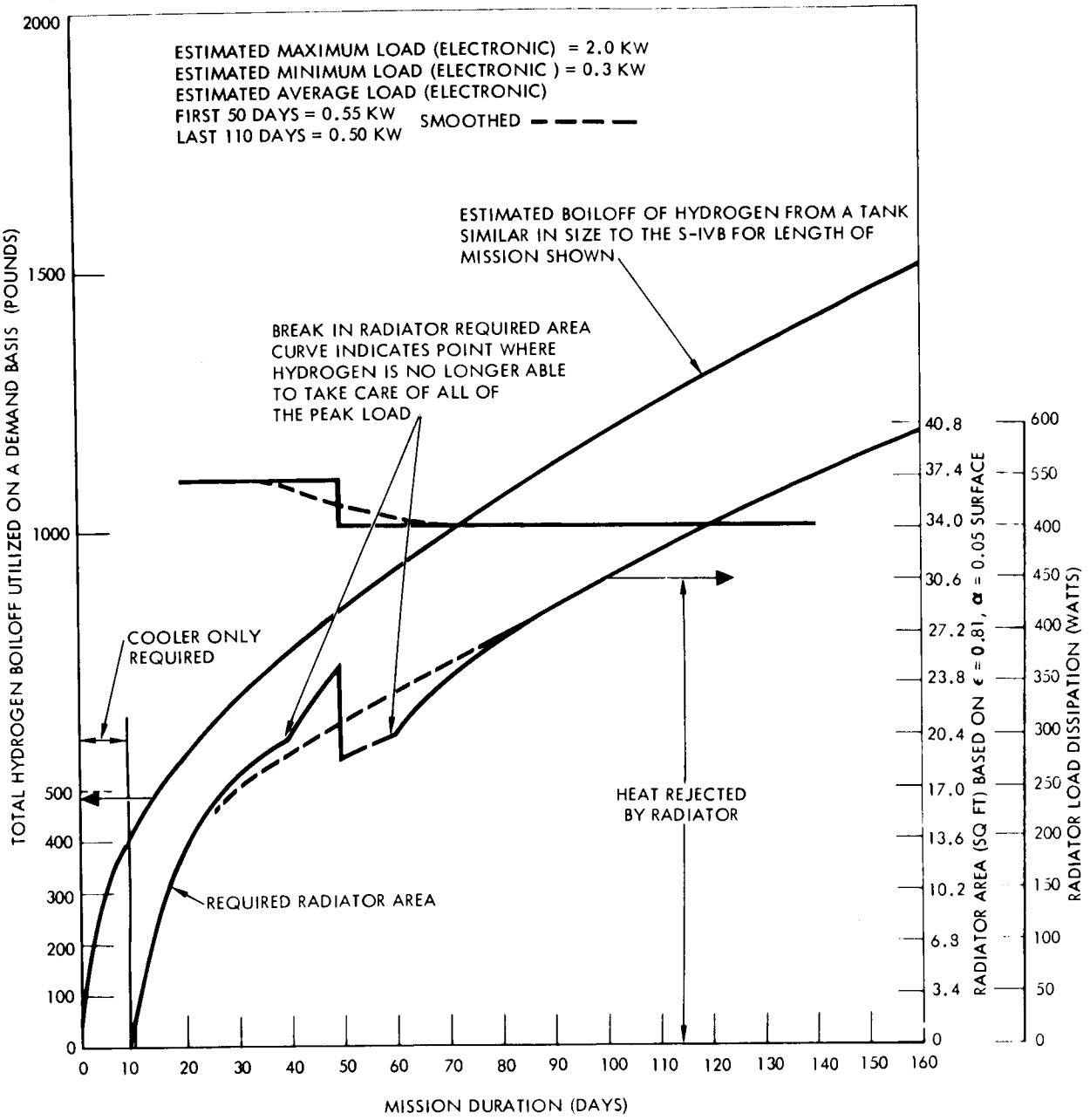


Figure 3C-13. Radiator Area Requirement Versus Mission Duration for Specified Hydrogen Boiloff

4.0 SYSTEM ANALYSIS

Section 3.2 of this report deals with possible modifications to the current, or baseline, thermal conditioning system (TCS). The objective of these modifications is to extend the life of the current system to make it applicable for the entire range of mission durations (4-1/2 hours to 180 days) contemplated for this study. Among the modifications that require the fewest TCS design changes are changes in coolant flow rate, coolant temperature, and solar absorptivity (α_s) of the instrument unit outer shell. A comprehensive thermal analysis was conducted for a number of orbital conditions to determine the effect of such changes on instrument unit (IU) heat load and on component temperatures. The analysis was concerned with establishing coolant temperature limits to satisfy individual component temperature requirements and thermal control methods for maintaining such temperatures. The analysis technique is outlined in the following sections, together with a discussion of the results obtained.

4.1 FLUID TEMPERATURE LIMITS

The tolerable inlet temperature ranges for the methanol-water coolant or other heat transfer fluids (e.g., 1 butene) in the coldplates and in the integrally cooled equipment were established for the equipment presently in the IU. These coolant temperatures were based on both the NASA-specified equipment temperature tolerances and on modified tolerances suggested by North American Aviation. In determining the tolerable temperature ranges, those items of equipment that require special consideration are identified, and the approaches to bring the tolerable range in line with the requirements for the other equipment are discussed.

One aim of the coolant temperature investigation was to establish the maximum tolerable range and the highest permissible temperature. The maximum tolerable range is desirable from the standpoint of simplifying the control, or maintenance, of the coolant temperature within desired values. The upper permissible temperature should be as high as possible to obtain maximum utilization from radiation heat transfer, which is used for the rejection of waste heat to the deep space heat sink. It is considered important to maximize radiation heat transfer to space because of the limited surface area available on the instrument unit for placement of radiators. The variation of required radiator surface area as a function of effective sink

temperature is illustrated in Figure 4-1, in which radiator surface temperature is a parameter. The graph applies to a cooling load of 1.0 kilowatt and a radiator surface emissivity of 0.9. Areas required for cooling loads other than 1.0 kilowatt are directly proportional to the areas shown in Figure 4-1, which was established with the equation

$$Q = (\epsilon)(\sigma)(A_r)(T_R^4 - T_S^4)$$

where

Q = heat load, Btu/hr

ϵ = radiator surface emissivity = 0.9

σ = Stefan-Boltzmann constant, 0.1713×10^{-8} Btu/hr-ft^2-(°R)^4

A_r = radiator area, square feet

T_R = radiator surface temperature, degrees R

T_S = effective sink temperature, degrees R

In this equation, the effective sink temperature accounts for the effect on radiator performance of the absorbed incident heat load due to direct solar radiation, reflected solar radiation, and earth emittance. The effective sink temperature is equal to the radiator surface temperature when the internal heat load (Q) is zero. Figure 4-1 shows that, when the effective sink temperature is relatively high, significant reductions in required radiator areas are possible if high radiator temperatures can be tolerated. When the effective sink temperature is low, indicating that the radiator is subject to little or no incident radiation, the variation in radiator operating temperature is less significant in its influence on required area. The available area of the present IU is approximately 200 square feet. Hence, only 40 square feet per kilowatt is available to dissipate the current IU heat load of approximately 5 kilowatts. With a radiator surface emissivity of 0.9, this capacity can be obtained at an effective sink temperature of 290 R (-170 F) and a radiator surface temperature of 40 F. If the effective sink temperature is as high as 455 R (-5 F), the radiator surface temperature must be 100 F to maintain the same heat rejection capacity.

One means of reducing the total electronic systems heat load to a minimum is to utilize the minimum necessary coolant flow rate. For a given coldplate fluid passage configuration, the circuit pressure drop and, hence, the pump input power requirements are reduced if the flow rate is reduced; and, since the pump power represents a thermal load on the system, lowering the pump power is equivalent to reducing the system heat load.

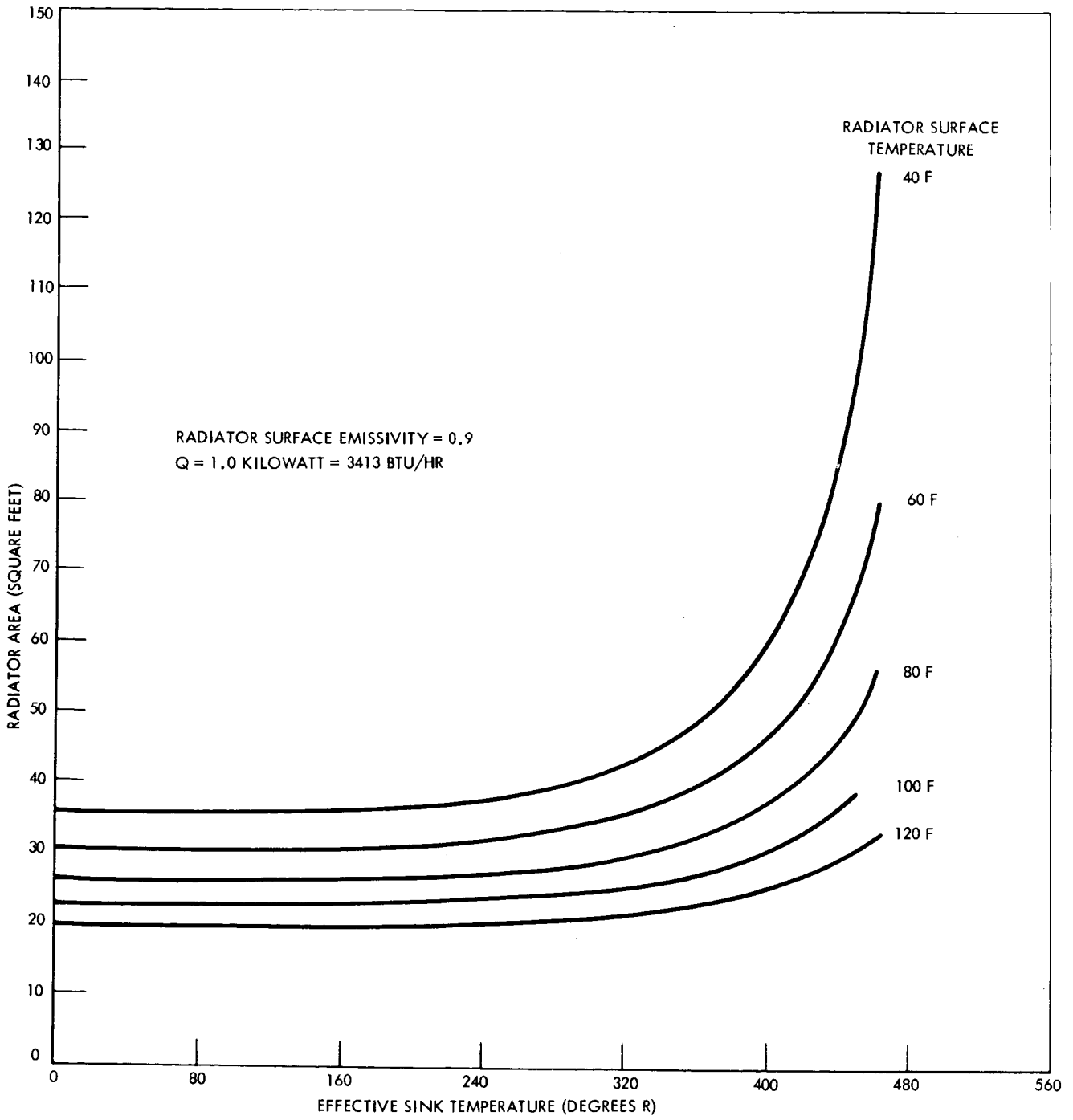


Figure 4-1. Radiator Area Versus Effective Sink Temperature

In determining the tolerable temperature range, the integrally cooled pieces of equipment were treated separately from the coldplate-mounted equipment. For the former, the temperature drop between the equipment and the coolant is relatively easy to establish since there is a direct contact between the coolant and the interface surface. For the latter, the determination of temperature drop is more complicated because of uncertainty concerning the value of joint thermal resistance and because of heat transfer along the coldplate surface, both of which are considered in the following discussion.

Based on current practice in electronic package design, the joint contact resistance was estimated at 0.5 F per watt of heat transfer across the joint. The use of this resistance in the preparation of Figures 4-2 through 4-5 is illustrated by the following example. The heat dissipation of each of the four batteries on the instrument unit is listed as 150 watts, which is transferred to the coldplate through six supports per battery. Therefore, the heat transfer per joint (support) is 150 divided by 6, or 25 watts, and the temperature drop across the joint is 25 watts times 0.5°F/watt, or 12.5 F. Hence, if the maximum permissible battery case temperature is 122 F, the coldplate surface temperature can be a maximum of 122 F minus 12.5 F, or 109.5 F. This condition is represented by the upper portion of the cross-hatched areas in Figures 4-2 through 4-5.

The temperature drop between the coldplate surface and the fluid bulk temperature was determined by using Figures 4A-2 through 4A-5 in Appendix 4A, based on an estimated joint contact diameter. Figures 4A-2 through 4A-5 show temperature drop (degrees F) per unit heat transfer rate (Btu/hr) as functions of coldplate equivalent skin thickness, contact diameter, and equivalent heat transfer coefficient. The heat transfer coefficient is related to the coolant flow rate as shown in Table 4-1. These coolant flow

Table 4-1. Relationship of Heat Transfer Coefficient to Coolant Flow Rate

Coolant Flow Rate (lb/min)	Heat Transfer Coefficient (Btu/hr-°F-ft^2)	
	Methanol-Water	Organic Fluid
1	200	156
2	250	195
4	380	295
6	490	380

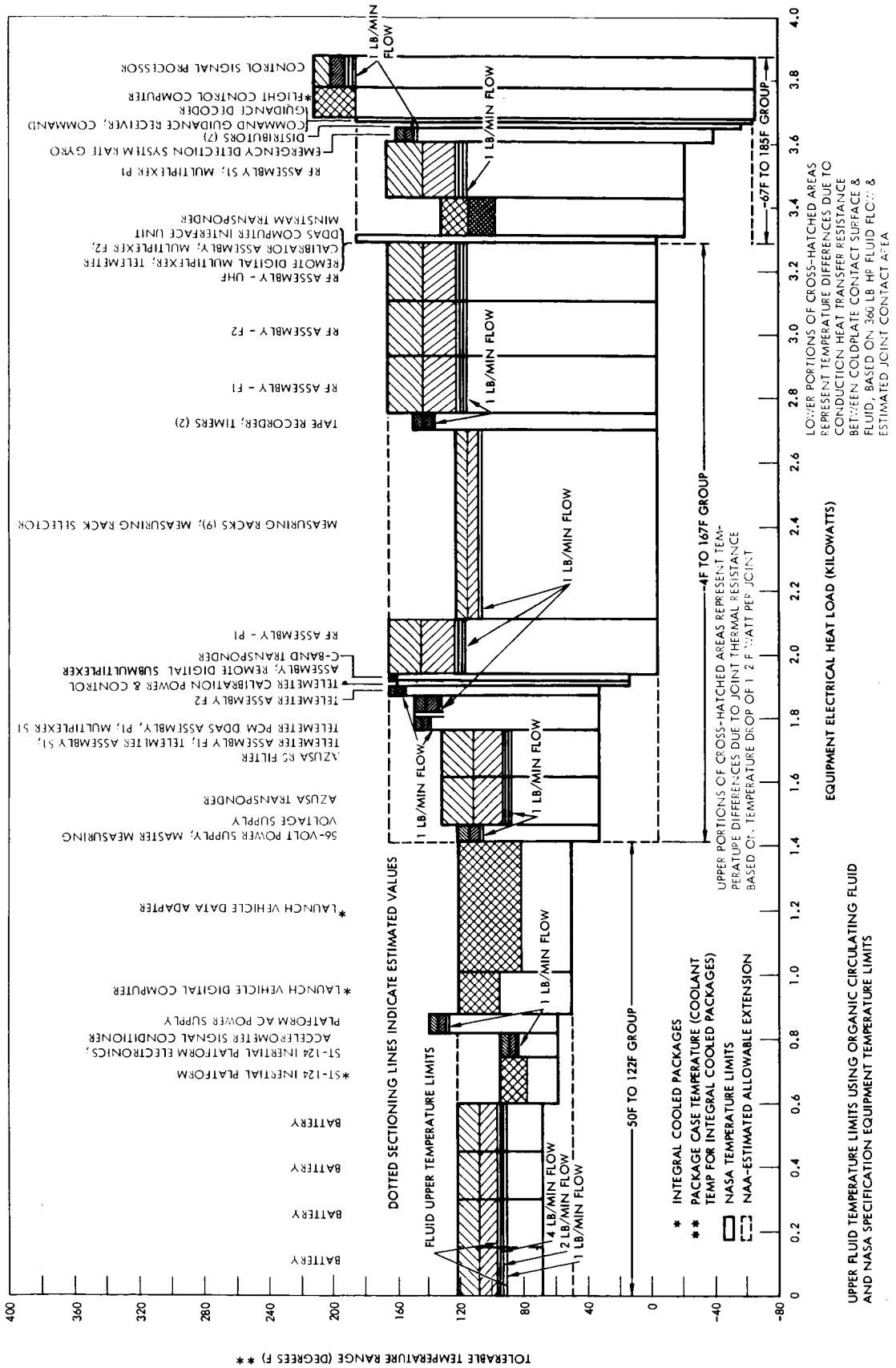
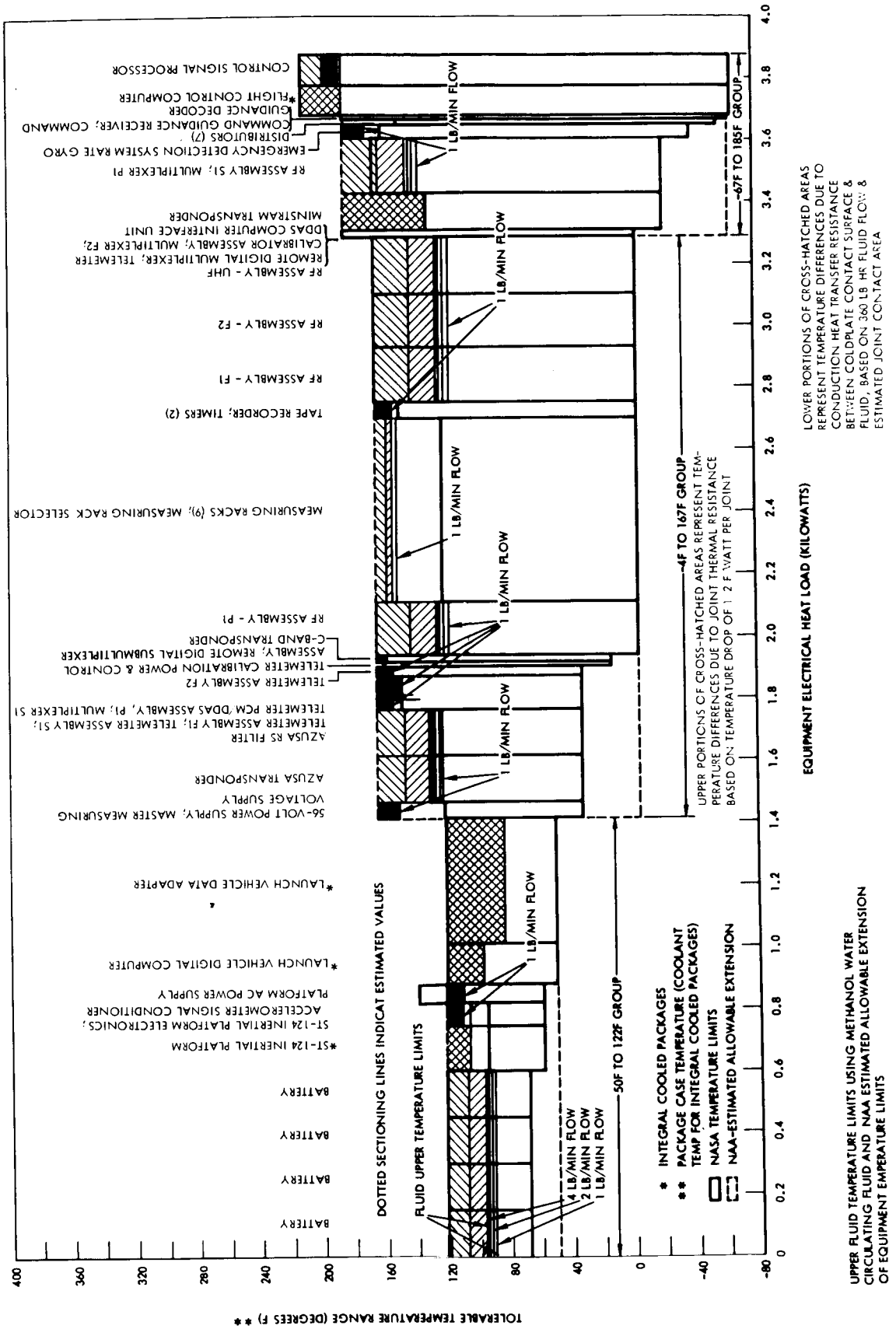


Figure 4-2 . Upper Fluid Temperature Limits, NASA Specification Equipment Temperature Limits



UPPER FLUID TEMPERATURE LIMITS USING METHANOL WATER CIRCULATING FLUID AND NAA ESTIMATED ALLOWABLE EXTENSION OF EQUIPMENT EMPERATURE LIMITS

Figure 4-3. Upper Fluid Temperature Limits, NAA Modified Temperature Limits

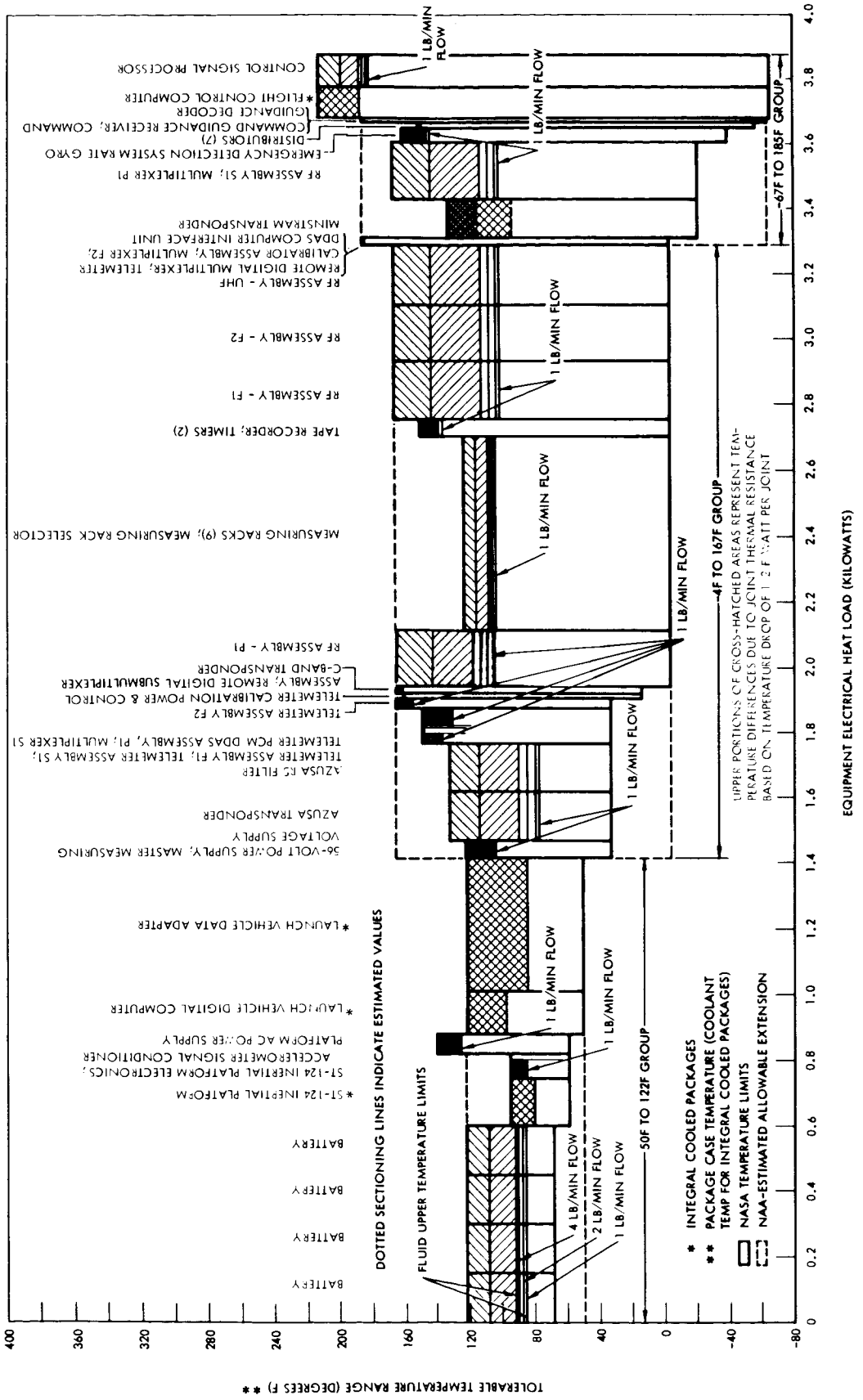


Figure 4-4 • Upper Fluid Temperature Limits, Organic Circulating Fluid

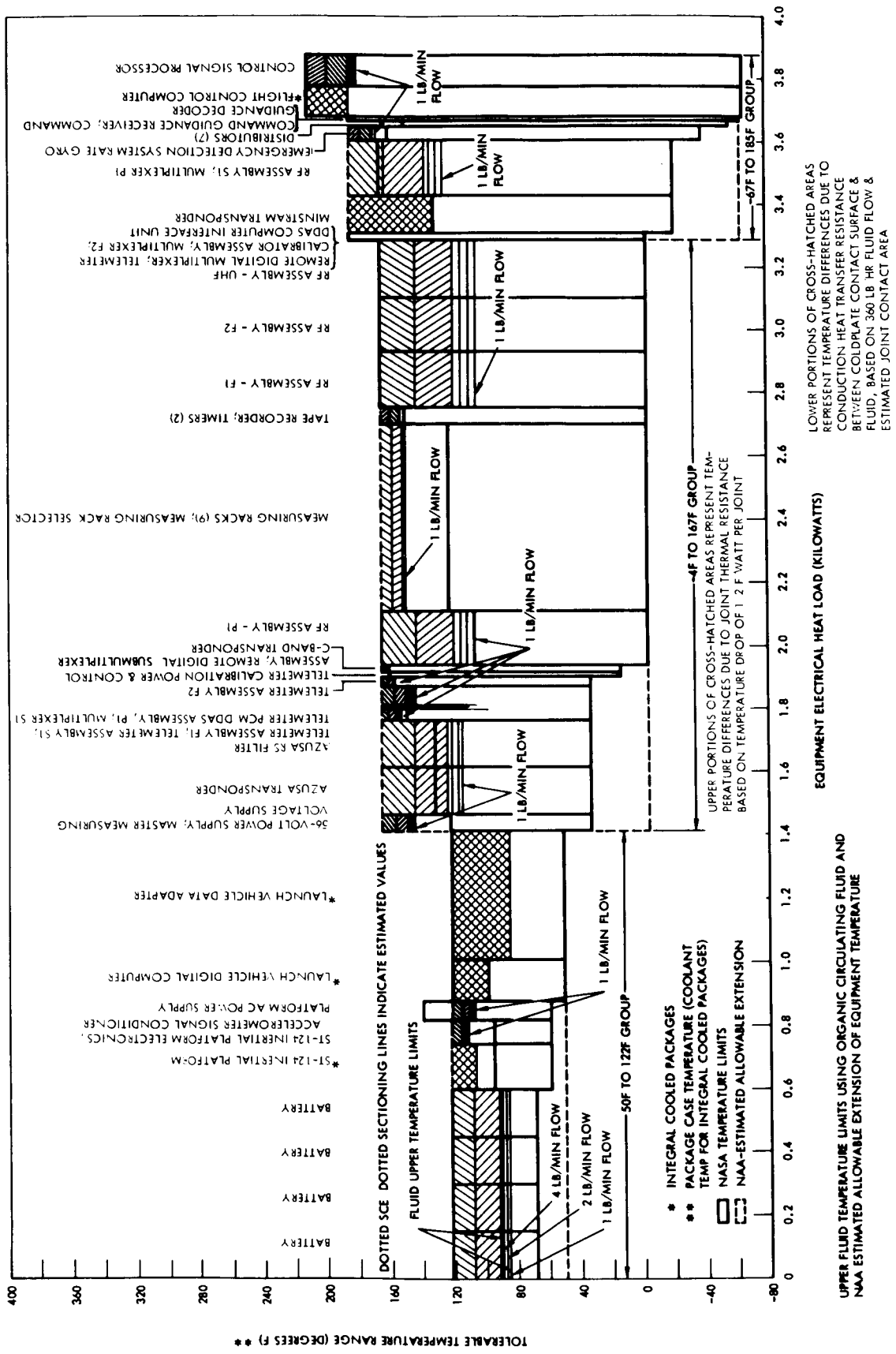


Figure 4-5. Upper Fluid Temperature Limits, Organic Circulating Fluid

rates are applicable to a single coldplate, and the corresponding heat transfer coefficients must be multiplied by the ratio of total coldplate heat transfer area to contact area when values of $\frac{\Delta T}{Q}$ are to be read from Figures 4A-2 through 4A-5. For example, the coldplate configuration on the present IU represents an area ratio of approximately 3 to 1, which takes into account the top and bottom plates that bound the fluid passage, as well as the heat transfer area represented by the fins between the plates. Assuming a methanol-water flow rate of six pounds per minute, the equivalent heat transfer coefficient per unit contact area is 3 times 490, or 1470 Btu/hr-°F-ft^2. The equivalent skin thickness (δ) for the coldplate is 0.10 inch. By extrapolating the line representing δ = 0.10 inch in Figure 4A-2, the calculated $\frac{\Delta T}{Q}$ corresponding to this thickness and heat transfer coefficient is read as 0.115 F per Btu per hour for a 0.725-inch mounting pad diameter. Applying this value of $\frac{\Delta T}{Q}$ to the RF assembly P1, which transfers 150 Btu's per hour through each mounting pad, a joint-to-fluid temperature drop of 0.115 times 150, or 17.2 F is obtained. This temperature drop is represented by the lower portion of the cross-hatched areas in Figures 4-2 through 4-5, which also show temperature drops corresponding to fluid flow rates of 4, 2, and 1 pound per minute.

Figure 4-2 shows the maximum permissible temperature of the heat transfer fluid, based on the equipment temperature limits of NASA drawings number A50 M04001 and A50 M123434. As indicated previously, the lower boundaries of the cross-hatched areas in Figure 4-2 represent this temperature for each item of electronic equipment on the basis of a cooling fluid flow rate of 6 pounds per minute per coldplate (the maximum design value). Other limits shown correspond to coolant flow rates of 4, 2, and 1 pound per minute per coldplate, respectively. The data show that, from the standpoint of cooling fluid temperature, the most critical piece of equipment is the ST-124M inertial platform assembly, which is estimated to require a maximum coolant temperature of 80 F, based on the fact that the mass temperature of the platform stabilizes at approximately 108 F when a water-methanol coolant at 60 F is used. Assuming that a temperature of 108 F does not represent the upper limit for this equipment, a coolant temperature in excess of 60 F would appear permissible.

The influence of variation in coolant flow rate on maximum permissible fluid temperature is also shown in Figure 4-2. In nearly all cases, the variations in permissible fluid temperature due to flow rate variations are relatively small. Thus, a flow rate of 1 pound per minute per coldplate, or even less, may be suitable for most of the equipment, which suggests a possible grouping of the equipment on the basis of fluid flow rate, in addition to the grouping indicated previously.

Two approaches to raising the maximum permissible fluid temperature are design modification of the equipment and reduction of joint thermal resistance. The former would produce the expected result by either reducing the required heat transfer rate for each support or permitting a higher equipment operating temperature. For the RF assembly P1, significantly higher fluid temperatures are permissible if joint thermal resistance is reduced. If the estimated value of 0.5 F per watt for the joint contact resistance were reduced to 0.25 F per watt, the temperature drop would decrease from 22 F to 11 F in the case of this assembly. However, an increase in joint contact resistance to 1.0 F per watt would result in a temperature drop of 44 F. These numbers suggest the desirability of reducing the joint thermal resistance by appropriate surface treatment so as to permit the coolant temperature to increase.

Several methods exist for reducing the thermal contact resistance in bolted joints. One method consists of using soft, metallic shims or washers. Under pressure produced by a tightening of the bolts, the washers fill up all the crevices in the mating surfaces, thus creating a solid joint of material with good thermal conductivity characteristics. Lead, indium, and dead soft aluminum have been used for washer material; none of these materials is expected to cause any difficulty through evaporation in a vacuum environment. However, the vapor pressure of lead is high enough that the possibility of some lead evaporation may need to be considered for long-duration space missions. If the gaskets or shims of material are very soft, the bolt is normally tightened until all the soft material (except that in the crevices) is extruded out of the joint. This procedure requires a number of tightenings.

Another method for reducing thermal contact resistance is to apply a high-conductivity grease or liquid to mating joint surfaces. This grease or liquid replaces the thin layer of condensed vapors that normally exists on surfaces exposed to the atmosphere and that aids thermal conductance across joints. One requirement for the substitute materials is that they not sublime or evaporate under conditions of a space vacuum. Vacuum grease meets this requirement, and certain solids and liquids have vapor pressures low enough that normally very little material will be lost in a hard vacuum. Tri-cresyl-phosphate is among the suitable substances, some of which contain high thermal conductivity fillers to improve heat transfer still further. A better, but more expensive, technique involves the use of a metal between mating surfaces that is easily liquefied. The properties of gallium make it an excellent candidate for this purpose, but the ease with which gallium alloys with other materials represents a detriment to its use.

In addition to the ST-124M inertial platform assembly, other pieces of equipment, including the ST-124 electronic assembly, accelerometer signal conditioner, launch vehicle data computer, launch vehicle data adapter, Azusa RF filter, Azusa transponder, and batteries, will influence the selection

of the upper permissible coolant temperature and flow rate. With increased mission time, for example, the number of batteries could increase and have a proportionally lower average output. Consequently, the internal power dissipation (I^2R) would decrease, resulting in a smaller temperature difference between the battery case and the circulating coolant. This temperature difference is inversely proportional to the square of the number of batteries. Thus, for increased mission time, the coolant temperature tolerance for batteries may be less restrictive than shown. A further consideration is the temperature rise of the cooling fluid as it passes through the coldplate. This rise is determined by the heat dissipation rate of the equipment mounted on the individual coldplate.

On the basis of this discussion, an upper permissible temperature limit of 80 F and a flow rate of 1 pound per minute, or possibly less, appear feasible for the present equipment. A more detailed analysis of the contact resistance and internally cooled equipment could result in further reductions in fluid flow and increases in maximum fluid temperature. Only the critical pieces of equipment need to be examined. Of these, only equipment that gives off a considerable amount of heat will be significantly affected by contact resistance, which is a function of size, force, and surface finish.

Figure 4-3 is similar to Figure 4-2, except that the coolant temperature limits have been modified in accordance with expected equipment modifications. Figure 4-3 shows that the maximum cooling fluid temperature limit can probably be raised to the 90-to-100 F range for the majority of equipment coldplates without raising minimum flow rate requirements. This new temperature limit represents a 10-to-20 F increase in the 80 F limit imposed by the ST-124M inertial platform assembly under present design conditions. Some pieces of equipment have relatively wide temperature limits, and it may be possible to restrict coolant flow to this equipment to the prelaunch and injection phases of a mission. During orbital operation, heat conduction from the equipment to the coldplate, and radiation from the coldplate to the instrument unit outer skin, may be sufficient for temperature control without coolant flow.

Figure 4-4 shows the effect of substituting a hydrocarbon circulating fluid (such as 1 butene) on temperature limitations. The hydrocarbon circulating fluid would eliminate any overcooling problems in the sublimator or in a radiator. It also has certain advantages for internally cooled equipment. However, the heat transfer coefficient decreases at comparable fluid flow rates. Figure 4-4 shows the much lower fluid temperature that would be required with a hydrocarbon fluid than with the methanol-water solution. Slightly greater pumping power may also be required.

Figure 4-5 is similar to Figure 4-3, except that a hydrocarbon circulating fluid is substituted for the methanol-water solution. It also shows a slightly lower required fluid temperature.

The data in Figure 4-6 are similar to those in Figure 4-2, except that a better approximation for joint contact diameter was used. This approximation is based on a true contact diameter that was calculated by assuming a 65,000-psi bolt yield strength, a yield strength of 18,000 psi for the softest structural material, and 50 percent of maximum bolt tightening torque. (See Figure 4B-1 in Appendix 4B.) The temperature drop between the coldplate surface and the cooling fluid is then determined from Figures 4A-2 through 4A-5 in Appendix 4A, on the basis of the true contact diameter. Figure 4-6 also shows the effect of using thin, dead soft aluminum washers for critical pieces of equipment. Some increase in the upper permissible fluid temperature is indicated for the RF assembly P1.

A plot of the lower temperature limit is shown in Figure 4-7. The long dashed lines indicate the minimum fluid temperature, based on NAA-estimated allowable temperature limits for the individual pieces of equipment. The highest minimum temperature occurs for packages with very small electrical loads. Insulation between these extremely small heat rejection packages and the coldplate can improve the minimum temperature condition. Minimum temperature of packages that always have a sizable heat rejection can be controlled by a thermostatic valve on the coldplate, set so that the valve closes from 10 to 20 degrees Fahrenheit below the maximum permissible temperature. Temperature of packages that have a very low heat rejection can be controlled if they are located on the downstream portion of the coldplate that is controlled by the presence of a large heat source and exit thermostatic valve. Very low heat rejection packages can also be controlled by electrical heat or Peltier cooling, with insulation between the package and the coldplate. Low fluid temperature can be effectively controlled by by-passing the radiator area or eliminating cooling from capacitive cooling devices.

These graphs are useful for grouping equipment on coldplates, equalizing coldplate loads, and setting fluid outside temperature limits for individual coldplates.

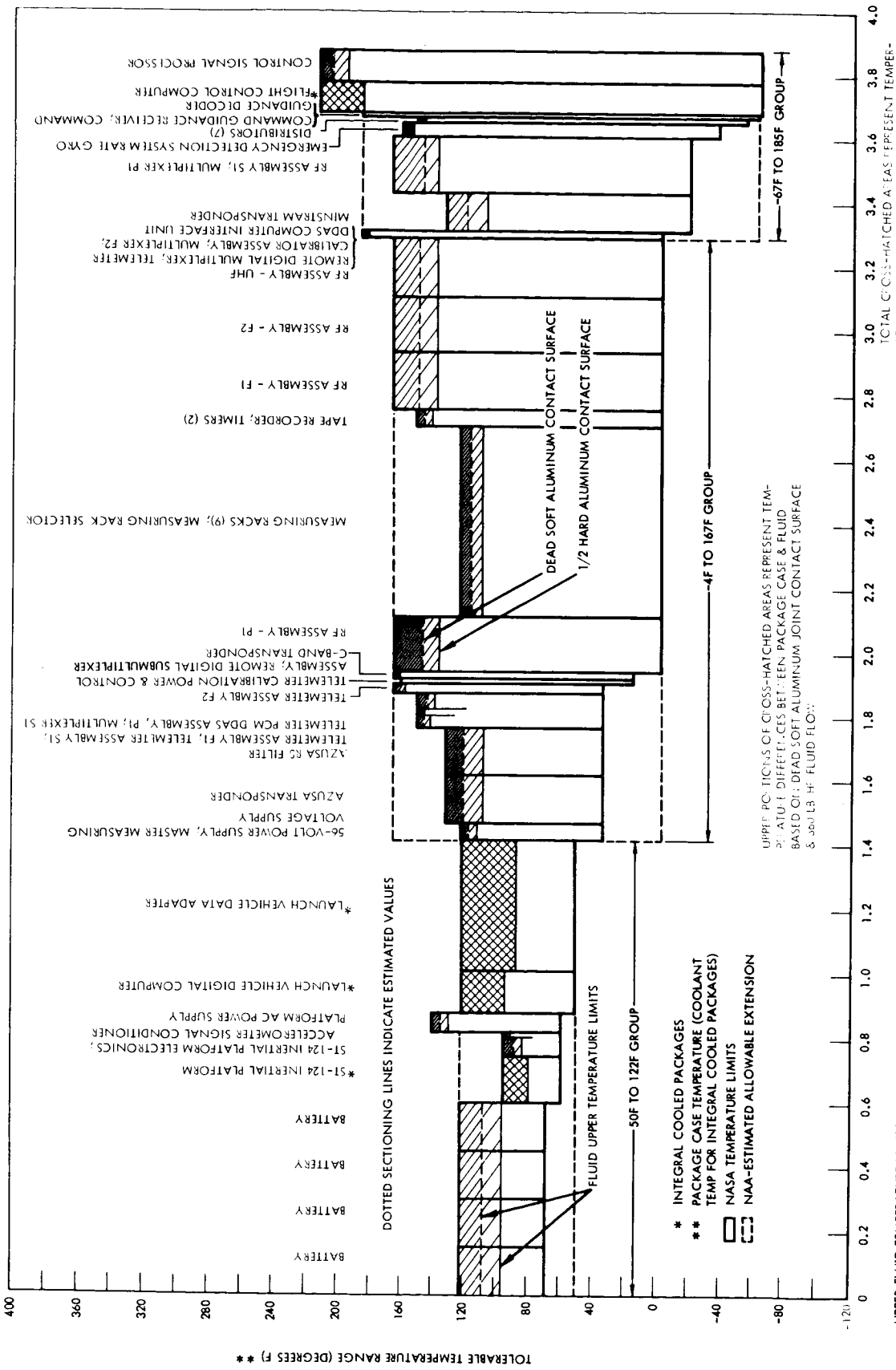


Figure 4-6. Upper Fluid Temperature Limits, Effect of Reduced Joint Thermal Resistance

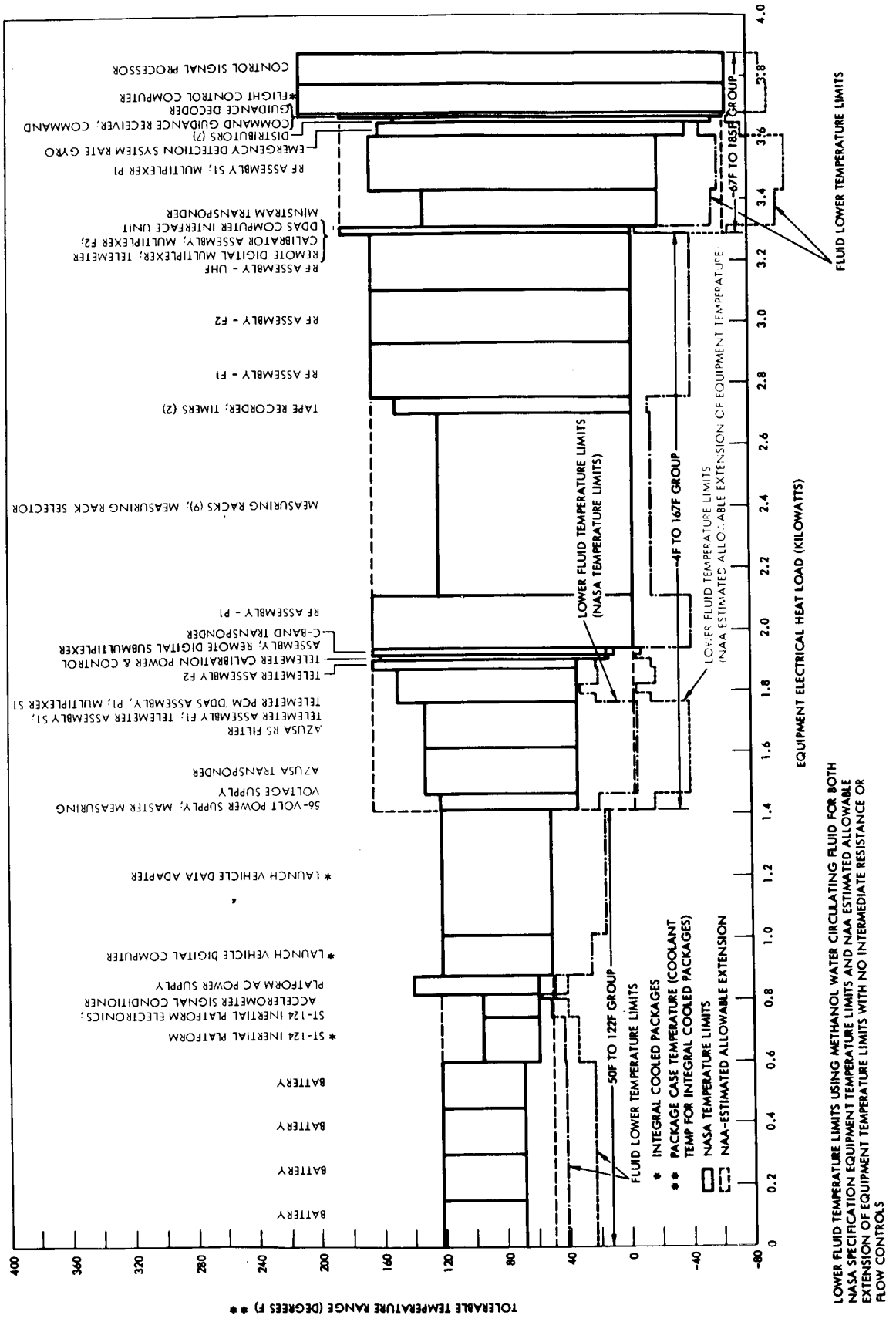


Figure 4-7. Lower Fluid Temperature Limits (Based on NASA Specification Equipment Temperature Limits and NAA Modified Equipment Temperature Limits)

4.2 THERMAL ANALYSIS (HEAT BALANCE)

ACTIVE THERMAL CONTROL

Heat balances were obtained for the current, or baseline, active thermal control system consisting of a closed liquid coolant loop with coldplates and integrally cooled electronic packages. Major portion of the analytical effort was conducted for the condition of fixed coolant flow rate and for a range of values for the electronic package heat dissipation rate and for a range of values for the coolant inlet temperature to the coldplates. Heat balances were also obtained for the condition which assumes the coldplate and electronic components mounted thereon are considered as an adiabatic surface with "no-load" on the electronic components. To provide additional data, the thermal analysis of the active thermal control system included an evaluation of the effect of coolant flow rate variation and step-type increase in electrical heat load. The analyses conducted, the heat balances obtained, and the two digital computer programs (References 4-1 and 4-2) used for the analysis are described in the following paragraphs.

The IU outer skin is subject to the influence of the ambient environment, which varies as a function of orbital altitude and position. To calculate the effect of this environment, a general computer program that simulates the thermal environment of a stabilized multisurfaced space vehicle in planetary orbit was used. This program employs vector notation to provide a simplified method of handling the complicated geometrical relationships inherent in this type of situation. The program was used to compute configuration factors for direct solar radiation, reflected solar radiation, and earth-emitted thermal radiation as a function of time and orbital position (true anomaly) for an IU outer skin consisting of 12 plane surfaces simulating the actual curved surface. The incident heat flux was then computed on the basis of the configuration factors. The program output (incident absorbed radiation) was used subsequently as input data in a general thermal analyzer program.

The thermal analyzer is a general heat transfer program that can solve transient or steady-state n-dimensional heat transfer problems involving conduction, convection, and radiation. Problem solutions are obtained by means of explicit-finite difference approximation procedures. The versatility of the program is based on the analogy between heat transfer and electrical current flow through resistance-capacitance networks. The program was used to obtain temperature histories of the IU skin and individual electronic packages, as well as the total net heat gain or loss of the cooling fluid circuit.

Among the parameters required by the orbital heating program as input data are orbital altitude, angle of inclination of the orbit, launch date, and spacecraft orientation. These parameters are listed in Table 4-2 for the various cases investigated. These data pertain only to circular orbits. The spacecraft orientation is based on specifying the direction of spacecraft surface normals with respect to an orthogonal coordinate system, which is itself related to the appropriate orbit coordinate system. The X axis of the orthogonal system was chosen to coincide with the longitudinal axis through the center of the S-IVB/IU combination. Hence, if this axis is to remain along the orbit path, its direction is specified to be identical to the vector $\bar{R}$, in Figure 4 of Reference 4-1.

Table 4-2 shows that only one vehicle orientation was investigated for the 100-nautical-mile orbit, while three vehicle orientations were used for each of the other three orbits. This was because a limit had to be placed on the scope of the investigation, and the 200-nautical-mile and synchronous earth orbits were considered to be more appropriate for future missions than the 100-nautical-mile orbit. In addition, the determination of incident thermal radiation (Section 2.4) indicated that there is very little difference between the amounts of such radiation at altitudes of 100 and 200 nautical miles.

Regarding the relationship between IU locations in Figure 6 of Reference 4-3 and the vehicle coordinate axes, the positive Y axis was chosen to pass through IU location 21 (Vehicle Position IV) and the positive Z axis was chosen to pass through IU location 15 (Vehicle Position III). The orientation of the IU with respect to the earth is as follows:

1. With the X axis of the vehicle coordinate system along the orbit path (x-tan), Vehicle Position I (IU location 3) faces the earth at all times.

2. When the X axis of the vehicle coordinate system is sun-oriented (X-solar), Vehicle Position IV (IU location 21) faces the earth at 0 degrees true anomaly for cases with 0- or 29-degree angle of inclination, and Position IV faces the earth at 180 degrees true anomaly for case with 90-degree angle of inclination.

3. When the Y axis of the vehicle coordinate system is sun-oriented (Y-solar), the X axis is in the orbit plane and points toward the earth at 0 degrees true anomaly.

Apart from the orbital parameters in Table 4-2, the absorbed incident heat load is affected by the surface properties (solar absorptivity α_s, and infrared emissivity, ϵ) of the IU outer skin. The effect of variation in solar absorptivity was investigated by using values of 0.18 and 0.9, which represent the practical α_s range in currently available thermal

Table 4-2. Orbital Parameters

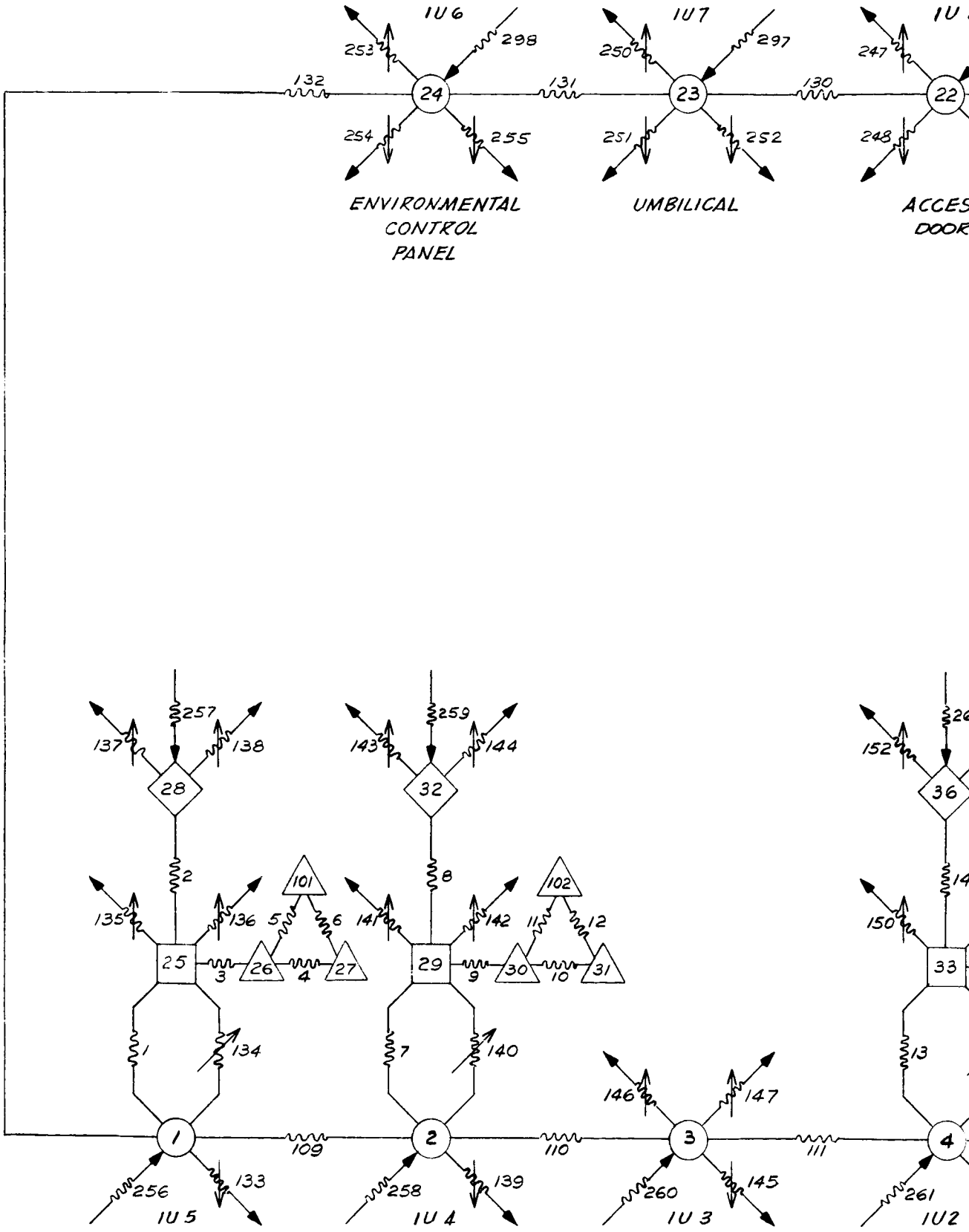
	Case No.	Altitude (nautical miles)	Angle of Inclination (degrees)	Launch Date	Spacecraft Orientation	IU Orientation
IU-1a	1	200	29	June 21	X axis along orbit path	Location 3 toward earth
IU-1b	2				X axis toward sun	Varies with orbit position
IU-1c	3				Y axis toward sun	Location 21 toward sun
IU-3a	4	200	90	March 21	X axis along orbit path	Location 3 toward earth
IU-3b	5				X axis toward sun	Varies with orbit position
IU-3c	6				Y axis toward sun	Location 21 toward sun
IU-4a	7	100	0	March 21	X axis along orbit path	Location 3 toward earth
IU-6a	8	19,327 (synchronous)	0	March 21	Y axis toward sun	Location 21 toward sun
IU-6b	9				X axis toward sun	Varies with orbit position
IU-6c	10				X axis along orbit path	Location 3 toward earth
IU-10a	11	100	34	Dec 21	X axis along orbit path	Location 3 toward earth
IU-11a	12	200	34	Dec 21	X axis along orbit path	Location 3 toward earth

control coatings. The value of ϵ was chosen on the basis that it should be as high as practical to aid heat rejection through low surface temperatures. An obtainable emissivity of 0.9, selected for the heat balance calculations, results in α_s/ϵ ratios of 0.2 to 1.0 for the α_s range from 0.18 to 0.9.

Other factors that determine the magnitude of the incident heat load are the solar constant, the magnitude of albedo radiation, and the resulting earth emission. Values for these factors used in the orbital heating program are 443 Btu/hr-ft^2 for the solar constant, 40 percent of solar radiation for albedo radiation, and 66.4 Btu/hr-ft^2 for earth-emitted radiation. These values are the same as those used in Reference 4-3. The variation in the value of the solar constant with variation in launch date was not considered significant and, therefore, was not taken into account.

The vehicle configuration selected for the thermal analysis consists of an IU, an S-IVB stage aft of the IU, and a spacecraft/LM adapter (SLA) forward of the IU. This arrangement is shown in Configuration A of Figure 2-2. For the purpose of the computer analysis, the complete IU was represented by an equivalent electrical network (Figure 4-8), a portion of which is shown in Figure 4-9. In this network portion, the circle with number 1 in its center represents one of the 24 nodes into which the IU outer shell was divided. The square enclosing number 24 is a node representation of one of the 16 coldplates, and the diamond enclosing number 28 represents the electronic package mounted on the coldplate. The triangles enclosing numbers 26, 27, and 101 are nodes in the coolant flow network, which was constructed in accordance with the method outlined in Reference 4-4.

The heat capacities for the network nodes are listed in Table 4-3, and the electrical heat loads (q_{el}) applicable to the coldplates and integrally cooled equipment are listed in Table 4-4. With the exception of the IU outer shell, the heat capacities were calculated on the basis of an average specific heat of 0.20 Btu/lb-°F. The outer shell specific heat equivalent of 0.228 Btu/lb-°F reflects the influence of the honeycomb material used in the construction of the shell. The electronic package weight assigned to each coldplate location was determined by dividing the total electronic package weight for coldplate-mounted equipment (2370.3 pounds) by the number of coldplates (16). This approach results in a thermally ideal system, as compared with the package arrangement on the present IU, which is on a functional basis. However, the equal distribution of electronic package weight and, hence, heat capacity was not expected to affect the total heat load on the cooling system, and the rate of change in the incident heat load was expected to be slow enough to make the effect of heat capacity on individual package temperatures negligible. This expectation was reinforced by the assumption, for analysis purposes only, of constant coldplate coolant inlet temperature, regardless of the incident heat load on the IU outer shell.


IU 6
IU 7
IU
253
298
250
297
247
132
24
131
23
130
22
254
255
251
252
248
ENVIRONMENTAL CONTROL PANEL
UMBILICAL
ACCES DOOR
257
259
137
138
143
144
152
28
32
36
2
8
101
102
135
136
5
6
141
142
11
12
150
25
3
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4
27
29
9
30
10
31
33
1
134
7
140
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111
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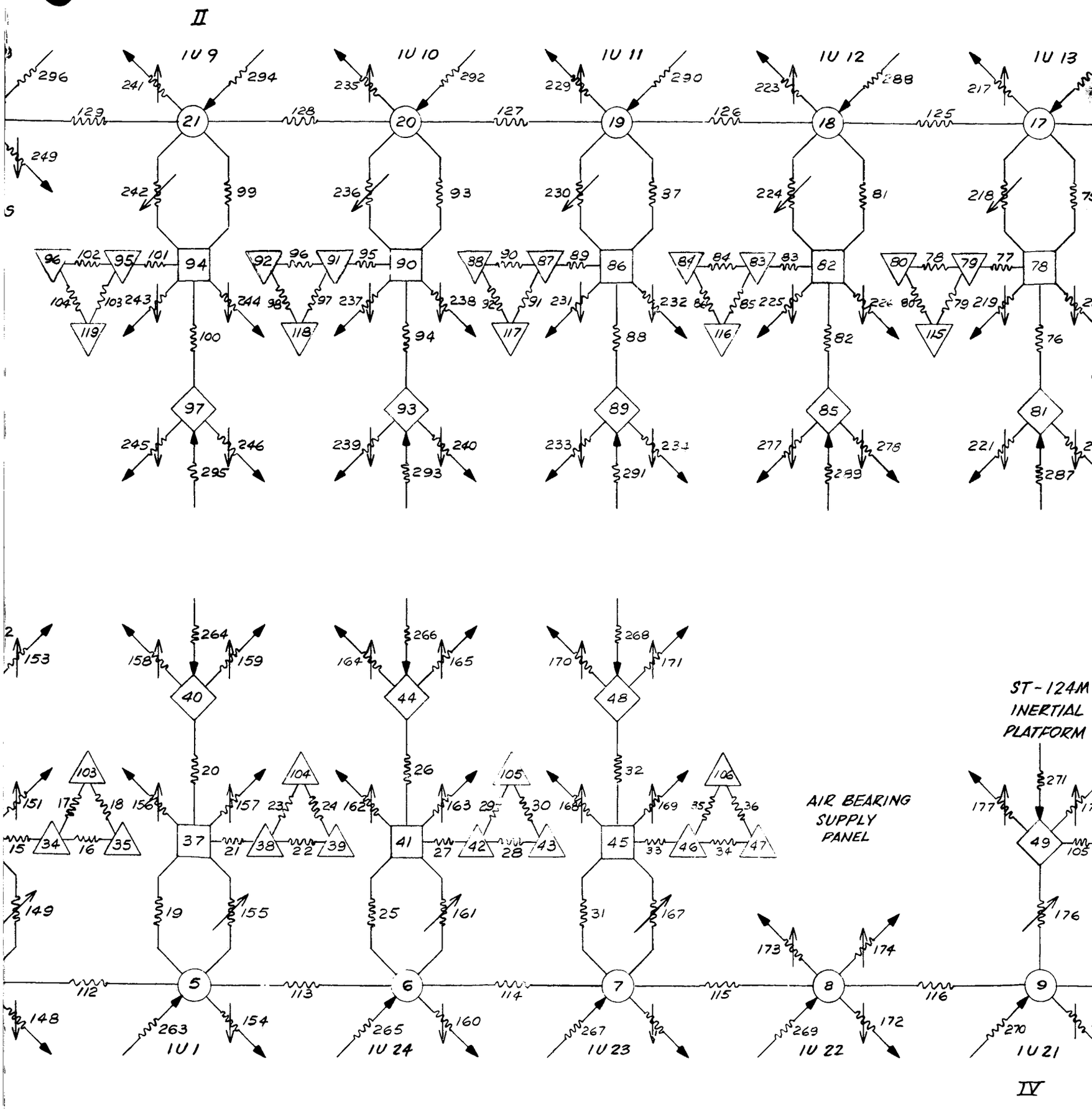
IU 5
IU 4
IU 3
IU2

I


II
IU 9
IU 10
IU 11
IU 12
IU 13
ST-124M
INERTIAL
PLATFORM
AIR BEARING
SUPPLY
PANEL
IU 1
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IU 23
IU 22
IU 21
IV

III

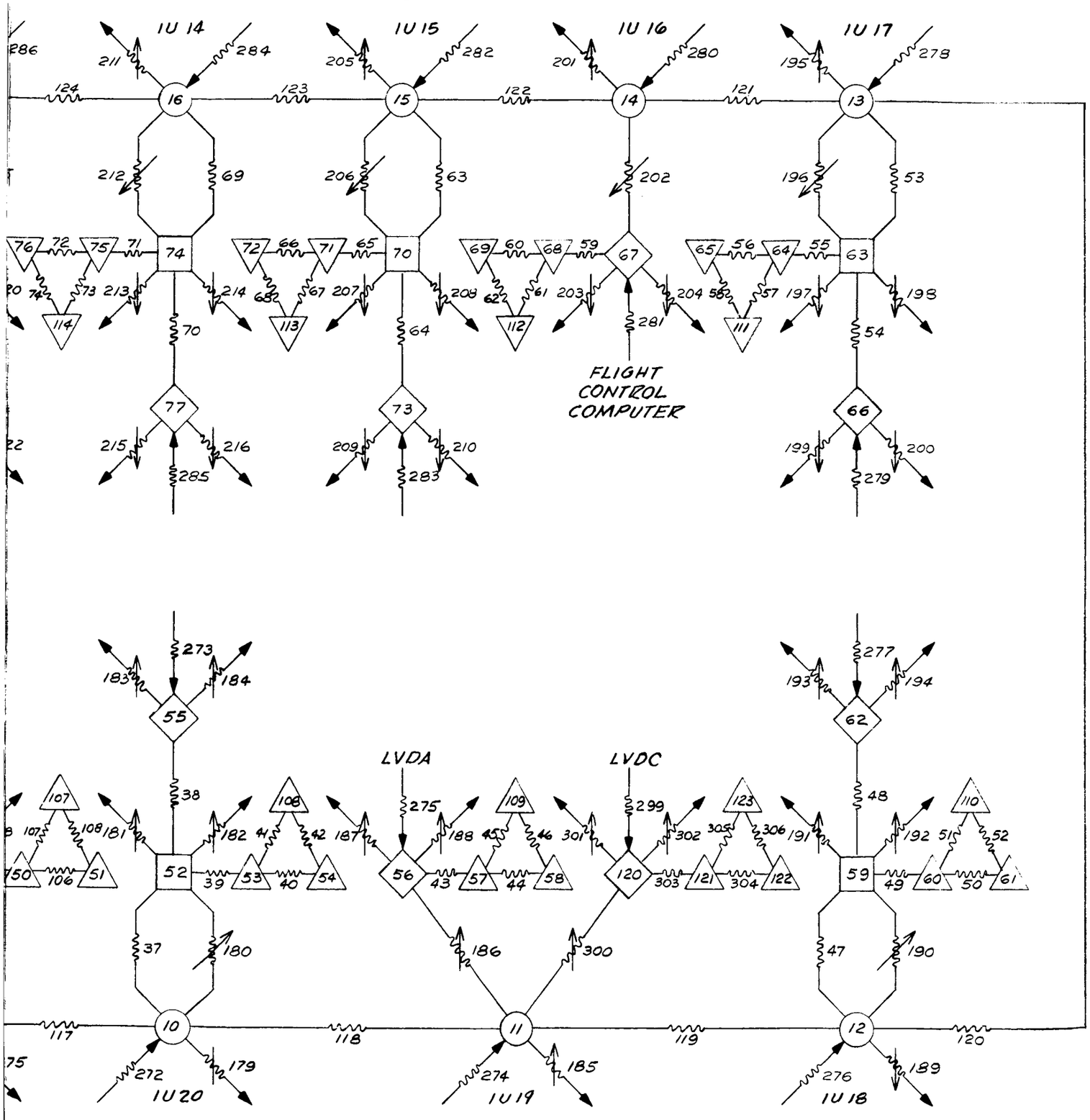

Figure 4-8. Electrical Network

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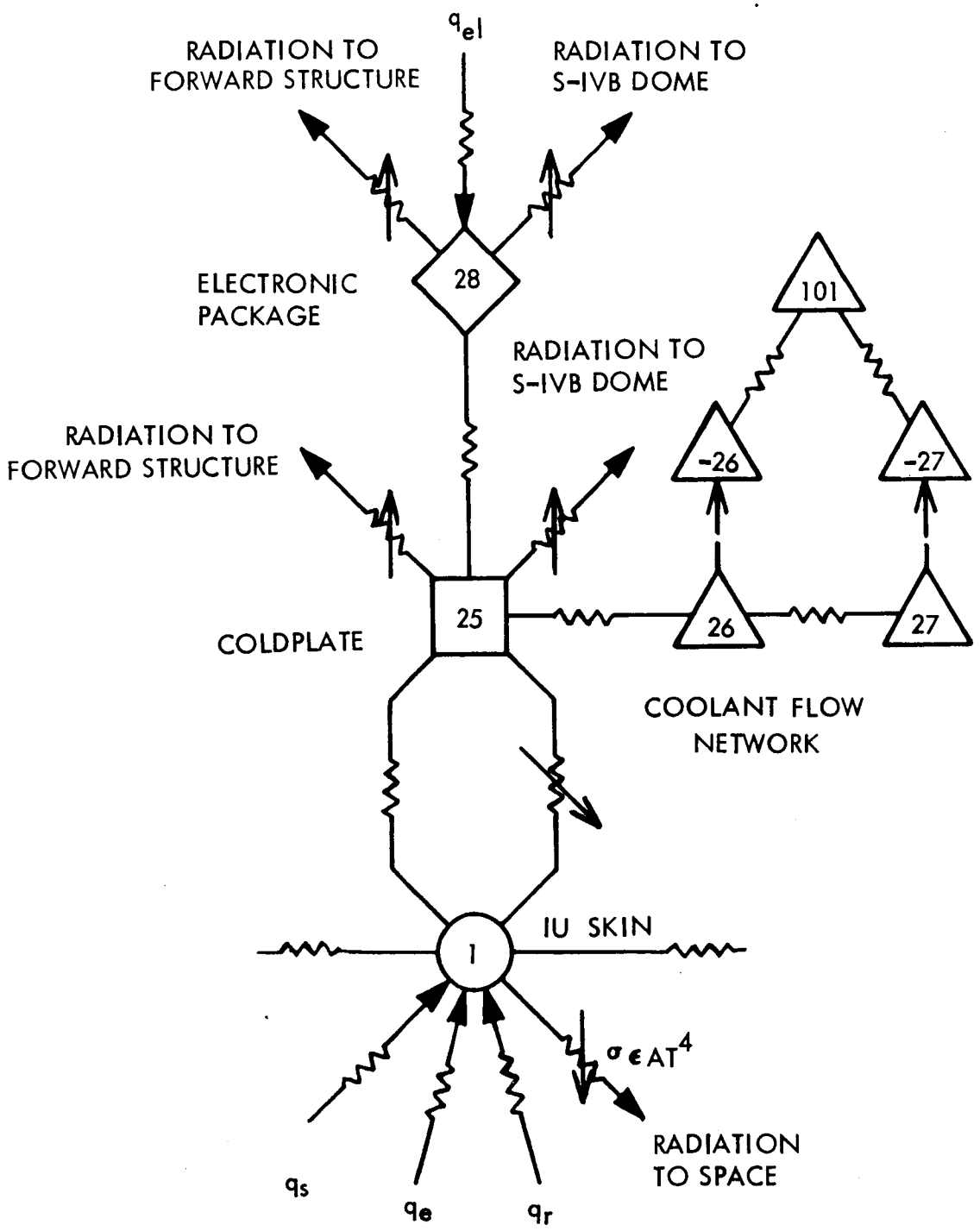

Figure 4-9. Thermal Network, Equipment Mounted on Coldplate

Further assumptions applicable to the construction and analysis of the IU equivalent network are as follows:

1. The single node representation for each coldplate is sufficiently accurate for obtaining data to be used in TCS selection.

2. The heat capacity of the coolant within the coldplate passages is small enough to be neglected in the equivalent network representation.

3. The temperature difference between the IU and adjacent structure is small enough to neglect conduction heat transfer between the two.

4. The electronic package cover and the coldplate surface are equivalent to a single flat surface for the purpose of defining internal thermal radiation. In the absence of detailed information regarding package dimensions and relative position on the coldplates, this assumption is believed to produce results of reasonable accuracy because the omission of radiation from the package sides to the S-IVB dome and the SLA is offset by neglecting the shadowing effect of the packages with respect to radiation from the bare coldplate surface area.

Table 4-3. Thermal Network Weights and Heat Capacities

Item	Weight (lb)	Heat Capacity (Btu/°F)
Electronic Packages (per coldplate)	148	29.6
Coldplate	27.8	5.56
Instrument Unit Outer Shell (per node)	8.17	1.86
ST-124 Inertial Platform	118	23.6
LVDC	88	17.6
LVDA	190	38.0
Flight Control Computer	125	25.0

As indicated in Table 4-4, the electronic package heat load for coldplate-mounted equipment was also assumed to be distributed uniformly and, as mentioned previously in the discussion of heat capacity, this thermally ideal distribution was not expected to affect total system heat load. Heat loads for integrally cooled items of equipment are, of course, actual loads. In this connection, it should be noted also that, for the earth-oriented orbital conditions (Cases No. 1, 4, 7, and 10 in Table 4-2), only

Table 4-4. Electrical Heat Loads

Item	Load (watts)
Coldplates (each)	50, 150, and 250
ST-124-M Inertial Platform Assembly	70
LVDC	142
LVDA	400
Flight Control Computer	100

one value of electronic package heat load (150 watts per coldplate) was used in the heat balance calculations. For the other six orbital cases investigated, heat balances were obtained over the electronic package heat load range from 50 to 250 watts per coldplate. The reason for limiting the number of heat balances obtained for Cases No. 1, 4, 7, and 10 is that IU heat load values in these cases will fall between heat loads for the other two vehicle orientations (X axis toward sun and Y axis toward sun), which represent minimum and maximum solar heating conditions for any one orbital condition. The values for other variables affecting this system, such as coldplate coolant inlet temperatures, IU outer shell solar absorptivity, and coolant flow rate, are listed in Table 4-5. With regard to coolant network temperatures in Figure 4-9, nodes 27, 26, and 101 are at coldplate inlet, average, and outlet temperature, respectively.

Table 4-5. ECS Variables

Variable	Value
Coldplate Coolant Inlet Temperature	30, 50, and 75 F
Instrument Unit Skin Solar Absorptivity (α_s)	0.18 and 0.9
Coolant Flow Rate (per coldplate)	60 lb/hr

The values of the conductors representing radiation heat transfer paths in Figure 4-9 were determined on the basis of the surface emissivities listed in Table 4-6. For the S-IVB dome, a possible range of emissivity value between 0.05 and 0.90 was assumed. The current dome emissivity value is 0.80 and a lower value is being considered. It was considered desirable to enhance radiation heat transfer from the electronic packages. Therefore, they were assumed to be covered with a thermal control coating of high emissivity ($\epsilon = 0.9$). The same value was assumed for the outboard surface of the IU outer shell, which must be effective in rejecting absorbed incident radiation to the deep space heat sink. For the remainder of radiating

surfaces (coldplates, SLA, and the inboard surface of the IU outer shell), an emissivity value corresponding to the lowest available value with commonly used thermal control coatings was used.

Table 4-6. Surface Infrared Emissivities

Item	Emissivity
S-IVB Dome	0.05 and 0.90
SLA (Spacecraft/LM Adapter)	0.18
Coldplates	0.18
Electronic Packages	0.90
Instrument Unit Skin	
Outboard Surface	0.90
Inboard Surface	0.18

The conductors identified as q_s, q_r, and q_e in Figure 4-9 represent direct solar radiation, earth-reflected solar radiation, and earth-emitted radiation, respectively. Individual heat transfer rates as a function of time for these conductors were obtained by using the orbital heating computer program mentioned earlier, and were based on an 8.5-square-foot-per-node surface area. Since the number of outer shell nodes (24) was twice the number of surfaces used in the orbital heating simulation of the IU, the unit heat input for each of the 12 surfaces was applied to the two outer shell nodes within the range of the surface. Thus, the heat input calculated for outer shell surface 1 was applied to network nodes 10 and 11, and the input for surface 2 was applied to nodes 12 and 13. In this connection, it should be noted that both surfaces and nodes were numbered in a counter-clockwise direction in the aft looking view of the IU. This numbering system placed surface 1 in the same location as NASA location 20 in Figure 6 of Reference 4-3; node 1 was considered to be at NASA location 5. The surface locations are the result of the identification sequence used in the orbital heating program, while node 1 was placed so that it would be at the first coldplate location in the coolant circuit.

For the purposes of the thermal analysis, it was assumed that coldplate-mounted equipment would cover one half of the available area (30-by-30 inches) of each coldplate. Hence, radiating coldplate and electronic package areas were considered as 450 square inches each. Radiant heat exchange areas for the S-IVB dome and the SLA forward structure were calculated to be 106,200 and 20,100 square inches, respectively. The conduction resistances between the IU skin and the coldplates were considered as 0.07 hr-°F/Btu each, in accordance with information contained in Reference 4-3. Further assumptions applicable to the thermal analysis were a con-

stant SLA structure temperature of 40 F, a joint conductance of 14.0 Btu/hr-°F between an electronic package and its coldplate, and an S-IVB dome temperature variation as shown in Figure 4-10. The joint conductance value of 14.0 Btu/hr-°F is equivalent to a resistance of 0.25 F per watt, which is a value shown to be desirable in the section of this report dealing with fluid temperature limits. Table 4-7 gives the values for the conductance and fA's used in radiation heat transfer.

The conductance from the coldplate to the node representing the average coolant temperature was held constant at hA = 20 Btu/hr-°F, and the conductance between the average and inlet coolant temperature nodes was calculated as (2) ($\dot{w}$) (C_p). In this expression, $\dot{w}$ = coolant flow rate (lb/hr) and C_p = coolant specific heat (Btu/lb-°F).

The starting time for the thermal analysis was considered as that of injection into orbit; the IU skin temperature at that instant was assumed to be 200 F. The corresponding S-IVB dome temperature is -210 F (Figure 4-10). Because this temperature does not reach equilibrium conditions until approximately 30 hours after launch, heat balances were calculated for a total of 40 hours to evaluate the effect of variations in this temperature.

The results of the heat balance analysis for the active thermal control system are summarized in Figures 4-11 through 4-33, for both the initial orbits (0 to 35 hours of orbit time) and the condition of S-IVB dome temperature equilibrium. For the latter condition, the IU heat load shown in the Figures 4-11 through 4-21 represents the average heat load rate over a complete orbit. In many instances, the variation in heat load as a function of orbital position was found to be relatively large, especially in cases in which the environmental conditions are subject to wide variation because of a high value of α_s (solar absorptivity) for the IU shell. This situation is evident from a comparison of Figures 4-34 and 4-35, which represent data for the same orbital condition, vehicle orientation, coolant coldplate inlet temperature (50 F), and electrical equipment heat load (150 watts per coldplate). An increase in the value of solar absorptivity from 0.18 to 0.90 results in not only a greater than threefold increase in IU heat load (in this example) but also an excursion of about ±3000 Btu's per hour from the average value during one complete orbit. With the lower value of α_s, this excursion is limited to about ±650 Btu's per hour, as shown in Figure 4-34.

The appendix to this report (SID 67-373-3) contains the results of the heat balance analysis in the form of CRT plots, such as Figures 4-34 and 4-35. These CRT plots, together with the printouts from the computer runs, were used to develop the summary plots (Figures 4-11 through 4-33).

The variation in IU heat load as a function of coolant coldplate inlet temperature is shown in Figures 4-11, 4-12, and 4-13 for the ten orbital conditions described in Table 4-2. The data presented are for constant

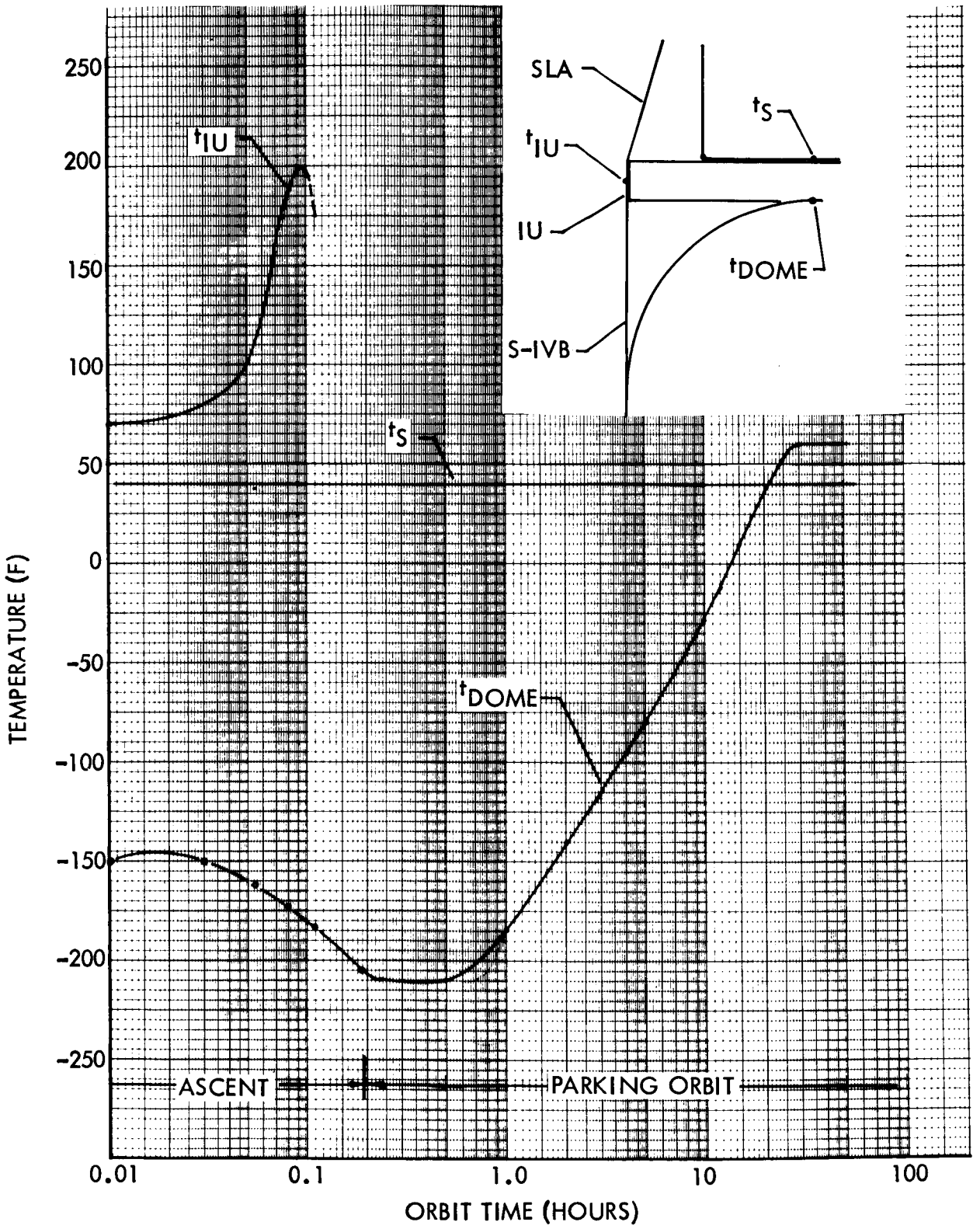

Figure 4-10. IU and Internal Structure Temperature

Table 4-7. Values for Conductance and fA's

Component	Component/IU Skin		Component/S-IVB Dome fA (sq in.)		Component/SLA fA (sq in.)	
	Radiation	Conduction				
	fA (sq in.)	$\frac{kL}{A}$ [(Btu/(hr) (F)]	S-IVB Dome $\epsilon = 0.05$	S-IVB Dome $\epsilon = 0.90$	S-IVB Dome $\epsilon = 0.05$	S-IVB Dome $\epsilon = 0.90$
Coldplate	104	14.28	10.0	91.5	36.0	14.0
Electronic package (coldplate mounted)	-	-	28.0	267.0	105.0	40.0
ST-124 inertial platform	173	-	95.0	902.0	356.0	136.0
LVDA	198	-	159.0	1505.0	595.0	228.0
LVDC	185	-	126.0	1195.0	473.0	181.0
Flight control computer	202	-	174.0	1650.0	652.0	250.0

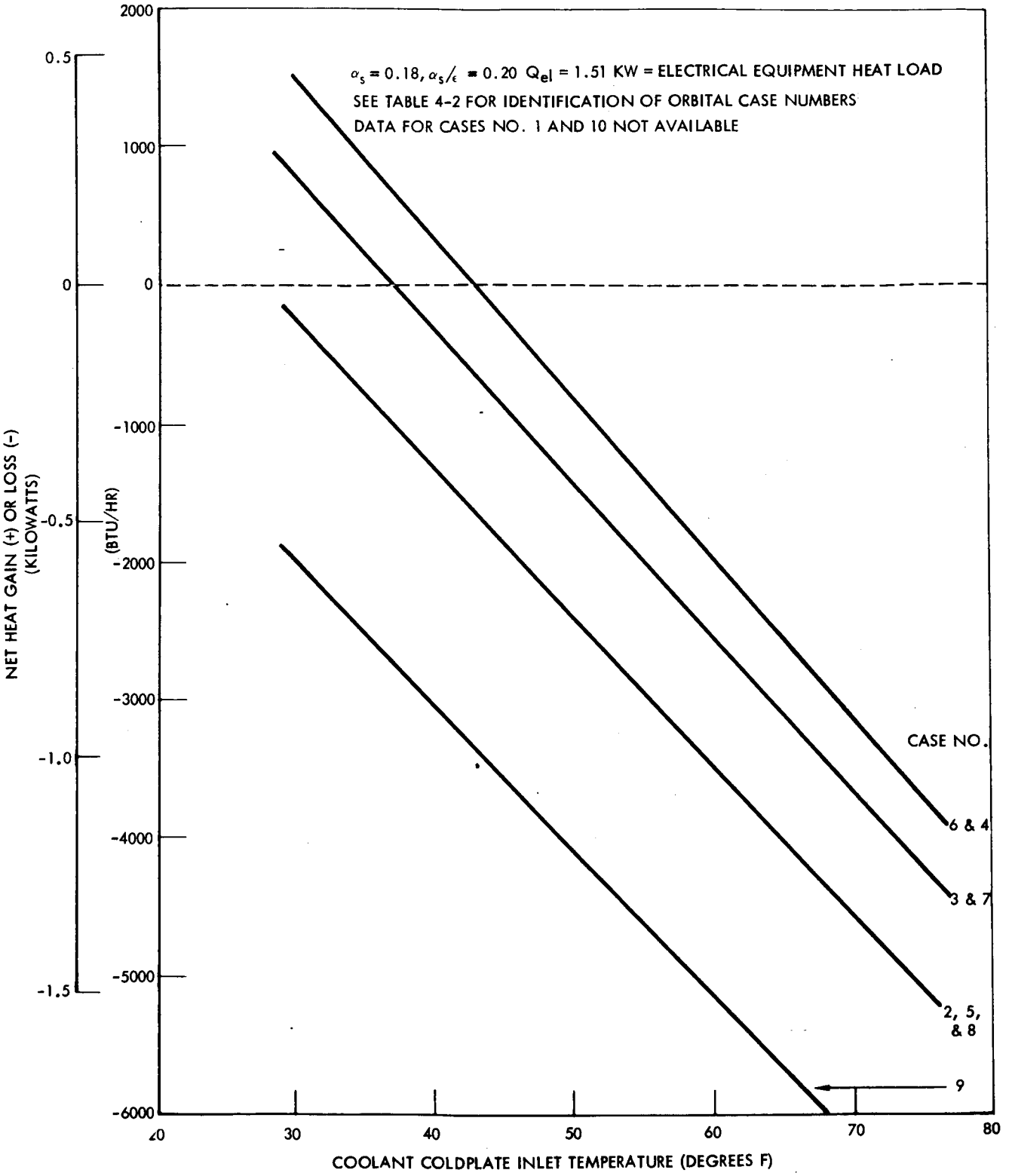

Figure 4-11. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, α_s = 0.18, Q_{el} = 1.51 kw

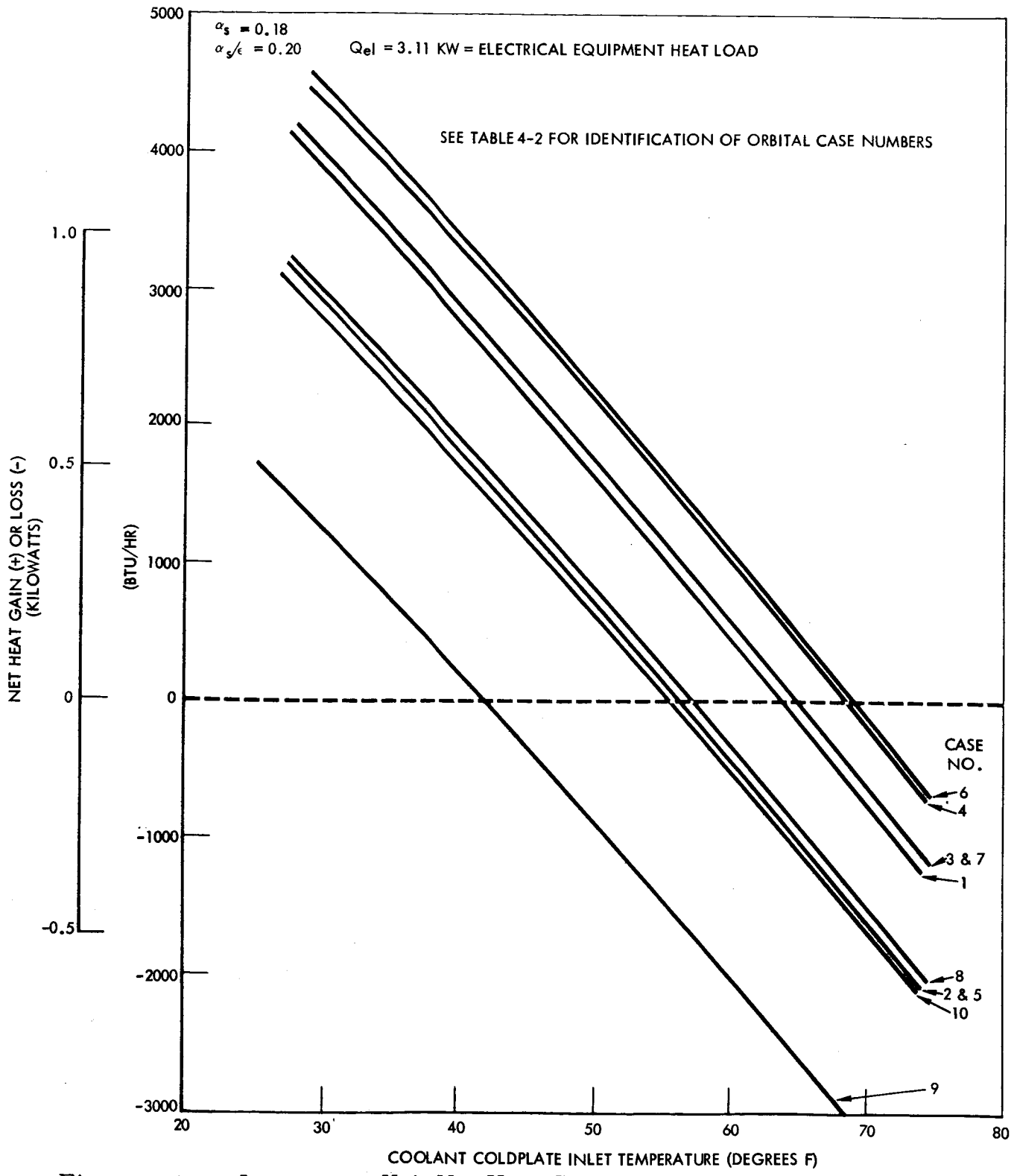

Figure 4-12. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, α_s = 0.18, Q_{el} = 3.11 kw

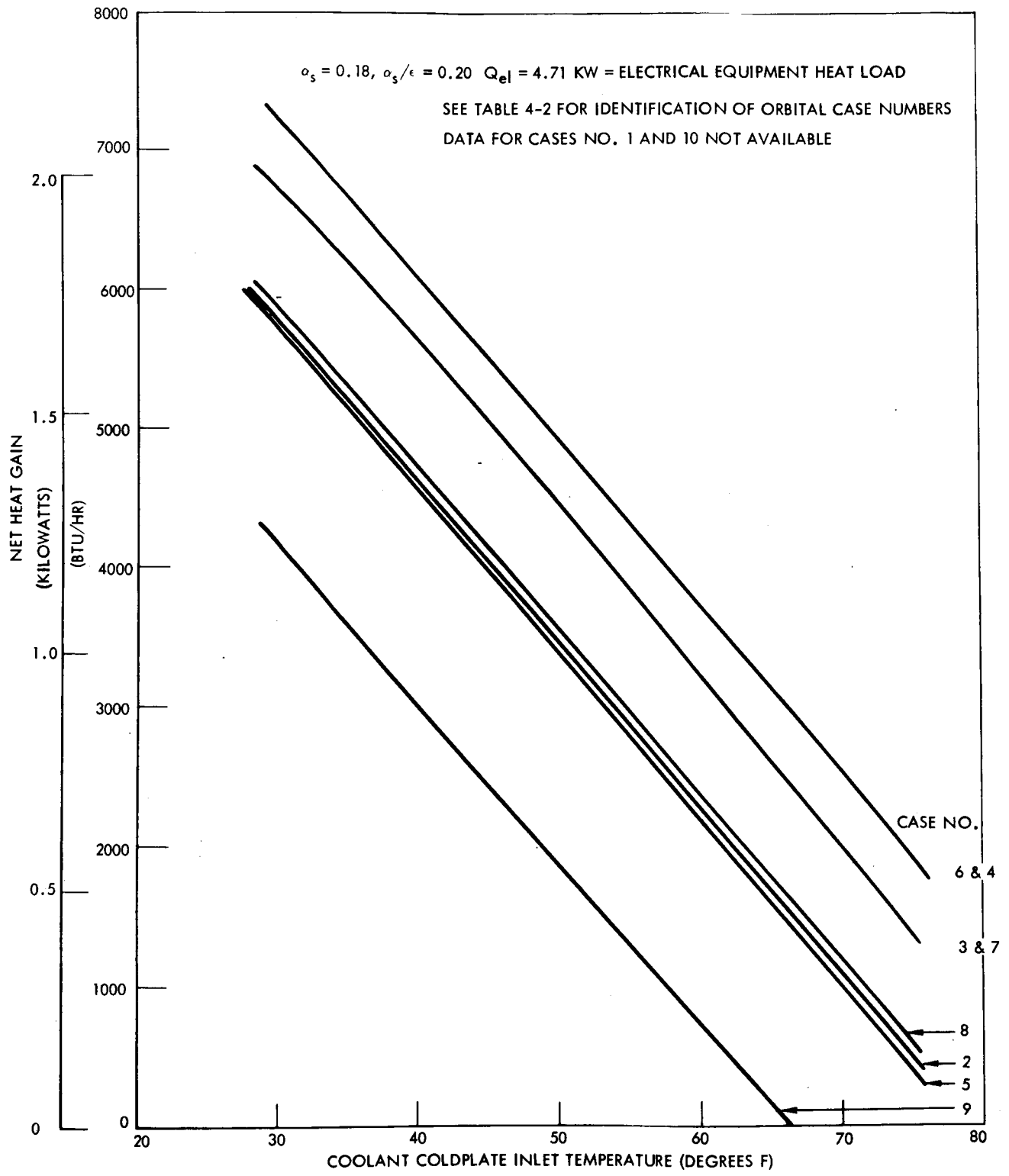

Figure 4-13. Instrument Unit Net Heat Gain Vs Coolant Coldplate Inlet Temperature, $\alpha_s = 0.18$, $Q_{el} = 4.71$ kw

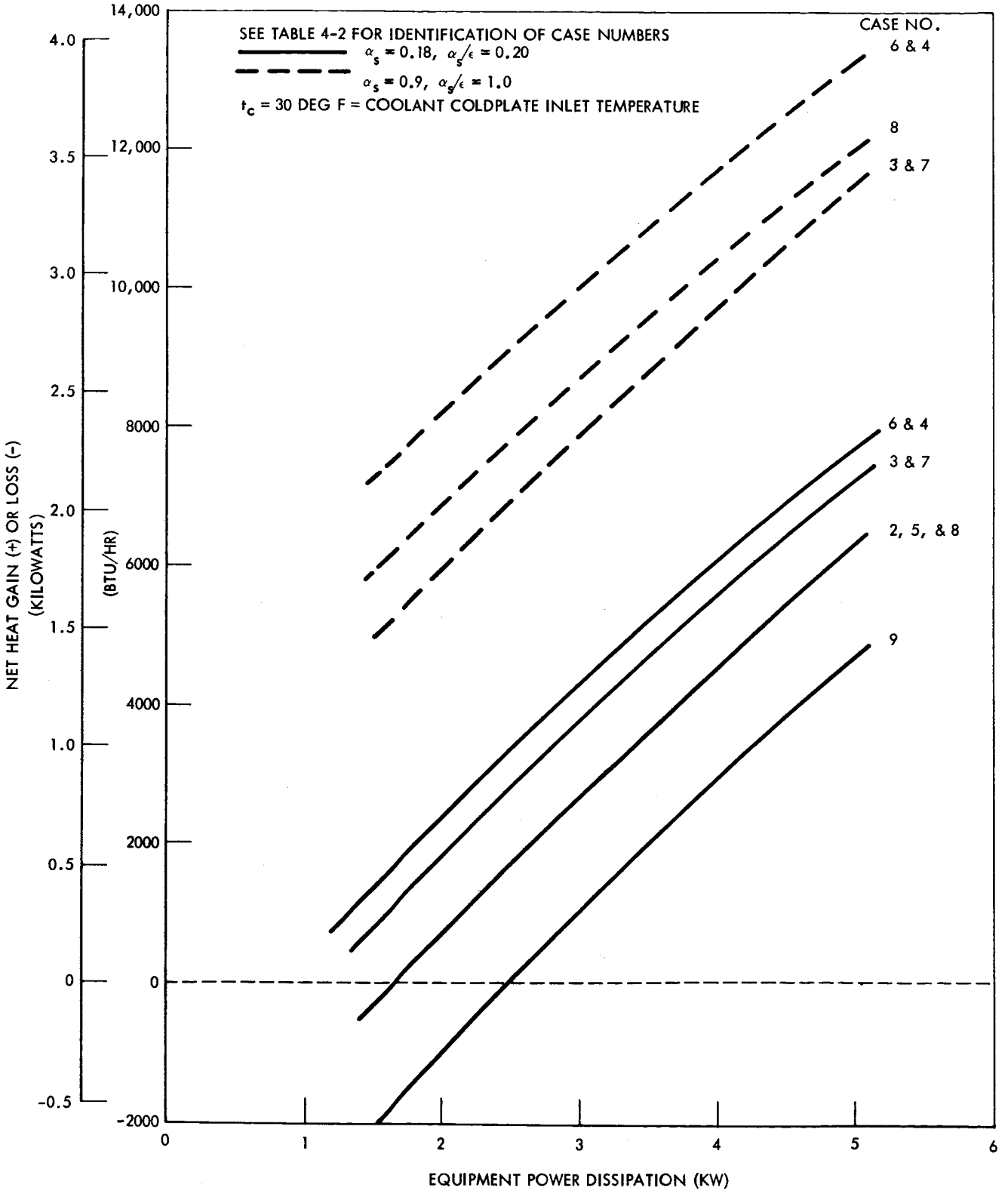

Figure 4-14. Instrument Unit Net Heat Gain or Loss Vs Equipment Power Dissipation, t_c = 30 F

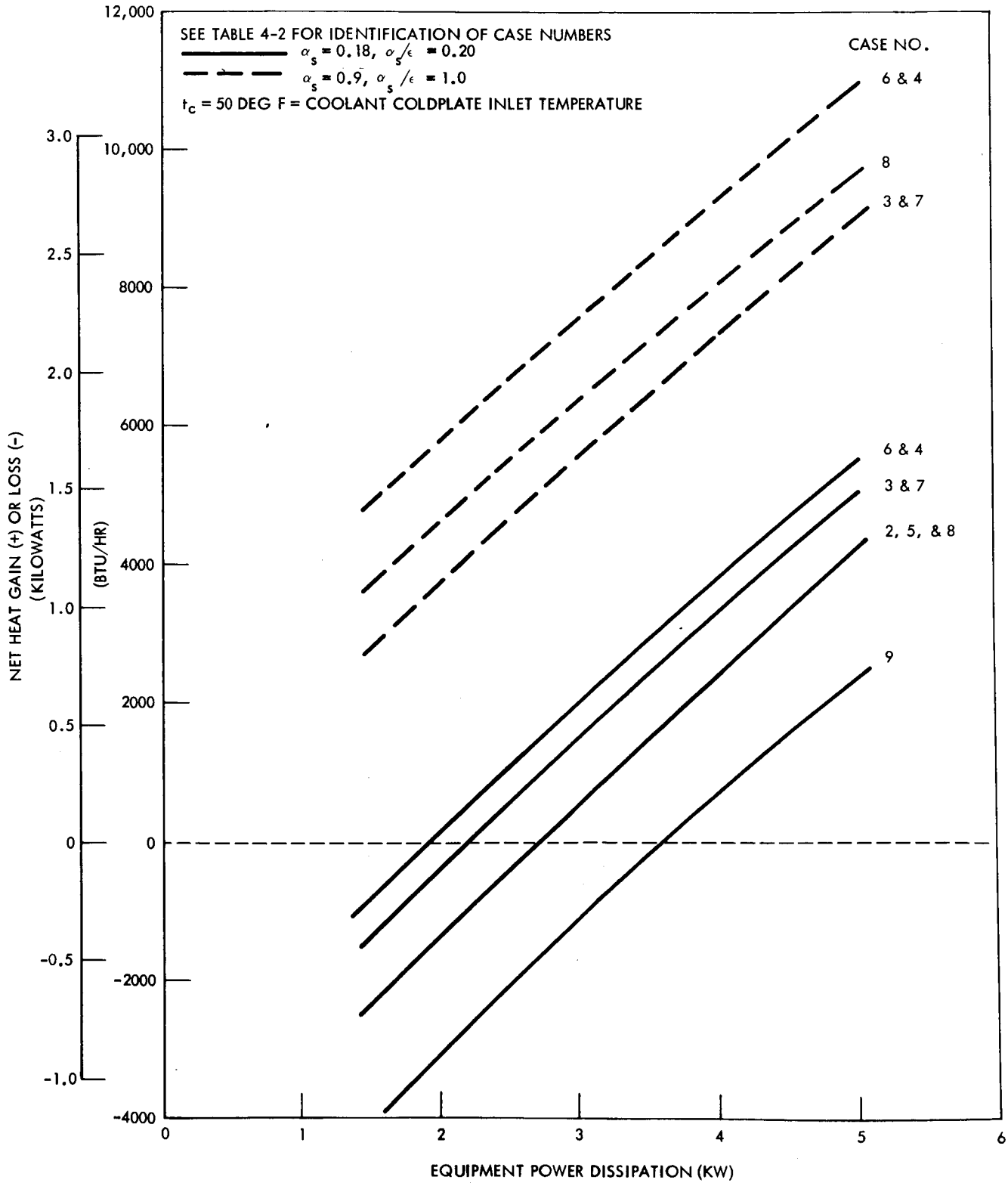

Figure 4-15. Instrument Unit Net Heat Gain or Loss Vs Equipment Power Dissipation, t_c = 50 F

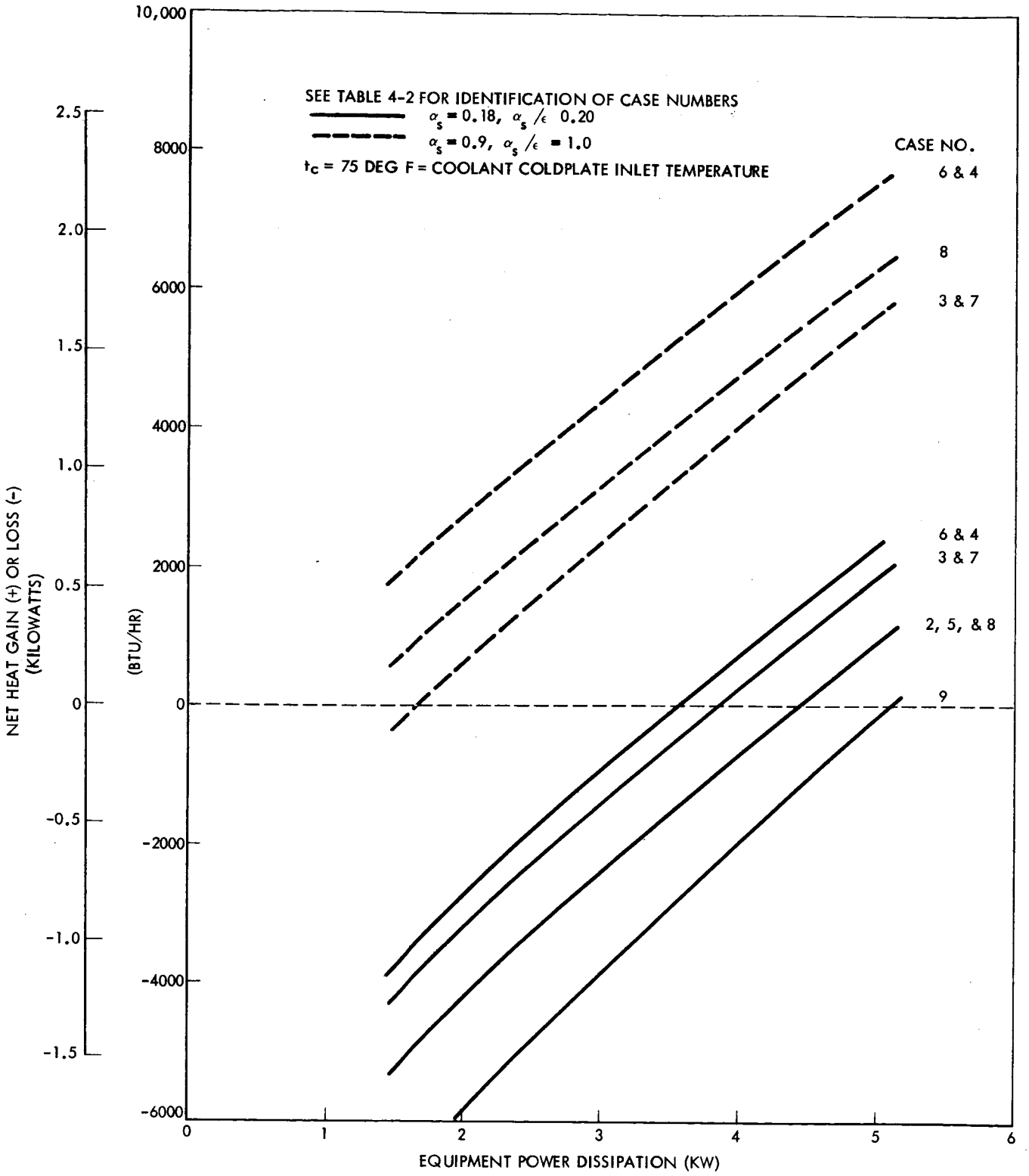

Figure 4-16 . Instrument Unit Net Heat Gain or Loss Vs Equipment Power Dissipation, t_c = 75 F

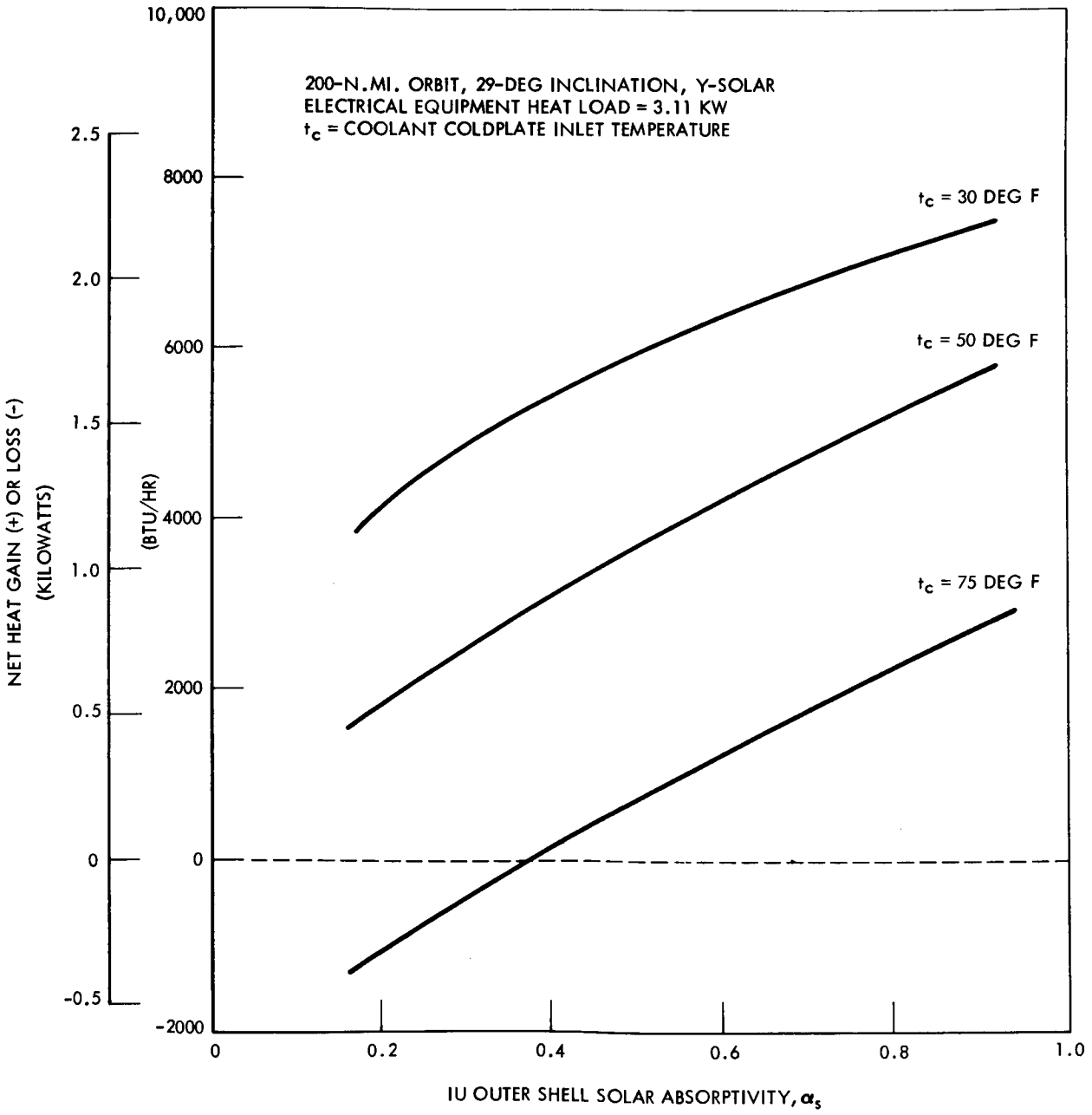

Figure 4-17. Instrument Unit Net Heat Gain or Loss Vs IU Outer Shell Solar Absorptivity (α_s), 200-N. Mi. Orbit, Q_{el} = 3.11 kw

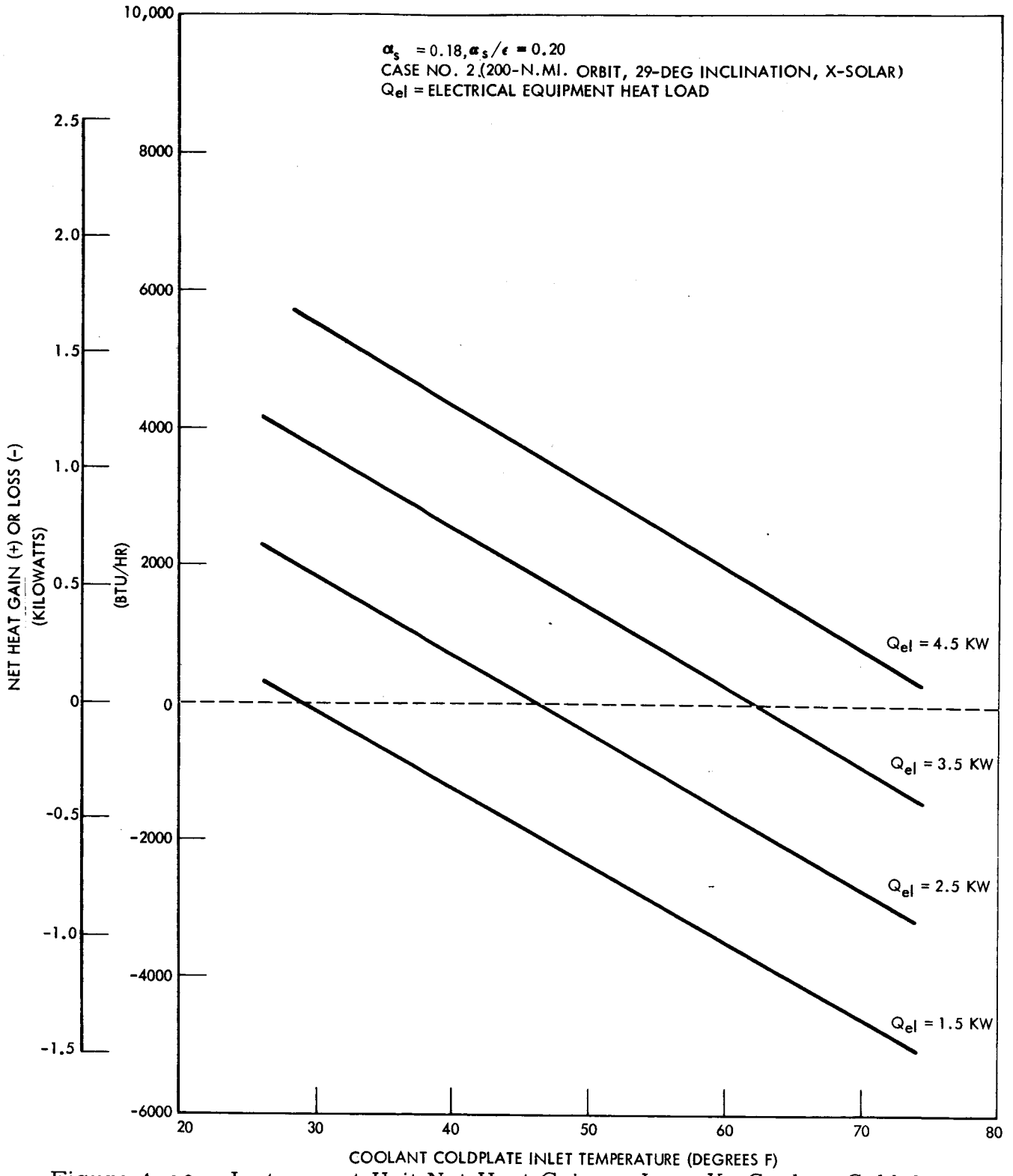

Figure 4-18. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, Case No. 2

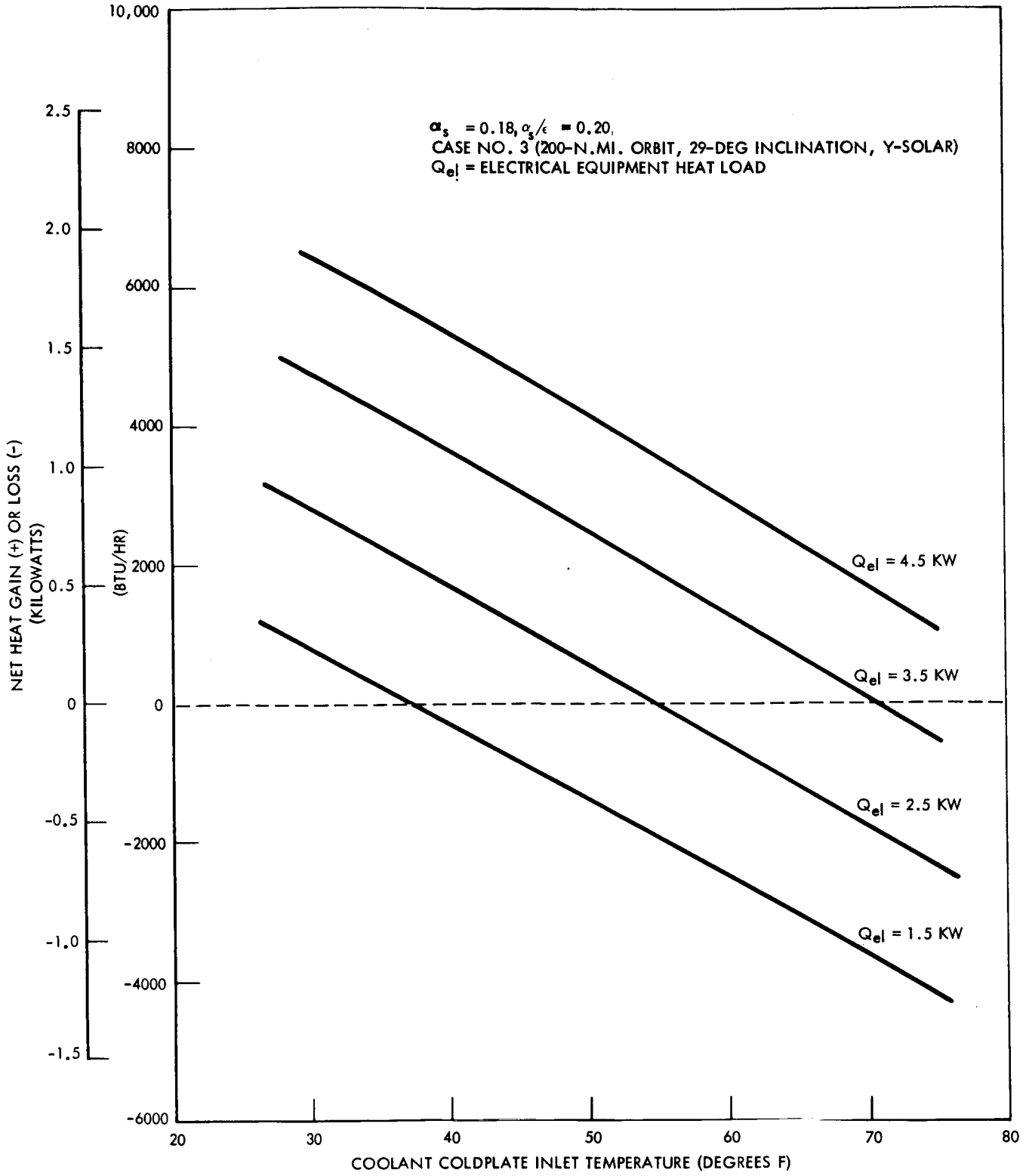

Figure 4-19. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, Case No. 3

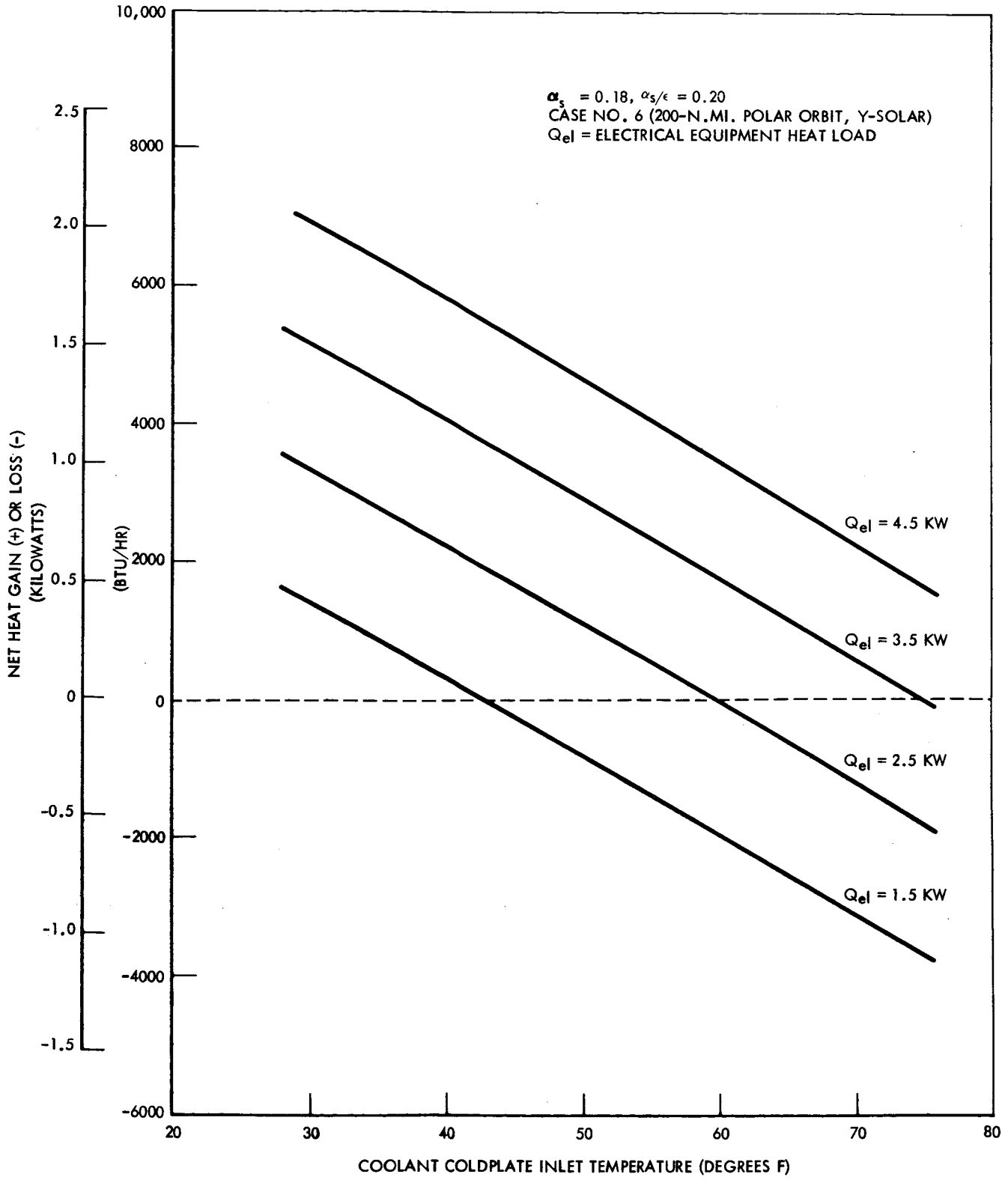

Figure 4-20. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, Case No. 6

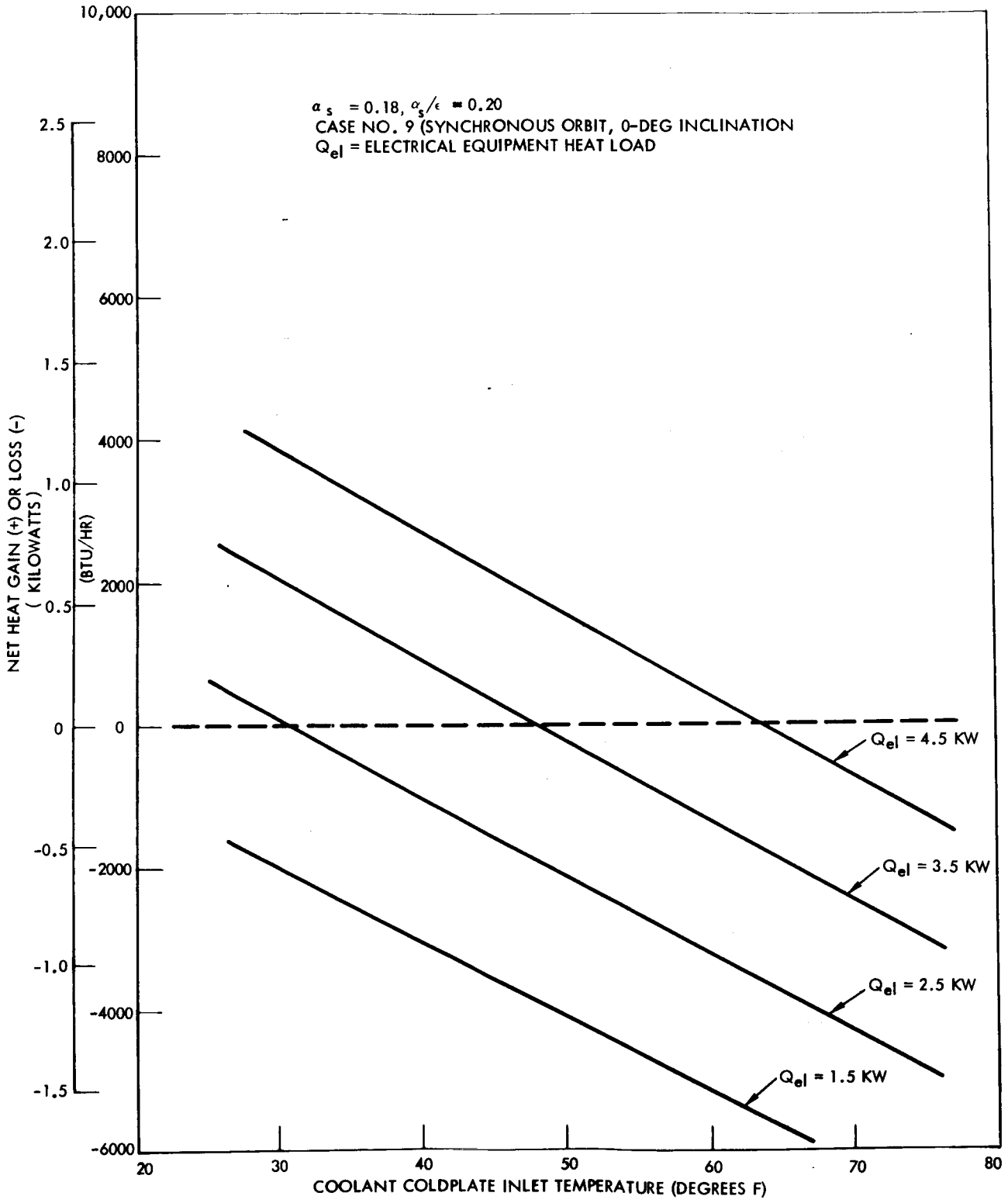

Figure 4-21. Instrument Unit Net Heat Gain or Loss Vs Coolant Coldplate Inlet Temperature, Case No. 9

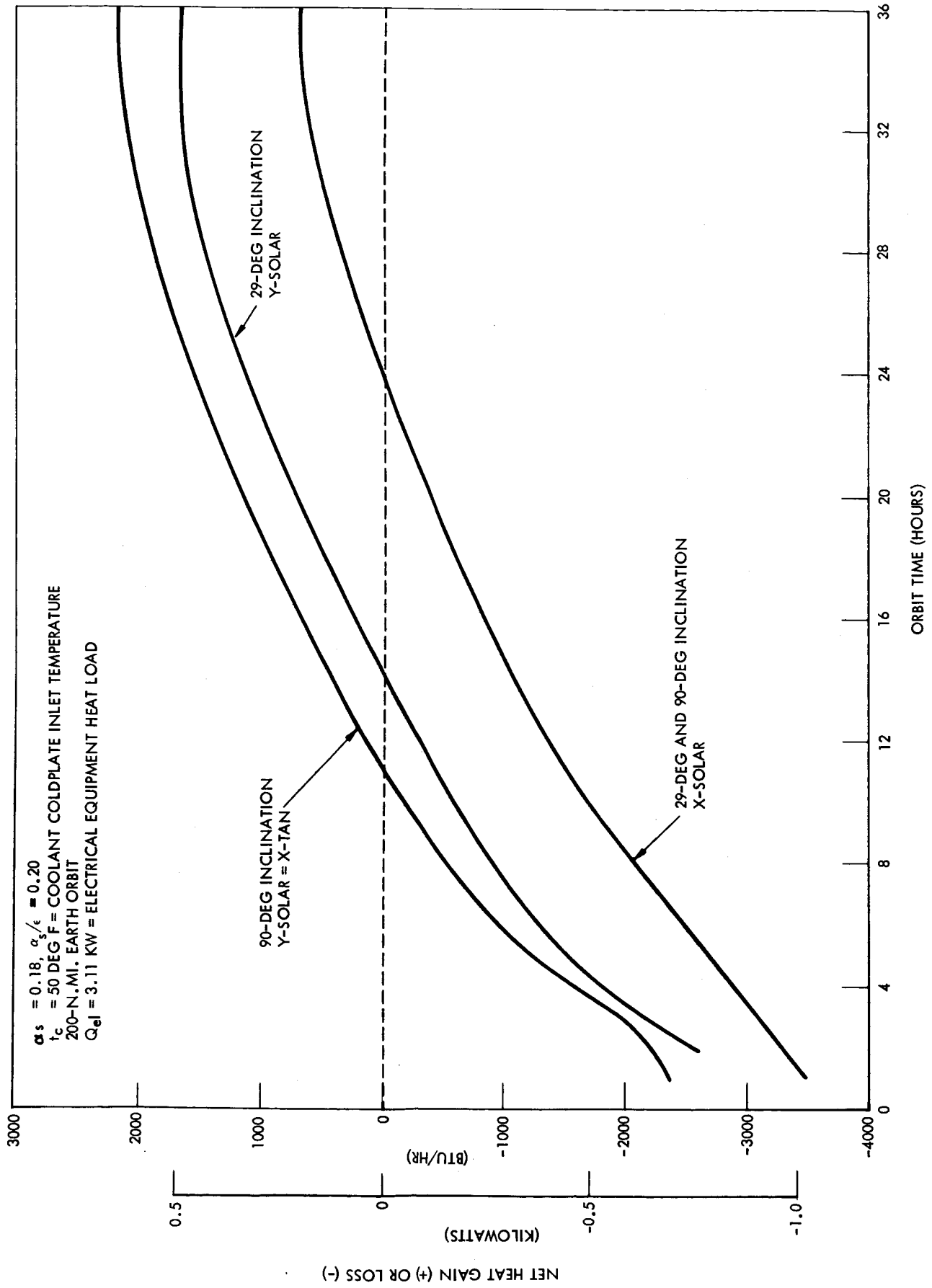

Figure 4-22. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, 200-N. Mi. Orbit, t_c = 50 F, Qel = 3.11 kw

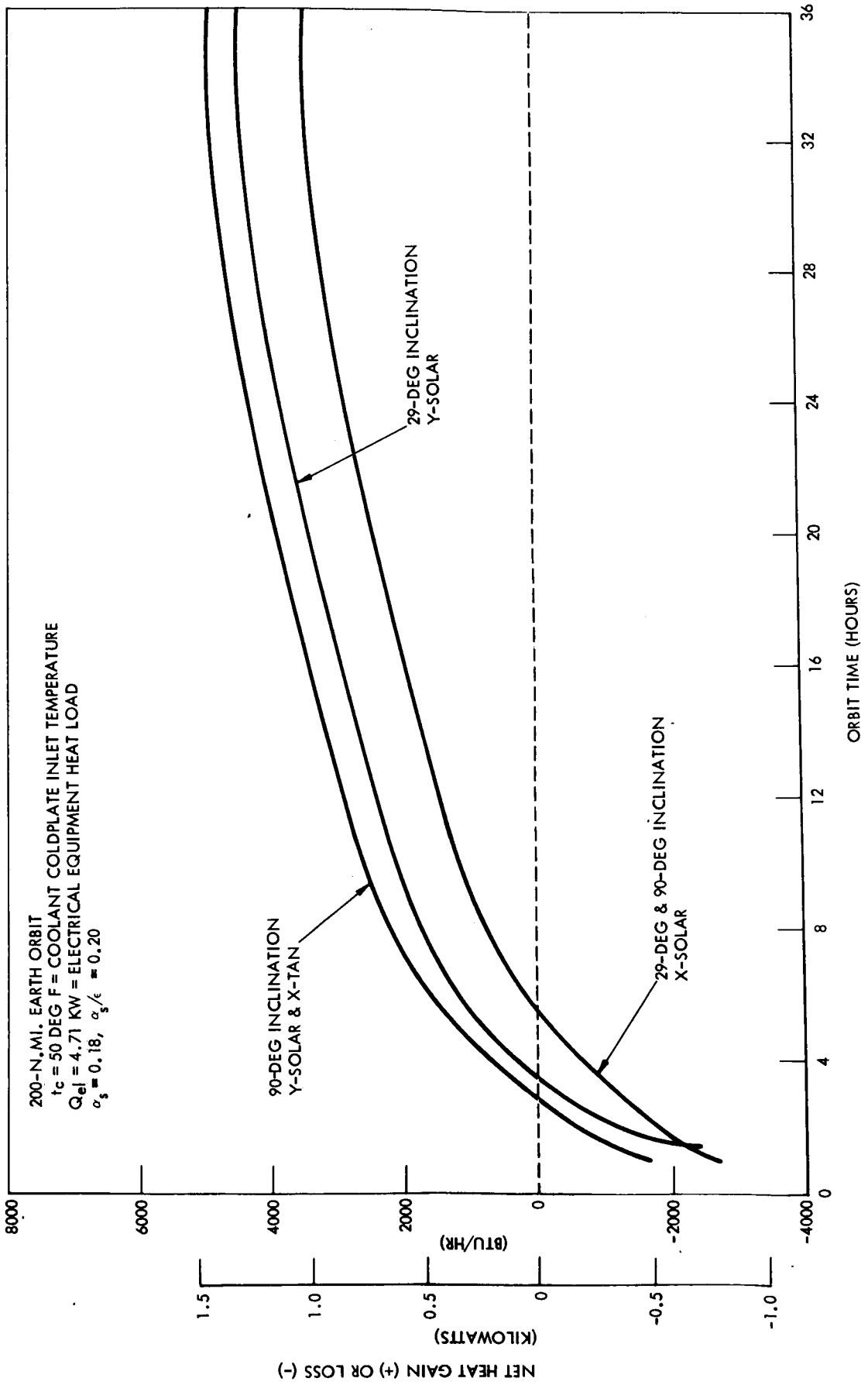

Figure4- 23. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, 200-N. Mi. Orbit, t_c = 50 F, Q_{el} = 4.71 kw

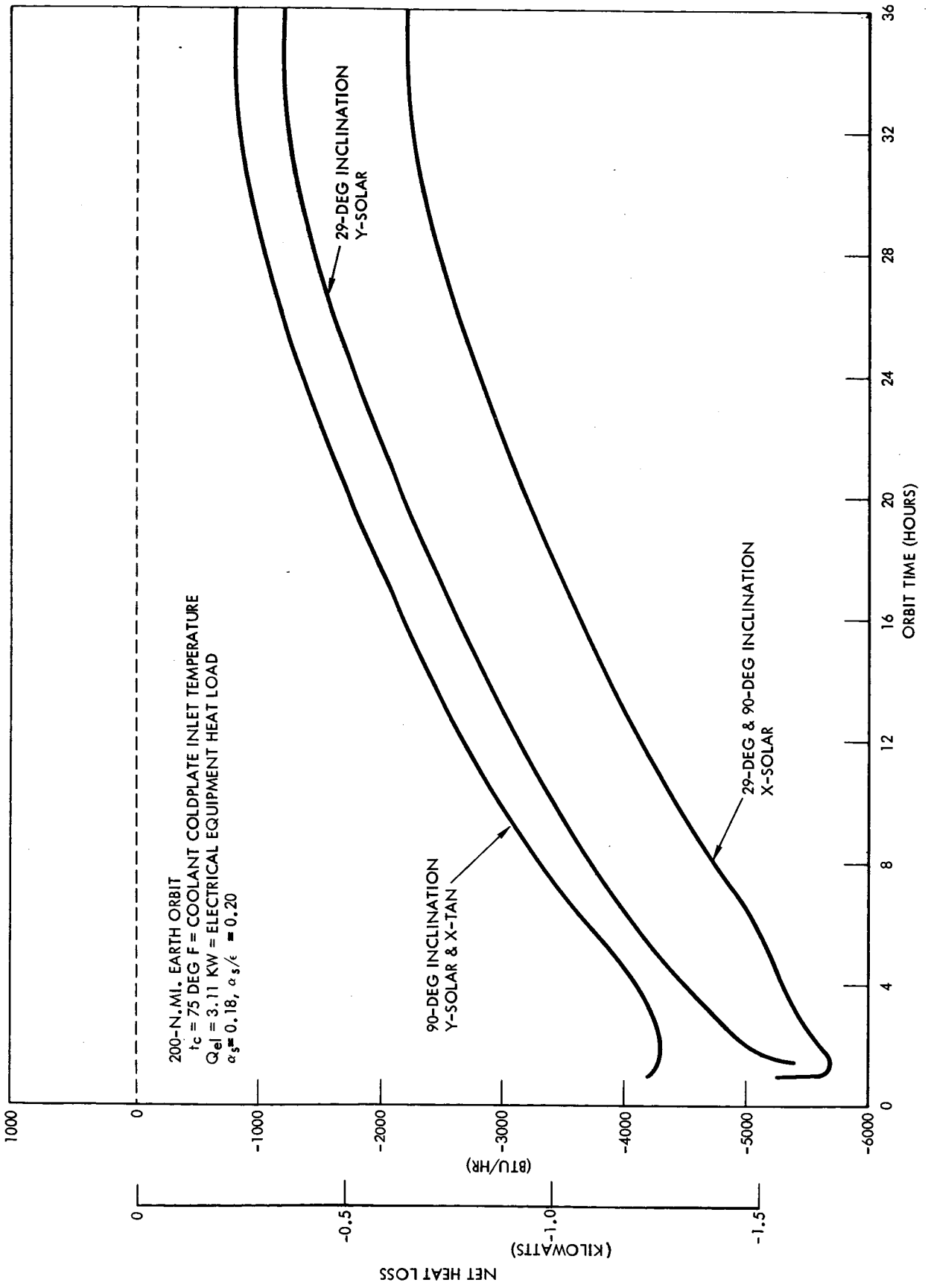

Figure 4-24. Instrument Unit Net Heat Loss Vs Orbit Time, 200-N. Mi. Orbit, t_c = 75 F, Qel = 3.11 kw

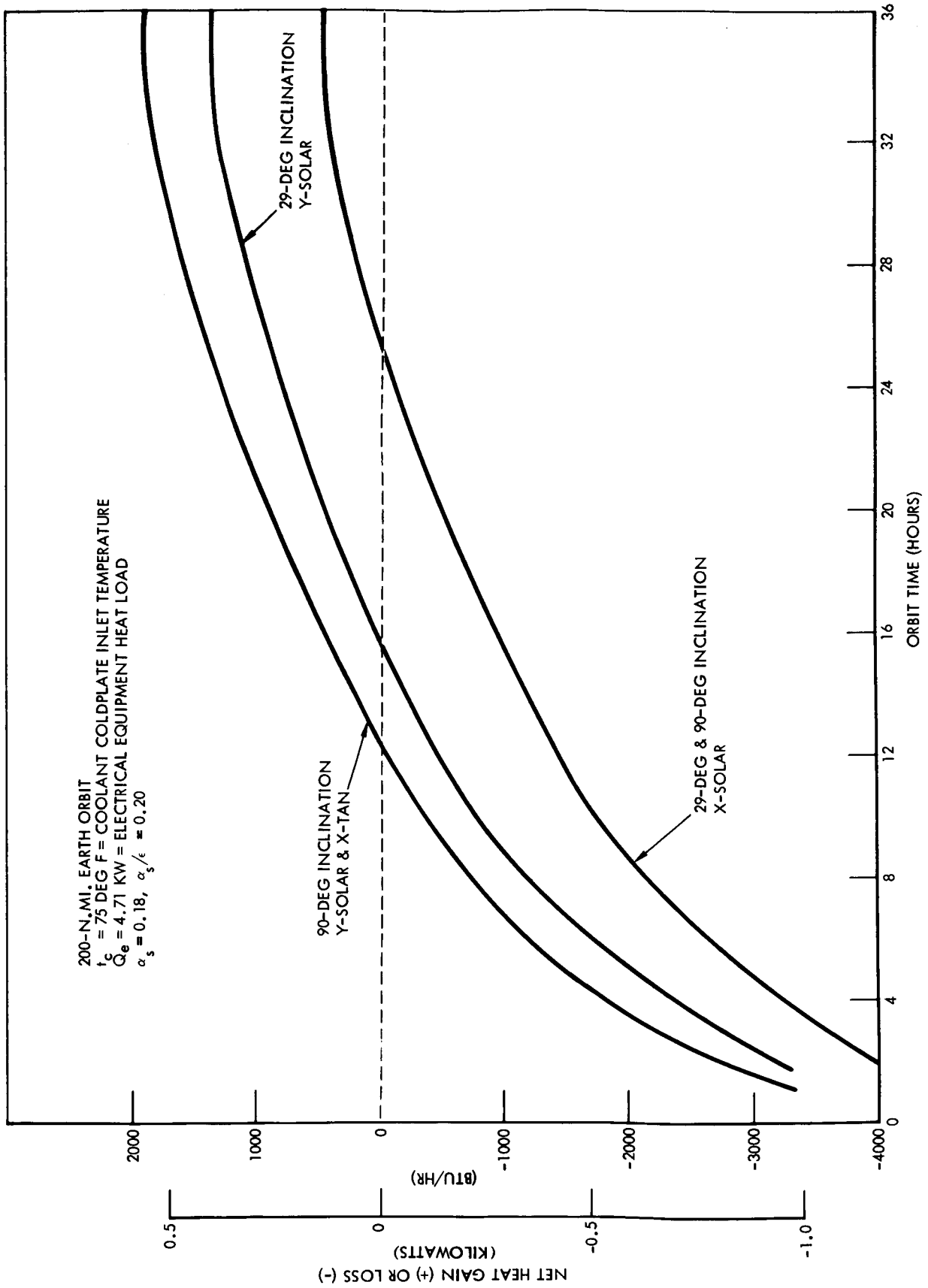

Figure 4-25. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, 200-N. Mi. Orbit, t_c = 75 F, Qel = 4.71 kw

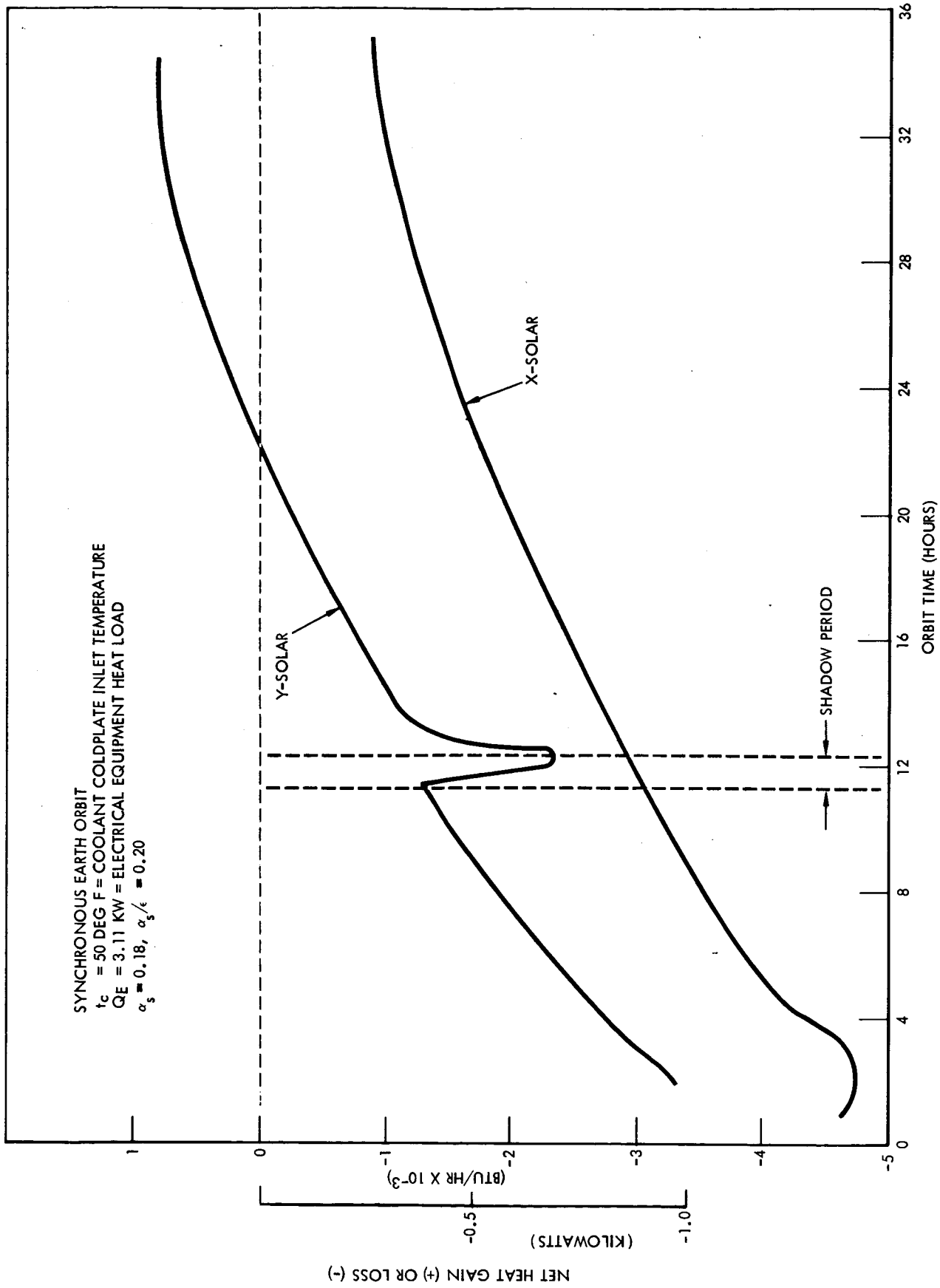

Figure 4-26. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Synchronous Orbit, t_c = 50 F, Q_{el} = 3.11 kw

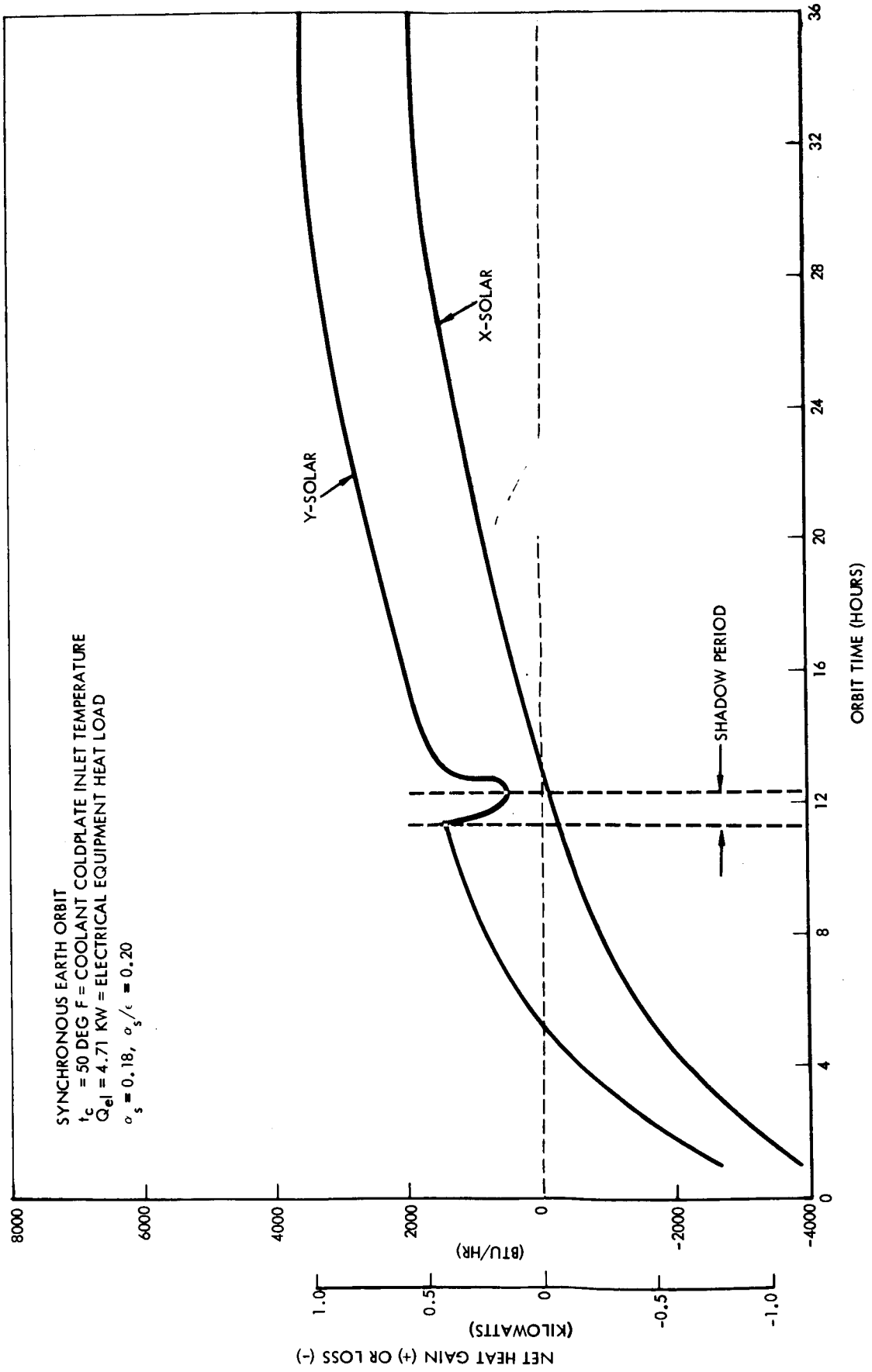

Figure 4-27. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Synchronous Orbit, t_c = 50 F, Q_{el} = 4.71 kw

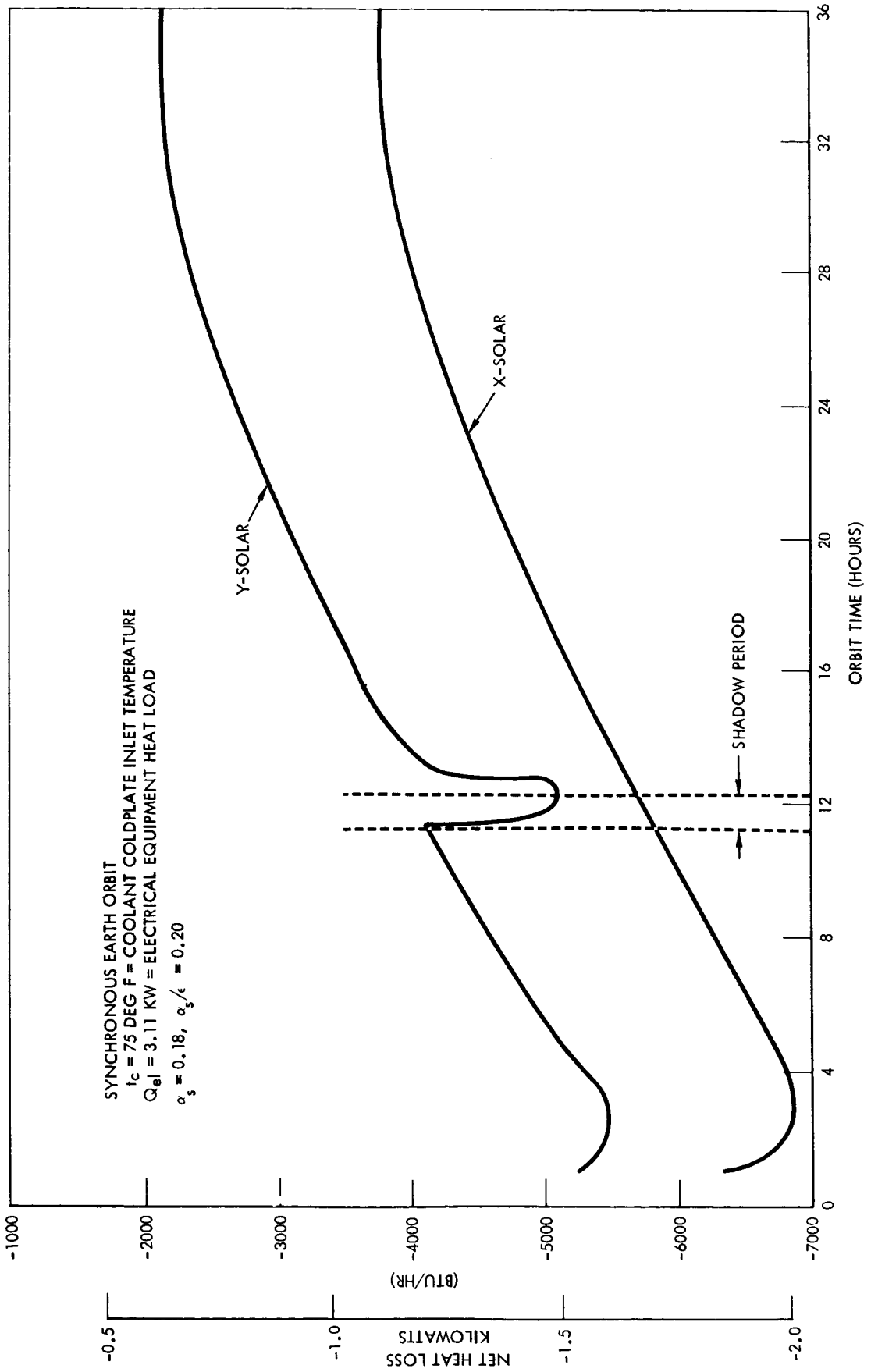

Figure 4-28. Instrument Unit Net Heat Loss Vs Orbit Time, Synchronous Orbit, t_c = 75 F, Q_{el} = 3.11 kw

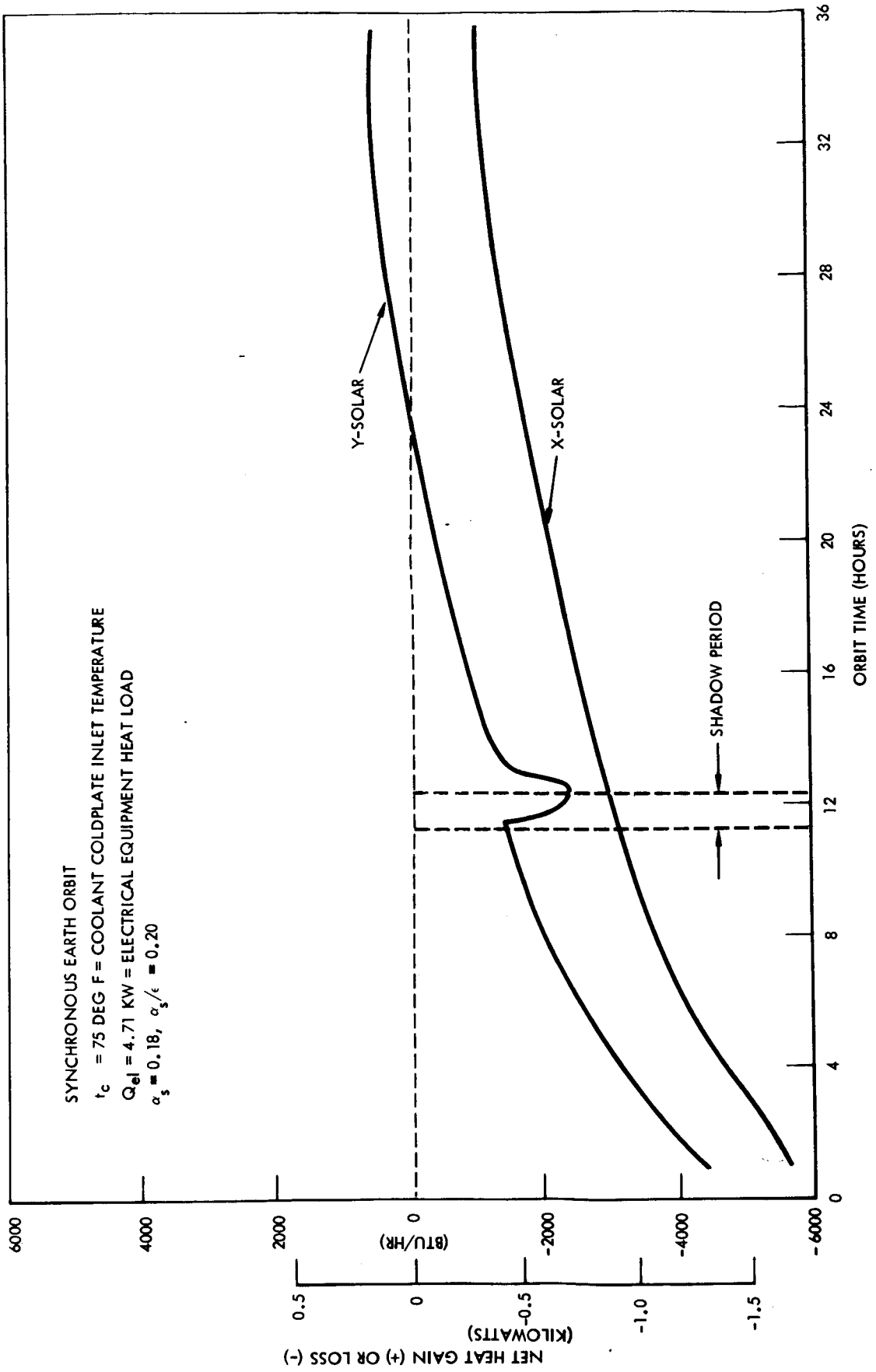

Figure 4-29. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Synchronous Orbit, t_c = 75 F, Qel = 4.71 kw

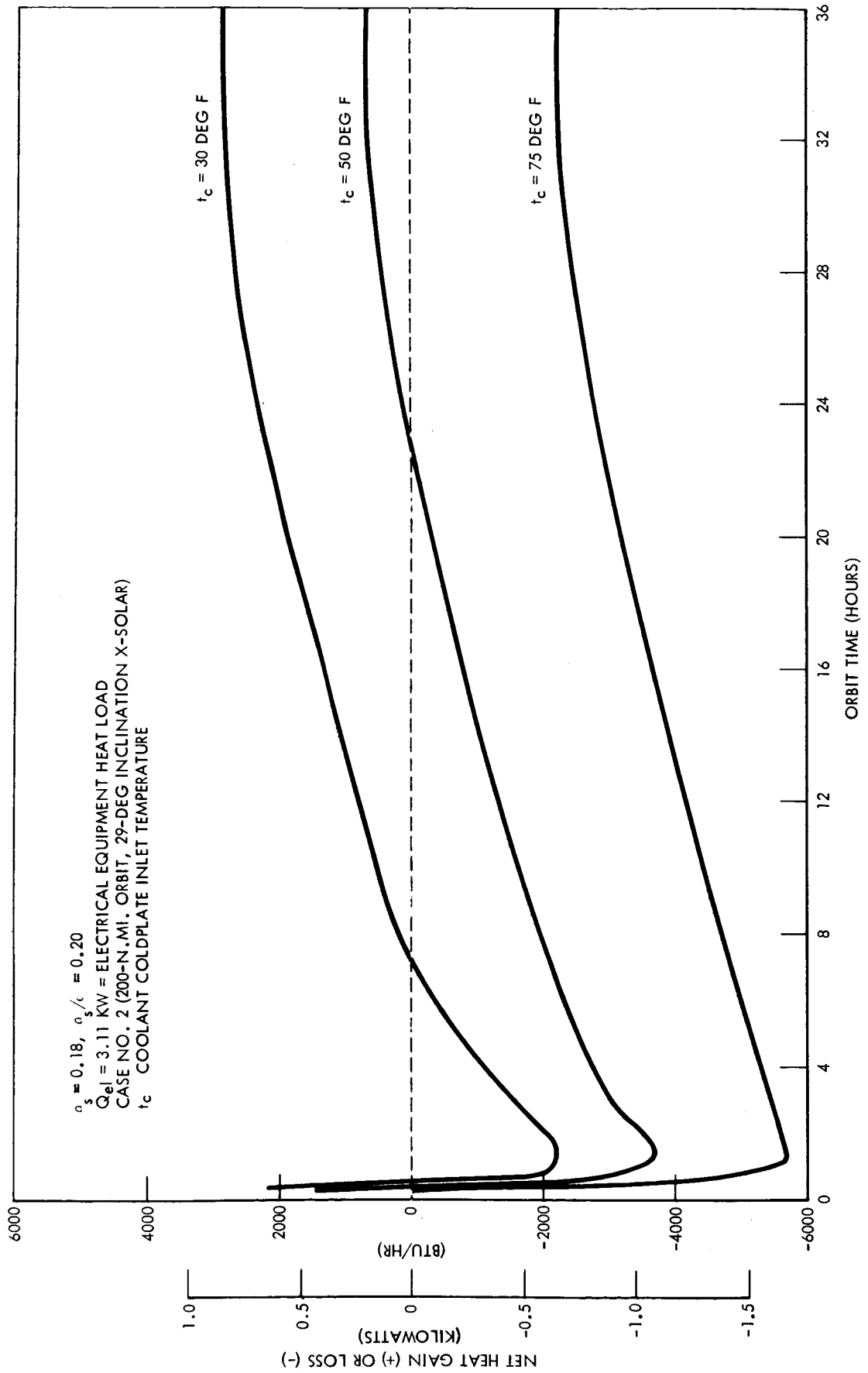

Figure 4-30. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Case No. 2, Q_{el} = 3.11 kw

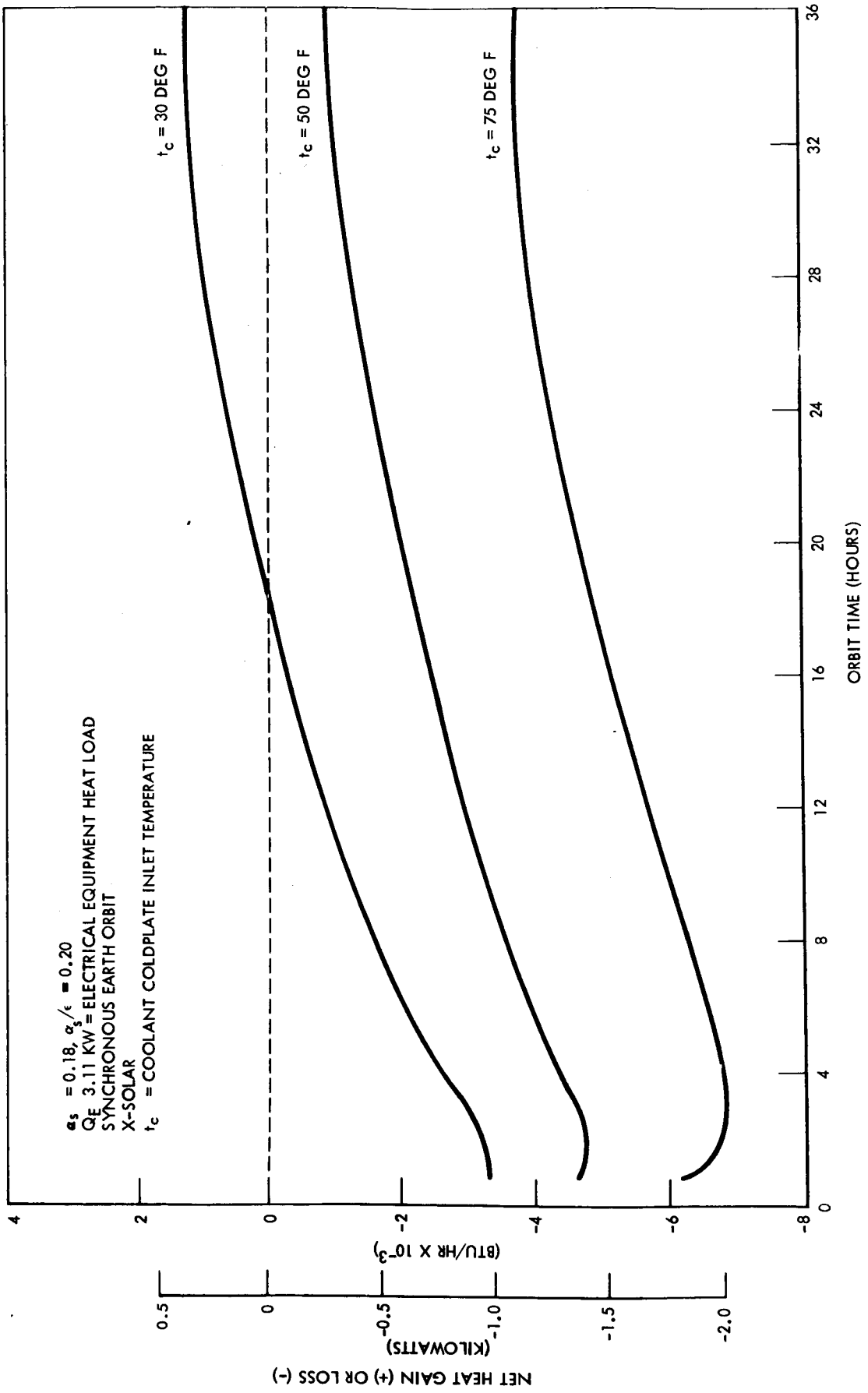

Figure 4-31. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Synchronous Orbit, Q_{el} = 3.11 kw, X-Solar

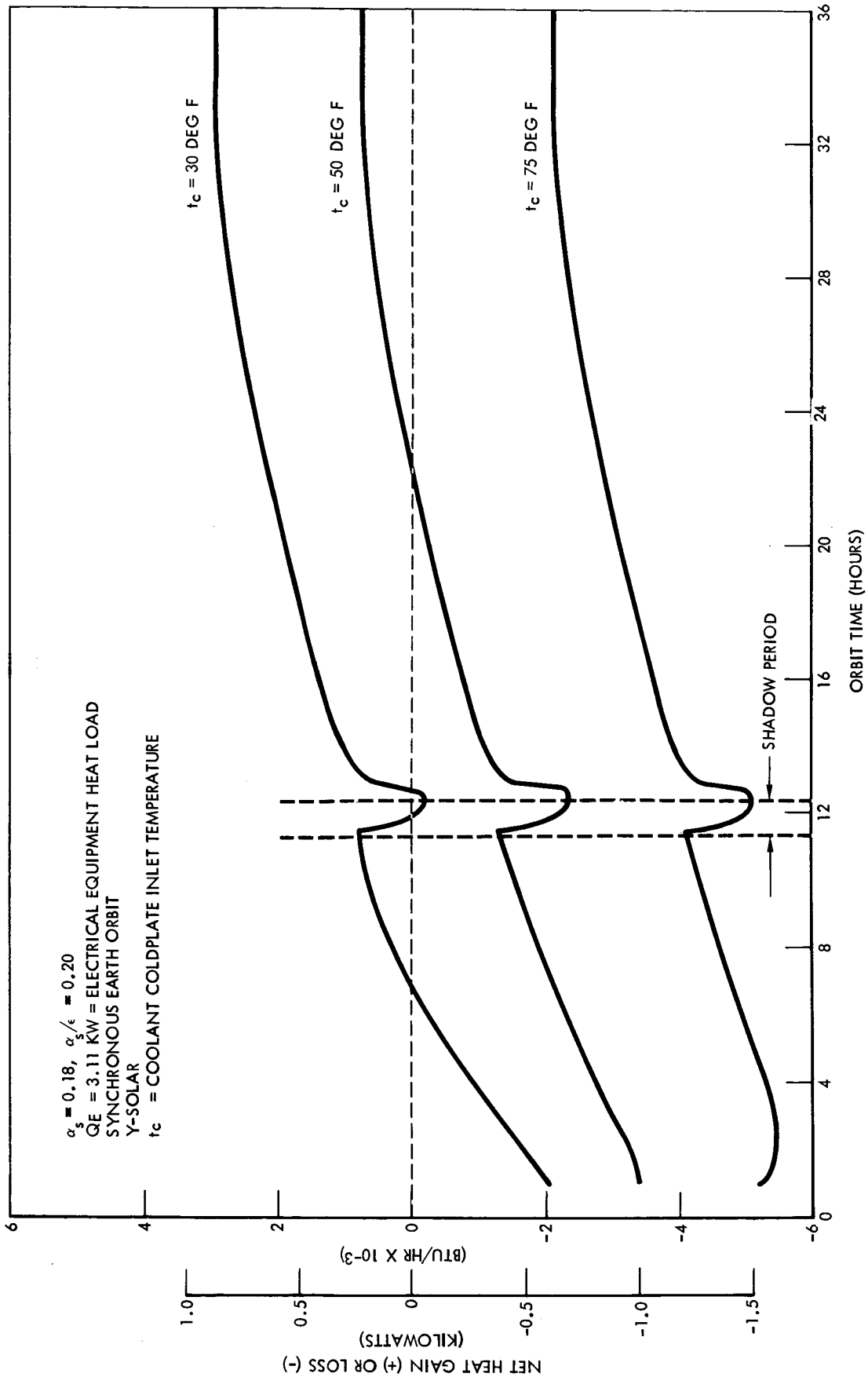

Figure 4-32. Instrument Unit Net Neat Gain or Loss Vs Orbit Time, Synchronous Orbit, Qel = 3.11 kw, Y-Solar

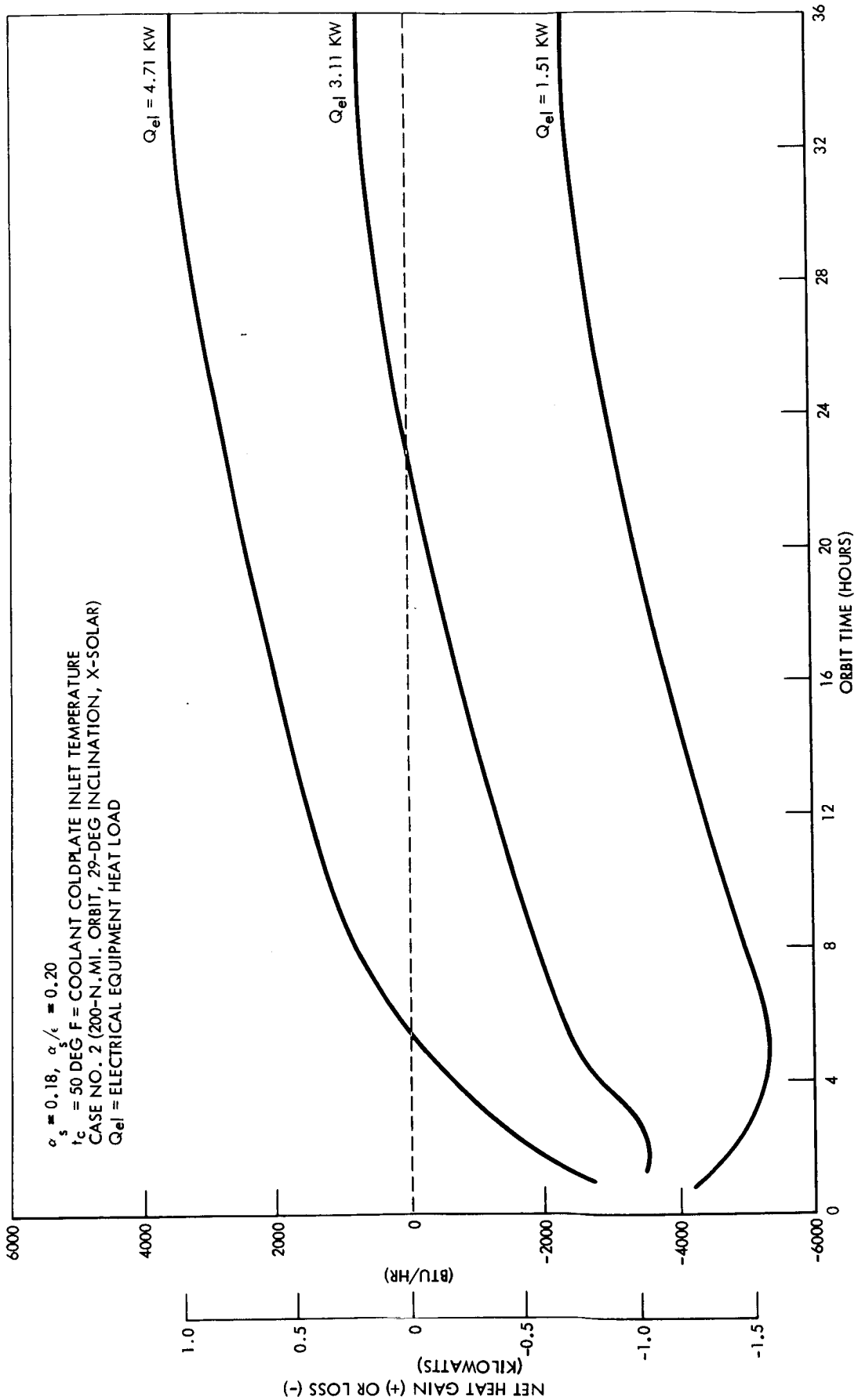

Figure 4-33. Instrument Unit Net Heat Gain or Loss Vs Orbit Time, Case No. 2, t_c = 50 F

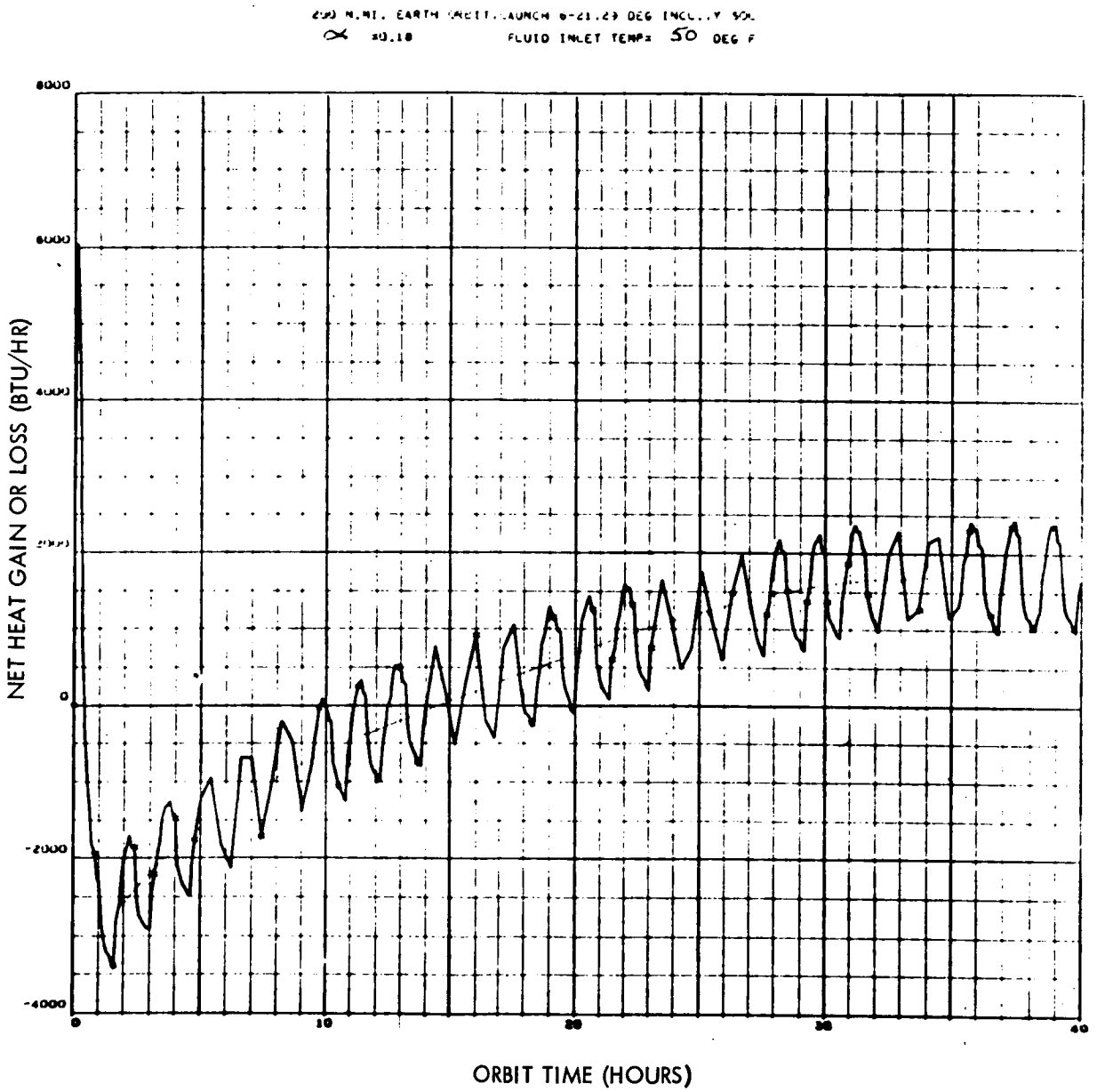

Figure 4-34. Instrument Unit Net Heat Load, Solar Absorptivity = 0.18

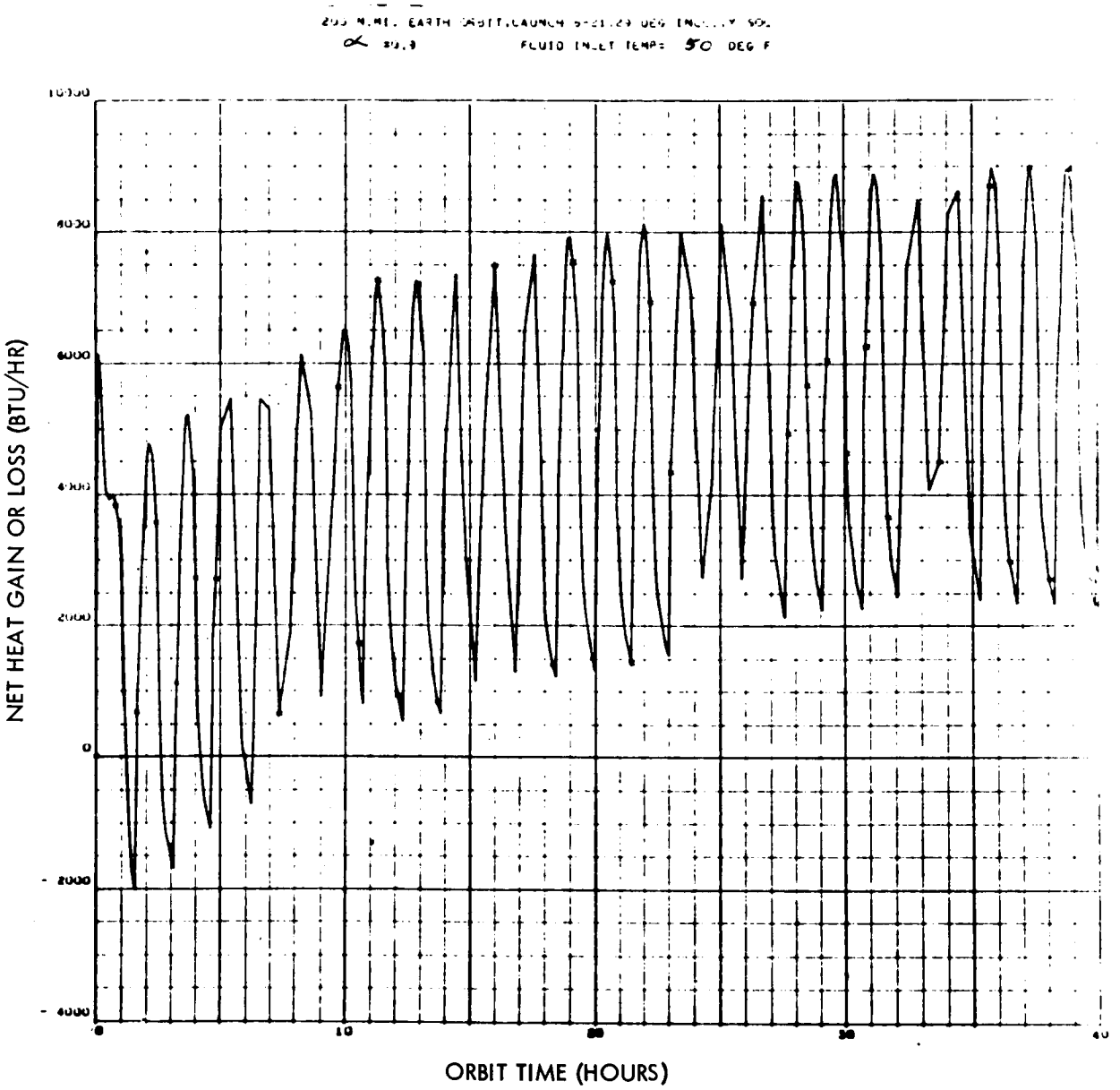

Figure 4-35. Instrument Unit Net Heat Load, Solar Absorptivity = 0.9

electrical equipment heat loads of 1.51, 3.11, and 4.71 kilowatts, respectively, corresponding to individual coldplate heat loads of 50, 150, and and 250 watts. A solar absorptivity (α_s) value of 0.18 for the IU outer shell is applicable to all three figures. A net heat gain in this and subsequent figures indicates the amount of heat that must be absorbed by a heat rejection system, while a net heat loss indicates the amount of heat that must be added to the system to maintain the assumed coolant temperature. Thus, for orbital Case No. 9 in Figure 4-12, 1250 Btu's per hour must be rejected from the thermal control system to maintain the coolant coldplate inlet temperature at 30 F. No heat rejection or addition is required for this case if a coolant coldplate inlet temperature of 42 F is used. In connection with the data in Figure 4-12, it should be noted that the differences between the results for some of the cases are considered insignificant. Orbital case No. 4, for example, is identical to Case No. 6. Hence, heat loads for these cases may be expected to be the same. However, calculated results show a difference between the two cases, reflecting the lack of complete accuracy in the calculation method. In this method, the IU heat load was obtained by the summation of individual coolant circuit heat flows applicable to each coldplate and each integrally cooled piece of equipment.

The variation in IU heat load as a function of equipment power dissipation is shown in Figures 4-14, 4-15, and 4-16 for constant coolant coldplate inlet temperatures of 30 F, 50 F, and 75 F, respectively. These plots also illustrate the effect of variation in α_s on average IU heat load. It should be noted, however, that the data for Cases No. 5 and 9, which represent solar orientation, indicate that the heat load for these cases is not affected by variation in α_s. In this connection, the lines representing Case No. 2 in Figures 4-14, 4-15, and 4-16 also represent results for Cases No. 5 and 8 when $\alpha_s = 0.18$; and the lines applicable to Case No. 3 at $\alpha_s = 0.18$ also represent Case No. 2 at $\alpha_s = 0.9$. Finally, the data for Cases No. 3 and 4 also represent results for Cases No. 7 and 6, respectively.

Another method of presenting the variation in IU heat load as a function of IU outer shell solar absorptivity is illustrated in Figure 4-17 for Case No. 3. These data are for a constant electrical equipment heat load of 3.11 kilowatts (150 watts per coldplate) and for coolant coldplate inlet temperatures of 30 F, 50 F, and 75 F. It may be observed that the heat load variation in response to variation in α_s is practically linear. Hence, straight-line interpolation may be employed for calculating IU heat loads at α_s values between 0.18 and 0.9 from the data presented in Figures 4-14, 4-15, and 4-16. Cross-plotting the data in these figures results in graphs that show IU heat load as a function of coolant coldplate inlet temperature, with electrical equipment heat load as a parameter. This type of plot is illustrated in Figures 4-18 through 4-21, which can be used to determine the coolant temperature range resulting from equipment heat load variation. For example, Figure 4-18 shows that, when there is no heat rejection from or addition to the coolant circuit (zero IU heat load), the coolant temperature ranges from 28.5 F at $Q_{el} = 1.5$ kilowatts to

77 F at Q_{el} = 4.5 kilowatts. If this represents the possible variation in electrical equipment heat load for the orbital case in question, and if the resulting coolant temperature range is permissible as far as equipment operation is concerned, no cooling or heating is necessary. Conversely, if the permissible coolant temperature range is defined, maximum cooling and/or heating requirements may be determined for a given equipment heat load variation. Thus, if the permissible coolant temperature range is assumed to be 40 F to 55 F and the equipment heat load varies between 1.5 and 3.5 kilowatts, Figure 4-18 indicates a maximum heating requirement of 1250 Btu's per hour and a maximum cooling requirement of 700 Btu's per hour.

The data discussed to this point refer to equilibrium environmental conditions, i.e., when the S-IVB dome temperature has reached its final value of 60 F. (See Figure 4-10.) To illustrate conditions applicable to operation between injection into orbit and the time that this equilibrium is reached (0 to 35 hours of orbit time), Figures 4-22 through 4-29 have been prepared to summarize the transient conditions of 200-nautical-mile and synchronous earth orbits. These figures show IU heat load as a function of orbit time for coolant coldplate inlet temperatures of 50 F and 75 F and electrical equipment heat loads of 3.11 and 4.71 kilowatts. A characteristic common to all operating conditions selected for this investigation is the requirement for heat addition to the coolant circuit during the initial portion of each mission. This requirement is readily apparent from an examination of Figures 4-22 through 4-29, which also indicate that some missions will require continuous heat addition. Data for the synchronous orbit with the X axis along the orbit path (X-tan) were not plotted in Figures 4-26 through 4-29. The heating or cooling requirements for this orbital condition will generally fall between those for the two other conditions shown (X-solar and Y-solar). This fact has been confirmed by comparison of tabular data in the computer program output. However, the results appear to contain an error that may lead to erroneous conclusions. Hence, they were omitted from the graphs. It should also be noted that the dip in some of the curves, beginning at an orbit time of 11.4 hours, corresponds to the passage of the IU through the earth's shadow.

Another method of presenting data for the transient condition is illustrated in Figures 4-30, 4-31, and 4-32, which show IU heat load versus orbit time, with coolant coldplate inlet temperature as a parameter. These three graphs apply to a constant electrical equipment heat load of 3.11 kilowatts and to three specific orbit conditions. For the 200-nautical-mile orbit, Figure 4-33 shows IU heat load versus orbit time, with electrical equipment heat load as a parameter, based on a constant coolant coldplate inlet temperature of 50 F.

Data similar to those shown in Figures 4-22 through 4-29 are presented in Figures 4-36 through 4-43. The latter results were obtained under the same conditions of orbital altitude, vehicle orientation, electrical equipment

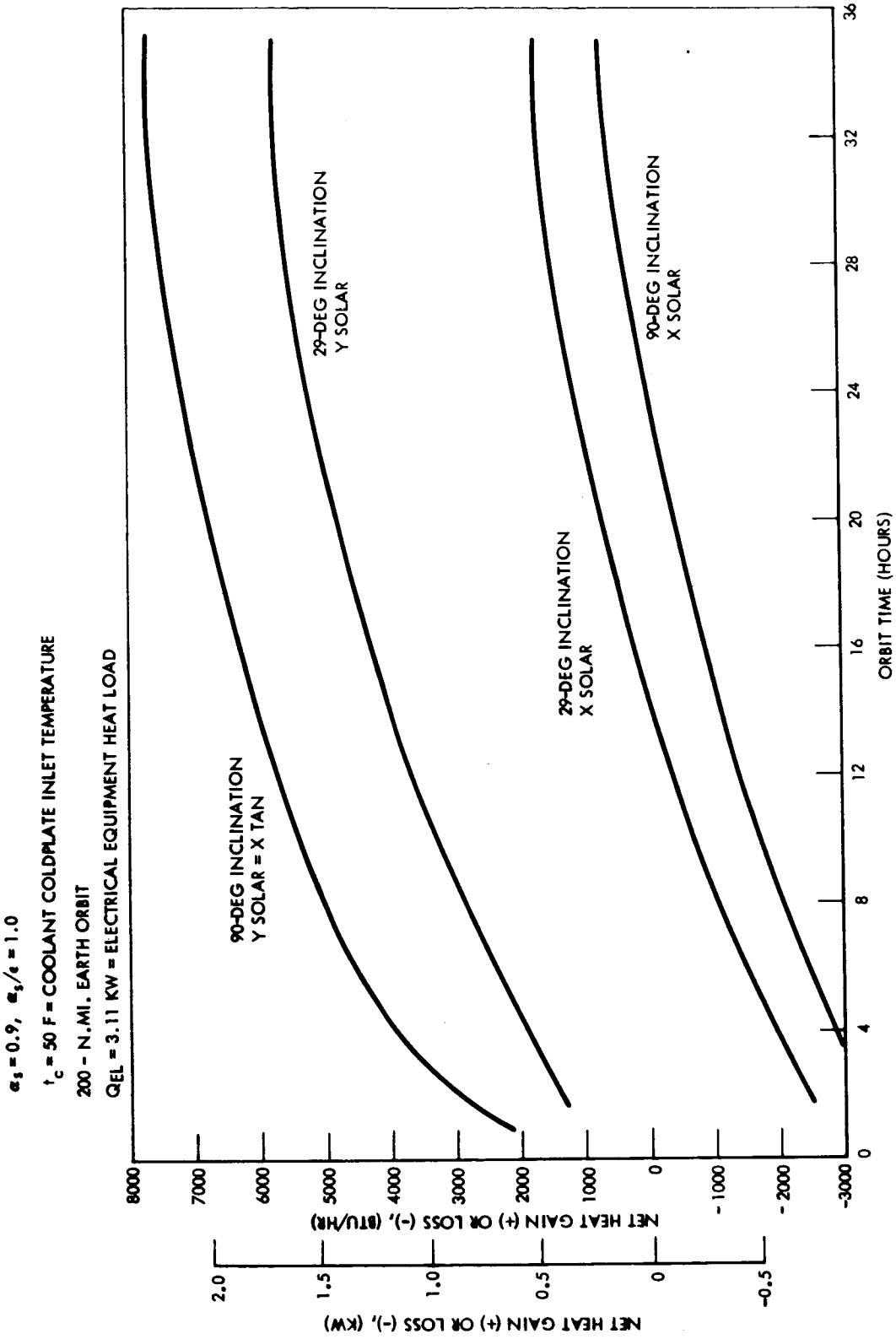

Figure 4-36. Instrument Unit Net Heat Gain or Loss Versus Orbit Time— 200-N.Mi. Earth Orbit, $t_c = 50$ F, $Q_{el} = 3.11$ kw, $\alpha_s = 0.9$

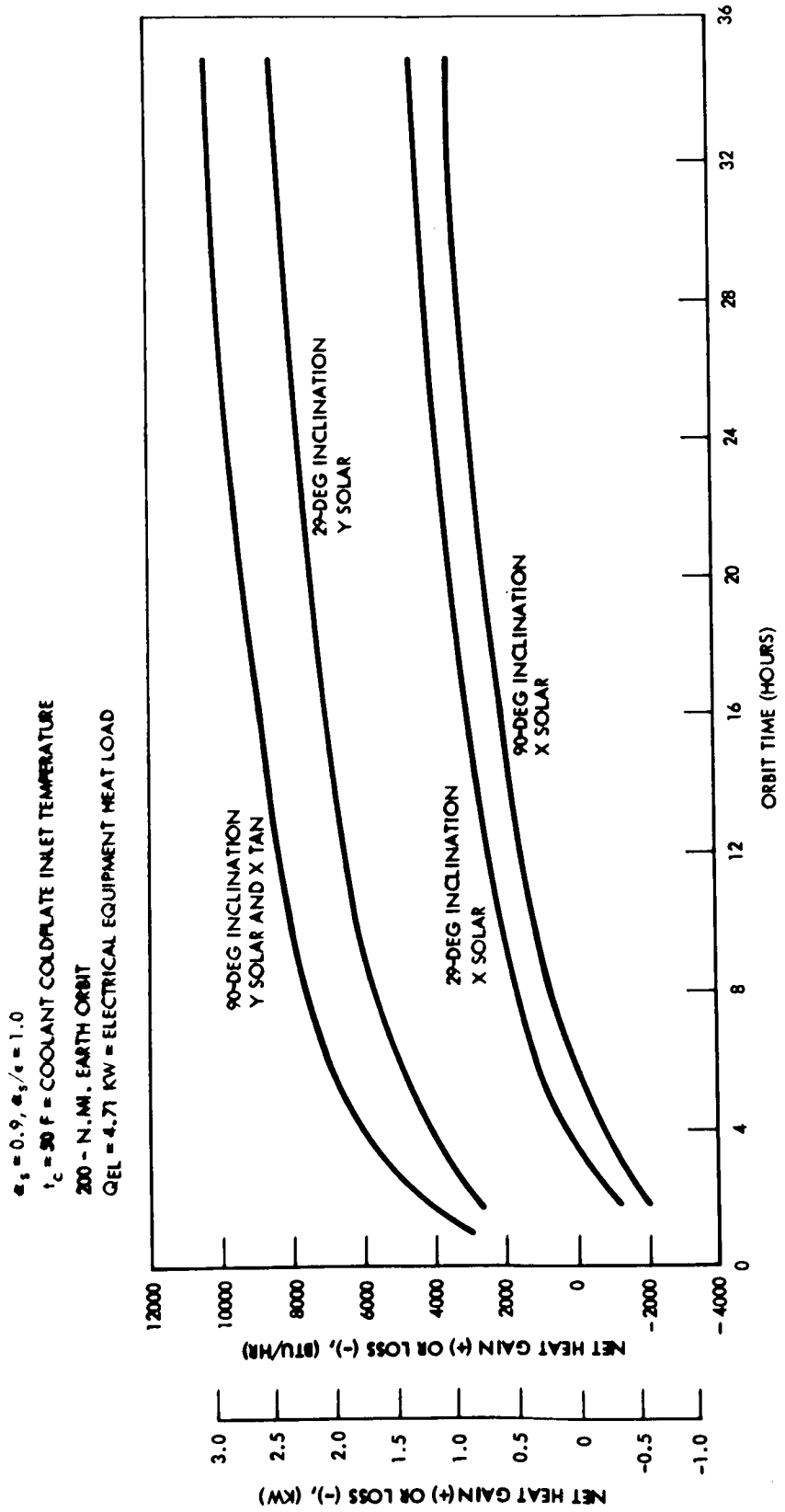

Figure 4-37. Instrument Unit Net Heat Gain or Loss Versus Orbit Time — 200-N.Mi. Earth Orbit, t_c = 50 F, Q_{el} = 4.71 kw, α_s = 0.90

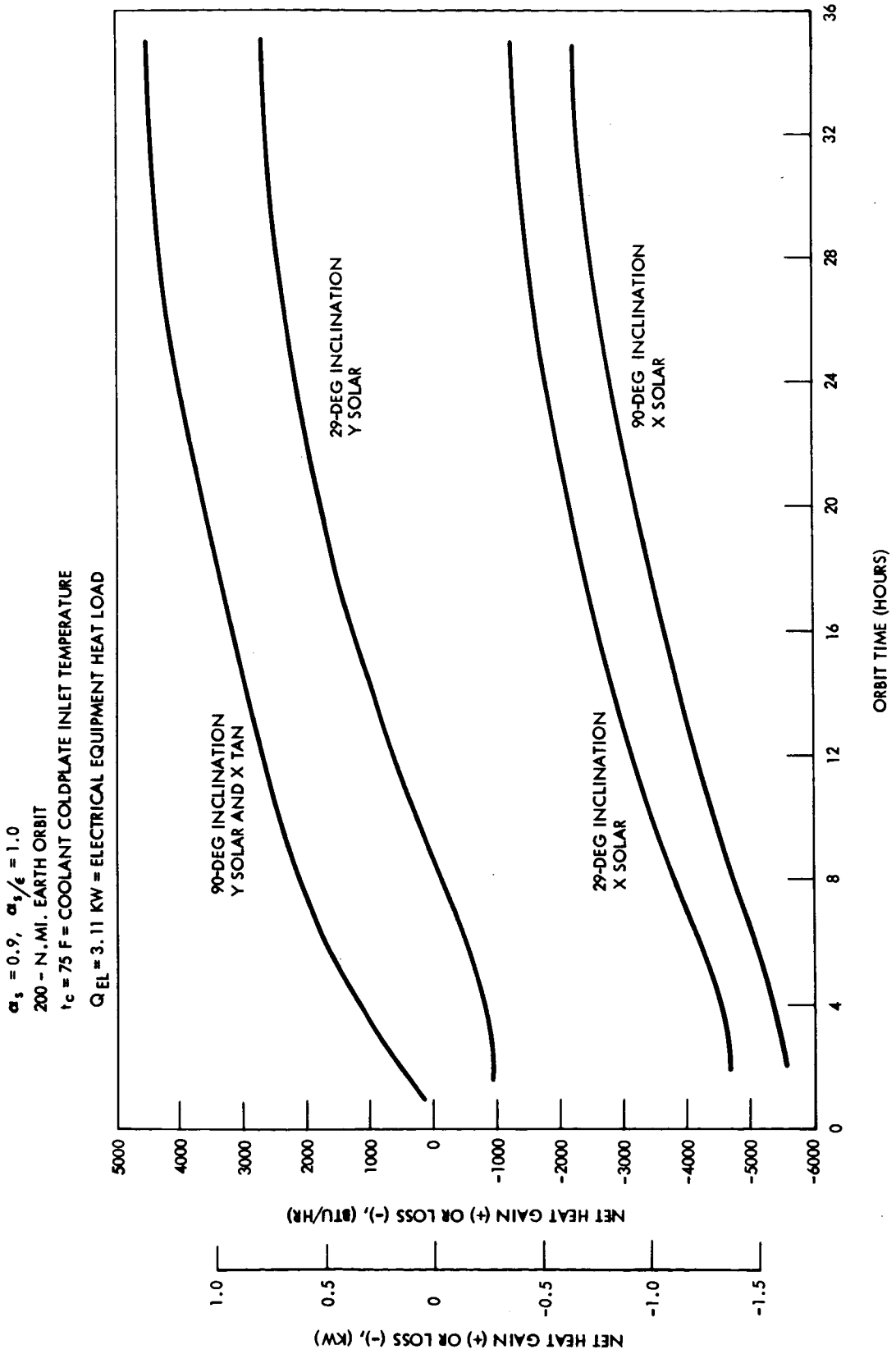

Figure 4-38. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N. Mi. Earth Orbit, t_c = 75 F, Q_{el} = 3.11 kw, α_s = 0.90

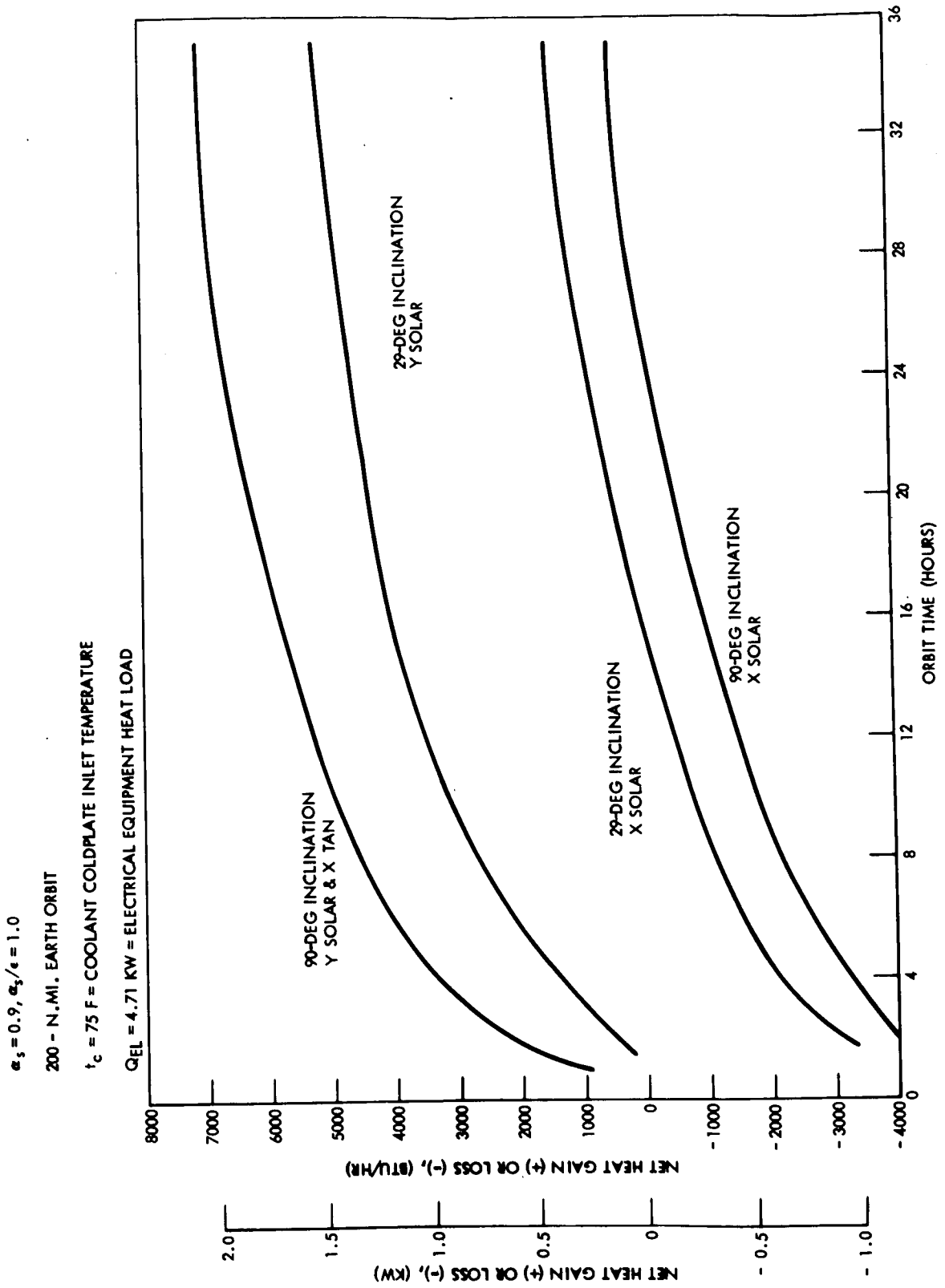

Figure 4-39. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N. Mi. Earth Orbit, t_c = 75 F, Q_{el} = 4.71 kw, α_s = 0.90

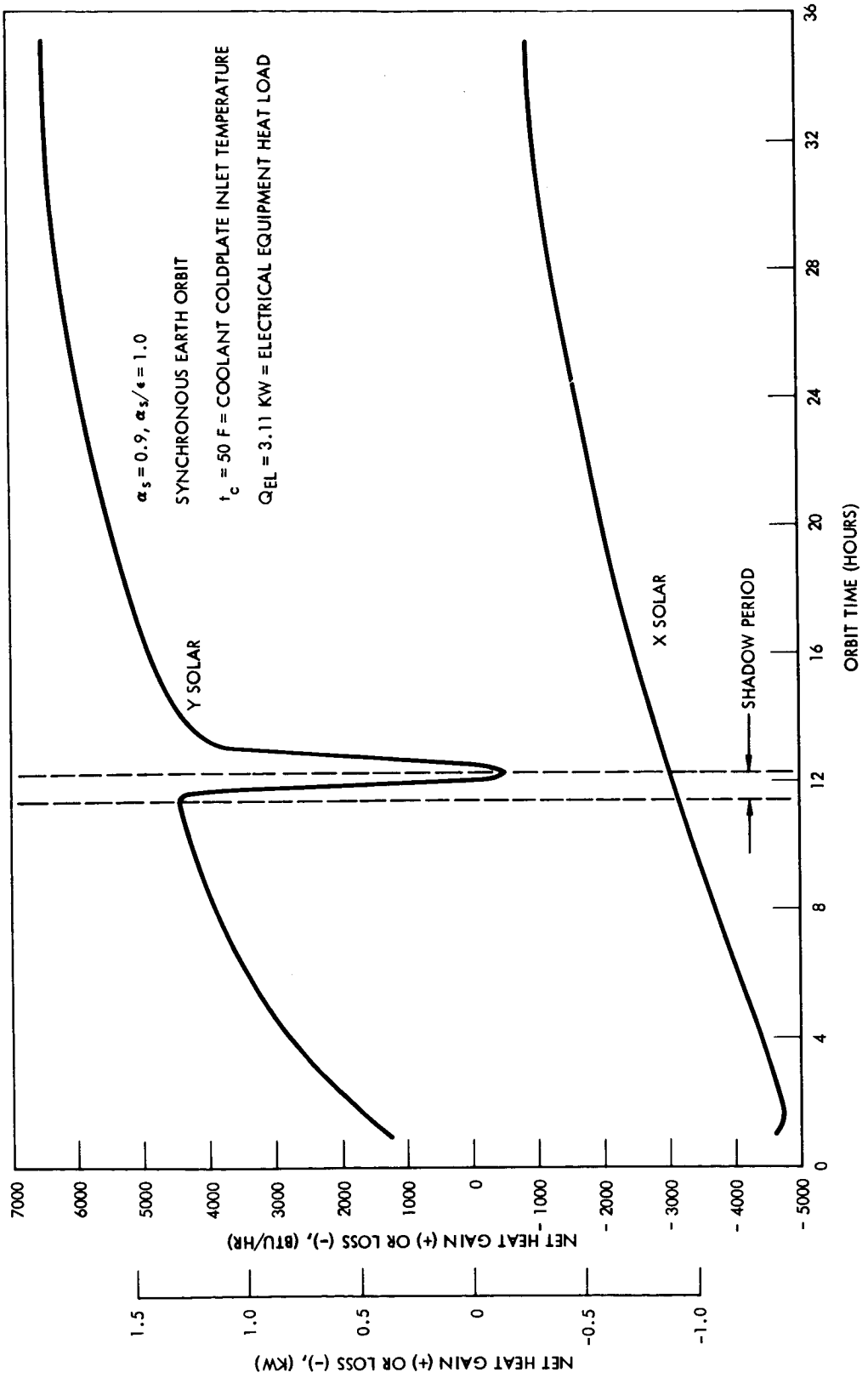

Figure 4-40. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—Synchronous Orbit, t_c = 50 F, Q_{el} = 3.11 kw, α_s = 0.90

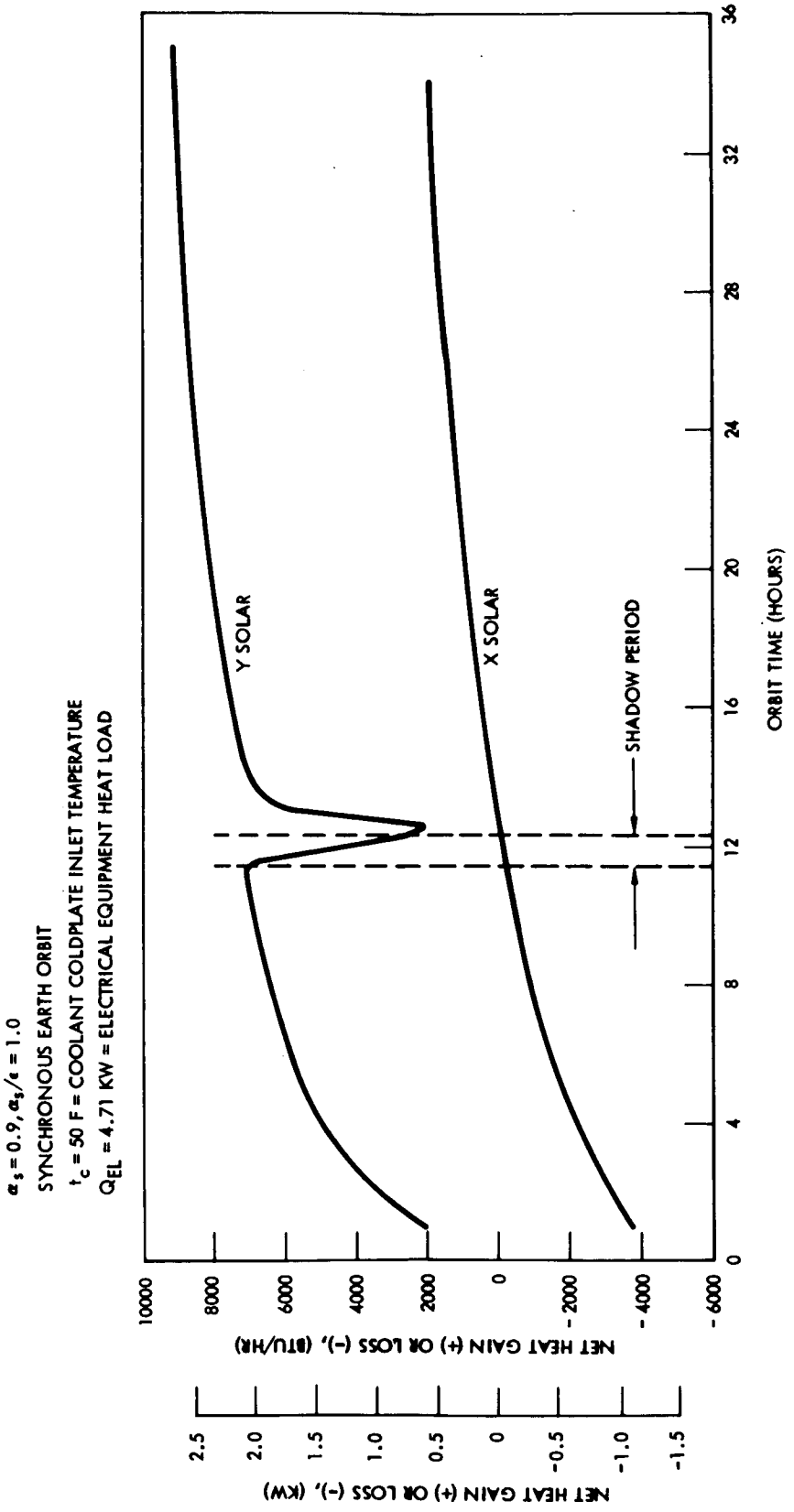

Figure 4-41. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—Synchronous Orbit, t_c = 50 F, Q_{el} = 4.71 kw, α_s = 0.90

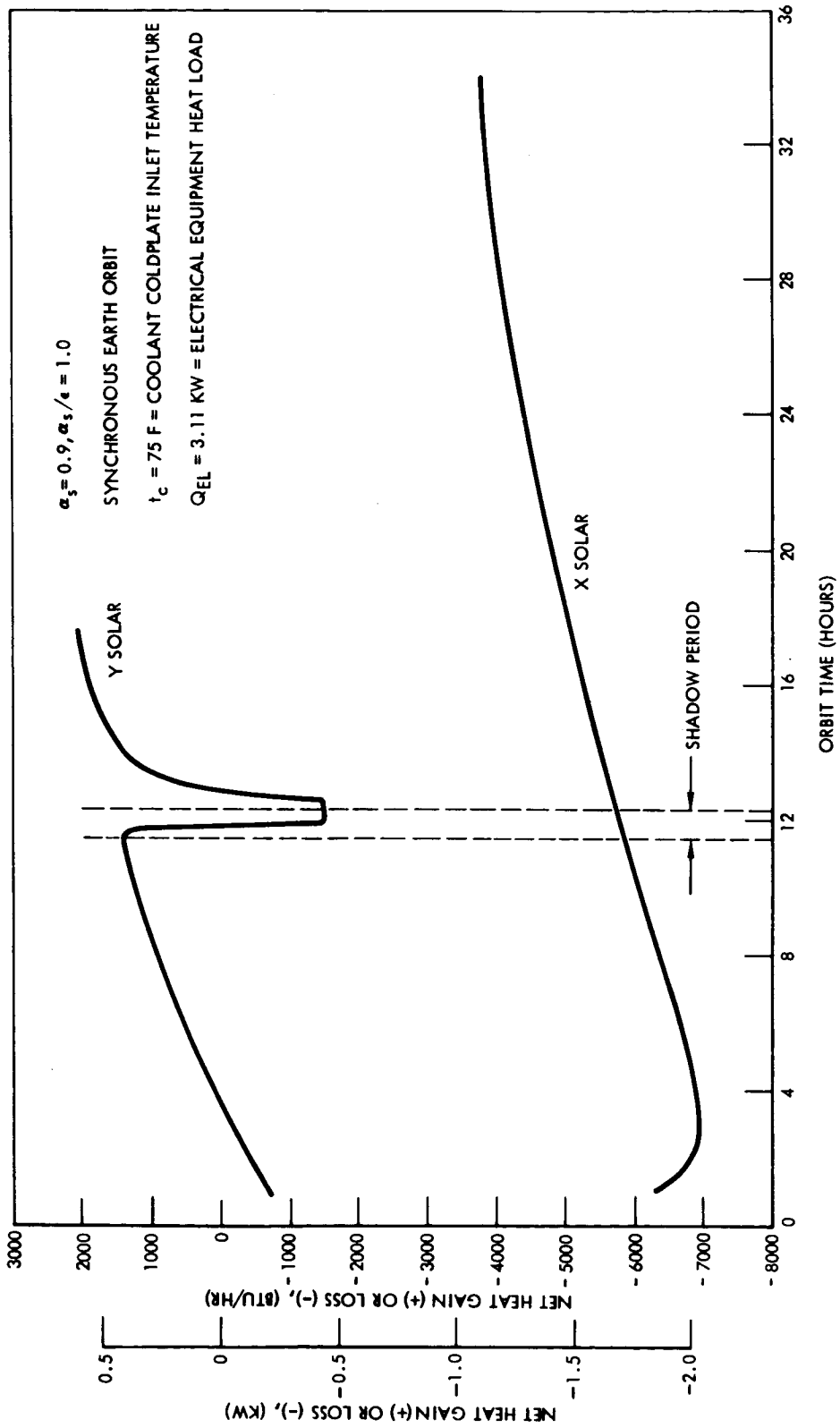

Figure 4-42. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—Synchronous Orbit, t_c = 75 F, Q_{el} = 3.11 kw, α_s = 0.90

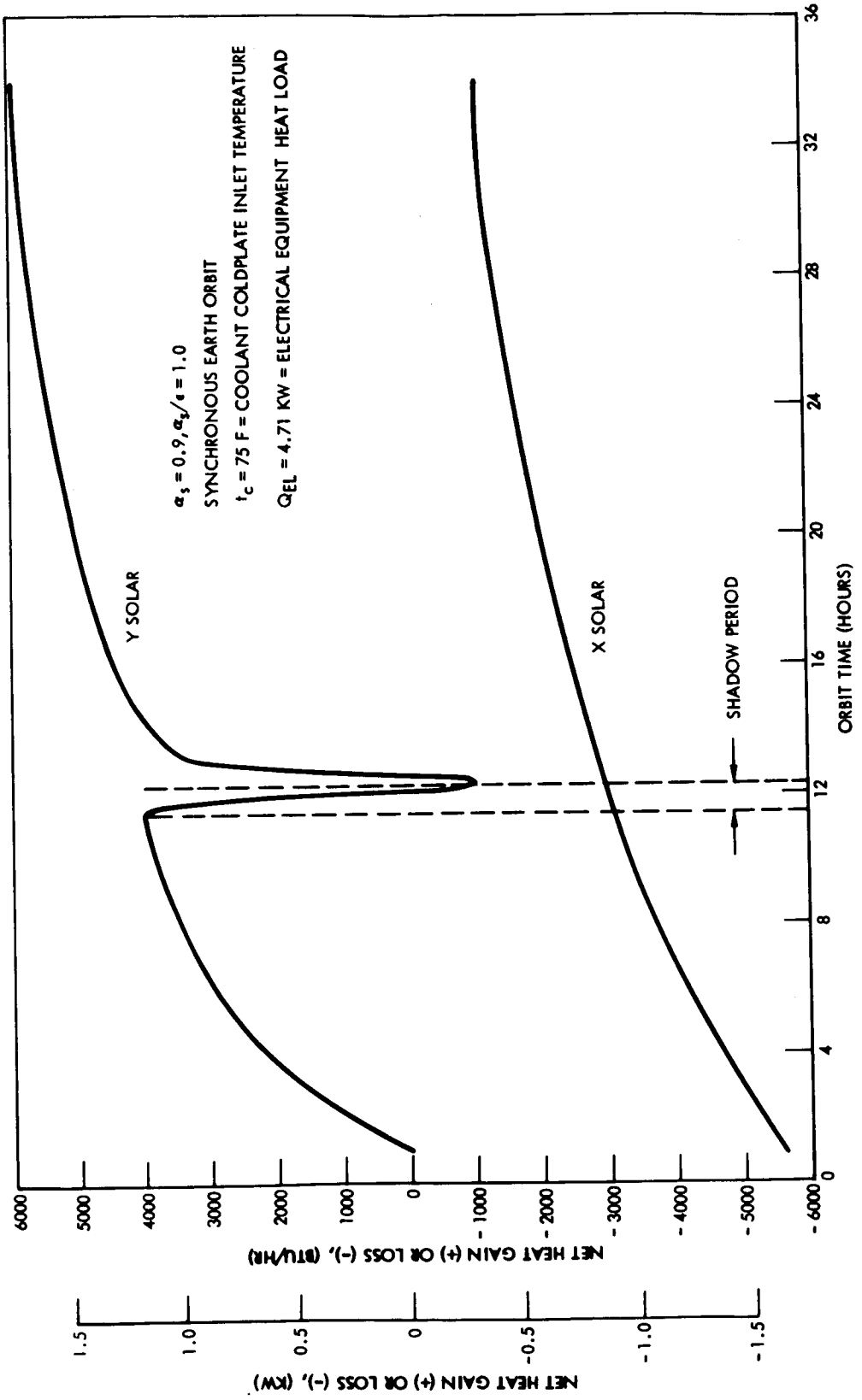

Figure 4-43. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—Synchronous Orbit, t_c = 75 F, Q_{el} = 4.71 kw, α_s = 0.90

heat loads, and coolant coldplate inlet temperatures as the former data, but a solar absorptivity value of 0.9 was used for the instrument unit outer shell instead of the previous value of 0.18. Bearing in mind that the net heat gain or loss shown in the graphs represents the average during a complete orbit, a comparison can be made to evaluate the effect of change in solar absorptivity on instrument unit heat load during varying S-IVB dome temperature conditions. This comparison reveals the following:

1. The shape of the curves of net heat gain or loss as a function of time is not affected by variation in IU outer shell solar absorptivity.

2. The instrument unit heat load is not affected by variation in IU outer shell solar absorptivity when the IU is in the miminum solar heating orientation (x-solar) and in a synchronous orbit or a 200-nautical-mile polar orbit. This is due to the absence of any direct solar radiation incident upon the IU outer shell and the negligible effect of albedo radiation.

3. When the IU is in the minimum solar heating orientation (x-solar) and in a 200-nautical-mile earth orbit at 29-degree inclination, a change in IU outer shell solar absorptivity from 0.18 to 0.9 results in an increase in instrument unit heat load of 1000 Btu/hr. This increase is due to albedo radiation alone because, in the x-solar orientation, there is no direct solar radiation incident upon the IU outer shell.

4. When the IU is in the maximum solar heating orientation (y-solar) and in a 200-nautical-mile earth orbit at 29-degree inclination, a change in IU outer shell solar absorptivity from 0.18 to 0.9 results in an increase in instrument unit heat load of 4000 Btu/hr for a coolant coldplate inlet temperature of 50 F. When this temperature is 75 F, the increase in heat load varies from 3700 to 3950 Btu/hr from the beginning to the end of the period investigated.

5. When the IU is in the maximum solar heating orientation (y-solar) and in a 200-nautical-mile polar orbit, a change in IU outer shell solar absorptivity from 0.18 to 0.9 results in an increase in instrument unit heat load of 5500 Btu/hr for a coolant coldplate inlet temperature of 50 F. When this temperature is 75 F, the increase in heat load varies from 4750 to 5400 Btu/hr, depending on orbit time and electrical equipment heat load level.

6. When the IU is in the maximum solar heating orientation (y-solar) and in a synchronous orbit, a change in IU outer shell solar absorptivity from 0.18 to 0.9 results in an increase in instrument unit heat load of 5400-5700 Btu/hr, depending on coolant coldplate inlet temperature and electrical equipment heat load level.

These results, summarized in Table 4-8, suggest the possibility of using the solar absorptivity of the IU outer shell to counteract the influence of the S-IVB dome during the first few hours of a mission. During 200-nautical-mile orbits, however, higher values of solar absorptivity produce large variations in solar heating rate with change in orbital position. As a result, control system requirements may become difficult to meet if the coolant temperature needs to be maintained within a narrow band.

Table 4-8. Instrument Unit Net Heat Increment due to Change in α_s From 0.18 to 0.9

Mission	Net Heat Increment (Btu/hr)			
	Coolant Coldplate Inlet Temperature (50 F)		Coolant Coldplate Inlet Temperature (75 F)	
	Electrical Equipment Heat Load (kw)		Electrical Equipment Heat Load (kw)	
	3.11	4.71	3.11	4.71
Synchronous Orbit x-solar	←		No change	→
200-n.mi. Polar Orbit x-solar	←		No change	→
200-n.mi. Orbit, 29-degree inclination x-solar	+1000	+1000	+1000	+1000
200-n.mi. Orbit, 29-degree inclination y-solar	+4000	+4000	+3700 to +3950	+3700 to +3900
200-n.mi. Polar Orbit y-solar	+5500	+5500	+5400	+4750 to +5200
Synchronous Orbit y-solar	+5700	+5500	+5500	+5400

For instrument unit orientations that are not affected by variations in solar absorptivity of the outer shell, and for cases in which the increase in solar heating with increase in α_s is less than desired, the temperature level of the coolant may be raised by using an outer shell coating with an infrared emissivity lower than the value of 0.9 used in the thermal analysis. The effect of variation in emissivity on instrument unit total heat load is illustrated in Figure 4-44, which represents data for the synchronous orbit condition and with the instrument unit in a minimum solar heating orientation (x-solar). The instrument unit heat loads were calculated for a constant equipment heat load of 3.11 kilowatts and coolant coldplate inlet temperatures of 30, 50, and 75 F. The strong influence of emissivity on net heat gain or loss is readily seen in the illustration.

Electronic package and coldplate temperatures at IU locations 2, 9, 15, and 20 and corresponding to the foregoing operating conditions have been summarized in Table 4-9, in which electronic package temperatures falling within the Group I range of Figure 4-2 (50 F to 122 F) are indicated with asterisks. Table 4-9 reveals that the majority of the electronic package temperatures falls within this Group I range under the assumed operating conditions. With the exception of Cases No. 6 and 8 at $\alpha_s = 0.90$ and a coldplate heat load of 250 watts, the remaining electronic package temperatures fall within the Group II range (-4 F to 167 F), which indicates that a relatively wide choice exists for placement of electronic packages on available coldplates, and that placement of most packages in a specific IU location is not critical. It has already been indicated that data for Cases No. 1, 4, 7, and 10 at coldplate heat loads of 50 and 250 watts were not obtained.

The relationship between coolant temperature at coldplate inlet and equipment total power dissipation is further illustrated in Figures 4-45 through 4-51. For the various missions and orbital conditions under consideration, these figures indicate the upper and lower limits of equipment power dissipation such that no heat rejection from, or addition to, the coolant circuit will be required. The criterion that establishes these equipment power dissipation limits is the permissible coolant temperature range determined in Section 4-1. In Figure 4-45, for example, a Group I coolant temperature range of 60 F to 80 F is indicated by a solid horizontal line. Corresponding to this temperature range, and for the Case 3 orientation, the equipment total power dissipation upper and lower limits are 4.2 and 2.8 kilowatts, respectively. Likewise, the limits for Group II equipment are 4.7 and 1.1 kilowatts, respectively. As long as the equipment total power dissipation remains within these limits, the resulting coolant temperature at the coldplate inlet will satisfy equipment temperature requirements without heat rejection from, or addition to, the environmental control loop. The specific items of equip-

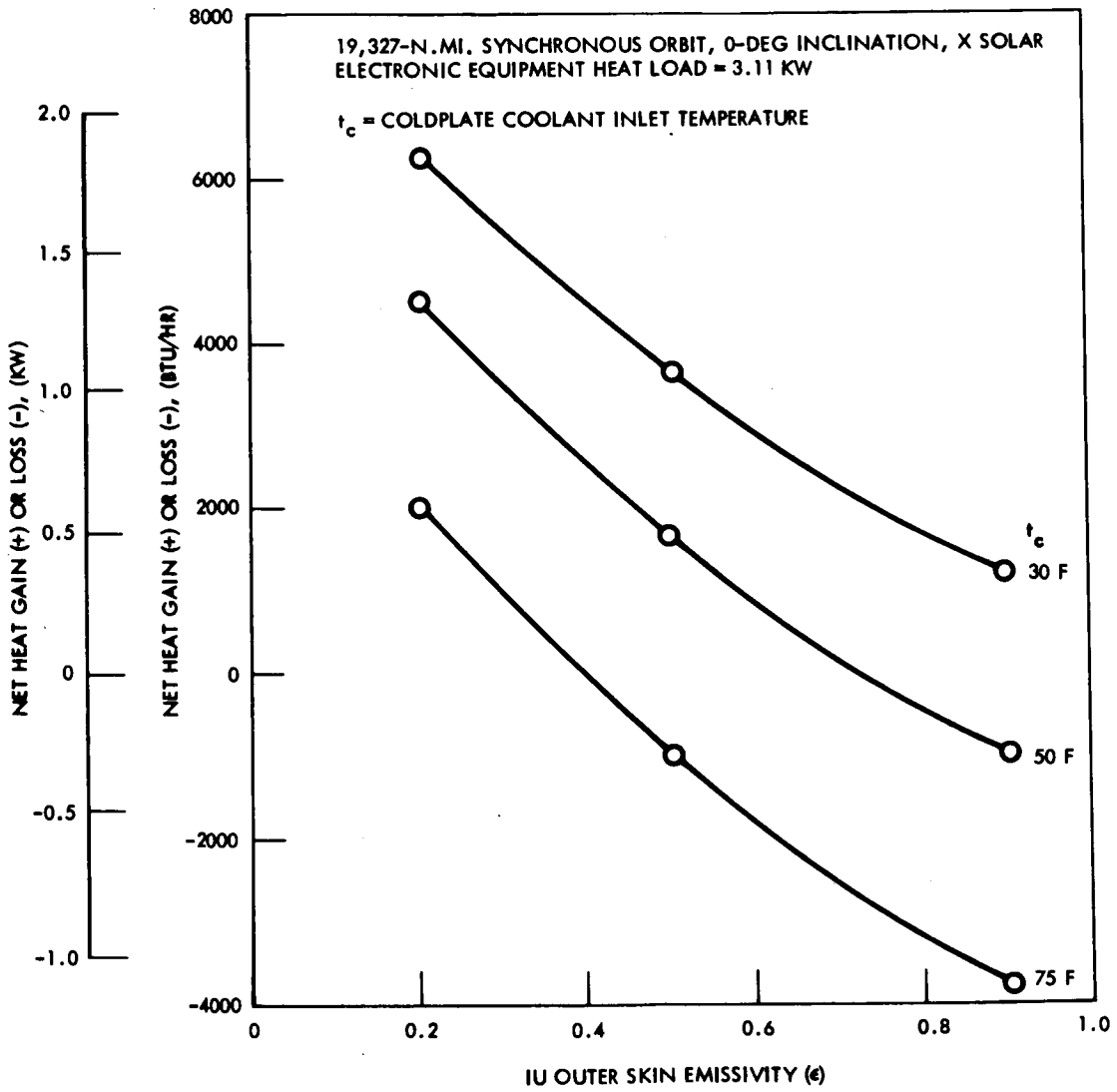

Figure 4-44. Instrument Unit Net Heat Gain or Loss Versus Outer Skin Emissivity

Case No.	Orbit Characteristics	IU Outer Skin, α	50 Watts		
			30	50	75
IU-1a 1	200-n. mi. circ orbit Angle of incl: 29 deg Launch date: June 21 X axis along orbit path **IU Location 3 toward earth**	0.18	NA		
		0.90	NA		
IU-1b 2	200-n. mi. circ orbit Angle of incl: 29 deg Launch date: June 21 X axis toward sun **IU earth orientation varies with orbit position**	0.18	36 / 21	47 / 35	62* /
		0.90	39 / 26	50* / 39	65* /
IU-1c 3	200-n. mi. circ orbit Angle of incl: 29 deg Launch date: June 21 Y axis toward sun **IU Location 21 toward sun**	0.18	38 / 24	50* / 32	64* /
		0.90	49 / 36	61* / 50	75* /
IU-3a 4	200-n. mi. circ polar orbit Angle of incl: 90 deg Launch date: March 21 X axis along orbit path **IU Location 3 toward earth**	0.18	NA		
		0.90	NA		
IU-3b 5	200-n. mi. circ polar orbit Angle of incl: 90 deg Launch date: March 21 X axis toward sun **IU earth orientation varies with orbit position**	0.18	36 / 22	47 / 35	62* /
		0.90	36 / 22	48 / 35	62* /
IU-3c 6	200-n. mi. circ polar orbit Angle of incl: 90 deg Launch date: March 21 Y axis toward sun **IU Location 21 toward sun**	0.18	40 / 27	52* / 41	66* /
		0.90	57* / 47	68* / 59	81* /
IU-4a 7	100-n. mi. circ equatorial orbit Angle of incl: 29 deg Launch date: March 21 X axis along orbit path **IU Location 3 toward earth**	0.18	NA		
		0.90	NA		
IU-6a 8	Synchronous orbit Angle of incl: 0 deg Launch date: March 21 Y axis toward sun **IU Location 21 toward sun**	0.18	34 / 20	47 / 33	60* /
		0.90	50* / 40	61* / 53	75* /
IU-6b 9	Synchronous orbit Angle of incl: 0 deg Launch date: March 21 X axis toward sun **IU earth orientation varies with orbit position**	0.18	30 / 14	42 / 29	57* /
		0.90	30 / 14	42 / 29	57* /
IU-6c 10	Synchronous orbit Angle of incl: 0 deg Launch date: March 21 X axis along orbit path **IU Location 3 toward earth**	0.18	NA		
		0.90	NA		

*Indicates electric package temperatures that fall within the Group I range of Fig

NA = Not available

	IU Location 2						IU Location 9										
	Heat Load/Coldplate						Heat Load/Coldplate										
	150 Watts			250 Watts			50 Watts			150 Watts			250 Watts			50 Watts	
	30	50	75	30	50	75	30	50	75	30	50	75	30	50	75	30	50
→	75* / 43	86* / 57	99* / 73	← NA →			← NA →			67* / 33	78* / 47	92* / 64	← NA →			← NA →	
→	83* / 55	92* / 66	104* / 89	← NA →			← NA →			78* / 48	87* / 60	100* / 82	← NA →			← NA →	
52	66* / 33	78* / 47	91* / 63	94* / 44	105* / 57	117* / 73	37 / 22	48 / 36	62* / 53	67* / 34	78* / 47	92* / 64	95* / 45	106* / 58	118* / 74	35 / 21	47 / 34
56	69* / 38	80* / 51	94* / 66	97* / 48	108* / 52	120* / 77	40 / 27	52* / 40	65* / 56	70* / 38	81* / 51	95* / 67	98* / 49	108* / 62	121 / 78	38 / 24	50* / 38
54	69* / 36	80* / 49	93* / 66	96* / 47	107* / 59	119* / 76	37 / 24	49 / 37	63* / 54	68* / 36	79* / 49	92* / 65	96* / 47	106* / 60	118* / 76	38 / 23	50* / 37
67	79* / 48	90* / 61	104* / 78	107* / 61	117* / 72	129 / 86	43 / 30	55* / 48	69* / 64	74* / 46	85* / 59	98* / 74	102* / 57	112* / 69	124 / 84	50* / 37	62* / 52
→	78* / 47	88* / 59	100* / 75	← NA →			← NA →			64* / 30	76* / 44	89* / 60	← NA →			← NA →	
→	92* / 65	103* / 78	107* / 92	← NA →			← NA →			67* / 30	77* / 44	89* / 60	← NA →			← NA →	
52	67* / 33	78* / 47	91* / 63	94* / 43	105* / 57	118* / 73	35 / 22	47 / 35	62* / 52	66* / 33	78* / 47	92* / 63	93* / 43	105* / 57	117* / 73	35 / 22	47 / 35
52	67* / 33	78* / 47	91* / 63	95* / 44	105* / 57	118* / 73	36 / 22	48 / 35	62* / 52	67* / 33	78* / 47	91* / 63	94* / 43	105* / 57	117* / 73	35 / 22	47 / 35
57	71* / 39	82* / 52	95* / 69	98* / 48	109* / 62	121* / 77	35 / 20	47 / 34	61* / 51	66* / 32	77* / 46	90* / 62	93* / 43	104* / 56	117* / 72	40 / 27	52* / 41
76	87* / 58	NA	NA	113* / 68	123 / 81	135 / 96	35 / 20	47 / 34	61* / 51	66* / 32	NA	NA	93* / 43	104* / 56	117* / 72	58* / 47	68* / 60
→	76* / 45	87* / 58	99* / 73	← NA →			← NA →			67* / 34	78* / 48	91* / 63	← NA →			← NA →	
→	83* / 53	92* / 67	NA	← NA →			← NA →			74* / 45	84* / 57	NA	← NA →			← NA →	
51	65* / 32	77* / 46	90* / 62	93* / 43	104* / 57	117* / 73	30 / 15	42 / 29	57* / 46	61* / 27	72* / 40	87* / 58	91* / 38	100* / 52	113* / 68	35 / 20	47 / 34
70	82* / 52	92* / 66	NA	109* / 63	119* / 75	132 / 91	30 / 15	42 / 29	57* / 46	61* / 28	72* / 40	NA	89* / 38	100* / 51	113* / 68	51* / 41	62* / 53
46	61* / 28	72* / 41	87* / 57	90* / 39	100* / 51	107* / 68	30 / 14	42 / 29	57* / 46	61* / 28	72* / 40	87* / 58	90* / 39	100* / 51	107* / 68	30 / 14	42 / 29
46	61* / 28	72* / 41	87* / 57	90* / 39	100* / 51	107* / 68	30 / 14	42 / 29	57* / 46	61* / 28	72* / 40	87* / 57	← NA →			← NA →	
→	73* / 40	83* / 52	97* / 69	← NA →			← NA →			61* / 28	73* / 41	87* / 58	← NA →			← NA →	
→	109* / 79	118* / 90	NA	← NA →			← NA →			62* / 28	74* / 42	NA	90* / 39	100* / 51	107 / 68	30 / 14	42 / 29

ure 4-2 (50 F to 122 F)

Electronic Package Temperature → 38 / 24 ← Coldplate Temperature

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Table 4-9. Electronic Package and Coldplate Temperatures

IU Location 15 Heat Load/Coldplate							IU Location 20 Heat Load/Coldplate								
	150 Watts			250 Watts			50 Watts			150 Watts			250 Watts		
75	30	50	75	30	50	75	30	50	75	30	50	75	30	50	75
→	66* / 35	78* / 48	91* / 65	← NA →			← NA →			65* / 32	76* / 45	90* / 62	← NA →		
→	83* / 62	93* / 71	105* / 87	← NA →			← NA →			70* / 39	80* / 51	93* / 67	← NA →		
62* / 52	66* / 33	77* / 46	91* / 63	94* / 44	105* / 57	117* / 73	35 / 21	47 / 35	62* / 52	66* / 33	78* / 47	91* / 63	94* / 44	105* / 57	117* / 73
64* / 55	68* / 37	80* / 49	93* / 66	96* / 47	107* / 60	119* / 76	39 / 27	50* / 40	64* / 56	70* / 38	81* / 52	94* / 67	97* / 48	107* / 62	120* / 77
63* / 54	69* / 36	80* / 49	93* / 66	96* / 47	107* / 59	119* / 76	46 / 33	57* / 46	71* / 62	76* / 44	86* / 58	99* / 74	103* / 54	113* / 67	125 / 23
75* / 67	80* / 49	90* / 62	105* / 79	108* / 60	118* / 72	130 / 87	77* / 67	90* / 81	102* / 95	105* / 77	114* / 89	129 / 107	132 / 85	141 / 100	152 / 114
→	67* / 32	78* / 47	91* / 62	← NA →			← NA →			80* / 50	81* / 63	104* / 79	← NA →		
→	83* / 52	94* / 67	101* / 79	← NA →			← NA →			129 / 110	137 / 121	148 / 135	← NA →		
62* / 52*	66* / 33	78* / 47	91* / 63	94* / 43	105* / 57	118* / 73	35 / 21	47 / 34	61* / 52	66* / 33	77* / 46	90* / 62	94* / 43	104* / 57	117* / 73
62* / 52	66* / 33	78* / 47	91* / 63	94* / 43	105* / 57	118* / 73	35 / 21	47 / 34	61* / 52	66* / 32	77* / 46	90* / 62	94* / 43	104* / 57	117* / 73
66* / 57	71* / 39	82* / 52	95* / 69	98* / 48	109* / 62	121* / 78	47 / 40	63* / 54	77* / 69	82* / 52	92* / 65	105* / 81	108* / 62	118* / 74	131 / 90
82* / 77	87* / 58	NA	NA	114* / 68	123 / 81	135 / 97	102* / 101	101* / 102	123 / 127	129 / 111	NA	NA	153 / 119	162 / 130	172 / 144
→	68* / 35	79* / 48	91* / 65	← NA →			← NA →			67* / 33	78* / 47	91* / 62	← NA →		
→	87* / 60	85* / 62	NA	← NA →			← NA →			75* / 52	95* / 72	NA	← NA →		
60* / 51	65* / 32	78* / 47	90* / 62	93* / 43	104* / 57	117* / 73	47 / 35	58* / 48	71* / 64	78* / 48	89* / 60	101* / 77	105* / 57	115* / 70	127 / 86
78* / 71	82* / 51	93* / 66	NA	110* / 63	120* / 76	132 / 92	94* / 96	110* / 110	120* / 123	128 / 108	136 / 119	NA	151 / 116	160 / 128	170 / 141
57* / 46	61* / 28	72* / 40	87* / 58	89* / 38	100* / 51	107* / 68	29 / 13	41 / 28	56* / 44	60* / 27	72* / 40	86* / 57	88* / 38	99* / 50	107* / 68
→	61* / 28	73* / 41	87* / 57	← NA →			← NA →			60* / 27	72* / 40	87* / 57	← NA →		
→	62* / 28	74* / 41	NA	← NA →			← NA →			62* / 28	73* / 41	NA	← NA →		
57* / 46	61* / 28	72* / 40	87* / 58	89* / 38	100* / 51	107* / 68	29 / 13	41 / 28	56* / 44	60* / 27	71* / 40	86* / 56	88* / 38	99* / 50	107* / 68

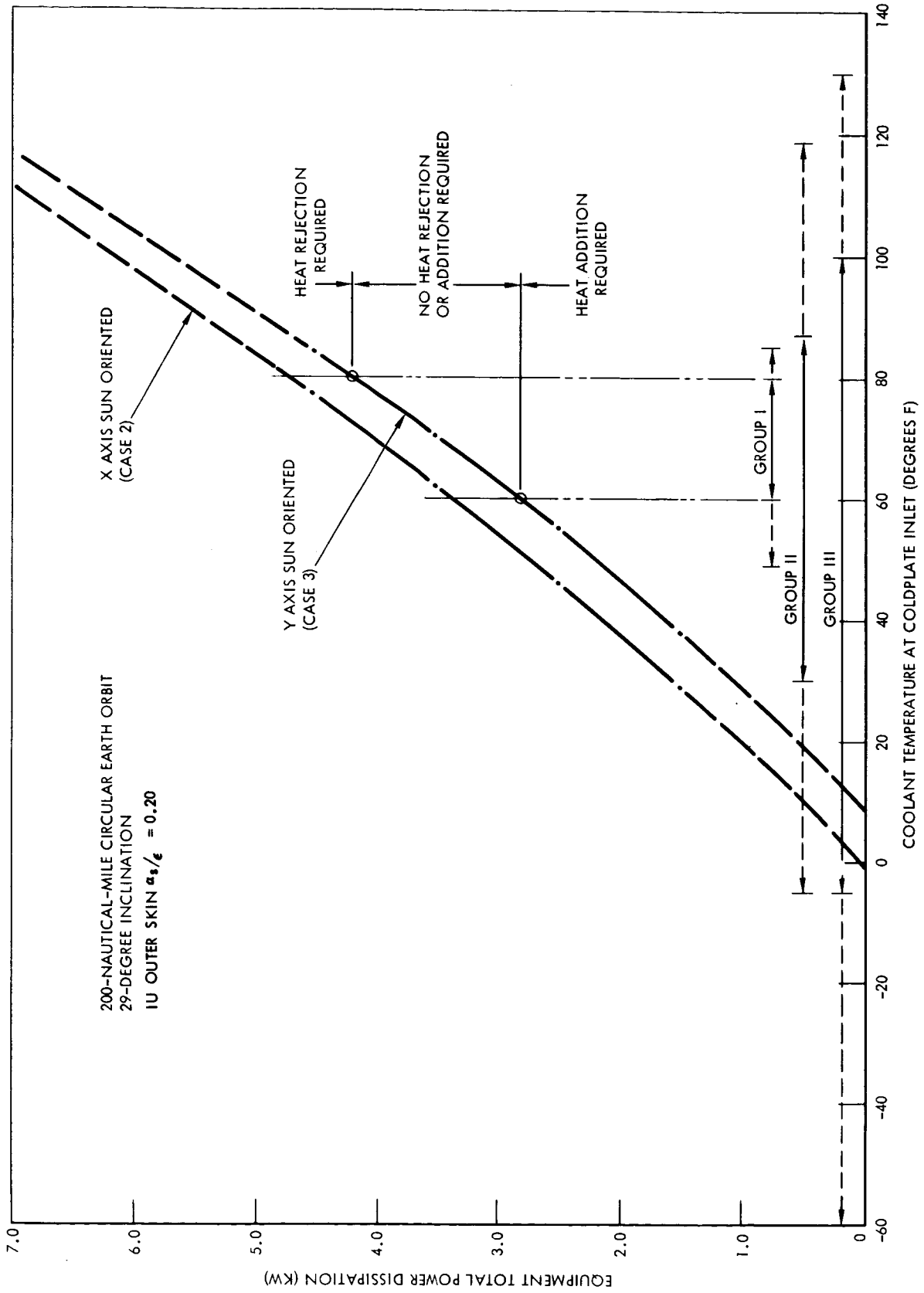

Figure 4-45. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

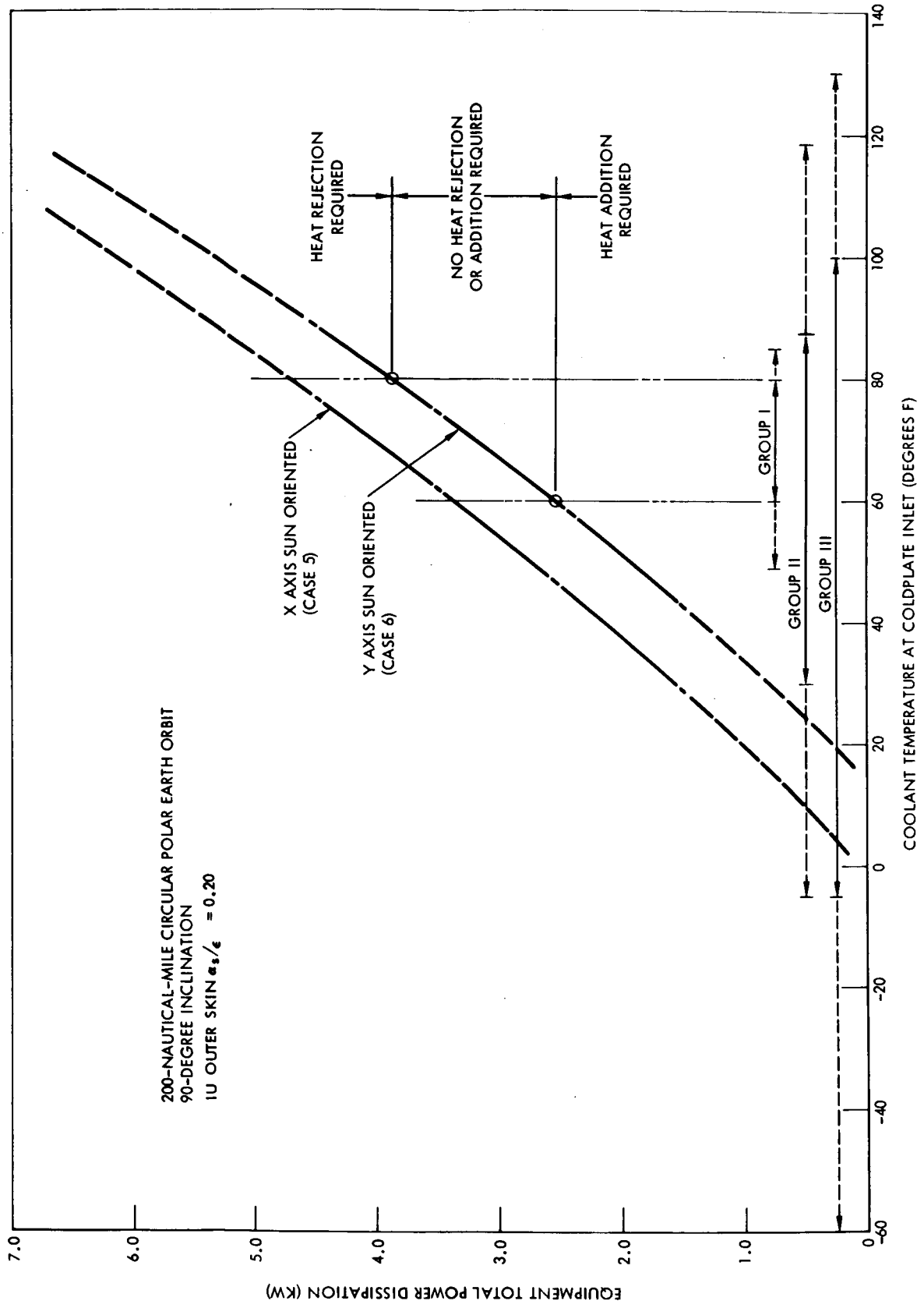

Figure 4-46. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

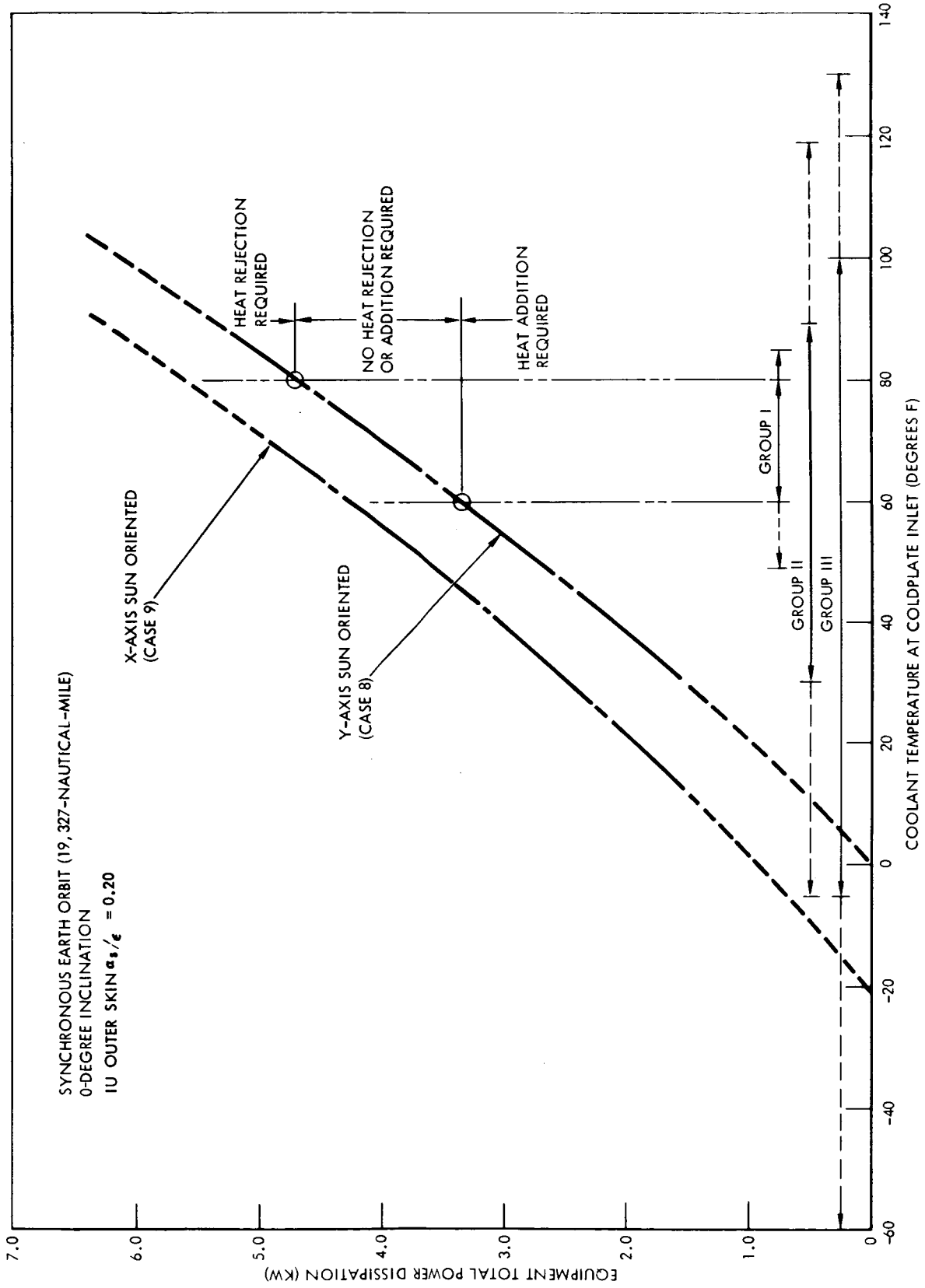

Figure 4-47. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

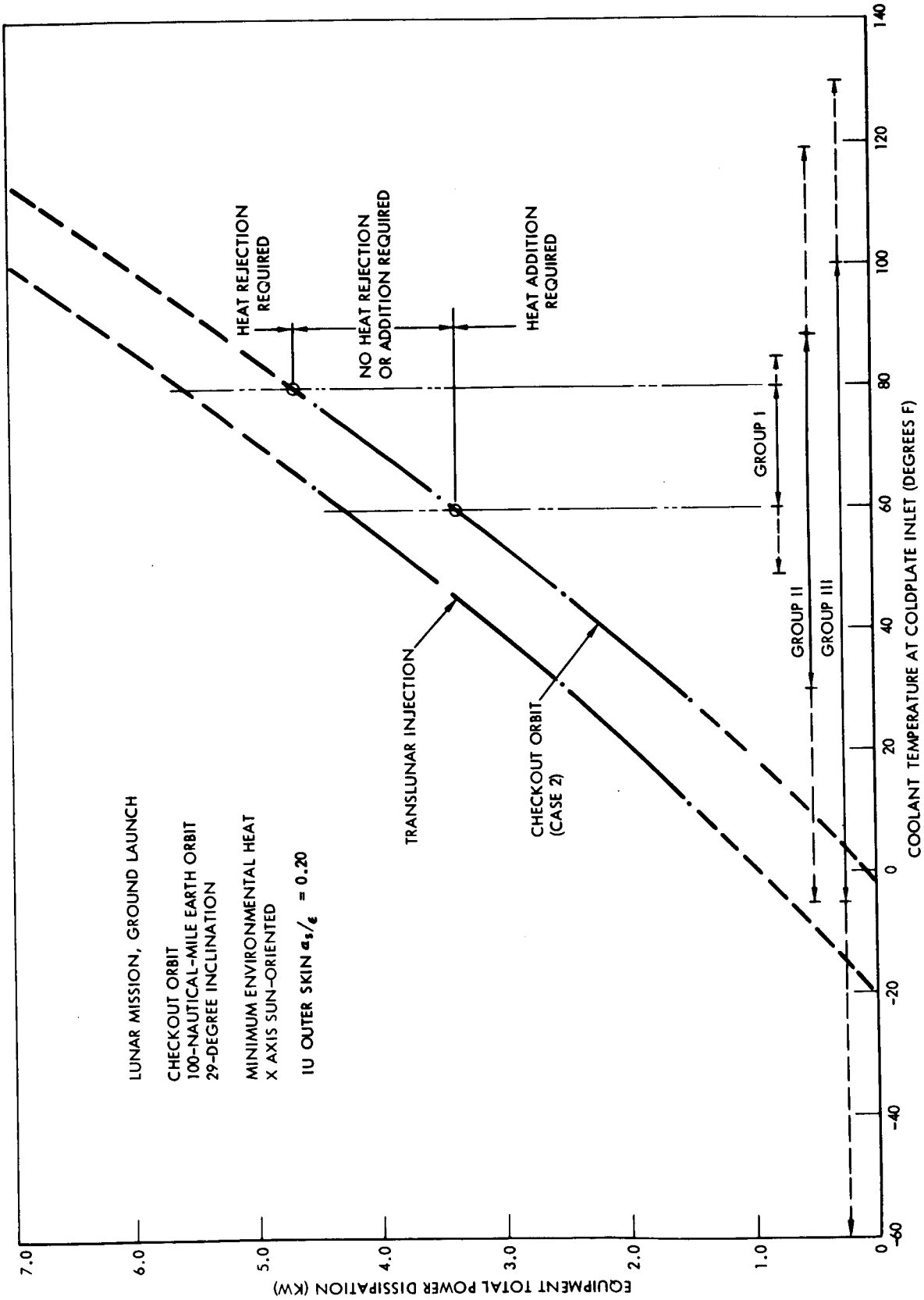

Figure 4-48. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

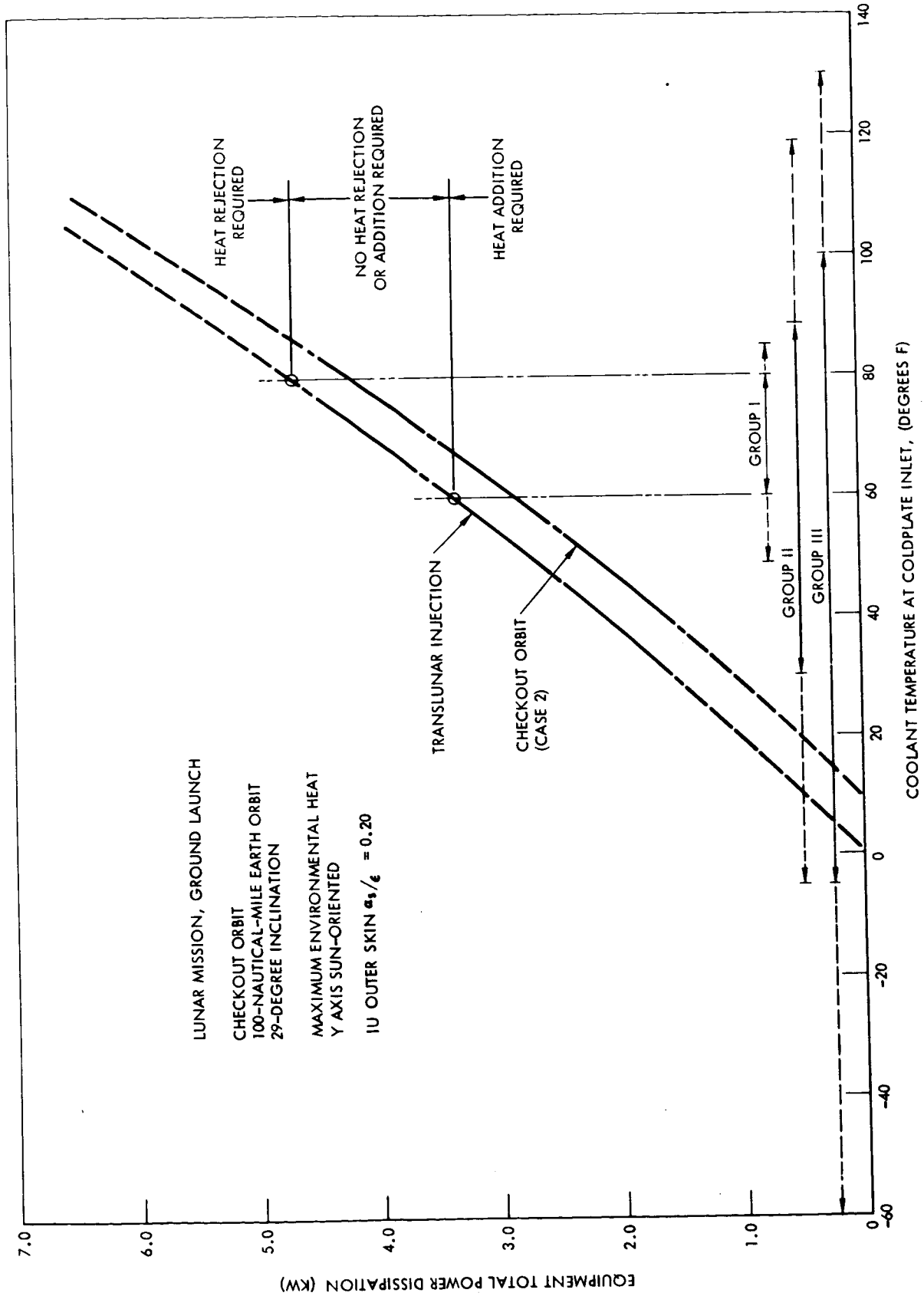

Figure 4-49. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

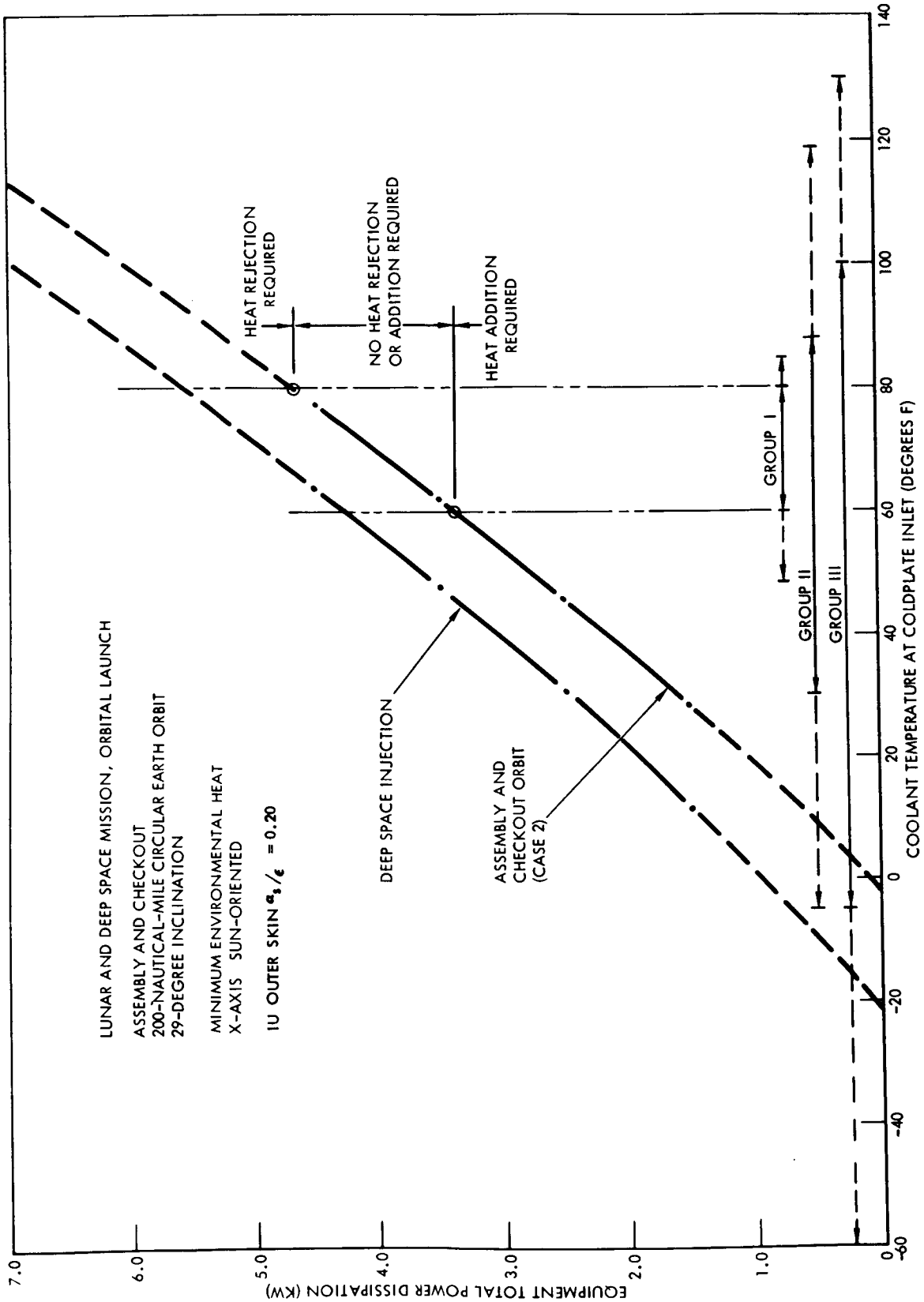

Figure 4-50. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

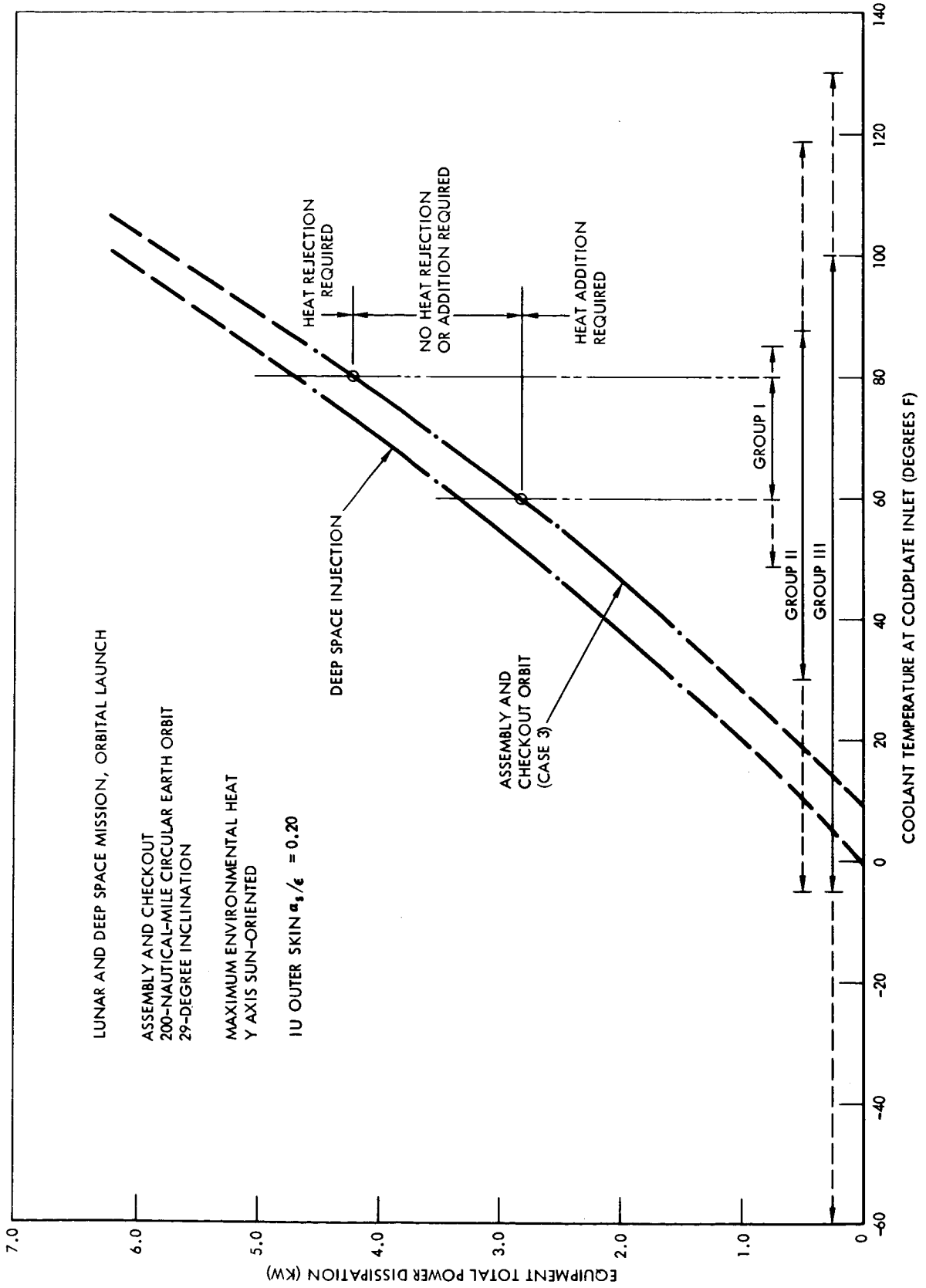

Figure 4-51. Coolant Temperature Versus Equipment Acceptable Total Power Dissipation

ment that determine the permissible coolant temperature limits for each group are listed in Table 4-10. The corresponding equipment power dissipation limits for all missions under consideration are summarized in Table 4-11. It is apparent that requirements for all three groups of equipment are satisfied if the permissible power dissipation limits for Group I equipment are maintained. The effect of extending the equipment temperature limitations on permissible power dissipation levels is indicated by the dashed-line extensions of the group limits in Figure 4-45 through 4-51. Of course, satisfactory operation under present conditions can be obtained by suitable heat rejection or addition methods under all conditions of equipment power dissipation.

The foregoing discussion regarding the results of the thermal analysis is applicable to the period when the S-IVB dome temperature has reached its equilibrium value of 60 F. To evaluate the effect of the S-IVB dome temperature on instrument unit net heat gain or loss during the initial phase of a mission, when this temperature is expected to be as low as -210 F, the effective emissivity of the dome was assumed to be controllable between values of 0.05 and 0.90. Instrument unit heat balances were obtained at the extremes of this emissivity range for the 200-nautical-mile earth orbit and with the y axis sun-oriented (Case No. 3). The electrical heat load was assumed to be 50 watts per coldplate, and coolant temperature at coldplate inlet was maintained at 30, 50, and 75 F, respectively. Results of the thermal analysis (Figures 4-52 through 4-57) indicate that an effective dome emissivity of 0.9 produces a significant heat loss from the instrument unit when the surface of the dome is at cryogenic temperatures. However, this heat loss can be suppressed quite readily by thermal isolation of the S-IVB dome through application of a cover having a low effective emissivity. This was confirmed by the results applicable to a dome emissivity of 0.05, which reduces the heat loss to a more manageable level. The data suggest the possibility of using the S-IVB dome as a heat sink during the initial phase of a mission through selection of a dome cover with an appropriate infrared emissivity.

To augment the above heat balances that are based on assumed values for equipment heat loads, additional heat balances were obtained which were based on consideration of the coldplate and electronics components mounted thereon as an adiabatic surface with no load on the electronic components. Heat balances were obtained for the current, or baseline, active thermal control system consisting of a closed liquid coolant loop with coldplates, electronic packages mounted on coldplates and integrally or internally cooled electronic packages.

For the adiabatic surface case, the temperature of the coldplates and the electronic packages was assumed to be constant. Also, it was assumed that the coldplates and electronic packages were at the same temperature.

Table 4-10. Coolant Temperature Limits and Critical Electronic Packages

Group	Coolant Temperature Limits (Degrees F)			
	NASA Specification		NAA Modification	
	Upper Limit (Figure 4-2)	Lower Limit (Figure 4-7)	Upper Limit (Figure 4-3)	Lower Limit (Figure 4-7)
I	80 ST-124 M Inertial Platform* (70 watts)	59 Accelerometer Signal Conditioner (6.5 watts)	85 LVDA* (400 watts)	49 Accelerometer Signal Conditioner (6.5 watts)
II	87 F Azusa Transponder and Filter (270 watts)	30 Telemeter Assembly, S1 (35 watts)	119 RF Assembly-P1 (177 watts)	-5 Telemeter Assembly, S1 (35 watts)
III	100 (140 watts, Minstram Transponder	-5 (4 watts) Remote Digital Multiplexer	130 Minstram Transponder (140 watts)	-60 Remote Digital Multiplexer (4 watts)

*Internally or integrally thermal-conditioned equipment

Table 4-11. Equipment Power Dissipation Limits for Zero Net Heat Gain or Loss

Mission		Limit	Equipment Power Dissipation Limit (kw)					
			NASA Specification Temperature Limits			NAA Modified Temperature Limits		
			Group I	Group II	Group III	Group I	Group II	Group III
200-n.mi. circular earth orbit 29-degree inclination	X axis: sun-oriented (Case 2)	Upper	4.7	5.2	6.2	5.1	>7.0	>7.0
		Lower	3.4	1.6	0	2.7	0	0
	Y axis: sun-oriented (Case 3)	Upper	4.2	4.7	5.7	4.6	>7.0	>7.0
		Lower	2.8	1.1	0	2.1	0	0
200-n.mi. polar earth orbit 90-degree inclination	X axis: sun-oriented (Case 5)	Upper	4.7	5.2	6.1	5.0	>7.0	>7.0
		Lower	3.4	1.6	0	2.7	0	0
	Y axis: sun-oriented (Case 6)	Upper	3.9	4.4	5.3	4.2	6.9	>7.0
		Lower	2.5	0.8	0	1.9	0	0
Synchronous earth orbit (19,327 n.mi.)	X axis: sun-oriented (Case 9)	Upper	5.6	6.1	6.9	5.9	>7.0	>7.0
		Lower	4.2	2.4	0.7	3.5	0.7	0
	Y axis: sun-oriented (Case 8)	Upper	4.7	5.2	6.1	5.0	>7.0	>7.0
		Lower	3.3	1.6	0	2.6	0	0
Lunar, Ground Launch Minimum environmental heat X axis: sun-oriented	Checkout orbit 100-n.mi. earth orbit	Upper	4.7	5.2	6.0	5.0	>7.0	>7.0
		Lower	3.4	1.6	0	2.7	0	0
	Injection period	Upper	5.6	6.0	6.9	5.9	>7.0	>7.0
		Lower	4.3	2.4	0.7	3.6	0	0
Lunar, Ground Launch Maximum environmental heat Y axis: sun-oriented	Checkout orbit 100-n.mi. earth orbit	Upper	4.2	4.7	5.7	4.6	7.0	>7.0
		Lower	2.8	1.1	0	2.7	0	0
	Injection period	Upper	4.7	5.2	6.1	5.0	>7.0	>7.0
		Lower	3.3	1.6	0	2.6	0	0

Table 4-11. Equipment Power Dissipation Limits for Zero Net Heat Gain or Loss (Cont)

Mission		Limit	Equipment Power Dissipation Limit (kw)					
			NASA Specification Temperature Limits			NAA Modified Temperature Limits		
			Group I	Group II	Group III	Group I	Group II	Group III
Lunar and Deep Space Orbital launch Minimum environmental heat X axis: sun-oriented	Assembly & checkout period 200-n.mi. earth orbit 29-degree inclination	Upper	4.7	5.2	6.0	5.0	>7.0	>7.0
		Lower	3.4	1.6	0	2.7	0	0
	Injection period	Upper	5.6	6.1	6.9	5.9	>7.0	>7.0
		Lower	4.3	2.4	0.7	2.6	0	0
Lunar and Deep Space Orbital launch Maximum environmental heat Y axis: sun-oriented	Assembly & checkout period 200-n.mi. earth orbit 29-degree inclination	Upper	4.2	4.7	5.7	4.6	7.0	>7.0
		Lower	2.8	1.1	0	2.1	0	0
	Injection period	Upper	4.7	5.2	6.1	5.0	>7.0	>7.0
		Lower	3.3	1.6	0	2.6	0	0

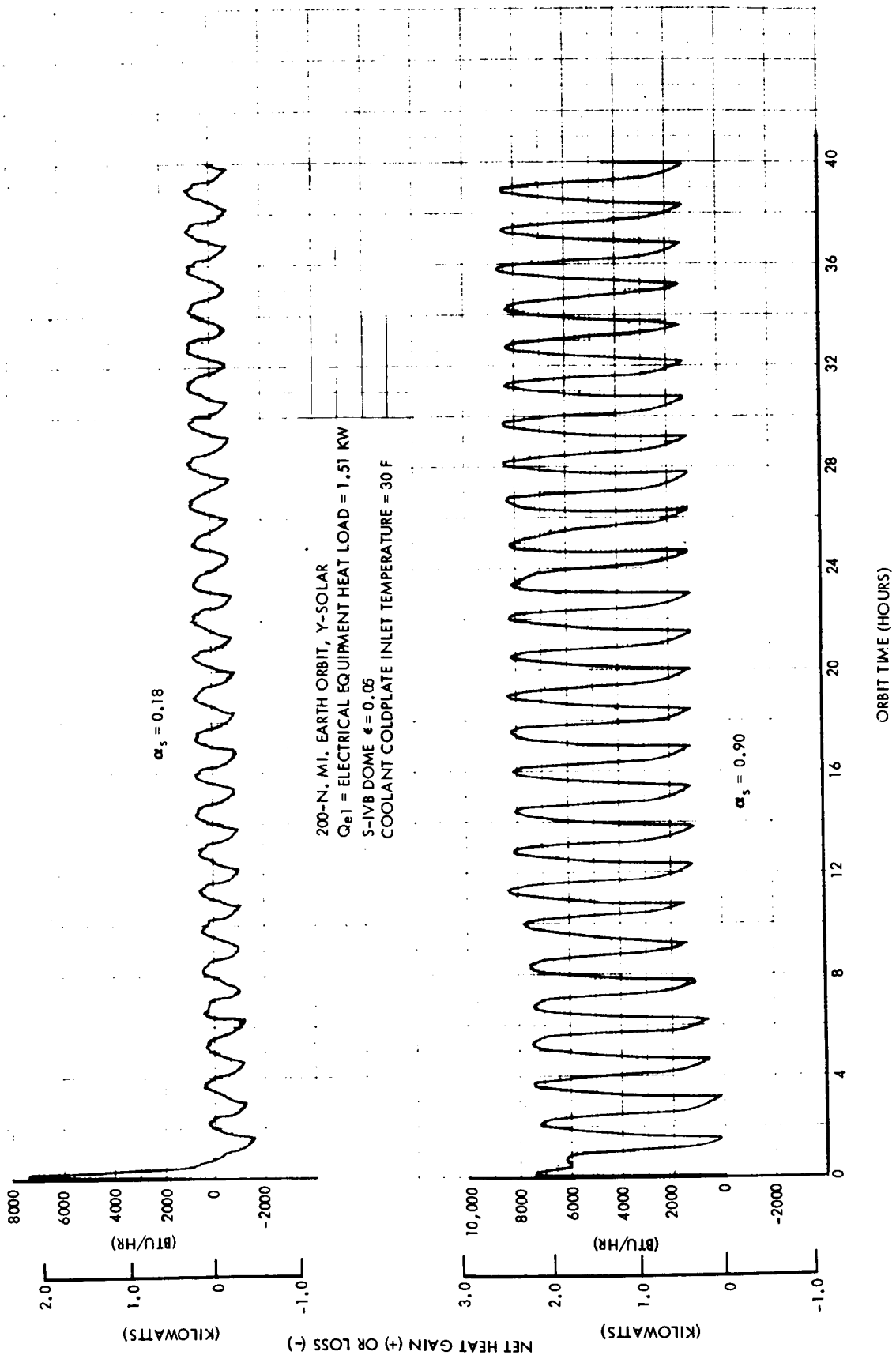

Figure 4-52. Instrument Unit Net Heat Gain or Loss Versus Orbit Time — 200-N. Mi. Orbit, Y-Solar, t_c = 30 F, S-IVB Dome ϵ = 0.05

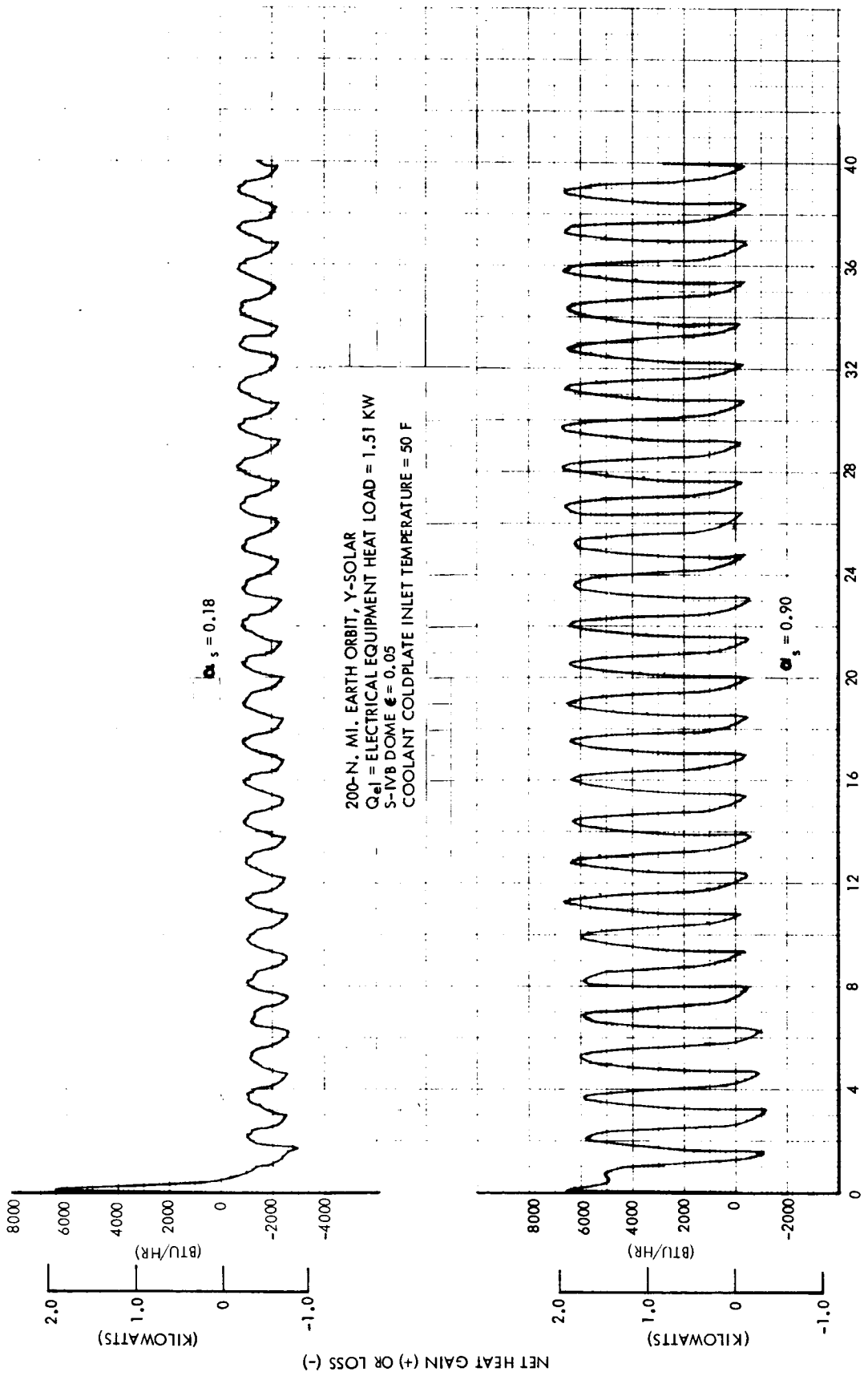

Figure 4-53. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N.Mi. Orbit, Y-Solar, t_c = 50 F, S-IVB Dome ϵ = 0.05

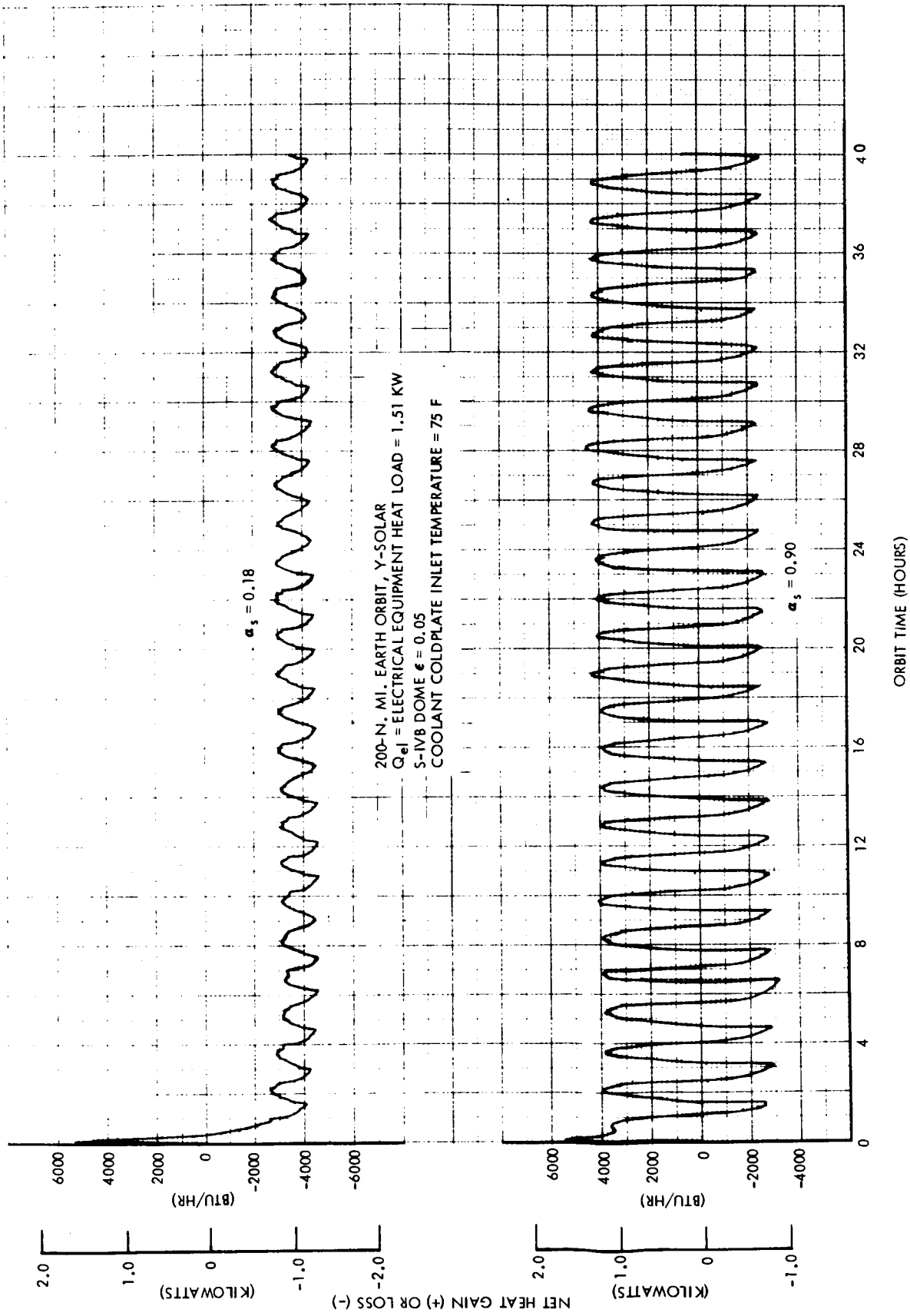

Figure 4-54. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N. Mi. Orbit, Y-Solar, t_c = 75 F, S-IVB Dome ϵ = 0.05

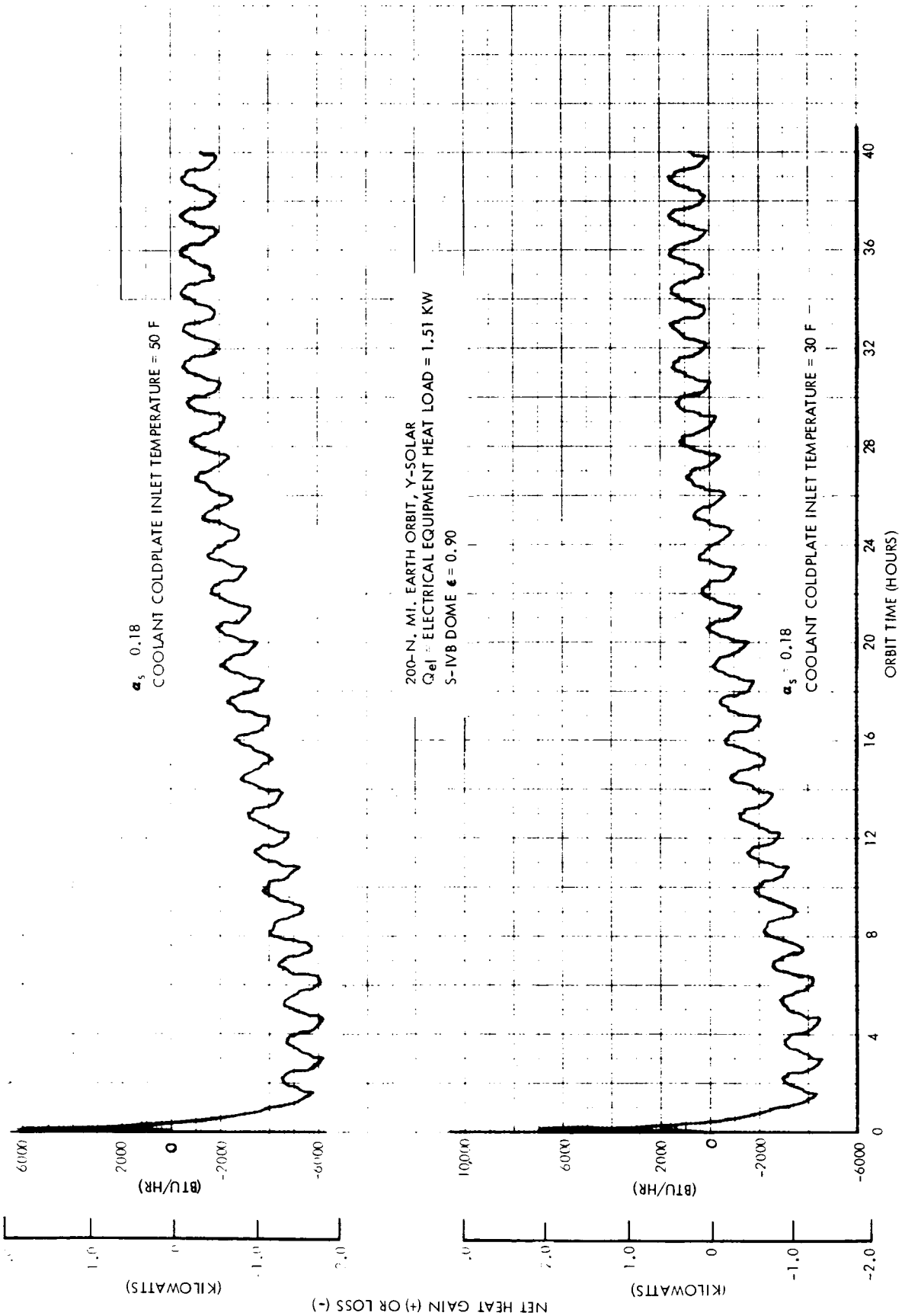

Figure 4-55. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N. Mi. Orbit, Y-Solar, t_c = 30 and 50 F, S-IVB Dome ϵ = 0.90

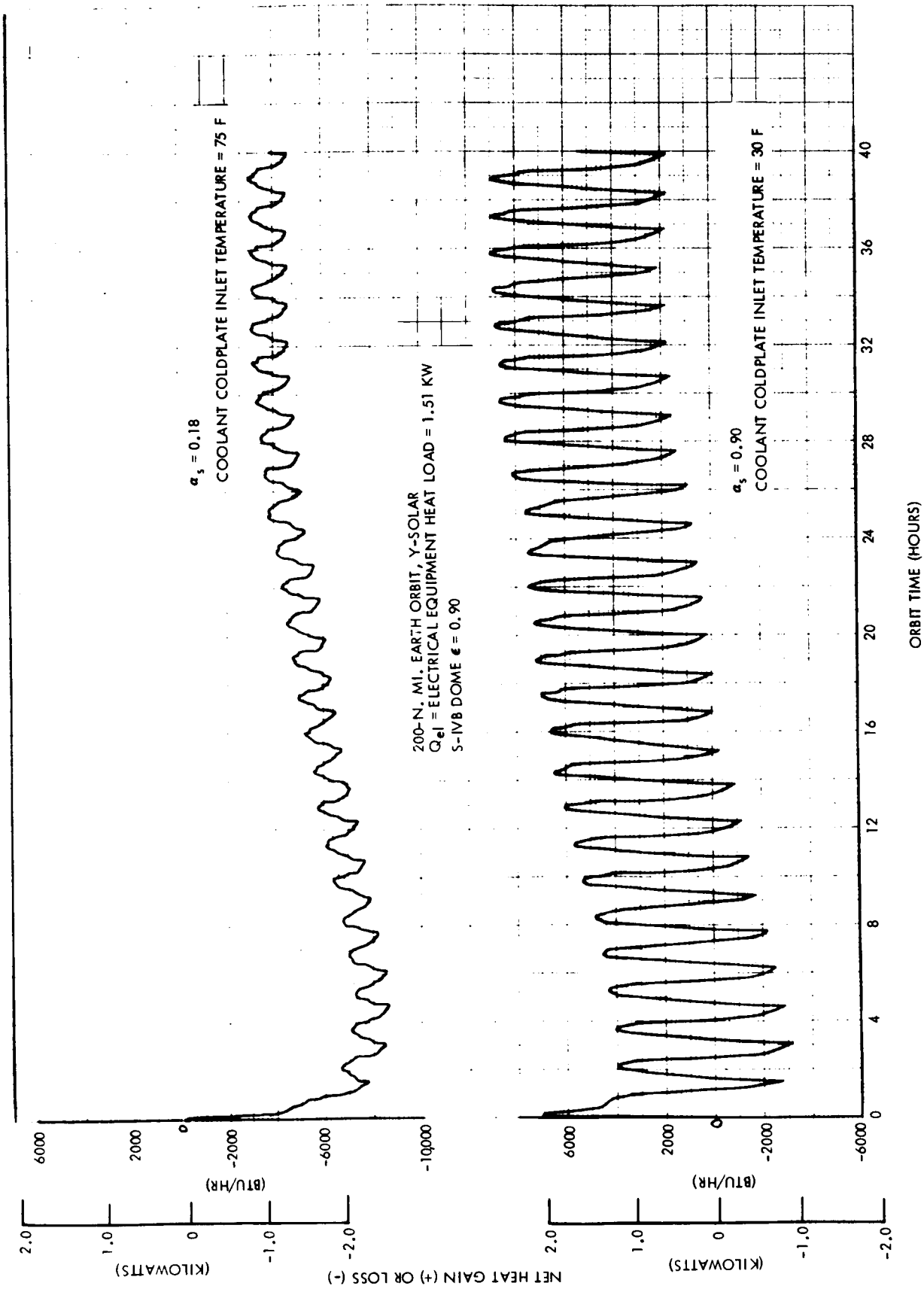

Figure 4-56. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N.Mi. Orbit, Y-Solar, t_c = 30 and 75 F, S-IVB Dome ϵ = 0.90

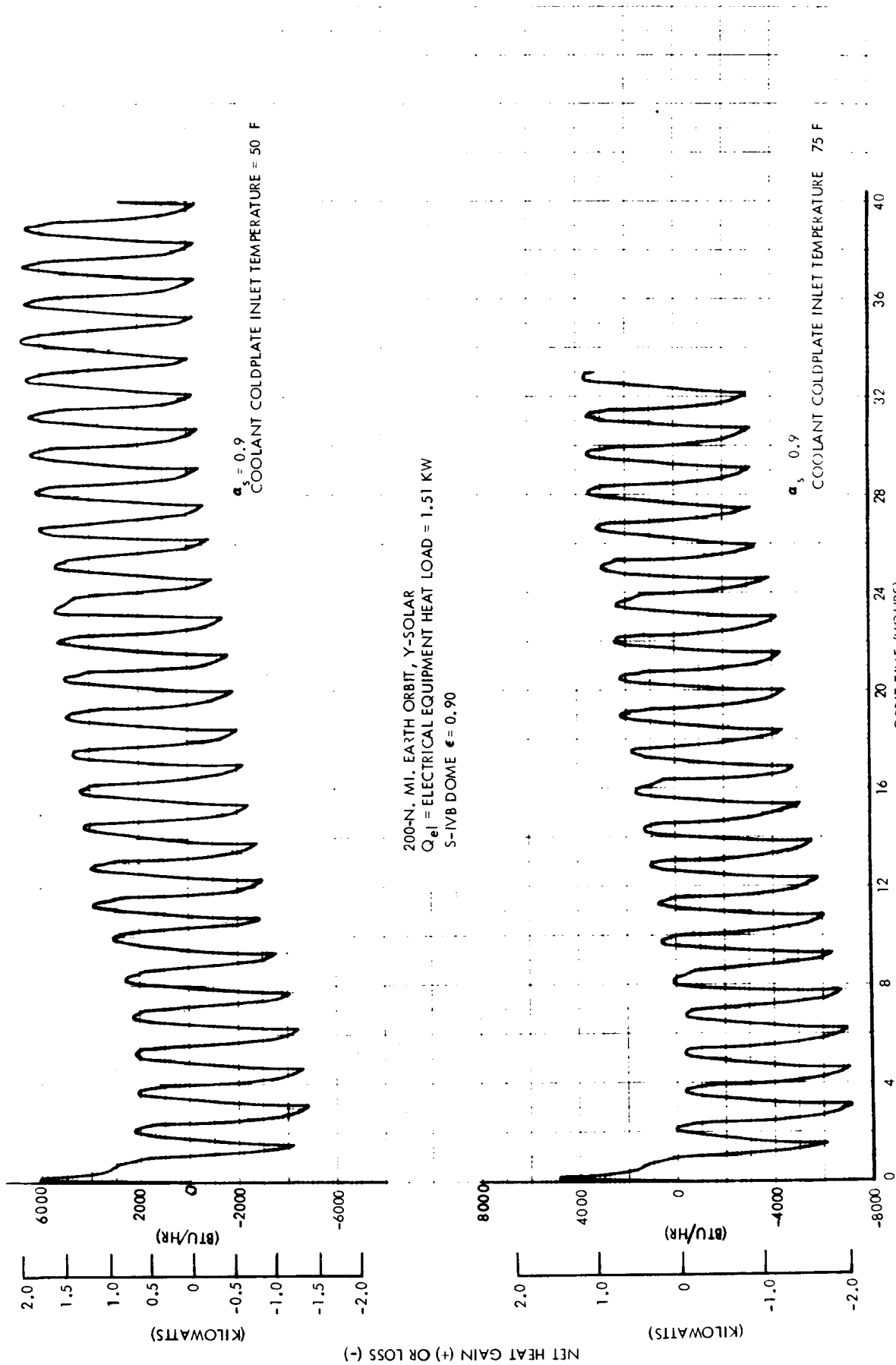

Figure 4-57. Instrument Unit Net Heat Gain or Loss Versus Orbit Time—200-N.Mi. Orbit, Y-Solar, t_c = 50 and 75 F, S-IVB Dome ϵ = 0.90

Temperature values of 30, 60, and 75 F were used for the coldplates and the electronic packages mounted thereon and for the internally cooled electronic packages.

The properties of the various surfaces involved in the heat transfer and the conduction between the coldplates and the instrument unit structure were considered the same as in the previous analysis. However, different values for fA's were used for the internal radiation heat transfer. This is the result of adding the radiation heat transfer between the IU structure at each coldplate location and the S-IVB dome and the SLA. This was not considered in the previous analysis because the amount of heat transferred is relatively small. The values for fA's are listed in Table 4-12, for two values for the emissivity of the S-IVB dome. For the coldplate and electronic packages mounted thereon, a single value for the fA's is given, computed for a coldplate emissivity of 0.18 and electronic packages emissivity of 0.90 (Table 4-6) and on the assumption that half of the coldplate surface was covered by the electronic packages.

To perform the thermal analysis with a digital computer, the thermal network used previously (Figure 4-9) was modified to include the internal radiation heat transfer between the IU skin at each coldplate location and the S-IVB dome and between an assumed forward structure (SLA), and by eliminating the coolant flow network and the coldplate-mounted electronic package network. The coolant flow network was eliminated, since the coldplate temperature was maintained at a selected value and thus coolant flow need not be included. The network for the coldplate-mounted electronic package was eliminated, since it was assumed that the coldplate and electronic packages mounted thereon were at the same temperature and thus both could be represented by a single node. The modified network for the coldplate and equipment mounted thereon is illustrated in Figure 4-58. The overall thermal network (Figure 4-8) for the instrument unit was modified to accommodate the changes. The assumptions made previously with regard to the construction and use of the thermal network were considered applicable.

Six orbital conditions were used to provide different environmental heat loads at various orbital altitudes and orbit inclinations. These conditions were considered to be the practical range of interest. Also, the vehicle orientation of X axis tangent to the flight path was considered to be the most significant.

The near-earth polar orbit (IU-3a) gives the maximum environmental heat load, since one side of the vehicle is continuously exposed to the sun, and the synchronous earth orbit (IU-6c) gives the minimum environmental heat load, since the earth emission and reflected solar energy are negligible and there is a considerable period of partial solar energy incident on the vehicle surface. The orbit identified as IU-7a is identical to the maximum shadow orbit in Reference 4-3, and orbit IU-10 is identical to the minimum

Table 4-12. Values for fA's (sq in.)

Component	Component /S-IVB Dome		Component /SLA	
	S-IVB Dome $\epsilon = 0.05$	S-IVB Dome $\epsilon = 0.90$	S-IVB Dome $\epsilon = 0.05$	S-IVB Dome $\epsilon = 0.90$
Coldplate /electronic package combined	34	318	126	48
ST-124 inertial platform	94	897	357	136
LVDA	74	708	280	107
LVDC	74	708	280	107
Flight control computer	74	708	280	107
IU skin (at coldplate location)	4	38	15	6

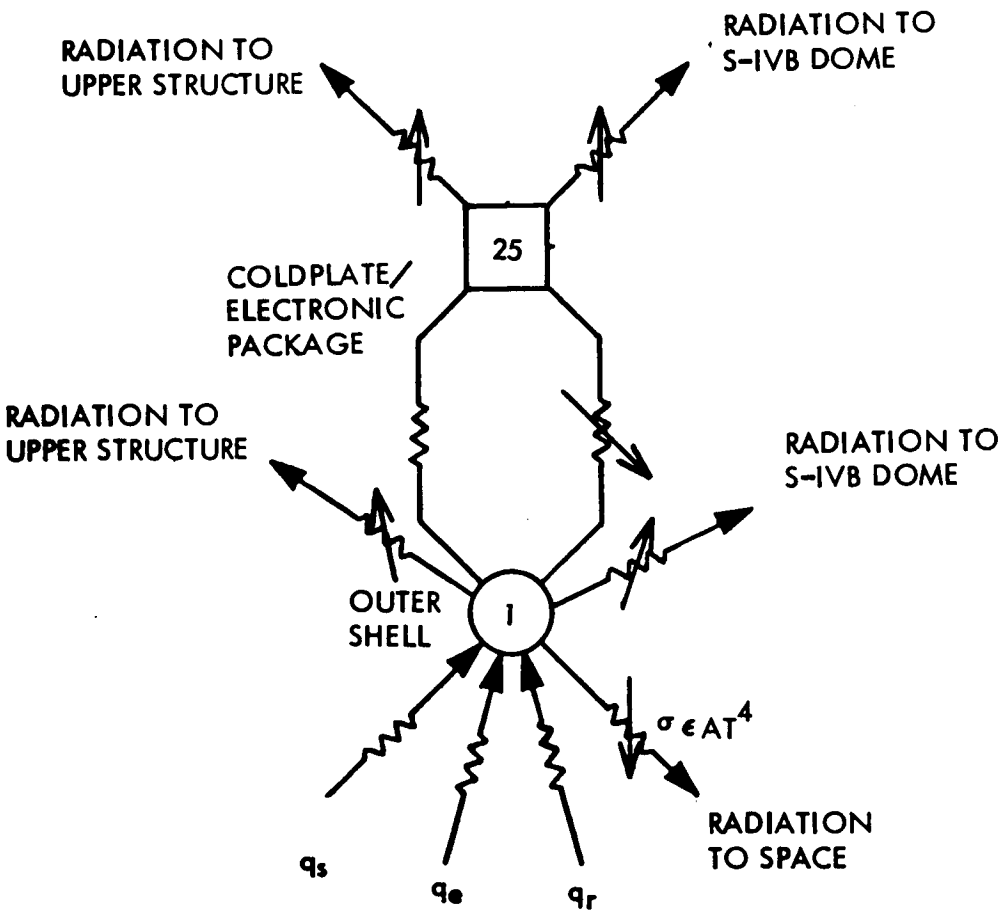

Figure 4-58. Thermal Network, Equipment Mounted on Coldplate

shadow orbit of Reference 4-3. Orbital cases IU-1a and IU-7a are identical except for the difference in the orbital altitude. The same is true for orbital cases IU-10 and IU-11.

Table 4-13 provides a convenient guide for the numerous heat balances for adiabatic coldplate surface conditions. This table gives the orbital data, S-IVB dome conditions, and the optical properties of the IU outer surfaces that were used. It is to be noted that for each of the 48 possible combinations indicated on the table, 3 coldplate/electronic package temperatures of 30, 60, and 75 F were used.

The results of the heat balances for the adiabatic coldplate surface condition are presented in Tables 4-14 through 4-37. These tables present the external heat gain or loss and internal heat gain or loss of the IU skin or coldplate/electronic component for the configuration given in Figure 3-2 or 3-3, and total heat gain or loss as a result of heat transfer with space, the S-IVB dome, and the forward structure (SLA). A net heat gain indicates the amount of heat that must be absorbed by a heat rejection system, while a net heat loss indicates the amount of heat that must be added to the system to maintain the assumed coldplate/electronic equipment temperature. Through the use of these tables, the desired active thermal system parameters can be established based on the type of mission, equipment heat load profile and temperature tolerance, and the S-IVB dome temperature profile. In each of the tables, the environmental heat absorbed and the IU skin temperature are averaged values for one orbit.

A review of the data presented in these tables indicates some general trends to be noted. First, the total heat gain or loss appears to vary linearly with the coldplate/electronic component temperature so that interpolations can can be made with reasonable accuracy. Further, the data could be extrapolated to give some indication of the temperature value for the coldplate/electronic component for zero heat balance for zero equipment power dissipation. Second, minimum environmental heat absorption—i.e., low value for the absorptivity of IU outer surface—and minimum heat transfer between thermal conditioning system and the S-IVB dome appear desirable. These conditions are particularly desirable for the case of equipment heat rejection rate between two and three kilowatts, since this would minimize the need for heat addition or heat rejection to maintain the desired equipment temperature. For the cases where the equipment heat dissipation rate is less than one kilowatt, high value for the absorptivity of the IU outer surface may be desirable in order to maintain the desired equipment temperature. Conversely, for the cases of high heat dissipation rate, four to five kilowatts, minimum environmental heat absorption, and maximum heat transfer between thermal conditioning system and the S-IVB dome appear desirable, particularly if the S-IVB dome temperature is in the cryogenic temperature range (-210 F). Third, for the coldplate/electronic equipment temperature of

Table 4-13. Orbital Data and Conditions for Heat Balances - Active System, Adiabatic Coldplate Surface

Case No. (Table 2-3)	Type of Orbit	Orientation	Orbital Altitude (n. mi.)	Launch Date	Angle of Inclination (deg)	S-IVB Dome		Outer Surface Optical Properties		Table No.
						Emissivity (G)	Temp (F)	α_s	α_s/ϵ	
IU-1a	Circular earth orbit	X axis tangent to flight path	200	June 21	29	0.05	60	0.18 0.90	0.20 1.00	4-14
							-210	0.18 0.90	0.20 1.00	4-15
						0.90	60	0.18 0.90	0.20 1.00	4-16
							-210	0.18 0.90	0.20 1.00	4-17
IU-3a	Circular earth orbit (polar orbit)	X axis tangent to flight path	200	March 21	90	0.05	60	0.18 0.90	0.20 1.00	4-18
							-210	0.18 0.90	0.20 1.00	4-19
						0.90	60	0.18 0.90	0.20 1.00	4-20
							-210	0.18 0.90	0.20 1.00	4-21
IU-6c	Circular earth orbit (synchronous altitude)	X axis tangent to flight path	19,327	March 21	0	0.05	60	0.18 0.90	0.20 1.00	4-22
							-210	0.18 0.90	0.20 1.00	4-23
						0.90	60	0.18 0.90	0.20 1.00	4-24
							-210	0.18 0.90	0.20 1.00	4-25
IU-7a	Circular earth orbit	X axis tangent to flight path	100	June 21	29	0.05	60	0.18 0.90	0.20 1.00	4-26
							-210	0.18 0.90	0.20 1.00	4-27
						0.90	60	0.18 0.90	0.20 1.00	4-28
							-210	0.18 0.90	0.20 1.00	4-29
IU-10	Circular earth orbit (right ascension -180 deg)	X axis tangent to flight path	100	Dec. 21	34	0.05	60	0.18 0.90	0.20 1.00	4-30
							-210	0.18 0.90	0.20 1.00	4-31
						0.90	60	0.18 0.90	0.20 1.00	4-32
							-210	0.18 0.90	0.20 1.00	4-33
IU-11	Circular earth orbit (right ascension -180 deg)	X axis tangent to flight path	200	Dec. 21	34	0.05	60	0.18 0.90	0.20 1.00	4-34
							-210	0.18 0.90	0.20 1.00	4-35
						0.90	60	0.18 0.90	0.20 1.00	4-36
							-210	0.18 0.90	0.20 1.00	4-37

Orbit Data: Case No. (Table 2-3) : IU-1a
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight p
Orbital Altitude, N. Mi. : 200
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Ne
1	520.6	18.7	-687.9	-167.3	1.0	1.8	6.3	7.3	16
2	520.6	18.3	-685.4	-164.8	1.0	1.8	6.3	7.3	16
3	523.9	-3.9	-	-	-	-	-	-	-
4	523.9	18.3	-685.5	-161.6	1.0	1.8	6.3	7.3	16
5	409.5	13.2	-657.0	-247.5	1.1	2.2			16
6	409.5	-30.4	-	-	-	-	-	-	-
7	260.8	-65.7	-	-	-	-	-	-	-
8	260.8	-62.6	-	-	-	-	-	-	-
9	201.8	1.6	-594.6	-392.8	1.3	3.0	6.3	7.3	17
10	201.8	3.2	-602.8	-401.0	1.3	2.9	6.3	7.3	17
11	197.7	3.0	-602.0	-404.3	1.3	2.9	6.3	7.3	17
12	197.7	3.0	-602.1	-404.4	1.3	2.9	6.3	7.3	17
13	215.9	3.9	-606.6	-390.7	1.3	2.9	6.3	7.3	17
14	215.9	3.8	-606.4	-390.5	1.3	2.9	6.3	7.3	17
15	199.0	1.5	-594.5	-395.5	1.3	3.0	6.3	7.3	17
16	199.0	-59.4	-337.3	-138.3	-	-	13.6	16.2	29
17	151.3	-0.8	-582.2	-430.9	1.4	3.2	6.3	7.3	18
18	151.3	-0.8	-582.4	-431.1	1.4	3.2	6.3	7.3	18
19	138.6	-58.3	-340.8	-202.2	-	-	27.2	32.4	59
20	138.6	-2.8	-572.1	-433.5	1.4	3.4	6.3	7.3	18
21	248.3	-58.6	-399.8	-91.5	-	-	17.3	20.4	37
22	248.3	-63.4	-	-	-	-	-	-	-
23	400.4	11.2	-645.5	-245.1	1.1	2.4	6.3	7.3	17
24	400.4	13.1	-656.3	-255.9	1.1	2.2	6.3	7.3	16
Totals	6935.6	-	-10981.2	-5748.9	19.4	42.6	158.9	185.8	406
1	848.9	34.2	-781.8	67.1	0.6	0.5	6.3	7.3	14
2	848.9	34.8	-785.1	63.8	0.6	0.5	6.3	7.3	14
3	865.6	45.1	-	-	-	-	-	-	-
4	865.6	35.3	-788.6	77.0	0.6	0.4	6.3	7.3	14
5	688.2	27.0	-737.2	-49.0	0.8	1.1	6.3	7.3	15
6	688.2	17.8	-	-	-	-	-	-	-
7	454.3	-18.1	-	-	-	-	-	-	-
8	454.3	-18.0	-	-	-	-	-	-	-
9	629.4	23.0	-713.2	-83.8	0.9	1.4	6.3	7.3	15
10	629.4	24.4	-721.4	-92.0	0.9	1.3	6.3	7.3	15
11	913.2	37.2	-800.4	112.8	0.6	0.3	6.3	7.3	14
12	913.2	37.2	-803.8	109.4	0.6	0.2	6.3	7.3	14
13	1079.7	45.0	-852.1	227.6	0.4	-0.5	6.3	7.3	13
14	1079.7	45.1	-852.8	226.9	0.4	-0.5	6.3	7.3	13
15	994.8	41.8	-830.8	164.0	0.5	-0.2	6.3	7.3	13
16	994.8	56.8	-934.9	59.9	-	-	13.6	16.2	29
17	681.3	27.4	-739.1	-57.8	0.8	1.1	6.3	7.3	15
18	681.3	25.3	-726.5	-45.2	0.8	1.3	6.3	7.3	15
19	313.0	-26.7	-461.5	-148.5	-	-	27.2	32.4	59
20	313.0	6.9	-622.5	-309.5	1.2	2.7	6.3	7.3	17
21	391.8	-27.9	-456.3	-64.5	-	-	17.3	20.4	37
22	391.8	-29.9	-	-	-	-	-	-	-
23	642.7	23.4	-715.2	-72.5	0.9	1.4	6.3	7.3	15
24	642.7	24.9	-724.6	-81.9	0.8	1.3	6.3	7.3	15
Totals	17005.7	-	-14047.9	103.8	11.3	12.3	158.9	185.8	368

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Angle of Inclination (Degrees): 29

t	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
.4	-150.9	520.6	39.9	-818.1	-297.5	0.5	0.0	0	-15.9	-15.4	-312.9
.4	-148.4	520.6	39.0	-812.5	-291.9	0.5	0.1	0	-15.9	-15.3	-307.2
	-	523.9	-0.1	-	-	-	-	-	-	-	-
.4	-145.2	523.9	39.0	-812.5	-288.6	0.5	0.1	0	-15.9	-15.3	-303.9
.9	-230.6	409.5	34.5	-783.2	-373.7	0.6	0.5	0	-15.9	-14.8	-388.5
	-	409.5	-27.6	-	-	-	-	-	-	-	-
	-	260.8	-65.0	-	-	-	-	-	-	-	-
	-	260.8	-59.9	-	-	-	-	-	-	-	-
.9	-374.9	201.8	23.0	-712.9	-511.1	0.9	1.4	0	-15.9	-13.6	-524.7
8	-383.2	201.8	25.0	-724.8	-523.0	0.8	1.3	0	-15.9	-13.8	-536.8
8	-386.5	197.7	24.8	-724.0	-526.3	0.8	1.3	0	-15.9	-13.8	-540.1
8	-386.6	197.7	24.9	-724.1	-526.4	0.8	1.3	0	-15.9	-13.8	-540.2
8	-372.9	215.9	25.7	-729.0	-513.1	0.8	1.2	0	-15.9	-13.9	-527.0
8	-372.7	215.9	25.6	-728.8	-512.9	0.8	1.2	0	-15.9	-13.9	-526.8
9	-377.6	199.0	23.2	-713.9	-514.9	0.9	1.4	0	-15.9	-13.6	-528.5
8	-108.5	199.0	-47.4	-379.3	-180.3	-	-	0	-35.4	-35.4	-215.7
2	-412.7	151.3	20.9	-700.5	-549.2	0.9	1.6	0	-15.9	-13.4	-562.6
2	-412.9	151.3	21.0	-701.2	-549.9	0.9	1.6	0	-15.9	-13.4	-563.3
6	-142.6	138.6	-42.2	-399.1	-260.5	-	-	0	-70.8	-70.8	-331.3
4	-415.1	138.6	18.7	-687.8	-549.2	1.0	1.8	0	-15.9	-13.1	-562.3
7	-53.8	248.3	-49.8	-371.5	-123.2	-	-	0	-44.7	-44.7	-167.9
	-	248.3	-59.8	-	-	-	-	-	-	-	-
1	-228.0	400.4	32.2	-768.9	-368.5	0.7	0.7	0	-15.9	-14.5	-383.0
9	-239.0	400.4	34.5	-783.6	-383.2	0.6	0.5	0	-15.9	-14.8	-398.0
7	-5342.1	6935.6	-	-13075.7	-7843.4	12.3	16.0	0	-405.3	-377.0	-8220.7
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
7	81.8	848.9	54.8	-920.3	-71.4	0.1	-1.4	0	-15.9	-17.2	-88.6
7	78.5	848.9	54.8	-920.6	-71.7	0.1	-1.4	0	-15.9	-17.2	-88.9
	-	865.6	48.0	-	-	-	-	-	-	-	-
6	91.6	865.6	55.4	-924.4	-58.8	0.1	-1.4	0	-15.9	-17.2	-76.0
5	-33.5	688.2	47.7	-870.5	-182.3	0.3	-0.7	0	-15.9	-16.3	-198.6
	-	688.2	20.0	-	-	-	-	-	-	-	-
	-	454.3	-17.7	-	-	-	-	-	-	-	-
	-	454.3	-16.0	-	-	-	-	-	-	-	-
9	-67.9	629.4	43.6	-842.5	-213.1	0.4	-0.3	0	-15.9	-15.8	-228.9
8	-76.2	629.4	45.4	-854.6	-225.2	0.3	-0.5	0	-15.9	-16.1	-241.3
5	127.3	913.2	57.6	-940.5	-27.3	0.1	-1.7	0	-15.9	-17.5	-44.8
4	123.8	913.2	58.1	-944.2	-31.0	0.1	-1.7	0	-15.9	-17.5	-48.5
5	241.1	1079.7	65.1	-996.3	83.4	-0.1	-2.4	0	-15.9	-18.4	65.0
5	240.4	1079.7	65.2	-997.0	82.7	-0.1	-2.4	0	-15.9	-18.4	64.3
9	177.9	994.8	61.7	-970.6	24.2	-0.0	-2.1	0	-15.9	-18.0	6.2
8	89.7	994.8	63.0	-980.4	14.4	-	-	0	-35.4	-35.4	-21.0
5	-42.3	681.3	47.8	-871.4	-190.1	0.3	-0.7	0	-15.9	-16.3	-206.4
7	-29.5	681.3	45.9	-858.6	-177.3	0.4	-0.5	0	-15.9	-16.0	-193.3
5	-88.9	313.0	-13.3	-521.3	-208.3	-	-	0	-70.8	-70.8	-279.1
5	-292.0	313.0	28.0	-742.7	-429.7	0.8	1.0	0	-15.9	-14.1	-443.8
7	-26.8	391.8	-20.5	-488.8	-97.0	-	-	0	-44.7	-44.7	-141.7
	-	391.8	-27.0	-	-	-	-	-	-	-	-
9	-56.6	642.7	43.9	-844.8	-202.1	-0.4	-0.4	0	-15.9	-15.9	-218.0
7	-66.2	642.7	45.9	-858.1	-215.4	0.4	-0.5	0	-15.9	-16.0	-231.4
3	472.2	17005.7	-	-16347.6	-2195.9	3.5	-17.0	0	-405.3	-418.8	-2614.8

e 4-14. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
520.6	50.2	-887.8	-367.2	0.3	-0.9	-3.6	-29.1	-33.3	-400.5
520.6	49.1	-880.5	-359.7	0.3	-0.8	-3.6	-29.1	-33.2	-393.1
523.9	1.8	-	-	-	-	-	-	-	-
523.9	49.1	-880.5	-356.6	0.3	-0.8	-3.6	-29.1	-33.2	-389.8
409.5	44.8	-850.8	-441.3	0.4	-0.4	-3.6	-29.1	-32.7	-474.0
409.5	-26.1	-	-	-	-	-	-	-	-
260.8	-64.6	-	-	-	-	-	-	-	-
260.8	-58.5	-	-	-	-	-	-	-	-
201.8	33.4	-776.6	-574.8	0.7	0.6	-3.6	-29.1	-31.4	-606.2
201.8	35.6	-790.5	-588.7	0.6	0.4	-3.6	-29.1	-31.7	-620.4
197.7	35.5	-789.7	-592.0	0.6	0.4	-3.6	-29.1	-31.7	-623.7
197.7	35.5	-789.9	-592.2	0.6	0.4	-3.6	-29.1	-31.7	-623.9
215.9	36.3	-795.0	-579.1	0.6	0.3	-3.6	-29.1	-31.8	-610.9
215.9	36.3	-794.7	-578.8	0.6	0.3	-3.6	-29.1	-31.8	-610.6
199.0	33.7	-778.4	-579.4	0.7	0.6	-3.6	-29.1	-31.4	-610.8
199.0	-41.3	-402.4	-203.4	-	-	-7.8	-64.7	-72.5	-275.9
151.3	31.4	-764.3	-613.0	0.7	0.7	-3.6	-29.1	-31.3	-644.3
151.3	31.6	-765.3	-614.0	0.7	0.7	-3.6	-29.1	-31.3	-645.3
138.6	-33.9	-431.7	-293.1	-	-	-15.6	-129.4	-145.0	-438.1
138.6	29.2	-750.3	-611.7	0.8	0.9	-3.6	-29.1	-31.0	-642.7
248.3	-44.8	-389.1	-140.8	-	-	-9.8	-81.8	-91.6	-232.4
248.3	-57.9	-	-	-	-	-	-	-	-
400.4	42.4	-835.0	-434.6	0.4	-0.2	-3.6	-29.1	-32.5	-467.1
400.4	45.0	-851.9	-451.5	0.4	-0.4	-3.6	-29.1	-32.7	-484.2
6935.6	-	-14204.5	-8972.2	8.5	1.7	-90.8	-741.5	-822.1	-9794.3
848.9	64.8	-949.0	-145.1	-0.1	-2.4	-3.6	-29.1	-35.2	-180.3
848.9	64.6	-992.7	-143.8	-0.1	-2.4	-3.6	-29.1	-35.2	-179.0
865.6	49.4	-	-	-	-	-	-	-	-
865.6	65.1	-996.6	-131.0	-0.1	-2.4	-3.6	-29.1	-35.2	-166.2
688.2	57.7	-941.6	-253.4	0.1	-1.7	-3.6	-29.1	-34.3	-287.7
688.2	21.1	-	-	-	-	-	-	-	-
454.3	-17.4	-	-	-	-	-	-	-	-
454.3	-14.9	-	-	-	-	-	-	-	-
629.4	53.6	-911.6	-282.2	0.2	-1.3	-3.6	-29.1	-33.8	-316.0
629.4	55.6	-925.9	-296.5	0.1	-1.5	-3.6	-29.1	-34.1	-330.6
913.2	67.5	-1015.0	-101.8	-0.2	-2.7	-3.6	-29.1	-35.6	-137.4
913.2	68.0	-1018.9	-105.7	-0.2	-2.7	-3.6	-29.1	-35.6	-141.3
1079.7	74.9	-1072.9	6.8	-0.4	-3.4	-3.6	-29.1	-36.5	-29.7
1079.7	75.0	-1073.6	6.1	-0.4	-3.5	-3.6	-29.1	-36.6	-30.5
994.8	71.4	-1044.9	-50.1	-0.3	-3.1	-3.6	-29.1	-36.1	-86.2
994.8	66.3	-1005.2	-10.4	-	-	-7.8	-64.7	-72.5	-82.9
681.3	57.8	-942.0	-260.7	0.1	-1.7	-3.6	-29.1	-34.3	-295.0
681.3	56.0	-929.2	-247.9	0.1	-1.5	-3.6	-29.1	-34.1	-282.0
313.0	-6.4	-554.6	-241.6	-	-	-15.6	-129.4	-145.0	-386.6
313.0	38.2	-807.4	-494.4	0.5	0.2	-3.6	-29.1	-32.0	-526.4
391.8	-16.5	-506.7	-114.9	-	-	-9.8	-81.8	-91.6	-206.5
391.8	-25.5	-	-	-	-	-	-	-	-
642.7	53.9	-914.0	-271.3	0.2	-1.3	-3.6	-29.1	-33.8	-305.1
642.7	56.1	-929.4	-286.7	0.1	-1.5	-3.6	-29.1	-34.1	-320.8
17005.7	-	-17576.3	-3424.6	-0.6	-32.7	-90.8	-741.5	-865.6	-4290.2

Orbit Data: Case No. (Table 2-3) : IU-1a
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight pat
Orbital Altitude, N. Mi. : 200
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	520.6	18.5	-686.9	-166.3	-2.3	1.8	-21.7	7.3	-14.9
2	520.6	18.1	-684.3	-163.7	-2.3	1.8	-21.7	7.3	-14.9
3	523.9	-5.9	-	-	-	-	-	-	-
4	523.9	18.1	-684.3	-160.4	-2.3	1.8	-21.7	7.3	-14.9
5	409.5	13.0	-656.0	-246.5	-2.2	2.2	-21.7	7.3	-14.4
6	409.5	-33.0	-	-	-	-	-	-	-
7	260.8	-69.2	-	-	-	-	-	-	-
8	260.8	-65.8	-	-	-	-	-	-	-
9	201.8	1.4	-593.5	-391.7	-2.0	3.1	-21.7	7.3	-13.3
10	201.8	3.0	-601.2	-399.4	-2.0	2.9	-21.7	7.3	-13.5
11	197.7	2.8	-601.1	-403.4	-2.0	3.0	-21.7	7.3	-13.4
12	197.7	2.9	-601.2	-403.5	-2.0	3.0	-21.7	7.3	-13.4
13	215.9	3.7	-605.7	-389.8	-2.0	2.9	-21.7	7.3	-13.5
14	215.9	3.7	-605.5	-389.6	-2.0	2.9	-21.7	7.3	-13.5
15	199.0	1.4	-593.6	-394.6	-2.0	3.1	-21.7	7.3	-13.3
16	199.0	-59.4	-337.2	-138.2	-	-	-47.3	16.2	-31.1
17	151.3	-1.0	-581.4	-430.1	-1.9	3.2	-21.7	7.3	-13.1
18	151.3	-1.0	-581.5	-430.2	-1.9	3.2	-21.7	7.3	-13.1
19	138.6	-58.4	-340.7	-202.1	-	-	-94.6	32.4	-62.2
20	138.6	-3.0	-571.3	-432.7	-1.9	3.4	-21.7	7.3	-12.9
21	248.3	-58.9	-338.8	-90.5	-	-	-60.1	20.4	-39.7
22	248.3	-66.3	-	-	-	-	-	-	-
23	400.4	10.9	-644.3	-243.9	-2.1	2.4	-21.7	7.3	-14.1
24	400.4	12.9	-655.4	-255.0	-2.2	2.2	-21.7	7.3	-14.4
Totals	6935.6	-	-10964.8	-5732.5	-33.1	42.8	-549.2	185.6	-353.9
1	848.9	34.1	-780.8	68.1	-2.6	0.5	-21.7	7.3	-16.5
2	848.9	34.6	-783.9	65.0	-2.7	0.5	-21.7	7.3	-16.6
3	865.6	43.6	-	-	-	-	-	-	-
4	865.6	35.1	-787.4	78.2	-2.7	0.4	-21.7	7.3	-16.7
5	688.2	26.9	-736.1	-47.9	-2.5	1.1	-21.7	7.3	-15.8
6	688.2	15.9	-	-	-	-	-	-	-
7	454.3	-20.6	-	-	-	-	-	-	-
8	454.3	-20.4	-	-	-	-	-	-	-
9	629.4	22.8	-712.0	-82.6	-2.4	1.5	-21.7	7.3	-15.3
10	629.4	24.2	-720.4	-91.0	-2.4	1.3	-21.7	7.3	-15.5
11	913.2	37.0	-799.4	113.8	-2.7	0.3	-21.7	7.3	-16.8
12	913.2	37.5	-802.8	110.4	-2.7	0.2	-21.7	7.3	-16.9
13	1079.7	44.8	-851.1	228.6	-2.9	-0.4	-21.7	7.3	-17.7
14	1079.7	44.9	-851.8	227.9	-2.9	-0.4	-21.7	7.3	-17.7
15	994.8	41.6	-829.8	165.0	-2.8	-0.1	-21.7	7.3	-17.3
16	994.8	56.8	-934.8	60.0	-	-	-47.3	16.2	-31.1
17	681.3	27.2	-738.2	-56.9	-2.5	1.1	-21.7	7.3	-15.8
18	681.3	25.1	-725.5	-44.2	-2.4	1.3	-21.7	7.3	-15.5
19	313.0	-26.8	-461.4	-148.4	-	-	-94.6	32.4	-62.2
20	313.0	6.7	-621.6	-308.6	-2.1	2.7	-21.7	7.3	-13.8
21	391.8	-28.2	-455.4	-63.6	-	-	-60.1	20.4	-39.7
22	391.8	-32.2	-	-	-	-	-	-	-
23	642.7	23.2	-714.0	-71.3	-2.4	1.4	-21.7	7.3	-15.4
24	642.7	24.8	-723.6	-80.9	-2.4	1.3	-21.7	7.3	-15.5
Totals	17005.71	-	-14030.3	121.4	-41.1	12.5	-549.2	185.6	-392.2

h

Angle of Inclination (Degrees): 29

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-181.2	520.6	39.7	-817.1	-296.5	-2.8	0.0	-28.0	-15.9	-46.7	-343.2
-178.6	520.6	38.8	-811.3	-290.7	-2.8	0.1	-28.0	-15.9	-46.6	-337.3
-	523.9	-2.0	-	-	-	-	-	-	-	-
-175.3	523.9	38.8	-811.3	-287.4	-2.8	0.1	-28.0	-15.9	-46.6	-334.0
-260.9	409.5	34.3	-782.1	-372.6	-2.6	0.5	-28.0	-15.9	-46.0	-418.6
-	409.5	-30.1	-	-	-	-	-	-	-	-
-	260.8	-68.5	-	-	-	-	-	-	-	-
-	260.8	-63.0	-	-	-	-	-	-	-	-
-405.0	201.8	22.8	-711.6	-509.8	-2.4	1.5	-28.0	-15.9	-44.8	-554.6
-412.9	201.8	24.8	-723.8	-522.0	-2.4	1.3	-28.0	-15.9	-45.0	-567.0
-416.8	197.7	24.7	-723.1	-525.4	-2.4	1.3	-28.0	-15.9	-45.0	-570.4
-416.9	197.7	24.7	-723.2	-525.5	-2.4	1.3	-28.0	-15.9	-45.0	-570.5
-403.3	215.9	25.5	-728.1	-512.2	-2.5	1.2	-28.0	-15.9	-45.2	-557.4
-403.1	215.9	25.5	-727.8	-511.9	-2.5	1.2	-28.0	-15.9	-45.2	-557.1
-407.9	199.0	23.0	-713.0	-514.0	-2.4	1.4	-28.0	-15.9	-44.9	-558.9
-169.3	199.0	-47.5	-379.2	-180.2	-	-	-60.9	-35.4	-96.3	-276.5
-443.2	151.3	20.7	-699.6	-548.3	-2.3	1.6	-28.0	-15.9	-44.6	-592.9
-443.3	151.3	20.8	-700.3	-549.0	-2.4	1.6	-28.0	-15.9	-44.7	-593.7
-264.3	138.6	-42.2	-399.0	-260.4	-	-	-121.8	-70.8	-192.6	-453.0
-445.6	138.6	18.5	-686.9	-548.3	-2.3	1.8	-28.0	-15.9	-44.4	-592.7
-130.2	248.3	-49.9	-370.5	-122.2	-	-	-77.4	-44.7	-122.1	-244.3
-	248.3	-62.5	-	-	-	-	-	-	-	-
-258.0	400.4	32.0	-767.6	-367.2	-2.6	0.7	-28.0	-15.9	-45.8	-413.0
-269.4	400.4	34.4	-782.6	-382.2	-2.6	0.5	-28.0	-15.9	-46.0	-428.2
-6086.4	6935.6	-	-13057.9	-7825.6	-40.2	16.2	-708.1	-405.3	-1137.4	-8963.0
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
51.6	848.9	54.6	-919.2	-70.3	-3.1	-1.4	-28.0	-15.9	-48.4	-118.7
48.4	848.9	54.7	-919.3	-70.4	-3.1	-1.4	-28.0	-15.9	-48.4	-118.8
-	865.6	46.5	-	-	-	-	-	-	-	-
61.5	865.6	55.2	-923.1	-57.5	-3.2	-1.4	-28.0	-15.9	-48.5	-106.0
-63.7	688.2	47.5	-869.4	-181.2	-3.0	-0.7	-28.0	-15.9	-47.6	-228.8
-	688.2	18.1	-	-	-	-	-	-	-	-
-	454.3	-20.1	-	-	-	-	-	-	-	-
-	454.3	-18.3	-	-	-	-	-	-	-	-
-97.9	629.4	43.4	-841.2	-211.8	-2.9	-0.3	-28.0	-15.9	-47.1	-258.9
-106.5	629.4	45.2	-853.6	-224.2	-2.9	-0.5	-28.0	-15.9	-47.3	-271.5
97.0	913.2	57.4	-939.4	-26.2	-3.2	-1.6	-28.0	-15.9	-48.7	-74.9
93.5	913.2	57.9	-943.1	-29.9	-3.2	-1.7	-28.0	-15.9	-48.8	-78.7
210.9	1079.7	65.0	-995.2	84.5	-3.4	-2.4	-28.0	-15.9	-49.7	34.8
210.2	1079.7	65.0	-995.9	83.8	-3.4	-2.4	-28.0	-15.9	-49.7	34.1
147.7	994.8	61.5	-969.5	25.3	-3.3	-2.0	-28.0	-15.9	-49.2	-23.9
28.9	994.8	63.0	-980.3	14.5	-	-	-60.9	-35.4	-96.3	-81.8
-72.7	681.3	47.7	-870.4	-189.1	-3.0	-0.7	-28.0	-15.9	-47.6	-236.7
-59.7	681.3	45.8	-857.6	-176.3	-2.9	-0.5	-28.0	-15.9	-47.3	-223.6
-210.6	313.0	-13.4	-521.2	-208.2	-	-	-121.8	-70.8	-192.6	-400.8
-322.4	313.0	27.8	-741.8	-428.8	-2.5	1.0	-28.0	-15.9	-45.4	-474.2
-103.3	391.8	-20.7	-487.8	-96.0	-	-	-77.4	-44.7	-122.1	-218.1
-	391.8	-29.3	-	-	-	-	-	-	-	-
-86.7	642.7	43.7	-843.4	-200.7	-2.9	-0.3	-28.0	-15.9	-47.1	-247.8
-96.4	642.7	45.7	-857.0	-214.3	-2.9	-0.5	-28.0	-15.9	-47.3	-261.6
-270.8	17005.71	-	-16328.6	-2176.9	-49.0	-16.8	-708.1	-405.3	-1179.2	-3356.1

e 4-15. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
520.6	50.0	-886.8	-366.2	-3.0	-0.9	-31.6	-29.1	-64.6	-430.8
520.6	49.0	-879.2	-358.6	-3.0	-0.8	-31.6	-29.1	-64.5	-423.1
523.9	-0.2	-	-	-	-	-	-	-	-
523.9	49.0	-879.2	-355.3	-3.0	-0.8	-31.6	-29.1	-64.5	-419.8
409.5	44.6	-849.7	-440.2	-2.9	-0.4	-31.6	-29.1	-64.0	-504.2
409.5	-28.6	-	-	-	-	-	-	-	-
260.8	-68.1	-	-	-	-	-	-	-	-
260.8	-61.7	-	-	-	-	-	-	-	-
201.8	33.2	-775.3	-573.5	-2.6	0.6	-31.6	-29.1	-62.7	-636.2
201.8	35.5	-789.5	-587.7	-2.7	0.4	-31.6	-29.1	-63.0	-650.7
197.7	35.3	-788.8	-591.1	-2.7	0.4	-31.6	-29.1	-63.0	-654.1
197.7	35.4	-788.9	-591.2	-2.7	0.4	-31.6	-29.1	-63.0	-654.2
215.9	36.2	-794.0	-578.1	-2.7	0.3	-31.6	-29.1	-63.1	-641.2
215.9	36.1	-793.7	-577.8	-2.7	0.3	-31.6	-29.1	-63.1	-640.9
199.0	33.5	-777.4	-578.4	-2.6	0.6	-31.6	-29.1	-62.7	-641.1
199.0	-41.3	-402.3	-203.3	-	-	-68.7	-64.7	-133.4	-336.7
151.3	31.3	-763.3	-612.0	-2.6	0.8	-31.6	-29.1	-62.5	-674.5
151.3	31.5	-764.3	-613.0	-2.6	0.7	-31.6	-29.1	-62.6	-675.6
138.6	-33.9	-431.6	-293.0	-	-	-137.4	-129.4	-266.8	-559.8
138.6	29.0	-749.3	-610.7	-2.5	0.9	-31.6	-29.1	-62.3	-673.0
248.3	-45.1	-388.1	-139.8	-	-	-87.2	-81.8	-169.0	-308.8
248.3	-60.7	-	-	-	-	-	-	-	-
400.4	42.2	-833.7	-433.3	-2.8	-0.2	-31.6	-29.1	-63.7	-497.0
400.4	44.8	-850.9	-450.5	-2.9	-0.4	-31.6	-29.1	-64.0	-514.5
6935.6	-	-14186.0	-9004.1	-44.0	1.9	-798.9	-741.5	-1582.5	-10536.2
848.9	64.6	-992.9	-144.0	-3.4	-2.4	-31.6	-29.1	-66.5	-210.5
848.9	64.4	-991.4	-142.5	-3.4	-2.3	-31.6	-29.1	-66.4	-208.9
865.6	48.0	-	-	-	-	-	-	-	-
865.6	65.0	-995.3	-129.7	-3.4	-2.4	-31.6	-29.1	-66.5	-196.2
688.2	57.6	-940.4	-252.2	-3.2	-1.6	-31.6	-29.1	-65.5	-317.7
688.2	19.2	-	-	-	-	-	-	-	-
454.2	-19.9	-	-	-	-	-	-	-	-
454.2	-17.2	-	-	-	-	-	-	-	-
629.4	53.4	-910.2	-280.8	-3.1	-1.2	-31.6	-29.1	-65.0	-345.8
629.4	55.4	-924.8	-295.4	-3.2	-1.4	-31.6	-29.1	-65.3	-360.7
913.2	67.4	-1013.9	-100.7	-3.5	-2.6	-31.6	-29.1	-66.8	-167.5
913.2	67.9	-1017.8	-104.6	-3.5	-2.7	-31.6	-29.1	-66.9	-171.5
1079.7	74.8	-1071.8	7.9	-3.7	-3.4	-31.6	-29.1	-67.8	-59.9
1079.7	74.8	-1072.5	7.2	-3.7	-3.4	-31.6	-29.1	-67.8	-60.6
994.8	71.2	-1043.8	-49.0	-3.6	-3.1	-31.6	-29.1	-67.4	-116.4
994.8	66.3	-1005.1	-10.3	-	-	-68.7	-64.7	-133.4	-143.7
681.3	57.7	-941.0	-259.7	-3.2	-1.7	-31.6	-29.1	-65.6	-325.3
681.3	55.9	-928.2	-246.9	-3.2	-1.5	-31.6	-29.1	-65.4	-312.3
313.0	-6.4	-554.5	-241.5	-	-	-137.4	-129.4	-266.8	-508.3
313.0	38.1	-806.5	-493.5	-2.7	0.2	-31.6	-29.1	-63.2	-556.7
391.8	-16.7	-505.8	-114.0	-	-	-87.2	-81.8	-169.0	-283.0
391.8	-27.8	-	-	-	-	-	-	-	-
642.7	53.7	-912.6	-269.9	-3.1	-1.3	-31.6	-29.1	-65.1	-335.0
642.7	55.9	-928.4	-285.7	-3.2	-1.5	-31.6	-29.1	-65.4	-351.1
17005.71	-	-17556.6	-3404.9	-53.1	-32.4	-798.9	-741.5	-1625.9	-5030.8

Orbit Data: Case No. (Table 2-3) : IU-1a
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight
Orbital Altitude, N. Mi. : 200
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	520.6	19.1	-690.1	-169.1	9.2	0.7	58.5	2.8	71
2	520.6	18.8	-688.7	-168.1	9.3	0.7	58.5	2.8	71
3	523.9	1.1	-	-	-	-	-	-	-
4	523.9	18.9	-689.0	-165.1	9.3	0.7	58.5	2.8	71
5	409.5	13.8	-660.4	-250.9	10.2	0.9	58.5	2.8	72
6	409.5	-21.2	-	-	-	-	-	-	-
7	260.8	-52.1	-	-	-	-	-	-	-
8	260.8	-50.3	-	-	-	-	-	-	-
9	201.8	2.6	-599.7	-397.9	12.3	1.2	58.5	2.8	74
10	201.8	3.6	-605.3	-403.5	12.1	1.2	58.5	2.8	74
11	197.7	3.5	-604.4	-406.7	12.2	1.2	58.5	2.8	74
12	197.7	3.5	-604.4	-406.7	12.2	1.2	58.5	2.8	74
13	215.9	4.3	-608.9	-393.0	12.0	1.1	58.5	2.8	74
14	215.9	4.3	-608.8	-392.9	12.0	1.1	58.5	2.8	74
15	199.0	2.2	-597.9	-398.9	12.4	1.2	58.5	2.8	74
16	199.0	-61.6	-329.8	-130.8	-	-	130.3	6.2	136
17	151.3	-0.1	-585.8	-434.5	12.8	1.3	58.5	2.8	75
18	151.3	-0.1	-585.9	-434.6	12.8	1.3	58.5	2.8	75
19	138.6	-60.2	-334.5	-195.9	-	-	260.6	12.4	273
20	138.6	-1.9	-576.8	-438.2	13.1	1.3	58.5	2.8	75
21	248.3	-58.6	-339.8	-91.5	-	-	165.1	7.8	172
22	248.3	-52.5	-	-	-	-	-	-	-
23	400.4	12.1	-650.7	-250.3	10.6	0.9	58.5	2.8	72
24	400.4	13.5	-658.4	-258.0	10.3	0.9	58.5	2.8	72
Totals	6935.6	-	-11019.4	-5787.1	182.8	16.8	1492.0	71.2	1762
1	848.9	34.5	-783.7	65.2	6.0	0.2	58.5	2.8	67
2	848.9	35.0	-786.4	62.5	5.9	0.2	58.5	2.8	67
3	865.6	47.0	-	-	-	-	-	-	-
4	865.6	35.6	-790.3	75.3	5.8	0.2	58.5	2.8	67
5	688.2	27.3	-739.0	-50.8	7.5	0.4	58.5	2.8	69
6	688.2	22.5	-	-	-	-	-	-	-
7	454.2	-11.1	-	-	-	-	-	-	-
8	454.2	-11.2	-	-	-	-	-	-	-
9	629.4	23.7	-717.1	-87.7	8.3	0.6	58.5	2.8	70
10	629.4	24.6	-722.8	-93.4	8.1	0.5	58.5	2.8	69
11	913.2	37.4	-802.3	110.9	5.4	0.1	58.5	2.8	66
12	913.2	37.9	-804.9	108.3	5.3	0.1	58.5	2.8	66
13	1079.7	45.2	-853.5	226.2	3.6	-0.2	58.5	2.8	64
14	1079.7	45.3	-854.1	225.6	3.6	-0.2	58.5	2.8	64
15	994.8	41.9	-831.2	163.6	4.4	-0.1	58.5	2.8	65
16	994.8	57.5	-940.2	54.6	-	-	130.3	6.2	136
17	681.3	27.5	-739.8	-58.5	7.5	0.4	58.5	2.8	69
18	681.3	25.8	-729.6	-48.3	7.9	0.5	58.5	2.8	69
19	313.0	-28.1	-455.7	-142.7	-	-	260.6	12.4	273
20	313.0	7.6	-626.4	-313.4	11.4	1.0	58.5	2.8	73
21	391.8	-28.0	-456.2	-64.4	-	-	165.1	7.8	172
22	391.8	-22.6	-	-	-	-	-	-	-
23	642.7	24.1	-719.5	-76.8	8.2	0.5	58.5	2.8	70
24	642.7	25.2	-726.1	-83.4	8.0	0.5	58.5	2.8	69
Totals	17005.71	-	-14078.9	72.8	106.7	4.8	1492.0	71.2	1674

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Angle of Inclination (Degrees): 29

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
2	-98.3	520.6	40.1	-819.7	-299.1	4.8	-0.0	0	-6.1	-1.3	-300.
3	-96.8	520.6	39.5	-815.8	-295.2	4.9	0.0	0	-6.1	-1.2	-296.
	-	523.9	3.8	-	-	-	-	-	-	-	-
3	-93.8	523.9	39.6	-816.1	-292.2	4.9	0.0	0	-6.1	-1.2	-293.
4	-178.5	409.5	35.0	-786.8	-377.3	5.9	0.2	0	-6.1	0	-377.
	-	409.5	-19.0	-	-	-	-	-	-	-	-
	-	260.8	-51.7	-	-	-	-	-	-	-	-
	-	260.8	-48.4	-	-	-	-	-	-	-	-
8	-323.1	201.8	23.9	-718.3	-516.5	8.2	0.5	0	-6.1	2.6	-513.
6	-328.9	201.8	25.3	-726.8	-525.0	8.0	0.5	0	-6.1	2.4	-522.
7	-332.0	197.7	25.1	-725.8	-528.1	8.0	0.5	0	-6.1	2.4	-525.
7	-332.0	197.7	25.2	-725.9	-528.2	8.0	0.5	0	-6.1	2.4	-525.
4	-318.6	215.9	26.0	-730.9	-515.0	7.8	0.5	0	-6.1	2.2	-512.
4	-318.5	215.9	26.0	-730.7	-514.8	7.8	0.5	0	-6.1	2.2	-512.
9	-324.0	199.0	23.7	-717.4	-518.4	8.3	0.6	0	-6.1	2.8	-515.
5	5.7	199.0	-50.2	-369.2	-170.2	-	-	0	-13.5	-13.5	-183.
4	-359.1	151.3	21.5	-704.0	-552.7	8.7	0.6	0	-6.1	3.2	-549.
4	-359.2	151.3	21.6	-704.7	-553.4	8.7	0.6	0	-6.1	3.2	-550.
0	77.1	138.6	-44.3	-391.0	-252.4	-	-	0	-27.0	-27.0	-279.
7	-362.5	138.6	19.6	-693.1	-554.5	9.1	0.7	0	-6.1	3.7	-550.
9	81.4	248.3	-49.9	-370.2	-121.9	-	-	0	-17.2	-17.2	-139.
	-	248.3	-49.9	-	-	-	-	-	-	-	-
8	-177.5	400.4	33.0	-774.2	-373.8	6.3	0.2	0	-6.1	0.4	-373.
5	-185.5	400.4	34.8	-785.0	-384.6	6.0	0.2	0	-6.1	0.1	-384.
8	-4024.1	6935.6	-	-13105.6	-7873.3	115.4	6.1	0	-155.3	-33.8	-7907.
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
5	132.7	848.9	54.9	-921.3	-72.4	1.3	-0.6	0	-6.1	-5.4	-77.
4	129.9	848.9	55.0	-921.8	-72.9	1.3	-0.6	0	-6.1	-5.4	-78.
	-	865.6	49.1	-	-	-	-	-	-	-	-
3	142.6	865.6	55.6	-925.9	-60.3	1.1	-0.6	0	-6.1	-5.6	-65.
2	18.4	688.2	48.0	-872.4	-184.2	2.9	-0.3	0	-6.1	-3.5	-187.
	-	688.2	24.2	-	-	-	-	-	-	-	-
	-	454.2	-10.9	-	-	-	-	-	-	-	-
	-	454.2	-9.8	-	-	-	-	-	-	-	-
2	-17.5	629.4	44.2	-846.5	-217.1	3.8	-0.1	0	-6.1	-2.4	-219.
9	-23.5	629.4	45.4	-855.3	-225.9	3.5	-0.2	0	-6.1	-2.8	-228.
8	177.7	913.2	57.7	-941.6	-28.4	0.6	-0.7	0	-6.1	-6.2	-34.
7	175.0	913.2	58.1	-944.3	-31.1	0.5	-0.7	0	-6.1	-6.3	-37.
7	290.9	1079.7	65.2	-996.8	83.7	-1.3	-1.0	0	-6.1	-8.4	75.
7	290.3	1079.7	65.2	-997.3	82.4	-1.3	-1.0	0	-6.1	-8.4	74.
6	229.2	994.8	61.7	-970.7	24.1	-0.4	-0.8	0	-6.1	-7.3	16.
5	191.1	994.8	63.3	-982.5	12.3	-	-	0	-13.5	-13.5	-1
2	10.7	681.3	47.9	-871.8	-190.5	3.0	-0.3	0	-6.1	-3.4	-193.
7	21.4	681.3	46.4	-861.6	-180.3	3.3	-0.2	0	-6.1	-3.0	-183.
0	130.3	313.0	-15.0	-513.4	-200.4	-	-	0	-27.0	-27.0	-227.
7	-239.7	313.0	28.7	-747.1	-434.1	7.3	0.4	0	-6.1	1.6	-432.
9	108.5	391.8	-20.8	-487.3	-95.5	-	-	0	-17.2	-17.2	-112.
	-	391.8	-20.5	-	-	-	-	-	-	-	-
0	-6.8	642.7	44.5	-849.2	-206.5	3.7	-0.2	0	-6.1	-2.6	-209.
8	-13.6	642.7	46.0	-858.9	-216.2	3.4	-0.2	0	-6.1	-2.9	-219.
7	1747.6	17005.71	-	-16365.5	-2213.8	32.6	-6.9	0	-155.3	-129.6	-2343.

4-16. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
520.6	50.4	-889.0	-368.4	2.4	-0.4	-33.3	-11.1	-42.4	-410.8
520.6	49.6	-883.8	-363.2	2.6	-0.4	-33.3	-11.1	-42.2	-405.4
523.9	5.1	-	-	-	-	-	-	-	-
523.9	49.7	-884.1	-360.2	2.5	-0.4	-33.3	-11.1	-42.3	-402.5
409.5	45.3	-854.5	-445.0	3.6	-0.2	-33.3	-11.1	-41.0	-486.0
409.5	-18.0	-	-	-	-	-	-	-	-
260.8	-51.6	-	-	-	-	-	-	-	-
260.8	-47.5	-	-	-	-	-	-	-	-
201.8	34.3	-782.1	-580.3	6.1	0.2	-33.3	-11.1	-38.1	-618.4
201.8	35.9	-792.2	-590.4	5.7	0.1	-33.3	-11.1	-38.6	-629.0
197.7	35.7	-791.2	-593.4	5.7	0.2	-33.3	-11.1	-38.5	-632.0
197.9	35.7	-791.3	-593.4	5.7	0.2	-33.3	-11.1	-38.5	-631.9
215.9	36.5	-796.5	-580.6	5.6	0.1	-33.3	-11.1	-38.7	-619.3
215.9	36.5	-796.3	-580.4	5.6	0.1	-33.3	-11.1	-38.7	-619.1
199.0	34.2	-781.8	-582.8	6.1	0.2	-33.3	-11.1	-38.1	-620.9
199.0	-44.3	-390.9	-191.9	-	-	-74.2	-24.7	-98.9	-290.8
151.3	32.0	-767.8	-616.5	6.5	0.3	-33.3	-11.1	-37.6	-654.1
151.3	32.2	-768.7	-617.4	6.5	0.3	-33.3	-11.1	-37.6	-655.0
138.6	-36.1	-422.6	-284.0	-	-	-148.4	-49.4	-197.8	-481.8
138.6	30.1	755.8	-617.2	7.0	0.3	-33.3	-11.1	-37.1	-654.3
248.3	-45.4	-387.0	-138.7	-	-	94.0	-31.4	-125.4	-264.1
248.3	-48.6	-	-	-	-	-	-	-	-
400.4	43.3	-840.5	-440.1	4.0	-0.1	-33.3	-11.1	-40.5	-480.6
400.4	45.1	-853.0	-452.6	3.6	-0.2	-33.3	-11.1	-41.0	-493.6
6935.6	-	-14229.2	-8996.9	79.2	0.4	-849.4	-283.1	-1052.9	-10049.6
848.9	64.9	-994.6	-145.7	1.3	-1.0	-33.3	-11.1	-46.7	-192.4
848.9	64.7	-993.8	-144.9	1.2	-0.9	-33.3	-11.1	-46.5	-191.4
865.6	50.1	-	-	-	-	-	-	-	-
865.6	65.3	-998.1	-132.5	-1.4	-1.0	-33.3	-11.1	-46.8	-179.3
688.2	58.0	-943.5	-255.3	0.5	-0.7	-33.3	-11.1	-44.6	-299.9
688.2	25.0	-	-	-	-	-	-	-	-
454.2	-10.8	-	-	-	-	-	-	-	-
454.2	-9.0	-	-	-	-	-	-	-	-
629.4	54.1	-915.7	-286.3	1.5	0.5	-33.3	-11.1	-43.4	-329.7
629.4	55.6	-926.0	-296.6	1.1	0.6	-33.3	-11.1	-43.9	-340.5
903.2	67.6	-1015.6	-102.4	-2.0	-1.1	-33.3	-11.1	-47.5	-149.9
913.2	68.0	-1018.4	-105.2	-2.1	-1.1	-33.3	-11.1	-47.6	-152.8
1079.7	74.9	-1072.8	6.9	-3.9	-1.4	-33.3	-11.1	-49.7	-42.8
1079.7	75.0	-1073.3	6.4	-4.0	-1.4	-33.3	-11.1	-49.8	-43.4
994.8	71.4	-1044.7	-49.9	-3.0	1.2	-33.3	-11.1	-46.2	-96.1
994.8	66.3	-1005.6	-10.8	-	-	-74.2	-24.7	-98.9	-109.7
681.3	57.8	-942.2	-260.9	0.5	-0.7	-33.3	-11.1	-44.6	-305.5
681.3	56.4	-932.0	-250.7	0.9	-0.6	-33.3	-11.1	-44.1	-294.8
313.0	-8.2	-545.7	-232.7	-	-	-148.4	-49.4	-197.8	-430.5
313.0	38.9	-812.1	-499.1	5.0	0.0	-33.3	-11.1	-39.4	-538.5
391.8	-17.0	-504.4	-112.6	-	-	-94.0	-31.4	-125.4	-238.0
391.8	-19.5	-	-	-	-	-	-	-	-
642.7	54.5	-918.4	-275.7	1.4	-0.5	-33.3	-11.1	-43.5	-319.2
642.7	56.1	-929.8	-287.1	1.0	-0.6	-33.3	-11.1	-44.0	-331.1
17005.71	-	-17586.7	-3435.0	-6.9	-13.2	-849.4	-283.1	-1152.6	-4587.6

Orbit Data: Case No. (Table 2-3) : IU - 1a
Type of Orbit and Orientation: Circular Earth Orbit, X-axis tangent to flight
Orbital Altitude, N. Mi. : 200
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	520.6	17.6	-681.4	-160.8	-21.7	0.7	-203.3	2.8	-221
2	520.6	17.0	-678.1	-157.5	-21.6	0.8	-203.3	2.8	-221
3	523.9	-17.7	-	-	-	-	-	-	-
4	523.9	17.0	-678.4	-154.5	-21.6	0.8	-203.3	2.8	-221
5	409.5	12.3	-651.6	-242.1	20.7	0.9	-203.3	2.8	-220
6	409.5	-45.0	-	-	-	-	-	-	-
7	260.8	-83.7	-	-	-	-	-	-	-
8	260.8	-79.6	-	-	-	-	-	-	-
9	201.8	0.5	-588.9	-387.1	-18.5	1.2	-203.3	2.8	-217
10	201.8	2.1	-597.2	-395.4	-18.8	1.2	-203.3	2.8	-218
11	197.7	1.9	-596.3	-398.6	-18.8	1.2	-203.3	2.8	-218
12	197.7	1.9	-596.4	-398.7	-18.8	1.2	-203.3	2.8	-218
13	215.9	2.8	-600.9	-385.0	-18.9	1.2	-203.3	2.8	-218
14	215.9	2.8	-600.8	-384.9	-18.9	1.2	-203.3	2.8	-218
15	199.0	0.7	-590.1	-391.1	-18.5	1.2	-203.3	2.8	-217
16	199.0	-61.9	-328.9	-129.9	-	-	-452.6	6.2	-446
17	151.3	-1.7	-578.0	-426.7	-18.1	1.3	-203.3	2.8.	-217
18	151.3	-1.6	-578.2	-426.9	-18.1	1.3	-203.3	2.8	-217
19	138.6	-60.4	-333.7	-195.1	-	-	-905.2	12.4	-892
20	138.6	-3.5	-569.1	-430.5	-17.8	1.4	-203.3	2.8	-216
21	248.3	-61.1	-331.5	-83.2	-	-	-573.5	7.6	-565
22	248.3	-79.3	-	-	-	-	-	-	-
23	400.4	10.1	-639.7	-239.3	-20.2	1.0	-203.3	2.8	-219
24	400.4	12.0	-650.0	-249.6	-20.6	0.9	-203.3	2.8	-220
Totals	6935.6	-	-10869.1	-5636.8	-311.5	17.5	-5184.1	71.2	-5406
1	848.9	33.1	-774.5	74.4	-24.9	0.2	-203.3	2.8	-225
2	848.9	33.3	-775.6	73.3	-24.9	0.2	-203.3	2.8	-225
3	865.6	32.8	-	-	-	-	-	-	-
4	865.6	33.9	-779.4	86.2	-25.0	0.2	-203.3	2.8	-225
5	688.2	25.8	-729.8	-41.6	-23.3	0.5	-203.3	2.8	-223
6	688.2	4.9	-	-	-	-	-	-	-
7	454.3	-34.2	-	-	-	-	-	-	-
8	454.3	-33.1	-	-	-	-	-	-	-
9	629.4	21.8	-706.0	-76.6	-22.5	0.6	-203.3	2.8	-222
10	629.4	23.2	-714.0	-84.6	-22.8	0.6	-203.3	2.8	-222
11	913.2	36.0	-793.0	120.2	-25.5	0.1	-203.3	2.8	-225
12	913.2	36.4	-795.6	117.6	-25.6	0.1	-203.3	2.8	-226
13	1079.7	43.8	-844.0	235.7	-27.3	-0.1	-203.3	2.8	-227
14	1079.7	43.9	-844.5	235.2	-27.3	-0.1	-203.3	2.8	-227
15	994.8	40.5	-821.9	172.9	-26.5	0	-203.3	2.8	-227
16	994.8	57.4	-939.2	55.6	-	-	-452.6	6.2	-446
17	681.3	26.0	-731.0	-49.7	-24.4	0.5	-203.3	2.8	-224
18	681.3	24.3	-720.9	-39.6	-23.0	0.5	-203.3	2.8	-223
19	313.0	-28.3	-454.8	-141.8	-	-	-905.2	12.4	-892
20	313.0	6.1	-618.4	-305.4	-19.5	1.1	-203.3	2.8	-218
21	391.8	-29.7	-449.0	-57.2	-	-	-573.5	7.6	-565
22	391.8	-44.4	-	-	-	-	-	-	-
23	642.7	22.2	-708.4	-65.7	-22.6	0.6	-203.3	2.8	-222
24	642.7	23.7	-717.2	-74.5	-22.9	0.6	-203.3	2.8	-222
Totals	17005.71	-	-13917.0	234.7	-387.1	5.6	-5184.1	71.2	-5494

path

Angle of Inclination (Degrees): 29

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gai or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
.5	-382.3	520.6	38.7	-810.2	-289.6	-26.1	0	-261.8	-6.1	-294.0	-583.
.3	-378.8	520.6	37.8	-804.3	-283.7	-25.9	0.1	-261.8	-6.1	-293.7	-577.
	-	523.9	-14.7	-	-	-	-	-	-	-	-
.3	-375.8	523.9	37.8	-804.6	-280.7	-25.9	0.1	-261.8	-6.1	-293.7	-574.
.3	-462.4	409.5	33.5	-777.2	-367.7	-25.0	0.2	-261.8	-6.1	-292.7	-660.
	-	409.5	-42.5	-	-	-	-	-	-	-	-
	-	260.8	-83.2	-	-	-	-	-	-	-	-
	-	260.8	-77.3	-	-	-	-	-	-	-	-
.8	-604.9	201.8	21.9	-706.5	-504.7	-22.5	0.6	-261.8	-6.1	-289.8	-794.
.1	-613.5	201.8	23.8	-717.9	-516.1	-22.9	0.5	-261.8	-6.1	-290.3	-806.
.1	-616.7	197.7	23.7	-717.0	-519.3	-22.9	0.6	-261.8	-6.1	-290.2	-809.
.1	-616.8	197.7	23.7	-717.1	-519.4	-22.9	0.6	-261.8	-6.1	-290.2	-809.
.2	-603.2	215.9	24.5	-722.0	-506.1	-23.1	0.5	-261.8	-6.1	-290.5	-796.
.2	-603.1	215.9	24.5	-721.8	-505.9	-23.1	0.5	-261.8	-6.1	-290.5	-796.
.8	-608.9	199.0	22.3	-708.8	-509.8	-22.6	0.6	-261.8	-6.1	-289.9	-799.
.4	-576.3	199.0	-50.5	-368.3	-169.3	-	-	-582.9	-13.5	-596.4	-765.
.3	-644.0	151.3	20.0	-695.5	-544.2	-22.2	0.7	-261.8	-6.1	-289.4	-833.
.3	-644.2	151.3	20.1	-696.1	-544.8	-22.2	0.7	-261.8	-6.1	-289.4	-834.
.8	-1087.9	138.6	-44.5	-390.2	-251.6	-	-	-1165.8	-27.0	-1192.8	-1444.
.9	-647.4	138.6	18.1	-684.5	-545.9	-21.8	0.7	-261.8	-6.1	-289.0	-834.
.9	-649.1	248.3	-52.3	-361.9	-113.6	-	-	-738.5	-17.2	-755.7	-869.
	-	248.3	-76.2	-	-	-	-	-	-	-	-
.7	-459.0	400.4	31.1	-762.3	-361.9	-24.5	0.3	-261.8	-6.1	-292.1	-654.
.2	-469.8	400.4	33.3	-775.8	-375.4	-24.9	0.2	-261.8	-6.1	-292.6	-668.
.9	-11043.7	6935.6	-	-12941.9	-7709.6	-378.5	7.0	-6676.0	-155.3	-7202.8	-14912.
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
.2	-150.8	848.9	53.5	-911.3	-62.4	-29.6	-0.5	-261.8	-6.1	-298.0	-360.
.2	-151.9	848.9	53.4	-910.1	-61.2	-29.5	-0.5	-261.8	-6.1	-297.9	-359.
	-	865.6	35.0	-	-	-	-	-	-	-	-
.3	-139.1	865.6	53.9	-914.2	-48.6	-29.7	-0.5	-261.8	-6.1	-298.1	-346.
.3	-264.9	688.2	46.5	-862.3	-174.1	-27.9	-0.2	-261.8	-6.1	-296.0	-470.
	-	688.2	6.7	-	-	-	-	-	-	-	-
	-	454.3	-33.9	-	-	-	-	-	-	-	-
	-	454.3	-31.4	-	-	-	-	-	-	-	-
.4	-299.0	629.4	42.4	-834.5	-205.1	-26.9	-0.1	-261.8	-6.1	-294.9	-500.
.7	-307.3	629.4	44.0	-845.6	-216.2	-27.3	-0.1	-261.8	-6.1	-295.3	-511.
.9	-105.7	913.2	56.3	-931.5	-18.3	-30.3	-0.6	-261.8	-6.1	-298.8	-317.
.0	-108.4	913.2	56.7	-934.3	-21.1	-30.4	-0.6	-261.8	-6.1	-298.9	-320.
.9	+7.8	1079.7	63.8	-986.5	93.2	-32.2	-0.9	-261.8	-6.1	-301.0	-207.
.9	7.3	1079.7	63.9	-987.0	92.7	-32.2	-0.9	-261.8	-6.1	-301.0	-208.
.0	-54.1	994.8	60.3	-960.6	34.2	-31.3	-0.8	-261.8	-6.1	-300.0	-265.
.4	-390.8	994.8	63.1	-981.5	13.3	-	-	-582.9	-13.5	-596.4	-583.
.4	-274.1	681.3	46.5	-862.3	-181.0	-27.9	-0.2	-261.8	-6.1	-296.0	-477.
.0	-262.6	681.3	45.0	-852.1	-170.8	-27.5	-0.2	-261.8	-6.1	-295.6	-466.
.8	-1034.6	313.0	-15.2	-512.6	-199.6	-	-	-1165.8	-27.0	-1192.8	-1392.
.9	-524.3	313.0	27.2	-738.3	-425.3	-23.6	0.4	-261.8	-6.1	-291.1	-716.
.9	-623.1	391.8	-22.5	-480.0	-88.2	-	-	-738.5	-17.2	-755.7	-843.
	-	391.8	-42.0	-	-	-	-	-	-	-	-
.5	-288.2	642.7	42.8	-837.1	-194.4	-27.0	-0.1	-261.8	-6.1	-295.0	-489.
.8	-297.3	642.7	44.6	-849.2	-206.5	-27.4	-0.2	-261.8	-6.1	-295.5	-502.
.4	-5259.7	17005.71	-	-16191.0	-2039.3	-460.8	-6.0	-6676.0	-155.3	-7298.1	-9337.

e 4-17. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ε = 0.90

	Coldplate/Electrical Component Temperature = 75 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
p	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
)	520.6	48.9	-879.2	-358.6	-28.5	-0.3	-295.1	-11.1	-335.0	-693.6
4	520.6	47.9	-871.8	-351.2	-28.2	-0.3	-295.1	-11.1	-334.7	-685.9
	523.9	-13.2	-	-	-	-	-	-	-	-
4	523.9	47.9	-872.1	-348.2	-28.2	-0.3	-295.1	-11.1	-334.7	-682.9
4	409.5	43.9	-844.5	-435.0	-27.3	-0.1	-295.1	-11.1	-333.6	-768.6
	409.5	-41.3	-	-	-	-	-	-	-	-
	260.8	-82.9	-	-	-	-	-	-	-	-
	260.8	-76.1	-	-	-	-	-	-	-	-
5	201.8	32.3	-769.8	-568.0	-24.7	0.3	-295.1	-11.1	-330.6	-898.6
4	201.8	34.4	-782.9	-581.1	-25.2	0.2	-295.1	-11.1	-331.2	-912.3
5	197.7	34.3	-782.0	-584.3	-25.1	0.2	-295.1	-11.1	-331.1	-915.4
5	197.7	34.3	-782.1	-584.4	-25.1	0.2	-295.1	-11.1	-331.1	-915.5
5	215.9	35.1	-787.2	-571.3	-25.3	0.2	-295.1	-11.1	-331.3	-902.6
4	215.9	35.1	-787.0	-571.1	-25.3	0.2	-295.1	-11.1	-331.3	-902.4
7	199.0	32.8	-772.8	-573.8	-24.8	0.3	-295.1	-11.1	-330.7	-904.5
7	199.0	-44.6	-390.0	-191.0	-	-	-657.1	-24.7	-681.8	-872.8
5	151.3	30.6	-758.9	-607.6	-24.3	0.3	-295.1	-11.1	-330.2	-937.8
2	151.3	30.7	-759.8	-608.5	-24.4	0.3	-295.1	-11.1	-330.3	-938.8
4	138.6	-36.4	-421.8	-283.2	-	-	-1314.2	-49.4	-1363.6	-1646.8
9	138.6	28.6	-746.9	-608.3	-23.9	0.4	-295.1	-11.1	-329.7	-938.0
3	248.3	-47.6	-378.8	-130.5	-	-	-832.5	-31.4	-863.9	-994.4
	248.3	-74.7	-	-	-	-	-	-	-	-
0	400.4	41.4	-828.0	-427.6	-26.7	0	-295.1	-11.1	-332.9	-760.5
0	400.4	43.7	-843.3	-442.9	-27.2	-0.1	-295.1	-11.1	-333.5	-776.4
4	6935.6	-	-14059.0	-8826.7	-414.5	1.3	-7525.4	-283.1	-8221.7	-17048.4
4	848.9	63.5	-984.3	-135.4	-32.1	-0.9	-295.1	-11.1	-339.2	-474.6
1	848.9	63.2	-981.6	-132.7	-32.0	-0.9	-295.1	-11.1	-339.1	-471.8
	856.6	36.1	-	-	-	-	-	-	-	-
7	865.6	63.7	-985.9	-120.3	-32.1	-0.9	-295.1	-11.1	-339.2	-459.5
1	688.2	56.6	-933.1	-244.9	-30.3	-0.6	-295.1	-11.1	-337.1	-582.0
	688.2	7.6	-	-	-	-	-	-	-	-
	454.3	-33.8	-	-	-	-	-	-	-	-
	454.3	-30.6	-	-	-	-	-	-	-	-
0	629.4	52.4	-903.1	-273.7	-29.3	-0.5	-295.1	-11.1	-336.0	-609.7
5	629.4	54.2	-916.0	-286.6	-29.7	-0.5	-295.1	-11.1	-336.4	-623.0
1	913.2	66.3	-1005.2	-92.0	-32.8	-1.0	-295.1	-11.1	-340.0	-432.0
0	913.2	66.6	-1008.0	-94.8	-32.9	-1.0	-295.1	-11.1	-340.1	-434.9
8	1079.7	73.6	-1062.1	17.6	-34.8	-1.3	-295.1	-11.1	-342.3	-324.7
3	1079.7	73.6	-1062.6	17.1	-34.8	-1.3	-295.1	-11.1	-342.3	-325.2
8	994.8	70.0	-1034.3	-39.5	-33.8	-1.2	-295.1	-11.1	-341.2	-380.7
1	994.8	66.2	-1004.7	-9.9	-	-	-657.1	-24.7	-681.8	-691.7
0	681.3	56.5	-932.3	-251.0	-30.3	-0.6	-295.1	-11.1	-337.1	-588.1
4	681.3	55.1	-922.2	-240.9	-30.0	-0.6	-295.1	-11.1	-336.8	-577.7
4	313.0	-8.4	-544.8	-231.8	-	-	-1314.2	-49.4	-1363.6	-1595.4
4	313.0	37.5	-802.9	-489.9	-25.9	0.1	-295.1	-11.1	-332.0	-821.9
9	391.8	-18.6	-497.3	-105.5	-	-	-832.5	-31.4	-863.9	-969.4
	391.8	-40.9	-	-	-	-	-	-	-	-
4	642.7	52.8	-905.9	-263.2	-29.4	-0.5	-295.1	-11.1	-336.1	-599.3
0	642.7	54.7	-919.7	-277.0	-29.9	-0.5	-295.1	-11.1	-336.6	-613.6
4	17005.71	-	-17406.0	-3254.3	-500.1	-12.3	-7525.4	-283.1	-8320.9	-11575.2

Orbit Data: Case No. (Table 2-3) : IU-3a
Type of Orbit and Orientation: Circular Polar Earth Orbit, X axis tangent to
Orbital Altitude, N. Mi. : 200
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	616.3	23.7	-717.1	-100.8	0.9	1.4	6.3	7.3	15.
2	616.3	22.4	-709.7	-93.4	0.9	1.5	6.3	7.3	16.
3	440.3	-17.5	-	-	-	-	-	-	-
4	440.3	14.0	-661.3	-221.0	1.1	2.1	6.3	7.3	16.
5	340.9	9.8	-638.0	-297.1	1.2	2.5	6.3	7.3	17.
6	340.9	-45.0	-	-	-	-	-	-	-
7	213.4	-80.3	-	-	-	-	-	-	-
8	213.4	-76.0	-	-	-	-	-	-	-
9	95.2	-3.9	-566.7	-471.5	1.4	3.4	6.3	7.3	18.
10	95.2	-2.3	-575.0	-479.8	1.4	3.3	6.3	7.3	18.
11	18.7	-5.9	-557.0	-538.3	1.5	3.6	6.3	7.3	18.
12	18.7	-6.0	-556.4	-537.7	1.5	3.6	6.3	7.3	18.
13	0.0	-6.9	-552.0	-552.0	1.5	3.6	6.3	7.3	18.
14	0.0	-6.8	-552.8	-552.8	1.5	3.6	6.3	7.3	18.
15	175.1	0.1	-586.9	-411.8	1.3	3.1	6.3	7.3	18.
16	175.1	-62.5	-326.9	-151.8	-	-	13.6	16.2	29.
17	497.3	15.8	671.3	-174.0	1.0	2.0	6.3	7.3	16.
18	497.3	18.0	-683.7	-186.4	1.0	1.8	6.3	7.3	16.
19	749.7	28.7	-747.2	2.5	-	-	27.2	32.4	59.
20	749.7	30.2	-756.3	-6.6	0.7	0.8	6.3	7.3	15.
21	867.9	44.1	-846.4	21.5	-	-	17.3	20.4	37.
22	867.9	45.9	-	-	-	-	-	-	-
23	821.1	33.5	-777.2	43.9	0.7	0.6	6.3	7.3	14.
24	821.1	32.9	-773.6	47.5	0.7	0.6	6.3	7.3	14.
Totals	9671.8	-	-12255.2	-4659.3	18.1	37.6	158.8	185.8	400.
1	1326.9	58.0	-943.6	383.3	0.1	-1.7	6.3	7.3	12.
2	1326.9	54.7	-919.9	407.0	0.1	-1.4	6.3	7.3	12.
3	447.1	-13.1	-	-	-	-	-	-	-
4	447.1	14.4	-663.7	-216.6	1.1	2.1	6.3	7.3	16.
5	346.8	10.1	-639.6	-292.8	1.2	2.4	6.3	7.3	17.
6	346.8	-43.7	-	-	-	-	-	-	-
7	216.8	-79.2	-	-	-	-	-	-	-
8	216.8	-75.1	-	-	-	-	-	-	-
9	96.9	-3.8	-567.2	-470.3	1.4	3.4	6.3	7.3	18.
10	96.9	-2.2	-575.4	-478.5	1.4	3.3	6.3	7.3	18.
11	19.6	-5.9	-557.2	-537.6	1.5	3.6	6.3	7.3	18.
12	19.6	-6.0	-556.6	-537.0	1.5	3.6	6.3	7.3	18.
13	0.1	-6.9	-552.1	-552.0	1.5	3.6	6.3	7.3	18.
14	0.1	-5.8	-557.5	-557.4	1.5	3.5	6.3	7.3	18.
15	873.8	35.0	-786.3	87.5	0.6	0.4	6.3	7.3	14.
16	873.8	48.7	-877.6	-3.8	-	-	13.6	16.2	29.
17	2412.3	101.4	-1302.0	1110.3	-1.2	-6.6	6.3	7.3	5.
18	2412.3	105.8	-1343.8	1068.5	-1.4	-7.1	6.3	7.3	5.
19	3368.6	207.0	-2596.1	772.5	-	-	27.2	32.4	59.
20	3368.6	144.7	-1753.2	1615.4	-2.9	-12.7	6.3	7.3	-2.
21	3490.1	235.0	-3058.9	431.2	-	-	17.3	20.4	37.
22	3490.1	243.9	-	-	-	-	-	-	-
23	2744.7	120.0	-1483.4	1261.3	-1.9	-9.0	6.3	7.3	2.
24	2744.7	114.6	-1429.0	1315.7	-1.7	-8.3	6.3	7.3	3.
Totals	30684.5	-	-21163.1	4803.8	2.5	-20.7	158.9	185.8	326.

Tabl

flight path

Angle of Inclination (Degrees): 90

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
	Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
9	-84.9	616.3	44.7	-849.9	-233.6	0.4	-0.4	0	-15.9	-15.9	-249.5
0	-77.4	616.3	43.0	-839.0	-222.7	0.4	-0.3	0	-15.9	-15.9	-238.5
	-	440.3	-13.4	-	-	-	-	-	-	-	-
3	-204.2	440.3	34.9	-786.2	-345.9	0.6	0.4	0	-15.9	-14.9	-360.8
5	-279.8	340.9	31.1	-762.4	-421.5	0.7	0.8	0	-15.9	-14.4	-435.9
	-	340.9	-41.9	-	-	-	-	-	-	-	-
	-	213.4	-79.5	-	-	-	-	-	-	-	-
	-	213.4	-73.1	-	-	-	-	-	-	-	-
4	-453.1	95.2	17.7	-682.1	-586.9	1.0	1.9	0	-15.9	-13.0	-599.9
3	-461.5	95.2	19.8	-694.1	-598.9	1.0	1.7	0	-15.9	-13.2	-612.1
7	-519.6	18.7	16.3	-674.3	-655.6	1.0	2.0	0	-15.9	-12.9	-668.5
7	-519.0	18.7	16.2	-673.6	-654.9	1.0	2.0	0	-15.9	-12.9	-667.8
7	-533.3	0.0	15.3	-668.8	-668.8	1.0	2.0	0	-15.9	-12.9	-681.7
7	-534.1	0.0	15.5	-669.6	-669.6	1.0	2.0	0	-15.9	-12.9	-682.5
0	-393.8	175.1	21.7	-705.6	-530.5	0.9	1.5	0	-15.9	-13.5	-544.0
3	-122.0	175.1	-50.3	-368.8	-193.7	-	-	0	-35.4	-35.4	-229.1
5	-157.4	497.3	36.8	-798.2	-300.9	0.6	0.3	0	-15.9	-15.0	-315.9
4	-170.0	497.3	38.9	-811.7	-314.4	0.5	0.1	0	-15.9	-15.3	-329.7
5	62.1	749.7	38.5	-808.8	-59.1	-	-	0	-70.8	-70.8	-129.9
	8.5	749.7	50.2	-887.8	-138.1	0.3	-1.0	0	-15.9	-16.6	-154.7
7	59.2	867.9	49.1	-880.0	-12.1	-	-	0	-44.7	-44.7	-56.8
	-	867.9	47.7	-	-	-	-	-	-	-	-
9	58.8	821.1	53.6	-911.9	-90.8	0.2	-1.3	0	-15.9	-17.0	-107.8
9	62.4	821.1	53.5	-911.3	-90.2	0.2	-1.3	0	-15.9	-17.0	-107.2
4	-4258.9	9671.8	-	-14384.1	-6788.2	10.9	10.5	0	-405.3	-383.9	-7172.1
	Optical Properties of IU Outer Surface = α 0.90, $\alpha/\epsilon = 1.0$										
	395.3	1326.9	77.6	-1094.6	232.3	-0.5	-3.7	0	-15.9	-20.1	212.2
	419.3	1326.9	74.0	-1065.8	261.1	-0.4	-3.4	0	-15.9	-19.7	241.4
	-	447.1	-9.1	-	-	-	-	-	-	-	-
3	-199.8	447.1	35.3	-788.8	-341.7	0.6	0.4	0	-15.9	-14.9	-356.6
2	-275.6	346.8	31.4	-764.2	-417.4	0.7	0.7	0	-15.9	-14.5	-431.9
	-	346.8	-40.6	-	-	-	-	-	-	-	-
	-	216.8	-78.4	-	-	-	-	-	-	-	-
	-	216.8	-72.1	-	-	-	-	-	-	-	-
2	-451.9	96.9	17.8	-682.7	-585.8	1.0	1.8	0	-15.9	-13.1	-598.9
	-460.2	96.9	19.8	-694.6	-597.7	1.0	1.7	0	-15.9	-13.2	-610.9
	-518.9	19.6	16.4	-674.5	-654.9	1.0	2.0	0	-15.9	-12.9	-667.8
	-518.3	19.6	16.2	-673.9	-654.3	1.0	2.0	0	-15.9	-12.9	-667.2
	-533.3	0.1	15.4	-668.9	-668.8	1.0	2.0	0	-15.9	-12.9	-681.7
	-538.8	0.1	16.4	-674.8	-674.7	1.0	2.0	0	-15.9	-12.9	-687.6
	102.1	873.8	55.1	-922.6	-48.8	0.1	-1.4	0	-15.9	-17.2	-66.0
	26.0	873.8	55.2	-923.1	-49.3	-	-	0	-35.4	-35.4	-84.7
	1116.1	2412.3	118.9	-1472.2	940.1	-1.9	-8.9	0	-15.9	-26.7	913.4
	1073.6	2412.3	123.2	-1516.1	896.2	-2.0	-9.5	0	-15.9	-27.4	868.8
	832.1	3368.6	211.2	-2661.1	707.5	-	-	0	-70.8	-70.8	636.7
	1613.4	3368.6	160.2	-1939.9	1428.7	-3.6	-15.2	0	-15.9	-34.7	1394.0
	468.9	3490.1	236.9	-3094.2	395.9	-	-	0	-44.7	-44.7	351.2
	-	3490.1	244.6	-	-	-	-	-	-	-	-
	1264.0	2744.7	136.7	-1661.5	1083.2	-2.5	-11.4	0	-15.9	-29.8	1053.4
	1319.3	2744.7	131.9	-1609.0	1135.7	-2.4	-10.7	0	-15.9	-29.0	1106.7
	5130.3	30684.5	-	-23582.7	2384.2	-5.7	-51.6	0	-405.3	-462.6	1921.6

e 4-18. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
616.3	54.9	-921.0	-304.7	0.1	-1.4	-3.6	-29.1	-34.0	-338.7
616.3	53.1	-908.0	-291.7	0.2	-1.2	-3.6	-29.1	-33.7	-325.4
440.3	-11.4	-	-	-	-	-	-	-	-
440.3	45.1	-853.1	-412.8	0.4	-0.5	-3.6	-29.1	-32.8	-445.6
340.9	41.6	-829.1	-488.2	0.5	-0.1	-3.6	-29.1	-32.3	-520.5
340.9	-40.3	-	-	-	-	-	-	-	-
213.4	-79.1	-	-	-	-	-	-	-	-
213.4	-71.6	-	-	-	-	-	-	-	-
95.2	28.2	-744.5	-649.3	0.8	1.0	-3.6	-29.1	-30.9	-680.2
95.2	30.5	-758.4	-663.2	0.7	0.8	-3.6	-29.1	-31.2	-694.4
18.7	27.1	-737.7	-719.0	0.8	1.1	-3.6	-29.1	-30.8	-749.8
18.7	27.0	-737.1	-718.4	0.8	1.1	-3.6	-29.1	-30.8	-749.2
0.0	26.2	-732.0	-732.0	0.8	1.2	-3.6	-29.1	-30.7	-762.7
0.0	26.3	-732.8	-732.8	0.8	1.2	-3.6	-29.1	-30.7	-763.5
175.1	32.3	-769.6	-594.5	0.7	0.7	-3.6	-29.1	-31.3	-625.8
175.1	-44.1	-391.8	-216.7	-	-	-7.8	-64.7	-72.5	-289.2
497.3	47.1	-866.2	-368.9	0.3	-0.6	-3.6	-29.1	-33.0	-401.9
497.3	49.1	-880.2	-382.9	0.3	-0.8	-3.6	-29.1	-33.2	-416.1
749.7	43.6	-843.1	-93.4	-	-	-15.6	-129.4	-145.0	-238.4
749.7	60.0	-958.0	-208.3	0.0	-1.9	-3.6	-29.1	-34.6	-242.9
867.9	51.7	-898.6	-30.7	-	-	-9.8	-81.8	-91.6	-122.3
867.9	48.6	-	-	-	-	-	-	-	-
821.1	63.4	-983.5	-162.4	-0.1	-2.2	-3.6	-29.1	-35.0	-197.4
821.1	63.6	-984.8	-163.7	-0.1	-2.3	-3.6	-29.1	-35.1	-198.8
9671.8	-	-15529.6	-7933.7	7.0	-4.0	-90.8	-741.5	-829.3	-8763.0
1326.9	87.1	-1174.5	152.4	-0.8	-4.8	-3.6	-29.1	-38.3	114.1
1326.9	83.4	-1143.0	183.9	-0.7	-4.4	-3.6	-29.1	-37.8	146.1
447.1	-7.1	-	-	-	-	-	-	-	-
447.1	45.5	-855.8	-408.7	0.4	-0.5	-3.6	-29.1	-32.8	-441.5
346.8	41.8	-831.0	-484.2	0.5	-0.2	-3.6	-29.1	-32.4	-516.6
346.8	-39.0	-	-	-	-	-	-	-	-
216.8	-78.0	-	-	-	-	-	-	-	-
216.8	-70.6	-	-	-	-	-	-	-	-
96.9	28.3	-745.1	-648.2	0.8	1.0	-3.6	-29.1	-30.9	-679.1
96.9	30.6	-758.9	-662.0	0.7	0.8	-3.6	-29.1	-31.2	-693.2
19.6	27.2	-738.0	-718.4	0.8	1.1	-3.6	-29.1	-30.8	-749.2
19.6	27.1	-737.3	-717.7	0.8	1.1	-3.6	-29.1	-30.8	-748.5
0.1	26.2	-732.1	-732.0	0.8	1.2	-3.6	-29.1	-30.7	-762.7
0.1	27.2	-738.3	-738.2	0.8	1.1	-3.6	-29.1	-30.8	-769.0
873.8	64.9	-995.2	-121.4	-0.1	-2.4	-3.6	-29.1	-35.2	-156.6
873.8	58.6	-947.9	-74.1	-	-	-7.8	-64.7	-72.5	-146.6
2412.3	127.4	-1561.2	851.1	-2.2	-10.1	-3.6	-29.1	-45.0	806.1
2412.3	131.6	-1606.1	806.2	-2.3	-10.7	-3.6	-29.1	-45.7	760.5
3368.6	213.4	-2697.0	671.6	-	-	-15.6	-129.4	-145.0	526.6
3368.6	167.8	-2036.6	1332.0	-3.9	-16.5	-3.6	-29.1	-53.1	1278.9
3490.1	238.0	-3113.6	376.5	-	-	9.8	-81.8	-91.6	284.9
3490.1	244.9	-	-	-	-	-	-	-	-
2744.7	144.8	-1754.2	990.5	-2.9	-12.7	-3.6	-29.1	-48.3	942.2
2744.7	140.3	-1702.9	1041.8	-2.7	-12.0	-3.6	-29.1	-47.4	994.4
30684.5	-	-24868.8	1098.1	-10.1	-68.0	-90.8	-741.5	-910.4	187.7

Orbit Data: Case No. (Table 2-3) : IU-3a
Type of Orbit and Orientation: Circular Polar Earth Orbit, X-axis tangent to
Orbital Altitude, N. Mi. : 200
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	616.3	23.5	-716.1	-99.8	-2.4	1.4	-21.7	7.3	-15.
2	616.3	22.2	-708.5	-92.2	-2.4	1.5	-21.7	7.3	-15.
3	440.3	-19.6	-	-	-	-	-	-	-
4	440.3	13.8	-660.1	-219.8	-2.2	2.2	-21.7	7.3	-14.
5	340.9	9.6	-637.0	-296.1	-2.1	2.5	-21.7	7.3	-14.
6	340.9	-47.8	-	-	-	-	-	-	-
7	213.4	-84.2	-	-	-	-	-	-	-
8	213.4	-79.5	-	-	-	-	-	-	-
9	95.2	-4.2	-565.5	-470.3	-1.9	3.4	-21.7	7.3	-12.
10	95.2	-2.4	-574.1	-478.9	-1.9	3.3	-21.7	7.3	-13.
11	18.7	-6.1	-556.1	-537.4	-1.8	3.6	-21.7	7.3	-12.
12	18.7	-6.2	-555.6	-536.9	-1.8	3.6	-21.7	7.3	-12.
13	0.0	-7.1	-551.2	-551.2	-1.8	3.6	-21.7	7.3	-12.
14	0.0	-6.9	-551.9	-551.9	-1.8	3.6	-21.7	7.3	-12.
15	175.1	-0.1	-586.0	-410.9	-1.9	3.2	-21.7	7.3	-13.
16	175.1	-62.5	-326.7	-151.6	-	-	-47.3	16.2	-31.
17	497.3	15.6	-670.5	-173.2	-2.2	2.0	-21.7	7.3	-14.
18	497.3	17.8	-682.8	-185.5	-2.3	1.8	-21.7	7.3	-14.
19	749.7	28.7	-747.1	2.6	-	-	-94.6	32.4	-62.
20	749.7	30.0	-755.4	-5.7	-2.5	0.9	-21.7	7.3	-16.
21	867.9	44.0	-845.7	22.2	-	-	-60.1	20.4	-39.
22	867.9	44.5	-	-	-	-	-	-	-
23	821.1	33.3	-776.0	45.1	-2.6	0.6	-21.7	7.3	-16.
24	821.1	32.8	-772.6	48.5	-2.6	0.6	-21.7	7.3	-16.
Totals	9671.8	-	-12239.0	-4643.1	-34.4	37.8	-549.2	185.8	-360.
1	1326.9	57.9	-942.5	384.4	-3.2	-1.7	-21.7	7.3	-19.
2	1326.9	54.5	-918.5	408.4	-3.1	-1.4	-21.7	7.3	-18.
3	447.1	-15.2	-	-	-	-	-	-	-
4	447.1	14.2	-662.5	-215.4	-2.2	2.1	-21.7	7.3	-14.
5	346.8	9.9	-638.7	-291.9	-2.1	2.4	-21.7	7.3	-14.
6	346.8	-46.5	-	-	-	-	-	-	-
7	216.8	-83.1	-	-	-	-	-	-	-
8	216.8	-78.6	-	-	-	-	-	-	-
9	96.9	-4.1	-566.0	-469.1	-1.9	3.4	-21.7	7.3	-12.
10	96.9	-2.4	-574.5	-477.6	-1.9	3.3	-21.7	7.3	-13.
11	19.6	-6.0	-556.4	-536.8	-1.8	3.6	-21.7	7.3	-12.
12	19.6	-6.1	-555.8	-536.2	-1.8	3.6	-21.7	7.3	-12.
13	0.1	-7.1	-551.3	-551.2	-1.8	3.6	-21.7	7.3	-12.
14	0.1	-6.0	-556.6	-556.5	-1.8	3.6	-21.7	7.3	-12.
15	873.8	34.8	-785.4	88.4	-2.7	0.5	-21.7	7.3	-16.
16	873.8	48.7	-877.5	-3.7	-	-	-47.3	16.2	-31.
17	2412.3	101.3	-1300.8	1111.5	-4.5	-6.5	-21.7	7.3	-25.
18	2412.3	105.7	-1342.6	1069.7	-4.7	-7.1	-21.7	7.3	-26.
19	3368.6	207.0	-2596.0	772.6	-	-	-94.6	32.4	-62.
20	3368.6	144.6	-1751.8	1616.8	-6.2	-12.7	-21.7	7.3	-33.
21	3490.1	234.9	-3058.4	431.7	-	-	-60.1	20.4	-39.
22	3490.1	243.3	-	-	-	-	-	-	-
23	2744.7	119.8	-1481.9	1262.8	-5.2	-9.0	-21.7	7.3	-28.
24	2744.7	114.5	-1427.7	1317.0	-5.0	-8.3	-21.7	7.3	-27.
Totals	30684.5	-	-21144.9	4822.0	-49.9	-20.5	-549.2	185.8	-433.

Table 4-

flight path

Angle of Inclination (Degrees): 90

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
4	-115.2	616.3	44.5	-848.9	-232.6	-2.9	-0.4	-28.0	-15.9	-47.2	-279.8
3	-107.5	616.3	42.8	-837.6	-221.3	-2.8	-0.3	-28.0	-15.9	-47.0	-268.3
	-	440.3	-15.5	-	-	-	-	-	-	-	-
4	-234.2	440.3	34.7	-784.9	-344.6	-2.7	0.5	-28.0	-15.9	-46.1	-390.7
0	-310.1	340.9	31.0	-761.3	-420.4	-2.6	0.8	-28.0	-15.9	-45.7	-466.1
	-	340.9	-44.7	-	-	-	-	-	-	-	-
	-	213.4	-83.4	-	-	-	-	-	-	-	-
	-	213.4	-76.5	-	-	-	-	-	-	-	-
9	-483.2	95.2	17.5	-680.8	-585.6	-2.3	1.9	-28.0	-15.9	-44.3	-629.9
0	-491.9	95.2	19.6	-693.2	-598.0	-2.3	1.7	-28.0	-15.9	-44.5	-642.5
6	-550.0	18.7	16.1	-673.4	-654.7	-2.3	2.0	-28.0	-15.9	-44.2	-698.9
6	-549.5	18.7	16.0	-672.7	-654.0	-2.3	2.0	-28.0	-15.9	-44.2	-698.2
6	-563.8	0.0	15.2	-667.9	-667.9	-2.2	2.1	-28.0	-15.9	-44.0	-711.9
6	-564.5	0.0	15.3	-668.7	-668.7	-2.2	2.0	-28.0	-15.9	-44.1	-712.8
1	-424.0	175.1	21.6	-704.7	-529.6	-2.4	1.6	-28.0	-15.9	-44.7	-574.3
1	-182.7	175.1	-50.4	-368.7	-193.6	-	-	-60.9	-35.4	-96.3	-289.9
6	-187.8	497.3	36.7	-797.2	-299.9	-2.7	0.3	-28.0	-15.9	-46.3	-346.2
9	-200.4	497.3	38.7	-810.7	-313.4	-2.8	0.1	-28.0	-15.9	-46.6	-360.0
2	-59.6	749.7	38.4	-808.7	-59.0	-	-	-121.8	-70.8	-192.6	-251.6
0	-21.7	749.7	50.0	-886.8	-137.1	-3.0	-0.9	-28.0	-15.9	-47.8	-184.9
7	-17.5	867.9	49.0	-879.3	-11.4	-	-	-77.4	-44.7	-122.1	-133.5
	-	867.9	46.3	-	-	-	-	-	-	-	-
4	28.7	821.1	53.4	-910.6	-89.5	-3.1	-1.2	-28.0	-15.9	-48.2	-137.7
4	32.1	821.1	53.4	-910.3	-89.2	-3.1	-1.2	-28.0	-15.9	-48.2	-137.4
0	-5003.1	9671.8	-	-14366.4	-6770.5	-41.6	10.8	-708.1	-405.3	-1144.2	-7914.7
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
3	365.1	1326.9	77.4	-1093.4	233.5	-3.8	-3.7	-28.0	-15.9	-51.4	182.1
9	389.5	1326.9	73.8	-1064.4	262.5	-3.7	-3.3	-28.0	-15.9	-50.9	211.6
	-	447.1	-11.1	-	-	-	-	-	-	-	-
5	-229.9	447.1	35.1	-787.5	-340.4	-2.7	0.4	-28.0	-15.9	-46.2	-386.6
1	-306.0	346.8	31.3	-763.1	-416.3	-2.6	0.8	-28.0	-15.9	-45.7	-462.0
	-	346.8	-43.4	-	-	-	-	-	-	-	-
	-	216.8	-82.2	-	-	-	-	-	-	-	-
	-	216.8	-75.5	-	-	-	-	-	-	-	-
9	-482.0	96.9	17.6	-681.4	-584.5	-2.3	1.9	-28.0	-15.9	-44.3	-628.8
9	-490.6	96.9	19.7	-693.6	-596.7	-2.3	1.7	-28.0	-15.9	-44.5	-641.2
9	-549.4	19.6	16.2	-673.6	-654.0	-2.3	2.0	-28.0	-15.9	-44.2	-698.2
9	-548.8	19.6	16.1	-673.0	-653.4	-2.3	2.0	-28.0	-15.9	-44.2	-697.6
9	-563.8	0.1	15.2	-668.0	-667.9	-2.2	2.0	-28.0	-15.9	-44.1	-712.0
9	-569.1	0.1	16.2	-673.9	-673.8	-2.3	2.0	-28.0	-15.9	-44.2	-718.0
9	71.8	873.8	55.0	-921.6	-47.8	-3.2	-1.4	-28.0	-15.9	-48.5	-96.3
	-34.8	873.8	55.2	-923.0	-49.2	-	-	-60.9	-35.4	-96.3	-145.5
	1086.1	2412.3	118.8	-1471.0	941.3	-5.1	-8.9	-28.0	-15.9	-57.9	883.4
	1043.5	2412.3	123.0	-1514.8	897.5	-5.3	-9.4	-28.0	-15.9	-58.6	838.9
	710.4	3368.6	211.2	-2660.9	707.7	-	-	-121.8	-70.8	-192.6	515.1
	1583.5	3368.6	160.1	-1938.5	1430.1	-6.8	-15.2	-28.0	-15.9	-65.9	1364.2
	392.0	3490.1	236.9	-3093.7	396.4	-	-	-77.4	-44.7	-122.1	274.3
	-	3490.1	244.0	-	-	-	-	-	-	-	-
	1234.2	2744.7	136.5	-1659.9	1084.8	-5.8	-11.4	-28.0	-15.9	-61.1	1023.7
	1289.3	2744.7	131.8	-1607.7	1137.0	-5.6	-10.7	-28.0	-15.9	-60.2	1076.3
	4388.2	30684.5	-	-23563.2	2403.7	-58.2	-51.3	-708.1	-405.3	-1222.9	1180.

19. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↑ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↑ SLA	Coldplate/ ElecComp ↑ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
616.3	54.7	-919.9	-303.6	-3.1	-1.4	-31.6	-29.1	-65.2	-368.8
616.3	52.9	-906.7	-290.4	-3.1	-1.2	-31.6	-29.1	-65.0	-355.4
440.3	-13.5	-	-	-	-	-	-	-	-
440.3	44.9	-851.8	-411.5	-2.9	-0.4	-31.6	-29.1	-64.0	-475.5
340.9	41.4	-828.0	-487.1	-2.8	-0.1	-31.6	-29.1	-63.6	-550.7
340.9	-43.1	-	-	-	-	-	-	-	-
213.4	-83.0	-	-	-	-	-	-	-	-
213.4	-75.0	-	-	-	-	-	-	-	-
95.2	28.0	-743.1	-647.9	-2.5	1.0	-31.6	-29.1	-62.2	-710.1
95.2	30.4	-757.5	-662.3	-2.6	0.8	-31.6	-29.1	-62.5	-724.8
18.7	27.0	-736.8	-718.1	-2.5	1.1	-31.6	-29.1	-62.1	-780.2
18.7	26.9	-736.1	-717.4	-2.5	1.1	-31.6	-29.1	-62.1	-779.5
0.0	26.0	-731.0	-731.0	-2.5	1.2	-31.6	-29.1	-62.0	-793.0
0.0	26.2	-731.9	-731.9	-2.5	1.2	-31.6	-29.1	-62.0	-793.9
175.1	32.2	-768.7	-593.6	-2.6	0.7	-31.6	-29.1	-62.6	-656.2
175.1	-44.1	-391.7	-216.6	-	-	-68.7	-64.7	-133.4	-350.0
497.3	46.9	-865.2	-367.9	-2.9	-0.6	-31.6	-29.1	-64.2	-432.1
497.3	49.0	-879.2	-381.9	-3.0	-0.8	-31.6	-29.1	-64.5	-446.4
749.7	43.6	-842.9	-93.2	-	-	-137.4	-129.4	-266.8	-360.0
749.7	59.8	-956.9	-207.2	-3.3	-1.9	-31.6	-29.1	-65.9	-273.1
867.9	51.6	-897.8	-29.9	-	-	-87.2	-81.8	-169.0	-198.9
867.9	47.2	-	-	-	-	-	-	-	-
821.1	63.2	-988.2	-161.1	-3.4	-2.2	-31.6	-29.1	-66.3	-227.4
821.1	63.4	-983.7	-162.6	-3.4	-2.2	-31.6	-29.1	-66.3	-228.9
9671.8	-	-15511.2	-7915.3	-45.5	-3.7	-798.9	-741.5	-1589.6	-9504.9
1326.9	87.0	-1173.3	153.6	-4.1	-4.8	-31.6	-29.1	-69.6	84.0
1326.9	83.3	-1141.5	185.4	-3.9	-4.4	-31.6	-29.1	-69.0	116.4
447.1	-9.1	-	-	-	-	-	-	-	-
447.1	45.3	-854.5	-407.4	-2.9	-0.5	-31.6	-29.1	-64.1	-471.5
346.8	41.7	-829.9	-483.1	-2.8	-0.1	-31.6	-29.1	-63.6	-546.7
346.8	-41.8	-	-	-	-	-	-	-	-
216.8	-81.8	-	-	-	-	-	-	-	-
216.8	-74.0	-	-	-	-	-	-	-	-
96.9	28.1	-743.7	-646.8	-2.5	1.0	-31.6	-29.1	-62.2	-709.0
96.9	30.4	-758.0	-661.1	-2.6	0.8	-31.6	-29.1	-62.5	-723.6
19.6	27.0	-737.1	-717.5	-2.5	1.1	-31.6	-29.1	-62.1	-779.6
19.6	26.9	-736.4	-716.8	-2.5	1.1	-31.6	-29.1	-62.1	-778.9
0.1	26.0	-731.2	-731.1	-2.5	1.2	-31.6	-29.1	-62.0	-793.1
0.1	27.1	-737.3	-737.2	-2.5	1.1	-31.6	-29.1	-62.1	-799.3
873.8	64.8	-994.1	-120.3	-3.4	-2.4	-31.6	-29.1	-66.5	-186.8
873.8	58.6	-947.8	-74.0	-	-	-68.7	-64.7	-133.4	-207.4
2412.3	127.3	-1559.9	852.4	-5.5	-10.1	-31.6	-29.1	-76.3	776.1
2412.3	131.5	-1604.8	807.5	-5.6	-10.7	-31.6	-29.1	-77.0	730.5
3368.6	213.4	-2696.9	671.7	-	-	-137.4	-129.4	-266.8	404.9
3368.6	167.7	-2035.2	1333.4	-7.2	-16.5	-31.6	-29.1	-84.4	1249.0
3490.1	238.0	-3113.1	377.0	-	-	-87.2	-81.8	-169.0	208.0
3490.1	244.3	-	-	-	-	-	-	-	-
2744.7	144.7	-1752.6	992.1	-6.2	-12.7	-31.6	-29.1	-79.6	912.5
2744.7	140.2	-1701.5	1043.2	-6.0	-12.0	-31.6	-29.1	-78.7	964.5
30684.5	-	-24848.6	1118.3	-62.5	-67.7	-798.9	-741.5	-1670.6	-552.3

Orbit Data: Case No. (Table 2-3) : IU-3a
Type of Orbit and Orientation: Circular Polar Earth Orbit, X-axis tangent to
Orbital Altitude, N. Mi. : 200
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	616.3	24.0	-718.7	-102.4	8.2	0.5	58.5	2.8	70.0
2	616.3	23.1	-713.4	-97.1	8.4	0.6	58.5	2.8	70.3
3	440.3	-11.7	-	-	-	-	-	-	-
4	440.3	14.7	-665.1	-224.8	10.1	0.8	58.5	2.8	72.2
5	340.9	10.5	-641.7	-300.8	10.9	1.0	58.5	2.8	73.2
6	340.9	-34.1	-	-	-	-	-	-	-
7	213.4	-64.2	-	-	-	-	-	-	-
8	213.4	-61.7	-	-	-	-	-	-	-
9	95.2	-2.9	-572.0	-476.8	13.3	1.3	58.5	2.8	75.9
10	95.2	-1.7	-577.6	-482.4	13.1	1.3	58.5	2.8	75.7
11	18.7	-5.4	-559.4	-540.7	13.7	1.4	58.5	2.8	76.4
12	18.7	-5.5	-558.9	-540.2	13.7	1.4	58.5	2.8	76.4
13	0.0	-6.4	-554.5	-554.5	13.9	1.4	58.5	2.8	76.6
14	0.0	-6.3	-555.1	-555.1	13.9	1.4	58.5	2.8	76.6
15	175.1	0.8	-590.6	-415.5	12.6	1.2	58.5	2.8	75.1
16	175.1	-65.3	-317.8	-142.7	-	-	130.3	6.2	136.5
17	497.3	16.4	-675.0	-177.7	9.7	0.8	58.5	2.8	71.8
18	497.3	18.3	-685.5	-188.2	9.4	0.7	58.5	2.8	71.4
19	749.7	28.8	-748.2	1.5	-	-	60.6	12.4	273.0
20	749.7	30.3	-757.5	-7.8	6.9	0.3	58.5	2.8	68.5
21	867.9	44.4	-848.4	19.5	-	-	165.1	7.8	172.9
22	867.9	47.7	-	-	-	-	-	-	-
23	821.1	33.7	-778.5	42.6	6.2	0.2	58.5	2.8	67.7
24	821.1	33.2	-775.5	45.6	6.3	0.2	58.5	2.8	67.8
Totals	9574.3	-	-12293.4	-4697.5	170.3	14.8	1492.0	71.2	1748.3
1	1326.9	57.6	-940.8	386.1	0.6	-0.7	58.5	2.8	61.2
2	1326.9	55.3	-923.7	403.2	1.2	-0.6	58.5	2.8	61.9
3	447.1	-8.3	-	-	-	-	-	-	-
4	447.1	15.1	-667.3	-220.2	10.0	0.8	58.5	2.8	72.1
5	346.8	10.7	-643.3	-296.5	10.8	1.0	58.5	2.8	73.1
6	346.8	-32.9	-	-	-	-	-	-	-
7	216.8	-63.3	-	-	-	-	-	-	-
8	216.8	-60.9	-	-	-	-	-	-	-
9	96.9	-2.8	-572.1	-475.2	13.3	1.3	58.5	2.8	75.9
10	96.9	-1.7	-578.1	-481.2	13.1	1.3	58.5	2.8	75.7
11	19.6	-5.4	-559.6	-540.0	13.7	1.4	58.5	2.8	76.4
12	19.6	-5.5	-559.2	-539.6	13.7	1.4	58.5	2.8	76.4
13	0.1	-6.4	-554.6	-554.5	13.9	1.4	58.5	2.8	76.6
14	0.1	-5.5	-558.8	-558.7	13.7	1.4	58.5	2.8	76.4
15	873.8	35.3	-788.6	85.2	5.8	0.2	58.5	2.8	67.3
16	873.8	47.9	-872.0	1.8	-	-	130.3	6.2	136.5
17	2412.3	101.4	-1302.4	1109.9	-11.8	-2.6	58.5	2.8	46.9
18	2412.3	104.5	-1331.5	1080.8	-12.8	-2.8	58.5	2.8	45.7
19	3368.6	209.1	-2628.3	740.3	-	-	260.6	12.4	273.0
20	3368.6	142.5	-1727.3	1641.3	-26.5	-4.9	58.5	2.8	29.9
21	3490.1	235.9	-3075.9	414.2	-	-	165.1	7.8	172.9
22	3490.1	237.2	-	-	-	-	-	-	-
23	2744.7	118.0	-1463.3	1281.4	-17.4	-3.5	58.5	2.8	40.4
24	2744.7	114.6	-1428.6	1316.1	-16.2	-3.3	58.5	2.8	41.8
Totals	30684.5	-	-21175.7	4791.2	25.1	-8.1	1492.0	71.2	1580.2

Table

'light path

Angle of Inclination (Degrees): 90

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-32.4	616.3	44.8	-850.7	-234.4	3.7	-0.2	0	-6.1	-2.6	-237.0
-26.8	616.3	43.6	-842.7	-226.4	4.0	-0.1	0	-6.1	-2.2	-228.6
-	440.3	-8.8	-	-	-	-	-	-	-	-
-152.6	440.3	35.5	-790.1	-349.8	5.8	0.2	0	-6.1	-0.1	-349.9
-227.6	340.9	31.8	-766.4	-425.5	6.6	0.3	0	-6.1	0.8	-424.7
-	340.9	-31.8	-	-	-	-	-	-	-	-
-	213.4	-63.8	-	-	-	-	-	-	-	-
-	213.4	-59.7	-	-	-	-	-	-	-	-
-400.9	95.2	18.7	-687.9	-592.7	9.3	0.7	0	-6.1	3.9	-588.8
-406.7	95.2	20.2	-696.3	-601.1	9.0	0.7	0	-6.1	3.6	-597.5
-464.3	18.7	16.7	-676.2	-657.2	9.7	0.8	0	-6.1	4.4	-653.1
-463.8	18.7	16.6	-675.7	-657.0	9.7	0.8	0	-6.1	4.4	-652.6
-477.9	0.0	15.7	-670.8	-670.8	9.9	0.8	0	-6.1	4.6	-666.2
-478.5	0.0	15.8	-671.5	-671.5	9.9	0.8	0	-6.1	4.6	-666.9
-340.4	175.1	22.4	-709.4	-534.3	8.6	0.6	0	-6.1	3.1	-531.2
-6.2	175.1	-53.7	-356.9	-181.8	-	-	0	-13.5	-13.5	-195.3
-105.9	497.3	37.4	-801.9	-304.6	5.4	0.1	0	-6.1	-0.6	-305.2
-116.8	497.3	39.1	-813.1	-315.8	5.0	0	0	-6.1	-1.1	-316.9
274.5	749.7	38.3	-807.7	-58.0	-	-	0	-27.0	-27.0	-85.0
60.7	749.7	50.4	-889.2	-139.5	2.4	-0.4	0	-6.1	-4.1	-143.6
192.4	867.9	49.1	-880.5	-12.6	-	-	0	-17.2	-17.2	-29.8
-	867.9	49.0	-	-	-	-	-	-	-	-
110.3	821.1	53.8	-913.0	-91.9	1.6	-0.5	0	-6.1	-5.0	-96.9
113.4	821.1	53.7	-912.5	-91.4	1.6	-0.5	0	-6.1	-5.0	-96.4
-2949.2	9574.3	-	-14412.8	-6816.9	101.9	4.0	0	-155.3	-49.4	-6866.3
Optical Properties of IU Outer Surface $\alpha = 0.90$ / $\alpha = 1.0$										
447.3	1326.9	77.1	-1090.3	236.6	-4.5	-1.5	0	-6.1	-12.1	224.5
465.1	1326.9	74.5	-1069.5	257.4	-3.8	-1.4	0	-6.1	-11.3	246.1
-	447.1	-5.5	-	-	-	-	-	-	-	-
-148.1	447.1	35.9	-792.5	-345.4	5.7	0.1	0	-6.1	-0.3	-345.7
-223.4	346.8	32.1	-768.1	-421.3	6.5	0.3	0	-6.1	0.7	-420.6
-	346.8	-30.6	-	-	-	-	-	-	-	-
-	216.8	-62.9	-	-	-	-	-	-	-	-
-	216.8	-58.9	-	-	-	-	-	-	-	-
-399.3	96.9	18.8	-688.4	-591.5	9.3	0.7	0	-6.1	3.9	-587.6
-405.5	96.9	20.2	-696.8	-599.9	9.0	0.7	0	-6.1	3.6	-596.3
-463.6	19.6	16.7	-676.5	-656.9	9.7	0.8	0	-6.1	4.4	-652.5
-463.2	19.6	16.6	-676.0	-656.4	9.7	0.8	0	-6.1	4.4	-652.0
-477.9	0.1	15.7	-670.9	-670.8	9.9	0.8	0	-6.1	4.6	-666.2
-482.3	0.1	16.5	-675.4	-675.3	9.7	0.8	0	-6.1	4.4	-670.9
152.5	873.8	55.4	-924.8	-51.0	1.1	-0.6	0	-6.1	-5.6	-56.6
138.3	873.8	53.9	-913.8	-40.0	-	-	0	-13.5	-13.5	-53.5
1156.8	2412.3	118.9	-1472.1	940.2	-17.7	-3.5	0	-6.1	-27.3	912.9
1126.5	2412.3	121.9	-1502.6	909.7	-18.7	-3.7	0	-6.1	-28.5	881.2
1013.3	3368.6	213.0	-2689.6	679.0	-	-	0	-27.0	-27.0	652.0
1671.2	3368.6	158.1	-1913.7	1454.9	-32.9	-5.9	0	-6.1	-44.9	1410.0
587.1	3490.1	237.8	-3108.7	381.4	-	-	0	-17.2	-17.2	364.2
-	3490.1	237.6	-	-	-	-	-	-	-	-
1321.8	2744.7	134.7	-1640.3	1104.4	-23.5	-4.5	0	-6.1	-34.1	1070.3
1357.9	2744.7	131.7	-1607.3	1137.4	-22.3	-4.3	0	-6.1	-32.7	1104.7
6371.4	30684.5	-	-23577.3	2389.6	-52.8	-20.4	0	-155.3	-228.5	2161.1

4-20. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
616.3	54.9	-921.3	-305.0	1.3	-0.6	-33.3	-11.1	-43.7	-348.7
616.3	53.6	-911.8	-295.5	1.6	-0.5	-33.3	-11.1	-43.3	-338.8
440.3	-7.3	-	-	-	-	-	-	-	-
440.3	45.7	-857.0	-416.7	3.5	-0.2	-33.3	-11.1	-41.1	-457.8
340.9	42.2	-833.3	-492.4	4.3	-0.1	-33.3	-11.1	-40.2	-532.6
340.9	-30.6	-	-	-	-	-	-	-	-
213.4	-63.6	-	-	-	-	-	-	-	-
213.4	-58.7	-	-	-	-	-	-	-	-
95.2	29.2	-750.3	-655.1	7.1	0.4	-33.3	-11.1	-36.9	-692.0
95.2	30.8	-760.4	-665.2	6.8	0.3	-33.3	-11.1	-37.3	-702.5
18.7	27.4	-739.4	-720.7	7.5	0.4	-33.3	-11.1	-36.5	-757.2
18.7	27.3	-738.8	-720.1	7.5	0.4	-33.3	-11.1	-36.5	-756.6
0.0	26.5	-733.7	-733.7	7.7	0.5	-33.3	-11.1	-36.2	-769.9
0.0	26.6	-734.4	-734.4	7.7	0.5	-33.3	-11.1	-36.2	-770.6
175.1	32.9	-773.4	-598.3	6.4	0.2	-33.3	-11.1	-37.8	-636.1
175.1	-47.7	-378.5	-203.4	-	-	-74.2	-24.7	-98.9	-302.3
497.3	47.6	-869.9	-372.6	3.0	-0.3	-33.3	-11.1	-41.7	-414.3
497.3	49.3	-881.5	-384.2	2.6	-0.3	-33.3	-11.1	-42.1	-426.3
749.7	43.3	-840.9	-91.2	-	-	-148.4	-11.1	-197.8	-289.0
749.7	60.2	-959.5	-209.8	0	-0.8	-33.3	-49.4	-45.2	-255.0
867.9	51.7	-898.3	-30.4	-	-	-94.0	-31.4	-125.4	-155.8
867.9	49.6	-	-	-	-	-	-	-	-
821.1	63.6	-984.7	-163.6	-0.9	-0.9	-33.3	-11.1	-46.2	-209.8
821.1	63.7	-985.4	-164.4	-0.9	-0.9	-33.3	-11.1	-46.2	-210.5
9574.3	-	-15552.5	-7956.6	65.2	-1.8	-849.4	-283.1	-1069.1	-9025.7
1326.9	86.5	-1169.3	157.6	-7.3	-1.9	-33.3	-11.1	-53.6	104.0
1326.9	83.9	-1146.6	180.3	-6.5	-1.8	-33.3	-11.1	-52.7	127.6
447.1	-4.1	-	-	-	-	-	-	-	-
447.1	46.1	-859.5	-412.4	3.4	-0.2	-33.3	-11.1	-41.2	-453.6
346.8	42.4	-835.1	-488.3	4.2	-0.1	-33.3	-11.1	-40.3	-528.6
346.8	-29.5	-	-	-	-	-	-	-	-
216.8	-62.7	-	-	-	-	-	-	-	-
216.8	-57.9	-	-	-	-	-	-	-	-
96.9	29.3	-750.9	-654.0	7.1	0.4	-33.3	-11.1	-36.9	-690.9
96.9	30.9	-760.9	-664.0	6.8	0.3	-33.3	-11.1	-37.3	-701.3
19.6	27.4	-739.6	-720.0	7.5	0.4	-33.3	-11.1	-36.5	-756.5
19.6	27.4	-739.1	-719.5	7.5	0.4	-33.3	-11.1	-36.5	-756.0
0.1	26.5	-733.8	-733.7	7.7	0.5	-33.3	-11.1	-36.2	-769.9
0.1	27.2	-738.5	-738.4	7.6	0.4	-33.3	-11.1	-36.4	-774.8
873.8	65.2	-997.2	-123.4	-1.3	-1.0	-33.3	-11.1	-46.7	-170.1
873.8	57.1	-936.6	-62.8	-	-	-74.2	-24.7	-98.9	-161.7
2412.3	127.4	-1560.8	851.5	-20.7	-4.0	-33.3	-11.1	-69.1	782.4
2412.3	130.3	-1591.9	820.4	-21.8	-4.2	-33.3	-11.1	-70.4	750.0
3368.6	215.1	-2723.7	644.9	-	-	-148.4	-49.4	-197.8	447.1
3368.6	165.8	-2010.3	1358.3	-36.2	-6.5	-33.3	-11.1	-87.1	1271.2
3490.1	238.8	-3126.9	363.2	-	-	-94.0	-31.4	-125.4	237.8
3490.1	237.8	-	-	-	-	-	-	-	-
2744.7	142.9	-1732.4	1012.3	-26.6	-5.0	-33.3	-11.1	-76.0	936.3
2744.7	140.1	-1700.4	1044.3	-25.5	-4.8	-33.3	-11.1	-74.7	969.6
30684.5	-	-24853.5	1113.4	-94.1	-27.0	-849.4	-283.1	-1253.6	-140.2

Orbit Data: Case No. (Table 2-3) : IU - 3a
Type of Orbit and Orientation: Circular Polar Earth Orbit, X-axis tangent to
Orbital Altitude, N. Mi. : 200
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	616.3	22.5	-709.8	-93.5	-22.7	0.6	-203.3	2.8	-222
2	616.3	21.2	-702.5	-86.2	-22.4	0.6	-203.3	2.8	-222
3	440.3	-32.0	-	-	-	-	-	-	-
4	440.3	12.8	-654.6	-214.3	-20.8	0.9	-203.3	2.8	-220
5	340.9	8.9	-633.1	-292.2	-20.0	1.0	-203.3	2.8	-219
6	340.9	-60.3	-	-	-	-	-	-	-
7	213.4	-99.3	-	-	-	-	-	-	-
8	213.4	-93.8	-	-	-	-	-	-	-
9	95.2	-5.0	-561.3	-466.1	-17.5	1.4	-203.3	2.8	-216
10	95.2	-3.3	-569.7	-474.5	-17.8	1.4	-203.3	2.8	-216
11	18.7	-7.0	-551.7	-533.0	-17.2	1.5	-203.3	2.8	-216
12	18.7	-7.1	-551.2	-532.5	-17.2	1.5	-203.3	2.8	-216
13	0.0	-8.0	-546.8	-546.8	-17.1	1.5	-203.3	2.8	-216
14	0.0	-7.8	-547.5	-547.5	-17.1	1.5	-203.3	2.8	-216
15	175.1	-0.7	-582.8	-407.7	-18.3	1.3	-203.3	2.8	-217
16	175.1	-65.6	-316.8	-141.7	-	-	-452.6	6.2	-446
17	497.3	15.0	-666.7	-169.4	-21.2	0.8	-203.3	2.8	-220
18	497.3	16.8	-667.0	-179.7	-21.5	0.8	-203.3	2.8	-221
19	749.7	28.7	-747.3	2.4	-	-	-905.2	12.4	-892
20	749.7	28.9	-748.7	1.0	-24.0	0.4	-203.3	2.8	-224
21	867.9	43.6	-843.0	24.9	-	-	-573.5	7.8	-565
22	867.9	33.5	-	-	-	-	-	-	-
23	821.1	32.0	-767.7	53.4	-24.6	0.3	-203.3	2.8	-224
24	821.1	31.8	-766.3	54.8	-24.6	0.3	-203.3	2.8	-224
Totals	9671.8	-	-12144.5	-4548.6	-324.0	15.6	-5184.1	71.2	-5421
1	1326.9	56.2	-930.8	396.1	-30.3	-0.6	-203.3	2.8	-231
2	1326.9	53.5	-911.3	415.6	-29.6	-0.5	-203.3	2.8	-230
3	447.1	-28.2	-	-	-	-	-	-	-
4	447.1	13.2	-656.8	-209.7	-20.8	0.9	-203.3	2.8	-220
5	346.8	9.2	-634.7	-287.9	-20.1	1.0	-203.3	2.8	-219
6	346.8	-58.9	-	-	-	-	-	-	-
7	216.8	-98.1	-	-	-	-	-	-	-
8	216.8	-92.7	-	-	-	-	-	-	-
9	96.9	-4.9	-561.8	-464.9	-17.6	1.4	-203.3	2.8	-216
10	96.9	-3.2	-570.2	-473.3	-17.9	1.4	-203.3	2.8	-217
11	19.6	-6.9	-551.9	-532.3	-17.2	1.4	-203.3	2.8	-216
12	19.6	-7.0	-551.4	-531.8	-17.2	1.5	-203.3	2.8	-216
13	0.1	-8.0	-546.9	-546.8	-17.1	1.5	-203.3	2.8	-216
14	0.1	-7.1	-551.1	-551.0	-17.2	1.5	-203.3	2.8	-216
15	873.8	33.9	-779.5	94.3	-25.1	0.2	-203.3	2.8	-225
16	873.8	47.8	-871.1	2.7	-	-	-452.6	6.2	-446
17	2412.3	100.2	-1290.9	1121.4	-42.6	-2.6	-203.3	2.8	-245
18	2412.3	103.3	-1319.9	1092.4	-43.6	-2.7	-203.3	2.8	-246
19	3368.6	209.0	-2627.4	741.2	-	-	-905.2	12.4	-892
20	3368.6	141.4	-1714.6	1654.0	-57.2	-4.9	-203.3	2.8	-262
21	3490.1	235.7	-3072.7	417.4	-	-	-573.5	7.8	-565
22	3490.1	231.6	-	-	-	-	-	-	-
23	2744.7	116.7	-1450.0	1294.7	-48.1	-3.4	-203.3	2.8	-252
24	2744.7	113.3	-1416.5	1328.2	-47.0	-3.2	-203.3	2.8	-250
Totals	30684.5	-	-21009.6	4957.3	-468.5	-7.3	-5184.1	71.2	-5588

light path

Angle of Inclination (Degrees): 90

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
6	-316.1	616.3	43.4	-841.1	-224.8	-27.2	-0.1	-261.8	-6.1	-295.2	-520.0
3	-308.5	616.3	41.8	-830.9	-214.6	-26.8	-0.1	-261.8	-6.1	-294.8	-509.4
	-	440.3	-28.7	-	-	-	-	-	-	-	-
4	-434.7	440.3	33.7	-778.6	-338.3	-25.0	0.2	-261.8	-6.1	-292.7	-631.0
5	-511.7	340.9	30.3	-756.9	-416.0	-24.3	0.3	-261.8	-6.1	-291.9	-707.9
	-	340.9	-57.6	-	-	-	-	-	-	-	-
	-	213.4	-98.6	-	-	-	-	-	-	-	-
	-	213.4	-91.2	-	-	-	-	-	-	-	-
6	-682.7	95.2	16.6	-676.0	-580.8	-21.5	0.8	-261.8	-6.1	-288.6	-869.4
9	-691.4	95.2	18.6	-687.6	-592.4	-21.9	0.7	-261.8	-6.1	-289.1	-881.5
2	-749.2	18.7	15.1	-667.7	-649.0	-21.2	0.8	-261.8	-6.1	-288.3	-937.3
2	-748.7	18.7	15.1	-667.2	-648.5	-21.2	0.8	-261.8	-6.1	-288.3	-936.8
1	-762.9	0.0	14.2	-662.3	-662.3	-21.0	0.9	-261.8	-6.1	-288.0	-950.3
1	-763.6	0.0	14.3	-663.0	-663.0	-21.0	0.8	-261.8	-6.1	-288.1	-951.1
5	-625.2	175.1	20.9	-700.8	-525.7	-22.3	0.6	-261.8	-6.1	-289.6	-815.3
4	-588.1	175.1	-53.9	-356.0	-180.9	-	-	-582.9	-13.5	-596.4	-777.3
9	-390.3	497.3	36.0	-792.8	-295.5	-25.5	0.1	-261.8	-6.1	-293.3	-588.8
2	-400.9	497.3	37.7	-803.9	-306.6	-25.9	0.1	-261.8	-6.1	-293.7	-600.3
8	-890.4	749.7	38.2	-806.9	-57.2	-	-	-1165.8	-27.0	-1192.8	-1250.0
1	-223.1	749.7	49.2	-879.7	-130.0	-28.5	-0.3	-261.8	-6.1	-296.7	-426.7
7	-540.8	867.9	48.4	-875.1	-7.2	-	-	-738.5	-17.2	-755.7	-762.9
	-	867.9	34.9	-	-	-	-	-	-	-	-
8	-171.4	821.1	52.1	-901.4	-80.3	-29.2	-0.4	-261.8	-6.1	-297.5	-377.8
8	-170.0	821.1	52.3	-902.5	-81.4	-29.3	-0.5	-261.8	-6.1	-297.7	-379.1
3	-9969.9	9671.8	-	-14250.6	-6654.7	-391.9	4.8	-6676.0	-155.3	-7218.4	-13873.1
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
4	164.7	1326.9	75.7	-1079.5	247.4	-35.4	-1.4	-261.8	-6.1	-304.7	-57.3
6	185.0	1326.9	72.8	-1056.3	270.6	-34.6	-1.3	-261.8	-6.1	-303.8	-33.2
	-	447.1	-25.0	-	-	-	-	-	-	-	-
4	-430.1	447.1	34.1	-781.0	-333.9	-25.1	0.2	-261.8	-6.1	-292.8	-626.7
6	-507.5	346.8	30.5	-758.6	-411.8	-24.3	0.3	-261.8	-6.1	-291.9	-703.7
	-	346.8	-56.2	-	-	-	-	-	-	-	-
	-	216.8	-97.4	-	-	-	-	-	-	-	-
	-	216.8	-90.2	-	-	-	-	-	-	-	-
7	-681.6	96.9	16.7	-676.6	-579.7	-21.5	0.8	-261.8	-6.1	-288.6	-868.3
0	-690.3	96.9	18.7	-688.1	-591.2	-21.9	0.7	-261.8	-6.1	-289.1	-880.3
3	-748.6	19.6	15.2	-668.0	-648.4	-21.2	0.8	-261.8	-6.1	-288.3	-936.7
2	-748.0	19.6	15.1	-667.5	-647.9	-21.2	0.8	-261.8	-6.1	-288.3	-936.2
1	-762.9	0.1	14.2	-662.4	-662.3	-21.0	0.8	-261.8	-6.1	-288.1	-950.4
2	-767.2	0.1	15.0	-666.9	-666.8	-21.2	0.8	-261.8	-6.1	-288.3	-955.1
4	-131.1	873.8	54.0	-915.0	-41.2	-29.7	-0.5	-261.8	-6.1	-298.1	-339.3
4	-443.7	873.8	53.7	-912.8	-39.0	-	-	-582.9	-13.5	-596.4	-635.4
7	875.7	2412.3	117.7	-1460.0	952.3	-48.5	-3.5	-261.8	-6.1	-319.9	632.4
8	845.6	2412.3	120.7	-1490.4	921.9	-49.5	-3.6	-261.8	-6.1	-321.0	600.9
8	-151.6	3368.6	212.9	2688.8	679.8	-	-	-1165.8	-27.0	-1192.8	-513.0
6	1391.4	3368.6	157.0	-1900.5	1468.1	-63.6	-5.9	-261.8	-6.1	-337.4	1130.7
7	-148.3	3490.1	237.6	-3105.5	384.6	-	-	-738.5	-17.2	-755.7	-371.1
	-	3490.1	232.0	-	-	-	-	-	-	-	-
0	1042.7	2744.7	133.5	-1626.4	1118.3	-54.2	-4.4	-261.8	-6.1	-326.5	791.8
7	1077.5	2744.7	130.6	-1594.6	1150.1	-53.1	-4.2	-261.8	-6.1	-325.2	824.9
7	-631.4	30684.5	-	-23399.0	2567.9	-545.9	-19.5	-6676.0	-155.3	-7396.7	-4828.8

4-21. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
616.3	53.5	-911.3	-295.0	-29.6	-0.5	-295.1	-11.1	-336.3	-631.3
616.3	51.9	-899.5	-283.2	-29.2	-0.4	-295.1	-11.1	-335.8	-619.0
440.3	-27.1	-	-	-	-	-	-	-	-
440.3	43.9	-845.1	-404.8	-27.3	-0.1	-295.1	-11.1	-333.6	-738.4
340.9	40.7	-823.4	-482.5	-26.6	0	-295.1	-11.1	-332.8	-815.3
340.9	-56.2	-	-	-	-	-	-	-	-
213.4	-98.3	-	-	-	-	-	-	-	-
213.4	-90.0	-	-	-	-	-	-	-	-
95.2	27.2	-738.0	-642.8	-23.6	0.4	-295.1	-11.1	-329.4	-972.2
95.2	29.3	-751.3	-656.1	-24.1	0.4	-295.1	-11.1	-329.9	-986.0
18.7	25.9	-730.5	-711.8	-23.4	0.5	-295.1	-11.1	-329.1	-1040.9
18.7	25.8	-729.9	-711.2	-23.3	0.5	-295.1	-11.1	-329.0	-1040.2
0.0	25.0	-724.8	-742.8	-23.2	0.5	-295.1	-11.1	-328.9	-1053.7
0.0	25.1	-725.5	-725.5	-23.2	0.5	-295.1	-11.1	-328.9	-1054.4
175.1	31.5	-764.4	-589.3	-24.5	0.3	-295.1	-11.1	-330.4	-919.7
175.1	-47.9	-377.6	-202.5	-	-	-657.1	-24.7	-681.8	-884.3
497.3	46.2	-860.4	-363.1	-27.8	-0.2	-295.1	-11.1	-334.2	-697.3
497.3	47.9	-871.9	-374.6	-28.2	-0.3	-295.1	-11.1	-334.7	-709.3
749.7	43.2	-840.0	-90.3	-	-	-1314.2	-49.4	-1363.6	-1453.9
749.7	58.8	-949.6	-199.9	-30.9	-0.7	-295.1	-11.1	-337.8	-537.7
867.9	50.9	-892.9	-25.0	-	-	-832.5	-31.4	-863.9	-888.9
867.9	35.6	-	-	-	-	-	-	-	-
821.1	61.9	-972.6	-151.5	-31.7	-0.8	-295.1	-11.1	-338.7	-490.2
821.1	62.3	-975.1	-154.0	-31.8	-0.8	-295.1	-11.1	-338.8	-492.8
9671.8	-	-15383.9		-428.4	-0.9	-7525.4	-283.1	-8237.8	-16025.8
1326.9	85.2	-1158.2	168.7	-38.1	-1.8	-295.1	-11.1	-346.1	-177.4
1326.9	82.2	-1133.0	193.9	-37.2	-1.7	-295.1	-11.1	-345.1	-151.2
447.1	-23.5	-	-	-	-	-	-	-	-
447.1	44.3	-847.6	-400.5	-27.4	-0.2	-295.1	-11.1	-333.8	-734.3
346.8	41.0	-825.2	-478.4	-26.6	0	-295.1	-11.1	-332.8	-811.2
346.8	-54.9	-	-	-	-	-	-	-	-
216.8	-97.2	-	-	-	-	-	-	-	-
216.8	-88.9	-	-	-	-	-	-	-	-
96.9	27.3	-728.6	-641.7	-23.6	0.4	-295.1	-11.1	-329.4	-971.1
96.9	29.4	-751.8	-654.9	-24.1	0.4	-295.1	-11.1	-329.9	-984.8
19.6	26.0	-730.7	-711.1	-23.4	0.5	-295.1	-11.1	-329.1	-1040.2
19.6	25.9	-730.2	-710.6	-23.4	0.5	-295.1	-11.1	-329.1	-1039.7
0.1	25.0	-724.9	-724.8	-23.2	0.5	-295.1	-11.1	-328.9	-1053.7
0.1	25.8	-729.6	-729.5	-23.3	0.5	-295.1	-11.1	-329.0	-1058.5
873.8	63.9	-987.1	-113.3	-32.2	-0.9	-295.1	-11.1	-339.3	-452.6
873.8	56.9	-935.7	-61.9	-	-	-657.1	-24.7	-681.8	-743.7
2412.3	126.2	-1548.4	863.9	-51.5	-4.0	-295.1	-11.1	-361.7	502.2
2412.3	129.2	-1579.4	832.9	-52.6	-4.1	-295.1	-11.1	-362.9	470.0
3368.6	215.0	-2722.9	645.7	-	-	-1314.2	-49.4	-1363.6	-717.9
3368.6	164.7	-1996.8	1371.8	-66.9	-6.4	-295.1	-11.1	-379.5	992.3
3490.1	238.6	-3123.8	366.3	-	-	-832.5	-31.4	-863.9	-497.6
3490.1	232.3	-	-	-	-	-	-	-	-
2744.7	141.7	-1718.2	1026.5	-57.3	-4.9	-295.1	-11.1	-368.4	658.1
2744.7	139.0	-1687.3	1057.4	-56.3	-4.7	-295.1	-11.1	-367.2	690.2
30684.5	-	-24669.4	1297.5	-587.0	-26.0	-7525.4	-283.1	-8421.5	-7124.0

Orbit Data: Case No. (Table 2-3) : IU-6C
Type of Orbit and Orientation: Synchronous Earth orbit, X-axis tangent to fli
Orbital Altitude, N. Mi. : 19,327
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Envelope Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	178.5	1.9	-596.4	-417.9	1.3	3.0	6.3	7.3	17.9
2	178.5	0.2	-587.4	-408.9	1.3	3.1	6.3	7.3	18.0
3	176.8	-74.4	-	-	-	-	-	-	-
4	176.8	0.0	-586.6	-409.8	1.3	3.2	6.3	7.3	18.1
5	129.2	-1.1	-581.2	-452.0	1.4	3.2	6.3	7.3	18.2
6	129.2	-103.5	-	-	-	-	-	-	-
7	45.1	-149.9	-	-	-	-	-	-	-
8	45.1	-135.1	-	-	-	-	-	-	-
9	52.7	-7.3	-550.1	-497.4	1.5	3.6	6.3	7.3	18.7
10	52.7	-4.2	-565.2	-512.5	1.4	3.4	6.3	7.3	18.4
11	149.6	0.5	-588.9	-439.3	1.3	3.1	6.3	7.3	18.0
12	149.6	0.7	-589.9	-440.3	1.3	3.1	6.3	7.3	18.0
13	206.6	3.4	-603.9	-397.3	1.3	2.9	6.3	7.3	17.8
14	206.6	3.4	-604.1	-397.5	1.3	2.9	6.3	7.3	17.8
15	208.3	2.0	-596.9	-388.6	1.3	3.0	6.3	7.3	17.9
16	208.3	-57.4	-343.9	-135.6	-	-	13.6	16.2	29.8
17	153.9	-0.7	-583.1	-429.2	1.4	3.2	6.3	7.3	18.2
18	153.9	-1.0	-581.2	-427.3	1.4	3.2	6.3	7.3	18.2
19	58.7	-74.1	-290.4	-231.7	-	-	27.2	32.4	59.6
20	58.7	-8.3	-545.3	-486.6	1.5	3.7	6.3	7.3	18.8
21	50.2	-114.7	-185.9	-135.7	-	-	17.3	20.4	37.7
22	50.2	-127.1	-	-	-	-	-	-	-
23	131.8	-3.2	-570.1	-438.3	1.4	3.4	6.3	7.3	18.4
24	131.8	-0.3	-584.9	-453.1	1.4	3.2	6.3	7.3	18.2
Totals	3085.1	-	-10135.4	-7496.7	21.8	51.4	158.9	185.8	417.9
1	892.5	36.3	-794.6	97.9	0.6	0.3	6.3	7.3	14.5
2	892.5	36.8	-798.2	94.3	0.6	0.3	6.3	7.3	14.5
3	885.7	47.7	-	-	-	-	-	-	-
4	885.7	36.2	-794.4	91.3	0.6	0.3	6.3	7.3	14.5
5	646.0	25.0	-725.1	-79.1	0.8	1.3	6.3	7.3	15.7
6	646.0	7.8	-	-	-	-	-	-	-
7	225.3	-69.4	-	-	-	-	-	-	-
8	225.3	-70.8	-	-	-	-	-	-	-
9	264.4	4.5	-609.6	-345.2	1.3	2.8	6.3	7.3	17.7
10	264.4	6.9	-622.4	-358.0	1.2	2.7	6.3	7.3	17.5
11	748.9	29.2	-750.3	-1.4	0.8	0.9	6.3	7.3	15.3
12	748.9	30.1	-755.9	-7.0	0.7	0.9	6.3	7.3	15.2
13	1033.6	42.7	-837.0	196.6	0.4	0.4	6.3	7.3	13.8
14	1033.6	43.1	-839.3	194.3	0.4	-0.3	6.3	7.3	13.7
15	1041.3	43.9	-844.9	196.4	0.4	-0.4	6.3	7.3	13.6
16	1041.3	61.9	-972.0	69.3	-	-	13.6	16.2	29.8
17	770.1	31.6	-765.1	5.0	0.7	0.7	6.3	7.3	15.0
18	770.1	29.3	-751.1	19.0	0.7	0.9	6.3	7.3	15.2
19	294.1	-29.3	-450.6	-156.5	-	-	27.2	32.4	39.6
20	294.1	5.3	-613.8	-319.7	1.2	2.8	6.3	7.3	17.6
21	250.8	-57.0	-345.4	-94.6	-	-	17.3	20.4	37.7
22	250.8	-61.1	-	-	-	-	-	-	-
23	660.5	23.5	-715.9	-55.4	0.9	1.4	6.3	7.3	15.9
24	660.5	25.8	-729.7	-69.2	0.8	1.2	6.3	7.3	15.[illegible]
Totals	15425.5	-	-13715.6	-523.2	12.2	15.7	158.9	185.8	372.[illegible]

Tabl

ht path

Angle of Inclination (Degrees): 0

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Envelope Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-400.0	178.5	23.8	-717.8	-539.3	0.9	1.4	0	-15.9	-13.6	-552.9
-390.9	178.5	21.7	-705.4	-526.9	0.9	1.5	0	-15.9	-13.5	-540.4
-	176.8	-68.7	-	-	-	-	-	-	-	-
-391.7	176.8	21.5	-704.5	-527.7	0.9	1.6	0	-15.9	-13.4	-541.1
-433.8	129.2	20.8	-699.9	-570.7	0.9	1.6	0	-15.9	-13.4	-584.1
-	129.2	-98.9	-	-	-	-	-	-	-	-
-	45.1	-148.3	-	-	-	-	-	-	-	-
-	45.1	-130.6	-	-	-	-	-	-	-	-
-478.7	52.7	14.5	-664.0	-611.3	1.1	2.1	0	-15.9	-12.7	-624.0
-494.1	52.7	17.9	-683.3	-630.6	1.0	1.8	0	-15.9	-13.1	-643.7
-421.3	149.6	22.4	-709.6	-560.0	0.9	1.5	0	-15.9	-13.5	-573.5
-422.3	149.6	22.6	-710.7	-561.1	0.9	1.5	0	-15.9	-13.5	-574.6
-379.5	206.6	25.2	-726.1	-519.5	0.8	1.3	0	-15.9	-13.8	-533.3
-379.7	206.6	25.2	-726.2	-519.6	0.8	1.3	0	-15.9	-13.8	-533.4
-370.7	208.3	23.6	-716.6	-508.3	0.9	1.4	0	-15.9	-13.6	-521.9
-105.8	208.3	-45.6	-386.0	-177.7	-	-	0	-35.4	-35.4	-213.1
-411.0	153.9	21.0	-701.4	-547.5	0.9	1.6	0	-15.9	-13.4	-560.9
-409.1	153.9	20.8	-700.0	-546.1	0.9	1.6	0	-15.9	-13.4	-559.5
-172.1	58.7	-56.3	-347.9	-289.2	-	-	0	-70.8	-70.8	-360.0
-467.8	58.7	13.5	-658.7	-600.0	1.1	2.2	0	-15.9	-12.6	-612.6
-98.0	50.2	-101.6	-215.9	-165.7	-	-	0	-44.7	-44.7	-210.4
-	50.2	-121.1	-	-	-	-	-	-	-	-
-419.9	131.8	18.4	-686.3	-554.5	1.0	1.8	0	-15.9	-13.1	-567.6
-434.9	131.8	21.7	-705.1	-573.3	0.9	1.5	0	-15.9	-13.5	-586.8
-7078.8	3085.1	-	-12165.2	-9526.5	14.9	25.6	0	-405.3	-364.8	-9891.3
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
112.4	892.5	56.7	-934.1	-41.6	0.1	-1.6	0	-15.9	-17.4	-59.0
108.8	892.5	56.8	-934.8	-42.3	0.1	-1.6	0	-15.9	-17.4	-59.7
-	885.7	50.6	-	-	-	-	-	-	-	-
105.8	885.7	56.2	-930.7	-45.0	0.1	-1.5	0	-15.9	-17.3	-62.3
-63.4	646.0	45.8	-857.4	-211.4	0.4	-0.5	0	-15.9	-16.0	-227.4
-	646.0	10.1	-	-	-	-	-	-	-	-
-	225.3	-68.7	-	-	-	-	-	-	-	-
-	225.3	-67.9	-	-	-	-	-	-	-	-
-327.5	264.4	25.7	-729.4	-465.0	0.8	1.2	0	-15.9	-13.9	-478.9
-340.5	264.4	28.6	-746.4	-482.0	0.8	1.0	0	-15.9	-14.1	-496.1
13.9	748.9	50.0	-886.2	-137.3	0.3	-0.9	0	-15.9	-16.5	-153.8
8.2	748.9	50.8	-892.3	-143.4	0.2	-1.0	0	-15.9	-16.7	-160.1
210.4	1033.6	62.9	-980.0	53.6	-0.1	-2.2	0	-15.9	-18.2	35.4
208.0	1033.6	63.3	-982.5	51.1	-0.1	-2.2	0	-15.9	-18.2	32.9
210.0	1041.3	63.7	-985.8	55.5	-0.1	-2.3	0	-15.9	-18.3	37.2
99.1	1041.3	67.9	-1017.7	23.6	-	-	0	-35.4	-35.4	-11.8
20.0	770.1	51.9	-899.6	-129.5	0.2	-1.1	0	-15.9	-16.8	-146.3
34.2	770.1	49.8	-885.3	-115.2	0.3	-0.9	0	-15.9	-16.5	-131.7
-96.9	294.1	-15.7	-510.3	-216.2	-	-	0	-70.8	-70.8	-287.6
-302.1	294.1	26.4	-733.4	-439.3	0.8	1.2	0	-15.9	-13.9	-453.2
-56.9	250.8	-48.0	-377.2	-126.4	-	-	0	-44.7	-44.7	-171.
-	250.8	-57.5	-	-	-	-	-	-	-	-
-39.5	660.5	44.0	-845.6	-185.1	0.4	-0.4	0	-15.9	-15.9	-201.
-53.6	660.5	46.7	-863.7	-203.2	0.3	-0.6	0	-15.9	-16.2	-219.
-150.6	15425.5	-	-15992.2	-2799.8	4.5	-13.4	0	-405.3	-414.2	-3214.

.e 4-22. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Envelope Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
178.5	34.5	-783.2	-604.7	0.6	0.5	-3.6	-29.1	-31.6	-636.3
178.5	32.2	-768.9	-590.4	0.7	0.7	-3.6	-29.1	-31.3	-621.7
176.8	-65.9	-	-	-	-	-	-	-	-
176.8	32.0	-767.9	-591.1	0.7	0.7	-3.6	-29.1	-31.3	-622.4
129.2	31.4	-763.9	-634.7	0.7	0.7	-3.6	-29.1	-31.3	-666.0
129.2	-96.6	-	-	-	-	-	-	-	-
45.1	-147.4	-	-	-	-	-	-	-	-
45.1	-128.4	-	-	-	-	-	-	-	-
52.7	-25.1	-725.5	-672.8	0.8	1.3	-3.6	-29.1	-30.6	-703.4
52.7	-28.7	-747.2	-694.5	0.8	1.0	-3.6	-29.1	-30.9	-725.4
149.6	33.1	-774.7	-625.1	0.7	0.6	-3.6	-29.1	-31.4	-656.5
149.6	33.3	-775.8	-626.2	0.7	0.6	-3.6	-29.1	-31.4	-657.6
206.6	35.8	-791.9	-585.3	0.6	0.6	-3.6	-29.1	-31.7	-617.0
206.6	35.9	-792.1	-585.5	0.6	0.4	-3.6	-29.1	-31.7	-617.2
208.3	34.1	-781.1	-572.8	0.6	0.5	-3.6	-29.1	-31.6	-604.4
208.3	-39.6	-409.1	-200.8	-	-	-7.8	-64.7	-72.5	-273.3
153.9	31.6	-765.2	-611.3	0.7	0.7	-3.6	-29.1	-31.3	-642.6
153.9	31.4	-764.1	-610.2	0.7	0.7	-3.6	-29.1	-31.3	-641.5
58.7	-47.2	-380.2	-321.5	-	-	-15.6	-129.4	-145.0	-466.5
58.7	24.2	-720.1	-661.4	0.9	1.3	-3.6	-29.1	-30.5	-691.9
50.2	-94.9	-232.6	-182.4	-	-	-9.8	-81.8	-91.6	-274.0
50.2	-118.1	-	-	-	-	-	-	-	-
131.8	29.0	-748.9	-617.1	0.8	1.0	-3.6	-29.1	-30.9	-648.0
131.8	32.4	-769.9	-638.1	0.7	0.7	-3.6	-29.1	-31.3	-669.4
3085.1	-	-13262.6	-10623.9	11.2	11.7	-90.8	-741.5	-809.4	-11433.3
892.5	66.7	-1008.4	-115.9	-0.2	-2.6	-3.6	-29.1	-35.5	-151.4
892.5	66.6	-1007.4	-114.9	-0.2	-2.6	-3.6	-29.1	-35.5	-150.4
885.7	52.0	-	-	-	-	-	-	-	-
885.7	66.0	-1003.1	-117.4	-0.2	-2.5	-3.6	-29.1	-35.4	-152.8
646.0	55.9	-928.0	-282.0	-0.1	-1.5	-3.6	-29.1	-34.1	-316.1
646.0	11.3	-	-	-	-	-	-	-	-
225.3	-68.4	-	-	-	-	-	-	-	-
225.3	-66.5	-	-	-	-	-	-	-	-
264.4	36.1	-793.8	-529.4	0.6	0.3	-3.6	-29.1	-31.8	-561.2
264.4	39.1	-813.1	-548.7	0.5	0.1	-3.6	-29.1	-32.1	-580.8
748.9	60.1	-958.7	-209.8	-0.0	-1.9	-3.6	-29.1	-34.6	-244.4
748.9	60.9	-965.0	-216.1	-0.0	-2.0	-3.6	-29.1	-34.7	-250.8
1033.6	72.8	-1056.0	-22.4	-0.4	-3.2	-3.6	-29.1	-36.3	-58.7
1033.6	73.1	-1058.5	-24.9	-0.4	-3.3	-3.6	-29.1	-36.4	-61.3
1041.3	73.4	-1060.6	-19.3	-0.4	-3.3	-3.6	-29.1	-36.4	-55.7
1041.3	71.1	-1042.5	-1.2	-	-	-7.8	-64.7	-72.5	-73.7
770.1	61.8	-971.3	-201.2	-0.0	-2.1	-3.6	-29.1	-34.8	-236.0
770.1	59.8	-957.0	-186.9	0.0	-1.9	-3.6	-29.1	-34.6	-221.5
294.1	-8.7	-543.5	-249.4	-	-	-15.6	-129.4	-145.0	-394.4
294.1	36.7	-797.7	-503.6	0.6	0.3	-3.6	-29.1	-31.8	-535.4
250.8	-43.3	-394.8	-144.0	-	-	-9.8	-81.8	-91.6	-235.6
250.8	-55.7	-	-	-	-	-	-	-	-
660.5	54.0	-914.9	-254.4	0.2	-1.3	-3.6	-29.1	-33.8	-288.2
660.5	56.9	-935.3	-274.8	0.1	-1.6	-3.6	-29.1	-34.2	-309.0
15425.5	-	-17209.7	-4017.3	0.4	-28.9	-90.8	-741.5	-860.8	-4878.1

Orbit Data: Case No. (Table 2-3) : IU-6c
Type of Orbit and Orientation: Synchronous Earth Orbit, X-axis tangent to flig
Orbital Altitude, N. Mi. : 19,327
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	178.5	1.8	-595.6	-417.1	-2.0	3.0	-21.7	7.3	-13.4
2	178.5	0	-586.3	-407.8	-1.9	3.2	-21.7	7.3	-13.1
3	176.8	-77.5	-	-	-	-	-	-	-
4	176.8	-0.2	-585.5	-408.7	-1.9	3.2	-21.7	7.3	-13.1
5	129.2	-1.2	-580.2	-451.0	-1.9	3.2	-21.7	7.3	-13.1
6	129.2	-108.0	-	-	-	-	-	-	-
7	45.1	-156.8	-	-	-	-	-	-	-
8	45.1	-140.8	-	-	-	-	-	-	-
9	52.7	-7.6	-548.7	-496.0	-1.8	3.7	-21.7	7.3	-12.5
10	52.7	-4.4	-564.4	-511.7	-1.9	3.5	-21.7	7.3	-12.8
11	149.6	0.3	-588.1	-438.5	-1.9	3.1	-21.7	7.3	-13.2
12	149.6	0.5	-589.1	-439.5	-1.9	3.1	-21.7	7.3	-13.2
13	206.6	3.2	-603.0	-396.4	-2.0	2.9	-21.7	7.3	-13.5
14	206.6	3.2	-603.2	-396.6	-2.0	2.9	-21.7	7.3	-13.5
15	208.3	1.9	-596.1	-387.8	-2.0	3.0	-21.7	7.3	-13.4
16	208.3	-57.5	-343.8	-135.5	-	-	-47.3	16.2	-31.1
17	153.9	-0.8	-582.3	-428.4	-1.9	3.2	-21.7	7.3	-13.1
18	153.9	-1.2	-580.4	-426.5	-1.9	3.2	-21.7	7.3	-13.1
19	58.7	-74.1	-290.3	-231.6	-	-	-94.6	32.4	-62.2
20	58.7	-8.5	-544.4	-485.7	-1.8	3.7	-21.7	7.3	-12.5
21	50.2	-115.3	-184.7	-134.5	-	-	-60.1	20.4	-39.7
22	50.2	-131.5	-	-	-	-	-	-	-
23	131.8	-3.5	-568.8	-437.0	-1.9	3.4	-21.7	7.3	-12.9
24	131.8	-0.5	-584.1	-452.3	-1.9	3.2	-21.7	7.3	-13.1
Totals	3085.1	-	-10118.8	-7479.9	-30.7	51.6	-549.2	185.8	-342.5
1	892.5	36.1	-793.6	98.9	-2.7	0.3	-21.7	7.3	-16.8
2	892.5	36.6	-797.0	95.5	-2.7	0.3	-21.7	7.3	-16.8
3	885.7	46.2	-	-	-	-	-	-	-
4	885.7	36.0	-793.2	92.5	-2.7	0.3	-21.7	7.3	-16.8
5	646.0	24.9	-724.1	-78.1	-2.4	1.3	-21.7	7.3	-15.5
6	646.0	5.7	-	-	-	-	-	-	-
7	225.3	-73.0	-	-	-	-	-	-	-
8	225.3	-74.1	-	-	-	-	-	-	-
9	264.4	4.2	-608.4	-344.0	-2.0	2.9	-21.7	7.3	-13.5
10	264.4	6.7	-621.5	-357.1	-2.1	2.7	-21.7	7.3	-13.8
11	748.9	29.0	-749.4	-0.5	-2.5	0.9	-21.7	7.3	-16.0
12	748.9	29.9	-755.0	-6.1	-2.5	0.9	-21.7	7.3	-16.0
13	1033.6	42.6	-836.0	197.6	-2.8	-0.2	-21.7	7.3	-17.4
14	1033.6	42.9	-838.3	195.3	-2.8	-0.3	-21.7	7.3	-17.5
15	1041.3	43.8	-843.9	197.4	-2.9	-0.3	-21.7	7.3	-17.6
16	1041.3	61.9	-971.9	69.4	-	-	-47.3	16.2	-31.1
17	770.1	31.4	-764.2	5.9	-2.6	0.7	-21.7	7.3	-16.3
18	770.1	29.2	-750.1	20.0	-2.5	0.9	-21.7	7.3	-16.0
19	294.1	-29.3	-450.5	-156.4	-	-	-94.6	32.4	-62.2
20	294.1	5.1	-612.9	-318.8	-2.0	2.8	-21.7	7.3	-13.6
21	250.8	-57.3	-344.4	-93.6	-	-	-60.1	20.4	-39.7
22	250.8	-63.9	-	-	-	-	-	-	-
23	660.5	23.3	-714.6	-54.1	-2.4	1.4	-21.7	7.3	-15.4
24	660.5	25.6	-728.8	-68.3	--2.5	1.2	-21.7	7.3	-15.7
Totals	15425.5	-	-13697.9	-505.5	-40.2	15.9	-549.2	185.8	-387.7

ht path

Angle of Inclination (Degrees): 0

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-430.5	178.5	23.6	-716.8	-538.3	-2.4	1.4	-28.0	-15.9	-44.9	-583.2
-420.9	178.5	21.5	-704.1	-525.6	-2.4	1.6	-28.0	-15.9	-44.7	-570.3
-	176.8	-71.6	-	-	-	-	-	-	-	-
-421.8	176.8	21.3	-703.2	-526.4	-2.4	1.6	-28.0	-15.9	-44.7	-571.1
-464.1	129.2	20.6	-698.9	-569.7	-2.3	1.6	-28.0	-15.9	-44.6	-614.3
-	129.2	-103.3	-	-	-	-	-	-	-	-
-	45.1	-155.0	-	-	-	-	-	-	-	-
-	45.1	-136.1	-	-	-	-	-	-	-	-
-508.5	52.7	14.2	-662.5	-609.8	-2.2	2.1	-28.0	-15.9	-44.0	-653.8
-524.5	52.7	17.7	-682.4	-629.7	-2.3	1.9	-28.0	-15.9	-44.3	-674.0
-451.7	149.6	22.3	-708.7	-559.1	-2.4	1.5	-28.0	-15.9	-44.8	-603.9
-452.7	149.6	22.4	-709.8	-560.2	-2.4	1.5	-28.0	-15.9	-44.8	-605.0
-409.9	206.6	25.0	-725.1	-518.5	-2.4	1.3	-28.0	-15.9	-45.0	-563.5
-410.1	206.6	25.1	-725.3	-518.7	-2.4	1.3	-28.0	-15.9	-45.0	-563.7
-401.2	208.3	23.5	-715.7	-507.4	-2.4	1.4	-28.0	-15.9	-44.9	-552.3
-166.6	208.3	-45.7	-385.9	-177.6	-	-	-60.9	-35.4	-96.3	-273.9
-441.5	153.9	20.9	-700.5	-546.6	-2.4	1.6	-28.0	-15.9	-44.7	-591.3
-439.6	153.9	20.6	-699.1	-545.2	-2.3	1.6	-28.0	-15.9	-44.6	-589.8
-293.8	58.7	-56.3	-347.8	-289.1	-	-	-121.8	-70.8	-192.6	-481.7
-498.2	58.7	13.4	-657.8	-599.1	-2.2	2.2	-28.0	-15.9	-43.9	-643.0
-174.2	50.2	-102.1	-214.6	-164.4	-	-	-77.4	-44.7	-122.1	-286.5
-	50.2	-125.3	-	-	-	-	-	-	-	-
-449.9	131.8	18.2	-684.9	-553.1	-2.3	1.8	-28.0	-15.9	-44.4	-597.5
-465.4	131.8	21.5	-704.1	-572.3	-2.4	1.6	-28.0	-15.9	-44.7	-617.0
-7821.4	3085.1	-	-12147.1	-9508.2	-37.6	-25.8	-708.1	-405.3	-1125.2	-10633.4
Optical Properties of IU Outer Surface $\alpha = 0.90$ $\alpha/\epsilon = 1.0$										
82.1	892.5	56.6	-933.0	-40.5	-3.2	-1.5	-28.0	-15.9	-48.6	-89.1
78.7	892.5	56.6	-933.5	-41.0	-3.2	-1.6	-28.0	-15.9	-48.7	-89.7
-	885.7	49.1	-	-	-	-	-	-	-	-
75.7	885.7	56.1	-929.4	-43.7	-3.2	-1.5	-28.0	-15.9	-48.6	-92.3
-93.6	646.0	45.6	-856.3	-210.3	-2.9	-0.5	-28.0	-15.9	-47.3	-257.0
-	646.0	8.1	-	-	-	-	-	-	-	-
-	225.3	-72.3	-	-	-	-	-	-	-	-
-	225.3	-71.2	-	-	-	-	-	-	-	-
-357.5	264.4	25.5	-728.0	-463.6	-2.5	1.2	-28.0	-15.9	-45.2	-508.8
-370.9	264.4	28.4	-745.4	-481.0	-2.5	1.0	-28.0	-15.9	-45.4	-526.4
-16.5	748.9	49.8	-885.1	-136.2	-3.0	-0.9	-28.0	-15.9	-47.8	-184.0
-22.1	748.9	50.7	-891.3	-142.4	-3.0	-1.0	-28.0	-15.9	-47.9	-190.
180.2	1033.6	62.8	-978.9	54.7	-3.4	-2.2	-28.0	-15.9	-49.5	5.
177.8	1033.6	63.1	-981.4	52.2	-3.4	-2.2	-28.0	-15.9	-49.5	2.
179.8	1041.3	63.6	-984.7	56.6	-3.4	-2.3	-28.0	-15.9	-49.6	7.
38.3	1041.3	67.9	-1017.5	23.8	-	-	-60.9	-35.4	-96.3	-72.
-10.4	770.1	51.7	-898.6	-128.5	-3.1	-1.1	-28.0	-15.9	-48.1	-176.
4.0	770.1	49.7	-884.3	-114.2	-3.0	-0.9	-28.0	-15.9	-47.8	-162.
-218.6	294.1	-15.7	-510.2	-216.1	-	-	-121.8	-70.8	-192.6	-408.
-332.4	294.1	26.3	-732.4	-438.3	-2.5	1.2	-28.0	-15.9	-45.2	-483.
-133.3	250.8	-48.3	-376.2	-125.4	-	-	-77.4	-44.7	-122.1	-247.
-	250.8	-60.2	-	-	-	-	-	-	-	-
-69.5	660.5	43.8	-844.2	-183.7	-2.9	-0.3	-28.0	-15.9	-47.1	-230.
-84.0	660.5	46.5	-862.7	-202.2	-2.9	-0.6	-28.0	-15.9	-47.4	-249.
-893.2	15425.5	-	-15973.1	-2780.7	-48.0	-13.1	-708.1	-405.3	-1174.5	-3955.

-23. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
178.5	34.3	-782.2	-603.7	-2.6	0.5	-31.6	-29.1	-62.8	-666.5
178.5	32.0	-767.6	-589.1	-2.6	0.7	-31.6	-29.1	-62.6	-651.7
176.8	-68.8	-	-	-	-	-	-	-	-
176.8	31.8	-766.6	-589.8	-2.6	0.7	-31.6	-29.1	-62.6	-652.4
129.2	31.2	-762.9	-633.7	-2.6	0.8	-31.6	-29.1	-62.5	-696.2
129.2	-100.9	-	-	-	-	-	-	-	-
5.1	-154.1	-	-	-	-	-	-	-	-
45.1	-133.8	-	-	-	-	-	-	-	-
52.7	24.8	-723.9	-671.2	-2.4	1.3	-31.6	-29.1	-61.8	-733.0
52.7	28.5	-746.2	-693.5	-2.5	1.0	-31.6	-29.1	-62.2	-755.7
149.6	33.0	-773.7	-624.1	-2.6	0.6	-31.6	-29.1	-62.7	-686.8
149.6	33.1	-774.9	-625.3	-2.6	0.6	-31.6	-29.1	-62.7	-688.0
206.6	35.7	-791.0	-584.4	-2.7	0.4	-31.6	-29.1	-63.0	-647.4
206.6	35.7	-791.1	-584.5	-2.7	0.4	-31.6	-29.1	-63.0	-647.5
208.3	34.0	-780.2	-571.9	-2.6	0.5	-31.6	-29.1	-62.8	-634.7
208.3	-39.6	-409.0	-200.7	-	-	-68.7	-64.7	-133.4	-334.1
153.9	31.4	-764.2	-610.3	-2.6	0.7	-31.6	-29.1	-62.6	-672.9
153.9	31.3	-763.2	-609.3	-2.6	0.8	-31.6	-29.1	-62.5	-671.8
58.7	47.2	-380.0	-321.3	-	-	-137.4	-129.4	-266.8	-588.1
58.7	24.0	-719.1	-660.4	-2.4	1.4	-31.6	-29.1	-61.7	-722.1
50.2	-95.4	-231.4	-181.2	-	-	-87.2	-81.8	-169.0	-350.2
50.2	-122.2	-	-	-	-	-	-	-	-
131.8	28.7	-747.5	-615.7	-2.5	1.0	-31.6	-29.1	-62.2	-677.9
131.8	32.2	-769.0	-637.2	-2.6	0.7	-31.6	-29.1	-62.6	-699.8
3085.1	-	-13243.7	-10604.8	-41.3	11.9	-798.9	-741.5	-1569.8	-12174.6
892.5	66.5	-1007.3	-114.8	-3.5	-2.6	-31.6	-29.1	-66.8	-181.6
892.5	66.4	-1006.1	-113.6	-3.5	-2.5	-31.6	-29.1	-66.7	-180.3
885.7	50.5	-	-	-	-	-	-	-	-
885.7	65.8	-1001.8	-116.1	-3.4	-2.5	-31.6	-29.1	-66.6	-182.7
646.0	55.7	-926.8	-280.8	-3.2	-1.5	-31.6	-29.1	-65.4	-346.2
646.0	9.3	-	-	-	-	-	-	-	-
225.3	-71.9	-	-	-	-	-	-	-	-
225.3	-69.7	-	-	-	-	-	-	-	-
264.4	35.9	-792.4	-528.0	-2.7	0.4	-31.6	-29.1	-63.0	-591.0
264.4	39.0	-812.1	-547.7	-2.8	0.1	-31.6	-29.1	-63.4	-611.1
748.9	59.9	-957.6	-208.7	-3.3	-1.9	-31.6	-29.1	-65.9	-274.6
748.9	60.8	-964.0	-215.1	-3.3	-2.0	-31.6	-29.1	-66.0	-281.1
1033.6	72.6	-1054.8	-21.2	-3.6	-3.2	-31.6	-29.1	-67.5	-88.7
1033.6	73.0	-1057.4	-23.8	-3.6	-3.2	-31.6	-29.1	-67.5	-91.3
1041.3	73.2	-1059.5	-18.2	-3.7	-3.3	-31.6	-29.1	-67.7	-85.9
1041.3	71.1	-1042.4	-1.1	-	-	-68.7	-64.7	-133.4	-134.5
770.1	61.6	-970.2	-200.1	-3.3	-2.1	-31.6	-29.1	-66.1	-266.2
770.1	59.7	-955.9	-185.8	-3.3	-1.9	-31.6	-29.1	-65.9	-251.7
294.1	-8.7	-543.4	-249.3	-	-	-137.4	-129.4	-266.8	-516.1
294.1	36.6	-796.8	-502.7	-2.7	0.3	-31.6	-29.1	-63.1	-565.8
250.8	-43.6	-393.8	-143.0	-	-	-87.2	-81.8	-169.0	-312.0
250.8	-58.4	-	-	-	-	-	-	-	-
660.5	53.8	-913.5	-253.0	-3.1	-1.3	-31.6	-29.1	-65.1	-318.1
660.5	56.7	-934.2	-273.7	-3.2	-1.6	-31.6	-29.1	-65.5	-399.2
15425.5	-	-17189.9	-3997.5	-52.1	-28.6	-798.9	-741.5	-1459.7	-5618.6

Orbit Data: Case No. (Table 2-3) : IU-6C
Type of Orbit and Orientation: Synchronous Earth Orbit, X axis tangent to fli
Orbital Altitude, N. Mi. : 19,327
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	178.5	2.4	-599.0	-420.5	12.4	1.2	58.5	2.8	74.
2	178.5	1.2	-592.5	-414.0	12.6	1.2	58.5	2.8	75.
3	176.8	-63.3	-	-	-	-	-	-	-
4	176.8	1.0	-591.8	-415.0	12.6	1.2	58.5	2.8	75.
5	129.2	-0.1	-585.9	-456.7	12.8	1.3	58.5	2.8	75.
6	129.2	-83.5	-	-	-	-	-	-	-
7	45.1	-118.4	-	-	-	-	-	-	-
8	45.1	-109.8	-	-	-	-	-	-	-
9	52.7	-5.9	-557.0	-504.3	13.8	1.4	58.5	2.8	76.
10	52.7	-3.7	-567.8	-515.1	13.4	1.4	58.5	2.8	76.
11	149.6	1.0	-591.5	-441.9	12.6	1.2	58.5	2.8	75.
12	149.6	1.1	-592.3	-442.7	12.6	1.2	58.5	2.8	75.
13	206.6	3.8	-606.3	-399.7	12.1	1.2	58.5	2.8	74.
14	206.6	3.9	-606.5	-399.9	12.1	1.2	58.5	2.8	74.
15	208.3	2.7	-600.4	-392.1	12.3	1.2	58.5	2.8	74.
16	208.3	-59.6	-336.5	-128.2	-	-	130.3	6.2	136.
17	153.9	0.0	-586.6	-432.7	12.8	1.3	58.5	2.8	75.
18	153.9	-0.3	-585.0	-431.1	12.8	1.3	58.5	2.8	75.
19	58.7	-76.4	-283.3	-224.6	-	-	260.6	12.4	273.
20	58.7	-7.2	-550.8	-492.1	14.0	1.5	58.5	2.8	76.
21	50.2	-114.5	-186.5	-136.3	-	-	165.1	7.8	172.
22	50.2	-107.3	-	-	-	-	-	-	-
23	131.8	-2.0	-576.6	-444.8	13.0	1.3	58.5	2.8	75.
24	131.8	0.2	-587.4	-455.6	12.7	1.3	58.5	2.8	75.
Totals	3085.1	-	-10183.6	-7544.7	204.7	20.2	1492.0	71.2	1788.
1	892.5	36.5	-796.5	96.0	5.6	0.1	58.5	2.8	67.
2	892.5	37.0	-799.4	93.1	5.5	0.1	58.5	2.8	66.
3	885.7	49.5	-	-	-	-	-	-	-
4	885.7	36.5	-796.1	89.6	5.6	0.1	58.5	2.8	67.
5	646.0	25.4	-727.2	-81.2	7.9	0.5	58.5	2.8	69.
6	646.0	-14.2	-	-	-	-	-	-	-
7	225.3	-56.7	-	-	-	-	-	-	-
8	225.3	-57.7	-	-	-	-	-	-	-
9	264.4	5.5	-614.9	-350.5	11.8	1.1	58.5	2.8	74.
10	264.4	7.2	-624.1	-359.7	11.5	1.1	58.5	2.8	73.
11	748.9	29.6	-752.8	-3.9	7.1	0.4	58.5	2.8	68.
12	748.9	30.3	-757.1	-8.2	6.9	0.3	58.5	2.8	68.
13	1033.6	43.0	-838.7	194.9	4.1	-0.1	58.5	2.8	65.
14	1033.6	43.3	-840.5	193.1	4.0	-0.1	58.5	2.8	65.
15	1041.3	44.0	-845.3	196.0	3.9	-0.1	58.5	2.8	65.
16	1041.3	62.7	-977.9	63.4	-	-	130.3	6.2	136.
17	770.1	31.7	-765.6	4.5	6.6	0.3	58.5	2.8	68.
18	770.1	29.8	-754.3	15.8	7.0	0.4	58.5	2.8	68.
19	294.1	-30.9	-444.2	-150.1	-	-	260.6	12.4	273.
20	294.1	6.1	-618.3	-324.2	11.7	1.1	58.5	2.8	74.
21	250.8	-57.2	-344.6	-93.8	-	-	165.1	7.8	172.
22	250.8	-50.8	-	-	-	-	-	-	-
23	660.5	24.4	-721.2	-60.7	8.1	0.5	58.5	2.8	69.
24	660.5	26.1	-731.3	-70.8	7.8	0.5	58.5	2.8	69.
Totals	15425.5	-	-13749.9	-557.5	115.1	6.1	1492.0	71.2	1684.

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Angle of Inclination (Degrees): 0

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
9	-345.6	178.5	24.2	-719.9	-541.4	8.2	0.5	0	-6.1	2.6	-538.8
1	-338.9	178.5	22.6	-710.7	-532.2	8.5	0.6	0	-6.1	3.0	-529.2
	-	176.8	-59.2	-	-	-	-	-	-	-	-
1	-339.9	176.8	22.5	-709.9	-533.1	8.5	0.6	0	-6.1	3.0	-530.1
4	-381.3	129.2	21.6	-705.0	-575.8	8.7	0.6	0	-6.1	3.2	-572.6
	-	129.2	-80.3	-	-	-	-	-	-	-	-
	-	45.1	-117.6	-	-	-	-	-	-	-	-
	-	45.1	-106.9	-	-	-	-	-	-	-	-
5	-427.8	52.7	15.8	-671.4	-618.7	9.9	0.8	0	-6.1	4.6	-614.1
1	-439.0	52.7	18.3	-685.4	-632.7	9.4	0.7	0	-6.1	4.0	-628.7
1	-366.8	149.6	22.8	-711.6	-562.0	8.5	0.6	0	-6.1	3.0	-559.0
1	-367.6	149.6	22.9	-712.5	-562.9	8.4	0.6	0	-6.1	2.9	-560.0
6	-325.1	206.6	25.5	-728.0	-521.4	7.9	0.5	0	-6.1	2.3	-519.1
6	-325.3	206.6	25.5	-728.1	-521.5	7.9	0.5	0	-6.1	2.3	-519.2
8	-317.3	208.3	24.2	-720.1	-511.8	8.2	0.5	0	-6.1	2.6	-509.2
5	8.3	208.3	-48.4	-376.0	-167.7	-	-	0	-13.5	-13.5	-181.2
4	-357.3	153.9	21.6	-704.9	-551.0	8.7	0.6	0	-6.1	3.2	-547.8
4	-355.7	153.9	21.4	-703.8	-549.9	8.7	0.6	0	-6.1	3.2	-546.7
0	-48.4	58.7	-58.9	-339.0	-280.3	-	-	0	-27.0	-27.0	-307.3
8	-415.3	58.7	14.6	-664.9	-606.2	10.1	0.8	0	-6.1	4.8	-601.4
9	36.6	50.2	-102.0	-214.9	-164.7	-	-	0	-17.2	-17.2	-181.9
	-	50.2	-103.2	-	-	-	-	-	-	-	-
7	-369.1	131.8	19.6	-693.1	-561.3	9.1	0.7	0	-6.1	3.7	-557.6
3	-380.3	131.8	22.0	-707.2	-575.4	8.6	0.6	0	-6.1	3.1	-572.3
1	-5756.6	3085.1	-	-12206.4	-9567.5	139.4	9.9	0	-155.3	6.0	-9573.5
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
)	163.0	892.7	56.9	-935.2	-42.5	0.8	-0.6	0	-6.1	-5.9	-48.4
)	160.0	892.7	56.9	-935.8	-43.1	0.8	-0.6	0	-6.1	-5.9	-49.0
	-	885.7	51.5	-	-	-	-	-	-	-	-
)	156.6	885.7	56.4	-932.2	-46.5	0.9	-0.6	0	-6.1	-5.8	-52.3
	-11.5	646.0	46.1	-859.6	-213.6	3.4	-0.2	0	-6.1	-2.9	-216.5
	-	646.0	16.0	-	-	-	-	-	-	-	-
	-	225.3	-56.3	-	-	-	-	-	-	-	-
	-	225.3	-55.8	-	-	-	-	-	-	-	-
	-276.3	264.4	26.7	-735.0	-470.6	7.7	0.5	0	-6.1	2.1	-468.5
	-285.8	264.4	28.7	-747.4	-483.0	7.2	0.4	0	-6.1	1.5	-481.5
	64.9	748.9	50.2	-887.9	-139.0	2.4	-0.4	0	-6.1	-4.1	-143.1
	60.3	748.9	50.9	-892.6	-143.7	2.3	-0.4	0	-6.1	-4.2	-147.9
	260.2	1033.6	63.0	-980.8	52.8	-0.8	-0.9	0	-6.1	-7.8	45.0
	258.3	1033.6	63.3	-982.7	50.9	-0.8	-0.9	0	-6.1	-7.8	43.1
	261.1	1041.3	63.7	-985.8	55.5	-1.0	-0.9	0	-6.1	-8.0	47.5
	199.9	1041.3	68.2	-1020.3	21.0	-	-	0	-13.5	-13.5	7.5
	72.7	770.1	51.9	-899.7	-129.6	2.0	-0.4	0	-6.1	-4.5	-134.1
	84.5	770.1	50.3	-888.4	-118.3	2.4	-0.4	0	-6.1	-4.1	-122.4
	122.9	294.1	-17.6	-501.8	-207.7	-	-	0	-27.0	-27.0	-234.7
	-250.1	294.1	27.2	-738.4	-444.3	7.6	0.4	0	-6.1	1.9	-442.4
	79.1	250.8	-48.6	-374.9	-124.1	-	-	0	-17.2	-17.2	-141.3
	-	250.8	-48.3	-	-	-	-	-	-	-	-
	9.2	660.5	44.8	-851.1	-190.6	3.7	-0.2	0	-6.1	-2.6	-193.2
	-1.2	660.5	46.8	-864.5	-204.0	3.2	-0.2	0	-6.1	-3.1	-207.1
	1126.9	15425.5	-	-16014.0	-2821.6	41.7	-5.5	0	-155.3	-119.1	-2940.7

e 4-24. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
178.5	34.7	-785.0	-606.5	6.0	0.2	-33.3	-11.1	-38.2	-644.7
178.5	33.0	-774.3	-595.8	6.3	0.2	-33.3	-11.1	-37.9	-633.7
176.8	-57.3	-	-	-	-	-	-	-	-
176.8	32.9	-773.5	-596.7	6.4	0.2	-33.3	-11.1	-37.8	-634.5
129.2	32.2	-769.2	-640.0	6.5	0.3	-33.3	-11.1	-37.6	-677.6
129.2	-78.7	-	-	-	-	-	-	-	-
45.1	-117.2	-	-	-	-	-	-	-	-
45.1	-105.5	-	-	-	-	-	-	-	-
52.7	26.4	-733.1	-680.4	7.7	0.5	-33.3	-11.1	-36.2	-716.6
52.7	29.0	-749.0	-696.3	7.2	0.4	-33.3	-11.1	-36.8	-733.1
149.6	33.4	-776.4	-626.8	6.2	0.2	-33.3	-11.1	-38.0	-664.8
149.6	33.5	-777.3	-627.7	6.2	0.2	-33.3	-11.1	-38.0	-665.7
206.6	36.1	-793.5	-586.9	5.7	0.1	-33.3	-11.1	-38.6	-625.5
206.6	36.1	-793.6	-587.0	5.7	0.1	-33.3	-11.1	-38.6	-625.6
208.3	34.7	-784.6	-576.3	6.0	0.2	-33.3	-11.1	-38.2	-614.5
208.3	-42.5	-397.7	-189.4	-	-	-74.2	-24.7	-98.9	-288.3
153.9	32.2	-768.7	-614.8	6.5	0.3	-33.3	-11.1	-37.6	-652.4
153.9	32.0	-767.9	-614.0	6.5	0.3	-33.3	-11.1	-37.6	-651.6
58.7	-49.9	-370.2	-311.5	-	-	-148.4	-49.4	-197.8	-509.3
58.7	25.3	-726.6	-667.9	8.0	0.5	-33.3	-11.1	-35.9	-703.8
50.2	-95.5	-230.9	-180.7	-	-	94.0	-31.4	-125.4	-306.1
50.2	-101.1	-	-	-	-	-	-	-	-
131.8	30.1	-755.9	-624.1	7.0	0.3	-33.3	-11.1	-37.1	-661.2
131.8	32.6	-771.7	-639.9	6.4	0.3	-33.3	-11.1	-37.7	-677.6
3085.1	-	-13299.1	-10660.2	104.2	4.4	-849.4	-283.1	-1023.9	-11684.1
892.7	66.8	-1009.0	-116.3	-1.7	-1.0	-33.3	-11.1	-47.1	-163.4
892.7	66.7	-1008.3	-115.6	-1.7	-1.0	-33.3	-11.1	-47.1	-162.7
885.7	52.5	-	-	-	-	-	-	-	-
885.7	66.2	-1004.6	-118.9	-1.6	-1.0	-33.3	-11.1	-47.0	-165.9
646.0	56.2	-930.2	-284.2	1.0	-0.6	-33.3	-11.1	-44.0	-328.2
646.0	16.9	-	-	-	-	-	-	-	-
225.3	-56.2	-	-	-	-	-	-	-	-
225.3	-54.8	-	-	-	-	-	-	-	-
264.4	37.0	-799.5	-535.1	5.5	0.1	-33.3	-11.1	-38.8	-573.9
264.4	39.2	-813.7	-549.3	5.0	0	-33.3	-11.1	-39.4	-588.7
748.9	60.3	-960.0	-211.1	-0.1	-0.8	-33.3	-11.1	-45.3	-256.4
748.9	60.9	-964.8	-215.9	-0.2	-0.8	-33.3	-11.1	-45.4	-261.3
1033.6	72.8	-1056.3	-22.7	-3.4	-1.3	-33.3	-11.1	-49.1	-71.8
1033.6	73.1	-1058.1	-24.5	-3.4	-1.3	-33.3	-11.1	-49.1	-73.6
1041.3	73.3	-1060.4	-19.1	-3.5	-1.3	-33.3	-11.1	-49.2	-68.3
1041.3	71.2	-1043.4	-2.1	-	-	-74.2	-24.7	-98.9	-101.0
770.1	61.8	-971.2	-201.1	-0.4	-0.8	-33.3	-11.1	-45.6	-246.7
770.1	60.2	-959.9	-189.8	-0.1	-0.8	-33.3	-11.1	-45.3	-235.1
294.1	-10.6	-534.0	-239.9	-	-	-148.4	-49.4	-197.8	-437.7
294.1	37.6	-803.0	-508.9	5.3	0.1	-33.3	-11.1	-39.0	-547.9
250.8	-44.1	-391.8	-141.0	-	-	-94.0	-31.4	-125.4	-266.4
250.8	-47.0	-	-	-	-	-	-	-	-
660.5	54.8	-920.4	-259.9	1.3	-0.6	-33.3	-11.1	-43.7	-303.6
660.5	56.9	-935.6	-275.1	0.8	-0.6	-33.3	-11.1	-44.2	-319.3
15425.5	-	-17224.2	-4031.8	2.6	-11.9	-849.4	-283.1	-1141.8	-5173.6

Orbit Data: Case No. (Table 2-3) : IU - 6c
Type of Orbit and Orientation: Synchronous Earth Orbit, X-axis tangent to flig
Orbital Altitude, N. Mi. : 19,327
Launch Date : March 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	178.5	0.9	-590.9	-412.4	-18.6	1.2	-203.3	2.8	-217.
2	178.5	-0.9	-581.9	-403.4	-18.3	1.3	-203.3	2.8	-217.
3	176.8	-92.1	-	-	-	-	-	-	-
4	176.8	-1.0	-581.2	-404.4	-18.2	1.3	-203.3	2.8	-217.
5	129.2	-1.8	-577.6	-448.4	-18.1	1.3	-203.3	2.8	-217.
6	129.2	-123.6	-	-	-	-	-	-	-
7	45.1	-177.1	-	-	-	-	-	-	-
8	45.1	-159.5	-	-	-	-	-	-	-
9	52.7	-8.4	-544.9	-492.2	-17.0	1.5	-203.3	2.8	-216.
10	52.7	-5.3	-559.9	-507.2	-17.5	1.4	-203.3	2.8	-216.
11	149.6	-0.6	-583.5	-433.9	-18.3	1.3	-203.3	2.8	-217.
12	149.6	-0.4	-584.3	-434.7	-18.3	1.3	-203.3	2.8	-217.
13	206.6	2.3	-598.3	-391.7	-18.8	1.2	-203.3	2.8	-218.
14	206.6	2.3	-598.5	-391.9	-18.8	1.2	-203.3	2.8	-218.
15	208.3	1.2	-592.5	-384.2	-18.6	1.2	-203.3	2.8	-217.
16	208.3	-59.9	-335.6	-127.3	-	-	-452.6	6.2	-446.
17	153.9	-1.5	-578.8	-424.9	-18.2	1.3	-203.3	2.8	-217.
18	153.9	-1.8	-577.2	-423.3	-18.1	1.3	-203.3	2.8	-217.
19	58.7	-76.7	-282.5	-223.8	-	-	-905.2	12.4	-892.
20	58.7	-8.8	-543.0	-484.3	-16.9	1.5	-203.3	2.8	-215.
21	50.2	-119.6	-175.6	-125.4	-	-	-573.5	7.8	-565.
22	50.2	-147.8	-	-	-	-	-	-	-
23	131.8	-4.3	-565.1	-433.3	-17.7	1.4	-203.3	2.8	-216.
24	131.8	-1.4	-579.5	-447.7	-18.2	1.3	-203.3	2.8	-217.
Totals	3085.1	-	-10030.7	-7391.8	-289.6	21.0	-5184.1	71.2	-5381.
1	892.5	35.1	-787.2	105.3	-25.3	0.2	-203.3	2.8	-225.
2	892.5	35.3	-788.5	104.0	-25.4	0.2	-203.3	2.8	-225.
3	885.7	35.4	-	-	-	-	-	-	-
4	885.7	34.8	-785.2	100.5	-25.2	0.2	-203.3	2.8	-225.
5	646.0	23.8	-718.0	-72.0	-22.9	0.5	-203.3	2.8	-222.
6	646.0	-4.9	-	-	-	-	-	-	-
7	225.3	-89.0	-	-	-	-	-	-	-
8	225.3	-88.6	-	-	-	-	-	-	-
9	264.4	3.4	-603.8	-339.4	-19.0	1.2	-203.3	2.8	-218.
10	264.4	5.6	-615.9	-351.5	-19.4	1.1	-203.3	2.8	-218.
11	748.9	28.1	-743.8	5.1	-23.8	0.4	-203.3	2.8	-223.
12	748.9	28.8	-748.1	0.8	-24.0	0.4	-203.3	2.8	-224.
13	1033.6	41.6	-829.2	204.4	-26.8	-0.1	-203.3	2.8	-227.
14	1033.6	41.8	-831.0	202.6	-26.8	-0.1	-203.3	2.8	-227.
15	1041.3	42.6	-835.9	205.4	-27.0	-0.1	-203.3	2.8	-227.
16	1041.3	62.5	-976.9	64.4	-	-	-452.6	6.2	-446.
17	770.1	30.2	-756.7	13.4	-24.3	0.3	-203.3	2.8	-224.
18	770.1	28.4	-745.5	24.6	-23.9	0.4	-203.3	2.8	-224.
19	294.1	-31.1	-443.3	-149.2	-	-	-905.2	12.4	-892.
20	294.1	4.6	-610.2	-316.1	-19.2	1.1	-203.3	2.8	-218.
21	250.8	-59.6	-336.4	-85.6	-	-	-573.5	7.8	-565.
22	250.8	-77.3	-	-	-	-	-	-	-
23	660.5	22.4	-709.6	-49.1	-22.6	0.6	-203.3	2.8	-222.
24	660.5	24.6	-722.3	-61.8	-23.1	0.5	-203.3	2.8	-223.
Totals	15425.5	-	-13587.4	-395.0	-378.8	6.9	-5184.1	71.2	-5484.

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Angle of Inclination (Degrees): 0

	Coldplate/Electrical Component Temperature = 60 F										
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
Total Heat Gain or Loss (-) Btu/hr		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	Total Heat Gain or Loss (-) Btu/hr
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$											
9	-630.3	178.5	22.7	-711.0	-532.5	-22.7	0.6	-261.8	-6.1	-290.0	-822.5
5	-620.9	178.5	20.6	-699.0	-520.5	-22.3	0.7	-261.8	-6.1	-289.5	-810.0
	-	176.8	-87.2	-	-	-	-	-	-	-	-
4	-621.8	176.8	20.5	-698.3	-521.5	-22.3	0.7	-261.8	-6.1	-289.5	-811.0
3	-665.7	129.2	20.1	-696.0	-566.8	-22.2	0.7	-261.8	-6.1	-289.4	-856.2
	-	129.2	-119.4	-	-	-	-	-	-	-	-
	-	45.1	-175.6	-	-	-	-	-	-	-	-
	-	45.1	-155.4	-	-	-	-	-	-	-	-
0	-708.2	52.7	13.4	-658.1	-605.4	-20.9	0.9	-261.8	-6.1	-287.9	-893.3
5	-723.8	52.7	16.7	-676.7	-624.0	-21.5	0.8	-261.8	-6.1	-288.6	-912.6
5	-651.4	149.6	21.3	-702.9	-553.3	-22.4	0.6	-261.8	-6.1	-289.7	-843.0
5	-652.2	149.6	21.4	-703.7	-554.1	-22.4	0.6	-261.8	-6.1	-289.7	-843.8
1	-609.8	206.6	24.0	-719.1	-512.5	-23.0	0.5	-261.8	-6.1	-290.4	-802.9
1	-610.0	206.6	24.1	-719.3	-512.7	-23.0	0.5	-261.8	-6.1	-290.4	-803.1
9	-602.1	208.3	22.7	-711.5	-503.2	-22.7	0.6	-261.8	-6.1	-290.0	-793.2
4	-573.7	208.3	-48.6	-375.1	-166.8	-	-	-582.9	-13.5	-596.4	-763.2
4	-642.3	153.9	20.2	-696.4	-542.5	-22.2	0.7	-261.8	-6.1	-289.4	-831.9
3	-640.6	153.9	20.0	-695.2	-541.3	-22.2	0.7	-261.8	-6.1	-289.4	-830.7
3	-1116.6	58.7	-59.1	-338.1	-279.4	-	-	-1165.8	-27.0	-1192.8	-1472.2
9	-700.2	58.7	13.1	-656.3	-597.6	-20.8	0.9	-261.8	-6.1	-287.8	-885.4
7	-691.1	50.2	-106.6	-204.1	-153.9	-	-	-738.5	-17.2	-755.7	-909.6
	-	50.2	-142.3	-	-	-	-	-	-	-	-
3	-650.1	131.8	17.4	-680.6	-548.8	-21.6	0.8	-261.8	-6.1	-288.7	-837.5
4	-665.1	131.8	20.5	-698.3	-566.5	-22.3	0.7	-261.8	-6.1	-289.5	-856.0
5	-12773.3	3085.1	-	-12039.7	-9400.8	-354.4	10.8	-6676.0	-155.3	-7174.9	-16575.7
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$											
5	-120.3	892.5	55.5	-925.1	-32.6	-30.1	-0.6	-261.8	-6.1	-298.6	-331.2
7	-121.7	892.5	55.3	-924.0	-31.5	-30.0	-0.6	-261.8	-6.1	-298.5	-330.0
	-	885.7	37.6	-	-	-	-	-	-	-	-
5	-125.0	885.7	54.8	-920.4	-34.7	-29.9	-0.6	-261.8	-6.1	-298.4	-333.1
9	-294.9	646.0	44.6	-849.6	-203.6	-27.5	-0.2	-261.8	-6.1	-295.6	-499.2
	-	646.0	-2.9	-	-	-	-	-	-	-	-
	-	225.3	-88.5	-	-	-	-	-	-	-	-
	-	225.3	-86.2	-	-	-	-	-	-	-	-
3	-557.7	264.4	24.7	-722.9	-458.5	-23.1	0.5	-261.8	-6.1	-290.5	-749.0
3	-570.3	264.4	27.2	-738.4	-474.0	-23.6	0.4	-261.8	-6.1	-291.1	-765.1
9	-218.8	748.9	48.8	-878.2	-129.3	-28.4	-0.3	-261.8	-6.1	-296.6	-425.9
1	-223.3	748.9	49.5	-882.8	-133.9	-28.6	-0.3	-261.8	-6.1	-296.8	-430.7
4	-23.0	1033.6	61.7	-970.6	63.0	-31.6	-0.8	-261.8	-6.1	-300.3	-237.3
4	-24.8	1033.6	61.9	-972.4	61.2	-31.7	-0.8	-261.8	-6.1	-300.4	-239.2
5	-22.2	1041.3	62.4	-975.7	65.6	-31.8	-0.9	-261.8	-6.1	-300.6	-235.0
4	-382.0	1041.3	68.1	-1019.3	22.0	-	-	-582.9	-13.5	-596.4	-574.4
5	-211.1	770.1	50.5	-890.1	-120.0	-28.9	-0.4	-261.8	-6.1	-297.2	-417.2
0	-199.4	770.1	48.9	-878.8	-108.7	-28.5	-0.3	-261.8	-6.1	-296.7	-405.4
3	-1042.0	294.1	-17.8	-501.0	-206.9	-	-	-1165.8	-27.0	-1192.8	-1399.7
5	-534.7	294.1	25.8	-729.6	-435.5	-23.3	0.5	-261.8	-6.1	-290.7	-726.2
7	-651.3	250.8	-50.9	-366.8	-116.0	-	-	-738.5	-17.2	-755.7	-871.7
	-	250.8	-74.2	-	-	-	-	-	-	-	-
5	-271.6	660.5	43.0	-838.6	-178.1	-27.1	-0.1	-261.8	-6.1	-295.1	-473.2
1	-284.9	660.5	45.4	-854.8	-194.3	-27.6	-0.2	-261.8	-6.1	-295.7	-490.0
3	-5879.8	15425.5	-	-15838.8	-2646.4	-451.7	-4.6	-6676.0	-155.3	-7287.6	-9934.0

4-25. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
178.5	33.3	-775.7	-597.2	-24.9	0.2	-295.1	-11.1	-330.9	-928.1
178.5	31.3	-762.2	-583.7	-24.5	0.3	-295.1	-11.1	-330.4	-914.1
176.8	-84.9	-	-	-	-	-	-	-	-
176.8	31.0	-761.4	-584.6	-24.4	0.3	-295.1	-11.1	-330.3	-914.9
129.2	30.7	-759.8	-630.6	-24.4	0.3	-295.1	-11.1	-330.3	-960.9
129.2	-117.3	-	-	-	-	-	-	-	-
45.1	-174.8	-	-	-	-	-	-	-	-
45.1	-153.4	-	-	-	-	-	-	-	-
52.7	24.1	-719.3	-666.6	-23.0	0.5	-295.1	-11.1	-328.7	-995.3
52.7	27.5	-739.9	-687.2	-23.7	0.4	-295.1	-11.1	-329.5	-1016.7
149.6	31.9	-767.3	-617.7	-24.6	0.3	-295.1	-11.1	-330.5	-948.2
149.6	32.1	-768.1	-618.5	-24.7	0.3	-295.1	-11.1	-330.6	-949.1
206.6	34.6	-784.2	-577.6	-25.2	0.2	-295.1	-11.1	-331.2	-908.8
206.6	34.6	-784.4	-577.8	-25.2	0.2	-295.1	-11.1	-331.2	-909.0
208.3	33.3	-775.6	-567.3	-24.9	0.2	-295.1	-11.1	-330.9	-898.2
208.3	-42.8	-396.8	-188.5	-	-	-657.1	-24.7	-681.8	-870.3
153.9	30.7	-759.8	-605.9	-24.4	0.3	-295.1	-11.1	-330.3	-936.2
153.9	30.6	-758.9	-605.0	-24.3	0.3	-295.1	-11.1	-330.2	-935.2
58.7	-50.2	-369.4	-310.7	-	-	-1314.2	-49.4	-1363.6	-1674.3
58.7	23.8	-717.6	-658.9	-22.9	0.6	-295.1	-11.1	-328.5	-987.4
50.2	-99.9	-220.1	-169.9	-	-	-832.5	-31.4	-863.9	-1033.8
50.2	-139.6	-	-	-	-	-	-	-	-
131.8	28.0	-742.9	-611.1	-23.8	0.4	-295.1	-11.1	-329.6	-940.7
131.8	31.2	-762.5	-630.7	-24.5	0.3	-295.1	-11.1	-330.4	-961.1
3085.1	-	-13125.8	-10486.9	-389.4	5.2	-7525.4	-283.1	-8192.7	-18679.6
892.5	65.4	-998.5	-106.0	-32.6	-1.0	-295.1	-11.1	-339.8	-445.8
892.5	65.1	-996.1	-103.6	-32.5	-1.0	-295.1	-11.1	-339.7	-443.3
885.7	38.7	-	-	-	-	-	-	-	-
885.7	64.6	-992.4	-106.7	-32.4	-0.9	-295.1	-11.1	-339.5	-446.2
646.0	54.7	-919.8	-273.8	-29.9	-0.5	-295.1	-11.1	-336.6	-610.4
646.0	-1.9	-	-	-	-	-	-	-	-
225.3	-88.3	-	-	-	-	-	-	-	-
225.3	-85.0	-	-	-	-	-	-	-	-
264.4	35.0	-786.9	-522.5	-25.3	0.2	-295.1	-11.1	-331.3	-853.8
264.4	37.8	-804.3	-539.9	-25.9	0.1	-295.1	-11.1	-332.0	-871.9
748.9	58.9	-949.9	-201.0	-30.9	-0.7	-295.1	-11.1	-337.8	-538.8
748.9	59.5	-954.6	-205.7	-31.1	-0.7	-295.1	-11.1	-338.0	-543.7
1033.6	71.5	-1045.6	-12.0	-34.2	-1.2	-295.1	-11.1	-341.6	-353.6
1033.6	71.7	-1047.5	-13.9	-34.3	-1.2	-295.1	-11.1	-341.7	-355.6
1041.3	72.0	-1049.9	-8.6	-34.4	-1.3	-295.1	-11.1	-341.9	-350.5
1041.3	71.1	-1042.5	-1.2	-	-	-657.1	-24.7	-681.8	-683.0
770.1	60.4	-961.2	-191.1	-31.3	-0.8	-295.1	-11.1	-338.3	-529.4
770.1	58.9	-949.9	-179.8	-30.9	-0.7	-295.1	-11.1	-337.8	-517.6
294.1	-10.8	-533.2	-239.1	-	-	-1314.2	-49.4	-1363.6	-1602.7
294.1	36.1	-793.8	-499.7	-25.5	0.1	-295.1	-11.1	-331.6	-831.3
250.8	-46.3	-383.6	-132.8	-	-	-832.5	-31.4	-863.9	-996.7
250.8	-72.7	-	-	-	-	-	-	-	-
660.5	53.0	-907.5	-247.0	-29.5	-0.5	-295.1	-11.1	-336.2	-583.2
660.5	55.5	-925.5	-265.0	-30.1	-0.6	-295.1	-11.1	-336.9	-601.9
15425.5	-	-17042.8	-3850.4	-490.6	-10.8	-7525.4	-283.1	-8309.9	-12160.3

Orbit Data: Case No. (Table 2-3) : IU-7a
Type of Orbit and Orientation: Circular Earth orbit, X axis tangent to flight pat
Orbital Altitude, N. Mi. : 100
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	545.7	19.9	-694.9	-149.2	1.0	1.7	6.3	7.3	16.3
2	545.7	19.5	-692.8	-147.1	1.0	1.7	6.3	7.3	16.3
3	548.3	0.1	-	-	-	-	-	-	-
4	548.3	19.5	-692.7	-144.4	1.0	1.7	6.3	7.3	16.3
5	439.5	14.7	-665.3	-225.8	1.1	2.1	6.3	7.3	16.8
6	439.5	-24.2	-	-	-	-	-	-	-
7	293.3	-56.9	-	-	-	-	-	-	-
8	293.3	-54.4	-	-	-	-	-	-	-
9	229.5	3.1	-602.6	-373.1	1.3	2.9	6.3	7.3	17.8
10	229.5	4.5	-609.9	-380.4	1.3	2.8	6.3	7.3	17.7
11	211.7	3.7	-605.7	-394.0	1.3	2.9	6.3	7.3	17.8
12	211.7	3.7	-605.6	-393.9	1.3	2.9	6.3	7.3	17.8
13	215.9	3.9	-606.7	-390.8	1.3	2.9	6.3	7.3	17.8
14	215.9	3.8	-606.4	-390.5	1.3	2.9	6.3	7.3	17.8
15	198.9	1.5	-594.4	-395.5	1.3	3.0	6.3	7.3	17.9
16	198.9	-59.3	-337.5	-138.6	-	-	13.6	16.2	29.8
17	164.9	-0.2	-585.6	-420.7	1.3	3.2	6.3	7.3	18.1
18	164.9	0.0	-586.4	-421.5	1.3	3.2	6.3	7.3	18.1
19	166.6	-53.1	-358.8	-192.2	-	-	27.2	32.4	59.6
20	166.6	-1.2	-580.4	-413.8	1.4	3.2	6.3	7.3	18.2
21	283.9	-50.5	-368.2	-84.3	-	-	17.3	20.4	37.7
22	283.9	-54.6	-	-	-	-	-	-	-
23	433.5	12.9	-655.4	-221.9	1.1	2.2	6.3	7.3	16.9
24	433.5	14.7	-665.3	-231.8	1.1	2.1	6.3	7.3	16.8
Totals	7463.4	-	-11114.7	-5509.6	19.1	41.4	158.9	185.8	405.2
1	873.8	35.4	-789.4	84.4	0.6	0.4	6.3	7.3	14.6
2	873.8	36.0	-792.8	81.0	0.6	0.4	6.3	7.3	14.6
3	885.7	47.7	-	-	-	-	-	-	-
4	885.7	36.3	-795.0	90.7	0.6	0.3	6.3	7.3	14.5
5	719.1	28.5	-746.2	-27.1	0.8	1.0	6.3	7.3	15.4
6	719.1	22.7	-	-	-	-	-	-	-
7	495.6	-10.1	-	-	-	-	-	-	-
8	495.6	-10.3	-	-	-	-	-	-	-
9	671.5	25.2	-726.0	-54.5	0.8	1.3	6.3	7.3	15.7
10	671.5	26.4	-733.3	-61.8	0.8	1.2	6.3	7.3	15.6
11	935.0	38.2	-807.1	127.9	0.5	0.2	6.3	7.3	14.3
12	935.0	38.7	-810.2	124.8	0.5	0.1	6.3	7.3	14.2
13	1079.5	45.0	-852.2	227.3	0.4	-0.5	6.3	7.3	13.5
14	1079.5	45.1	-852.8	226.7	0.4	-0.5	6.3	7.3	13.5
15	995.4	41.8	-831.0	164.4	0.5	-0.2	6.3	7.3	13.9
16	995.4	56.9	-935.8	59.6	-	-	13.6	16.2	29.8
17	703.0	28.4	-745.3	-42.3	0.8	1.0	6.3	7.3	15.4
18	703.0	26.4	-733.5	-30.5	0.8	1.2	6.3	7.3	15.6
19	357.0	-20.1	-490.6	-133.6	-	-	27.2	32.4	59.6
20	357.0	9.4	-635.8	-278.8	1.2	2.5	6.3	7.3	17.3
21	448.8	-17.4	-502.4	-53.6	-	-	17.3	20.4	37.7
22	448.8	-18.7	-	-	-	-	-	-	-
23	687.7	25.7	-729.3	-41.6	0.8	1.2	6.3	7.3	15.6
24	687.7	27.1	-737.4	-49.7	0.8	1.1	6.3	7.3	15.5
Totals	17702.6	-	-14246.1	411.7	10.9	10.7	158.9	185.8	366.3

Table

n

Angle of Inclination (Degrees): 29

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-132.9	545.7	41.0	-825.8	-280.1	0.5	-0.1	0	-15.9	-15.5	-295.6
-130.8	545.7	40.3	-820.6	-274.9	0.5	0	0	-15.9	-15.4	-290.3
-	548.3	3.8	-	-	-	-	-	-	-	-
-128.1	548.3	40.2	-820.4	-272.1	0.5	0	0	-15.9	-15.4	-287.5
-209.0	439.5	35.9	-792.2	-352.7	0.6	0.4	0	-15.9	-14.9	-367.6
-	439.5	-21.4	-	-	-	-	-	-	-	-
-	293.3	-56.2	-	-	-	-	-	-	-	-
-	293.3	-51.8	-	-	-	-	-	-	-	-
-355.3	229.5	24.5	-721.7	-492.2	0.9	1.3	0	-15.9	-13.7	-505.9
-362.7	229.5	26.3	-732.6	-503.1	0.8	1.2	0	-15.9	-13.9	-517.0
-376.2	211.7	25.5	-728.1	-516.4	0.8	1.2	0	-15.9	-13.9	-530.3
-376.1	211.7	25.5	-728.0	-516.3	0.8	1.2	0	-15.9	-13.9	-530.2
-373.0	215.9	25.7	-729.1	-513.2	0.8	1.2	0	-15.9	-13.9	-527.1
-372.7	215.9	25.6	-728.8	-512.9	0.8	1.2	0	-15.9	-13.9	-526.8
-377.6	198.9	23.2	-713.9	-515.0	0.9	1.4	0	-15.9	-13.6	-528.6
-108.8	198.9	-47.4	-379.5	-180.6	-	-	0	-35.4	-35.4	-216.0
-402.6	164.9	21.5	-704.2	-539.3	0.9	1.6	0	-15.9	-13.4	-552.7
-403.4	164.9	21.7	-705.5	-540.6	0.9	1.5	0	-15.9	-13.5	-554.1
-132.6	166.6	-37.5	-417.3	-250.7	-	-	0	-70.8	-70.8	-321.5
-395.6	166.6	20.2	-696.9	-530.3	0.9	1.7	0	-15.9	-13.3	-543.6
-46.6	283.9	-41.9	-400.1	-116.2	-	-	0	-44.7	-44.7	-160.9
-	283.9	-51.1	-	-	-	-	-	-	-	-
-205.0	433.5	33.9	-779.6	-346.1	0.6	0.5	0	-15.9	-14.8	-360.9
-215.0	433.5	36.1	-793.4	-359.9	0.6	0.3	0	-15.9	-15.0	-374.9
-5104.0	7463.4	-	-13217.9	-7612.8	12.0	14.7	0	-405.3	-378.6	-7991.5
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
99.0	873.8	55.9	-928.5	-54.7	0.1	-1.5	0	-15.9	-17.3	-72.0
95.6	873.8	56.0	-928.9	-55.1	0.1	-1.5	0	-15.9	-17.3	-72.4
-	885.7	50.5	-	-	-	-	-	-	-	-
105.2	885.7	56.3	-931.3	-45.6	0.1	-1.5	0	-15.9	-17.3	-62.9
-11.7	719.1	49.1	-880.3	-161.2	0.3	-0.8	0	-15.9	-16.4	-177.6
-	719.1	24.8	-	-	-	-	-	-	-	-
-	495.6	-9.7	-	-	-	-	-	-	-	-
-	495.6	-8.3	-	-	-	-	-	-	-	-
-38.8	671.5	45.6	-856.4	-184.9	0.4	-0.5	0	-15.9	-16.0	-200.9
-46.2	671.5	47.3	-867.6	-196.1	0.3	-0.7	0	-15.9	-16.3	-212.4
142.2	935.0	58.6	-947.8	-12.8	0	-1.7	0	-15.9	-17.6	-30.4
139.0	935.0	59.0	-951.1	-16.1	0	-1.8	0	-15.9	-17.7	-33.8
240.8	1079.5	65.1	-996.5	83.0	-0.1	-2.4	0	-15.9	-18.4	64.6
240.2	1079.5	65.2	-997.0	82.5	-0.1	-2.4	0	-15.9	-18.4	64.1
178.3	995.4	61.7	-970.8	24.6	0	-2.1	0	-15.9	-18.0	6.6
89.4	995.4	63.1	-981.3	14.1	-	-	0	-35.4	-35.4	-21.3
-26.9	703.0	48.8	-878.1	-175.1	0.3	-0.8	0	-15.9	-16.4	-191.5
-14.9	703.0	47.0	-866.1	-163.1	0.3	-0.6	0	-15.9	-16.2	-179.3
-74.0	357.0	-7.2	-550.6	-193.6	-	-	0	-70.8	-70.8	-264.4
-261.5	357.0	30.3	-757.3	-400.3	0.7	0.8	0	-15.9	-14.4	-414.7
-15.9	448.8	-10.4	-535.0	-86.2	-	-	0	-44.7	-44.7	-130.9
-	448.8	-16.0	-	-	-	-	-	-	-	-
-26.0	687.7	46.2	-860.1	-172.4	0.4	-0.6	0	-15.9	-16.1	-188.5
-34.2	687.7	47.9	-872.0	-184.3	0.3	-0.7	0	-15.9	-16.3	-200.6
779.6	17702.6	-	-16556.6	-1898.8	3.0	-18.8	0	-405.3	-421.1	-2318.3

4-26. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
545.7	51.3	-895.9	-350.2	0.2	-1.0	-3.6	-29.1	-33.5	-383.7
545.7	50.3	-888.9	-343.2	0.3	-0.9	-3.6	-29.1	-33.3	-376.5
548.3	5.6	-	-	-	-	-	-	-	-
548.3	50.3	-888.7	-340.4	0.3	-0.9	-3.6	-29.1	-33.3	-373.7
439.5	46.2	-860.3	-420.8	0.4	-0.6	-3.6	-29.1	-32.9	-453.7
439.5	-20.1	-	-	-	-	-	-	-	-
293.3	-55.9	-	-	-	-	-	-	-	-
293.3	-50.6	-	-	-	-	-	-	-	-
229.5	34.9	-785.7	-556.2	0.6	0.5	-3.6	-29.1	-31.6	-587.8
229.5	36.9	-798.7	-569.2	0.6	0.3	-3.6	-29.1	-31.8	-601.0
211.7	36.2	-794.0	-582.3	0.6	0.3	-3.6	-29.1	-31.8	-614.1
211.7	36.1	-793.9	-582.2	0.6	0.3	-3.6	-29.1	-31.8	-614.0
215.9	36.3	-795.1	-579.2	0.6	0.3	-3.6	-29.1	-31.8	-611.0
215.9	36.3	-794.7	-578.8	0.6	0.3	-3.6	-29.1	-31.8	-610.6
198.9	33.7	-778.3	-579.4	0.7	0.6	-3.6	-29.1	-31.4	-610.8
198.9	-41.3	-402.6	-203.7	-	-	-7.8	-64.7	-72.5	-276.2
164.9	32.1	-768.2	-603.3	0.7	0.7	-3.6	-29.1	-31.3	-634.6
164.9	32.3	-769.8	-604.9	0.7	0.7	-3.6	-29.1	-31.3	-636.2
166.6	-29.4	-450.1	-283.5	-	-	-15.6	-129.4	-145.0	-428.5
166.6	30.7	-759.7	-593.1	0.7	0.8	-3.6	-29.1	-31.2	-624.3
283.9	-37.4	-417.8	-133.9	-	-	-9.8	-81.8	-91.6	-225.5
283.9	-49.4	-	-	-	-	-	-	-	-
433.5	44.1	-846.2	-412.7	0.4	0.4	-3.6	-29.1	-32.7	-445.4
433.5	46.5	-862.2	-428.7	0.3	-0.6	-3.6	-29.1	-33.0	-461.7
7463.4	-	-14350.9	-8745.8	8.1	0.3	90.8	-741.5	-823.9	-9569.3
873.8	65.9	-1002.5	-128.7	-0.2	-2.5	-3.6	-29.1	-35.4	-164.1
873.8	65.8	-1001.3	-127.5	-0.2	-2.5	-3.6	-29.1	-35.4	-162.9
885.7	51.9	-	-	-	-	-	-	-	-
885.7	66.1	-1003.8	-118.1	-0.2	-2.5	-3.6	-29.1	-35.4	-153.5
719.1	59.1	-951.8	-232.7	0	-1.8	-3.6	-29.1	-34.5	-267.2
719.1	25.9	-	-	-	-	-	-	-	-
495.6	-9.5	-	-	-	-	-	-	-	-
495.6	-7.3	-	-	-	-	-	-	-	-
671.5	55.6	-926.0	-254.5	0.1	-1.5	-3.6	-29.1	-34.1	-288.6
671.5	57.4	-939.3	-267.8	0.1	-1.6	-3.6	-29.1	-34.2	-302.0
935.0	68.5	-1022.6	-87.6	-0.2	-2.8	-3.6	-29.1	-35.7	-123.3
935.0	69.0	-1026.1	-91.1	-0.2	-2.8	-3.6	-29.1	-35.7	-126.8
1079.5	74.9	-1073.0	6.5	-0.4	-3.4	-3.6	-29.1	-36.5	-30.0
1079.5	75.0	-1073.5	6.0	-0.4	-3.5	-3.6	-29.1	-36.6	-30.6
995.4	71.4	-1045.1	-49.7	-0.3	-3.1	-3.6	-29.1	-36.1	-85.8
995.4	66.4	-1006.1	-10.7	-	-	-7.8	-64.7	-72.5	-83.2
703.0	58.7	-948.9	-245.9	0	-1.8	-3.6	-29.1	-34.5	-280.4
703.0	57.1	-937.0	-234.0	0.1	-1.6	-3.6	-29.1	-34.2	-268.2
357.0	-0.5	-584.1	-227.1	-	-	-15.6	-129.4	-145.0	-372.1
357.0	40.5	-822.5	-465.5	0.5	0	-3.6	-29.1	-32.2	-497.7
448.8	-6.7	-553.1	-104.3	-	-	-9.8	-81.8	-91.6	-195.9
448.8	-14.6	-	-	-	-	-	-	-	-
687.7	56.1	-929.9	-242.2	0.1	-1.5	-3.6	-29.1	-34.1	-276.3
687.7	58.1	-943.9	-256.2	0.1	-1.7	-3.6	-29.1	-34.3	-290.5
17702.6	-	-17790.6	-3132.8	-1.1	-34.5	-90.8	-741.5	-859.5	-4000.7

Orbit Data: Case No. (Table 2-3) : IU-7a
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight pa
Orbital Altitude, N. Mi. : 100
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	545.7	19.7	-694.0	-148.3	-2.3	1.7	-21.7	7.3	-15.0
2	545.7	19.3	-691.7	-146.0	-2.3	1.7	-21.7	7.3	-15.0
3	548.3	-1.8	-	-	-	-	-	-	-
4	548.3	19.3	-691.6	-143.3	-2.3	1.7	-21.7	7.3	-15.0
5	439.5	14.5	-664.3	-224.8	-2.2	2.1	-21.7	7.3	-14.5
6	439.5	-26.7	-	-	-	-	-	-	-
7	293.3	-60.2	-	-	-	-	-	-	-
8	293.3	-57.5	-	-	-	-	-	-	-
9	229.5	2.9	-601.4	-371.9	-2.0	3.0	-21.7	7.3	-13.4
10	229.5	4.4	-609.1	-379.6	-2.0	2.8	-21.7	7.3	-13.6
11	211.7	3.6	-604.9	-393.2	-2.0	2.9	-21.7	7.3	-13.5
12	211.7	3.5	-604.8	-393.1	-2.0	2.9	-21.7	7.3	-13.5
13	215.9	3.7	-605.8	-389.9	-2.0	2.9	-21.7	7.3	-13.5
14	215.9	3.7	-605.5	-389.6	-2.0	2.9	-21.7	7.3	-13.5
15	198.9	1.4	-593.6	-394.7	-2.0	3.1	-21.7	7.3	-13.3
16	198.9	-59.3	-337.4	-138.5	-	-	-47.3	16.2	-31.1
17	164.9	-0.3	-584.8	-419.9	-1.9	3.2	-21.7	7.3	-13.1
18	164.9	-0.2	-585.5	-420.6	-1.9	3.2	-21.7	7.3	-13.1
19	166.6	-53.2	-358.7	-192.1	-	-	-94.6	32.4	-62.2
20	166.6	-1.4	-579.6	-413.0	-1.9	3.2	-21.7	7.3	-13.1
21	283.9	-50.8	-367.2	-83.3	-	-	-60.1	20.4	-39.7
22	283.9	-57.3	-	-	-	-	-	-	-
23	433.5	12.7	-654.1	-220.6	-2.2	2.2	-21.7	7.3	-14.4
24	433.5	14.6	-664.4	-230.9	-2.2	2.1	-21.7	7.3	-14.5
Totals	7464.4	-	-11098.4	-5493.3	-33.4	41.6	-549.2	185.8	-355.2
1	873.8	35.3	-788.4	85.4	-2.7	0.4	-21.7	7.3	-16.7
2	873.8	35.8	-791.6	82.2	-2.7	0.4	-21.7	7.3	-16.7
3	885.7	46.2	-	-	-	-	-	-	-
4	885.7	36.1	-793.8	91.9	-2.7	0.3	-21.7	7.3	-16.8
5	719.1	28.3	-745.2	-26.1	-2.5	1.0	-21.7	7.3	-15.9
6	719.1	20.8	-	-	-	-	-	-	-
7	495.6	-12.5	-	-	-	-	-	-	-
8	495.6	-12.5	-	-	-	-	-	-	-
9	671.5	25.0	-724.8	-53.3	-2.4	1.3	-21.7	7.3	-15.5
10	671.5	26.2	-732.3	-60.8	-2.5	1.2	-21.7	7.3	-15.7
11	935.0	38.0	-806.2	128.8	-2.7	0.2	-21.7	7.3	-16.9
12	935.0	38.5	-809.2	125.8	-2.7	0.1	-21.7	7.3	-17.0
13	1079.5	44.9	-851.2	228.3	-2.9	-0.4	-21.7	7.3	-17.7
14	1079.5	44.9	-851.8	227.7	-2.9	-0.4	-21.7	7.3	-17.7
15	995.4	41.7	-830.0	165.4	-2.8	-0.2	-21.7	7.3	-17.4
16	995.4	56.9	-935.7	59.7	-	-	-47.3	16.2	-31.1
17	703.0	28.2	-744.3	-41.3	-2.5	1.0	-21.7	7.3	-15.9
18	703.0	26.3	-732.5	-29.5	-2.5	1.2	-21.7	7.3	-15.7
19	357.0	-20.1	-490.4	-133.4	-	-	-94.6	32.4	-62.2
20	357.0	9.2	-635.0	-278.0	-2.1	2.5	-21.7	7.3	-14.0
21	448.8	-17.6	-501.5	-52.7	-	-	-60.1	20.4	-39.7
22	448.8	-20.8	-	-	-	-	-	-	-
23	687.7	25.5	-728.1	-40.4	-2.5	1.2	-21.7	7.3	-15.7
24	687.7	26.9	-736.4	-48.7	-2.5	1.1	-21.7	7.3	-15.8
Totals	17702.6	-	-14228.4	429.4	-41.6	10.9	-549.2	185.8	-394.1

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Angle of Inclination (Degrees): 29

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-163.3	545.7	40.9	-824.8	-279.1	-2.8	-0.1	-28.0	-15.9	-46.8	-325.9
-161.0	545.7	40.1	-819.3	-273.6	-2.8	0	-28.0	-15.9	-46.7	-320.3
-	548.3	1.9	-	-	-	-	-	-	-	-
-158.3	548.3	40.0	-819.2	-270.9	-2.8	0	-28.0	-15.9	-46.7	-317.6
-239.3	439.5	35.7	-791.2	-351.7	-2.7	0.4	-28.0	-15.9	-46.2	-397.9
-	439.5	-23.9	-	-	-	-	-	-	-	-
-	293.3	-59.5	-	-	-	-	-	-	-	-
-	293.3	-54.8	-	-	-	-	-	-	-	-
-385.3	229.5	24.2	-720.4	-490.9	-2.4	1.3	-28.0	-15.9	-45.0	-535.9
-393.2	229.5	26.1	-731.7	-502.2	-2.5	1.2	-28.0	-15.9	-45.2	-547.4
-406.7	211.7	25.4	-727.2	-515.5	-2.4	1.2	-28.0	-15.9	-45.1	-560.6
-406.6	211.7	25.4	-727.1	-515.4	-2.4	1.2	-28.0	-15.9	-45.1	-560.5
-403.4	215.9	25.5	-728.2	-512.3	-2.5	1.2	-28.0	-15.9	-45.2	-557.5
-403.1	215.9	25.5	-727.8	-511.9	-2.5	1.2	-28.0	-15.9	-45.2	-557.1
-408.0	198.9	23.0	-713.0	-514.1	-2.4	1.4	-28.0	-15.9	-44.9	-559.0
-169.6	198.9	-47.4	-379.4	-180.5	-	-	-60.9	-35.4	-96.3	-276.8
-433.0	164.9	21.3	-703.3	-538.4	-2.4	1.6	-28.0	-15.9	-44.7	-583.1
-433.7	164.9	21.6	-704.6	-539.7	-2.4	1.6	-28.0	-15.9	-44.7	-584.4
-254.3	166.6	-37.5	-417.2	-250.6	-	-	-121.8	-70.8	-192.6	-443.2
-426.1	166.6	20.1	-696.0	-529.4	-2.3	1.7	-28.0	-15.9	-44.5	-573.9
-123.0	283.9	-42.2	-399.1	-115.2	-	-	-77.4	-44.7	-122.1	-237.3
-	283.9	-53.8	-	-	-	-	-	-	-	-
-235.0	433.5	33.7	-778.3	-344.8	-2.6	0.6	-28.0	-15.9	-45.9	-390.7
-245.4	433.5	35.9	-792.4	-358.9	-2.7	0.4	-28.0	-15.9	-46.2	-405.1
-5848.5	7464.4	-	-13200.1	-7595.1	-40.5	14.9	-708.1	-405.3	-1139.0	-8734.0
Optical Properties of IU Outer Surface $\alpha = 0.90$ $\alpha/\epsilon = 1.0$										
68.7	873.8	55.8	-927.4	-53.6	-3.2	-1.5	-28.0	-15.9	-48.6	-102.2
65.5	873.8	55.8	-927.6	-53.8	-3.2	-1.5	-28.0	-15.9	-48.6	-102.4
-	885.7	49.0	-	-	-	-	-	-	-	-
75.1	885.7	56.1	-930.0	-44.3	-3.2	-1.5	-28.0	-15.9	-48.6	-92.9
-42.0	719.1	48.9	-879.2	-160.1	-3.0	-0.8	-28.0	-15.9	-47.7	-207.8
-	719.1	23.0	-	-	-	-	-	-	-	-
-	495.6	-12.1	-	-	-	-	-	-	-	-
-	495.6	-10.5	-	-	-	-	-	-	-	-
-68.8	671.5	45.4	-855.0	-183.5	-2.9	-0.5	-28.0	-15.9	-47.3	-230.8
-76.5	671.5	47.1	-866.6	-195.1	-3.0	-0.6	-28.0	-15.9	-47.5	-242.6
111.9	935.0	58.4	-946.7	-11.7	-3.2	-1.7	-28.0	-15.9	-48.8	-60.5
108.8	935.0	58.9	-950.0	-15.0	-3.3	-1.8	-28.0	-15.9	-49.0	-64.0
210.6	1079.5	65.0	-995.4	84.1	-3.4	-2.4	-28.0	-15.9	-49.7	34.4
210.0	1079.5	65.0	-995.9	83.6	-3.4	-2.4	-28.0	-15.9	-49.7	33.9
148.0	995.4	61.6	-969.8	25.6	-3.3	-2.0	-28.0	-15.9	-49.2	-23.6
28.6	995.4	63.1	-981.2	14.2	-	-	-60.9	-35.4	-96.3	-82.
-57.2	703.0	48.6	-877.1	-174.1	-3.0	-0.8	-28.0	-15.9	-47.7	-221.8
-45.2	703.0	46.9	-865.1	-162.1	-2.9	-0.6	-28.0	-15.9	-47.4	-209.
-195.6	357.0	-7.2	-550.5	-193.5	-	-	-121.8	-70.8	-192.6	-386.
-292.0	357.0	30.2	-756.3	-399.3	-2.6	-0.8	-28.0	-15.9	-45.7	-445.
-92.4	448.8	-10.6	-534.1	-85.3	-	-	-77.4	-44.7	-122.1	-207.
-	448.8	-18.1	-	-	-	-	-	-	-	-
-56.1	687.7	46.0	-858.7	-171.0	-2.9	-0.5	-28.0	-15.9	-47.3	-218.
-64.5	687.7	47.8	-871.0	-183.3	-3.0	-0.7	-28.0	-15.9	-47.6	-230.
35.1	17702.6	-	-16537.6	-1879.8	-49.4	-18.6	-708.1	-405.3	-1181.4	-3061.

e 4-27. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
545.7	51.2	-894.8	-349.1	-3.1	-1.0	-31.6	-29.1	-64.8	-413.9
545.7	50.2	-887.6	-341.9	-3.0	-0.9	-31.6	-29.1	-64.6	-406.5
548.3	3.8	-	-	-	-	-	-	-	-
548.3	50.1	-887.4	-339.1	-3.0	-0.9	-31.6	-29.1	-64.6	-403.7
439.5	46.0	-859.1	-419.6	-2.9	-0.5	-31.6	-29.1	-64.1	-483.7
439.5	-22.5	-	-	-	-	-	-	-	-
293.3	-59.2	-	-	-	-	-	-	-	-
293.3	-53.5	-	-	-	-	-	-	-	-
229.5	34.6	-784.4	-555.0	-2.7	0.5	-31.6	-29.1	-62.9	-617.9
229.5	36.7	-797.8	-568.3	-2.7	0.3	-31.6	-29.1	-63.1	-631.4
211.7	36.0	-793.1	-581.4	-2.7	0.4	-31.6	-29.1	-63.0	-644.4
211.7	36.0	-793.0	-581.3	-2.7	0.4	-31.6	-29.1	-63.0	-644.3
215.9	36.2	-794.1	-578.2	-2.7	0.3	-31.6	-29.1	-63.1	-641.3
215.9	36.1	-793.7	-577.8	-2.7	0.3	-31.6	-29.1	-63.1	-640.9
198.9	33.5	-777.4	-578.5	-2.6	0.6	-31.6	-29.1	-62.7	-641.2
198.9	-41.3	-402.5	-203.6	-	-	-68.7	-64.7	-133.4	-337.0
164.9	31.9	-767.2	-602.3	-2.6	0.7	-31.6	-29.1	-62.6	-664.9
164.9	32.2	-768.9	-604.0	-2.6	0.7	-31.6	-29.1	-62.6	-666.6
166.6	-29.5	-450.0	-283.4	-	-	-137.4	-129.4	-266.8	-550.2
166.6	30.6	-758.7	-592.1	-2.6	0.8	-31.6	-29.1	-62.5	-654.6
283.9	-37.6	-416.8	-132.9	-	-	-87.2	-81.8	-169.0	-301.9
283.9	-52.0	-	-	-	-	-	-	-	-
433.5	43.9	-844.8	-411.3	-2.9	-0.4	-31.6	-29.1	-64.0	-475.3
433.5	46.3	-861.1	-427.6	-2.9	-0.6	-31.6	-29.1	-64.2	-491.8
7464.4	-	-14332.4	-8727.3	-44.3	0.5	-798.9	-741.5	-1584.2	-10311.5
873.8	65.8	-1001.4	-127.6	-3.4	-2.5	-31.6	-29.1	-66.6	-194.2
873.8	65.6	-1000.0	-126.2	-3.4	-2.5	-31.6	-29.1	-66.6	-192.8
885.7	50.5	-	-	-	-	-	-	-	-
885.7	65.9	-1002.4	-116.7	-3.4	-2.5	-31.6	-29.1	-66.6	-183.3
719.1	59.0	-950.6	-231.5	-3.3	-1.8	-31.6	-29.1	-65.8	-297.3
719.1	24.1	-	-	-	-	-	-	-	-
495.6	-11.8	-	-	-	-	-	-	-	-
495.6	-9.5	-	-	-	-	-	-	-	-
671.5	55.4	-924.6	-253.1	-3.2	-1.4	-31.6	-29.1	-65.3	-318.4
671.5	57.3	-938.3	-266.8	-3.2	-1.6	-31.6	-29.1	-65.5	-332.3
935.0	68.4	-1021.5	-86.5	-3.5	-2.7	-31.6	-29.1	-66.9	-153.4
935.0	68.8	-1025.0	-90.0	-3.5	-2.8	-31.6	-29.1	-67.0	-157.0
1079.5	74.8	-1071.9	7.6	-3.7	-3.4	-31.6	-29.1	-67.8	-60.2
1079.5	74.8	-1072.4	7.1	-3.7	-3.4	-31.6	-29.1	-67.8	-60.7
995.4	71.3	-1044.0	-48.6	-3.6	-3.1	-31.6	-29.1	-67.4	-116.0
995.4	66.4	-1006.0	-10.6	-	-	-68.7	-64.7	-133.4	-144.0
703.0	58.6	-947.9	-244.9	-3.2	-1.8	-31.6	-29.1	-65.7	-310.6
703.0	57.0	-936.0	-233.0	-3.2	-1.6	-31.6	-29.1	-65.5	-298.5
357.0	-0.5	-583.9	-226.9	-	-	-137.4	-129.4	-266.8	-493.7
357.0	40.4	-821.5	-464.5	-2.8	0	-31.6	-29.1	-63.5	-528.0
448.8	-6.9	-552.2	-103.4	-	-	-87.2	-81.8	-169.0	-272.4
448.8	-16.7	-	-	-	-	-	-	-	-
687.7	55.9	-928.5	-240.8	-3.2	-1.5	-31.6	-29.1	-65.4	-306.2
687.7	57.9	-942.8	-255.1	-3.2	-1.7	-31.6	-29.1	-65.6	-320.7
17702.6	-	-17770.8	-3113.0	-53.6	-34.2	-798.9	-741.5	-1628.2	-4741.2

Orbit Data: Case No. (Table 2-3) : IU - 7a
Type of Orbit and Orientation: Circular Earth Orbit, X-axis tangent to flight p
Orbital Altitude, N. Mi. : 100
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	545.7	20.3	-697.1	-151.4	9.0	0.7	58.5	2.8	71.0
2	545.7	20.1	-695.9	-150.2	9.0	0.7	58.5	2.8	71.0
3	548.3	4.8	-	-	-	-	-	-	-
4	548.3	20.1	-696.1	-147.8	9.0	0.7	58.5	2.8	71.0
5	439.5	15.3	-668.6	-229.1	10.0	0.8	58.5	2.8	72.1
6	439.5	-15.7	-	-	-	-	-	-	-
7	293.3	-44.6	-	-	-	-	-	-	-
8	293.3	-43.2	-	-	-	-	-	-	-
9	229.5	4.0	-607.5	-378.0	12.0	1.1	58.5	2.8	74.4
10	229.5	5.0	-612.4	-382.9	11.9	1.1	58.5	2.8	74.3
11	211.7	4.2	-608.1	-396.4	12.0	1.1	58.5	2.8	74.4
12	211.7	4.1	-608.0	-396.3	12.0	1.1	58.5	2.8	74.4
13	215.9	4.3	-609.0	-393.1	12.0	1.1	58.5	2.8	74.4
14	215.9	4.3	-608.8	-392.9	12.0	1.1	58.5	2.8	74.4
15	198.9	2.2	-597.9	-399.0	12.4	1.2	58.5	2.8	74.9
16	198.9	-61.6	-329.9	-131.0	-	-	130.3	6.2	136.5
17	164.9	0.5	-589.2	-424.3	12.7	1.2	58.5	2.8	75.2
18	164.9	0.7	-589.9	-425.0	12.7	1.2	58.5	2.8	75.2
19	166.6	-54.8	-352.8	-186.2	-	-	260.6	12.4	273.0
20	166.6	-0.3	-585.0	-418.4	12.8	1.3	58.5	2.8	75.4
21	283.9	-50.5	-368.2	-84.3	-	-	165.1	7.8	172.9
22	283.9	-44.7	-	-	-	-	-	-	-
23	433.5	13.8	-660.2	-226.7	10.2	0.9	58.5	2.8	72.4
24	433.5	15.1	-667.4	-233.9	10.0	0.8	58.5	2.8	72.1
Totals	7464.4	-	-11151.9	-5546.7	179.8	16.3	1492.0	71.2	1759.3
1	873.8	35.7	-791.1	82.7	5.7	0.2	58.5	2.8	67.2
2	873.8	36.1	-794.0	79.8	5.6	0.1	58.5	2.8	67.0
3	885.7	49.4	-	-	-	-	-	-	-
4	885.7	36.5	-796.5	89.2	5.6	0.1	58.5	2.8	67.0
5	719.1	28.7	-747.9	-28.8	7.2	0.4	58.5	2.8	68.9
6	719.1	26.9	-	-	-	-	-	-	-
7	495.6	-4.0	-	-	-	-	-	-	-
8	495.6	-4.2	-	-	-	-	-	-	-
9	671.5	25.8	-729.6	-58.1	7.9	0.5	58.5	2.8	69.7
10	671.5	26.6	-734.7	-63.2	7.7	0.5	58.5	2.8	69.5
11	935.0	38.5	-809.0	126.0	5.1	0.1	58.5	2.8	66.5
12	935.0	38.8	-811.3	123.7	5.0	0.0	58.5	2.8	66.3
13	1079.5	45.2	-853.6	225.9	3.6	-0.2	58.5	2.8	64.7
14	1079.5	45.3	-854.0	225.5	3.6	-0.2	58.5	2.8	64.7
15	995.4	41.9	-831.4	164.0	4.4	-0.1	58.5	2.8	65.6
16	995.4	57.7	-941.0	54.0	-	-	130.3	6.2	136.5
17	703.0	28.5	-745.9	-42.9	7.3	0.4	58.5	2.8	69.0
18	703.0	26.9	-736.5	-33.5	7.6	0.4	58.5	2.8	69.3
19	357.0	-21.3	-485.2	-128.2	-	-	260.6	12.4	273.0
20	357.0	10.0	-639.5	-282.5	11.0	1.0	58.5	2.8	73.3
21	448.8	-17.4	-502.5	-53.7	-	-	165.1	7.8	172.9
22	448.8	-12.3	-	-	-	-	-	-	-
23	687.7	26.4	-733.2	-45.5	7.7	0.5	58.5	2.8	69.5
24	687.7	27.3	-738.9	-51.2	7.5	0.4	58.5	2.8	69.2
Totals	17702.6	-	-14275.8	382.0	102.6	4.1	1492.0	71.2	1669.9

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Angle of Inclination (Degrees): 29

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
80.4	545.7	41.3	-827.3	-281.6	4.5	-0.0	0	-6.1	-1.6	-283.2
-79.2	545.7	40.7	-823.7	-278.0	4.6	-0.0	0	-6.1	1.5	-279.5
-	548.3	7.4	-	-	-	-	-	-	-	-
-76.8	548.3	40.7	-823.8	-275.5	4.6	-0.0	0	-6.1	1.5	-277.0
-157.0	439.5	36.4	-795.7	-356.2	5.6	0.1	0	-6.1	-0.4	-356.6
-	439.5	-13.6	-	-	-	-	-	-	-	-
-	293.3	-44.3	-	-	-	-	-	-	-	-
-	293.3	-41.4	-	-	-	-	-	-	-	-
-303.6	229.5	25.3	-726.8	-497.3	8.0	0.5	0	-6.1	2.4	-494.9
-308.6	229.5	26.6	-734.6	-505.1	7.7	0.5	0	-6.1	2.1	-503.0
-322.0	211.7	25.8	-729.9	-518.2	7.9	0.5	0	-6.1	2.3	-515.9
-321.9	211.7	25.8	-729.8	-518.1	7.9	0.5	0	-6.1	2.3	-515.8
-318.7	215.9	26.0	-730.9	-515.0	7.8	0.5	0	-6.1	2.2	-512.8
-318.5	215.9	26.0	-730.7	-514.8	7.8	0.5	0	-6.1	2.2	-512.6
-324.1	198.9	23.7	-717.4	-518.5	8.3	0.6	0	-6.1	2.8	-515.7
5.5	198.9	-50.2	-369.3	-170.4	-	-	0	-13.5	-13.5	-183.9
-349.1	164.9	22.1	-707.8	-542.9	8.6	0.6	0	-6.1	3.1	-539.8
-349.8	164.9	22.3	-709.0	-544.1	8.6	0.6	0	-6.1	3.1	-541.0
86.8	166.6	-39.5	-409.5	-242.9	-	-	0	-27.0	-27.0	-269.9
-343.0	166.6	21.1	-702.0	-535.4	8.8	0.6	0	-6.1	+3.3	-532.1
88.6	283.9	-42.3	-398.8	-114.9	-	-	0	-17.2	-17.2	-132.1
-	283.9	-42.2	-	-	-	-	-	-	-	-
-154.3	433.5	34.7	-784.7	-351.2	6.0	0.2	0	-6.1	0.1	-351.1
-161.8	433.5	36.3	-794.8	-361.3	5.6	0.1	0	-6.1	0.4	-360.9
-3787.5	7464.4	-	-13246.5	-7641.4	112.2	5.6	0	-155.3	-37.5	-7678.9
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
149.9	873.8	56.0	-929.4	-55.6	1.0	-0.6	0	-6.1	-5.7	-61.3
146.8	873.8	56.1	-929.9	-56.1	1.0	-0.6	0	-6.1	-5.7	-61.8
-	885.7	51.5	-	-	-	-	-	-	-	-
156.2	885.7	56.5	-932.6	-46.9	0.9	-0.6	0	-6.1	-5.8	-52.7
40.1	719.1	49.4	-882.0	-162.9	2.6	-0.3	0	-6.1	-3.8	-166.7
-	719.1	28.6	-	-	-	-	-	-	-	-
-	495.6	-3.8	-	-	-	-	-	-	-	-
-	495.6	-2.8	-	-	-	-	-	-	-	-
11.6	671.5	46.2	-860.1	-188.6	3.4	-0.2	0	-6.1	-2.9	-191.5
6.3	671.5	47.3	-868.2	-196.7	3.1	-0.3	0	-6.1	-3.3	-200.
192.5	935.0	58.7	-948.7	-13.7	0.3	-0.7	0	-6.1	-6.5	-20.
190.0	935.0	59.1	-951.2	-16.2	0.2	-0.7	0	-6.1	-6.6	-22.8
290.6	1079.5	65.2	-996.9	82.6	-1.3	-1.0	0	-6.1	-8.4	74.2
290.2	1079.5	65.2	-997.3	82.2	-1.3	-1.0	0	-6.1	-8.4	73.8
229.6	995.4	61.7	-970.9	24.5	-0.4	-0.8	0	-6.1	-7.3	17.
190.5	995.4	63.4	-983.3	12.1	-	-	0	-13.5	-13.5	-1.
26.1	703.0	48.8	-878.4	-175.4	2.7	-0.3	0	-6.1	-3.7	-179.
35.8	703.0	47.5	-869.0	-166.0	3.1	-0.3	0	-6.1	-3.3	-169.
144.8	357.0	-8.7	-543.2	-186.2	-	-	0	-27.0	-27.0	-213.
-209.2	357.0	31.0	-761.3	-404.3	6.8	0.3	0	-6.1	1.0	-403.
119.2	448.8	-10.7	-533.7	-84.9	-	-	0	-17.2	-17.2	-102.
-	448.8	-10.4	-	-	-	-	-	-	-	-
24.0	687.7	46.7	-864.1	-176.4	3.2	-0.2	0	-6.1	-3.1	-179.
18.0	687.7	48.0	-872.7	-185.0	2.9	-0.3	0	-6.1	-3.5	-188.
2051.9	17702.6	-	-16573.1	-1915.3	28.1	-7.7	0	-155.3	-134.9	-2050.

e 4-28. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↑ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↑ SLA	Coldplate/ ElecComp ↑ S-IVB Dome	Coldplate/ ElecComp ↑ SLA	Net	
545.7	51.5	-897.0	-351.3	2.1	-0.4	-33.3	-11.1	-42.7	-394.0
545.7	50.8	-892.0	-346.0	2.3	-0.4	-33.3	-11.1	-42.5	-388.8
548.3	8.7	-	-	-	-	-	-	-	-
548.3	50.8	-892.1	-343.8	2.3	-0.4	-33.3	-11.1	-42.5	-386.3
439.5	46.7	-863.8	-424.3	3.2	-0.2	-33.3	-11.1	-41.4	-465.7
439.5	-12.6	-	-	-	-	-	-	-	-
293.3	-44.1	-	-	-	-	-	-	-	-
293.3	-40.5	-	-	-	-	-	-	-	-
229.5	35.7	-791.0	-561.5	5.7	0.2	-33.3	-11.1	-38.5	-600.0
229.5	37.1	-800.4	-570.9	5.4	0.1	-33.3	-11.1	-38.9	-609.8
211.7	36.4	-795.4	-583.7	5.6	0.1	-33.3	-11.1	-38.7	-622.4
211.7	36.4	-795.4	-583.7	5.6	0.1	-33.3	-11.1	-38.7	-622.4
215.9	36.6	-796.6	-580.7	5.6	0.1	-33.3	-11.1	-38.7	-619.4
215.9	36.5	-796.3	-580.4	5.6	0.1	-33.3	-11.1	-38.7	-619.1
198.9	34.2	-781.8	-582.9	6.1	0.2	-33.3	-11.1	-38.1	-621.0
198.9	-44.3	-391.0	-192.1	-	-	-74.2	-24.7	-98.9	-291.0
164.9	32.6	-771.7	-606.8	6.4	0.3	-33.3	-11.1	-37.7	-644.5
164.9	32.9	-773.2	-608.3	6.4	0.2	-33.3	-11.1	-37.8	-646.1
166.6	-31.6	-441.3	-274.7	-	-	-148.4	-49.4	-197.8	-472.5
166.6	31.6	-765.1	-598.5	6.6	0.3	-33.3	-11.1	-37.5	-636.0
283.9	-37.9	-415.7	-131.8	-	-	-94.0	-31.4	-125.4	-257.2
283.9	-41.0	-	-	-	-	-	-	-	-
433.5	44.9	-851.4	-417.9	3.7	-0.2	-33.3	-11.1	-40.9	-458.8
433.5	46.6	-863.2	-429.7	3.3	-0.2	-33.3	-11.1	-41.3	-471.0
7464.4	-	-14374.3	-8769.2	75.8	-0.1	-849.4	-283.1	-1056.8	-9826.0
873.8	66.0	-1003.0	-129.2	-1.5	-1.0	-33.3	-11.1	-46.9	-176.1
873.8	65.9	-1002.2	-128.4	-1.5	-1.0	-33.3	-11.1	-46.9	-175.3
885.7	52.5	-	-	-	-	-	-	-	-
885.7	66.2	-1005.0	-119.3	-1.6	-1.0	-33.3	-11.1	-47.0	-166.3
719.1	59.4	-953.6	-234.5	-0.2	-0.7	-33.3	-11.1	-44.9	-279.4
719.1	29.4	-	-	-	-	-	-	-	-
495.6	-3.7	-	-	-	-	-	-	-	-
495.6	-2.1	-	-	-	-	-	-	-	-
671.5	56.1	-929.8	-258.3	1.0	-0.6	-33.3	-11.1	-44.0	-302.3
671.5	57.4	-934.4	-262.9	0.6	-0.7	-33.3	-11.1	-44.5	-307.4
935.0	68.6	-1023.0	-88.0	-2.2	-1.1	-33.3	-11.1	-47.7	-135.7
935.0	68.9	-1025.6	-90.6	-2.3	-1.1	-33.3	-11.1	-47.8	-138.4
1079.5	74.9	-1072.9	6.6	-4.0	-1.4	-33.3	-11.1	-49.8	-43.2
1079.5	74.9	-1073.3	6.2	-4.0	-1.4	-33.3	-11.1	-49.8	-43.6
995.4	71.4	-1044.9	-49.5	-3.0	-1.2	-33.3	-11.1	-48.6	-98.1
995.4	66.4	-1006.4	-11.0	-	-	-74.2	-24.7	-98.9	-109.9
703.0	58.8	-949.1	-246.1	0.3	-0.7	-33.3	-11.1	-44.8	-290.9
703.0	57.5	-939.7	-236.7	0.6	-0.7	-33.3	-11.1	-44.5	-281.2
357.0	-2.2	-575.6	-218.6	-	-	-148.4	-49.4	-197.8	-416.4
357.0	41.2	-826.8	-469.8	4.5	-0.0	-33.3	-11.1	-39.9	-509.7
448.8	-7.1	-551.0	-102.2	-	-	-94.0	-31.4	-125.4	-227.6
448.8	-9.5	-	-	-	-	-	-	-	-
687.7	56.7	-933.9	-246.2	0.8	-0.6	-33.3	-11.1	-44.2	-290.4
687.7	58.1	-944.2	-256.5	0.5	-0.7	-33.3	-11.1	-44.6	-301.1
17702.6	-	-17799.3	-3141.5	-11.6	-13.9	-849.4	-283.1	-1158.0	-4299.5

Orbit Data: Case No. (Table 2-3) : IU-7a
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight
Orbital Altitude, N. Mi. : 100
Launch Date : June 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	545.7	18.8	-688.4	-142.7	-21.9	0.7	-203.3	2.8	-221
2	545.7	18.2	-685.4	-139.7	-21.8	0.7	-203.3	2.8	-221
3	548.3	-13.5	-	-	-	-	-	-	-
4	548.3	18.3	-685.5	-137.2	-21.8	0.7	-203.3	2.8	-221
5	439.5	13.7	-659.8	-220.3	-20.9	0.9	-203.3	2.8	-220
6	439.5	-38.6	-	-	-	-	-	-	-
7	293.3	-74.4	-	-	-	-	-	-	-
8	293.3	-70.9	-	-	-	-	-	-	-
9	229.5	2.0	-596.7	-367.2	-18.8	1.2	-203.3	2.8	-218.
10	229.5	3.4	-604.2	-374.7	-19.0	1.2	-203.3	2.8	-218.
11	211.7	2.6	-600.0	-388.3	-18.9	1.2	-203.3	2.8	-218.
12	211.7	2.6	-599.9	-388.2	-18.9	1.2	-203.3	2.8	-218.
13	215.9	2.8	-601.0	-385.1	-18.9	1.2	-203.3	2.8	-218.
14	215.9	2.8	-600.8	-384.9	-18.9	1.2	-203.3	2.8	-218.
15	198.9	0.7	-590.1	-391.2	-18.5	1.2	-203.3	2.8	-217.
16	198.9	-61.9	-329.0	-130.1	-	-	-452.6	6.2	-446.
17	164.9	-1.0	-581.4	-416.5	-18.2	1.3	-203.3	2.8	-217.
18	164.9	-0.9	-582.1	-417.2	-18.3	1.3	-203.3	2.8	-217.
19	166.6	-55.1	-351.9	-185.3	-	-	-905.2	12.4	-892.
20	166.6	-1.8	-577.2	-410.6	-18.1	1.3	-203.3	2.8	-217.
21	283.9	-52.7	-360.2	-76.3	-	-	-573.5	7.8	-565.
22	283.9	-70.0	-	-	-	-	-	-	-
23	433.5	11.8	-649.3	-215.8	-20.6	0.9	-203.3	2.8	-220.
24	433.5	13.6	-658.9	-225.4	-20.9	0.9	-203.3	2.8	-220.
Totals	7463.4	-	-11001.6	-5396.5	-314.5	17.1	-5184.1	71.2	-5410.
1	873.8	34.3	-781.9	91.9	-25.1	0.2	-203.3	2.8	-225.
2	873.8	34.4	-783.1	90.7	-25.2	0.2	-203.3	2.8	-225.
3	885.7	35.3	-	-	-	-	-	-	-
4	885.7	34.8	-785.6	100.1	-25.3	0.2	-203.3	2.8	-225.
5	719.1	27.3	-738.6	-19.5	-23.6	0.4	-203.3	2.8	-223.
6	719.1	9.8	-	-	-	-	-	-	-
7	495.6	-25.9	-	-	-	-	-	-	-
8	495.6	-25.1	-	-	-	-	-	-	-
9	671.5	23.9	-718.5	-47.0	-23.0	0.5	-203.3	2.8	-223.
10	671.5	25.1	-725.8	-54.3	-23.2	0.5	-203.3	2.8	-223.
11	935.0	37.0	-799.6	135.4	-25.7	0.1	-203.3	2.8	-226.
12	935.0	37.4	-802.0	133.0	-25.8	0.1	-203.3	2.8	-226.
13	1079.2	43.8	-844.0	235.2	-27.3	-0.1	-203.3	2.8	-227.
14	1079.2	43.8	-844.4	234.8	-27.3	-0.1	-203.3	2.8	-227.
15	995.4	40.5	-822.1	173.3	-26.5	-0.0	-203.3	2.8	-227.
16	995.4	57.5	-940.0	55.4	-	-	-452.6	6.2	-446.
17	703.0	27.0	-737.1	-34.1	-23.6	0.4	-203.3	2.8	-223.
18	703.0	25.5	-727.7	-24.7	-23.3	0.5	-203.3	2.8	-223.
19	357.0	-21.5	-484.3	-127.3	-	-	-905.2	12.4	-892.
20	357.0	8.5	-631.3	-274.3	-20.0	1.0	-203.3	2.8	-219.
21	448.8	-19.0	-495.5	-46.7	-	-	-573.5	7.8	-565.
22	448.8	-32.7	-	-	-	-	-	-	-
23	687.7	24.5	-722.1	-34.4	-23.1	0.5	-203.3	2.8	-223.
24	687.7	25.8	-729.9	-42.2	-23.3	0.5	-203.3	2.8	-223.
Totals	17702.6	-	-14113.8	544.0	-391.3	4.9	-5184.1	71.2	-5499.

Tabl

path

Angle of Inclination (Degrees): 29

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
.7	-364.4	545.7	39.8	-817.8	-272.1	-26.4	0.0	-261.8	-6.1	-294.3	-566.4
.6	-361.3	545.7	39.0	-812.2	-266.5	-26.2	0.0	-261.8	-6.1	-294.1	-560.6
	-	548.3	-10.6	-	-	-	-	-	-	-	-
.6	-358.8	548.3	39.0	-812.3	-264.0	-26.2	0.0	-261.8	-6.1	-294.1	-558.1
.5	-440.8	439.5	34.9	-786.1	-346.6	-25.3	0.2	-261.8	-6.1	-293.0	-639.6
	-	439.5	-36.2	-	-	-	-	-	-	-	-
	-	293.3	-73.9	-	-	-	-	-	-	-	-
	-	293.3	-68.7	-	-	-	-	-	-	-	-
1	-585.3	229.5	23.3	-715.1	-485.6	-22.8	0.6	-261.8	-6.1	-290.1	-775.7
3	-593.0	229.5	25.1	-725.6	-496.1	-23.2	0.5	-261.8	-6.1	-290.6	-786.7
2	-606.5	211.7	24.3	-721.0	-509.3	-23.0	0.5	-261.8	-6.1	-290.4	-799.7
2	-606.4	211.7	24.3	-720.9	-509.2	-23.0	0.5	-261.8	-6.1	-290.4	-799.6
2	-603.3	215.9	24.5	-722.1	-506.2	-23.1	0.5	-261.8	-6.1	-290.5	-796.7
2	-603.1	215.9	24.5	-721.8	-505.9	-23.1	0.5	-261.8	-6.1	-290.5	-796.4
8	-609.0	198.9	22.3	-708.8	-505.9	-22.6	0.6	-261.8	-6.1	-289.9	-799.8
4	-576.5	198.9	-50.4	-368.4	-169.5	-	-	-582.9	-13.5	-596.4	-765.9
4	-633.9	164.9	20.6	-699.2	-534.3	-22.3	0.7	-261.8	-6.1	-289.5	-823.8
5	-634.7	164.9	20.8	-700.4	-535.5	-22.3	0.6	-261.8	-6.1	-289.6	-825.1
8	-1078.1	166.6	-39.9	-408.7	-242.1	-	-	-1165.8	-27.0	-1192.8	-1434.9
3	-627.9	166.6	19.6	-693.4	-526.8	-22.1	0.7	-261.8	-6.1	-289.3	-816.1
7	-642.0	283.9	-44.4	-390.8	-106.9	-	-	-738.5	-17.2	-755.7	-862.6
	-	283.9	-67.1	-	-	-	-	-	-	-	-
2	-436.0	433.5	32.8	-772.8	-339.3	-24.8	0.3	-261.8	-6.1	-292.4	-631.7
5	-445.9	433.5	34.8	-785.5	-352.0	-25.3	0.2	-261.8	-6.1	-293.0	-645.0
3	-10,806.9	7463.4	-	-13082.9	-7477.8	-381.7	6.4	-6676.0	-155.3	-7206.6	-14684.4
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
4	-133.5	873.8	54.7	-919.4	-45.6	-29.9	-0.5	-261.8	-6.1	-298.3	-343.9
5	-134.8	873.8	54.5	-918.2	-44.4	-29.8	-0.5	-261.8	-6.1	-298.2	-342.6
	-	885.7	37.5	-	-	-	-	-	-	-	-
6	-125.5	885.7	54.9	-920.9	-35.2	-29.9	-0.6	-261.8	-6.1	-298.4	-333.6
7	-243.2	719.1	47.9	-871.9	-152.8	-28.2	-0.3	-261.8	-6.1	-296.4	-449.2
	-	719.1	11.6	-	-	-	-	-	-	-	-
	-	495.6	-25.6	-	-	-	-	-	-	-	-
	-	495.6	-23.5	-	-	-	-	-	-	-	-
)	-270.0	671.5	44.4	-848.1	-176.6	-27.4	-0.2	-261.8	-6.1	-295.5	-472.1
2	-277.5	671.5	45.9	-858.5	-187.0	-27.8	-0.2	-261.8	-6.1	-295.9	-482.9
1	-90.7	935.0	57.3	-938.6	-3.6	-30.5	-0.7	-261.8	-6.1	-299.1	-302.7
2	-93.2	935.0	57.7	-941.4	-6.4	-30.6	-0.7	-261.8	-6.1	-299.2	-305.6
9	7.3	1079.2	63.8	-986.5	92.7	-32.2	-0.9	-261.8	-6.1	-301.0	-208.3
9	6.9	1079.2	63.9	-986.9	92.3	-32.2	-0.9	-261.8	-6.1	-301.0	-208.7
)	-53.7	995.4	60.4	-960.8	34.6	-31.3	-0.8	-261.8	-6.1	-300.0	-265.4
4	-391.0	995.4	63.2	-982.4	13.0	-	-	-582.9	-13.5	-596.4	-583.4
7	-257.8	703.0	47.4	-868.9	-165.9	-28.1	-0.3	-261.8	-6.1	-296.3	-462.2
)	-248.0	703.0	46.1	-859.5	-156.5	-27.8	-0.2	-261.8	-6.1	-295.9	-452.4
)	-1020.1	357.0	-8.9	-542.4	-185.4	-	-	-1165.8	-27.0	-1192.8	-1378.2
	-493.8	357.0	29.5	-752.4	-395.4	-24.1	0.4	-261.8	-6.1	-291.6	-687.0
	-612.4	448.8	-12.2	-526.8	-78.0	-	-	-738.5	-17.2	-755.7	-833.7
	-	448.8	-30.6	-	-	-	-	-	-	-	-
	-257.5	687.7	45.0	-852.1	-164.4	-27.5	-0.2	-261.8	-6.1	-295.6	-460.0
	-265.5	687.7	46.6	-863.0	-175.3	-27.9	-0.2	-261.8	-6.1	-296.0	-471.3
	-4955.3	17702.6	-	-16398.4	-1740.6	-465.3	-6.8	-6676.0	-155.3	-7303.4	-9044.0

4-29. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ε = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
545.7	50.1	-887.1	-341.4	-28.8	-0.4	-295.1	-11.1	-335.4	-676.8
545.7	49.1	-880.0	-334.3	-28.5	-0.3	-295.1	-11.1	-335.0	-669.3
548.3	-9.1	-	-	-	-	-	-	-	-
548.3	49.1	-880.1	-331.8	-28.5	-0.3	-295.1	-11.1	-335.0	-666.8
439.5	45.2	-853.8	-414.3	-27.6	-0.2	-295.1	-11.1	-334.0	-748.3
439.5	-35.0	-	-	-	-	-	-	-	-
293.3	-73.7	-	-	-	-	-	-	-	-
293.3	-67.6	-	-	-	-	-	-	-	-
229.5	33.8	-778.8	-549.3	-25.0	0.2	-295.1	-11.1	-331.0	-880.3
229.5	35.7	-791.0	-561.5	-25.4	0.2	-295.1	-11.1	-331.4	-892.9
211.7	34.9	-786.2	-574.5	-25.3	0.2	-295.1	-11.1	-331.3	-905.8
211.7	34.9	-786.1	-574.4	-25.3	0.2	-295.1	-11.1	-331.3	-905.7
215.9	35.1	-787.3	-571.4	-25.3	0.2	-295.1	-11.1	-331.3	-902.7
215.9	35.1	-787.0	-571.1	-25.3	0.2	-295.1	-11.1	-331.3	-902.4
198.9	32.8	-772.8	-573.9	-24.8	0.3	-295.1	-11.1	-330.7	-904.6
198.9	-44.6	-390.1	-191.2	-	-	-657.1	-24.7	-681.8	-873.0
164.9	31.2	-762.8	-597.9	-24.5	0.3	-295.1	-11.1	-330.4	-928.3
164.9	31.4	-764.2	-599.3	-24.5	0.3	-295.1	-11.1	-330.4	-929.7
166.6	-31.8	-440.5	-273.9	-	-	-1314.2	-49.4	-1363.6	-1637.5
166.6	30.1	-756.1	-589.5	-24.2	0.3	-295.1	-11.1	-330.1	-919.6
283.9	-39.9	-407.8	-123.9	-	-	-832.5	-31.4	-863.9	-987.8
283.9	-65.7	-	-	-	-	-	-	-	-
433.5	43.0	-839.0	-405.5	-27.1	-0.1	-295.1	-11.1	-333.4	-738.9
433.5	45.2	-853.5	-420.0	-27.6	-0.2	-295.1	-11.1	-334.0	-754.0
7463.4	-	-14204.0	-8598.9	-417.8	0.7	-7525.4	-283.1	-8225.6	-16824.4
873.8	64.6	-992.6	-118.8	-32.4	-0.9	-295.1	-11.1	-339.5	-458.3
873.8	64.3	-990.0	-116.2	-32.3	-0.9	-295.1	-11.1	-339.4	-455.6
885.7	38.6	-	-	-	-	-	-	-	-
885.7	64.6	-992.8	-107.1	-32.4	-0.9	-295.1	-11.1	-339.5	-446.6
719.1	57.9	-943.1	-224.0	-30.7	-0.7	-295.1	-11.1	-337.6	-561.6
719.1	12.5	-	-	-	-	-	-	-	-
495.6	-25.5	-	-	-	-	-	-	-	-
495.6	-22.7	-	-	-	-	-	-	-	-
671.5	54.4	-917.3	-245.8	-29.8	-0.5	-295.1	-11.1	-336.5	-582.3
671.5	56.0	-929.3	-257.8	-30.2	-0.6	-295.1	-11.1	-337.0	-594.8
935.0	67.2	-1012.6	-77.6	-33.1	-1.1	-295.1	-11.1	-340.4	-418.0
935.0	67.6	-1015.2	-80.2	-33.2	-1.1	-295.1	-11.1	-340.5	-420.7
1079.2	73.6	-1062.2	17.0	-34.8	-1.3	-295.1	-11.1	-342.3	-325.3
1079.2	73.6	-1062.6	16.6	-34.8	-1.3	-295.1	-11.1	-342.3	-325.7
995.4	70.1	-1034.5	-39.1	-33.8	-1.2	-295.1	-11.1	-341.2	-380.3
995.4	66.3	-1005.5	-10.1	-	-	-657.1	-24.7	-681.8	-691.9
703.0	57.4	-939.2	-236.2	-30.5	-0.7	-295.1	-11.1	-337.4	-573.6
703.0	56.1	-929.8	-226.8	-30.2	-0.6	-295.1	-11.1	-337.0	-563.8
357.0	-2.3	-574.7	-217.7	-	-	-1314.2	-49.4	-1363.6	-1581.3
357.0	39.8	-817.6	-460.6	-26.4	0.0	-295.1	-11.1	-332.6	-793.2
448.8	-8.5	-544.1	-95.3	-	-	-832.5	-31.4	-863.9	-959.2
448.8	-29.5	-	-	-	-	-	-	-	-
687.7	55.0	-921.4	-233.7	-29.9	-0.6	-295.1	-11.1	-336.7	-570.4
687.7	56.7	-934.0	-244.3	-30.4	-0.6	-295.1	-11.1	-337.2	-581.5
17702.6	-	-17618.6	-2960.8	-504.8	-13.0	-7525.4	-283.1	-8326.3	-11287.1

Orbit Data: Case No. (Table 2-3) : IU-10
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight pa
Orbital Altitude, N. Mi. : 100
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	506.0	18.0	-684.0	-178.0	1.0	1.8	6.3	7.3	16.4
2	506.0	17.7	-682.1	-176.1	1.0	1.9	6.3	7.3	16.5
3	551.6	0.5	-	-	-	-	-	-	-
4	551.6	19.9	-694.8	-143.2	1.0	1.7	6.3	7.3	16.3
5	595.1	22.2	-708.5	-113.4	0.9	1.5	6.3	7.3	16.0
6	595.1	6.6	-	-	-	-	-	-	-
7	599.5	5.6	-	-	-	-	-	-	-
8	599.5	6.5	-	-	-	-	-	-	-
9	517.2	18.4	-686.0	-168.8	1.0	1.8	6.3	7.3	16.4
10	517.2	18.5	-686.8	-169.6	1.0	1.8	6.3	7.3	16.4
11	370.0	11.7	-648.5	-278.5	1.1	2.3	6.3	7.3	17.0
12	370.0	11.3	-646.4	-276.4	1.1	2.3	6.3	7.3	17.0
13	196.0	3.1	-602.6	-406.6	1.3	2.9	6.3	7.3	17.8
14	196.0	2.7	-600.3	-404.3	1.3	4.0	6.3	7.3	18.9
15	48.2	-6.5	-554.1	-505.9	1.5	3.6	6.3	7.3	18.7
16	48.2	-95.2	-231.8	-183.6	-	-	13.6	16.2	29.8
17	33.2	-7.5	-549.4	-516.2	1.5	3.7	6.3	7.3	18.8
18	33.2	-6.7	-553.1	-519.9	1.5	3.6	6.3	7.3	18.7
19	129.8	-60.6	-333.3	-203.5	-	-	27.2	32.4	59.6
20	129.8	-3.2	-570.2	-440.4	1.4	3.4	6.3	7.3	18.4
21	265.2	-54.8	-352.8	-87.6	-	-	17.3	20.4	37.7
22	265.2	-59.2	-	-	-	-	-	-	-
23	403.6	11.4	-646.9	-243.3	1.1	2.3	6.3	7.3	17.0
24	403.6	13.2	-657.1	-253.5	1.1	2.2	6.3	7.3	16.9
Totals	8430.8	-	-11088.7	-5268.8	18.7	39.8	158.9	185.9	403.2
1	674.9	26.1	-731.6	-56.7	0.8	1.2	6.3	7.3	15.6
2	674.9	26.9	-736.2	-61.3	0.8	1.1	6.3	7.3	15.5
3	903.0	49.2	-	-	-	-	-	-	-
4	903.0	38.1	-806.4	96.6	0.5	0.2	6.3	7.3	14.3
5	1496.0	63.9	-987.5	508.5	-0.1	-2.3	6.3	7.3	11.2
6	1496.0	116.5	-	-	-	-	-	-	-
7	2025.0	158.3	-	-	-	-	-	-	-
8	2025.0	157.6	-	-	-	-	-	-	-
9	2110.0	92.2	-1218.7	891.3	-0.9	-5.4	6.3	7.3	7.3
10	2110.0	89.9	-1198.4	911.6	-0.9	-5.2	6.3	7.3	7.5
11	1728.0	74.5	-1069.3	658.7	-0.4	-3.4	6.3	7.3	9.8
12	1728.0	73.2	-1059.5	668.5	-0.4	-3.3	6.3	7.3	9.9
13	980.0	41.5	-828.6	151.4	0.5	-0.1	6.3	7.3	14.0
14	980.0	39.7	-817.0	163.0	0.5	0.0	6.3	7.3	14.1
15	240.9	4.7	-610.8	-369.9	1.3	2.8	6.3	7.3	17.7
16	240.9	-51.3	-365.2	-124.3	-	-	13.6	16.2	29.8
17	44.4	-5.9	-557.0	-512.6	1.5	3.6	6.3	7.3	18.7
18	44.4	-5.9	-556.9	-512.5	1.5	3.6	6.3	7.3	18.7
19	173.2	-52.5	-361.1	-187.9	-	-	27.2	32.4	59.6
20	173.2	-0.5	-583.9	-410.7	1.4	3.2	6.3	7.3	18.2
21	353.8	-36.0	-423.3	-69.5	-	-	17.3	20.4	37.7
22	353.8	-38.4	-	-	-	-	-	-	-
23	538.7	18.3	-685.6	-146.9	1.0	1.8	6.3	7.3	16.4
24	538.7	19.9	-694.6	-155.9	1.0	1.7	6.3	7.3	16.3
Totals	22535.8	-	-14291.4	1441.6	7.9	0.5	158.9	185.9	353.1

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Angle of Inclination (Degrees): 34

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-161.6	506.0	39.2	-813.8	-307.8	0.5	0.1	0	-15.9	-15.3	-323.1
-159.6	506.0	38.5	-808.9	-302.9	0.5	0.1	0	-15.9	-15.3	-318.2
-	551.6	4.2	-	-	-	-	-	-	-	-
-126.9	551.6	40.6	-822.7	-271.1	0.5	0.1	0	-15.9	-15.5	-286.6
-97.4	595.1	43.1	-839.3	-244.2	0.4	-0.3	0	-15.9	-15.8	-260.0
-	595.1	8.9	-	-	-	-	-	-	-	-
-	599.5	6.0	-	-	-	-	-	-	-	-
-	599.5	8.3	-	-	-	-	-	-	-	-
-152.4	517.2	39.1	-812.9	-295.7	0.5	0.1	0	-15.9	-15.3	-311.0
-153.2	517.2	39.7	-816.9	-299.7	0.5	0.0	0	-15.9	-15.4	-315.1
-261.5	370.0	33.2	-775.1	-405.1	0.7	0.6	0	-15.9	-14.6	-419.7
-259.4	370.0	32.8	-772.8	-402.8	0.7	0.6	0	-15.9	-14.6	-417.4
-388.8	196.0	25.0	-724.7	-528.7	0.8	1.3	0	-15.9	-13.8	-542.5
-385.4	196.0	24.5	-722.1	-526.1	0.9	1.3	0	-15.9	-13.7	-539.8
-487.2	48.2	15.5	-669.7	-621.5	1.0	2.0	0	-15.9	-12.9	-634.4
-153.8	48.2	-80.3	-272.1	-223.9	-	-	0	-35.4	-35.4	-259.3
-497.4	33.2	14.6	-664.4	-631.2	1.1	2.1	0	-15.9	-12.7	-643.9
-501.2	33.2	15.3	-668.9	-635.7	1.0	2.0	0	-15.9	-12.9	-648.6
-143.9	129.8	-44.2	-391.5	-261.7	-	-	0	-70.8	-70.8	-332.5
-422.0	129.8	18.3	-685.7	-555.9	1.0	1.8	0	-15.9	-13.1	-569.0
-49.9	265.2	-46.0	-384.6	-119.4	-	-	0	-44.7	-44.7	-164.1
-	265.2	-55.6	-	-	-	-	-	-	-	-
-226.3	403.6	32.4	-770.4	-366.8	0.7	0.7	0	-15.9	-14.5	-381.3
-236.6	403.6	34.7	-784.4	-380.8	0.6	0.5	0	-15.9	-14.8	-395.6
-4865.6	8430.8	-	-13200.7	-7380.8	11.5	12.9	0	-405.3	-380.9	-7761.7
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
-41.1	674.9	47.0	-865.7	-190.8	0.3	-0.6	0	-15.9	-16.2	-207.0
-45.8	674.9	47.3	-867.6	-192.7	0.3	-0.7	0	-15.9	-16.3	-209.0
-	903.0	52.0	-	-	-	-	-	-	-	-
110.9	903.0	58.0	-943.6	-40.6	0.1	-1.7	0	-15.9	-17.5	-58.1
519.7	1496.0	83.1	-1139.8	356.2	-0.7	-4.4	0	-15.9	-21.0	335.2
-	1496.0	117.8	-	-	-	-	-	-	-	-
-	2025.0	158.4	-	-	-	-	-	-	-	-
-	2025.0	158.5	-	-	-	-	-	-	-	-
898.6	2110.0	109.9	-1383.2	726.8	-1.5	-7.7	0	-15.9	-25.1	701.7
919.1	2110.0	108.2	-1365.9	744.1	-1.5	-7.4	0	-15.9	-24.8	719.3
668.5	1728.0	93.4	-1229.0	499.0	-1.0	-5.6	0	-15.9	-22.5	476.5
678.4	1728.0	92.2	-1218.5	509.5	-0.9	-5.4	0	-15.9	-22.2	487.3
165.4	980.0	61.7	-971.0	9.0	-0.0	-2.1	0	-15.9	-18.0	-9.0
177.1	980.0	60.0	-958.3	21.7	0	-1.9	0	-15.9	-17.8	3.9
-352.2	240.9	26.2	-731.9	-491.0	0.8	1.2	0	-15.9	-13.9	-504.9
-94.5	240.9	-40.0	-407.5	-166.6	-	-	0	-35.4	-35.4	-202.0
-493.9	44.4	16.0	-672.6	-628.2	1.0	2.0	0	-15.9	-12.9	-641.1
-493.8	44.4	16.1	-673.0	-628.6	1.0	2.0	0	-15.9	-12.9	-641.5
-128.3	173.2	-36.9	-419.7	-246.5	-	-	0	-70.8	-70.8	-317.1
-392.5	173.2	20.8	-700.6	-527.4	0.9	1.6	0	-15.9	-13.4	-540.8
-31.8	353.8	-28.1	-455.6	-101.8	-	-	0	-44.7	-44.7	-146.5
-	353.8	-35.3	-	-	-	-	-	-	-	-
-130.5	538.7	39.0	-812.6	-273.9	0.5	0.1	0	-15.9	-15.3	-289.2
-139.6	538.7	41.0	-825.5	-286.8	0.5	-0.1	0	-15.9	-15.5	-302.3
1794.7	22535.8	-	-16641.4	-908.4	-0.1	-30.6	0	-405.3	-436.0	-1344.8

448-1

e 4-30. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
506.0	49.6	-883.4	-377.4	0.3	-0.9	-3.6	-29.1	-33.3	-410.7
506.0	48.6	-876.8	-370.8	0.3	-0.8	-3.6	-29.1	-33.2	-404.0
551.6	6.0	-	-	-	-	-	-	-	-
551.6	50.6	-891.1	-339.5	0.2	-1.0	-3.6	-29.1	-33.5	-373.0
595.1	53.2	-909.2	-314.1	0.2	-1.2	-3.6	-29.1	-33.7	-347.8
595.1	10.1	-	-	-	-	-	-	-	-
599.5	6.2	-	-	-	-	-	-	-	-
599.5	9.2	-	-	-	-	-	-	-	-
517.2	49.2	-880.7	-363.5	0.3	-0.8	-3.6	-29.1	-33.2	-396.7
517.2	50.0	-886.6	-369.4	0.3	-0.9	-3.6	-29.1	-33.3	-402.7
370.0	43.7	-843.1	-473.1	0.4	-0.3	-3.6	-29.1	-32.6	-505.7
370.0	43.3	-840.6	-470.6	0.4	-0.3	-3.6	-29.1	-32.6	-503.2
196.0	35.6	-790.5	-594.5	0.6	0.4	-3.6	-29.1	-31.7	-626.2
196.0	35.2	-787.7	-591.7	0.6	0.4	-3.6	-29.1	-31.7	-623.4
48.2	26.2	-732.2	-684.0	0.8	1.2	-3.6	-29.1	-30.7	-714.7
48.2	-72.8	-294.3	-246.1	-	-	-7.8	-64.7	-72.5	-318.6
33.2	25.3	-726.7	-693.5	0.8	1.3	-3.6	-29.1	-30.6	-724.1
33.2	26.1	-731.5	-698.3	0.8	1.2	-3.6	-29.1	-30.7	-729.0
129.8	-35.8	-424.1	-294.3	-	-	-15.6	-129.4	-145.0	-439.3
129.8	28.8	-748.1	-618.3	0.8	1.0	-3.6	-29.1	-30.9	-649.2
265.2	-41.4	-402.2	-137.0	-	-	-9.8	-81.8	-91.6	-228.6
265.2	-53.8	-	-	-	-	-	-	-	-
403.6	42.7	-836.6	-433.0	0.4	-0.2	-3.6	-29.1	-32.5	-465.5
403.6	45.1	-852.8	-449.2	0.4	-0.5	-3.6	-29.1	-32.8	-482.0
8430.8	-	-14338.2	-8518.2	7.6	-1.6	-90.8	-741.5	-826.3	-9344.4
674.9	57.2	-937.4	-262.5	0.1	-1.6	-3.6	-29.1	-34.2	-296.7
674.9	57.2	-937.8	-262.9	0.1	-1.6	-3.6	-29.1	-34.2	-297.1
903.0	53.4	-	-	-	-	-	-	-	-
903.0	67.7	-1016.5	-113.5	-0.2	-2.7	-3.6	-29.1	-35.6	-149.1
1496.0	92.4	-1220.2	275.8	-0.9	-5.4	-3.6	-29.1	-39.0	236.8
1496.0	118.5	-	-	-	-	-	-	-	-
2025.0	158.5	-	-	-	-	-	-	-	-
2025.0	158.9	-	-	-	-	-	-	-	-
2110.0	118.6	-1469.2	640.8	-1.9	-8.8	-3.6	-29.1	-43.4	597.4
2110.0	117.1	-1453.7	656.3	-1.8	-8.6	-3.6	-29.1	-43.1	613.2
1728.0	102.6	-1313.0	415.0	-1.3	-6.7	-3.6	-29.1	-40.7	374.3
1728.0	101.4	-1302.2	425.8	-1.2	-6.6	-3.6	-29.1	-40.5	385.3
980.0	71.6	-1046.6	-66.6	-0.3	-3.1	-3.6	-29.1	-36.1	-102.7
980.0	69.9	-1033.5	-53.5	-0.3	-2.9	-3.6	-29.1	-35.9	-89.4
240.9	36.6	-797.1	-556.2	0.6	-0.3	-3.6	-29.1	-32.4	-588.6
240.9	-34.1	-430.8	-189.9	-	-	-7.8	-64.7	-72.5	-262.4
44.4	26.7	-735.0	-690.6	0.8	1.1	-3.6	-29.1	-30.8	-721.4
44.4	26.8	-735.8	-691.4	0.8	1.1	-3.6	-29.1	-30.8	-722.2
173.2	-28.9	-452.4	-279.2	-	-	-15.6	-129.4	-145.0	-424.2
173.2	31.3	-763.5	-590.3	0.7	0.8	-3.6	-29.1	-31.2	-621.5
353.8	-24.0	-473.4	-119.6	-	-	-9.8	-81.8	-91.6	-211.2
353.8	-33.7	-	-	-	-	-	-	-	-
538.7	49.1	-880.5	-341.8	0.3	-0.8	-3.6	-29.1	-33.2	-375.0
538.7	51.3	-895.5	-356.8	0.2	-1.0	-3.6	-29.1	-33.5	-390.3
22535.8	-	-17894.2	-2161.2	-4.4	-46.6	-90.8	-741.5	-883.3	-3044.8

Orbit Data: Case No. (Table 2-3) : IU-10
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight pa
Orbital Altitude, N. Mi. : 100
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net
1	506.0	17.8	-683.0	-177.0	-2.3	1.8	-21.7	7.3	-14.
2	506.0	17.5	-681.0	-175.0	-2.3	1.9	-21.7	7.3	-14.
3	551.6	-1.4	-	-	-	-	-	-	-
4	551.6	19.7	-693.6	-142.0	-2.3	1.7	-21.7	7.3	-15.
5	595.1	22.1	-707.4	-112.3	-2.4	1.5	-21.7	7.3	-15.
6	595.1	4.6	-	-	-	-	-	-	-
7	599.5	3.5	-	-	-	-	-	-	-
8	599.5	4.5	-	-	-	-	-	-	-
9	517.2	18.2	-684.8	-167.6	-2.3	1.8	-21.7	7.3	-14.
10	517.2	18.3	-685.9	-168.7	-2.3	1.8	-21.7	7.3	-14.
11	370.0	11.5	-647.6	-277.6	-2.2	2.3	-21.7	7.3	-14.
12	370.0	11.1	-645.5	-275.5	-2.2	2.4	-21.7	7.3	-14.
13	196.0	3.0	-601.8	-405.8	-2.0	3.0	-21.7	7.3	-13.
14	196.0	2.5	-599.4	-403.4	-2.0	3.0	-21.7	7.3	-13.
15	48.2	-6.7	-553.3	-505.1	1.8	3.6	-21.7	7.3	-12.6
16	48.2	-95.2	-231.7	-183.5	-	-	-47.3	16.2	-31.
17	33.2	-7.6	-548.6	-515.4	-1.8	3.7	-21.7	7.3	-12.
18	33.2	-6.9	-552.3	-519.1	-1.8	3.6	-21.7	7.3	-12.6
19	129.8	-60.6	-333.2	-203.4	-	-	-94.6	32.4	-62.
20	129.8	-3.4	-569.4	-439.6	-1.9	3.4	-21.7	7.3	-12.
21	265.2	-55.1	-351.8	-86.6	-	-	-60.1	20.4	-39.
22	265.4	-62.0	-	-	-	-	-	-	-
23	403.6	11.2	-645.7	-242.1	-2.2	2.4	-21.7	7.3	-14.
24	403.6	13.1	-656.2	-252.6	-2.2	2.2	-21.7	7.3	-14.
Totals	8430.8	-	-11072.2	-5252.3	-33.8	40.0	-549.2	185.8	-357.
1	674.9	25.9	-730.6	-55.7	-2.5	1.2	-21.7	7.3	-15.7
2	674.9	26.7	-735.0	-60.1	-2.5	1.1	-21.7	7.3	-15.8
3	903.0	47.7	-	-	-	-	-	-	-
4	903.0	37.9	-805.1	97.9	-2.7	0.2	-21.7	7.3	-16.9
5	1496.0	63.8	-986.3	509.7	-3.4	-2.3	-21.7	7.3	-20.1
6	1496.0	115.4	-	-	-	-	-	-	-
7	2025.0	157.4	-	-	-	-	-	-	-
8	2025.0	156.7	-	-	-	-	-	-	-
9	2110.0	92.0	-1217.3	892.7	-4.2	-5.4	-21.7	7.3	-24.0
10	2110.0	89.8	-1197.2	912.8	-4.1	-5.1	-21.7	7.3	-23.6
11	1728.0	74.3	-1068.2	659.8	-3.7	-3.4	-21.7	7.3	-21.5
12	1728.0	73.1	-1058.3	669.7	-3.6	-3.2	-21.7	7.3	-21.2
13	980.0	41.3	-827.6	152.4	-2.8	-0.1	-21.7	7.3	-17.3
14	980.0	39.6	-816.0	164.0	-2.8	0.0	-21.7	7.3	-17.2
15	240.9	4.5	-610.0	-369.1	-2.0	2.8	-21.7	7.3	-13.6
16	240.9	-51.4	-365.1	-124.2	-	-	-47.3	16.2	-31.1
17	44.4	-6.1	-556.2	-511.8	-1.8	3.6	-21.7	7.3	-12.6
18	44.4	-6.1	-556.1	-511.7	-1.8	3.6	-21.7	7.3	-12.6
19	173.2	-52.5	-361.0	-187.8	-	-	-94.6	32.4	-62.2
20	173.2	-0.7	-583.0	-409.8	-1.9	3.2	-21.7	7.3	-13.1
21	353.8	-36.2	-422.4	-68.6	-	-	-60.1	20.4	-39.7
22	353.8	-40.8	-	-	-	-	-	-	-
23	538.7	18.1	-684.4	-145.7	-2.3	1.8	-21.7	7.3	-14.9
24	538.7	19.7	-693.7	-155.0	-2.3	1.7	-21.7	7.3	-15.0
Totals	22535.8	-	-14273.4	1459.6	-44.6	-0.3	-549.2	185.8	-408.3

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ıth

Angle of Inclination (Degrees): 34

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
9	-191.9	506.0	39.1	-812.8	-306.8	-2.8	0.1	-28.0	-15.9	-46.6	-353.4
8	-189.8	506.0	38.3	-807.6	-301.6	-2.7	0.2	-28.0	-15.9	-46.4	-348.0
	-	551.6	2.3	-	-	-	-	-	-	-	-
0	-157.0	551.6	40.4	-821.4	-269.8	-2.8	-0.0	-28.0	-15.9	-46.7	-316.5
8	-127.6	595.1	42.9	-838.2	-243.1	-2.8	-0.3	-28.0	-15.9	-47.0	-290.1
	-	595.1	6.9	-	-	-	-	-	-	-	-
	-	599.5	3.9	-	-	-	-	-	-	-	-
	-	599.5	6.3	-	-	-	-	-	-	-	-
9	-182.5	517.2	38.9	-811.6	-294.4	-2.8	0.1	-28.0	-15.9	-46.6	-341.0
9	-183.6	517.2	39.5	-815.9	-298.7	-2.8	0.0	-28.0	-15.9	-46.7	-345.4
3	-291.9	370.0	33.0	-774.2	-404.2	-2.6	0.6	-28.0	-15.9	-45.9	-450.1
2	-289.7	370.0	32.6	-771.8	-401.8	-2.6	0.6	-28.0	-15.9	-45.9	-447.7
4	-419.2	196.0	24.8	-723.8	-527.8	-2.4	1.3	-28.0	-15.9	-45.0	-572.8
4	-416.8	196.0	24.4	-721.1	-525.1	-2.4	1.3	-28.0	-15.9	-45.0	-570.1
5	-517.7	48.2	15.3	-668.8	-620.6	-2.2	2.0	-28.0	-15.9	-44.1	-664.7
1	-214.6	48.2	-80.3	-271.9	-223.7	-	-	-60.9	-35.4	-96.3	-320.0
5	-527.9	33.2	14.4	-663.5	-630.3	-2.2	2.1	-28.0	-15.9	-44.0	-674.3
5	-531.7	33.2	15.2	-668.0	-634.8	-2.2	2.0	-28.0	-15.9	-44.1	-678.9
2	-265.6	129.8	-44.2	-391.4	-261.6	-	-	-121.8	-70.8	-192.6	-454.2
9	-452-5	129.8	18.1	-684.8	-555.0	-2.3	1.8	-28.0	-15.9	-44.4	-599.4
7	-126.3	265.2	-46.3	-383.6	-118.4	-	-	-77.4	-44.7	-122.1	-240.5
	-	265.4	-58.3	-	-	-	-	-	-	-	-
2	-256.3	403.6	32.2	-769.0	-365.4	-2.6	0.7	-28.0	-15.9	-45.8	-411.2
4	-267.0	403.6	34.5	-783.4	-379.8	-2.7	0.5	-28.0	-15.9	-46.1	-425.9
2	-5609.5	8430.8	-	-13182.9	-7363.0	-41.0	13.1	-708.1	-405.3	-1141.3	-8504.3
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
	-71.4	674.9	46.8	864.7	-189.8	-2.9	-0.6	-28.0	-15.9	-47.4	-237.2
	-75.9	673.9	47.1	-866.4	-191.5	-3.0	-0.6	-28.0	-15.9	-47.5	-239.0
	-	903.0	50.5	-	-	-	-	-	-	-	-
	81.0	903.0	57.8	-942.2	-39.2	-3.2	-1.7	-28.0	-15.9	-48.8	-88.0
	489.6	1496.0	82.9	-1138.5	357.5	-3.9	-4.3	-28.0	-15.9	-52.1	305.4
	-	1496.0	116.7	-	-	-	-	-	-	-	-
	-	2025.0	157.5	-	-	-	-	-	-	-	-
	-	2025.0	157.6	-	-	-	-	-	-	-	-
	868.7	2110.0	109.8	-1381.7	728.3	-4.8	-7.6	-28.0	-15.9	-56.3	672.0
	889.2	2110.0	108.0	-1364.6	745.4	-4.8	-7.4	-28.0	-15.9	-56.1	689.3
	638.3	1728.0	93.2	-1227.8	500.2	-4.3	-5.6	-28.0	-15.9	-53.8	446.4
	648.5	1728.0	92.0	-1217.3	510.7	-4.2	-5.4	-28.0	-15.9	-53.5	457.2
	135.1	980.0	61.6	-969.9	10.1	-3.3	-2.0	-28.0	-15.9	-49.2	-39.1
	146.8	980.0	59.9	-957.2	22.8	-3.3	-1.9	-28.0	-15.9	-49.1	-26.3
	-382.7	240.9	26.0	-731.0	-490.1	-2.5	1.2	-28.0	-15.9	-45.2	-535.3
	-155.3	240.9	-40.0	-407.4	-166.5	-	-	-60.9	-35.4	-96.3	-262.8
	-524.4	44.4	15.8	-671.7	-627.3	-2.2	2.0	-28.0	-15.9	-44.1	-671.4
	-524.3	44.4	15.9	-672.1	-627.7	-2.2	2.0	-28.0	-15.9	-44.1	-671.8
	-250.0	173.2	-36.9	-419.6	-246.4	-	-	-121.8	-70.8	-192.6	-439.0
	-422.9	173.2	20.7	-699.7	-526.5	-2.3	1.6	-28.0	-15.9	-44.6	-571.1
	-108.3	353.8	-28.4	-454.6	-100.8	-	-	-77.4	-44.7	-122.1	-222.9
	-	353.8	-37.7	-	-	-	-	-	-	-	-
	-160.6	538.7	38.8	-811.2	-272.5	-2.8	0.1	-28.0	-15.9	-46.6	-319.1
	-170.0	538.7	40.8	-824.4	-285.7	-2.8	-0.1	-28.0	-15.9	-46.8	-332.5
	-1051.3	22535.8	-	-16622.0	-889.0	-52.6	-30.4	-708.1	-405.3	-1196.4	-2085.4

e 4-31. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ε = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
506.0	49.4	-882.3	-376.3	-3.0	-0.9	-31.6	-29.1	-64.6	-440.9
506.0	48.4	-875.5	-369.5	-3.0	-0.8	-31.6	-29.1	-64.5	-434.0
551.6	4.1	-	-	-	-	-	-	-	-
551.6	50.5	-889.7	-338.1	-3.0	-1.0	-31.6	-29.1	-64.7	-402.8
595.1	53.1	-908.1	-313.0	-3.1	-1.2	-31.6	-29.1	-65.0	-378.0
595.1	8.1	-	-	-	-	-	-	-	-
599.5	4.0	-	-	-	-	-	-	-	-
599.5	7.2	-	-	-	-	-	-	-	-
517.2	49.0	-879.4	-362.2	-3.0	-0.9	-31.6	-29.1	-64.6	-426.8
517.2	49.9	-885.5	-368.3	-3.0	-0.9	-31.6	-29.1	-64.6	-432.9
370.0	43.5	-842.1	-472.1	-2.9	-0.3	-31.6	-29.1	-63.9	-536.0
370.0	43.1	-839.6	-469.6	-2.9	-0.3	-31.6	-29.1	-63.9	-533.5
196.0	35.5	-789.5	-593.5	-2.7	0.4	-31.6	-29.1	-63.0	-656.5
196.0	35.0	-786.7	-590.7	-2.7	0.4	-31.6	-29.1	-63.0	-653.7
48.2	26.1	-731.3	-683.1	-2.5	1.2	-31.6	-29.1	-62.0	-745.1
48.2	-72.8	-294.2	-246.0	-	-	-68.7	-64.7	-133.4	-379.4
33.2	25.1	-725.8	-692.6	-2.4	1.3	-31.6	-29.1	-61.8	-754.4
33.2	25.9	-730.6	-697.4	-2.5	1.2	-31.6	-29.1	-62.0	-759.4
129.8	-35.8	-423.9	-294.1	-	-	-137.4	-129.4	-266.8	-560.9
129.8	28.7	-747.1	-617.3	-2.5	1.0	-31.6	-29.1	-62.2	-679.5
265.2	-41.6	-401.3	-136.1	-	-	-87.2	-81.8	-169.0	-305.1
265.4	-56.5	-	-	-	-	-	-	-	-
403.6	42.5	-835.2	-431.6	-2.8	-0.2	-31.6	-29.1	-63.7	-495.3
403.6	44.9	-851.8	-448.2	-2.9	-0.4	-31.6	-29.1	-64.0	-512.2
8430.8	-	-14319.6	-8499.7	-44.8	-1.3	-798.9	-741.5	-1586.5	-10086.2
674.9	57.0	-936.3	-261.4	-3.2	-1.6	-31.6	-29.1	-65.5	-326.9
674.9	57.0	-936.4	-261.5	-3.2	-1.6	-31.6	-29.1	-65.5	-327.0
903.0	52.0	-	-	-	-	-	-	-	-
903.0	67.6	-1015-1	-112.1	-3.5	-2.7	-31.6	-29.1	-66.9	-179.0
1496.0	92.2	-1218.9	277.1	-4.2	-5.4	-31.6	-29.1	-70.3	206.8
1496.0	117.4	-	-	-	-	-	-	-	-
2025.0	157.6	-	-	-	-	-	-	-	-
2025.0	158.0	-	-	-	-	-	-	-	-
2110.0	118.5	-1467.7	642.3	-5.1	-8.8	-31.6	-29.1	-74.6	567.7
2110.0	116.9	-1452.4	657.6	-5.1	-8.6	-31.6	-29.1	-74.4	583.2
1728.0	102.5	-1311.8	416.2	-4.6	-6.7	-31.6	-29.1	-72.0	344.2
1728.0	101.3	-1300.9	427.1	-4.5	-6.5	-31.6	-29.1	-71.7	355.4
980.0	71.5	-1045.5	-65.5	-3.6	-3.1	-31.6	-29.1	-67.4	-132.9
980.0	69.8	-1032.4	-52.4	-3.6	-2.9	-31.6	-29.1	-67.2	-119.6
240.9	36.5	-796.1	-555.2	-2.7	0.3	-31.6	-29.1	-63.1	-618.3
240.9	-34.2	-430.7	-190.0	-	-	-68.7	-64.7	-133.4	-323.4
44.4	26.5	-734.1	-689.7	-2.5	1.2	-31.6	-29.1	-62.0	-751.7
44.4	26.6	-734.8	-690.4	-2.5	1.1	-31.6	-29.1	-62.1	-752.5
173.2	-28.9	-452.3	-279.1	-	-	-137.4	-129.4	-266.8	-545.9
173.2	31.2	-762.6	-589.4	-2.6	0.8	-31.6	-29.1	-62.5	-651.9
353.8	-24.2	-472.5	-118.7	-	-	-87.2	-81.8	-169.0	-287.7
353.8	-36.1	-	-	-	-	-	-	-	-
538.7	48.9	-879.1	-340.4	3.0	-0.8	-31.6	-29.1	-64.5	-404.9
538.7	51.1	-894.5	-355.8	3.1	-1.0	-31.6	-29.1	-64.8	-420.6
22535.8	-	-17874.2	-2141.2	-56.8	-46.4	-798.9	-741.5	-1643.6	-3784.8

Orbit Data: Case No. (Table 2-3) : IU-10
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight p
Orbital Altitude, N. Mi. : 100
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	506.0	18.4	-686.2	-180.2	9.4	0.7	58.5	2.8	71.4
2	506.0	18.2	-685.2	-179.2	9.4	0.7	58.5	2.8	71.4
3	551.6	5.2	-	-	-	-	-	-	-
4	551.6	20.4	-697.8	-146.2	9.0	0.7	58.5	2.8	71.0
5	595.1	22.7	-711.1	-116.0	8.5	0.6	58.5	2.8	70.4
6	595.1	11.4	-	-	-	-	-	-	-
7	599.5	11.0	-	-	-	-	-	-	-
8	599.5	11.4	-	-	-	-	-	-	-
9	517.2	18.9	-689.0	-171.8	9.3	0.7	58.5	2.8	71.3
10	517.2	18.9	-689.0	-171.8	9.3	0.7	58.5	2.8	71.3
11	370.0	12.1	-650.5	-280.5	10.6	0.9	58.5	2.8	72.8
12	370.0	11.7	-648.8	-278.8	10.6	0.9	58.5	2.8	72.8
13	196.0	3.5	-604.8	-408.8	12.2	1.2	58.5	2.8	74.7
14	196.0	3.2	-602.9	-406.9	12.2	1.2	58.5	2.8	74.7
15	48.2	-5.8	-557.7	-509.5	13.8	1.4	58.5	2.8	76.5
16	48.2	-98.9	-222.6	-174.4	-	-	130.3	6.2	136.5
17	33.2	-6.7	-553.2	-520.0	13.9	1.4	58.5	2.8	76.6
18	33.2	-6.0	-556.6	-523.4	13.8	1.4	58.5	2.8	76.5
19	129.8	-62.4	-327.3	-197.5	-	-	260.6	12.4	273.0
20	129.8	-2.3	-574.9	-445.1	13.2	1.3	58.5	2.8	75.8
21	265.2	-54.8	-352.9	-87.7	-	-	165.1	7.8	172.9
22	265.4	-48.8	-	-	-	-	-	-	-
23	403.6	12.3	-651.9	-248.3	10.5	0.9	58.5	2.8	72.7
24	403.6	13.6	-659.2	-255.6	10.3	0.9	58.5	2.8	72.5
Totals	8430.8	-	-11121.7	-5301.8	175.8	15.7	1492.0	71.2	1754.7
1	674.9	26.4	-733.5	-58.6	7.7	0.5	58.5	2.8	69.5
2	674.9	27.1	-737.3	-62.4	7.6	0.4	58.5	2.8	69.3
3	903.0	51.0	-	-	-	-	-	-	-
4	903.0	38.0	-806.2	96.8	5.2	0.1	58.5	2.8	66.6
5	1496.0	63.7	-985.5	510.5	-1.0	-0.9	58.5	2.8	59.4
6	1496.0	112.9	-	-	-	-	-	-	-
7	2025.0	153.9	-	-	-	-	-	-	-
8	2025.0	153.4	-	-	-	-	-	-	-
9	2110.0	91.3	-1211.0	899.0	-8.7	-2.1	58.5	2.8	50.5
10	2110.0	89.8	-1197.6	912.4	-8.2	-1.4	58.5	2.8	51.7
11	1728.0	74.3	-1068.0	660.0	-3.8	-1.4	58.5	2.8	56.1
12	1728.0	73.4	-1060.7	667.3	-3.5	-1.3	58.5	2.8	56.5
13	980.0	41.4	-828.4	151.6	4.5	-0.1	58.5	2.8	65.7
14	980.0	40.1	-819.6	160.4	4.8	0.0	58.5	2.8	66.1
15	240.9	5.1	-613.1	-372.2	11.9	1.1	58.5	2.8	74.3
16	240.9	-53.2	-358.6	-117.7	-	-	130.3	6.2	136.5
17	44.4	-5.2	-560.4	-516.0	13.7	1.4	58.5	2.8	76.4
18	44.4	-5.2	-560.3	-515.9	13.7	1.4	58.5	2.8	76.4
19	173.2	-54.1	-355.5	-182.3	-	-	260.6	12.4	273.0
20	173.2	0.3	-588.2	-415.0	12.7	1.25	58.5	2.8	75.2
21	353.8	-35.9	-423.6	-69.8	-	-	165.1	7.8	172.9
22	353.8	-30.1	-	-	-	-	-	-	-
23	538.7	19.1	-690.1	-151.4	9.2	0.7	58.5	2.8	71.2
24	538.7	20.2	-696.5	-157.8	9.0	0.7	58.5	2.8	71.0
Totals	22535.8	-	-14293.7	1439.3	74.8	-0.3	1492.0	71.2	1637.7

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Angle of Inclination (Degrees): 34

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	Total Heat Gain or Loss (-) Btu/hr
Optical Properties of IU Outer Surface α = 0.18, α/ϵ = 0.20										
-108.8	506.0	39.5	-815.4	-309.4	4.9	0.0	0	-6.1	-1.2	-310.6
-107.8	506.0	38.9	-812.0	-306.0	5.0	0.0	0	-6.1	-1.1	-307.1
-	551.6	7.8	-	-	-	-	-	-	-	-
-75.2	551.6	41.0	-825.7	-274.1	4.6	0.0	0	-6.1	-1.5	-275.6
-45.6	595.1	43.5	-842.1	-247.0	4.0	-0.1	0	-6.1	-2.0	-249.0
-	595.1	13.2	-	-	-	-	-	-	-	-
-	599.5	11.2	-	-	-	-	-	-	-	-
-	599.5	12.7	-	-	-	-	-	-	-	-
-100.5	517.2	39.5	-815.9	-298.7	4.9	0.0	0	-6.1	-1.2	-299.9
-100.5	517.2	39.9	-818.5	-301.3	4.8	0.0	0	-6.1	-1.3	-302.6
-207.7	370.0	33.4	-776.4	-406.4	6.2	0.2	0	-6.1	0.3	-406.1
-206.0	370.0	33.1	-774.6	-404.6	6.3	0.2	0	-6.1	0.4	-404.2
-334.1	196.0	25.2	-726.3	-530.3	8.0	0.5	0	-6.1	2.4	-527.9
-332.2	196.0	24.9	-724.2	-528.2	8.0	0.5	0	-6.1	2.4	-526.2
-433.0	48.2	16.1	-673.3	-625.1	9.8	0.8	0	-6.1	4.5	-620.6
-37.9	48.2	-84.5	-260.3	-212.1	-	-	0	-13.5	-13.5	-225.6
-443.4	33.2	15.3	-668.4	-635.2	10.0	0.8	0	-6.1	4.7	-630.5
-446.9	33.2	16.0	-672.4	-639.2	9.8	0.8	0	-6.1	4.5	-634.7
75.5	129.8	-46.3	-383.7	-253.9	-	-	0	-6.1	-27.0	-280.9
-369.3	129.8	19.2	-690.9	-561.1	9.2	0.7	0	-6.1	3.8	-557.3
85.2	265.2	-46.3	-383.4	-118.2	-	-	0	-17.2	-17.2	-135.4
-	265.4	-46.2	-	-	-	-	-	-	-	-
-175.6	403.6	33.3	-775.6	-372.0	6.3	0.2	0	-6.1	0.4	-371.6
-183.1	403.6	34.9	-785.9	-382.3	5.9	0.2	0	-6.1	0	-382.3
-3546.9	8430.8	-	-13225.1	-7405.2	107.7	4.9	0	-155.3	-42.7	-7448.1
Optical Properties of IU Outer Surface = 0.90, α/ϵ = 1.0										
10.9	674.9	47.2	-867.0	-192.1	3.1	-0.3	0	-6.1	-3.3	-195.4
6.9	674.9	47.4	-868.5	-193.6	3.1	-0.3	0	-6.1	-3.3	-196.9
-	903.0	53.0	-	-	-	-	-	-	-	-
163.4	903.0	57.9	-943.1	40.1	0.5	-0.7	0	6.1	-6.3	-46.4
569.9	1496.0	82.8	-1137.7	358.3	-6.1	-1.7	0	6.1	-13.9	344.4
-	1496.0	113.9	-	-	-	-	-	-	-	-
-	2025.0	153.9	-	-	-	-	-	-	-	-
-	2025.0	153.9	-	-	-	-	-	-	-	-
949.5	2110.0	109.1	-1374.8	735.2	-14.3	-3.0	0	-6.1	-23.4	711.8
964.1	2110.0	107.9	-1363.7	746.3	-13.9	-3.0	0	-6.1	-23.0	723.3
716.1	1728.0	93.1	-1226.2	501.8	-9.2	-2.2	0	-6.1	-17.5	484.3
723.8	1728.0	92.2	-1218.6	509.4	-9.0	-2.2	0	-6.1	-17.3	492.1
217.3	980.0	61.5	-969.6	10.4	-0.4	-0.8	0	-6.1	-7.3	3.1
226.5	980.0	60.3	-960.2	19.8	-0.1	-0.8	0	-6.1	-7.0	12.8
-297.9	240.9	26.5	-734.0	-493.1	7.7	0.5	0	-6.0	2.1	-491.0
18.8	240.9	-42.4	-398.3	-157.4	-	-	0	-13.5	-13.5	-170.9
-439.6	44.4	16.6	-675.9	-631.5	9.7	0.8	0	-6.1	4.4	-627.1
-439.5	44.4	16.7	-676.3	-631.9	9.7	0.8	0	-6.1	4.4	-627.5
90.7	173.2	-38.8	-412.3	-239.1	-	-	0	-27.0	-27.0	-266.1
-339.8	173.2	21.7	-705.4	-532.2	8.7	0.6	0	-6.1	3.2	-529.0
103.1	353.8	-28.4	-454.5	-100.7	-	-	0	-17.2	-17.2	-117.9
-	353.8	-28.0	-	-	-	-	-	-	-	-
-80.2	538.7	39.7	-817.2	-278.5	4.8	0.0	0	-6.1	-1.3	-279.8
-86.8	538.7	41.2	-826.6	-287.9	4.5	-0.0	0	-6.1	-1.6	-289.5
3077.2	22535.8	-	-16629.9	-896.9	-1.2	-12.3	0	-155.3	-168.8	-1065.7

4-32. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
506.0	49.7	-884.6	-378.6	2.5	-0.4	-33.3	-11.1	-42.3	-420.9
506.0	49.0	-879.8	-373.8	2.7	-0.3	-33.3	-11.1	-42.0	-415.8
551.6	9.1	-	-	-	-	-	-	-	-
551.6	51.1	-894.1	-342.5	2.2	-0.4	-33.3	-11.1	-42.6	-385.1
595.1	53.6	-912.1	-317.0	1.6	-0.5	-33.3	-11.1	-43.3	-360.3
595.1	14.0	-	-	-	-	-	-	-	-
599.5	11.3	-	-	-	-	-	-	-	-
599.5	13.3	-	-	-	-	-	-	-	-
517.2	49.6	-883.8	-366.6	2.6	-0.4	33.3	11.1	-42.2	-408.8
517.2	50.2	-887.8	-370.6	2.4	-0.4	33.3	11.1	-42.4	-413.0
370.0	43.8	-844.0	-474.0	3.9	-0.1	33.3	11.1	-40.6	-514.6
370.0	43.5	-842.1	-472.1	4.0	-0.1	33.3	11.1	-40.5	-512.6
196.0	35.8	-791.7	-595.7	5.7	0.1	33.3	11.1	-38.6	-634.3
196.0	35.5	-789.6	-593.6	5.8	0.2	33.3	11.1	-38.4	-632.0
48.2	26.8	-735.8	-687.6	7.6	0.5	33.3	11.1	-36.3	-723.9
48.2	-77.2	-281.2	-233.0	-	-	-74.2	-24.7	-98.9	-331.9
33.2	26.0	-730.6	-697.4	7.8	0.5	-33.3	-11.1	-36.1	-733.5
33.2	26.7	-735.0	-701.8	7.7	0.5	-33.3	-11.1	-36.2	-738.0
129.8	-38.0	-415.3	-285.5	-	-	-33.3	-11.1	-197.8	-483.3
129.8	29.7	-753.6	-623.8	7.0	0.4	-33.3	-11.1	-37.0	-660.8
265.2	-41.9	-400.3	-135.1	-	-	-94.0	-31.4	-125.4	-260.5
265.4	-45.0	-	-	-	-	-	-	-	-
403.6	43.5	-841.9	-438.3	4.0	-0.1	-33.3	-11.1	-40.5	-478.8
403.6	45.2	-853.9	-450.3	3.6	-0.2	-33.3	-11.1	-41.0	-491.3
8430.8	-	-14357.1	-8537.2	71.2	-0.9	-849.4	-283.1	-1062.2	-9599.4
674.9	57.3	-938.2	-263.3	0.7	-0.6	-33.3	-11.1	-44.3	-307.6
674.9	57.3	-938.5	-263.6	0.7	-0.6	-33.3	-11.1	-44.3	-307.9
903.0	54.0	-	-	-	-	-	-	-	-
903.0	67.6	-1015.8	-112.8	-2.0	-1.1	-33.3	-11.1	-47.5	-160.3
1496.0	92.1	-1217.9	278.1	-8.9	-2.2	-33.3	-11.1	-55.5	222.6
1496.0	114.5	-	-	-	-	-	-	-	-
2025.0	154.0	-	-	-	-	-	-	-	-
2025.0	154.2	-	-	-	-	-	-	-	-
2110.0	117.7	-1460.5	649.5	-17.3	-3.5	-33.3	-11.1	-65.2	584.3
2110.0	116.8	-1450.8	659.2	-16.9	-3.4	-33.3	-11.1	-64.7	594.5
1728.0	102.2	-1309.4	418.6	-12.1	-2.7	-33.3	-11.1	-59.2	359.4
1728.0	101.4	-1301.7	426.3	-11.8	-2.6	-33.3	-11.1	-58.8	367.5
980.0	71.3	-1044.6	-64.6	-3.0	-1.2	-33.3	-11.1	-48.6	-113.2
980.0	70.1	-1034.9	-54.9	-2.6	-1.2	-33.3	-11.1	-48.2	-103.1
240.9	36.9	-799.0	-558.1	5.5	0.1	-33.3	-11.1	-38.8	-596.9
240.9	-36.8	-420.2	-179.3	-	-	-74.2	-24.7	-98.9	-278.2
44.4	27.2	-738.4	-694.0	7.6	0.4	-33.3	-11.1	-36.4	-730.4
44.4	27.3	-739.1	-694.7	7.5	0.4	-33.3	-11.1	-36.5	-731.2
173.2	-30.9	-444.1	-270.9	-	-	-148.4	-49.4	-197.8	-468.7
173.2	32.1	-768.6	-595.4	6.5	0.3	-33.3	-11.1	-37.6	-633.0
353.8	-24.4	-471.7	-117.9	-	-	-94.0	-31.4	-125.4	-243.3
353.8	-26.9	-	-	-	-	-	-	-	-
538.7	49.8	-885.2	-346.5	2.5	-0.4	-33.3	-11.1	-42.3	-388.8
538.7	51.4	-896.2	-357.5	2.1	-0.4	-33.3	-11.1	-42.7	-400.2
22535.8	-	-17874.8	-2141.8	-41.6	-18.7	-849.4	-283.1	-1192.8	-3334.5

Orbit Data: Case No. (Table 2-3) : IU-10
Type of Orbit and Orientation: Circular Earth Orbit, X Axis Tangent to Fligh
Orbital Altitude, N. Mi. : 100
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	506.0	16.7	-677.5	-171.5	-21.5	0.8	-203.3	2.8	-221.
2	506.0	16.4	-674.7	-168.7	-21.4	0.8	-203.3	2.8	-221.
3	551.6	-13.1	-	-	-	-	-	-	-
4	551.6	18.6	-687.3	-135.7	-21.9	0.7	-203.3	2.8	-221.
5	595.1	21.1	-702.0	-106.9	-22.4	0.6	-203.3	2.8	-222.
6	595.1	-7.3	-	-	-	-	-	-	-
7	599.5	-9.0	-	-	-	-	-	-	-
8	599.5	-7.4	-	-	-	-	-	-	-
9	517.2	17.0	-678.4	-161.2	-21.6	0.8	-203.3	2.8	-221.
10	517.2	17.4	-680.4	-163.2	-21.6	0.8	-203.3	2.8	-221.
11	370.0	10.5	-642.2	-272.2	-20.3	1.0	-203.3	2.8	-219.
12	370.0	10.2	-640.5	-270.5	-20.3	1.0	-203.3	2.8	-219.
13	196.0	2.0	-596.8	-400.8	-18.8	1.2	-203.3	2.8	-218.
14	196.0	1.6	-594.9	-398.9	-18.7	1.2	-203.3	2.8	-218.
15	48.2	-7.3	-550.1	-501.9	-17.2	1.5	-203.3	2.8	-216.
16	48.2	-99.2	-221.7	-173.5	-	-	-452.6	6.2	-446.
17	33.2	-8.2	-545.7	-512.5	-17.0	1.5	-203.3	2.8	-216.
18	33.2	-7.5	-549.1	-515.9	-17.1	1.5	-203.3	2.8	-216.
19	129.8	-62.6	-326.5	-196.7	-	-	-905.2	12.4	-892.
20	129.8	-3.8	-567.1	-437.3	-17.7	1.4	-203.3	2.8	-216.
21	265.2	-57.2	-344.8	-79.6	-	-	-573.5	7.8	-565.
22	265.2	-74.8	-	-	-	-	-	-	-
23	403.6	10.3	-641.0	-237.4	-20.3	1.0	-203.3	2.8	-219.
24	403.6	12.1	-650.7	-247.1	-20.6	0.9	-203.3	2.8	-220.
Totals	8430.8	—	-10971.2	-5151.3	-318.5	16.4	-5184.1	71.2	-5415.
1	674.9	25.0	-724.6	-49.7	-23.2	0.5	-203.3	2.8	-223.
2	674.9	25.3	-726.8	-51.9	-23.2	0.5	-203.3	2.8	-223.
3	903.0	37.0	-	-	-	-	-	-	-
4	903.0	36.3	-795.3	107.7	-25.6	0.1	-203.3	2.8	-226.
5	1496.0	62.2	-974.8	521.2	-31.8	-0.8	-203.3	2.8	-233.
6	1496.0	102.6	-	-	-	-	-	-	-
7	2025.0	145.2	-	-	-	-	-	-	-
8	2025.0	144.9	-	-	-	-	-	-	-
9	2110.0	89.9	-1198.4	911.6	-39.5	-2.1	-203.3	2.8	-242.
10	2110.0	88.5	-1186.3	923.7	-39.0	-2.0	-203.3	2.8	-241.
11	1728.0	73.0	-1057.3	670.7	-34.6	-1.3	-203.3	2.8	-236.
12	1728.0	72.0	-1050.0	678.0	-34.4	-1.3	-203.3	2.8	-236.
13	980.0	40.0	-818.9	161.1	-26.4	0	-203.3	2.8	-226.
14	980.0	38.7	-810.2	169.8	-26.1	0	-203.3	2.8	-226.
15	240.9	3.6	-605.2	-364.3	-19.1	1.2	-203.3	2.8	-218.
16	240.9	-53.5	-357.6	-116.7	-	-	-452.6	6.2	-446.
17	44.4	-6.8	-552.8	-508.4	-17.3	1.4	-203.3	2.8	-216.
18	44.4	-6.8	-552.7	-508.3	-17.3	1.4	-203.3	2.8	-216.
19	173.2	-54.3	-354.7	-181.5	-	-	-905.2	12.4	-892.
20	173.2	-1.2	-580.3	-407.1	-18.2	1.3	-203.3	2.8	-217.
21	353.8	-37.8	-416.1	-62.3	-	-	-573.5	7.8	-565.
22	353.8	-53.1	-	-	-	-	-	-	-
23	538.7	17.2	-679.1	-140.4	-21.6	0.8	-203.3	2.8	-221.
24	538.7	18.7	-687.8	-149.1	-21.9	0.7	-203.3	2.8	-221.
Totals	22535.8	—	-14128.9	1604.1	-419.0	0.6	-5184.1	71.2	-5531.

: Path

Angle of Inclination (Degrees): 34

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↑ S-IVB Dome	IU Skin ↑ SLA	Coldplate/ ElecComp ↑ S-IVB Dome	Coldplate/ ElecComp ↑ SLA	Net	
	Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
2	-392.7	506.0	38.0	-806.0	-300.0	-26.0	0.1	-261.8	-6.1	-293.8	-593.8
1	-389.8	506.0	37.2	-800.6	-294.6	-25.8	0.1	-261.8	-6.1	-293.6	-588.2
	-	551.6	-10.2	-	-	-	-	-	-	-	-
7	-357.4	551.6	39.3	-814.2	-262.6	-26.2	0	-261.8	-6.1	-294.1	-556.7
3	-329.2	595.1	42.0	-832.2	-237.1	-26.9	-0.1	-261.8	-6.1	-294.9	-532.0
	-	595.1	-5.4	-	-	-	-	-	-	-	-
	-	599.5	-8.7	-	-	-	-	-	-	-	-
	-	599.5	-6.0	-	-	-	-	-	-	-	-
3	-382.5	517.2	37.8	-804.4	-287.2	-25.9	0.1	-261.8	-6.1	-293.7	-580.9
3	-384.5	517.2	38.5	-809.1	-291.9	-26.1	0.1	-261.8	-6.1	-293.9	-585.8
3	-492.0	370.0	31.9	-767.3	-397.3	-24.6	0.3	-261.8	-6.1	-292.2	-689.5
3	-490.3	370.0	31.6	-765.5	-395.5	-24.6	0.3	-261.8	-6.1	-292.2	-687.7
1	-618.9	196.0	23.7	-717.4	-521.4	-22.9	0.6	-261.8	-6.1	-290.2	-811.6
0	-616.9	196.0	23.4	-715.4	-519.4	-22.8	0.6	-261.8	-6.1	-290.1	-809.5
2	-718.1	48.2	14.7	-665.0	-616.8	-21.1	0.8	-261.8	-6.1	-288.2	-905.0
4	-619.9	48.2	-84.8	-259.4	-211.2	-	-	-582.9	-13.5	-596.4	-807.6
0	-728.5	33.2	13.8	-660.0	-626.8	-20.9	0.9	-261.8	-6.1	-287.9	-914.7
	-732.0	33.2	14.5	-644.1	-610.9	-21.1	0.8	-261.8	-6.1	-288.2	-899.1
3	-1089.5	129.8	-46.5	-382.9	-253.1	-	-	-1165.8	-27.0	-1192.8	-1445.9
	-654.1	129.8	17.7	-682.4	-552.6	-21.7	0.7	-261.8	-6.1	-288.9	-841.5
	-645.3	265.2	-48.5	-375.3	-110.1	-	-	-738.5	-17.2	-755.7	-865.8
	-	265.2	-71.8	-	-	-	-	-	-	-	-
	-457.2	403.6	31.3	-763.7	-360.1	-24.5	0.3	-261.8	-6.1	-292.1	-652.2
	-467.3	403.6	33.4	-776.6	-373.0	-25.0	0.2	-261.8	-6.1	-292.7	-665.7
	-10566.3	8430.8	—	-13061.4	-7241.5	-386.1	5.8	-6676.0	-155.3	-7211.6	-14453.1
	Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
	-272.9	674.9	45.7	-857.3	-182.4	-27.7	-0.2	-261.8	-6.1	-295.8	-478.2
	-275.1	674.9	45.7	-857.2	-182.3	-27.7	-0.2	-261.8	-6.1	-295.8	-478.1
	-	903.0	39.2	-	-	-	-	-	-	-	-
	-118.3	903.0	56.3	-931.2	-28.2	-30.3	-0.6	-261.8	-6.1	-298.8	-327.0
	288.1	1496.0	81.4	-1126.3	370.0	-37.0	-1.7	-261.8	-6.1	-306.6	63.4
	-	1496.0	103.7	-	-	-	-	-	-	-	-
	-	2025.0	145.2	-	-	-	-	-	-	-	-
	-	2025.0	145.5	-	-	-	-	-	-	-	-
	669.5	2110.0	107.7	-1361.5	748.5	-45.1	-2.9	-261.8	-6.1	-315.9	432.6
	682.2	2110.0	106.7	-1351.8	758.2	-44.7	-2.9	-261.8	-6.1	-315.5	442.7
	434.3	1728.0	91.8	-1214.9	513.1	-40.0	-2.1	-261.8	-6.1	-310.0	203.1
	441.8	1728.0	90.9	-1207.3	520.7	-39.8	-2.1	-261.8	-6.1	-309.8	210.9
	-65.8	980.0	60.2	-959.4	20.6	-31.2	-0.8	-261.8	-6.1	-299.9	-279.3
	-56.8	980.0	58.9	-950.1	29.9	-30.9	-0.7	-261.8	-6.1	-299.5	-269.6
	-582.7	240.9	25.1	-725.3	-484.4	-23.2	0.5	-261.8	-6.1	-290.6	-775.0
	-563.1	240.9	-42.6	-397.4	-156.5	-	-	-582.9	-13.5	-596.4	-752.9
	-724.8	44.4	15.1	-667.6	-623.2	-21.2	0.8	-261.8	-6.1	-288.3	-911.5
	-724.7	44.4	15.2	-668.0	-623.6	-21.2	0.8	-261.8	-6.1	-288.3	-911.9
	-1074.3	173.2	-39.0	-411.5	-238.3	-	-	-1165.8	-27.0	-1192.8	-1431.1
	-624.5	173.2	20.2	-696.8	-523.6	-22.2	0.7	-261.8	-6.1	-289.4	-813.0
	-628.0	353.8	-30.2	-447.1	-93.3	-	-	-738.5	-17.2	-755.7	-849.0
	-	353.8	-50.6	-	-	-	-	-	-	-	-
	-361.7	538.7	37.9	-805.3	-266.6	-25.9	0.1	-261.8	-6.1	-293.7	-560.1
	-370.8	538.7	39.7	-817.1	-278.4	-26.3	0	-261.8	-6.1	-294.2	-572.6
	-3927.2	22535.8	—	-16452.8	-719.8	-494.5	-11.4	-6676.0	-155.3	-7337.2	-8057.0

e 4-33. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↓ Space	Net	IU Skin ↓ S-IVB Dome	IU Skin ↓ SLA	Coldplate/ ElecComp ↓ S-IVB Dome	Coldplate/ ElecComp ↓ SLA	Net	
506.0	48.3	-874.8	-368.8	-28.3	-0.3	-295.1	-11.1	-334.8	-703.6
506.0	47.3	-868.0	-362.0	-28.1	-0.3	-295.1	-11.1	-334.6	-696.6
551.6	-8.7	-	-	-	-	-	-	-	-
551.6	49.4	-882.1	-330.5	-28.6	-0.3	-295.1	-11.1	-335.1	-665.6
595.1	52.2	-901.8	-306.7	-29.3	-0.5	-295.1	-11.1	-336.0	-642.7
595.1	-4.4	-	-	-	-	-	-	-	-
599.5	-8.6	-	-	-	-	-	-	-	-
599.5	-5.3	-	-	-	-	-	-	-	-
517.2	47.9	-871.8	-354.6	-28.2	-0.3	-295.1	-11.1	-334.7	-689.3
517.2	48.8	-878.0	-360.8	-28.4	-0.3	-295.1	-11.1	-334.9	-695.7
370.0	42.4	-834.5	-464.5	-26.9	-0.1	-295.1	-11.1	-333.2	-797.7
370.0	42.1	-832.6	-462.6	-26.9	-0.1	-295.1	-11.1	-333.2	-795.8
196.0	34.3	-782.4	-586.4	-25.2	-0.2	-295.1	-11.1	-331.2	-917.6
196.0	34.0	-780.4	-584.4	-25.1	-0.2	-295.1	-11.1	-331.1	-915.5
48.2	25.4	-727.1	-678.9	-23.2	-0.5	-295.1	-11.1	-328.9	-1007.8
48.2	-77.5	-280.3	-232.1	-	-	-657.1	-24.7	-681.8	-913.9
33.2	24.5	-721.9	-688.7	-23.1	0.5	-295.1	-11.1	-328.8	-1017.5
33.2	25.2	-726.3	-693.1	-23.2	0.5	-295.1	-11.1	-328.9	-1022.0
129.8	-38.2	-414.5	-284.7	-	-	-1314.2	-49.4	-1363.6	-1648.3
129.8	28.3	-744.7	-614.9	-23.9	0.4	-295.1	-11.1	-329.7	-944.6
265.2	-44.0	-392.2	-127.0	-	-	-832.5	-31.4	-863.9	-990.9
265.2	-70.3	-	-	-	-	-	-	-	-
403.6	41.6	-829.5	-425.9	-26.8	-0.1	-295.1	-11.1	-333.1	-759.0
403.6	43.8	-844.2	-440.6	-27.3	-0.1	-295.1	-11.1	-333.6	-774.2
8430.8	—	-14186.9	-8367.0	-422.4	0.0	-7525.4	-283.1	-8230.9	-16597.9
674.9	55.9	-928.1	-253.2	-30.2	-0.6	-295.1	-11.1	-337.0	-590.2
674.9	55.7	-926.8	-251.9	-30.1	-0.6	-295.1	-11.1	-336.9	-588.8
903.0	40.3	-	-	-	-	-	-	-	-
903.0	66.0	-1003.5	-100.5	-32.8	-1.0	-295.1	-11.1	-340.0	-440.5
1496.0	90.8	-1206.2	289.8	-39.7	-2.1	-295.1	-11.1	-348.0	-58.2
1496.0	104.3	-	-	-	-	-	-	-	-
2025.0	145.3	-	-	-	-	-	-	-	-
2025.0	145.8	-	-	-	-	-	-	-	-
2110.0	116.4	-1446.9	663.1	-48.0	-3.4	-295.1	-11.1	-357.6	305.5
2110.0	115.6	-1438.5	671.5	-47.7	-3.4	-295.1	-11.1	-357.3	314.2
1728.0	100.9	-1297.8	430.2	-42.9	-2.6	-295.1	-11.1	-351.7	78.5
1728.0	100.1	-1290.0	438.0	-42.6	-2.6	-295.1	-11.1	-351.4	86.6
980.0	70.0	-1034.0	-54.0	-33.8	-1.2	-295.1	-11.1	-341.2	-395.2
980.0	68.8	-1024.4	-44.4	-33.5	-1.1	-295.1	-11.1	-340.8	-385.2
240.9	35.5	-789.9	-549.0	-25.4	0.2	-295.1	-11.1	-331.4	-880.4
240.9	-37.0	-419.2	-178.3	-	-	-657.1	-24.7	-681.8	-860.1
44.4	25.8	-729.6	-685.2	-23.3	0.5	-295.1	-11.1	-329.0	-1014.2
44.4	25.9	-730.3	-685.9	-23.4	0.5	-295.1	-11.1	-329.1	-1015.0
173.2	-31.1	-443.3	-270.1	-	-	-1314.2	-49.4	-1363.6	-1633.7
173.2	30.7	-759.7	-586.5	-24.4	0.3	-295.1	-11.1	-330.3	-916.8
353.8	-26.1	-464.2	-110.4	-	-	-832.5	-31.4	-863.9	-974.3
353.8	-49.3	-	-	-	-	-	-	-	-
538.7	48.0	-872.8	-334.1	-28.3	-0.3	-295.1	-11.1	-334.8	-668.9
538.7	50.0	-886.3	-347.6	-28.7	-0.4	-295.1	-11.1	-335.3	-682.9
22535.8		-17691.6	-1958.6	-534.7	-17.7	-7525.4	-283.1	-8360.9	-10319.6

Orbit Data: Case No. (Table 2-3) : IU-11
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight p
Orbital Altitude, N. Mi. : 200
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	480.8	16.8	-676.9	-196.1	1.0	1.9	6.3	7.3	16.5
2	480.8	16.5	-675.1	-194.3	1.0	2.0	6.3	7.3	16.6
3	542.0	-1.1	-	-	-	-	-	-	-
4	542.0	19.4	-692.0	-150.0	1.0	1.7	6.3	7.3	16.3
5	591.2	22.0	-707.3	-116.1	0.9	1.5	6.3	7.3	16.0
6	591.2	6.0	-	-	-	-	-	-	-
7	598.1	5.4	-	-	-	-	-	-	-
8	598.1	6.3	-	-	-	-	-	-	-
9	517.7	18.4	-686.1	-168.4	1.0	1.8	6.3	7.3	16.4
10	517.7	18.5	-686.9	-169.2	1.0	1.8	6.3	7.3	16.4
11	371.5	11.8	-648.9	-277.4	1.1	2.3	6.3	7.3	17.0
12	371.5	11.4	-646.8	-275.3	1.1	2.3	6.3	7.3	17.0
13	196.0	3.1	-602.7	-406.7	1.3	2.9	6.3	7.3	17.8
14	196.0	2.7	-600.3	-404.3	1.3	3.0	6.3	7.3	17.9
15	48.2	-6.5	-554.1	-505.9	1.5	3.6	6.3	7.3	18.7
16	48.2	-95.3	-231.6	-183.4	-	-	13.6	16.2	29.8
17	20.6	-8.1	-546.3	-525.7	1.5	3.7	6.3	7.3	18.8
18	20.6	-7.4	-549.5	-528.9	1.5	3.7	6.3	7.3	18.8
19	103.6	-65.6	-316.6	-213.0	-	-	27.2	32.4	59.6
20	103.6	-4.8	-562.5	-458.9	1.4	3.5	6.3	7.3	18.5
21	231.8	-62.7	-326.2	-94.4	-	-	17.3	20.4	37.7
22	231.8	-67.8	-	-	-	-	-	-	-
23	370.9	9.6	-637.3	-266.4	1.2	2.5	6.3	7.3	17.3
24	370.9	11.6	-648.3	-277.4	1.1	2.3	6.3	7.3	17.0
Totals	8144.8	-	-10995.3	-5411.7	18.9	40.5	158.9	185.9	404.1
1	649.7	24.9	-724.2	-74.5	0.8	1.3	6.3	7.3	15.7
2	649.7	25.9	-730.2	-80.5	0.8	1.2	6.3	7.3	15.6
3	956.2	55.4	-	-	-	-	-	-	-
4	956.2	40.7	-823.6	132.6	0.5	-0.1	6.3	7.3	14.0
5	1596.6	68.4	-1021.5	575.1	-0.2	-2.7	6.3	7.3	10.7
6	1596.6	125.2	-	-	-	-	-	-	-
7	2141.0	166.8	-	-	-	-	-	-	-
8	2141.0	166.0	-	-	-	-	-	-	-
9	2290.0	96.4	-1256.6	1033.4	-1.1	-5.9	6.3	7.3	6.6
10	2290.0	94.0	-1234.2	1055.8	-1.0	-5.6	6.3	7.3	7.0
11	1782.0	76.8	-1088.4	693.6	-0.5	-3.7	6.3	7.3	9.4
12	1782.0	75.5	-1077.6	704.4	-0.4	-3.5	6.3	7.3	9.7
13	980.0	41.5	-829.0	151.0	0.5	-0.1	6.3	7.3	14.0
14	980.0	39.7	-817.0	163.0	0.5	0.0	6.3	7.3	14.1
15	240.8	4.7	-610.8	-370.0	1.3	2.8	6.3	7.3	17.7
16	240.8	-51.4	-364.8	-124.0	-	-	13.6	16.2	29.8
17	27.4	-6.7	-552.9	-525.5	1.5	3.6	6.3	7.3	18.7
18	27.4	-6.9	-552.0	-524.6	1.5	3.6	6.3	7.3	18.7
19	138.3	-59.0	-338.7	-200.4	-	-	27.2	32.4	59.6
20	138.3	-2.6	-573.6	-435.4	1.4	3.3	6.3	7.3	18.3
21	309.4	-45.2	-387.7	-78.3	-	-	17.3	20.4	37.7
22	309.4	-48.3	-	-	-	-	-	-	-
23	494.9	16.0	-672.5	-177.6	1.0	2.0	6.3	7.3	16.6
24	494.9	17.8	-682.5	-187.6	1.0	1.9	6.3	7.3	16.5
Totals	23211.6	-	-14337.9	1729.5	7.5	-2.0	158.9	185.9	350.2

Table

ath

Angle of Inclination (Degrees): 34

Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ElecComp ↕ S-IVB Dome	Coldplate/ElecComp ↕ SLA	Net	Total Heat Gain or Loss (-) Btu/hr
Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$										
-179.6	480.8	38.0	-806.1	-325.3	0.6	0.2	0	-15.9	-15.1	-340.4
-177.7	480.8	37.3	-801.3	-320.5	0.6	0.2	0	-15.9	-15.1	-335.6
-	542.0	2.6	-	-	-	-	-	-	-	-
-133.7	542.0	40.1	-819.6	-277.6	0.5	-0.0	0	-15.9	-15.4	-293.0
-100.1	591.2	42.9	-838.0	-246.8	0.4	-0.3	0	-15.9	-15.8	-262.6
-	591.2	8.3	-	-	-	-	-	-	-	-
-	598.1	5.7	-	-	-	-	-	-	-	-
-	598.1	8.1	-	-	-	-	-	-	-	-
-152.0	517.7	39.1	-813.0	-295.3	0.5	0.1	0	-15.9	-15.3	-310.6
-152.8	517.7	39.7	-817.0	-299.3	0.5	0.0	0	-15.9	-15.4	-314.7
-260.4	371.5	33.2	-775.6	-404.1	0.7	0.6	0	-15.9	-14.6	-418.7
-258.3	371.5	32.9	-773.2	-401.7	0.7	0.6	0	-15.9	-14.6	-416.3
-388.9	196.0	25.0	-724.7	-528.7	0.8	1.3	0	-15.9	-13.8	-542.5
-386.4	196.0	24.5	-722.1	-526.1	0.9	1.3	0	-15.9	-13.7	-539.8
-487.2	48.2	15.5	-669.7	-621.5	1.0	2.0	0	-15.9	-12.9	-634.4
-153.6	48.2	-80.4	-271.8	-223.6	-	-	0	-35.4	-35.4	-259.0
-506.9	20.6	14.0	-661.1	-640.5	1.1	2.1	0	-15.9	-12.7	-653.2
-510.1	20.6	14.6	-664.9	-644.3	1.1	2.1	0	-15.9	-12.7	-657.0
-153.4	103.6	-48.7	-374.5	-270.9	-	-	0	-70.8	-70.8	-341.7
-440.4	103.6	16.8	-677.3	-573.7	1.0	1.9	0	-15.9	-13.0	-586.7
-56.7	231.8	-53.4	-357.8	-126.0	-	-	0	-44.7	-44.7	-170.7
-	231.8	-64.0	-	-	-	-	-	-	-	-
-249.1	370.9	30.7	-759.9	-389.0	0.7	0.8	0	-15.9	-14.4	-403.4
-260.4	370.9	33.1	-774.8	-403.9	0.7	0.6	0	-15.9	-14.6	-418.5
-5007.7	8144.8	-	-13102.3	-7518.7	11.7	13.6	0	-405.3	-380.0	-7898.8
Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$										
-58.8	649.7	45.8	-857.7	-208.0	0.4	-0.5	0	-15.9	-16.0	-224.0
-64.9	649.7	46.3	-861.1	-211.4	0.4	-0.6	0	-15.9	-16.1	-227.5
-	956.2	58.1	-	-	-	-	-	-	-	-
146.6	956.2	60.5	-962.1	-5.9	-0.0	-1.9	0	-15.9	-17.8	-23.7
585.8	1596.6	87.3	-1176.1	420.5	-0.8	-4.8	0	-15.9	-21.5	399.0
-	1596.6	126.5	-	-	-	-	-	-	-	-
-	2141.0	166.9	-	-	-	-	-	-	-	-
-	2141.0	166.8	-	-	-	-	-	-	-	-
1040.0	2290.0	114.0	-1423.2	866.8	-1.7	-8.2	0	-15.9	-25.8	841.0
1062.8	2290.0	112.1	-1403.9	886.1	-1.6	-7.9	0	-15.9	-25.4	860.7
703.0	1782.0	95.6	-1249.4	532.6	-1.1	-5.8	0	-15.9	-22.8	509.8
714.1	1782.0	94.4	-1237.8	544.2	-1.0	-5.7	0	-15.9	-22.6	521.6
165.0	980.0	61.8	-971.4	8.6	-0.0	-2.1	0	-15.9	-18.0	-9.4
177.1	980.0	60.0	-958.3	21.7	0	-1.9	0	-15.9	-17.8	3.9
-352.3	240.8	26.2	-731.9	-491.1	0.8	1.2	0	-15.9	-13.9	-505.0
-94.2	240.8	-40.1	-407.2	-166.4	-	-	0	-35.4	-35.4	-201.8
-506.8	27.4	15.2	-668.0	-640.6	1.1	2.0	0	-15.9	-12.8	-653.4
-505.9	27.4	15.1	-667.6	-640.2	1.1	2.1	0	-15.9	-12.7	-652.9
-140.8	138.3	-42.7	-396.9	-258.6	-	-	0	-70.8	-70.8	-329.4
-417.0	138.3	18.9	-689.3	-551.0	1.0	1.8	0	-15.9	-13.1	-564.1
-40.6	309.4	-36.9	-419.7	-110.3	-	-	0	-44.7	-44.7	-155.0
-	309.4	-45.0	-	-	-	-	-	-	-	-
-161.0	494.9	36.8	-798.3	-303.4	0.6	0.3	0	-15.9	-15.0	-318.4
-171.1	494.9	39.0	-812.3	-317.4	0.5	0.1	0	-15.9	-15.3	-332.7
2097.7	23211.6	-	-16692.3	-624.9	-0.5	-32.1	0	-405.3	-437.9	-1062.8

4-34. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
480.8	48.4	-875.4	-394.6	0.3	-0.8	-3.6	-29.1	-33.2	-427.8
480.8	47.4	-868.8	-388.0	0.3	-0.7	-3.6	-29.1	-33.1	-421.1
542.0	4.4	-	-	-	-	-	-	-	-
542.0	50.2	-887.9	-345.9	0.3	-0.9	-3.6	-29.1	-33.3	-379.2
591.2	53.0	-907.9	-316.7	0.2	-1.2	-3.6	-29.1	-33.7	-350.4
591.2	9.5	-	-	-	-	-	-	-	-
598.1	5.9	-	-	-	-	-	-	-	-
598.1	9.0	-	-	-	-	-	-	-	-
517.7	49.2	-880.8	-363.1	0.3	-0.8	-3.6	-29.1	-33.2	-396.3
517.7	50.2	-886.7	-369.0	0.3	-0.9	-3.6	-29.1	-33.3	-402.3
371.5	43.7	-843.6	-472.1	0.4	-0.3	-3.6	-29.1	-32.6	-504.7
371.5	43.3	-841.1	-469.6	0.4	-0.3	-3.6	-29.1	-32.6	-502.2
196.0	35.6	-790.5	-594.5	0.6	0.4	-3.6	-29.1	-31.7	-626.2
196.0	35.2	-787.7	-591.7	0.6	0.4	-3.6	-29.1	-31.7	-623.4
48.2	26.2	-732.2	-684.0	0.8	1.1	-3.6	-29.1	-30.8	-714.8
48.2	-72.9	-294.1	-245.9	-	-	-7.8	-64.7	-72.5	-318.4
20.6	24.7	-723.1	-702.5	0.9	1.3	-3.6	-29.1	-30.5	-733.0
20.6	25.4	-727.4	-706.8	0.8	1.2	-3.6	-29.1	-30.7	-737.5
103.6	-40.1	-407.0	-303.4	-	-	-15.6	-129.4	-145.0	-448.4
103.6	27.4	-739.3	-635.7	0.8	1.1	-3.6	-29.1	-30.8	-666.5
231.8	-48.5	-375.4	-143.6	-	-	-9.8	-81.8	-91.6	-235.2
231.8	-62.1	-	-	-	-	-	-	-	-
370.9	41.0	-825.7	-454.8	0.5	-0.1	-3.6	-29.1	-32.3	-487.1
370.9	43.6	-842.7	-471.8	0.4	-0.3	-3.6	-29.1	-32.6	-504.4
8144.8	-	-14237.3	-8653.7	7.9	-0.8	-90.8	-741.5	-825.2	-9478.9
649.7	56.0	-929.1	-279.4	0.1	-1.5	-3.6	-29.1	-34.1	-313.5
649.7	56.3	-931.0	-281.3	0.1	-1.5	-3.6	-29.1	-34.1	-315.4
956.2	59.5	-	-	-	-	-	-	-	-
956.2	70.2	-1035.7	-79.5	-0.3	-2.9	-3.6	-29.1	-35.9	-115.4
1596.6	96.6	-1257.6	339.0	-1.1	-6.0	-3.6	-29.1	-39.8	299.2
1596.6	127.2	-	-	-	-	-	-	-	-
2141.0	167.0	-	-	-	-	-	-	-	-
2141.0	167.2	-	-	-	-	-	-	-	-
2290.0	122.6	-1510.3	779.7	-2.0	-9.4	-3.6	-29.1	-44.1	735.6
2290.0	120.9	-1492.7	797.3	-1.9	-9.1	-3.6	-29.1	-43.7	753.6
1782.0	104.8	-1334.0	448.0	-1.4	-7.0	-3.6	-29.1	-41.1	406.9
1782.0	103.6	-1322.1	459.9	-1.3	-6.8	-3.6	-29.1	-40.8	419.1
980.0	71.7	-1047.1	-67.1	-0.3	-3.1	-3.6	-29.1	-36.1	-103.2
980.0	69.9	-1033.5	-53.5	-0.3	-2.9	-3.6	-29.1	-35.9	-89.4
240.8	36.6	-797.1	-556.3	0.6	0.3	-3.6	-29.1	-31.8	-588.1
240.8	-34.2	-430.4	-189.6	-	-	-7.8	-64.7	-72.5	-262.1
27.4	25.9	-730.2	-702.8	0.8	1.2	-3.6	-29.1	-30.7	-733.5
27.4	25.9	-730.2	-702.8	0.8	1.2	-3.6	-29.1	-30.7	-733.5
138.3	-34.4	-429.5	-291.2	-	-	-15.6	-129.4	-145.0	-436.2
138.3	29.4	-751.8	-613.5	0.7	0.9	-3.6	-29.1	-31.1	-644.6
309.4	-32.5	-437.5	-128.1	-	-	-9.8	-81.8	-91.6	-219.7
309.4	-43.4	-	-	-	-	-	-	-	-
494.9	47.0	-865.7	-370.8	0.3	-0.6	-3.6	-29.1	-33.0	-403.8
494.9	49.3	-881.8	-386.9	0.3	-0.9	-3.6	-29.1	-33.3	-420.2
23211.6	-	-17947.2	-1879.8	-4.8	-48.1	-90.8	-741.5	-885.2	-2765.0

Orbit Data: Case No. (Table 2-3) : IU-11
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight p
Orbital Altitude, N. Mi. : 200
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	480.8	16.6	-676.0	-195.2	-2.3	1.9	-21.7	7.3	-14.
2	480.8	16.2	-674.0	-193.2	-2.3	2.0	-21.7	7.3	-14.
3	542.0	-3.1	-	-	-	-	-	-	-
4	542.0	19.2	-690.8	-148.8	-2.3	1.7	-21.7	7.3	-15.
5	591.2	21.9	-706.3	-115.1	-2.4	1.5	-21.7	7.3	-15.
6	591.2	4.0	-	-	-	-	-	-	-
7	598.1	3.2	-	-	-	-	-	-	-
8	598.1	4.3	-	-	-	-	-	-	-
9	517.7	18.2	-684.9	-167.2	-2.3	1.8	-21.7	7.3	-14.
10	517.7	18.4	-686.0	-168.3	-2.3	1.8	-21.7	7.3	-14.
11	371.5	11.6	-648.0	-276.5	-2.2	2.3	-21.7	7.3	-14.
12	371.5	11.2	-645.9	-274.4	-2.2	2.3	-21.7	7.3	-14.
13	196.0	3.0	-601.8	-405.8	-2.0	2.9	-21.7	7.3	-13.
14	196.0	2.5	-599.4	-403.4	-2.0	3.0	-21.7	7.3	-13.
15	48.2	-6.7	-553.3	-505.1	-1.8	3.6	-21.7	7.3	-12.
16	48.2	-95.3	-231.4	-183.2	-	-	-47.3	16.2	-31.
17	20.6	-8.2	-545.5	-524.9	-1.8	3.7	-21.7	7.3	-12.
18	20.6	-7.6	-548.7	-528.1	-1.8	3.7	-21.7	7.3	-12.
19	103.6	-65.7	-316.5	-212.9	-	-	-94.6	32.4	-62.
20	103.6	-5.0	-561.6	-458.0	-1.8	3.5	-21.7	7.3	-12.
21	231.8	-63.0	-325.2	-93.4	-	-	-60.1	20.4	-39.
22	231.8	-70.8	-	-	-	-	-	-	-
23	370.9	9.4	-636.1	-265.2	-2.1	2.5	-21.7	7.3	-14.
24	370.9	11.5	-647.4	-276.5	-2.2	2.3	-21.7	7.3	-14.
Totals	8144.8	-	-10978.9	-5395.3	-33.6	40.7	-549.2	185.8	-356.
1	649.7	24.7	-723.3	-73.6	-2.4	1.3	-21.7	7.3	-15.
2	649.7	25.7	-729.0	-79.3	-2.5	1.2	-21.7	7.3	-15.
3	956.2	54.0	-	-	-	-	-	-	-
4	956.2	40.5	-822.3	133.9	-2.8	-0.0	-21.7	7.3	-17.
5	1596.6	68.2	-1020.3	576.3	-3.5	-2.7	-21.7	7.3	-20.
6	1596.6	124.2	-	-	-	-	-	-	-
7	2141.0	165.9	-	-	-	-	-	-	-
8	2141.0	165.1	-	-	-	-	-	-	-
9	2290.0	96.3	-1255.2	1034.8	-4.4	-5.9	-21.7	7.3	-24.
10	2290.0	93.8	-1233.0	1057.0	-4.3	-5.6	-21.7	7.3	-24.
11	1782.0	76.7	-1087.3	694.7	-3.8	-3.6	-21.7	7.3	-21.
12	1782.0	75.4	-1076.5	705.5	-3.7	-3.5	-21.7	7.3	-21.
13	980.0	41.4	-828.0	152.0	-2.8	-0.1	-21.7	7.3	-17.
14	980.0	39.6	-816.0	164.0	-2.8	0.0	-21.7	7.3	-17.
15	240.8	4.5	-609.9	-369.1	-2.0	2.8	-21.7	7.3	-13.
16	240.8	-51.5	-364.7	-123.9	-	-	-47.3	16.2	-31.
17	27.4	-6.9	-552.1	-524.7	-1.8	3.6	-21.7	7.3	-12.
18	27.4	-7.1	-551.2	-523.8	-1.8	3.6	-21.7	7.3	-12.
19	138.3	-59.0	-338.6	-200.3	-	-	-94.6	32.4	-62.
20	138.3	-2.7	-572.7	-434.4	-1.9	3.3	-21.7	7.3	-13.
21	309.4	-45.4	-386.7	-77.3	-	-	-60.1	20.4	-39.
22	309.4	-50.9	-	-	-	-	-	-	-
23	494.9	15.8	-671.3	-176.4	-2.2	2.0	-21.7	7.3	-14.
24	494.9	17.6	-681.6	-186.7	-2.3	1.9	-21.7	7.3	-14.
Totals	23211.6	-	-14319.8	1747.6	-44.9	-1.7	-549.2	185.8	-410.

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Angle of Inclination (Degrees): 34

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	Total Heat Gain or Loss (-) Btu/hr
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
8	-210.0	480.8	37.9	-805.1	-324.3	-2.7	0.2	-28.0	-15.9	-46.4	-370.7
7	-207.9	480.8	37.1	-800.0	-319.2	-2.7	0.3	-28.0	-15.9	-46.3	-365.5
	-	542.0	0.7	-	-	-	-	-	-	-	-
0	-163.8	542.0	39.9	-818.4	-276.4	-2.8	0.0	-28.0	-15.9	-46.7	-323.1
3	-130.4	591.2	42.7	-836.9	-245.7	-2.8	0.2	-28.0	-15.9	-46.9	-292.6
	-	591.2	6.3	-	-	-	-	-	-	-	-
	-	598.1	3.6	-	-	-	-	-	-	-	-
	-	598.1	6.1	-	-	-	-	-	-	-	-
9	-182.1	517.7	38.9	-811.7	-294.0	-2.8	0.1	-28.0	-15.9	-46.6	-340.6
9	-183.2	517.7	39.6	-816.0	-298.3	-2.8	0.0	-28.0	-15.9	-46.7	-345.0
3	-290.8	371.5	33.1	-774.6	-403.1	-2.6	0.6	-28.0	-15.9	-45.9	-449.0
3	-288.7	371.5	32.7	-772.2	-400.7	-2.6	0.6	-28.0	-15.9	-45.9	-446.6
5	-419.3	196.0	24.8	-723.8	-527.8	-2.4	1.3	-28.0	-15.9	-45.0	-572.8
4	-416.8	196.0	24.4	-721.1	-525.1	-2.4	1.3	-28.0	-15.9	-45.0	-570.1
6	-517.7	48.2	15.3	-668.8	-620.6	-2.2	2.0	-28.0	-15.9	-44.1	-664.7
1	-214.3	48.2	-80.4	-271.7	-223.5	-	-	-60.9	-35.4	-96.3	-319.8
5	-537.4	20.6	13.8	-660.2	-639.6	-2.2	2.2	-28.0	-15.9	-43.9	-683.5
5	-540.6	20.6	14.5	-664.0	-643.4	-2.2	2.1	-28.0	-15.9	-44.0	-687.4
2	-275.1	103.6	-48.8	-374.4	-270.8	-	-	-121.8	-70.8	-192.6	-463.4
7	-470.7	103.6	16.7	-676.4	-572.8	-2.3	1.9	-28.0	-15.9	-44.3	-617.1
7	-133.1	231.8	-53.7	-356.8	-125.0	-	-	-77.4	-44.7	-122.1	-247.1
	-	231.8	-66.9	-	-	-	-	-	-	-	-
0	-279.2	370.9	30.5	-758.5	-387.6	-2.6	0.8	-28.0	-15.9	-45.7	-433.3
3	-290.8	370.9	33.0	-773.8	-402.9	-2.6	0.6	-28.0	-15.9	-45.9	-448.8
3	-5751.6	8144.8	-	-13084.5	-7500.9	-40.8	13.9	-708.1	-405.3	-1140.3	-8641.2
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
	-89.1	649.7	45.7	-856.7	-207.0	-2.9	-0.5	-28.0	-15.9	-47.3	-254.3
	-95.0	649.7	46.1	-859.8	-210.1	-2.9	-0.6	-28.0	-15.9	-47.4	-257.5
	-	956.2	56.7	-	-	-	-	-	-	-	-
	116.7	956.2	60.4	-960.8	-4.6	-3.3	-1.9	-28.0	-15.9	-49.1	-53.7
	555.7	1596.6	87.2	-1174.8	421.8	-4.1	-4.8	-28.0	-15.9	-52.8	369.0
	-	1596.6	125.5	-	-	-	-	-	-	-	-
	-	2141.0	166.0	-	-	-	-	-	-	-	-
	-	2141.0	165.9	-	-	-	-	-	-	-	-
	1010.1	2290.0	113.9	-1421.7	868.3	-5.0	-8.2	-28.0	-15.9	-57.1	811.2
	1032.7	2290.0	111.9	-1402.6	887.4	-4.9	-7.9	-28.0	-15.9	-56.7	830.7
	672.9	1782.0	95.5	-1248.1	533.9	-4.3	-5.8	-28.0	-15.9	-54.0	479.9
	683.9	1782.0	94.2	-1236.6	545.4	-4.3	-5.7	-28.0	-15.9	-53.9	491.5
	134.7	980.0	61.6	-970.3	9.7	-3.3	-2.1	-28.0	-15.9	-49.3	-39.6
	146.8	980.0	59.9	-957.3	22.7	-3.3	-1.9	-28.0	-15.9	-49.1	-26.4
	-382.7	240.8	26.0	-731.0	-490.2	-2.4	1.2	-28.0	-15.9	-45.1	-535.3
	-155.0	240.8	-40.1	-407.0	-166.2	-	-	-121.8	-70.8	-192.6	-358.8
	-587.3	27.4	15.0	-667.1	-639.7	-2.2	2.1	-28.0	-15.9	-44.0	-683.7
	-536.4	27.4	15.0	-666.8	-639.4	-2.2	2.1	-28.0	-15.9	-44.0	-683.4
	-262.5	138.3	-42.8	-396.8	-258.5	-	-	-60.9	-35.4	-96.3	-354.8
	-447.4	138.3	18.8	-688.4	-550.1	-2.3	1.8	-28.0	-15.9	-44.4	-594.5
	-117.0	309.4	-37.1	-418.8	-109.4	-	-	-77.4	-44.7	-122.1	-231.5
	-	309.4	-47.6	-	-	-	-	-	-	-	-
	-191.0	494.9	36.6	-797.0	-302.1	-2.7	0.3	-28.0	-15.9	-46.3	-348.4
	-201.5	494.9	38.8	-811.3	-316.4	-2.8	0.1	-28.0	-15.9	-46.6	-363.0
	1337.6	23211.6	-	-16672.9	-605.5	-53.0	-31.9	-708.1	-405.3	-1198.3	-1803.8

le 4-35. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature =-210 F
Emissivity, ϵ = 0.05

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
480.8	48.2	-874.3	-393.5	-3.0	-0.8	-31.6	-29.1	-64.5	-458.0
480.0	47.2	-876.5	-386.7	-3.0	-0.7	-31.6	-29.1	-64.4	-451.1
542.0	2.5	-	-	-	-	-	-	-	-
542.0	50.0	-886.6	-344.6	-3.0	-0.9	-31.6	-29.1	-64.6	-409.2
591.2	52.9	-906.7	-315.5	-3.1	-1.2	-31.6	-29.1	-65.0	-380.5
591.2	7.5	-	-	-	-	-	-	-	-
598.1	3.8	-	-	-	-	-	-	-	-
598.1	7.0	-	-	-	-	-	-	-	-
517.7	49.0	-879.5	-361.8	-3.0	-0.8	-31.6	-29.1	-64.5	-426.3
517.7	49.9	-885.7	-368.0	-3.0	-0.9	-31.6	-29.1	-64.6	-432.6
371.5	43.6	-842.6	-471.1	-2.9	-0.3	-31.6	-29.1	-63.9	-535.0
371.5	43.2	-840.1	-468.6	-2.9	-0.3	-31.6	-29.1	-63.9	-532.5
196.0	35.5	-789.5	-593.5	-2.7	0.4	-31.6	-29.1	-63.0	-656.5
196.0	35.0	-786.7	-590.7	-2.7	0.4	-31.6	-29.1	-63.0	-653.7
48.2	26.1	-731.3	-683.1	-2.5	1.2	-31.6	-29.1	-62.0	-745.1
48.2	-72.9	-294.0	-245.8	-	-	-68.7	-64.7	-133.4	-379.2
20.6	24.5	-722.2	-701.6	-2.4	1.3	-31.6	-29.1	-61.8	-763.4
20.6	25.3	-726.5	-705.9	-2.4	1.3	-31.6	-29.1	-61.8	-767.7
103.6	-40.2	-406.8	-303.2	-	-	-137.4	-129.4	-266.8	-570.0
103.6	27.2	-738.3	-634.7	-2.5	1.1	-31.6	-29.1	-62.1	-696.8
231.8	-48.8	-374.3	-142.5	-	-	-87.2	-81.8	-169.0	-311.5
231.8	-65.0	-	-	-	-	-	-	-	-
370.9	40.8	-824.3	-453.4	-2.8	-0.1	-31.6	-29.1	-63.6	-517.0
370.9	43.4	-841.7	-470.8	-2.9	-0.3	-31.6	-29.1	-63.9	-534.7
8144.8	-	-14218.7	-8635.1	-44.6	-0.6	-798.9	-741.5	-1585.6	-10220.7
649.7	55.9	-928.0	-278.3	-3.2	-1.5	-31.6	-29.1	-65.4	-343.7
649.7	56.1	-929.7	-280.0	-3.2	-1.5	-31.6	-29.1	-65.4	-345.4
956.2	58.1	-	-	-	-	-	-	-	-
956.2	70.0	-1034.3	-78.1	-3.6	-2.9	-31.6	-29.1	-67.2	-145.3
1596.6	96.4	-1256.2	340.4	-4.4	-5.9	-31.6	-29.1	71.0	269.4
1596.6	126.2	-	-	-	-	-	-	-	-
2141.0	166.1	-	-	-	-	-	-	-	-
2141.0	166.4	-	-	-	-	-	-	-	-
2290.0	122.5	-1508.7	781.3	-5.3	-9.4	-31.6	-29.1	-75.4	705.9
2290.0	120.8	-1491.4	798.6	-5.2	-9.1	-31.6	-29.1	-75.0	723.6
1782.0	104.7	-1332.8	449.2	-4.6	-7.0	-31.6	-29.1	-72.3	376.9
1782.0	103.4	-1320.9	461.1	-4.6	-6.8	-31.6	-29.1	-72.1	389.0
980.0	71.5	-1046.0	-66.0	-3.6	-3.1	-31.6	-29.1	-67.4	-133.4
980.0	69.8	-1032.4	-52.4	-3.6	-2.9	-31.6	-29.1	-67.2	-119.6
240.8	36.5	-796.1	-555.3	-2.7	0.3	-31.6	-29.1	-63.1	-618.4
240.8	-34.3	-430.3	-189.5	-	-	-68.7	-68.7	-137.4	-326.9
27.4	25.7	-729.3	-701.9	-2.5	1.2	-31.6	-29.1	-62.0	-763.9
27.4	25.7	-729.3	-701.9	-2.5	1.2	-31.6	-29.1	-62.0	-763.9
138.3	-34.5	-429.4	-291.1	-	-	-137.4	-129.4	-266.8	-557.9
138.3	29.3	-750.9	-612.6	-2.5	0.9	-31.6	-29.1	-62.3	-674.9
309.4	-32.7	-436.5	-127.1	-	-	-87.2	-81.8	-169.0	-296.1
309.4	-45.9	-	-	-	-	-	-	-	-
494.9	46.8	-864.3	-369.4	-2.9	-0.6	-31.6	-29.1	-64.2	-433.6
494.9	49.2	-880.7	-385.8	-3.0	-0.8	-31.6	-29.1	-64.5	-450.3
23211.6	-	-17927.1	-1859.7	-57.2	-47.9	-798.9	-741.5	-1645.5	-3505.2

Orbit Data: Case No. (Table 2-3) : IU-11
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight p
Orbital Altitude, N. Mi. : 200
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ. Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	480.8	17.2	-679.2	-198.4	9.6	0.8	58.5	2.8	71.7
2	480.8	17.0	-678.2	-197.4	9.6	0.8	58.5	2.8	71.7
3	542.0	3.7	-	-	-	-	-	-	-
4	542.0	19.9	-695.1	-153.1	9.0	0.7	58.5	2.8	71.0
5	591.2	22.5	-710.0	-118.8	8.5	0.6	58.5	2.8	70.4
6	591.2	10.8	-	-	-	-	-	-	-
7	598.1	10.7	-	-	-	-	-	-	-
8	598.1	11.2	-	-	-	-	-	-	-
9	517.7	18.9	-689.1	-171.4	9.3	0.7	58.5	2.8	71.3
10	517.7	18.9	-689.2	-171.5	9.2	0.7	58.5	2.8	71.2
11	371.5	12.1	-650.9	-279.4	10.6	0.9	58.5	2.8	72.8
12	371.5	11.8	-649.2	-277.7	10.6	0.9	58.5	2.8	72.8
13	196.0	3.5	-604.8	-408.8	12.2	1.2	58.5	2.8	74.7
14	196.0	3.2	-602.9	-406.9	12.2	1.2	58.5	2.8	74.7
15	48.2	-5.8	-557.7	-509.5	13.8	1.4	58.5	2.8	76.5
16	48.2	-98.9	-222.4	-174.2	-	-	130.3	6.2	136.5
17	20.6	-7.3	-550.2	-529.6	14.0	1.5	58.5	2.8	76.8
18	20.6	-6.7	-553.1	-532.5	13.9	1.4	58.5	2.8	76.6
19	103.6	-67.6	-310.3	-206.7	-	-	260.6	12.4	273.0
20	103.6	-3.8	-567.3	-463.7	13.4	1.4	58.5	2.8	76.1
21	231.8	-62.7	-326.4	-94.6	-	-	165.1	7.8	172.9
22	231.8	-56.4	-	-	-	-	-	-	-
23	370.9	10.6	-642.5	-271.6	10.9	1.0	58.5	2.8	73.2
24	370.9	12.0	-650.4	-279.5	10.6	0.9	58.5	2.8	72.8
Totals	8144.8	-	-11028.8	-5445.2	177.5	15.9	1492.0	71.2	1756.6
1	649.7	25.2	-726.3	-76.6	8.0	0.5	58.5	2.8	69.8
2	649.7	26.0	-731.0	-81.3	7.8	0.5	58.5	2.8	69.6
3	956.2	56.9	-	-	-	-	-	-	-
4	956.2	40.6	-823.0	133.2	4.6	-0.0	58.5	2.8	65.9
5	1596.6	68.0	-1018.8	577.8	-2.1	-1.1	58.5	2.8	58.1
6	1596.6	121.2	-	-	-	-	-	-	-
7	2141.0	162.0	-	-	-	-	-	-	-
8	2141.0	161.4	-	-	-	-	-	-	-
9	2290.0	95.5	-1247.9	1042.1	-10.0	-2.2	58.5	2.8	49.1
10	2290.0	93.8	-1233.2	1056.8	-9.5	-2.2	58.5	2.8	49.6
11	1782.0	76.6	-1086.8	695.2	-4.4	-1.5	58.5	2.8	55.4
12	1782.0	75.6	-1078.9	703.1	-4.2	-1.4	58.5	2.8	55.7
13	980.0	41.5	-878.7	151.3	4.5	-0.1	58.5	2.8	65.7
14	980.0	40.1	-819.6	160.4	4.8	-0.0	58.5	2.8	66.1
15	240.8	5.1	-613.1	-372.3	11.9	1.1	58.5	2.8	74.3
16	240.8	-53.3	-358.2	-117.4	-	-	130.3	6.2	136.5
17	27.4	-6.1	-556.2	-528.8	13.8	1.4	58.5	2.8	76.5
18	27.4	-6.2	-555.5	-528.1	13.8	1.4	58.5	2.8	76.5
19	138.3	-60.7	-332.7	-194.4	-	-	260.6	12.4	273.0
20	138.3	-1.7	-578.1	-439.8	13.1	1.3	58.5	2.8	75.7
21	309.4	-45.1	-387.9	-78.5	-	-	165.1	7.8	172.9
22	309.4	-39.1	-	-	-	-	-	-	-
23	494.4	16.8	-677.2	-182.8	9.7	0.8	58.5	2.8	71.8
24	494.4	18.1	-684.4	-190.0	9.4	0.7	58.5	2.8	71.4
Totals	23211.6	-	-14337.5	1729.9	71.2	0.8	1492.0	71.2	1635.2

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Angle of Inclination (Degrees): 34

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
		Average Environ. Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.18$, $\alpha/\epsilon = 0.20$									
7	-126.7	480.8	38.3	-807.8	-327.0	5.2	0.1	0	-6.1	-0.8	-327.8
7	-125.7	480.8	37.8	-804.4	-323.6	5.3	0.1	0	-6.1	-0.7	-324.3
	-	542.0	6.3	-	-	-	-	-	-	-	-
)	-82.1	542.0	40.6	-822.7	-280.7	4.7	-0.0	0	-6.1	-1.4	-282.1
4	-48.4	591.2	43.3	-840.9	-249.7	4.0	-0.1	0	-6.1	-2.2	-251.9
	-	591.2	12.6	-	-	-	-	-	-	-	-
	-	598.1	10.9	-	-	-	-	-	-	-	-
	-	598.1	12.5	-	-	-	-	-	-	-	-
)	-100.1	517.1	39.6	-816.0	-298.9	4.9	0.0	0	-6.1	-1.2	-300.1
2	-100.3	517.1	40.0	-818.7	-301.6	4.8	0	0	-6.1	-1.3	-302.9
3	-206.6	371.5	33.5	-776.9	-405.4	6.2	0.2	0	-6.1	0.3	-405.1
3	-204.9	371.5	33.2	-775.0	-403.5	6.3	0.2	0	-6.1	0.4	-403.1
	-334.1	196.0	25.2	-726.3	-530.3	8.0	0.5	0	-6.1	2.4	-527.9
	-332.2	196.0	24.9	-724.2	-528.2	8.0	0.5	0	-6.1	2.4	-525.8
	-433.0	48.2	16.1	-673.3	-625.1	9.8	0.8	0	-6.1	4.5	-620.6
	-37.7	48.2	-85.5	-260.1	-211.9	-	-	0	-13.5	-13.5	-225.4
	-452.8	20.6	14.7	-665.0	-644.4	10.1	0.8	0	-6.1	4.8	-639.6
	-455.9	20.6	15.3	-668.5	-647.9	10.0	0.8	0	-6.1	4.8	-643.1
	66.3	103.6	-51.0	-366.5	-262.9	-	-	0	-27.0	-27.0	-289.9
	-387.6	103.6	17.8	-682.7	-579.1	9.5	0.7	0	-6.1	4.1	-575.0
	78.3	231.8	-53.8	-356.6	-124.8	-	-	0	-17.2	-17.2	-142.0
	-	231.8	-53.7	-	-	-	-	-	-	-	-
	-198.4	370.9	31.6	-765.3	-394.4	6.6	0.3	0	-6.1	0.8	-393.6
	-206.7	370.9	33.4	-776.3	-405.4	6.3	0.2	0	-6.1	0.4	-405.0
	-3688.6	8144.8	-	-13127.2	-7543.6	109.6	5.2	0	-155.3	-40.5	-7585.2
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
	-6.8	649.7	46.0	-859.1	-209.4	3.4	-0.2	0	-6.1	-2.9	-212.3
	-11.7	649.7	46.4	-861.7	-212.0	3.3	-0.2	0	-6.1	-3.0	-215.0
	-	956.2	58.9	-	-	-	-	-	-	-	-
	199.1	956.2	60.4	-961.1	-4.9	-0.1	-0.8	0	-6.1	-7.0	-11.9
	635.9	1596.6	87.0	-1173.3	423.3	-7.4	-1.9	0	-6.1	-15.4	407.9
	-	1596.6	122.3	-	-	-	-	-	-	-	-
	-	2141.0	162.1	-	-	-	-	-	-	-	-
	-	2141.0	161.9	-	-	-	-	-	-	-	-
	1091.2	2290.0	113.1	-1413.8	876.2	-15.7	-3.2	0	-6.1	-25.0	851.2
	1106.4	2290.0	111.8	-1401.4	888.6	-15.2	-3.2	0	-6.1	-24.5	864.1
	750.6	1782.0	95.3	-1246.3	535.7	-9.9	-2.3	0	-6.1	-18.3	517.4
	758.8	1782.0	94.4	-1237.9	544.1	-9.6	-2.3	0	-6.1	-18.0	526.1
	217.0	980.0	61.6	-969.9	10.1	-0.4	-0.8	0	-6.1	-7.3	2.8
	226.5	980.0	60.3	-960.2	19.8	0.1	-0.8	0	-6.1	-6.8	13.0
	-298.0	240.8	26.5	-734.0	-493.2	7.7	0.5	0	-6.1	2.1	-491.1
	19.1	240.8	-42.5	-398.0	-157.2	-	-	0	-13.5	-13.5	-170.7
	-452.3	27.4	15.8	-671.4	-644.0	9.9	0.8	0	-6.1	4.6	-639.4
	-451.6	27.4	15.7	-671.1	-643.7	9.9	0.8	0	-6.1	4.6	-639.1
	78.6	138.3	-44.8	-389.2	-250.9	-	-	0	-27.0	-27.0	-277.9
	-364.1	138.3	19.8	-694.4	-556.1	9.1	0.7	0	-6.1	3.7	-552.4
	94.4	309.4	-37.2	-418.6	-109.2	-	-	0	-17.2	-17.2	-126.4
	-	309.4	-36.8	-	-	-	-	-	-	-	-
	-111.0	494.4	37.6	-803.2	-308.8	5.3	0.1	0	-6.1	-0.7	-309.5
	-118.6	494.4	39.2	-813.5	-319.1	5.0	0.0	0	-6.1	-1.1	-320.2
	3363.5	23211.6	-	-16678.0	-610.6	-4.9	-12.9	0	-155.3	-173.1	-783.4

e 4-36. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = 60 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F									
External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ. Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
480.8	48.6	-876.6	-395.8	2.8	-0.3	-33.3	-11.1	-41.9	-437.7
480.8	47.9	-871.9	-391.1	3.0	-0.3	-33.3	-11.1	-41.7	-432.8
542.0	7.7	-	-	-	-	-	-	-	-
542.0	50.6	-891.0	-349.0	2.3	-0.4	-33.3	-11.1	-42.5	-391.5
591.2	53.5	-910.8	-319.6	1.6	-0.5	-33.3	-11.1	-43.3	-362.9
591.2	13.5	-	-	-	-	-	-	-	-
598.1	11.0	-	-	-	-	-	-	-	-
598.1	13.1	-	-	-	-	-	-	-	-
517.1	49.6	-883.9	-366.8	2.6	-0.4	-33.3	-11.1	-42.2	-409.0
517.1	50.2	-888.0	-370.9	2.4	-0.4	-33.3	-11.1	-42.2	-413.3
371.5	43.8	-844.5	-473.0	3.9	-0.1	-33.3	-11.1	-40.6	-513.6
371.5	43.6	-842.6	-471.1	4.0	-0.1	-33.3	-11.1	-40.5	-511.6
196.0	35.8	-791.7	-595.7	5.7	0.1	-33.3	-11.1	-38.6	-634.3
196.0	35.5	-789.6	-593.6	5.8	0.2	-33.3	-11.1	-38.4	-632.0
48.2	26.8	-735.8	-687.6	7.6	0.5	-33.3	-11.1	-36.3	-723.9
48.2	-77.2	-281.0	-232.8	-	-	-74.2	-24.7	-98.9	-331.7
20.6	25.4	-727.1	-706.5	7.9	0.5	-33.3	-11.1	-36.0	-742.5
20.6	26.0	-731.0	-710.4	7.8	0.5	-33.3	-11.1	-36.1	-746.5
103.6	-42.5	-398.0	-294.4	-	-	-148.4	-49.4	-197.8	-491.2
103.6	28.3	-745.0	-641.4	7.3	0.4	-33.3	-11.1	-36.7	-678.1
231.8	-49.1	-373.4	-141.6	-	-	-94.0	-31.4	-125.4	-267.0
231.8	-52.4	-	-	-	-	-	-	-	-
370.9	41.9	-831.2	-460.3	4.4	-0.1	-33.3	-11.1	-40.1	-500.4
370.9	43.8	-843.8	-472.9	3.9	-0.1	-33.3	-11.1	-40.6	-513.5
8144.8	-	-14256.8	-8673.2	73.1	-0.6	-849.4	-283.1	-1060.0	-9733.2
649.7	56.1	-930.0	-280.3	1.0	-0.6	-33.3	-11.1	-44.0	-324.3
649.7	56.3	-931.4	-281.7	0.9	-0.6	-33.3	-11.1	-44.1	-325.8
956.2	59.8	-	-	-	-	-	-	-	-
956.2	70.1	-1034.5	-78.3	-2.6	-1.2	-33.3	-11.1	-48.2	-126.5
1596.6	96.2	-1254.6	342.0	-10.2	-2.4	-33.3	-11.1	-57.0	285.0
1596.6	122.8	-	-	-	-	-	-	-	-
2141.0	162.1	-	-	-	-	-	-	-	-
2141.0	162.2	-	-	-	-	-	-	-	-
2290.0	121.7	-1500.5	789.5	-18.7	-3.7	-33.3	-11.1	-66.8	722.7
2290.0	120.6	-1489.5	800.5	-18.3	-3.6	-33.3	-11.1	-66.3	734.2
1782.0	104.4	-1330.1	451.9	-12.8	-2.8	-33.3	-11.1	-60.0	391.9
1782.0	103.5	-1321.6	460.4	-12.5	-2.7	-33.3	-11.1	-59.6	400.8
980.0	71.4	-1044.9	-64.9	-3.0	-1.2	-33.3	-11.1	-48.6	-113.5
980.0	70.1	-1034.9	-54.9	-2.6	-1.2	-33.3	-11.1	-48.2	-103.1
240.8	36.9	-799.0	-558.2	5.5	0.1	-33.3	-11.1	-38.8	-597.0
240.8	-36.9	-419.8	-179.0	-	-	-74.2	-24.7	-98.9	-277.9
27.4	26.4	-733.6	-706.2	7.7	0.5	-33.3	-11.1	-36.2	-742.4
27.4	26.4	-733.6	-706.2	7.7	0.5	-33.3	-11.1	-36.2	-742.4
138.3	-36.6	-420.9	-282.6	-	-	-148.4	-49.4	-197.8	-480.4
138.3	30.3	-757.2	-618.9	6.9	0.3	-33.3	-11.1	-37.2	-656.1
309.4	-32.9	-435.6	-126.2	-	-	-94.0	-31.4	-125.4	-251.6
309.4	-35.6	-	-	-	-	-	-	-	-
494.4	47.4	-870.7	-376.3	3.0	-0.3	-33.3	-11.1	-41.7	-418.0
494.4	49.4	-882.5	-388.1	2.6	-0.3	-33.3	-11.1	-42.1	-430.2
23211.6	-	-17924.9	-1857.5	-45.3	-19.3	-849.4	-283.1	-1197.1	-3054.6

Orbit Data: Case No. (Table 2-3) : IU-11
Type of Orbit and Orientation: Circular Earth Orbit, X axis tangent to flight
Orbital Altitude, N. Mi. : 200
Launch Date : December 21

IU Location	Coldplate/Electrical Component Temperature = 30 F								
	External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr				
	Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net
1	480.8	15.7	-670.6	-189.8	-21.3	0.8	-203.3	2.8	-221.
2	480.8	15.2	-667.8	-187.0	-21.2	0.8	-203.3	2.8	-220.
3	542.0	-14.8	-	-	-	-	-	-	-
4	542.0	18.1	-684.5	-142.5	-21.8	0.7	-203.3	2.8	-221.
5	591.2	20.9	-700.9	-109.7	-22.3	0.6	-203.3	2.8	-222.
6	591.2	-8.0	-	-	-	-	-	-	-
7	598.1	-9.3	-	-	-	-	-	-	-
8	598.1	-7.7	-	-	-	-	-	-	-
9	517.7	17.0	-678.5	-160.8	-21.6	0.8	-203.3	2.8	-221.
10	517.7	17.4	-680.5	-162.8	-21.6	0.8	-203.3	2.8	-221.
11	371.5	10.6	-642.5	-271.0	-20.3	1.0	-203.3	2.8	-219.
12	371.5	10.3	-640.9	-269.4	-20.3	1.0	-203.3	2.8	-219.
13	196.0	2.0	-596.8	-400.8	-18.8	1.2	-203.3	2.8	-218.
14	196.0	1.6	-594.9	-398.9	-18.7	1.2	-203.3	2.8	-218.
15	48.2	-7.3	-550.1	-501.9	-17.2	1.5	-203.3	2.8	-216.
16	48.2	-99.3	-221.5	-173.3	-	-	-452.6	6.2	-446.
17	20.6	-8.8	-542.6	-522.0	-16.9	1.5	-203.3	2.8	-215.
18	20.6	-8.2	-545.6	-525.0	-17.0	1.5	-203.3	2.8	-216.
19	103.6	-67.9	-309.5	-205.9	-	-	-905.2	12.4	-892.
20	103.6	-5.4	-559.6	-456.0	-17.4	1.4	-203.3	2.8	-216.
21	231.8	-65.3	-317.9	-86.1	-	-	-573.5	7.8	-565.
22	231.8	-83.9	-	-	-	-	-	-	-
23	370.9	8.6	-631.5	-260.6	-20.0	1.0	-203.3	2.8	-219.
24	370.9	10.5	-642.0	-271.1	-20.3	1.0	-203.3	2.8	-219.
Totals	8144.8	-	-10878.2	-5294.6	-316.8	16.7	-5184.1	71.2	-5413.
1	649.7	23.7	-717.4	-67.7	-22.9	0.6	-203.3	2.8	-222.
2	649.7	24.3	-720.6	-70.9	-23.0	0.5	-203.3	2.8	-223.
3	956.2	43.4	-	-	-	-	-	-	-
4	956.2	38.9	-811.9	144.3	-26.2	0.0	-203.3	2.8	-226.
5	1596.6	66.6	-1008.0	588.6	-32.9	-1.0	-203.3	2.8	-234.
6	1596.6	111.4	-	-	-	-	-	-	-
7	2141.0	153.6	-	-	-	-	-	-	-
8	2141.0	153.2	-	-	-	-	-	-	-
9	2290.0	94.1	-1235.1	1054.9	-40.7	-2.3	-203.3	2.8	-243.
10	2290.0	92.6	-1221.8	1068.2	-40.3	-2.2	-203.3	2.8	-243.
11	1782.0	75.3	-1076.1	705.3	-35.3	-1.4	-203.3	2.8	-237.
12	1782.0	74.3	-1068.1	713.9	-35.0	-1.4	-203.3	2.8	-236.
13	980.0	40.0	-819.3	160.7	-26.4	0.0	-203.3	2.8	-226.
14	980.0	38.7	-810.2	169.8	-26.1	0.0	-203.3	2.8	-226.
15	240.8	3.6	-605.2	-364.4	-19.1	1.2	-203.3	2.8	-218.
16	240.8	-53.6	-357.3	-116.5	-	-	-452.6	6.2	-446.
17	27.4	-7.6	-548.7	-521.3	-17.1	1.5	-203.3	2.8	-216.
18	27.4	-7.7	-548.0	-520.6	-17.1	1.5	-203.3	2.8	-216.
19	138.3	-61.0	-331.9	-193.6	-	-	-905.2	12.4	-892.
20	138.3	-3.2	-570.3	-432.0	-17.9	1.4	-203.3	2.8	-217.
21	309.4	-47.2	-380.1	-70.7	-	-	-573.5	7.8	-565.
22	309.4	-63.5	-	-	-	-	-	-	-
23	494.9	-14.9	-666.2	-171.3	-21.2	0.8	-203.3	2.8	-220.
24	494.9	16.6	-675.8	-180.9	-21.5	0.8	-203.3	2.8	-221.
Totals	23211.6	-	-14172.0	1895.4	-422.5	0.0	-5184.1	71.2	-5535.

Tabl

path

Angle of Inclination (Degrees): 34

	Total Heat Gain or Loss (-) Btu/hr	Coldplate/Electrical Component Temperature = 60 F									Total Heat Gain or Loss (-) Btu/hr
		External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					
		Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
		Optical Properties of IU Outer Surface $\alpha = 0.20$, $\alpha/\epsilon = 0.20$									
0	-410.8	480.8	36.8	-798.4	-317.6	-25.7	0.1	-261.8	-6.1	-293.5	-611.1
9	-407.9	480.8	36.0	-793.0	-312.2	-25.5	0.1	-261.8	-6.1	-293.3	-605.5
	-	542.0	-11.8	-	-	-	-	-	-	-	-
6	-364.1	542.0	38.8	-811.2	-269.2	-26.1	0.0	-261.8	-6.1	-294.0	-563.2
2	-331.9	591.2	41.8	-831.0	-239.8	-26.8	-0.1	-261.8	-6.1	-294.8	-534.6
	-	591.1	-6.0	-	-	-	-	-	-	-	-
	-	598.1	-9.0	-	-	-	-	-	-	-	-
	-	598.1	-6.2	-	-	-	-	-	-	-	-
3	-382.1	517.7	37.8	-804.5	-286.8	-25.9	0.1	-261.8	-6.1	-293.7	-580.5
3	-384.1	517.7	38.5	-809.2	-291.5	-26.1	0.1	-261.8	-6.1	-293.9	-585.4
8	-490.8	371.5	32.0	-767.7	-396.2	-24.6	0.3	-261.8	-6.1	-292.2	-688.4
8	-489.2	371.5	31.7	-765.9	-394.4	-25.6	0.3	-261.8	-6.1	-293.2	-687.6
1	-618.9	196.0	23.7	-717.4	-521.4	-21.9	0.6	-261.8	-6.1	-289.2	-810.6
0	-616.9	196.0	23.4	-715.4	-519.4	-22.8	0.6	-261.8	-6.1	-290.1	-809.5
2	-718.1	48.2	14.7	-665.0	-616.8	-21.1	0.8	-261.8	-6.1	-288.2	-905.0
4	-619.7	48.2	-84.9	-259.2	-211.0	-	-	-582.9	-13.5	-596.4	-807.4
9	-737.9	20.6	13.2	-656.7	-636.1	-20.8	0.9	-261.8	-6.1	-287.8	-923.9
0	-741.0	20.6	13.8	-660.2	-639.6	-20.9	0.9	-261.8	-6.1	-287.9	-927.5
8	-1098.7	103.6	-51.2	-365.6	-262.0	-	-	-1165.8	-27.0	-1192.8	-1454.8
5	-672.5	103.6	16.3	-674.1	-570.5	-21.4	0.8	-261.8	-6.1	-288.5	-859.0
7	-651.8	231.8	-56.2	-348.2	-116.4	-	-	-738.5	-17.2	-755.7	-872.1
	-	231.8	-80.7	-	-	-	-	-	-	-	-
5	-480.1	370.9	29.7	-753.3	-382.4	-24.2	0.4	-261.8	-6.1	-291.7	-674.1
8	-490.9	370.9	31.9	-767.1	-396.2	-24.6	0.3	-261.8	-6.1	-292.2	-688.4
0	-10707.4	8144.8	-	-12963.3	-7379.7	-384.3	6.0	-6676.0	-155.3	-7209.6	-14588.6
		Optical Properties of IU Outer Surface $\alpha = 0.90$, $\alpha/\epsilon = 1.0$									
8	-290.5	649.7	44.6	-849.4	-199.7	-27.5	-0.2	-261.8	-6.1	-295.6	-495.3
0	-293.9	649.7	44.7	-850.4	-200.7	-27.5	-0.2	-261.8	-6.1	-295.6	-496.3
	-	956.2	45.5	-	-	-	-	-	-	-	-
7	-82.4	956.2	58.8	-949.3	6.9	-30.9	0.7	-261.8	-6.1	-299.5	-292.6
4	354.2	1596.6	85.6	-1161.7	434.9	-38.2	-1.9	-261.8	-6.1	-308.0	126.9
	-	1596.6	112.5	-	-	-	-	-	-	-	-
	-	2141.0	153.7	-	-	-	-	-	-	-	-
	-	2141.0	153.8	-	-	-	-	-	-	-	-
5	811.4	2290.0	111.7	-1400.3	889.7	-46.4	-3.2	-261.8	-6.1	-317.5	572.2
0	825.2	2290.0	110.6	-1389.4	900.6	-46.0	-3.1	-261.8	-6.1	-317.0	583.6
	468.7	1782.0	94.0	-1234.8	547.2	-40.7	-2.3	-261.8	-6.1	-310.9	236.3
	477.0	1782.0	93.1	-1226.5	555.5	-40.4	-2.2	-261.8	-6.1	-310.5	245.0
	-66.2	980.0	60.2	-959.7	20.3	-31.2	-0.8	-261.8	-6.1	-299.9	-279.6
	-56.8	980.0	58.9	-950.1	29.9	-30.9	-0.7	-261.8	-6.1	-299.5	-269.6
	-582.8	240.8	25.1	-725.2	-484.4	-23.2	-0.5	-261.8	-6.1	-290.6	-775.0
	-562.9	240.8	-	-397.1	-156.3	-	-	-582.9	-13.5	-596.4	-752.7
	-737.4	27.4	14.3	-663.0	-635.4	-21.0	0.8	-261.8	-6.1	-288.1	-923.7
	-736.7	27.4	14.3	-662.8	-635.4	-21.0	0.8	-261.8	-6.1	-288.1	-923.5
	-1086.4	138.3	-45.0	-388.4	-250.1	-	-	-1165.8	-27.0	-1192.8	-1442.9
	-649.0	138.3	-18.3	-685.9	-547.6	-21.8	0.7	-261.8	-6.1	-289.0	-836.6
	-636.4	309.4	-39.1	-410.8	-101.4	-	-	-738.5	-17.2	-755.7	-857.1
	-	309.4	-60.8	-	-	-	-	-	-	-	-
	-392.2	494.9	35.1	-791.3	-296.4	-25.5	0.2	-261.8	-6.1	-293.2	-589.6
	-402.1	-494.9	-37.7	-804.0	-309.1	-25.9	0.1	-261.8	-6.1	-293.7	-602.8
	-3639.2	23211.6	-	-16500.2	-432.8	-498.2	-12.0	-6676.0	-155.3	-7341.5	-7773.

e 4-37. Heat Gain or Loss — Active System, Adiabatic Coldplate Surface

S-IVB Dome Data: Temperature = -210 F
Emissivity, ϵ = 0.90

Coldplate/Electrical Component Temperature = 75 F

External Heat Gain or Loss (-) of IU Skin, Btu/hr				Internal Heat Gain or Loss (-) of IU Skin or Coldplate, Btu/hr					Total Heat Gain or Loss (-) Btu/hr
Average Environ Heat Absorbed	IU Skin Temp (F)	IU Skin ↕ Space	Net	IU Skin ↕ S-IVB Dome	IU Skin ↕ SLA	Coldplate/ ElecComp ↕ S-IVB Dome	Coldplate/ ElecComp ↕ SLA	Net	
480.8	47.2	-866.9	-386.1	-28.1	-0.3	-295.1	-11.1	-334.6	-720.7
480.8	46.2	-860.1	-379.3	-27.8	-0.2	-295.1	-11.1	-334.2	-713.5
542.0	-10.4	-	-	-	-	-	-	-	-
542.0	48.9	-879.0	-337.0	-28.5	-0.3	-295.1	-11.1	-335.0	-672.0
591.2	52.0	-900.5	-309.3	-29.2	-0.4	-295.1	-11.1	-335.8	-645.1
591.2	-5.0	-	-	-	-	-	-	-	-
598.1	-8.9	-	-	-	-	-	-	-	-
598.1	-5.5	-	-	-	-	-	-	-	-
517.7	47.9	-871.9	-354.2	-28.2	-0.3	-295.1	-11.1	-334.7	-688.9
517.7	48.8	-878.2	-360.5	-28.4	-0.3	-295.1	-11.1	-334.9	-695.4
371.5	42.4	-834.9	-463.4	-27.0	-0.1	-295.1	-11.1	-333.3	-796.7
371.5	42.1	-833.0	-461.5	-26.9	-0.1	-295.1	-11.1	-333.2	-794.7
196.0	34.3	-782.4	-586.4	-25.2	0.2	-295.1	-11.1	-331.2	-917.6
196.0	34.0	-780.4	-584.4	-25.1	0.2	-295.1	-11.1	-331.1	-915.5
48.2	25.4	-727.1	-678.9	-23.2	0.5	-295.1	-11.1	-328.9	-1007.8
48.2	-77.5	-280.1	-231.9	-	-	-657.1	-24.7	-681.8	-913.7
20.6	23.9	-718.4	-697.8	-23.0	0.5	-295.1	-11.1	-328.7	-1026.5
20.6	24.6	-722.2	-701.6	-23.1	0.5	-295.1	-11.1	-328.8	-1030.4
103.6	-42.7	-397.1	-293.5	-	-	-1314.2	-49.4	-1363.6	-1657.1
103.6	26.9	-736.1	-632.5	-23.6	0.4	-295.1	-11.1	-329.4	-961.9
231.8	-51.4	-365.0	-133.2	-	-	-832.5	-31.4	-863.9	-997.1
231.8	-79.1	-	-	-	-	-	-	-	-
370.9	40.0	-818.8	-447.9	-26.4	0	-295.1	-11.1	-332.6	-780.5
370.9	42.3	-834.2	-463.3	-26.9	-0.1	-295.1	-11.1	-333.2	-796.5
8144.8	-	-14086.4	-8502.8	-420.5	0.3	-7525.4	-283.1	-8228.7	-16731.6
649.7	54.7	-919.9	-270.2	-29.9	-0.5	-295.1	-11.1	-336.6	-606.8
649.7	54.7	-919.7	-270.0	-29.9	-0.5	-295.1	-11.1	-336.6	-606.6
956.2	46.5	-	-	-	-	-	-	-	-
956.2	68.5	-1022.2	-66.0	-33.4	-1.1	-295.1	-11.1	-340.7	-406.7
1596.6	94.9	-1242.7	353.9	-41.0	-2.3	-295.1	-11.1	-349.5	4.4
1596.6	113.0	-	-	-	-	-	-	-	-
2141.0	153.7	-	-	-	-	-	-	-	-
2141.0	154.1	-	-	-	-	-	-	-	-
2290.0	120.3	-1486.7	803.3	-49.4	-3.6	-295.1	-11.1	-359.2	444.1
2290.0	119.4	-1477.1	812.9	-49.0	-3.6	-295.1	-11.1	-358.8	454.1
1782.0	103.1	-1318.3	463.7	-43.5	-2.7	-295.1	-11.1	-352.4	111.3
1782.0	102.2	-1309.8	472.2	-43.3	-2.7	-295.1	-11.1	-352.2	120.0
980.0	70.0	-1034.4	-54.4	-33.8	-1.2	-295.1	-11.1	-341.2	-395.6
980.0	68.8	-1024.4	-44.4	-33.5	-1.1	-295.1	-11.1	-340.8	-385.2
240.8	35.5	-789.9	-549.1	-25.4	0.2	-295.1	-11.1	-331.4	-880.5
240.8	-37.1	-418.9	-178.1	-	-	-657.1	-24.7	-681.8	-859.9
27.4	25.0	-724.9	-697.5	-23.2	0.5	-295.1	-11.1	-328.9	-1026.4
27.4	25.0	-724.9	-697.5	-23.2	0.5	-295.1	-11.1	-328.9	-1026.4
138.3	-36.8	-420.0	-281.7	-	-	-1314.2	-49.4	-1363.6	-1645.3
183.3	28.9	-748.2	-609.9	-24.0	0.4	-295.1	-11.1	-329.8	-939.7
309.4	-34.8	-427.9	-118.5	-	-	-832.5	-31.4	-863.9	-982.4
309.4	-59.4	-	-	-	-	-	-	-	-
494.4	45.9	-858.3	-363.9	-27.8	-0.2	-295.1	-11.1	-334.2	-698.1
494.4	48.0	-872.7	-378.3	-28.3	-0.3	-295.1	-11.1	-334.8	-713.1
23211.6	-	-17741.1	-1673.7	-538.5	-18.3	-7525.4	-283.1	-8365.3	-10039.0

60 F, the total heat loss is nearly the same for the combination of low environmental heat absorption (IU outer surface absorptivity of 0.18) and low heat transfer with the S-IVB dome and for the combination of high environmental heat absorption and high heat transfer with the S-IVB dome.

Although the indicated trends are generally applicable for all the orbital conditions considered, the determination of surface properties that greatly influence the heat transfer must still be made based on specific considerations. These are considered in the following section.

In addition to the heat balances calculated for the various conditions described in this discussion, the thermal analysis of the active thermal control system included an evaluation of the effect of coolant flow rate variation and step-type increase in electrical heat load.

Coldplate coolant flow rate effects were evaluated for the 200-nautical-mile orbit conditions of Case No. 3 in Table 4-2. Heat balances and temperatures were obtained for a coolant flow rate of 180 pounds per hour per coldplate and for a no-flow condition. Solar absorptivity values of 0.18 and 0.9 were used for the IU outer surface; coldplate coolant inlet temperatures of 30 F, 50 F, and 75 F were used, and coldplate electrical heat loads were assumed to be 50, 150, and 250 watts. S-IVB dome and SLA temperatures were assumed to be constant at 60 F and 40 F, respectively, and initial temperatures for the entire IU network were 30 F, 50 F, and 75 F. For the 180-pound-per-hour flow rate condition, coldplate heat loads were held constant for 5 hours each, at 50, 150, and 250 watts in succession. For the no-flow condition, the time at each coldplate heat load level was increased to 10 hours to obtain a better indication of equilibrium temperature conditions.

The results of the analysis for the 180-pound-per-hour flow rate condition are summarized in Table 4-38, which lists IU outer shell, coldplate, and electronic package temperatures at four instrument unit locations 90 degrees apart from each other. The table also lists appropriate heat loads (net heat gain or loss) for each location, as well as total cooling system heat loads The two values shown for each separate condition represent the minimum and maximum values during one complete orbit. A comparison of these data with similar data applicable to a coolant flow rate of 60 pounds per hour per coldplate showed no significant differences between results.

Results of the analysis for the no-flow condition are illustrated in Figures 4-59 through 4-63, which show the variation in electronic package temperature with orbit time at the same IU locations (2, 9, 15, and 20) as those in Table 4-38. The electronic package temperatures at location 9 are not shown for the $\alpha_s = 0.18$ condition because it was found that they do

not differ significantly from the temperatures at locations 2 and 15. The same comment applies to electronic package temperatures at location 15 for the $\alpha_s = 0.90$ condition since they are similar to temperatures at location 2. The figures indicate that electronic package temperatures can be maintained within Group I limits over a fairly wide range of electrical heat loads and under zero coolant flow conditions. The exceptions to this are location 20 when $\alpha_s = 0.18$ and all locations when $\alpha_s = 0.90$. However, the results suggest that, in the event of coolant pump failure or loss of coolant through leakage, IU performance can be maintained at satisfactory temperature levels by reducing the electrical heat dissipation level, changing the spacecraft orientation to the minimum ambient heat load condition (X-solar), or both.

With the exception of coldplate electrical heat loads, the same conditions that were applied to the investigation of the effects of coolant flow rate variation were also applied to a study of the effect of a step-type increase in electrical heat load. The latter was assumed to vary as shown in Figure 4-64, with the time interval, t, varying from 2 to 10 hours. The purpose of this study was to show the reaction of the TCS to step-type changes in load. Study results are illustrated in Figure 4-65 for coolant coldplate inlet temperatures of 30 to 50 F, while Table 4-39 lists corresponding electronic package temperatures for all three coolant temperatures under the same conditions of coldplate heat load vs. time variation. Figure 4-65 indicates the influence of the thermal capacity of the system on IU heat load (net heat gain or loss). It may be observed that, due to this capacity, it takes approximately 10 hours after an increase in coldplate heat load from 50 to 250 watts for the corresponding increase in IU heat load to reach its maximum value. In Table 4-39, it may be seen that equipment temperatures in most cases remain within Group I limits. These data can be used to advantage in the design of a TCS for extended mission durations. On the basis of Figure 4-65 and for equipment power profiles consisting of relatively short periods at high power levels followed by longer periods at power-down conditions, it should be possible to satisfy temperature requirements with a control system having a capacity based on the power-down condition. The thermal lag in the system, augmented by an expendable coolant system, could be used to furnish sufficient capacity at high power levels.

Coolant Inlet Temp (Deg F)	IU Outer Surface Absorptivity	Q_{el} (Watts)	IU Locat	
			Node 4 Outer Shell (Deg F)	Node 33 Coldplate (Deg F)
30	0.18	50	-2 / 3	24 / 25
		150	4 / 10	32 / 34
		250	12 / 17	42 / 43
	0.9	50	4 / 54	28 / 41
		150	9 / 60	36 / 50
		250	17 / 66	47 / 59
50	0.18	50	9 / 15	39 / 40
		150	15 / 21	46 / 49
		250	22 / 26	55 / 57
	0.9	50	15 / 65	43 / 56
		150	19 / 70	51 / 65
		250	27 / 75	61 / 73
75	0.18	50	23 / 29	58 / 59
		150	29 / 34	65 / 67
		250	34 / 39	73 / 75
	0.9	50	28 / 76	62 / 73
		150	32 / 81	69 / 80
		250	39 / 86	78 / 89

200-nautical-mile earth orbit
Y solar, 29-degree inclination, W_c = 18

Tal

ion 2		IU Location 9				IU Location		
Node 36 Package (Deg F)	Heat Load 4 (Btu/hr)	Node 21 Outer Shell (Deg F)	Node 94 Coldplate (Deg F)	Node 97 Package (Deg F)	Heat Load 19 (Btu/hr)	Node 15 Outer Shell (Deg F)	Node 70 Coldplate (Deg F)	P (I
38 / 38	-135 / -109	-14 / 19	20 / 28	37 / 37	-208 / -44	-4 / 6	23 / 25	38
61 / 64	37 / 82	-8 / 7	28 / 37	61 / 64	-36 / 151	2 / 12	31 / 34	61
90 / 92	256 / 276	0 / 31	39 / 46	89 / 91	182 / 343	10 / 19	42 / 43	91
45 / 46	-42 / 233	-12 / 64	22 / 41	41 / 43	-166 / 229	2 / 61	28 / 43	46
71 / 74	135 / 434	-6 / 69	31 / 48	66 / 69	11 / 419	7 / 66	36 / 52	71
99 / 100	353 / 620	2 / 75	41 / 58	95 / 96	231 / 607	15 / 72	46 / 61	10
52	-235 / -206	-3 / 30	36 / 44	51 / 52	-308 / -132	7 / 17	38 / 41	
74 / 76	-75 / -32	3 / 35	43 / 52	72 / 76	-148 / 37	14 / 23	46 / 49	75
101 / 103	105 / 155	10 / 41	53 / 60	100 / 103	64 / 222	20 / 29	56 / 58	10
59 / 60	-147 / 127	0 / 74	38 / 56	55 / 57	-268 / 126	13 / 71	43 / 58	59
83 / 86	18 / 310	5 / 79	45 / 64	78 / 82	-103 / 298	18 / 76	52 / 66	83
111 / 112	227 / 490	12 / 84	55 / 73	107 / 108	109 / 480	25 / 81	60 / 75	11
68 / 70	-368 / -335	11 / 44	54 / 63	68 / 69	-439 / -261	21 / 31	57 / 60	68
90 / 91	-223 / -181	16 / 48	61 / 70	90 / 91	-294 / -113	27 / 35	65 / 67	90
116 / 118	-1 / -20	23 / 53	71 / 78	115 / 117	-91 / 65	33 / 41	74 / 75	11
75 / 77	-286 / -12	13 / 86	56 / 75	71 / 75	-402 / -10	26 / 82	61 / 76	76
97 / 100	-136 / 150	18 / 91	63 / 81	93 / 96	-252 / 139	32 / 87	68 / 84	98
122 / 125	34 / 323	25 / 98	73 / 90	118 / 122	-49 / 315	37 / 92	78 / 92	12

0 pounds per hour

ble 4-38. Summary of Temperature and Heat Loads

15		IU Location 20				
Node 73 ackage Deg F)	Heat Load 13 (Btu/hr)	Node 10 Outer Shell (Deg F)	Node 52 Coldplate (Deg F)	Node 55 Package (Deg F)	Heat Load 8 (Btu/hr)	Total Heat Load (Btu/hr)
38	-147 / -96	9 / 27	29 / 33	43 / 43	-27 / 66	24 / 1400
64	25 / 93	15 / 37	37 / 43	67 / 70	147 / 275	2795 / 4431
92	244 / 285	23 / 43	47 / 51	95 / 97	368 / 462	6324 / 7505
47	-46 / 270	25 / 164	41 / 79	65 / 67	282 / 1040	2032 / 8529
75	131 / 470	28 / 175	50 / 89	92 / 98	424 / 1260	4879 / 11,702
0 / 101	348 / 655	37 / 179	60 / 97	118 / 123	631 / 1428	8390 / 14,643
52	-246 / -193	20 / 41	44 / 48	57	-131 / -29	-2127 / -715
77	-87 / -21	26 / 47	52 / 57	80 / 82	30 / 153	449 / 2044
1 / 103	125 / 164	33 / 53	61 / 66	107 / 109	243 / 336	3853 / 5023
61	-151 / 164	34 / 172	55 / 92	77 / 80	109 / 908	-217 / 6229
86	13 / 346	38 / 181	64 / 102	103 / 109	292 / 1112	2428 / 9128
0 / 112	223 / 525	46 / 185	73 / 110	131 / 134	492 / 1275	5808 / 11,967
70	-378 / -321	33 / 50	62 / 67	73 / 74	-270 / -165	-4993 / -3530
92	-233 / -170	37 / 59	69 / 75	95 / 97	-123 / -2	-2652 / -1106
6 / 118	-30 / 10	45 / 64	79 / 83	121 / 123	81 / 173	606 / 1761
77	-290 / +24	46 / 185	73 / 110	92 / 96	-45 / 740	-3202 / 3184
101	-139 / 184	49 / 190	81 / 118	116 / 122	122 / 922	-794 / 5764
2 / 126	60 / 357	56 / 193	90 / 126	143 / 146	313 / 1079	2430 / 8492

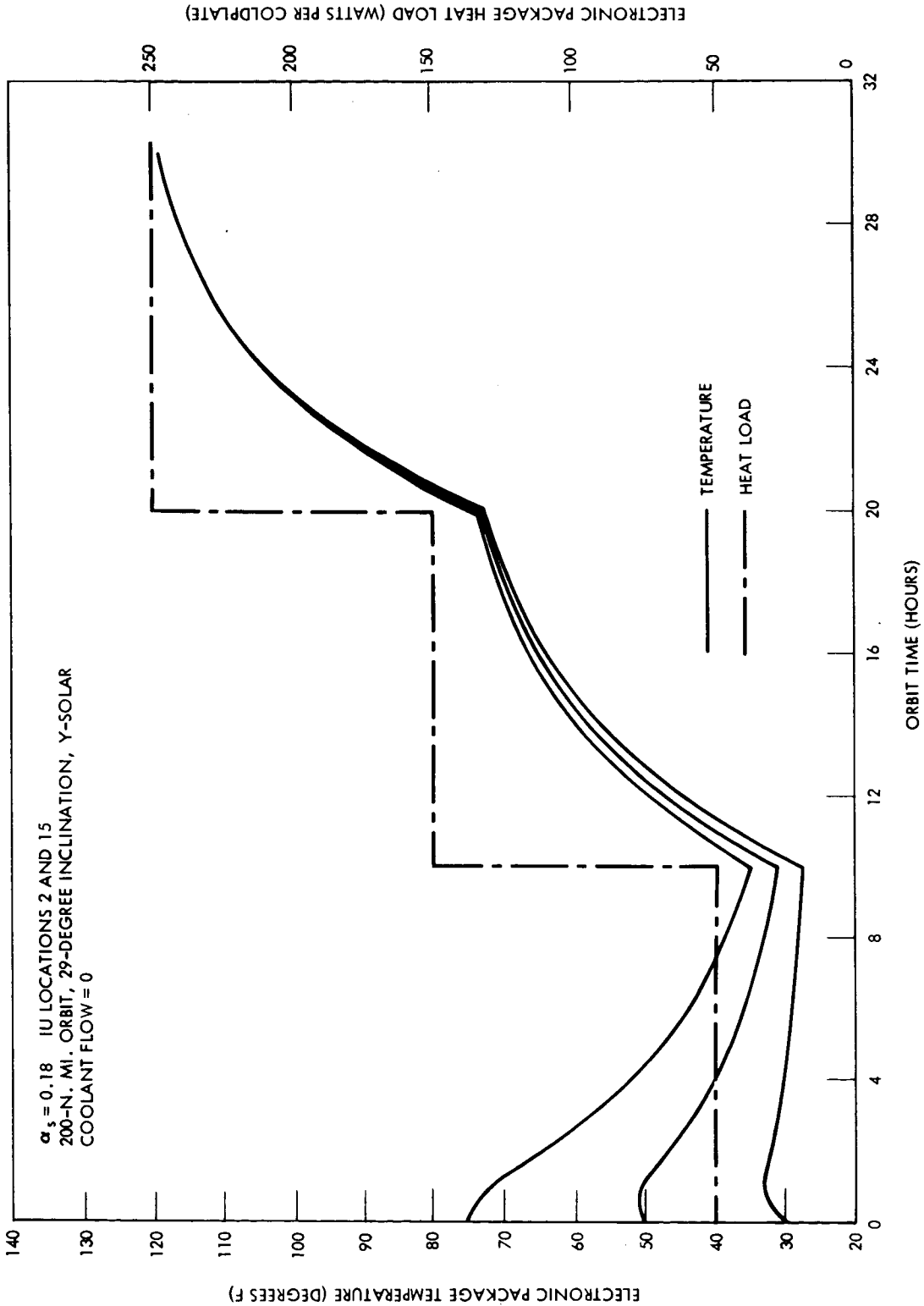

Figure 4-59. Electronic Package Temperature for Zero Coolant Flow

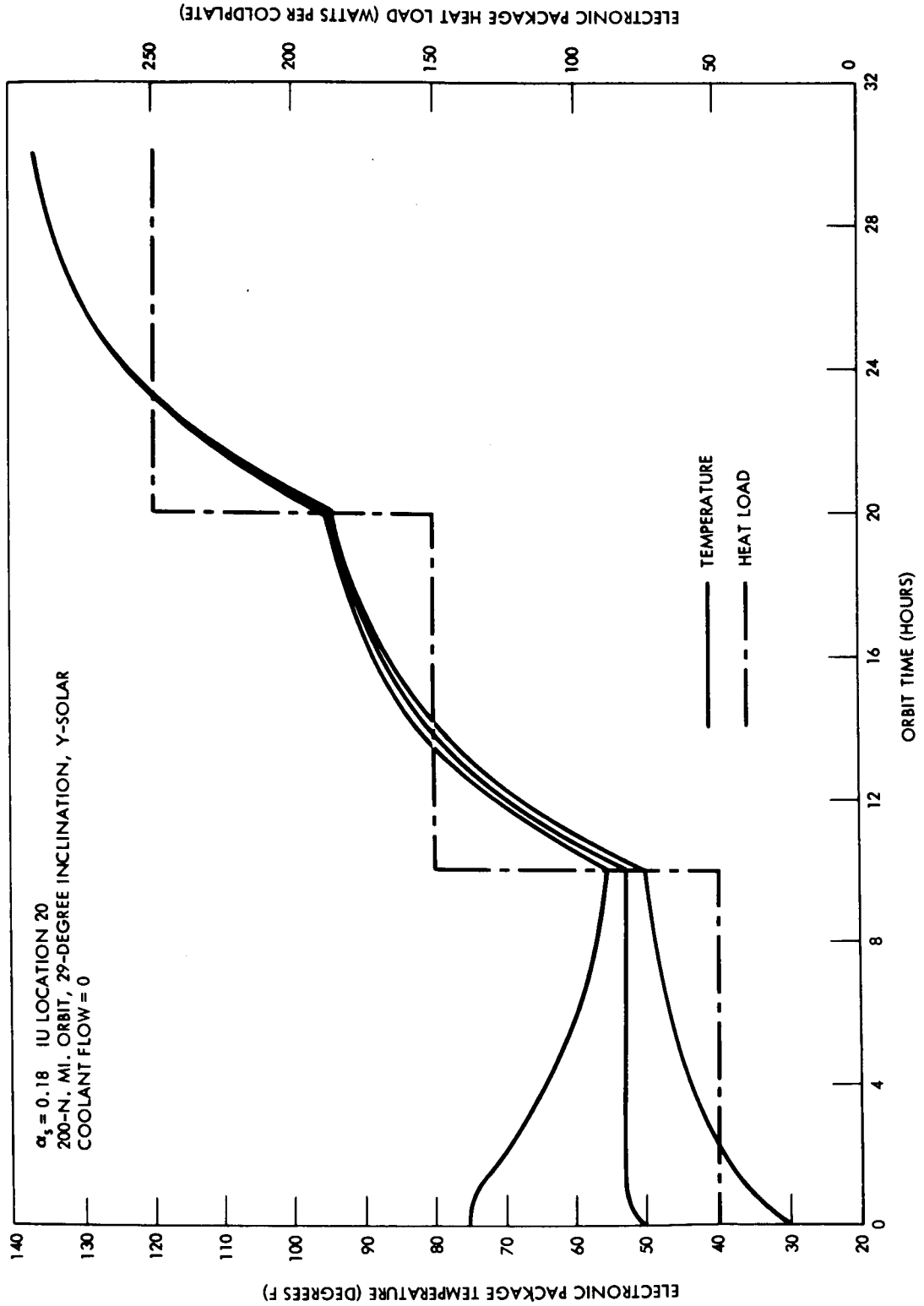

Figure 4-60. Electronic Package Temperature for Zero Coolant Flow

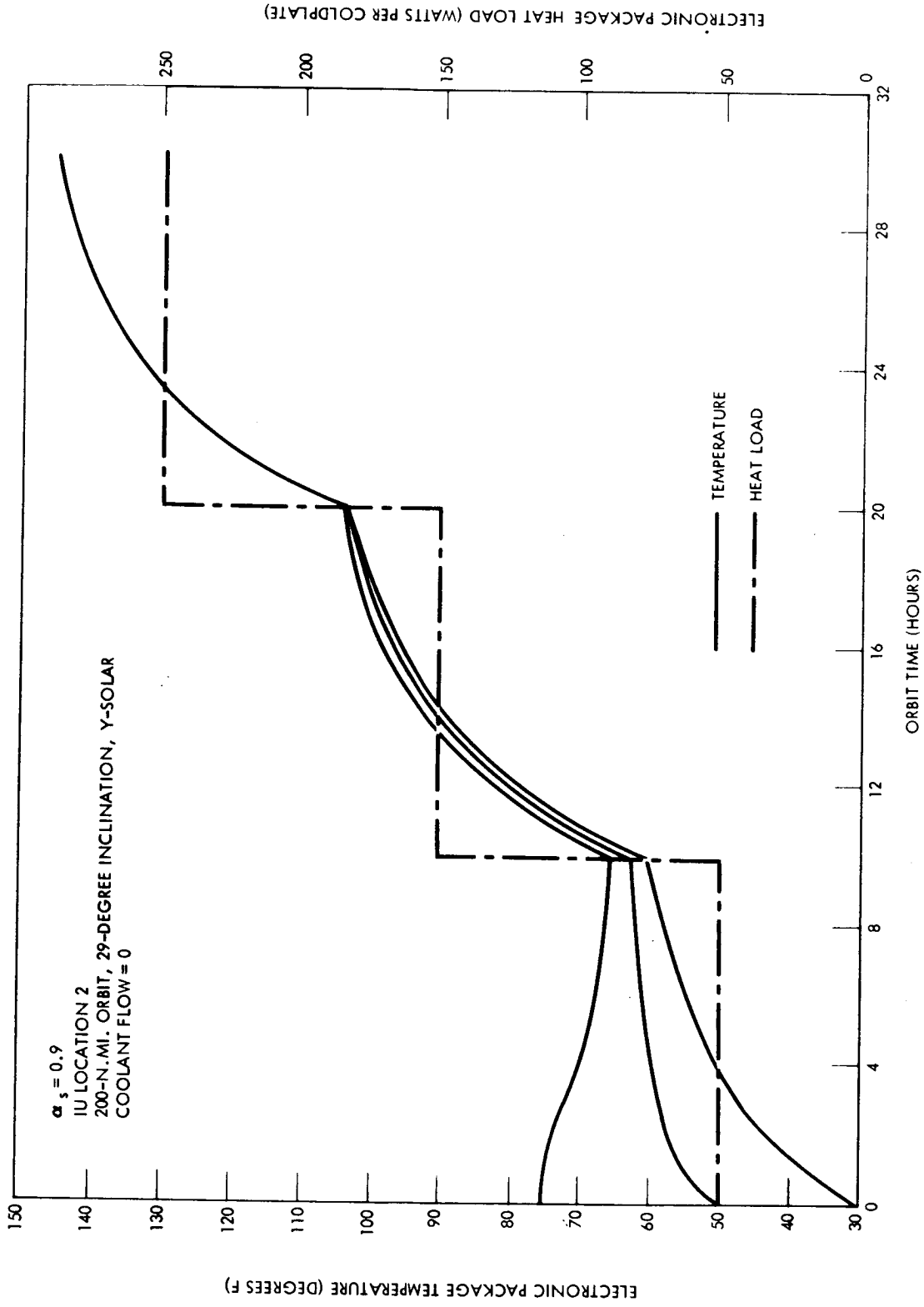

Figure 4-61. Electronic Package Temperature for Zero Coolant Flow

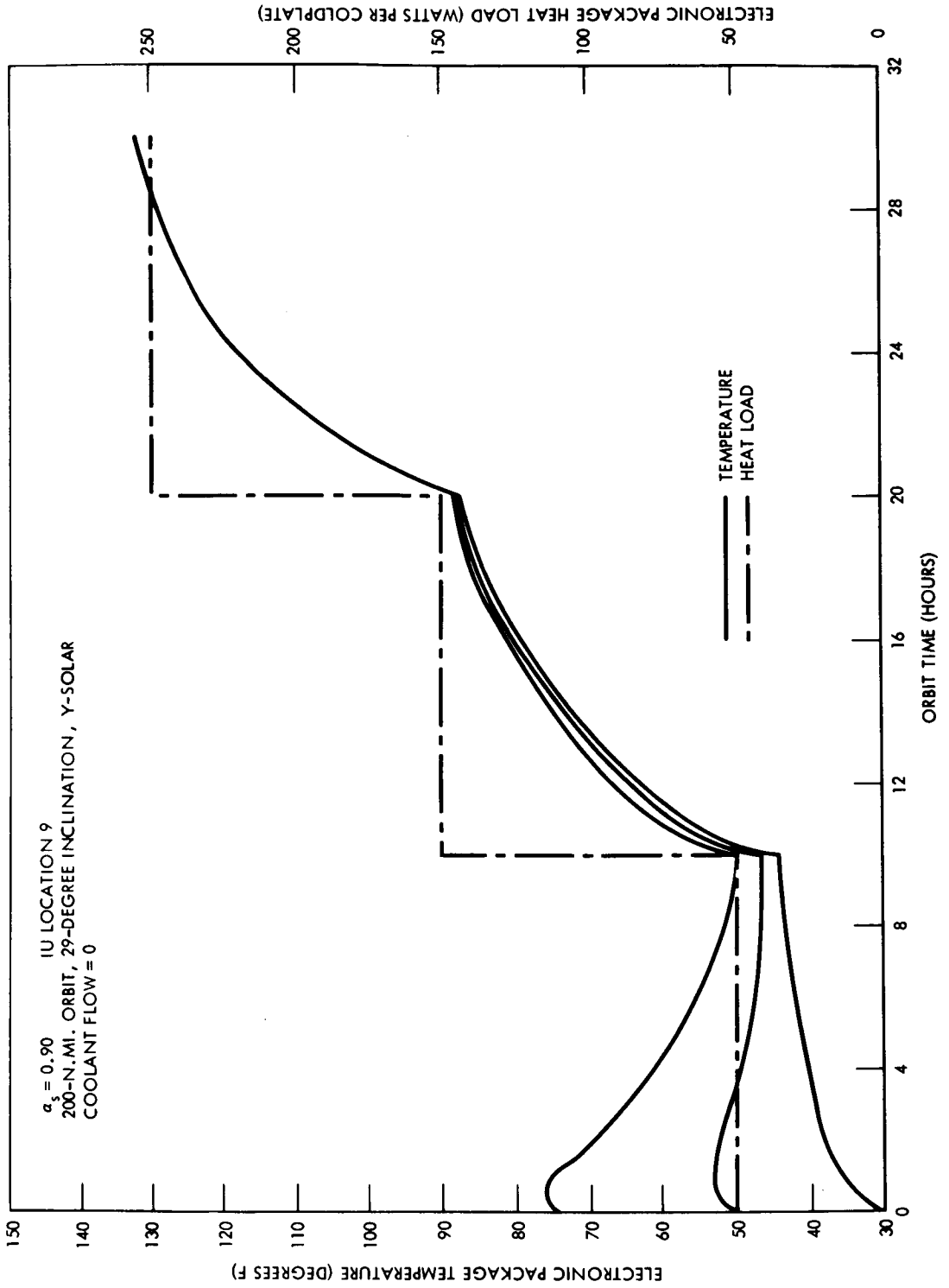

Figure 4-62. Electronic Package Temperature for Zero Coolant Flow

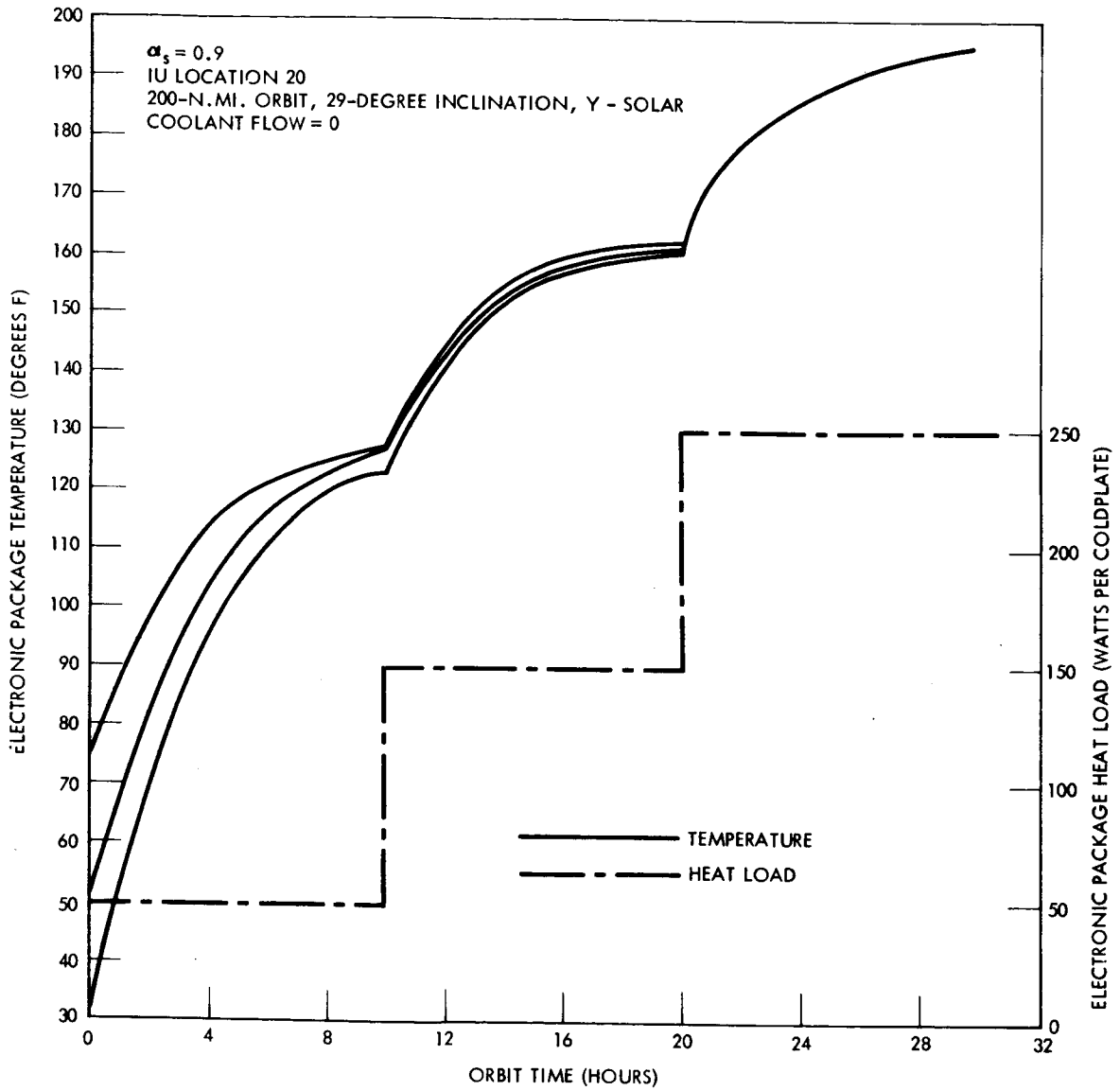

Figure 4-63. Electronic Package Temperature for Zero Coolant Flow

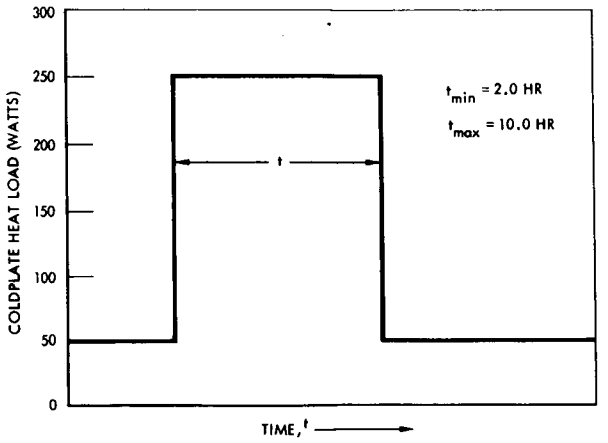

Figure 4-64. Coldplate Heat Load Versus Time

Table 4-39. Equipment Temperature

IU Location	Coolant Temperature								
	30 F			50 F			75 F		
	Duration of Maximum Heat Load (hours)								
	2	6	10	2	6	10	2	6	10
2	70 F	92 F	97 F	81 F	103 F	107 F	96 F	116 F	120 F
9	68 F	92 F	97 F	80 F	102 F	107 F	95 F	115 F	119 F
15	69 F	93 F	97 F	81 F	103 F	107 F	96 F	116 F	120 F
20	76 F	100 F	108 F	88 F	110 F	114 F	102 F	123 F	127 F

200-nautical-mile earth orbit; launch date June 21; 29-degree inclination; Y-Sol; outer surface α_s = 0.18; coolant flow rate = 60 pounds per hour
Maximum heat load = 250 watts/coldplate
Minimum heat load = 50 watts/coldplate

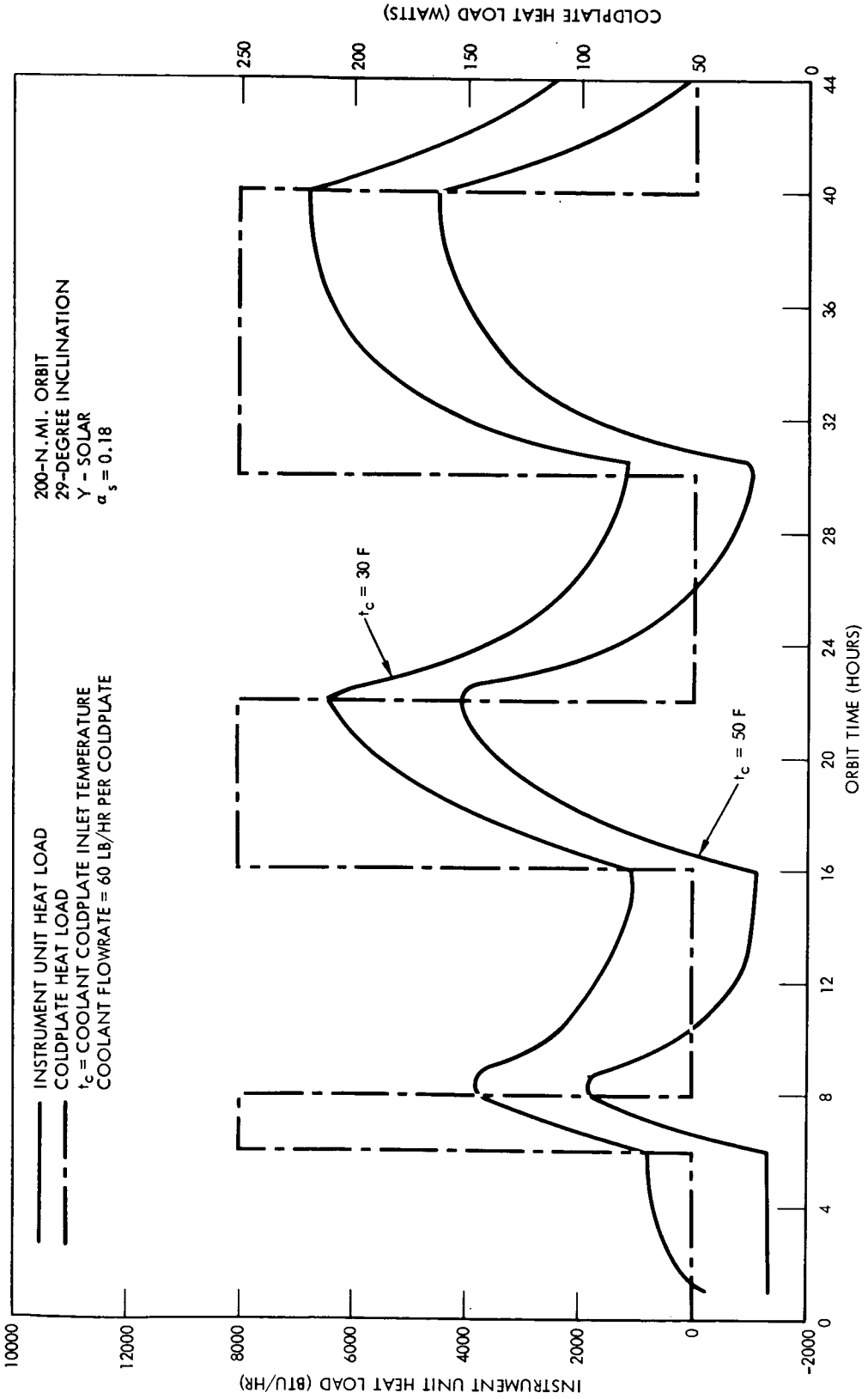

Figure 4-65. Electronic Package Temperature for Zero Coolant Flow

The effect of nonuniform coldplate heat dissipation on coolant heat gain or loss was investigated by analyzing the variation in heat flow to the coolant at each coldplate location. This analysis used as a starting point the coolant net heat gain or loss data of Figures 4-14, 4-15, and 4-16 for an IU outer skin solar absorptivity value of 0.18. For equipment power dissipation rates of 1.51, 3.11, and 4.71 kilowatts, which represent power dissipation rates of 50, 150, and 250 watts per coldplate, respectively, coolant heat gain or loss at each IU location was obtained from computer data printouts. These data are shown in Figures 4-66 through 4-95. For any given set of coolant temperature, orbital condition, and vehicle orientation, the graphical data permit the determination of equipment power dissipation that results in zero net heat gain of the coolant at each coldplate location. Examination of the data indicates that considerable variation in equipment heat dissipation is possible between coldplates at different IU locations for the same orbital and vehicle conditions. This situation suggested the possibility of utilizing nonuniform thermal loads on the coldplates so that coolant net heat gain would be zero at each IU location. Under the present assumption of no conduction heat transfer between the IU outer shell and internally cooled items of equipment, however, the power dissipation of the latter always results in a net heat gain of the coolant. Therefore, if the coolant net heat gain is to remain at zero, the thermal load at each coldplate location must be such as to result in a net heat loss from the coolant equal to the net heat gain due to internally cooled equipment.

As a first approximation, it may be assumed that the necessary heat balance can be obtained by uniform reduction of the coldplate equipment power dissipation rates that produce zero net heat gain so as to achieve a net heat loss from the coolant at each coldplate location. The sum of these heat losses must equal the net heat gain due to internally cooled equipment, which is indicated for each set of operating conditions.

The total permissible heat dissipation, which is the sum of the individual coldplate rates plus the dissipation of the internally cooled equipment, may be compared with the total equipment power dissipation for zero net heat gain as obtained from Figures 4-14, 4-15, and 4-16. For example, for Case IU-1b-2 at a coolant temperature of 30 F, the coolant net heat gain due to internally cooled equipment amounts to 2010 Btu/hr. Therefore, zero net heat gain of the coolant can be expected if the net heat loss at each of the 16 available coldplates is 126 Btu/hr.

The total permissible equipment heat dissipation at this coolant heat loss value, as determined from Figures 4-66 and 4-67, amounts to 740 watts. To this sum must be added the 712 watts dissipated by internally cooled equipment (Table 4-4), which results in a total equipment heat dissipation of 1.45 kilowatts. For the same case number, Figure 4-14 indicates that a total power dissipation of 1.63 kilowatts will produce zero net coolant heat

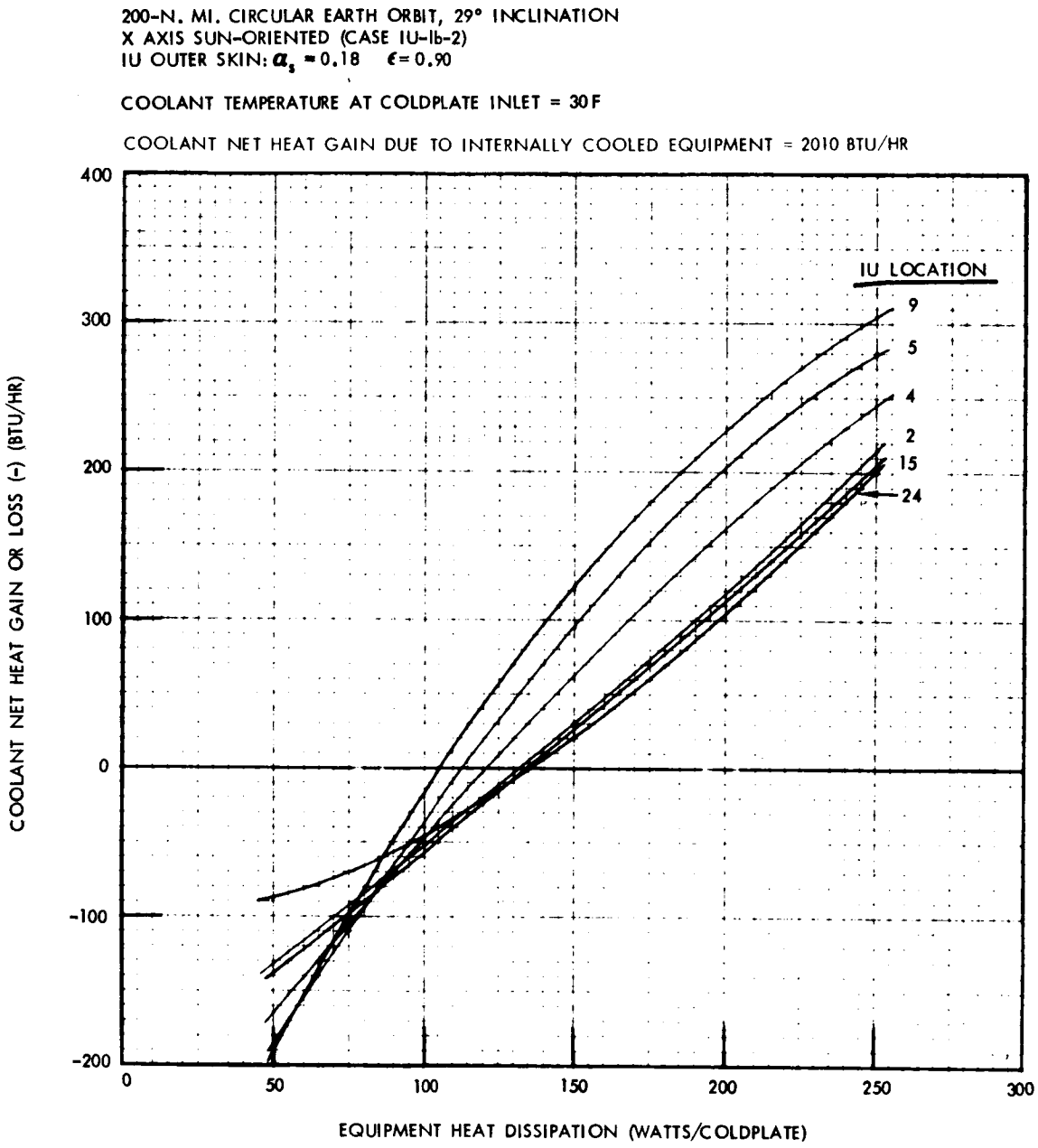

Figure 4-66. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1b-2, Coolant Temperature 30 F

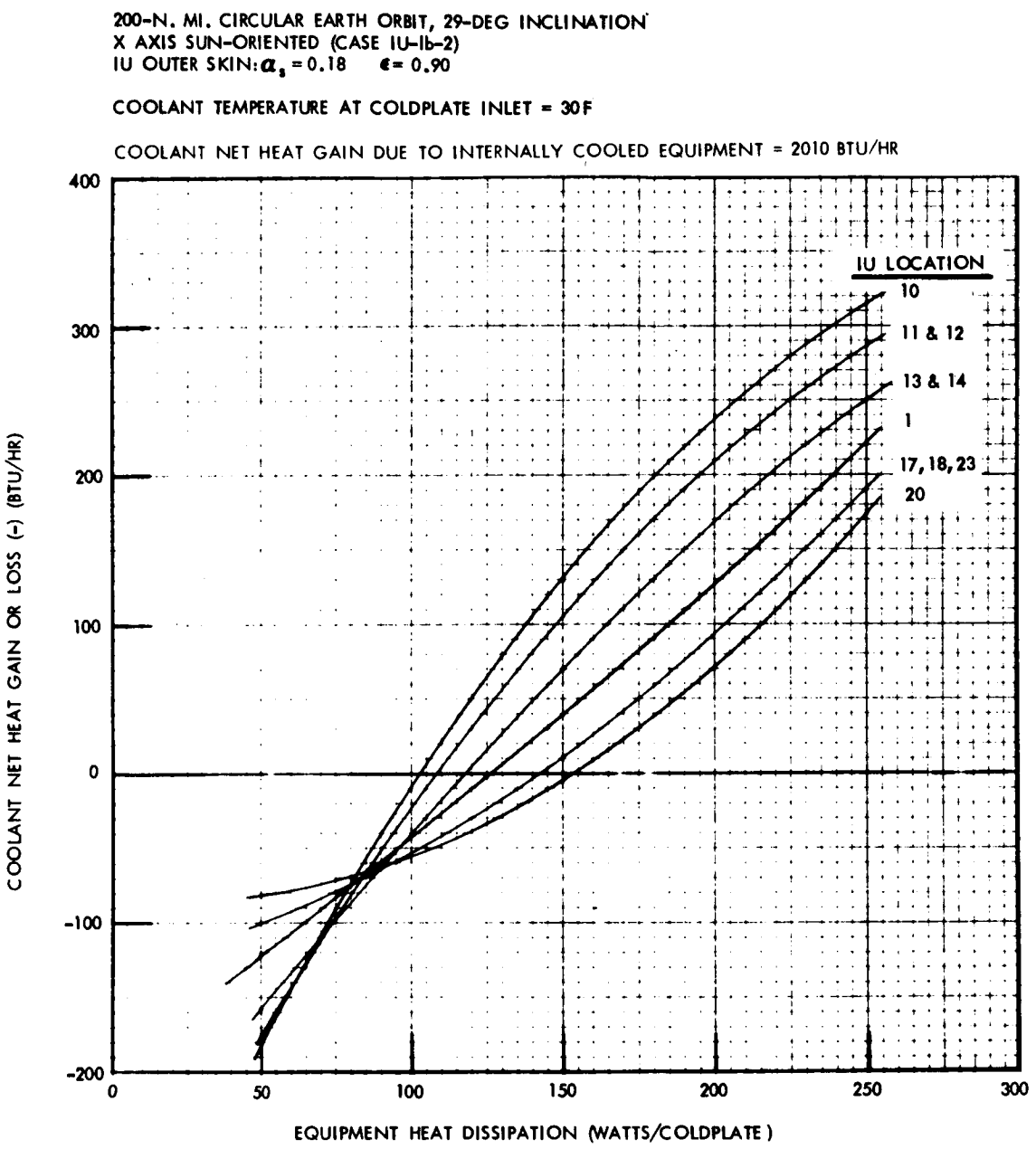

Figure 4-67. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1b-2, Coolant Temperature 30 F

200-N. MI. CIRCULAR EARTH ORBIT, 29-DEG INCLINATION
X AXIS SUN-ORIENTED (CASE IU-Ib-2)
IU OUTER SKIN: $\alpha_s = 0.18$ $\epsilon = 0.90$

COOLANT TEMPERATURE AT COLDPLATE INLET = 50F

COOLANT NET HEAT GAIN DUE TO INTERNALLY COOLED EQUIPMENT = 1490 BTU HR

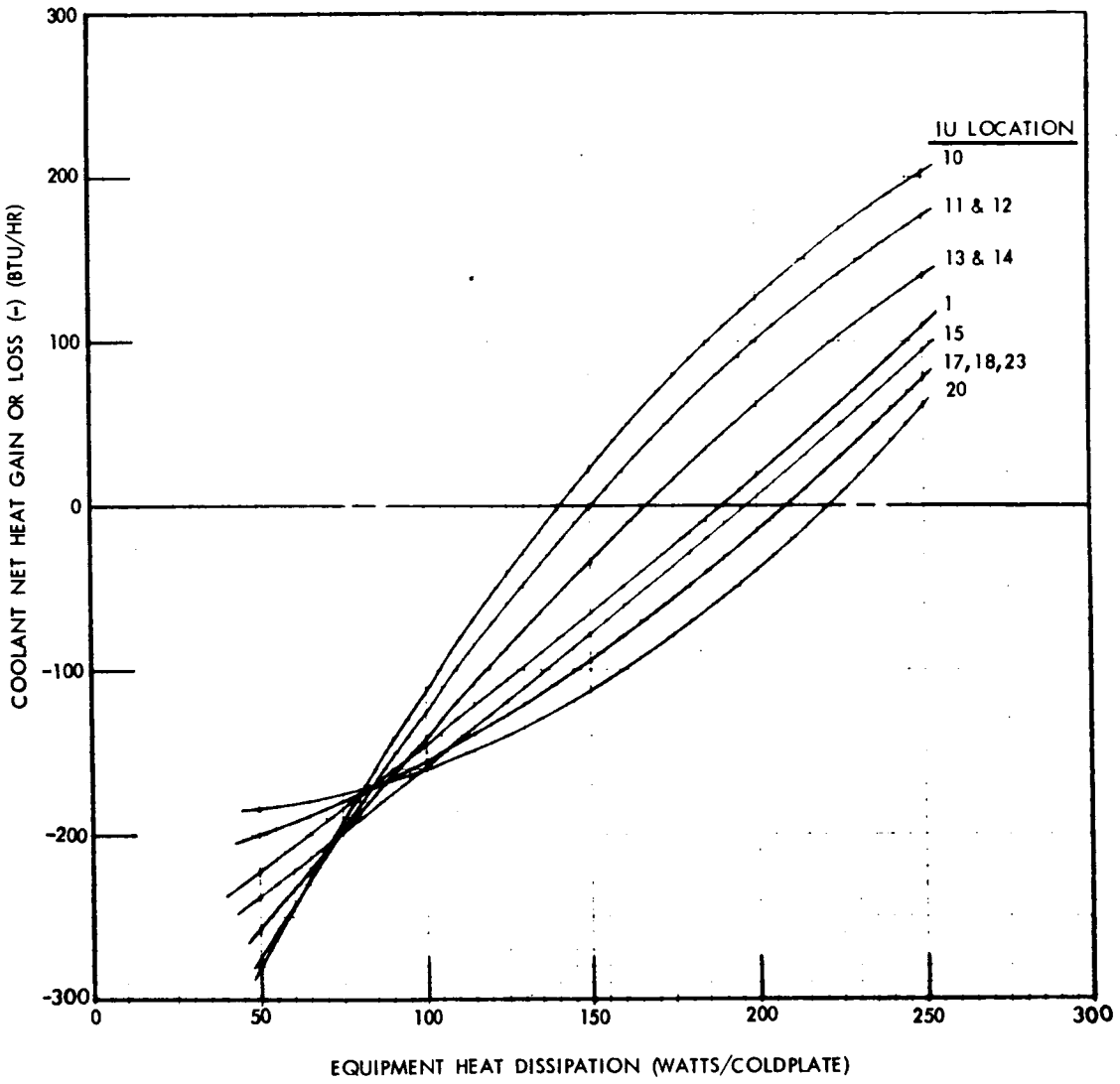

Figure 4-68. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1b-2, Coolant Temperature 50 F

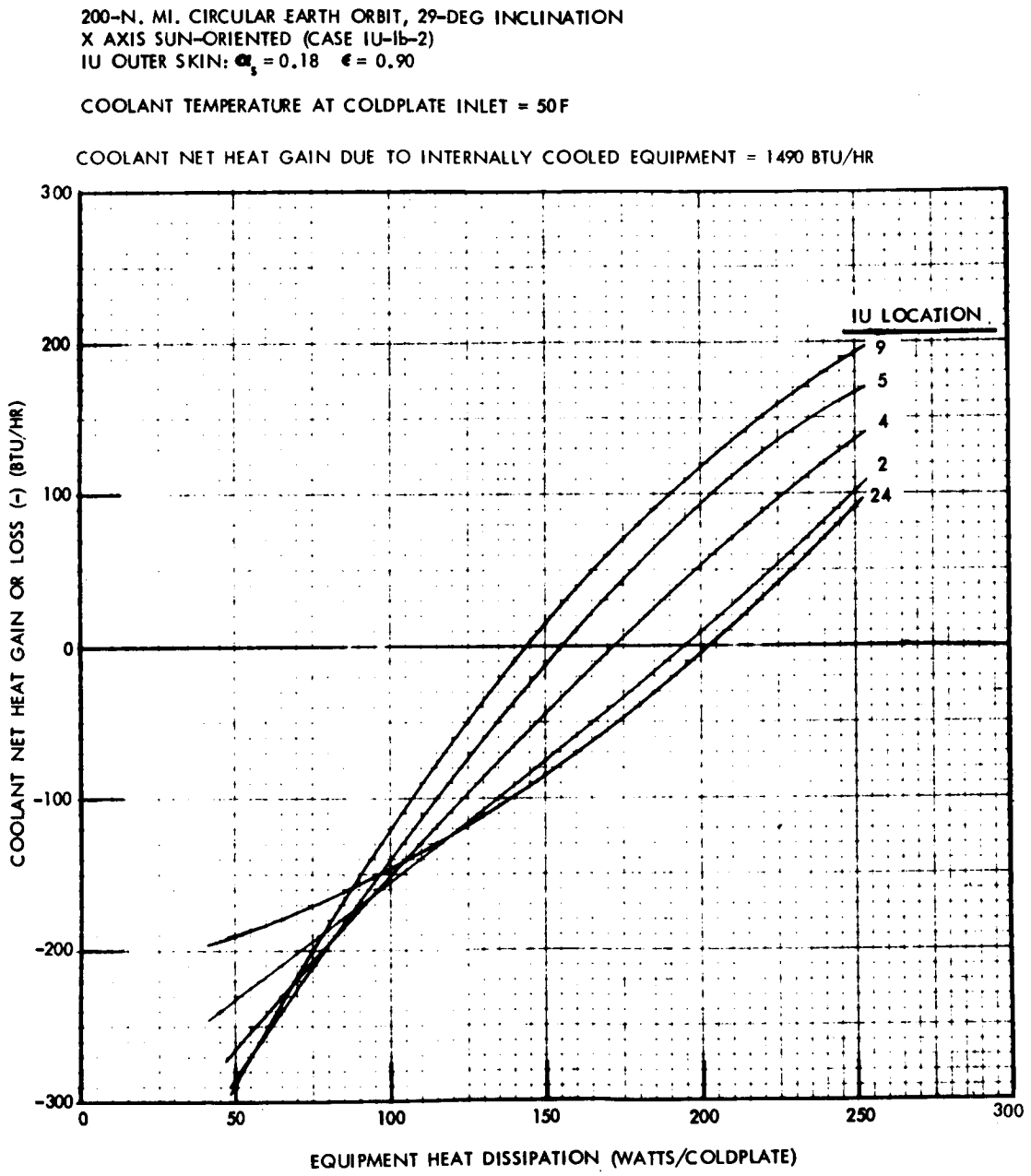

Figure 4-69. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1b-2, Coolant Temperature 50 F

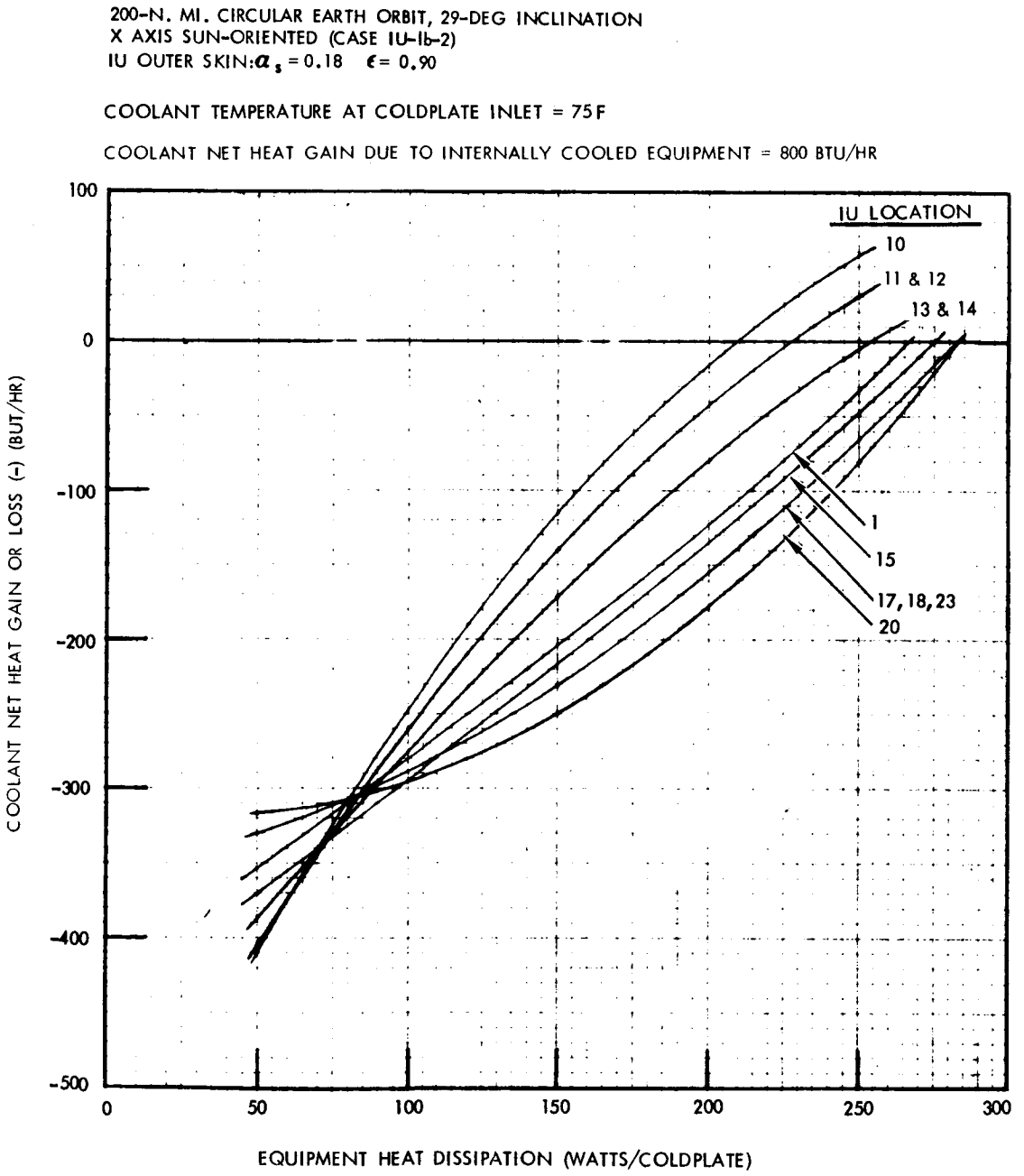

Figure 4-70. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1b-2, Coolant Temperature 75 F

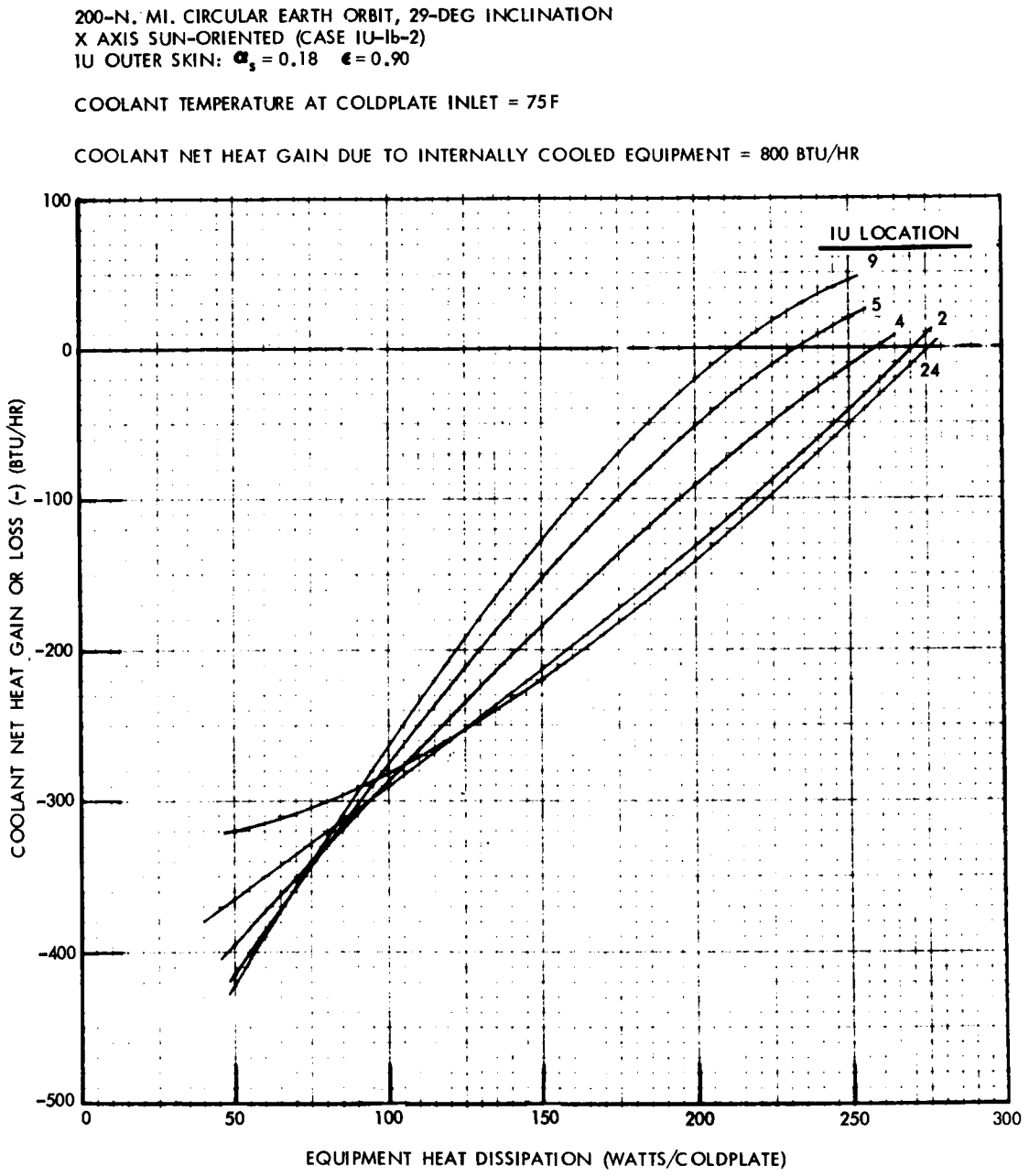

Figure 4-71. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-1b-2, Coolant Temperature 75 F

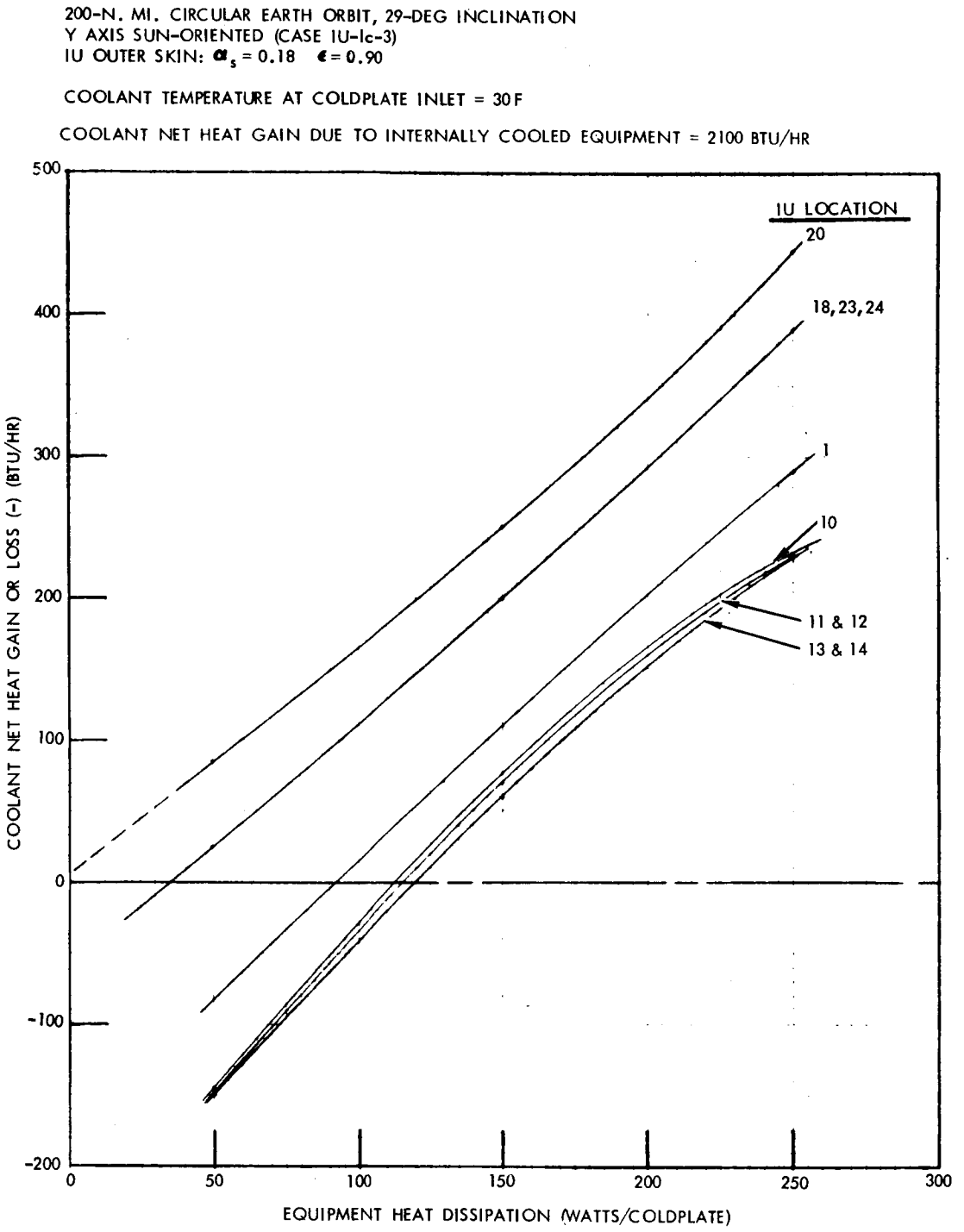

Figure 4-72. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1c-3, Coolant Temperature 30 F

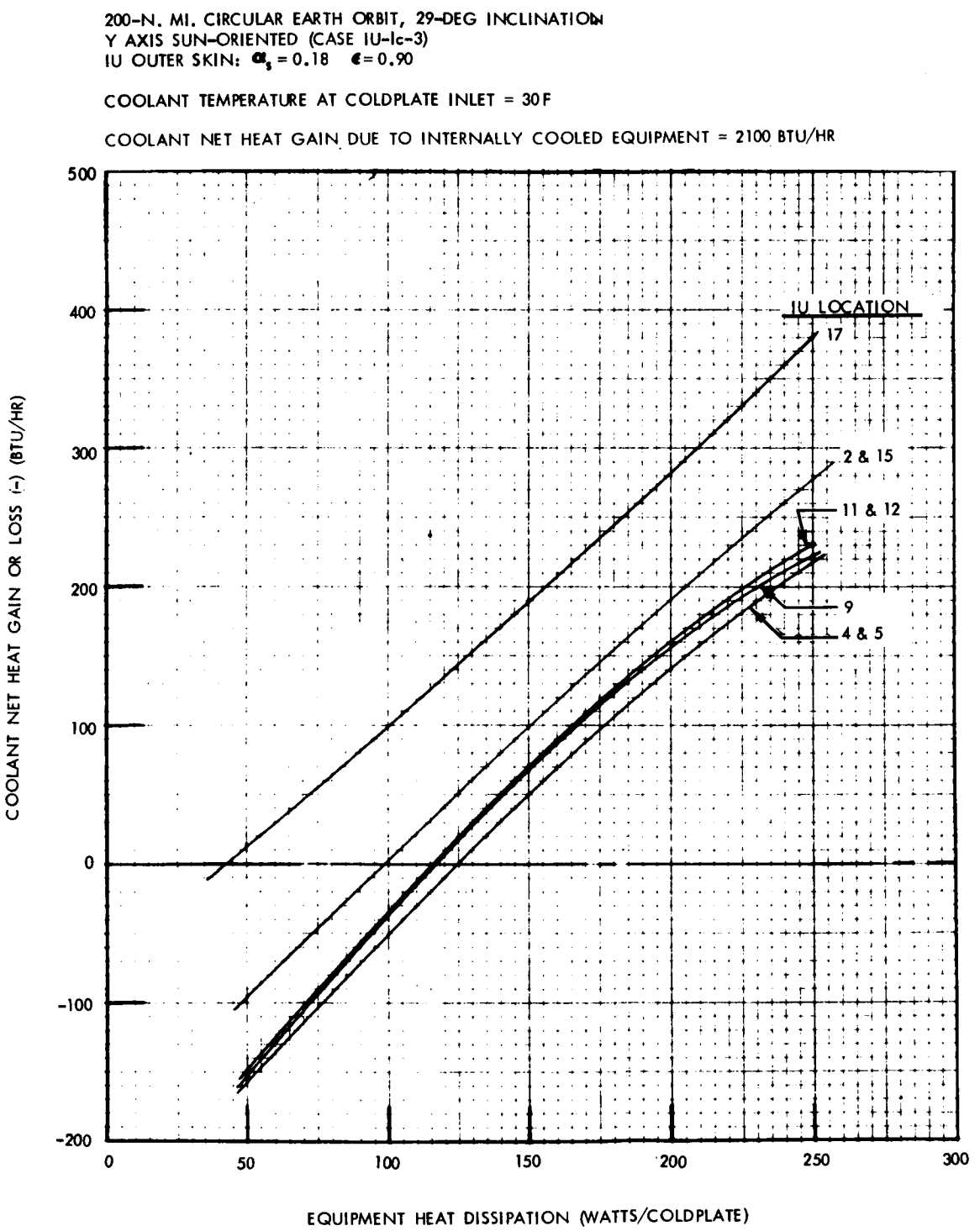

Figure 4-73. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-1c-3, Coolant Temperature 30 F

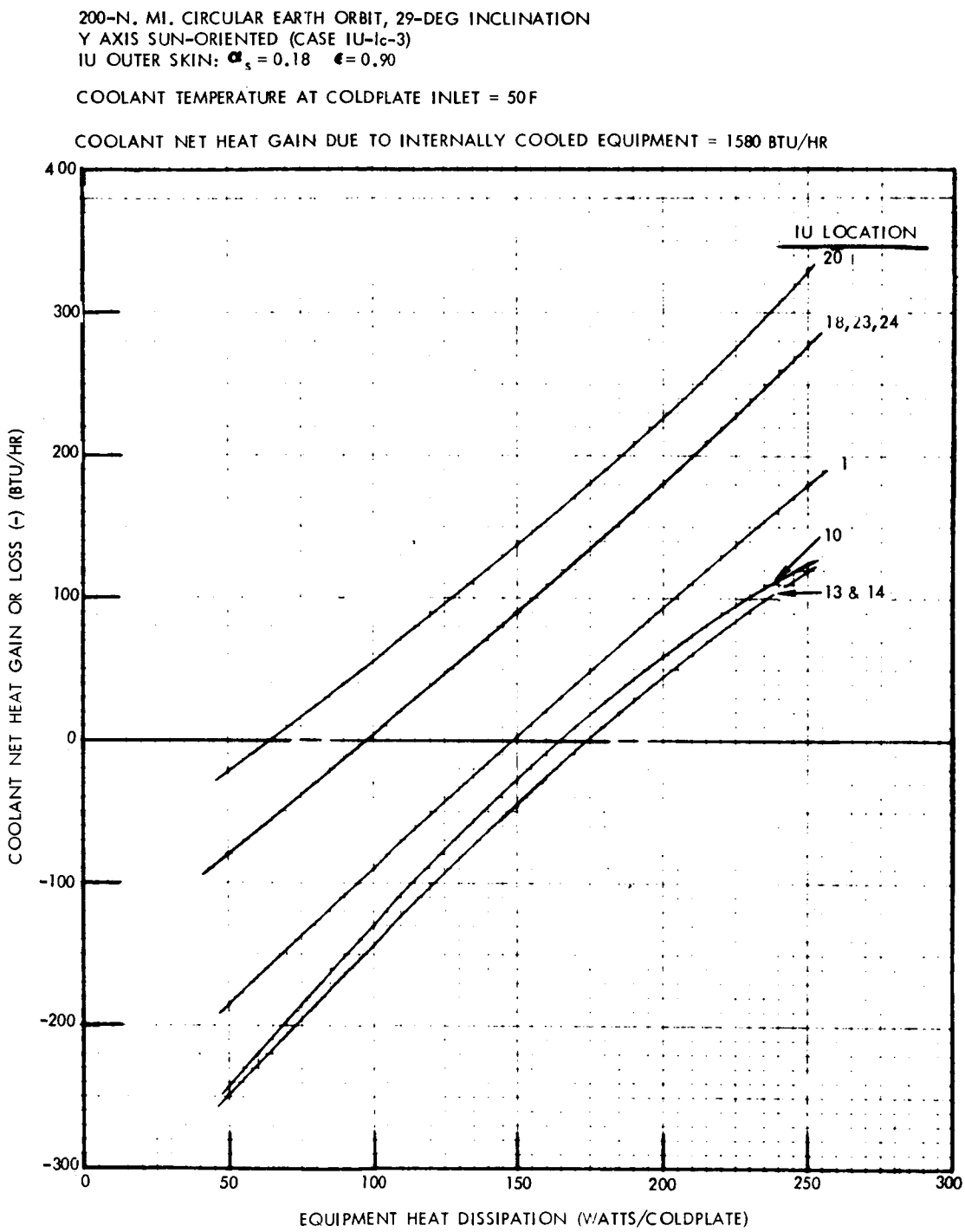

Figure 4-74. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1c-3, Coolant Temperature 50 F

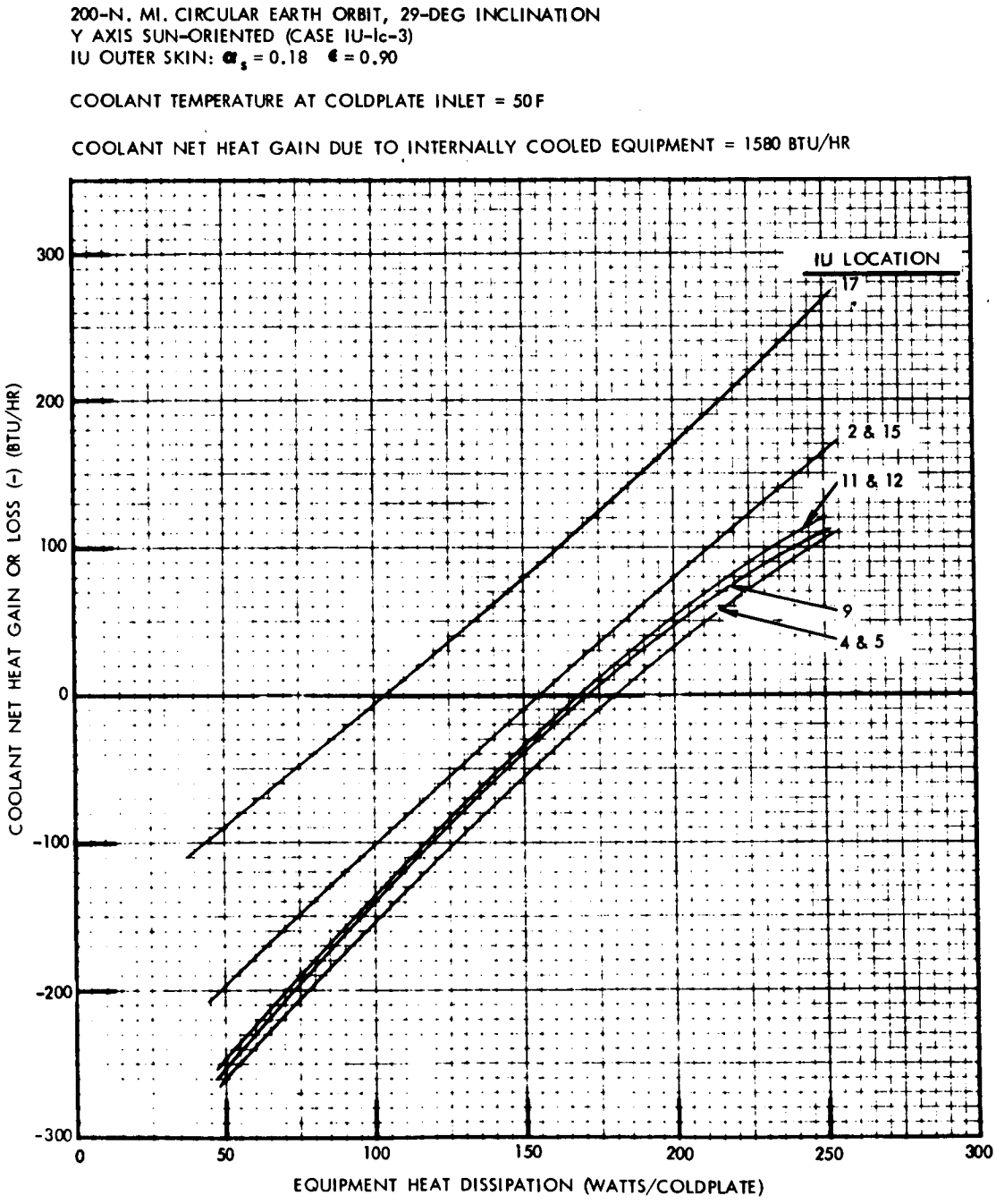

Figure 4-75. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-1c-3, Coolant Temperature 50 F

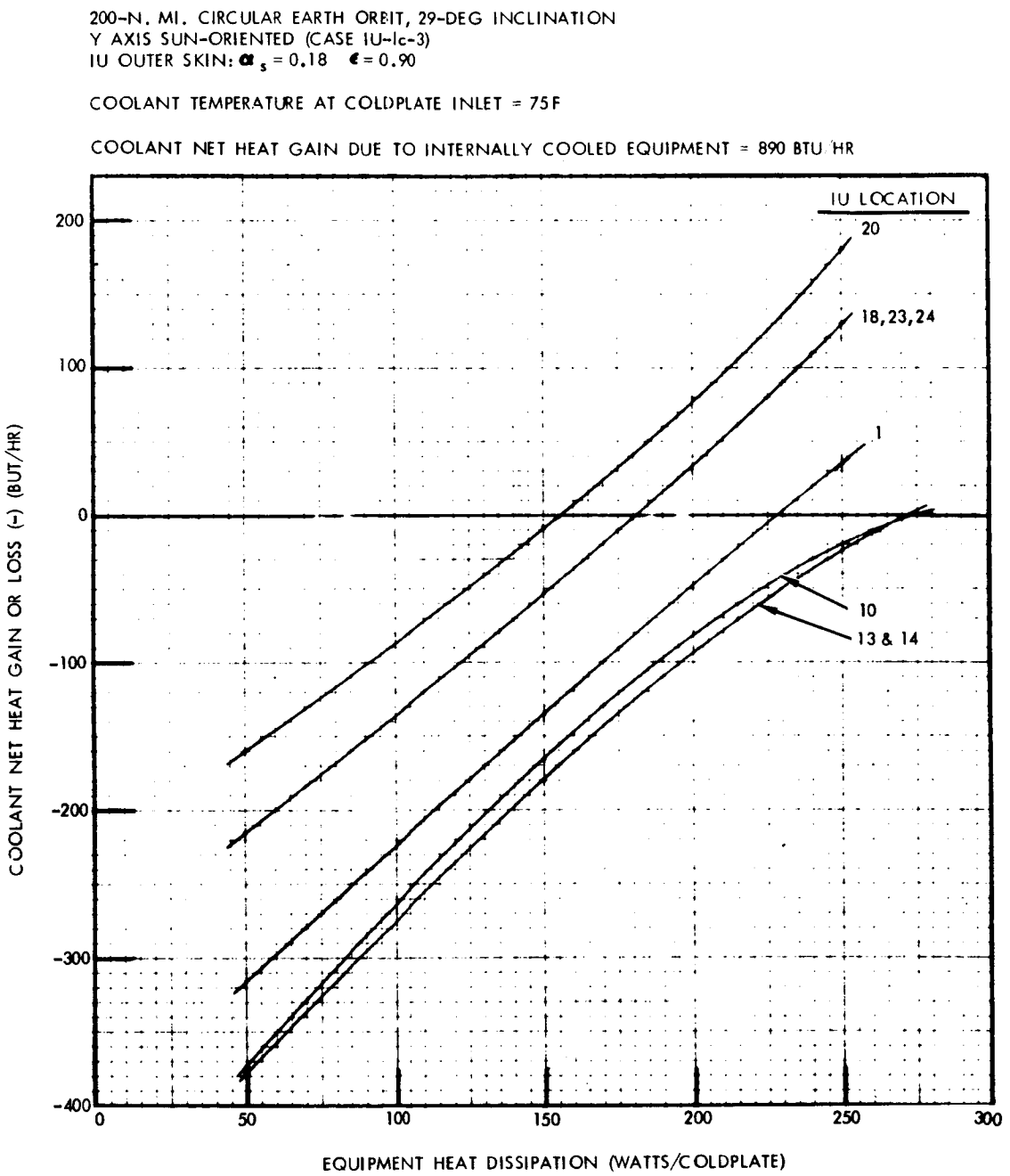

Figure 4-76. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1c-3, Coolant Temperature 75 F

200-N. MI. CIRCULAR EARTH ORBIT, 29-DEG INCLINATION
Y AXIS SUN-ORIENTED (CASE IU-lc-3)
IU OUTER SKIN: $\alpha_s = 0.18$ $\epsilon = 0.90$

COOLANT TEMPERATURE AT COLDPLATE INLET = 75F

COOLANT NET HEAT GAIN DUE TO INTERNALLY COOLED EQUIPMENT = 890 BTU/HR

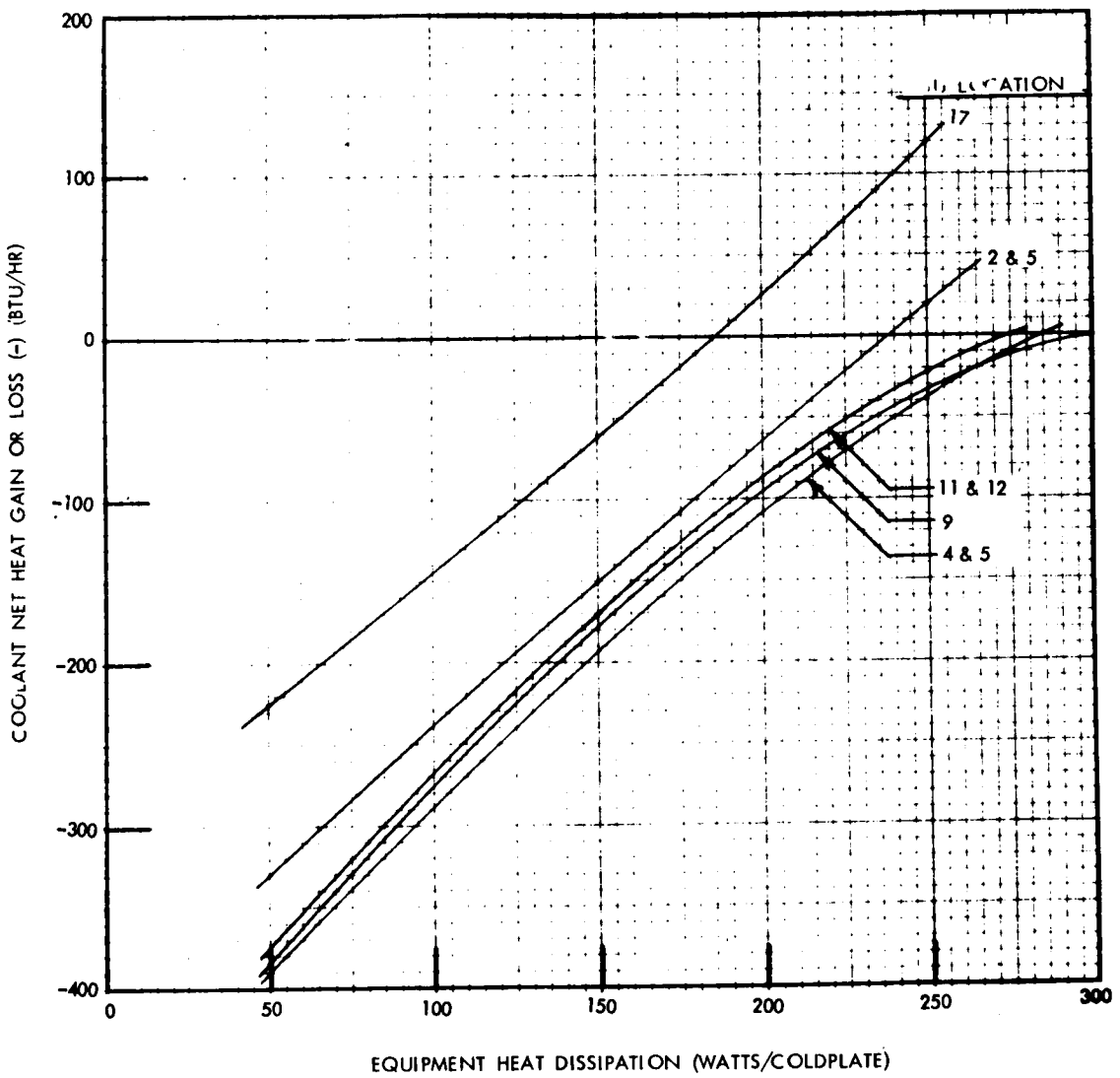

Figure 4-77. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-1c-3, Coolant Temperature 75 F

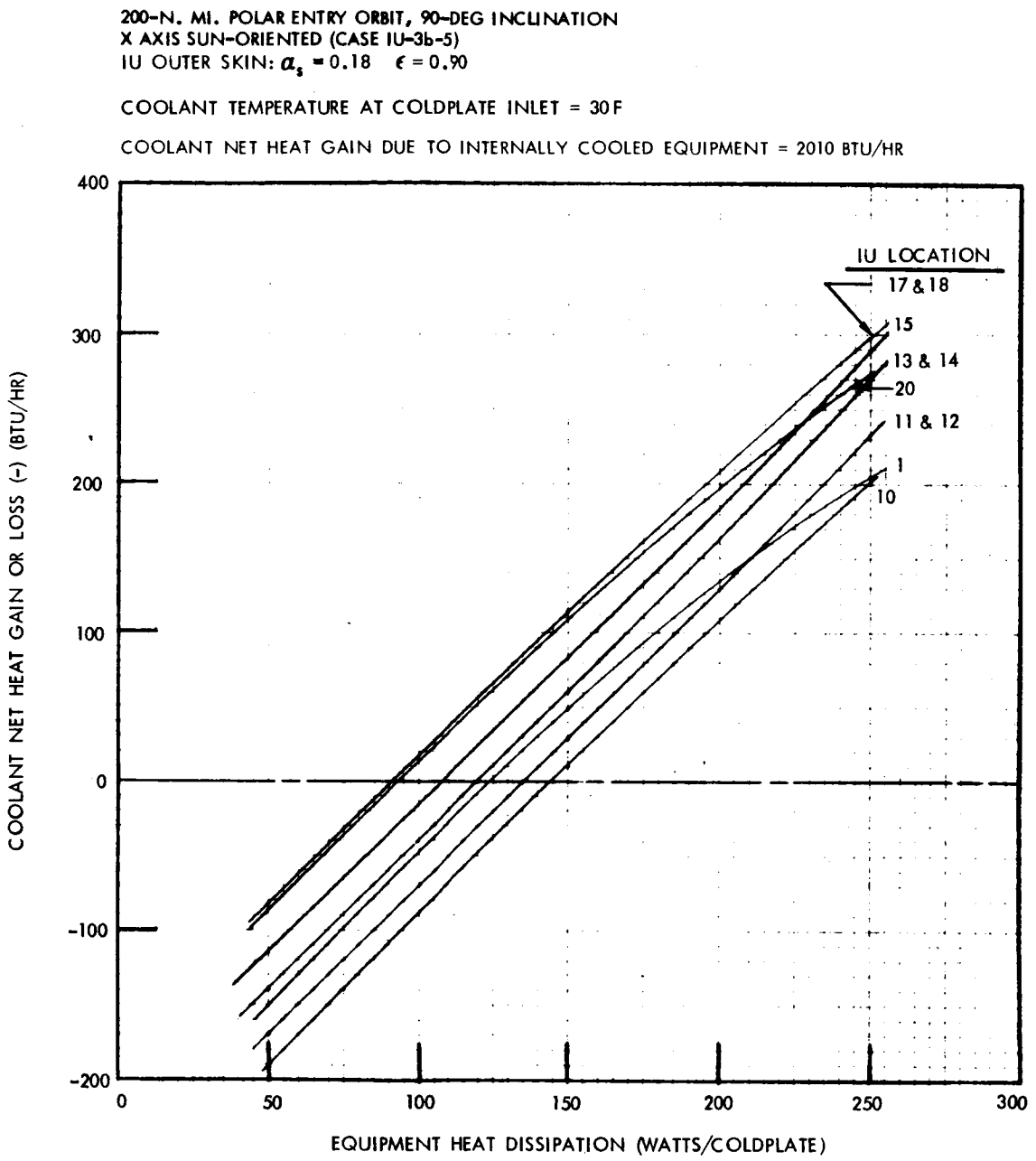

Figure 4-78. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3b-5, Coolant Temperature 30 F

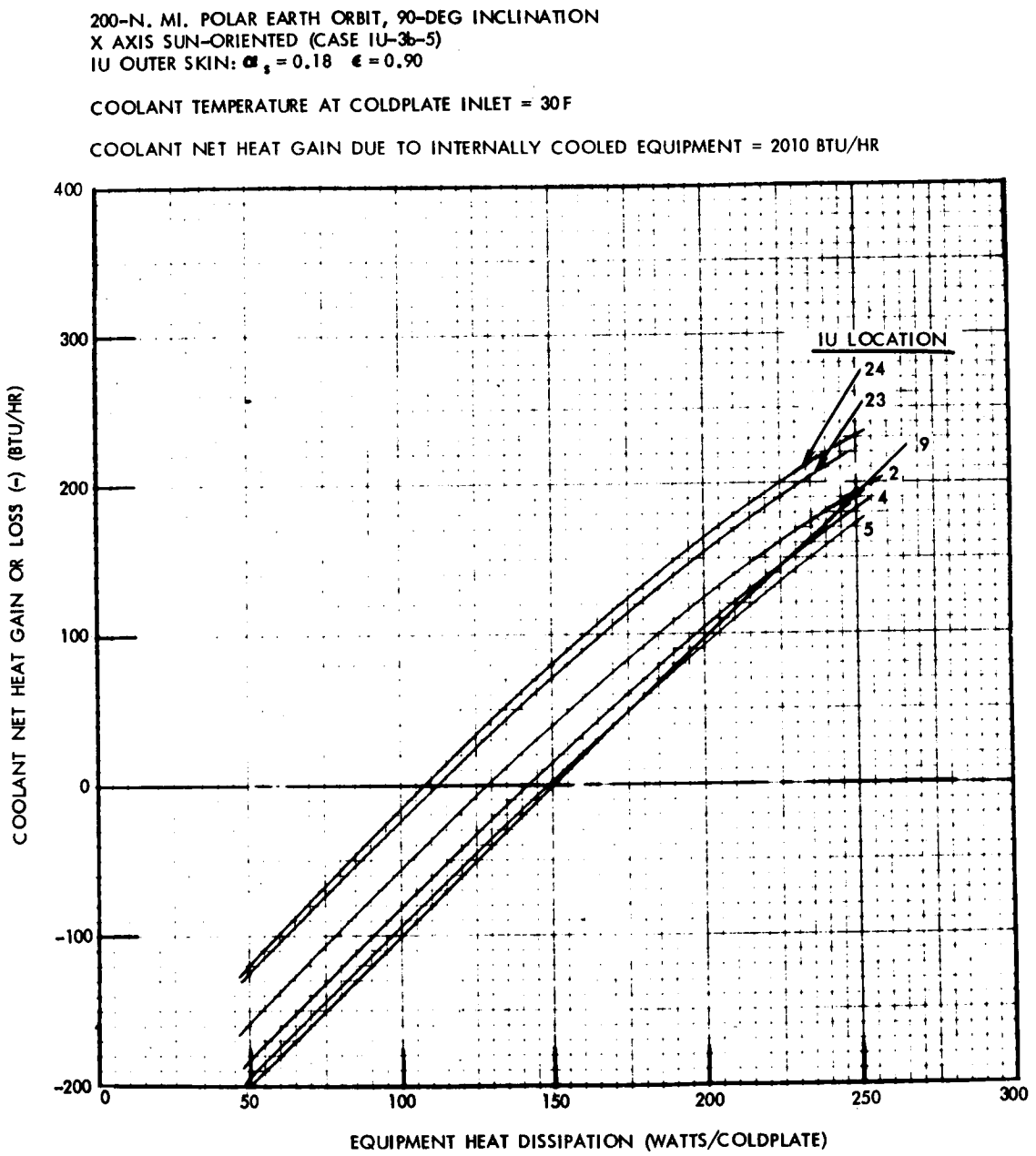

Figure 4-79. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-3b-5, Coolant Temperature 30 F

200-N. MI. POLAR EARTH ORBIT, 90-DEG INCLINATION
X AXIS SUN-ORIENTED (CASE IU-3b-5)
IU OUTER SKIN: $\alpha_s = 0.18$ $\epsilon = 0.90$

COOLANT TEMPERATURE AT COLDPLATE INLET = 50 F

COOLANT NET HEAT GAIN DUE TO INTERNALLY COOLED EQUIPMENT = 1490 BTU/HR

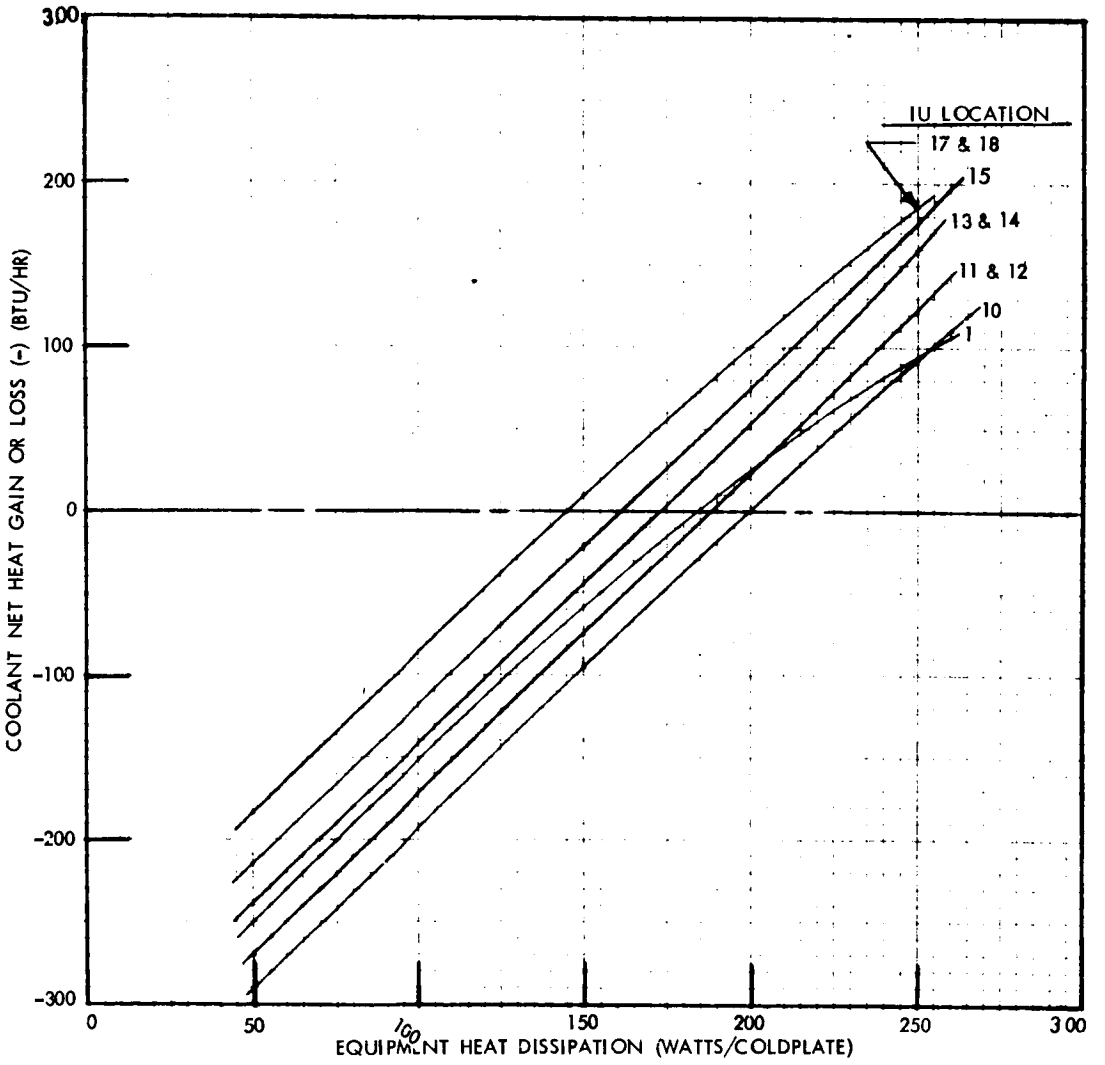

Figure 4-80. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3b-5, Coolant Temperature 50 F

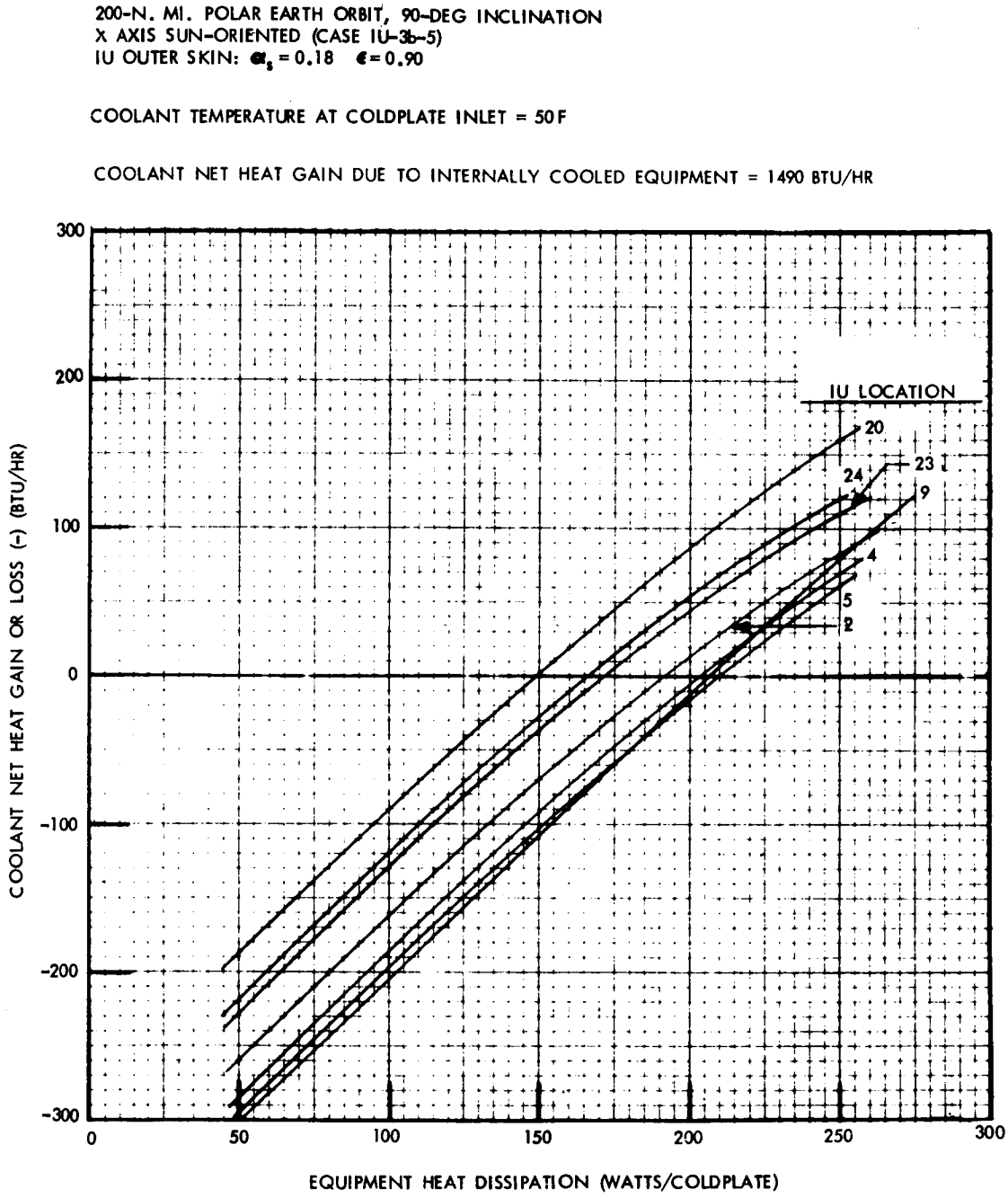

Figure 4-81. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-3b-5, Coolant Temperature 50 F

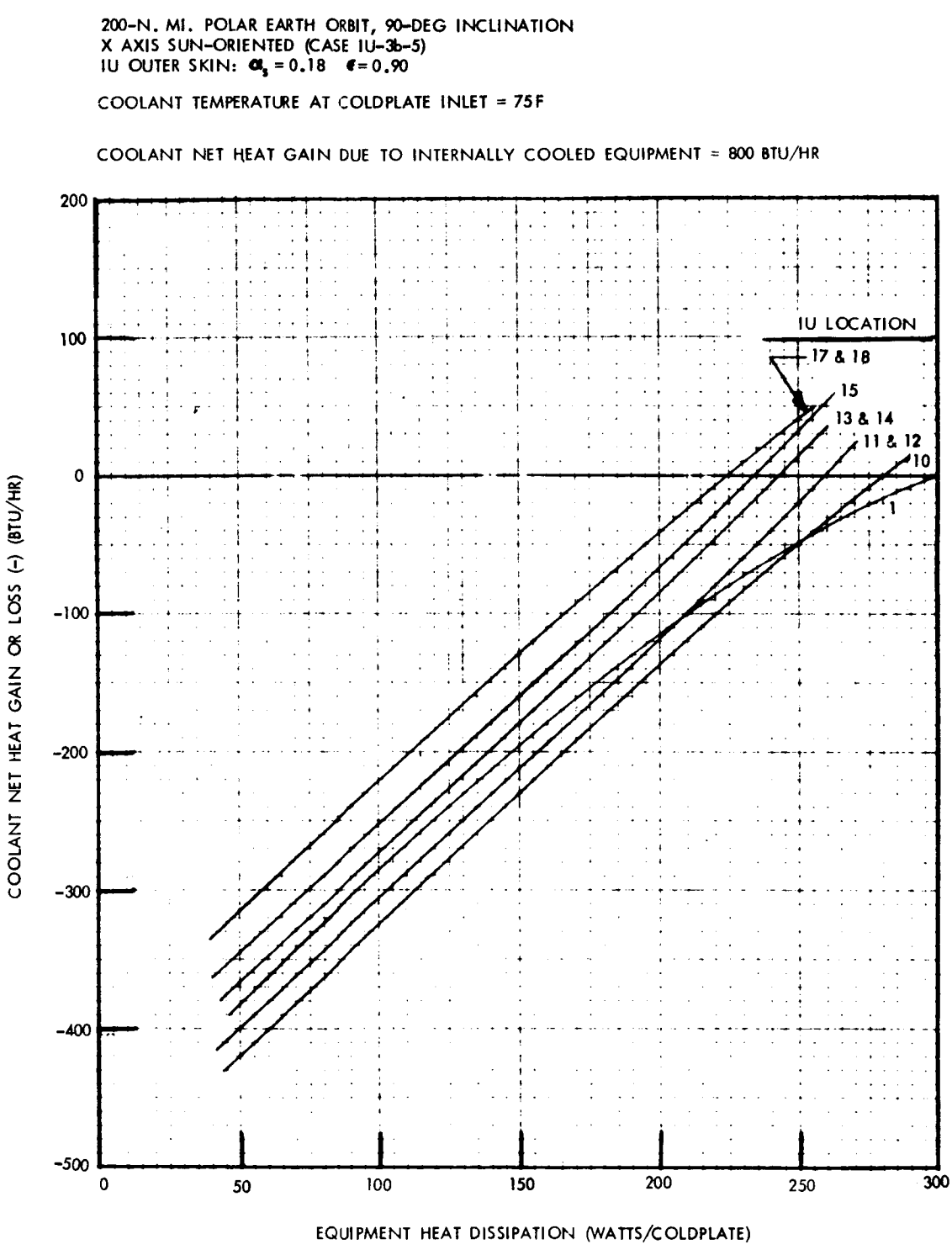

Figure 4-82. Coolant Net Heat Gain or Loss Versus Equipment Dissipation — Case No. IU-3b-5, Coolant Temperature 75 F

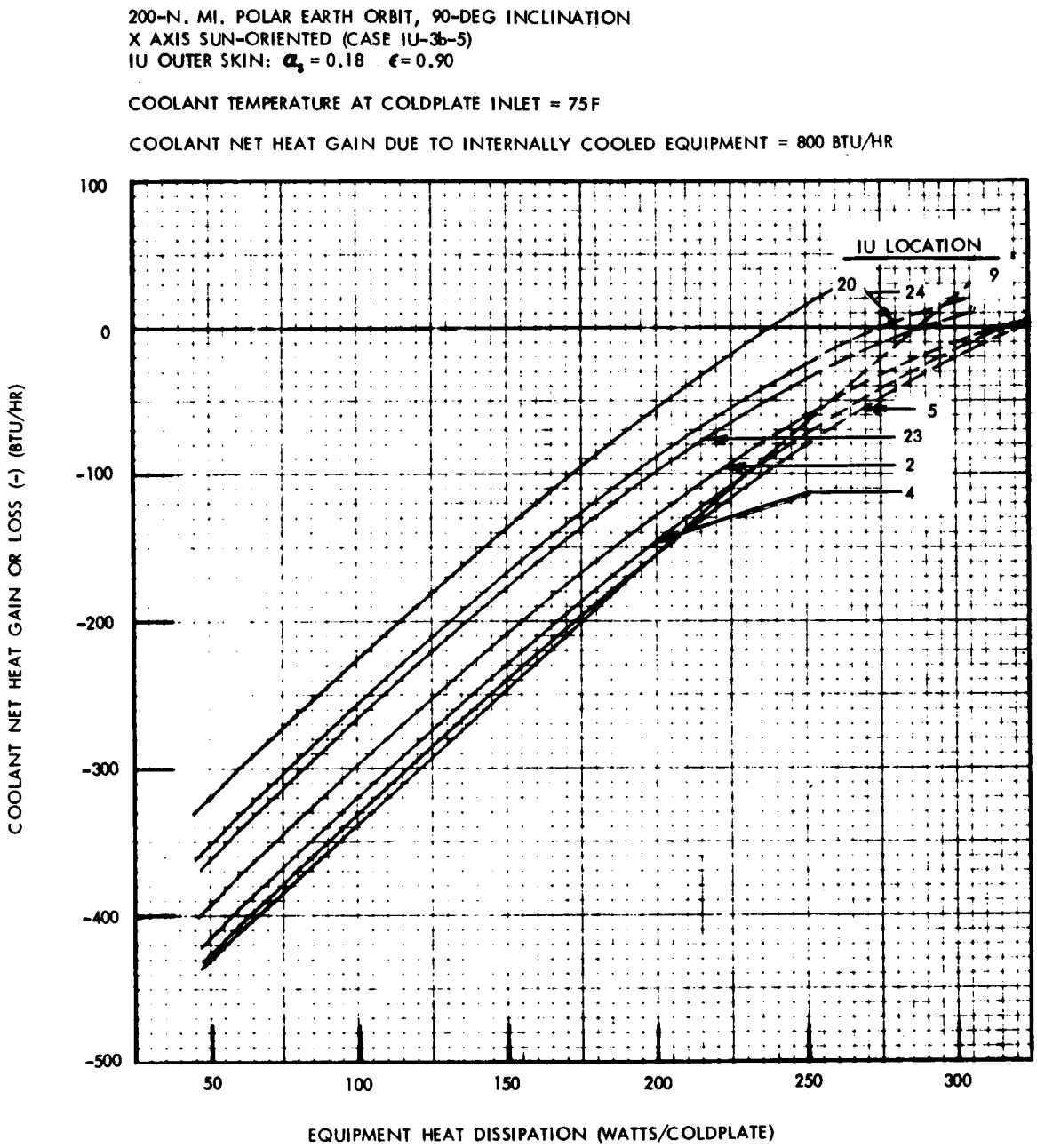

Figure 4-83. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3b-5, Coolant Temperature 75 F

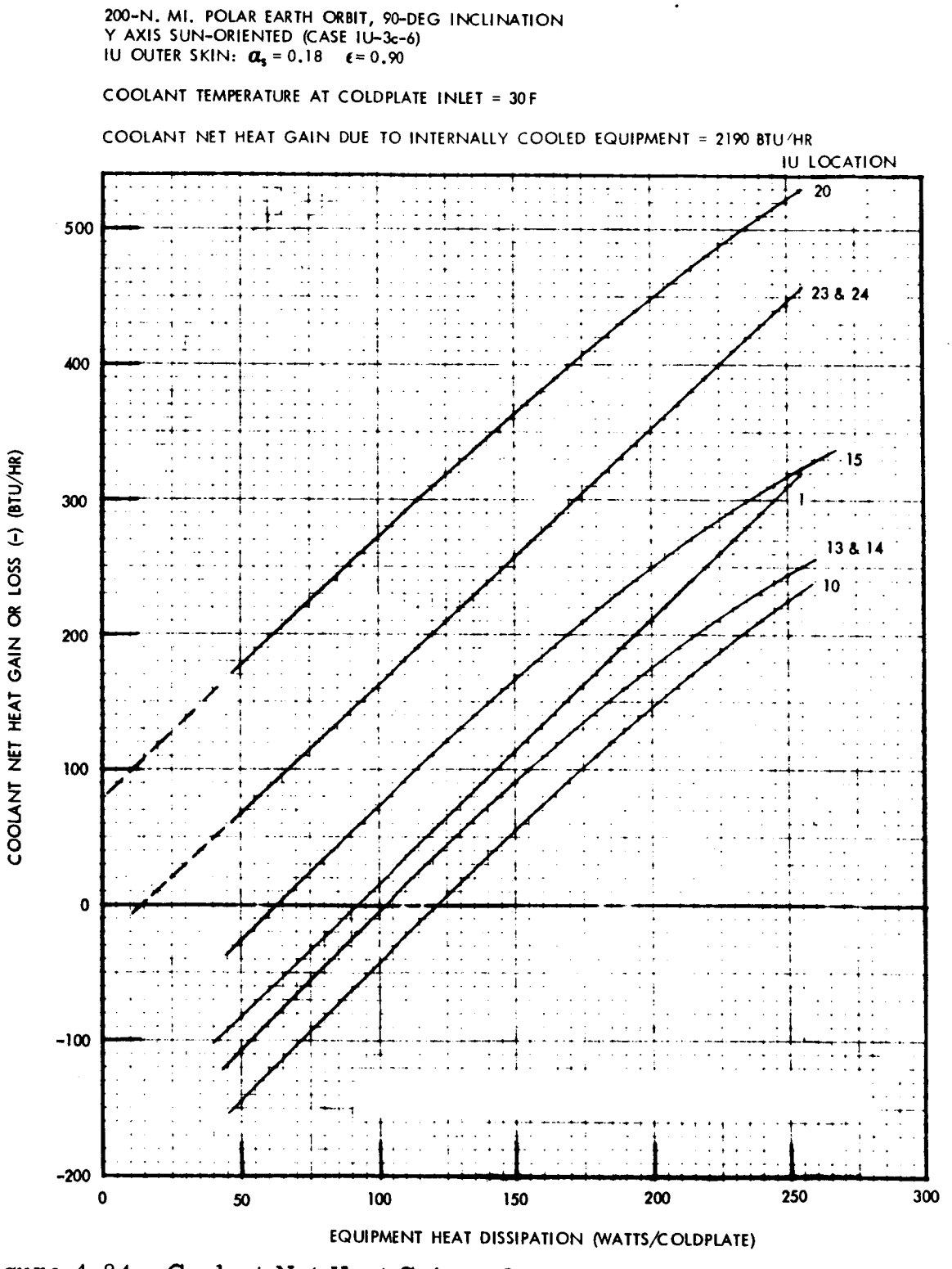

Figure 4-84. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-3c-6, Coolant Temperature 30 F

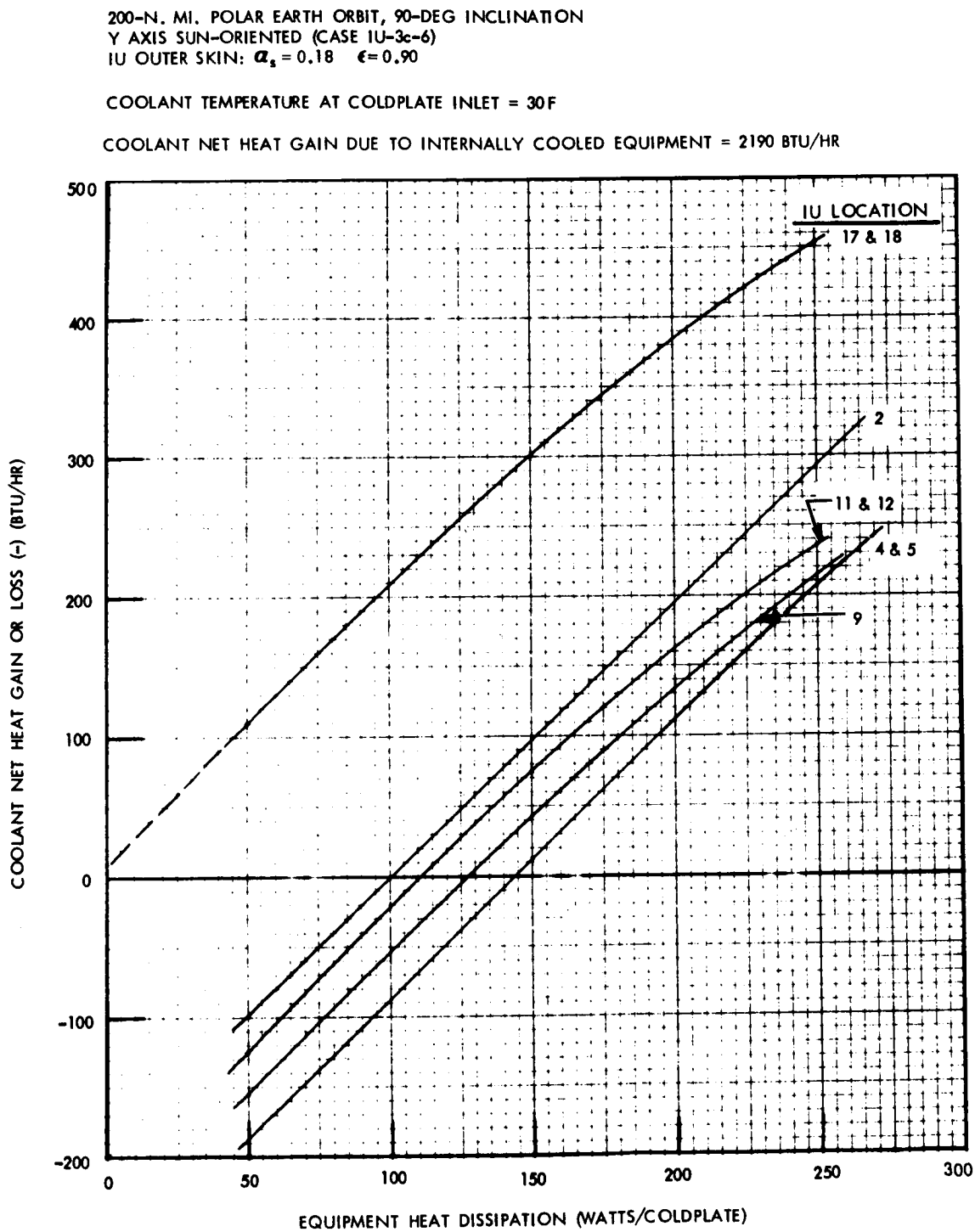

Figure 4-85. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-3c-6, Coolant Temperature 30 F

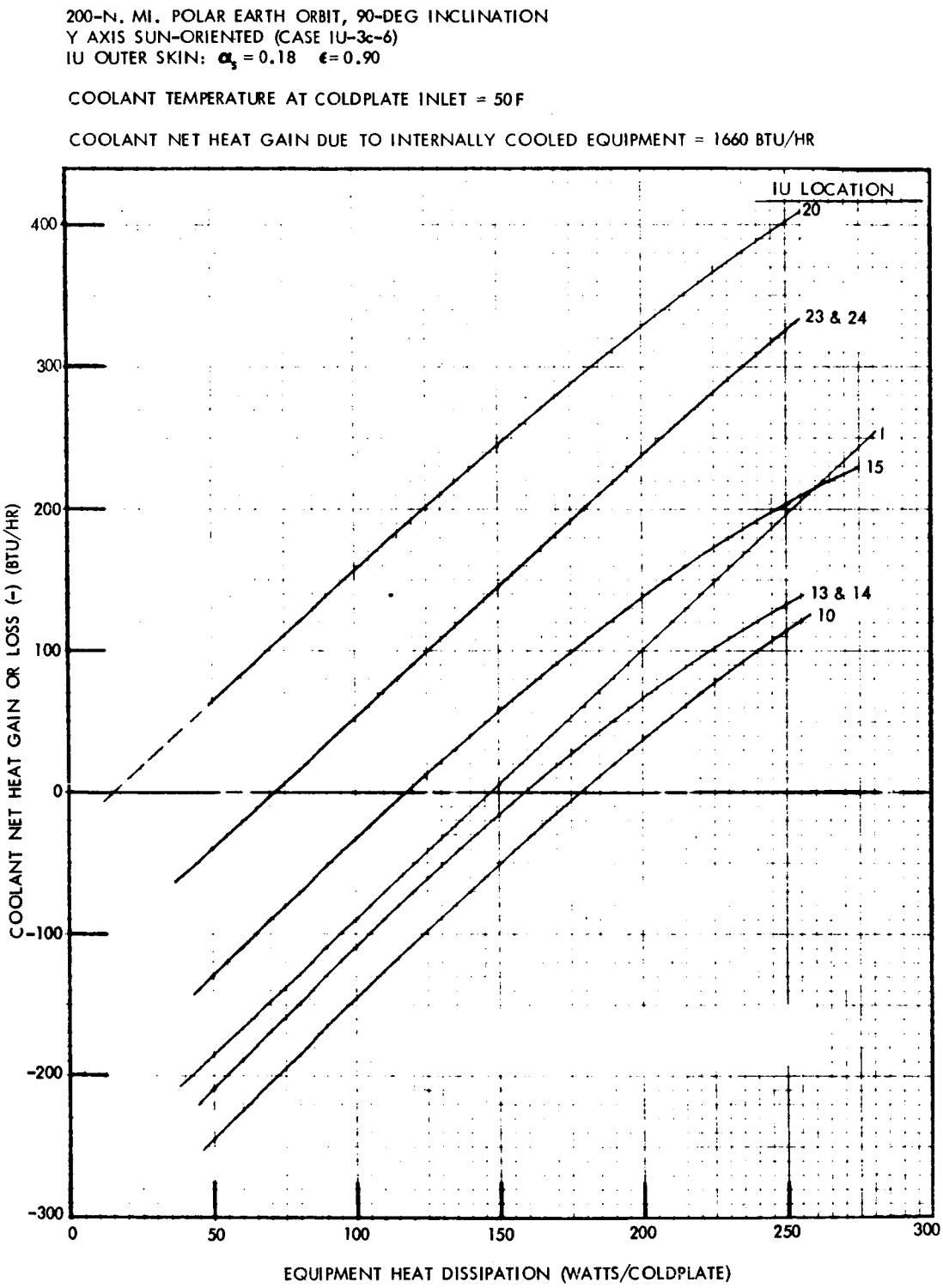

Figure 4-86. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3c-6, Coolant Temperature 50 F

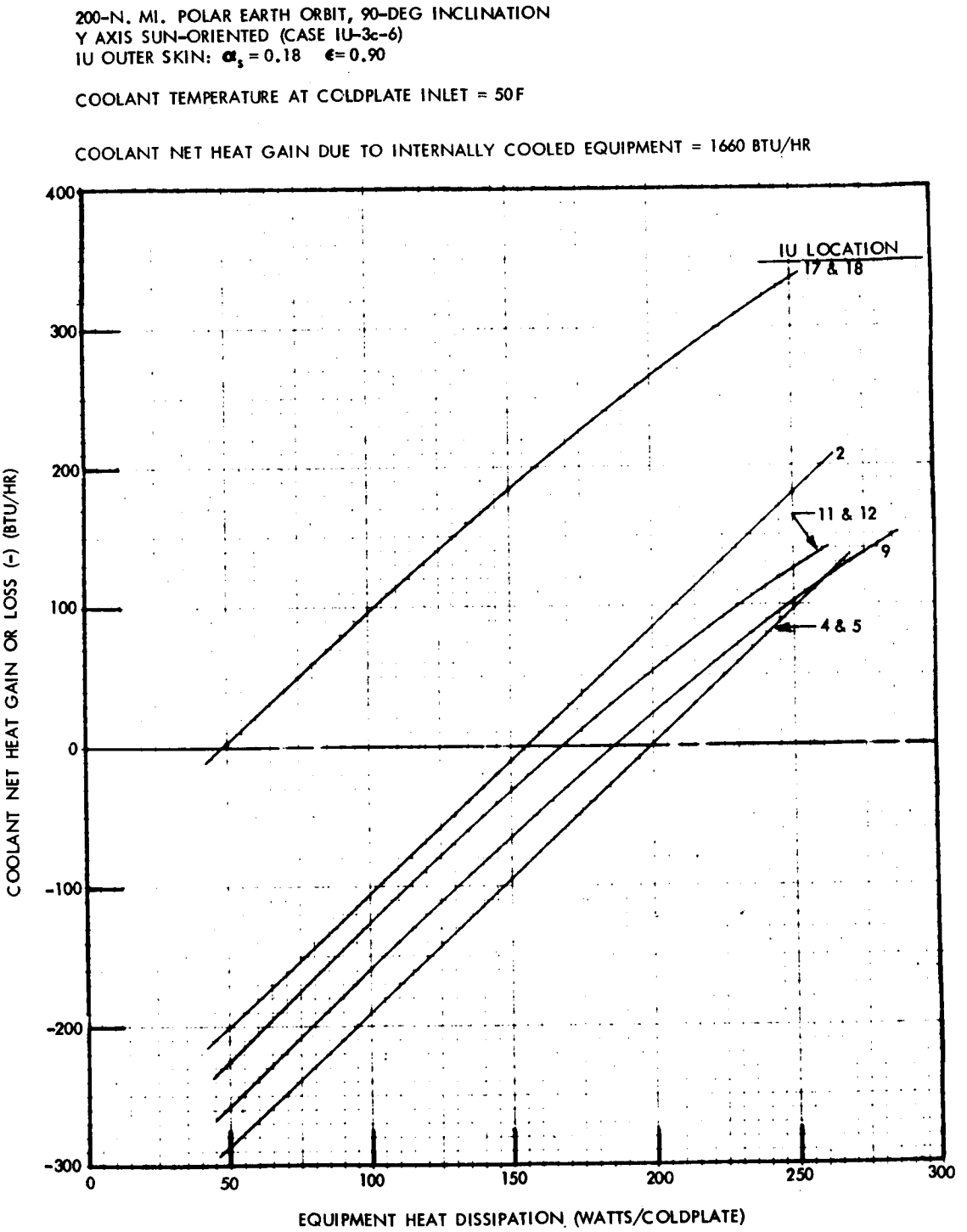

Figure 4-87. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3c-6, Coolant Temperature 50 F

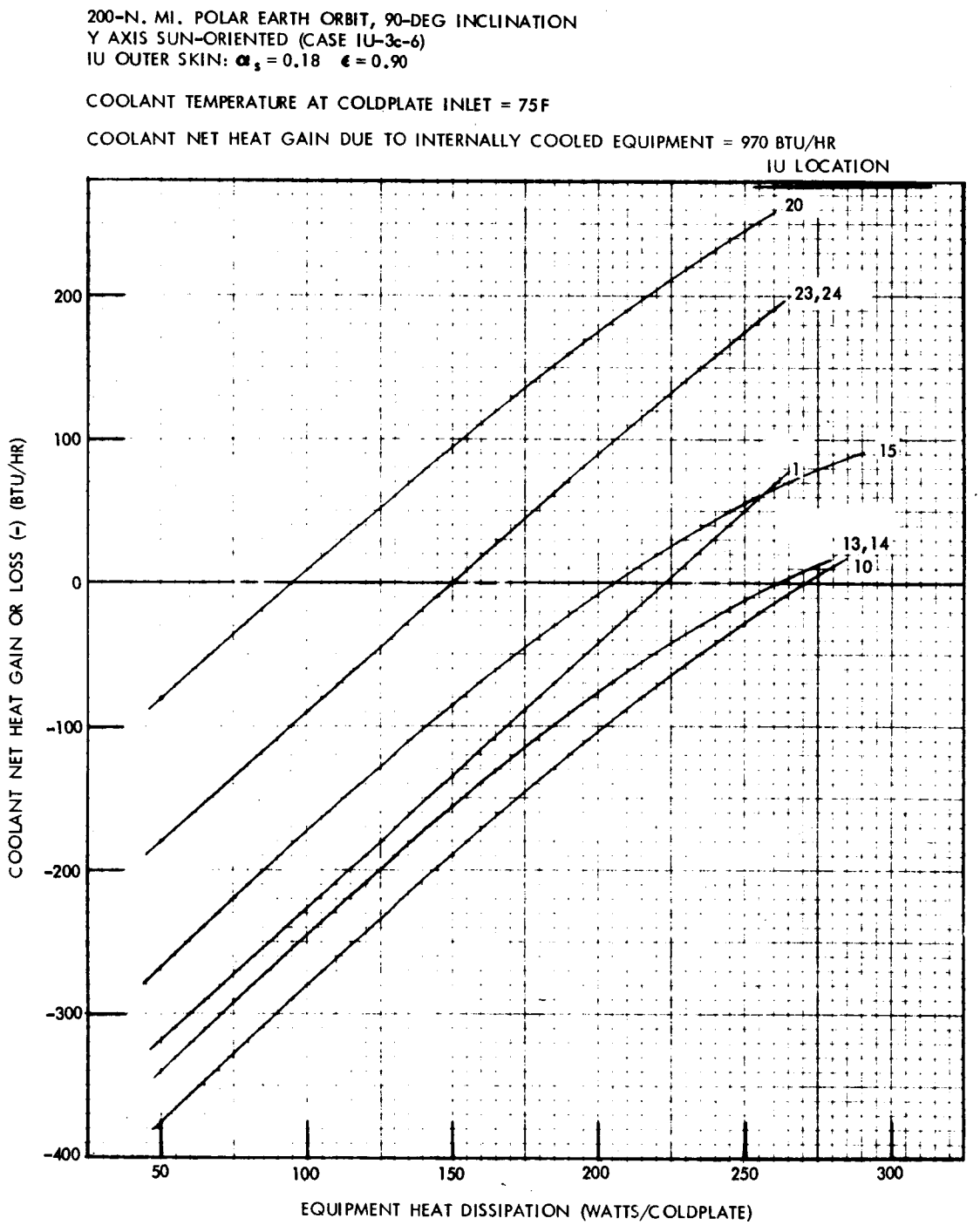

Figure 4-88. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3c-6, Coolant Temperature 75 F

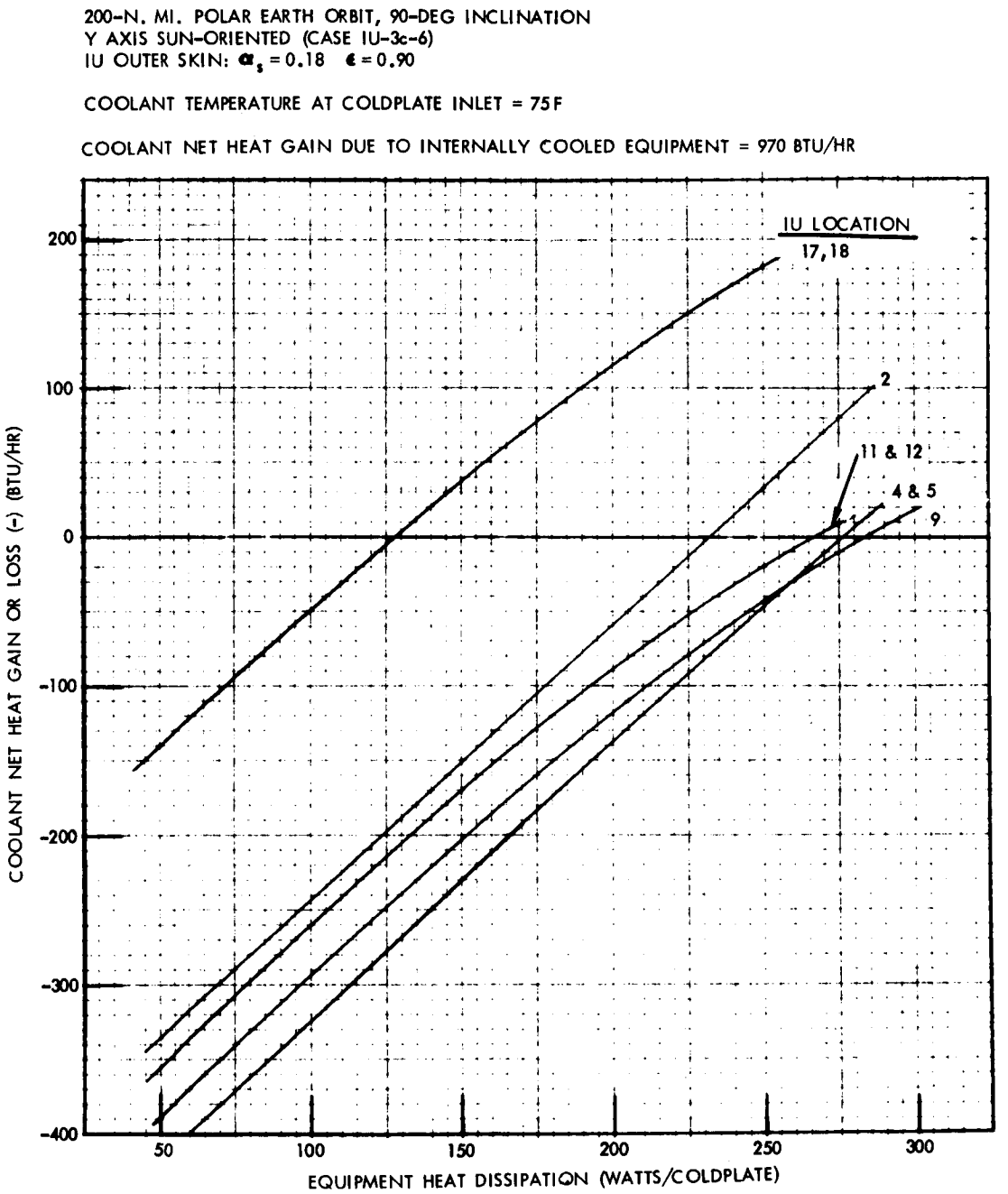

Figure 4-89. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-3c-6, Coolant Temperature 75 F

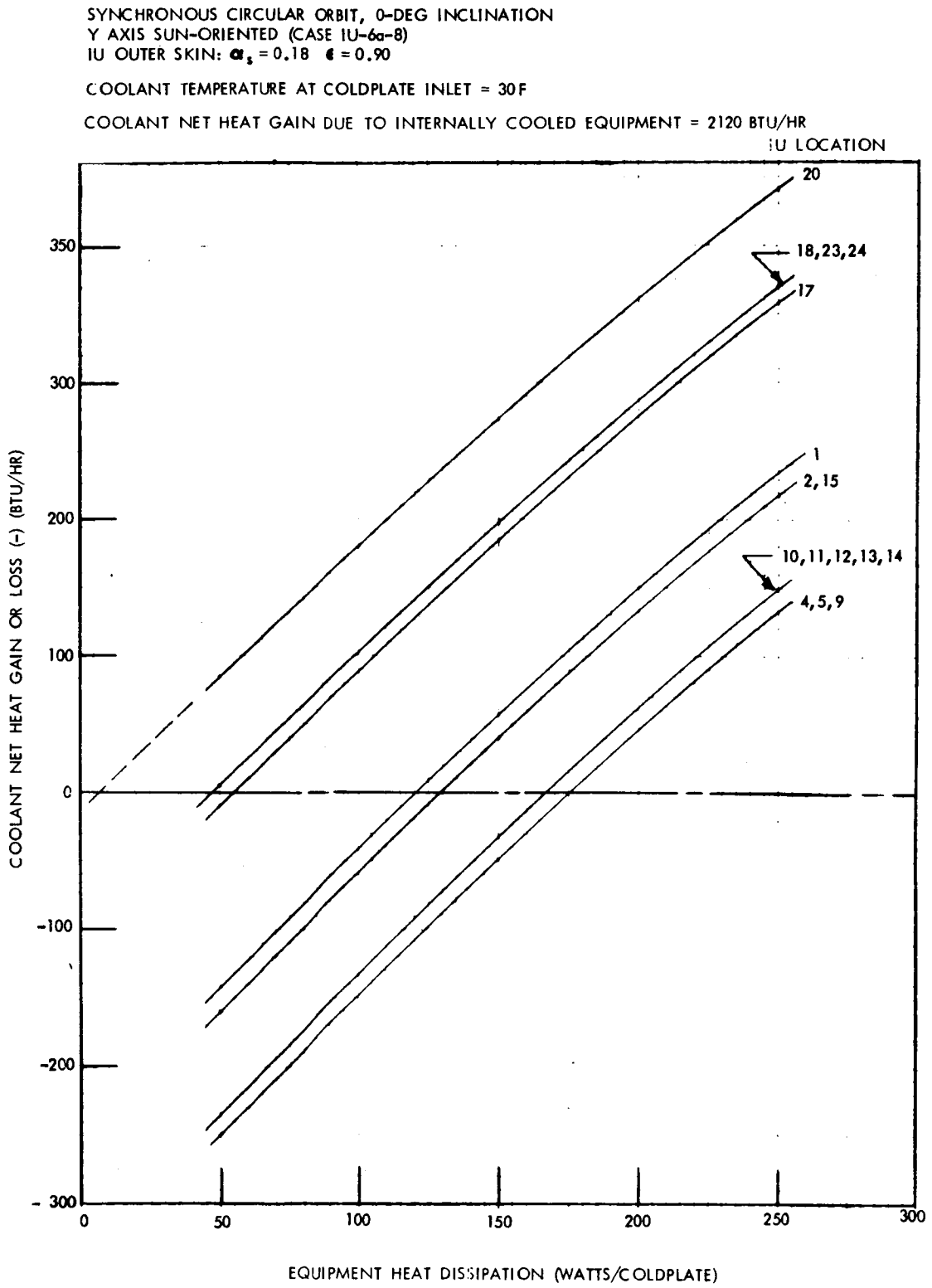

Figure 4-90. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-6a-8, Coolant Temperature 30 F

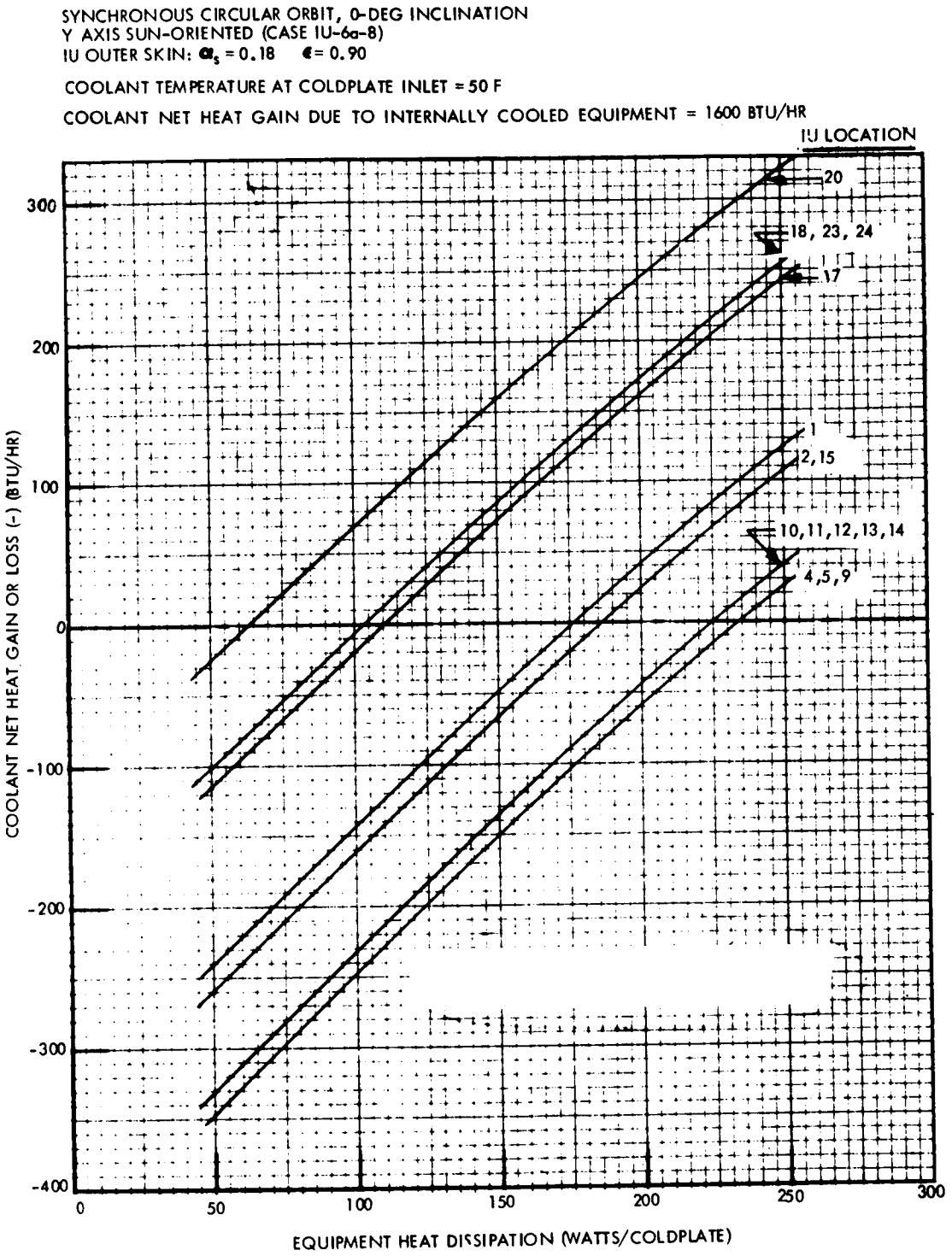

Figure 4-91. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-6a-8, Coolant Temperature 50 F

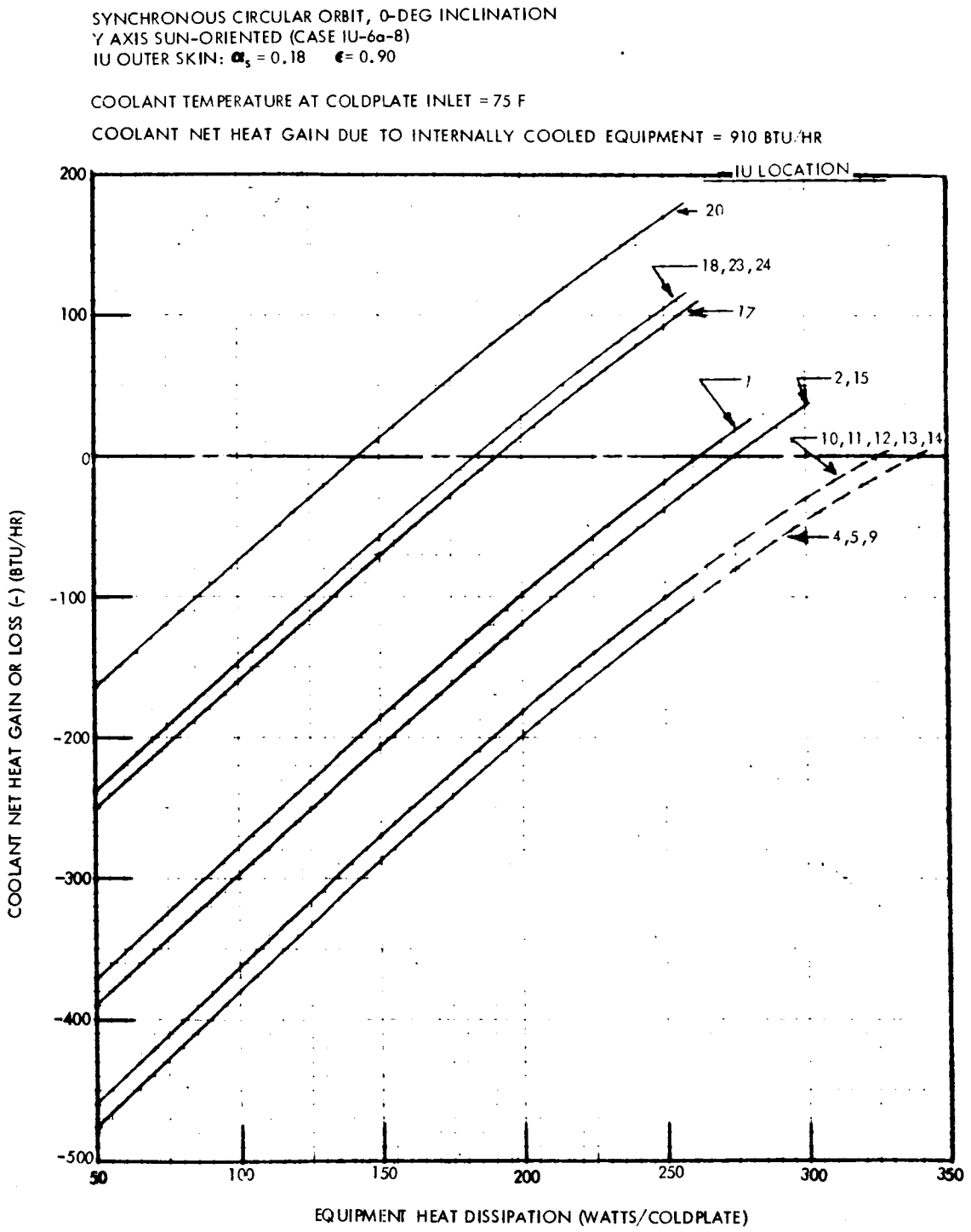

Figure 4-92. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-6a-8, Coolant Temperature 75 F

SYNCHRONOUS CIRCULAR ORBIT, 0-DEG INCLINATION
X AXIS SUN-ORIENTED (CASE IU-6b-9)

IU OUTER SKIN: α_s = 0.18, ϵ = 0.90

COOLANT TEMPERATURE AT COLDPLATE INLET = 30 F

COOLANT NET HEAT GAIN DUE TO INTERNALLY COOLED EQUIPMENT = 1940 BTU/HR

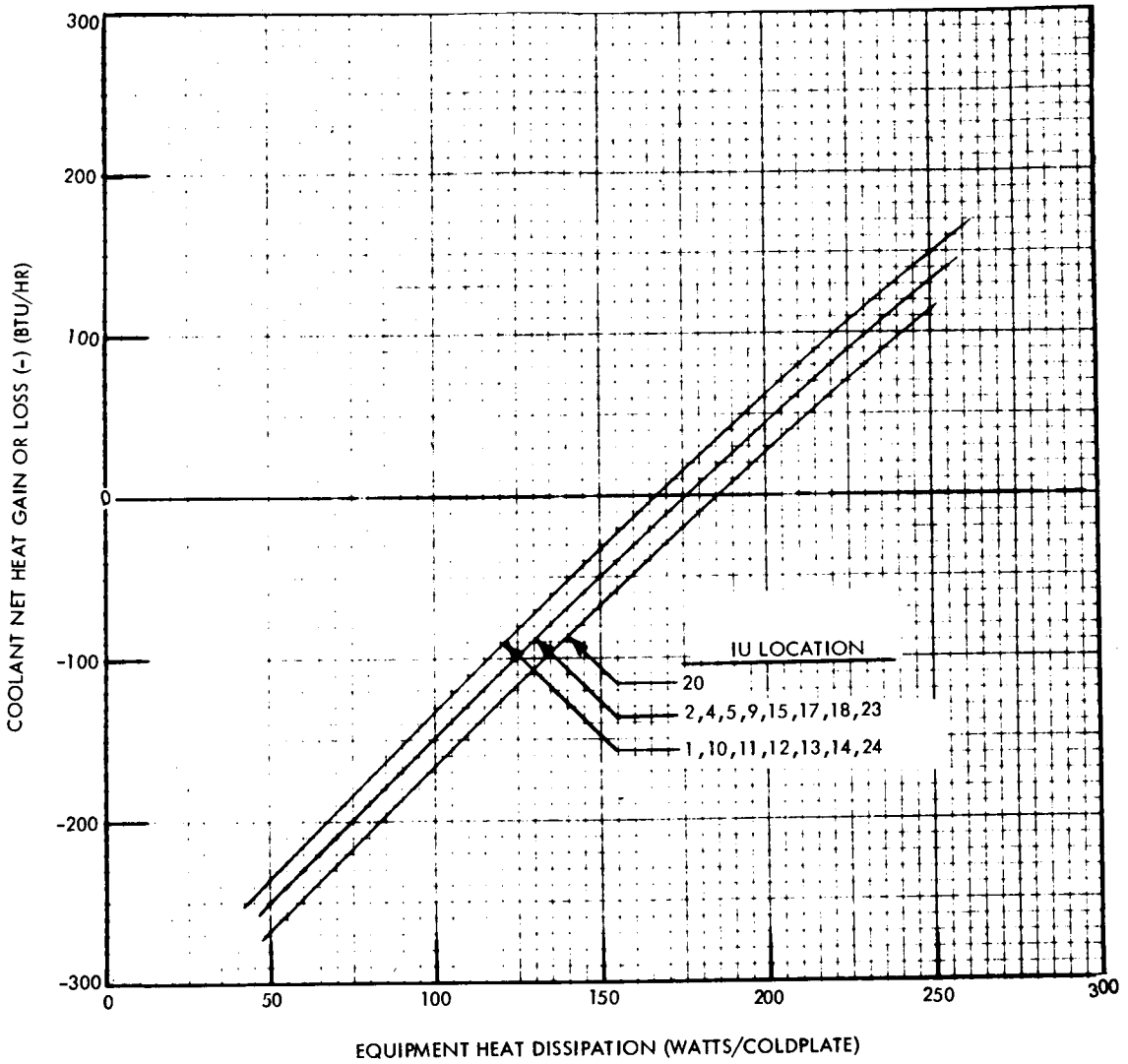

Figure 4-93. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-6b-9, Coolant Temperature 30 F

SYNCHRONOUS CIRCULAR ORBIT, 0-DEG INCLINATION
X AXIS SUN-ORIENTED (CASE IU-6b-9)
IU OUTER SKIN: α_s = 0.18, ϵ = 0.90

COOLANT TEMPERATURE AT COLDPLATE INLET = 50 F

COOLANT NET HEAT GAIN DUE TO INTERNALLY COOLED EQUIPMENT = 1420 BTU/HR

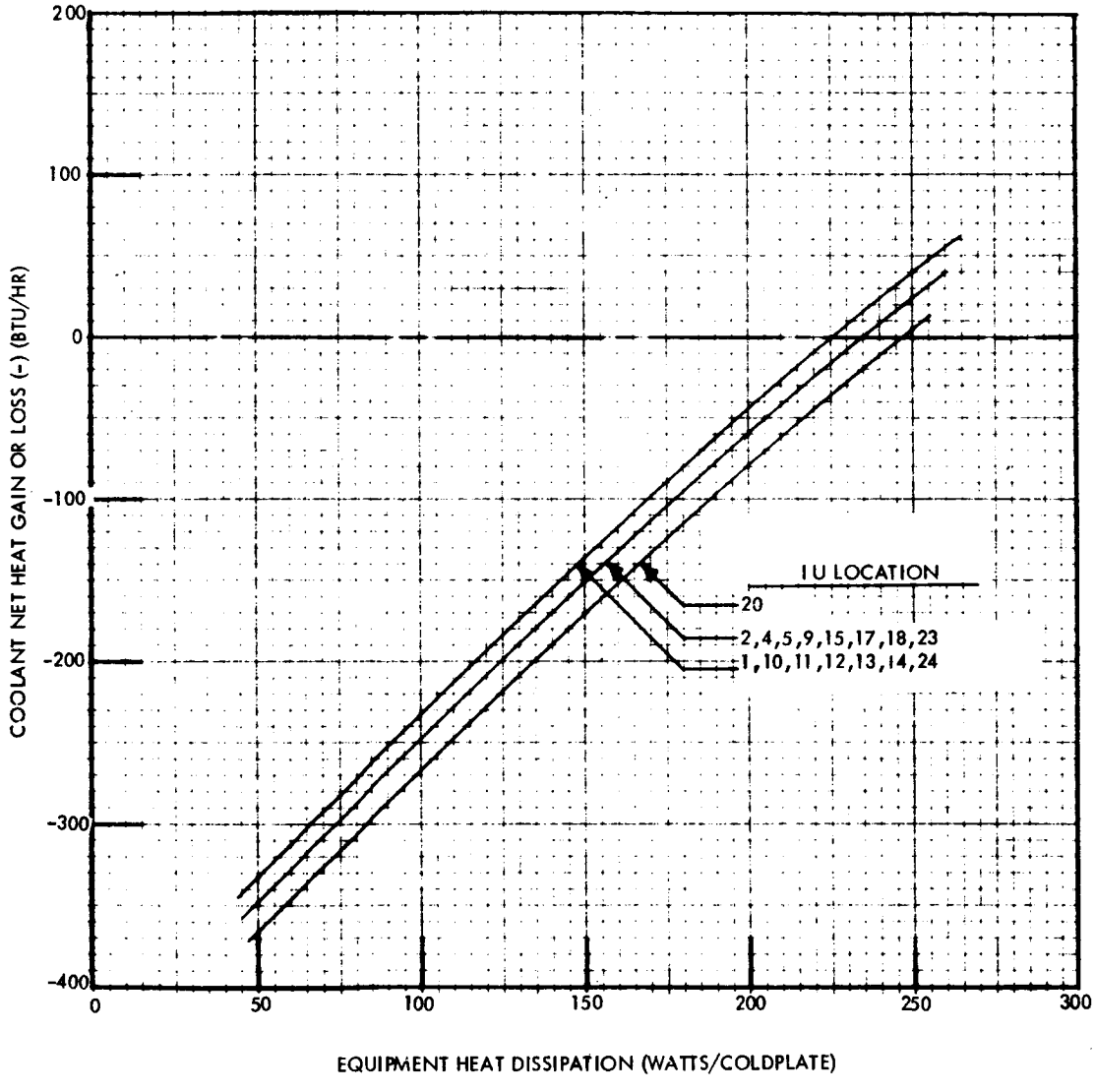

Figure 4-94. Coolant Net Heat Gain or Loss Versus Equipment Dissipation—Case No. IU-6b-9, Coolant Temperature 50 F

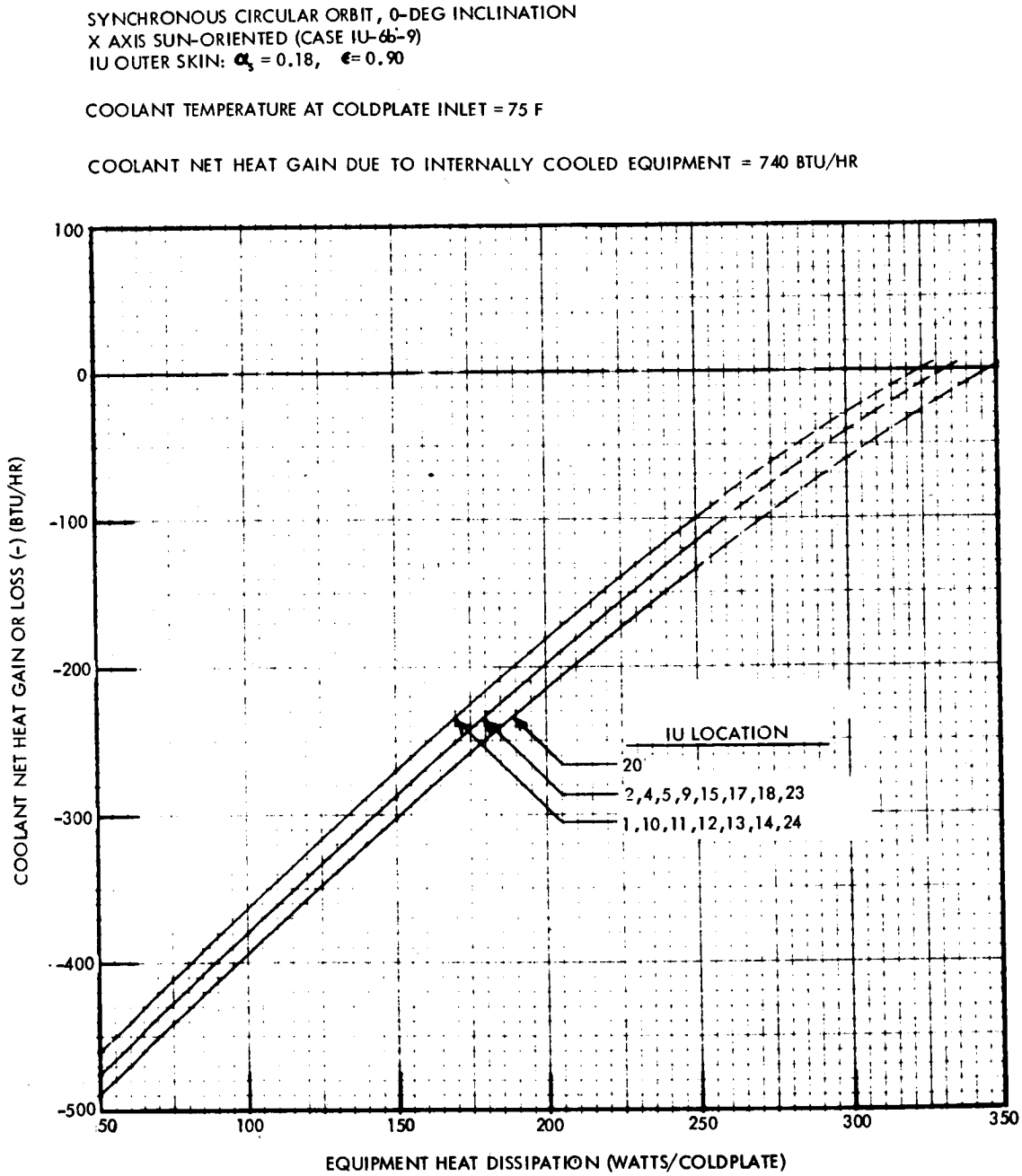

Figure 4-95. Coolant Net Heat Gain or Loss Versus Equipment Dissipation— Case No. IU-6b-9, Coolant Temperature 75 F

gain. This difference between the two results suggests two possibilities. One is that the same result (zero net heat gain of the coolant) may be possible with different total equipment power dissipation rates depending on distribution of the power dissipation among the available coldplates. The other possibility is that, due to the interaction between adjacent coldplates and internally cooled equipment, the approach of selecting the power dissipation rate for each individual coldplate may not be valid. Both of these possible explanations will require further computer analysis for verification.

PASSIVE THERMAL CONTROL

A brief investigation was made to determine the potential of thermal control by a purely passive means. A model electronic package was considered to be mounted on the inboard surface of the IU outer shell. Case temperature for the package as a function of time was determined at four different IU locations to determine the influence of the different environmental heat loads. A 200-nautical-mile circular earth orbit at an inclination of 34 degrees was selected for the investigation, with the longitudinal (X) axis of the IU along the orbit path. At the time of injection into orbit, the IU skin temperature and the electronic package case temperature were assumed to be 200 F and 100 F, respectively.

The thermal network simulating the electronic package mounted directly on the IU outer shell is illustrated in Figure 4-96. It should be noted that, in the simplified model used in this analysis, radiation heat transfer from the electronic package and the inboard surface of the IU outer shell to the S-IVB dome and the SLA structure has not be included. This approach was considered justifiable because only the potential of the passive control technique was to be determined. Hence, needless complication was avoided by omitting internal radiation and conduction heat transfer to adjacent package mounting locations. In addition, it was assumed that conduction heat transfer along the IU skin was uniform and radially outward from the electronic package mounting area. This area is represented in Figure 4-96 by the circle with the number 2 in its center. The circles numbered 3 through 7 are nodes representing annuli surrounding the electronic package mounting area. Dimensions for these annuli were chosen so that the thermal resistors connecting skin nodes are of equal value, with a limit of 36 inches on the outside diameter of the outermost ring.

Data required for the calculation of network parameters are listed in Table 4-40 for the four cases investigated. The joint conductances of 27.32 and 54.64 Btu/hr-°F correspond to resistances of 0.5 and 0.25 °F/watt, respectively. The electronic package size of 10 by 12 inches was simulated for network purposes by a circular area over which the temperature was considered to be uniform. Environmental heat loads were those obtained in the orbital heating computer program, described in Section 4-2.

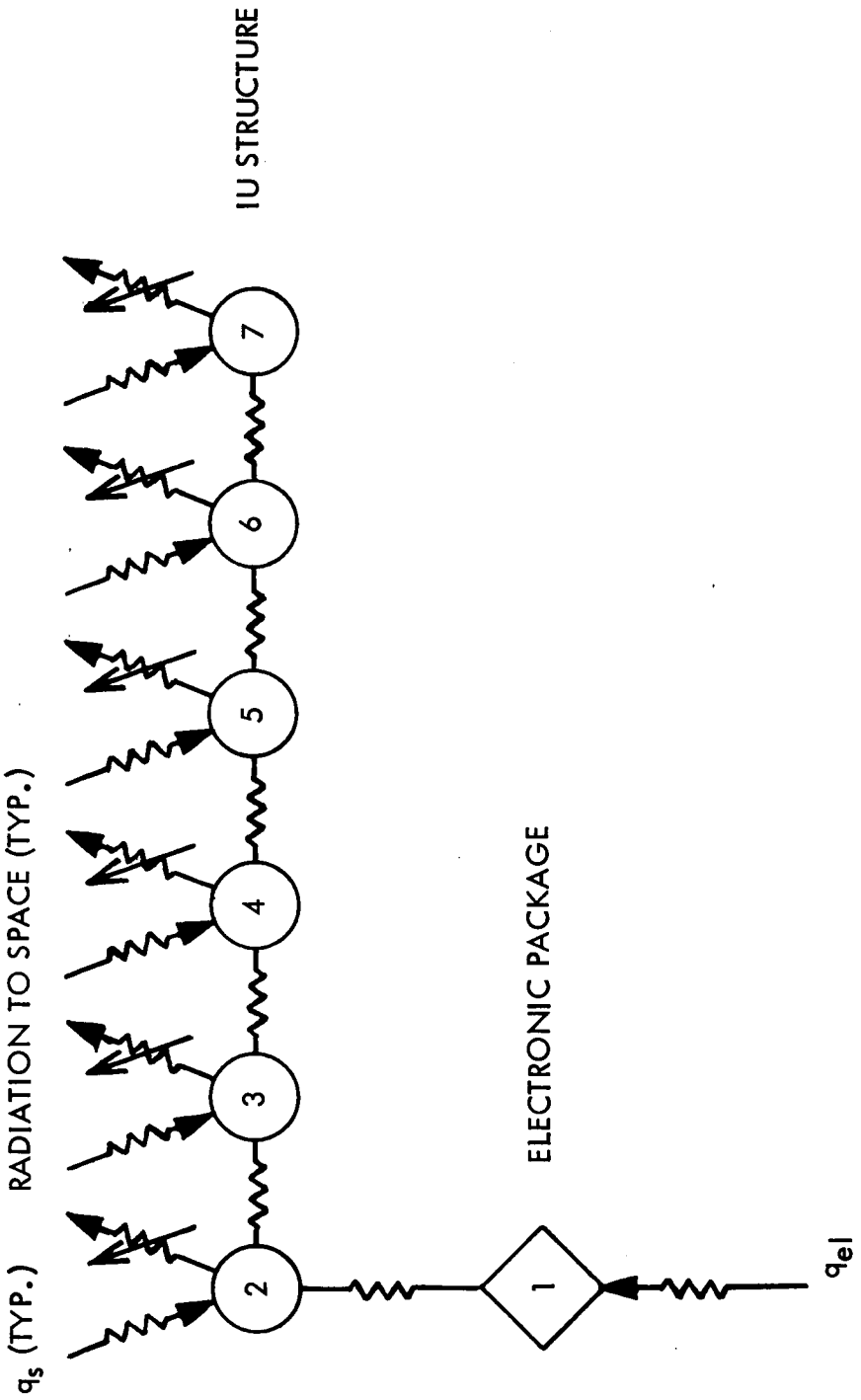

Figure 4-96. Thermal Network, Equipment Skin Mounted

The results of the analysis, which utilized the general thermal analyzer computer program, are shown in Figures 4-97 through 4-100 for the four cases investigated. These plots indicate the possibility of passive thermal control for equipment mounted directly on the IU outer shell. Although the analysis was limited to 20 hours of orbit time, there is an indication that temperatures were approaching equilibrium conditions. A comparison of the results for Case 1 with those for Case 2, or of Case 3 with Case 4, shows the influence of equipment-to-skin joint conductance and equivalent IU skin thickness on electronic package temperature level. It may also be observed, by comparing Case 1 results with Case 3, that higher electronic package heat capacities reduce temperature swings due to periodic variation in environmental heat loads. However, under the conditions assumed for the analysis, the temperature variation in the worst case (at IU location 8) will be only about 4 F when equilibrium conditions have been reached.

Table 4-40. Passive Thermal Control Analysis Data

Item	Electronic Package ($W\ C_p = 29.6$)		Electronic Package $W\ C_p = 14.8$	
	Case 1	Case 2	Case 3	Case 4
Equivalent IU Skin Thickness, inches	0.5	0.10	0.05	0.10
Equivalent Skin Thermal Conductivity, k, Btu/(hr) (ft) (F)	100	100	100	100
Surface Property, ϵ	0.90	0.90	0.90	0.90
α_s	0.18	0.18	0.18	0.18
Joint Conductance Equipment-to-Skin, Btu/hr-°F	27.32	54.64	27.32	54.64
Initial Skin Temperature, °F	200	200	200	200
Initial Electronic Package Temperature, °F	100	100	100	100
Equipment Heat Load, q_{el}, Btu/hr	400	400	400	400
Electronic Package Size, inches	10 x 12	10 x 12	10 x 12	10 x 12

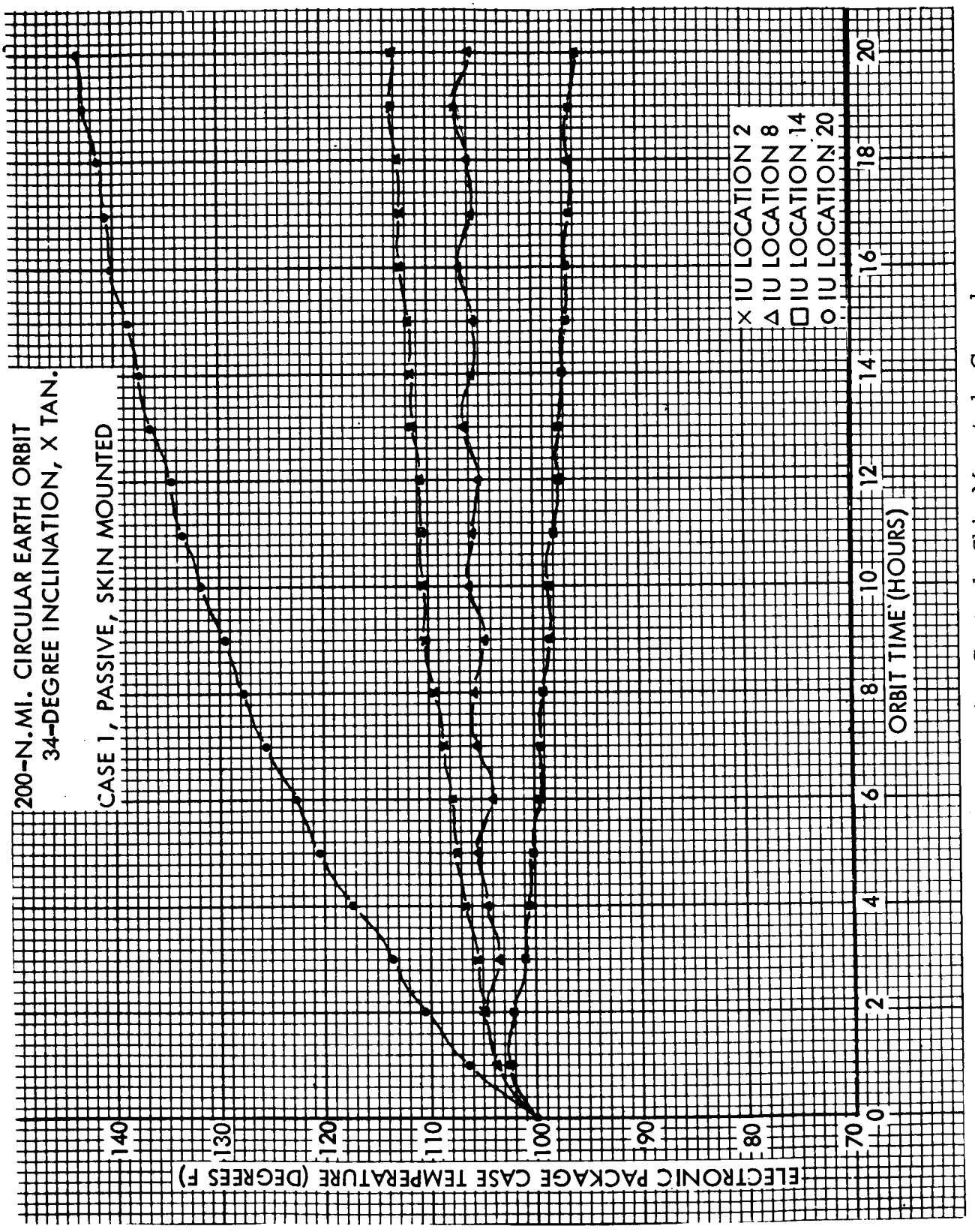

Figure 4-97. Passive Control, Skin Mounted, Case 1

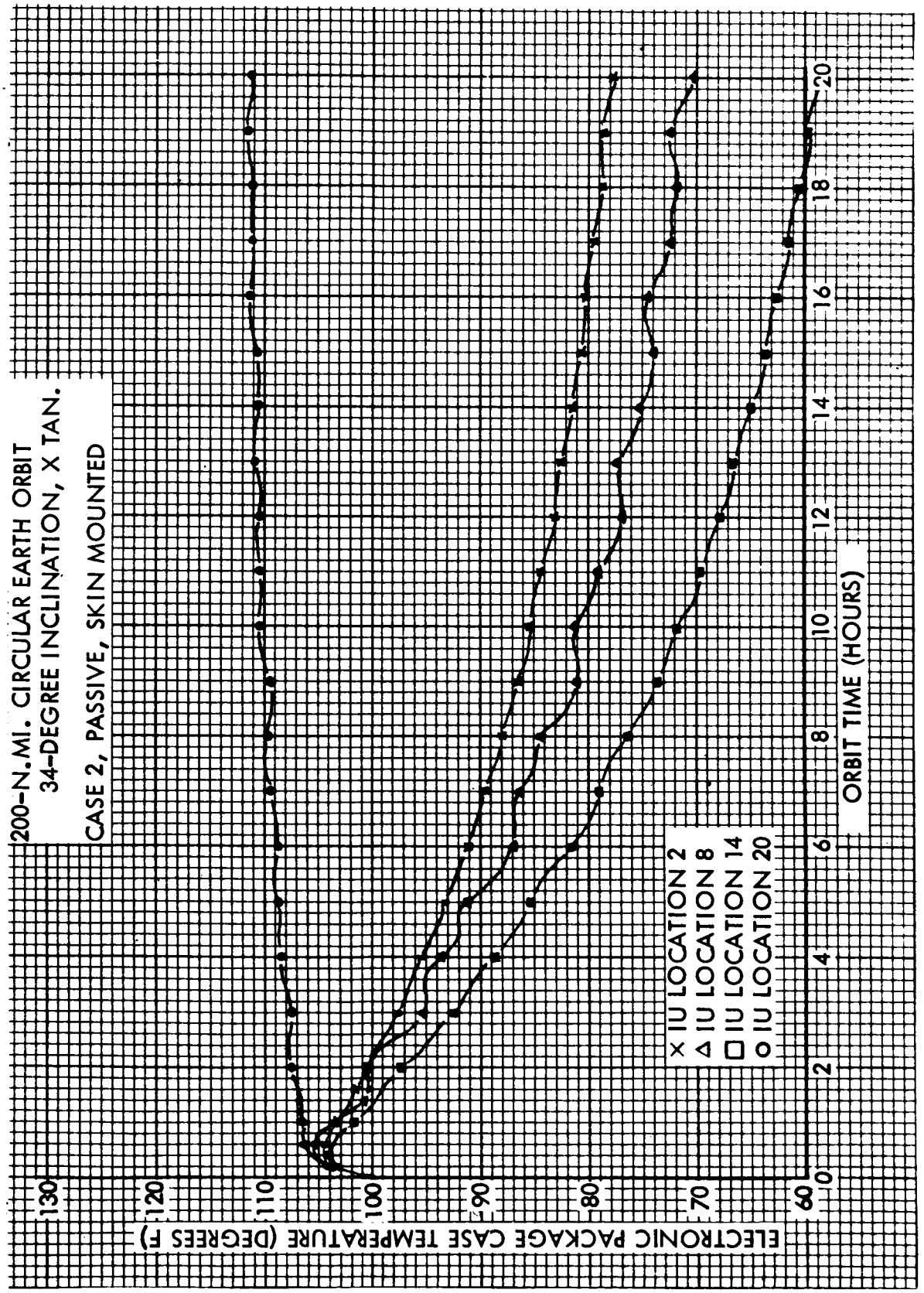

Figure 4-98. Passive Control, Skin Mounted, Case 2

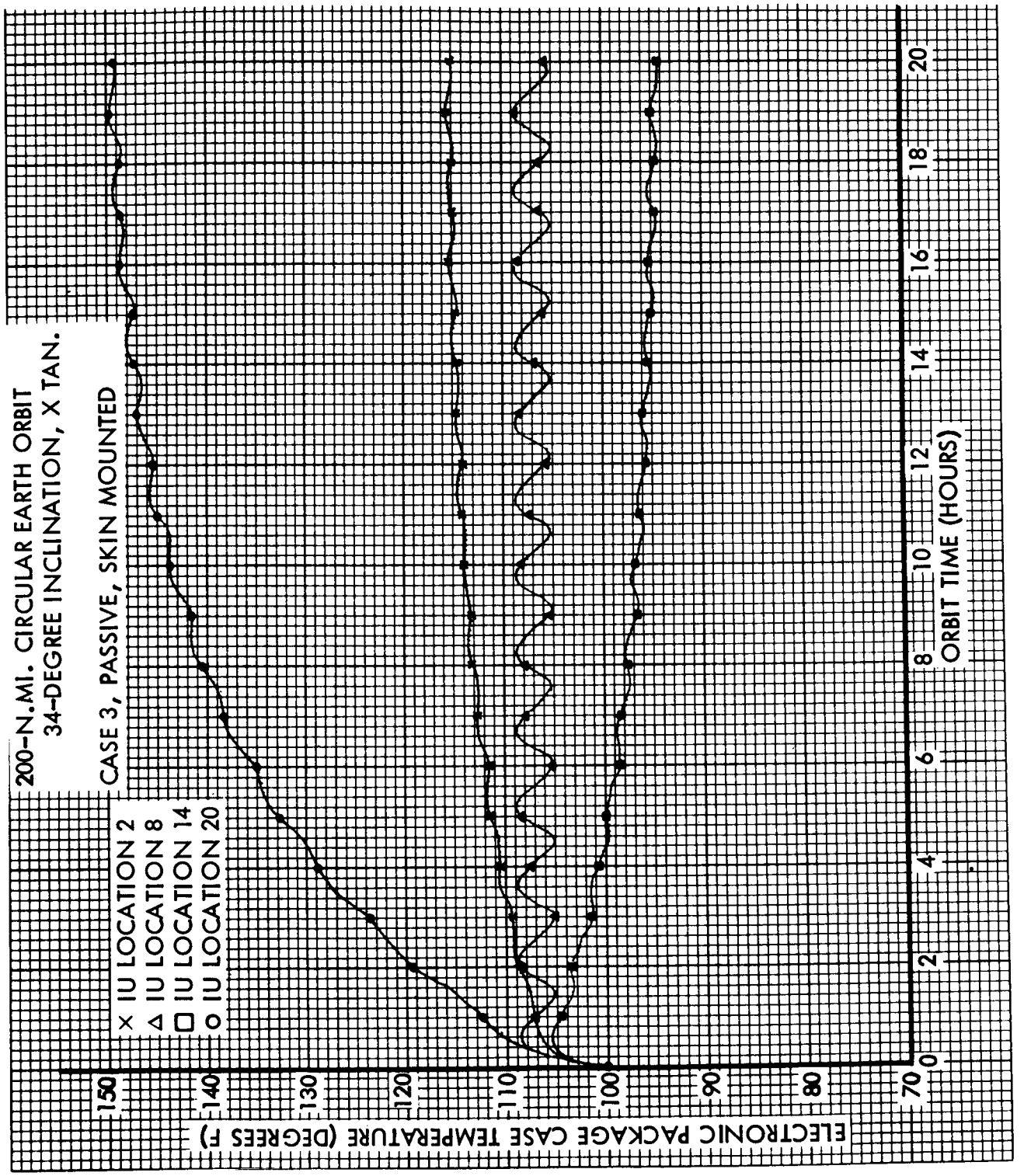

Figure 4-99. Passive Control, Skin Mounted, Case 3

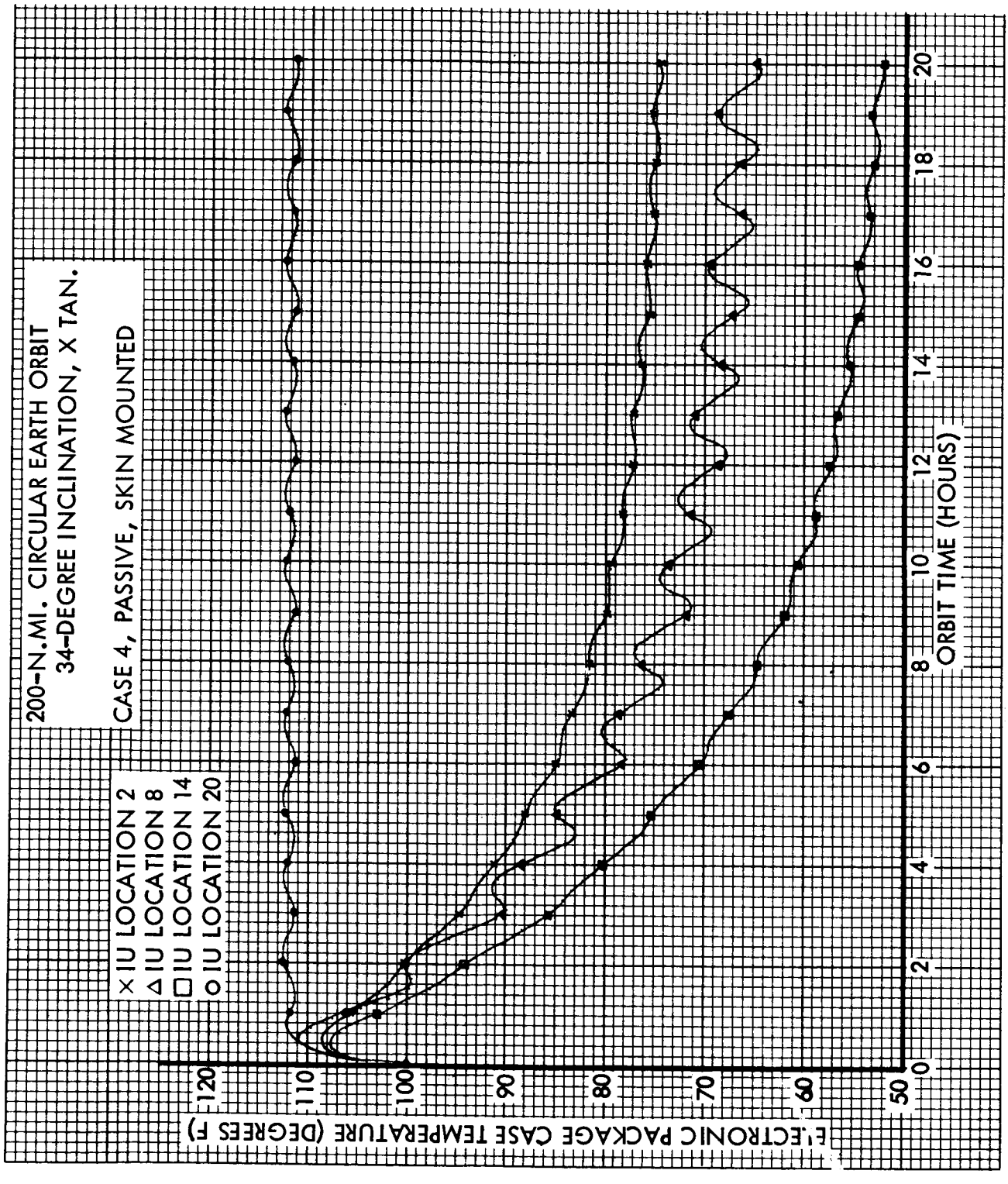

Figure 4-100. Passive Control, Skin Mounted, Case 4

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REFERENCES

4-1. McCue, G.A. Program for Determining the Thermal Environment and Temperature History of Orbiting Space Vehicles, Technical Note ASD-TN-61-83, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio (March 7, 1962).

4-2. Margosan, T.R. Engineering Supplement to Input Data Manual, APD 127 General Thermal Analyzer, NAA S&ID, SID 67-222 (February 1967).

4-3. Huneidi, F. IU/S-IVB Forward Skirt Orbital and Translunar Thermal Analysis, P&VE Internal Note No. P-66-1, George C. Marshall Space Flight Center, Huntsville, Alabama (January 13, 1966).

4-4. Grafton J.C. Transient Heat Transfer Analysis of Systems Involving Fluid Flow, ASD-TDR-63-260, Proceedings of the First Space Vehicle Thermal and Atmosphere Control Symposium, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. (April 1963).

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APPENDIX 4.0 THERMAL ANALYSIS

APPENDIX 4A. TEMPERATURE DROP IN COLDPLATE FROM CONTACT SURFACE TO FLUID

Heat is transferred from the contact face of a coldplate to the fluid through the coldplate's metal surface. The contact resistance is small for properly tightened bolted joints (Reference 4A-1). The referenced article also points out the contact is essentially circular. However, when the heat is transferred along the metal and then by convective coefficient to the heat transport fluid, there is an appreciable temperature drop. A computer program was used to determine the temperature drop.

A thermal model was set up to represent the transfer of heat from a surface contact of some particular diameter through the coldplate to the flowing fluid (Figure 4A-1). The plate surface is divided into an inside diameter (to which the heat will be added) and a number of concentric diameters, each of which is larger than the previous one by a factor of 1.111. The areas between the concentric circles are all assigned separate nodes. The area inside the inner circle and the fluid also are assigned node numbers. Node 1, the largest node, has a 20-inch outside diameter and an 18-inch inside diameter. Node 2 has an 18-inch outside diameter and 16.2-inch inside diameter. Only the nodes considered significant were used in the calculation. This relationship is continued for each successive node.

Heat is added to the inner circle node. This is transferred to the fluid through a conductance, which is determined by the convective coefficient and heat transfer area, and to the next larger "sheet" node whose conductance is determined by the plate thickness, circumference of the circle that separates the nodes, the difference in average radii of adjacent nodes, and the conductivity of the material (aluminum, k = 100). From the next larger "sheet" node, the heat is transferred to the fluid and to a still larger sheet node. This is continued until the temperature difference between node and fluid is negligible.

By impressing a unit heat flux on the central diameter, the temperature of the successive ring nodes was calculated. Since both conduction and convection are direct functions of the temperature difference, it is necessary only to calculate the temperature of the nodes with the sink at 0 F to obtain the $\Delta T/Q$ for various metal surface thicknesses and heat transfer coefficients.

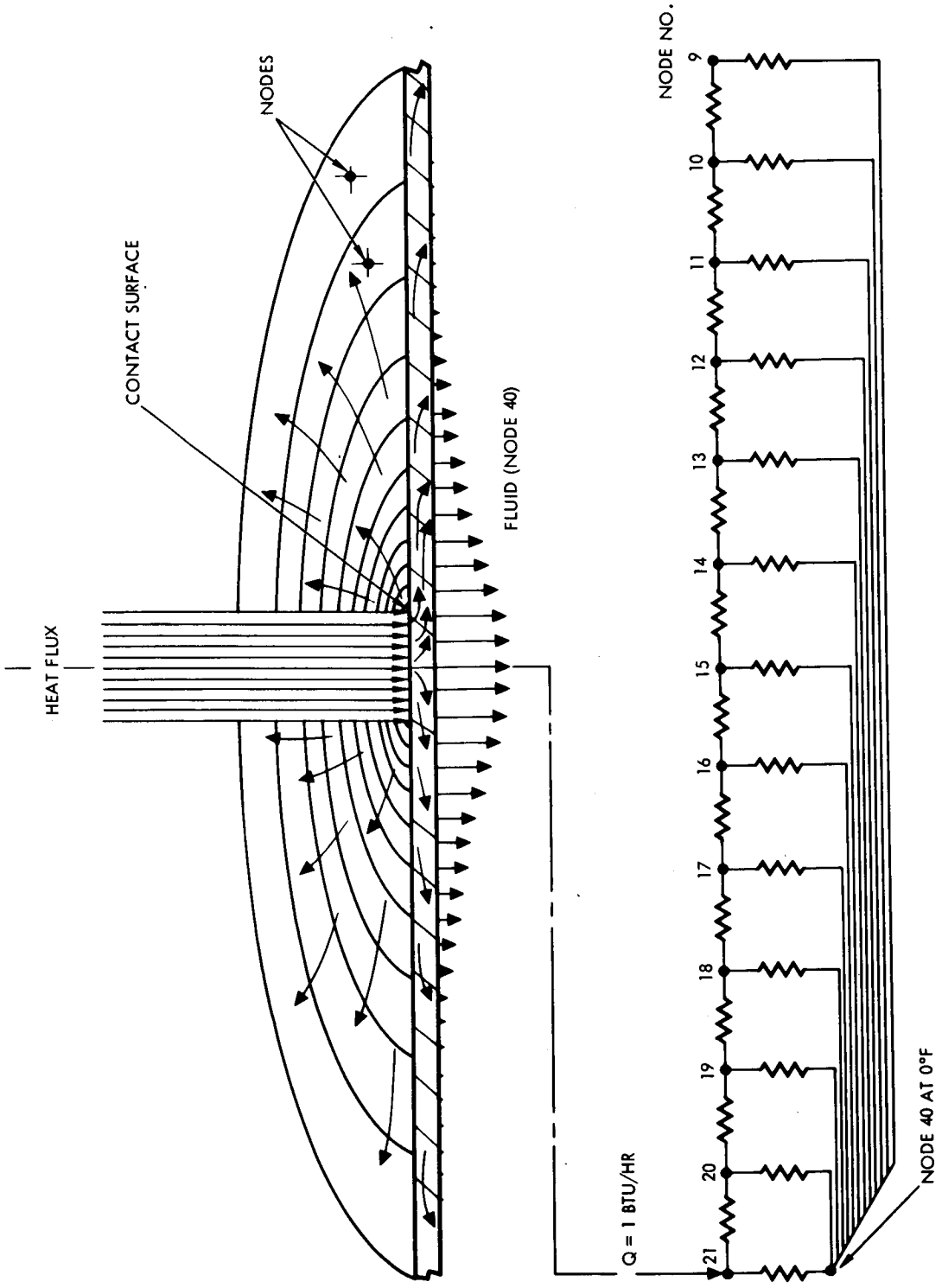

Figure 4A-1. Thermal Network of Heat Transfer From Coldplate to Fluid

The results of the calculations are given in Figures 4A-2 through 4A-5, for the temperature drop in the coldplate from contact surface to fluid.

Reference

4A-1. Aron, W., and G. Colombo. Controlling Factors of Thermal Conductance Across Bolted Joints in A Vacuum Environment. ASME Paper No. 63-NA-196, presented at the Winter Annual Meeting, Philadelphia, Pa. (November 1963).

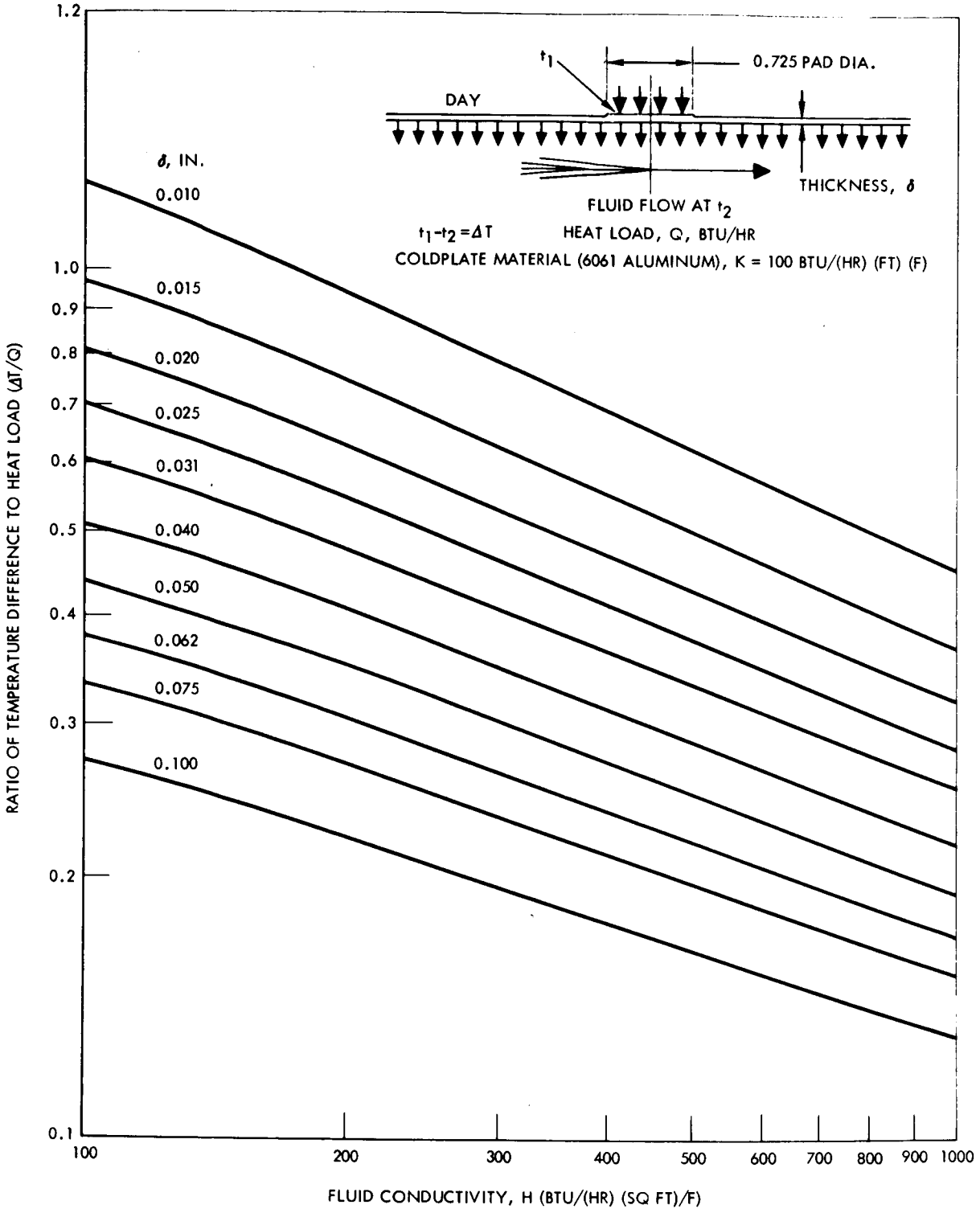

Figure 4A-2. Coldplate Temperature Drop, Pad Face to Fluid (0.725-Inch Pad Diameter)

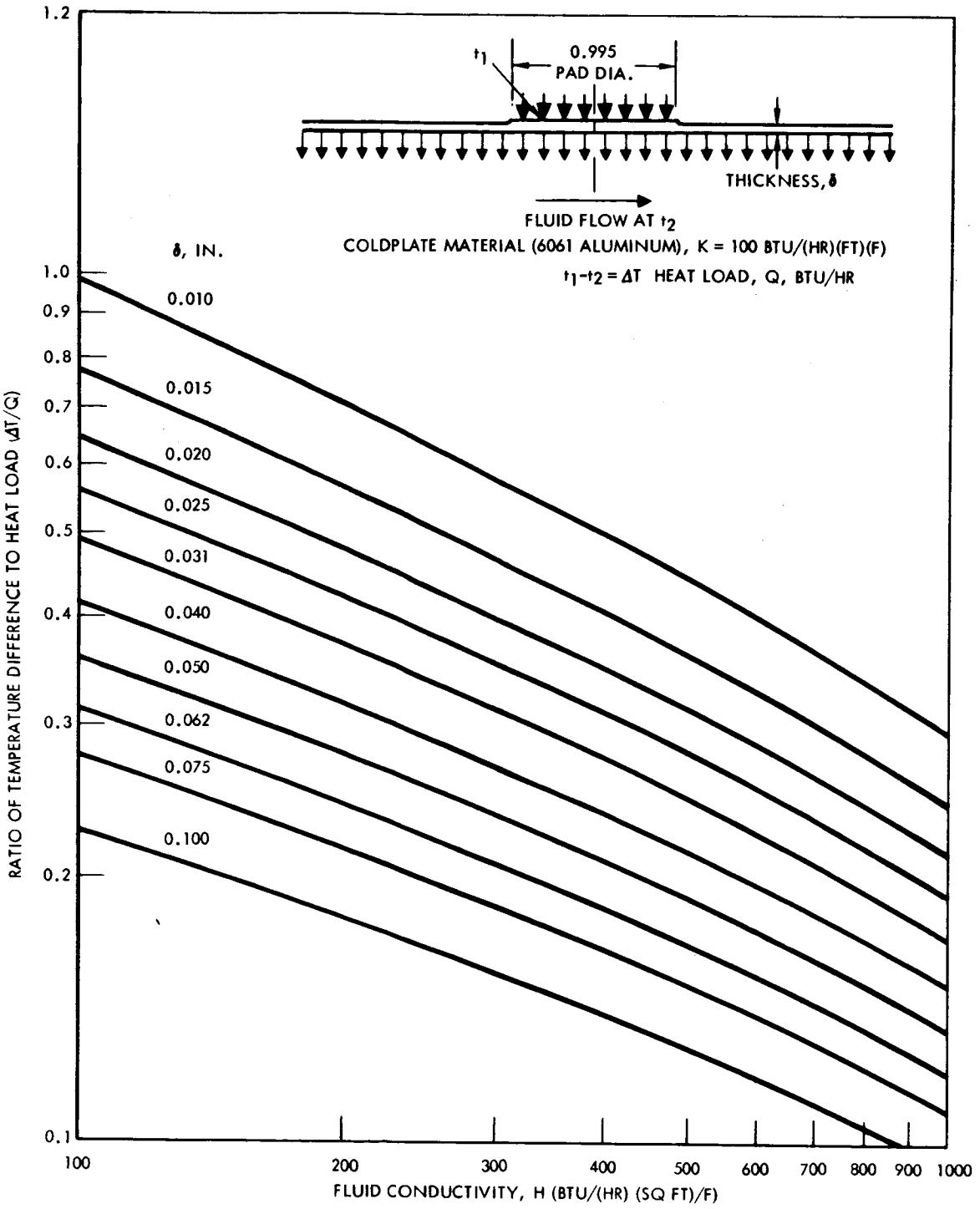

Figure 4A-3. Coldplate Temperature Drop, Pad Face to Fluid (0.995-Inch Pad Diameter)

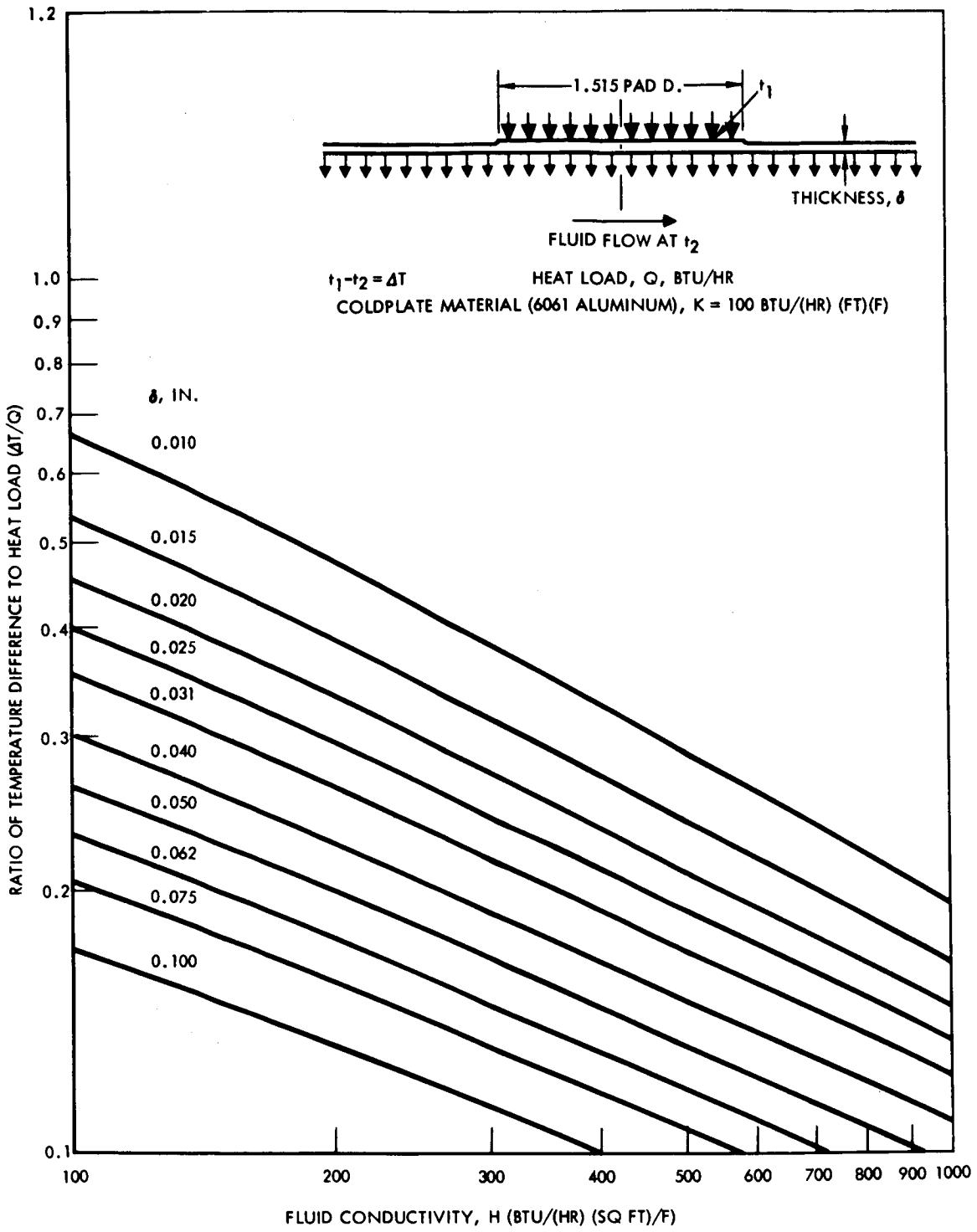

Figure 4A-4. Coldplate Temperature Drop, Pad Face to Fluid (1.515-Inch Pad Diameter)

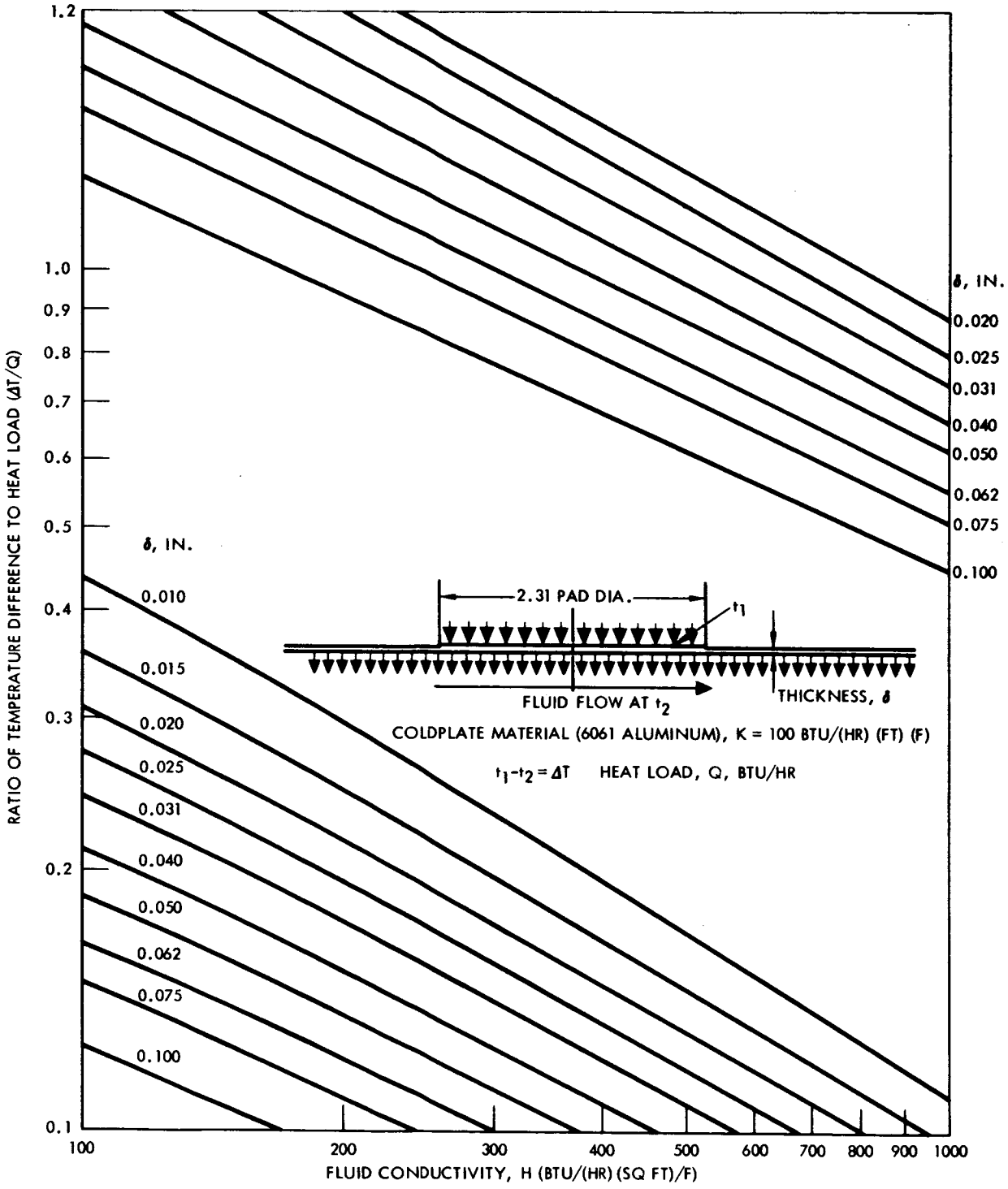

Figure 4A-5. Coldplate Temperature Drop, Pad Face to Fluid (2.31-Inch Pad Diameter)

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APPENDIX 4B. JOINT CONTACT RESISTANCE

The major part of joint contact resistance is caused by the greatly restricted area of heat transfer around the bolt and the temperature drop in the surrounding surface material. A better approximation of the total resistance can be obtained by estimating the true contact diameter, D_E.

$$D_E = D_B \sqrt{(T\% \times YS_R / YS_S) + 1}$$

where

D_B = bolt diameter (fine series), in.

$T\%$ = percent of maximum tightening torque

YS_R = yield strength of bolt, psi

YS_S = yield strength of material at junction surface interface, psi

This is shown in nomographic form in Figure 4B-1. It is used in conjunction with Figures 4A-2 through 4A-5 of Appendix 4A to determine the $\Delta T/Q$ for each of the bolted joints of the electronic package to the coldplate. The approximation also points the way to lower losses because the lower the yield strength of material at the junction interface, the larger the true contact diameter and lower the $\Delta T/Q$ for any given surface thickness and fluid heat transfer coefficient. The limit is a yield strength at the junction interface of 0 (a liquid). Here, only the pad dimensions would limit the true contact diameter.

Dead soft 1100 aluminum has a very low tensile strength and, used as an intermediate washer, would reduce the temperature drop considerably. The vapor pressure is very low, and so it would survive in a vacuum. Vacuum grease (possibly filled with flakes of high-conductivity metal) and the metal gallium both have suitable vapor pressures and would be suitable for obtaining contact for the entire black box.

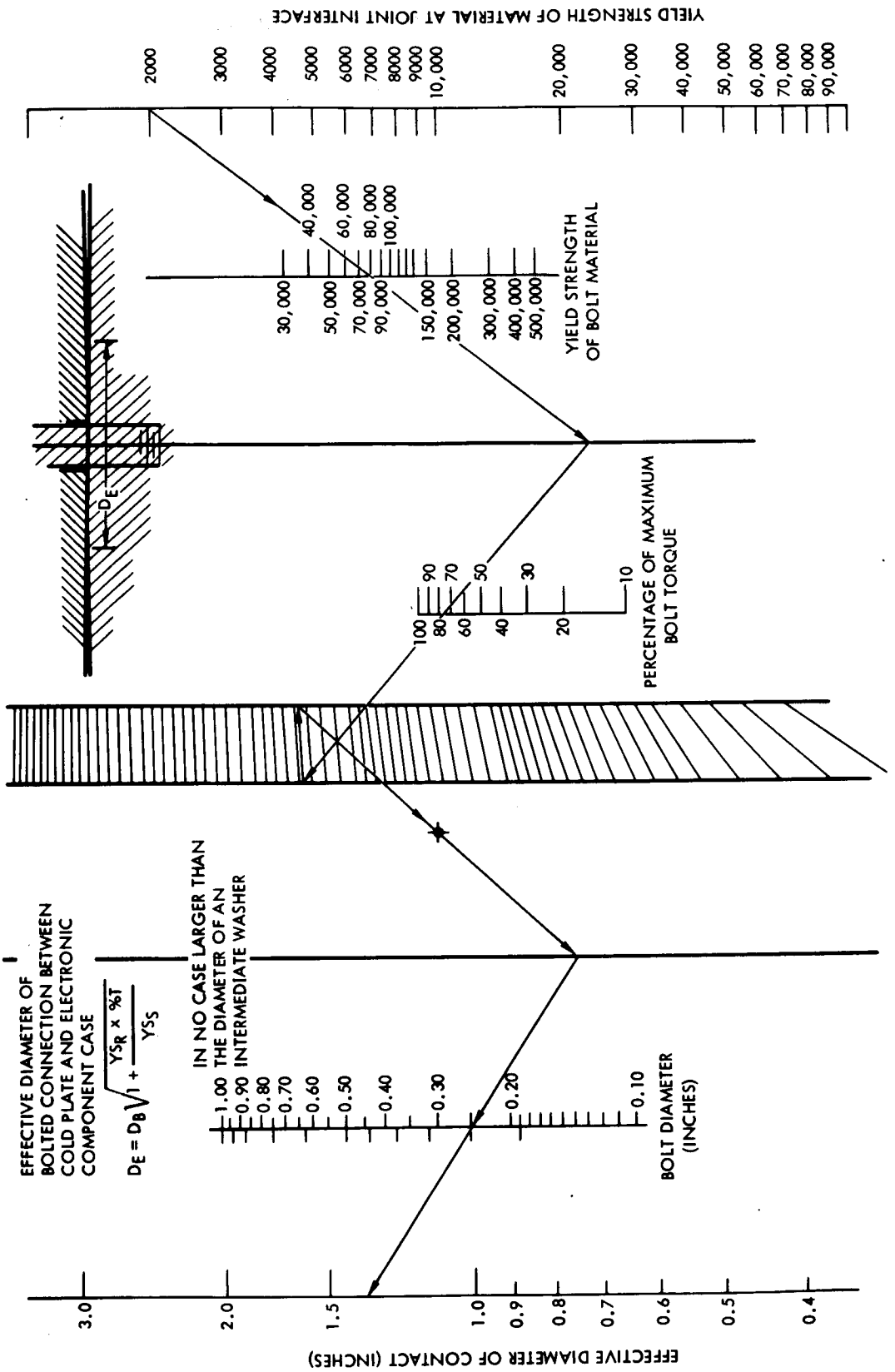

Figure 4B-1. Effective Diameter of Bolted Connection

APPENDIX 4C. PROBLEM OF METEOROID PENETRATIONS

The potential problem of meteoroid damage to the ECS must be considered and dealt with to achieve the high reliability required for long duration missions. Although much of the environmental control equipment is located within the instrument unit and is assumed to have sufficient protection, during certain mission periods the forward end of the IU may be exposed directly to the space environment. Also for long-duration missions, space radiators may be necessary. Because they are on the external surface, they are vulnerable to meteoroid damage.

When the forward end of the IU is exposed for such time periods as in assembly or disassembly in space, the most vulnerable components appear to be the coldplates. The coldplates, with their very large fluid-cooled surface areas, may be considered to be exposed to half the normal flux of meteoroid particles. Figure 4C-1 shows that the probability of meteoroid penetration becomes a critical item in a very short time. It also shows that there is an increasing probability of meteoroid puncture of the coldplate with time even when protected by the present IU structure and other surrounding structure. The most severe assumptions possible from existing data were used in preparation of Figure 4C-1. Even if conservative by an order of magnitude, a redesign of coldplates may be necessary for the longer-duration missions or alternate means for protection be provided.

Another component that may be vulnerable is the fluid duct located around the periphery of the instrument unit. For the protection of the ducts and coldplates, a meteoroid shield could be used with minimum weight penalty. Figure 4C-2 illustrates the possible weight increase of 16 coldplates with meteoroid protection as a function of mission duration and probability of penetration.

Since the fluid passages or ducts are the most critical parts of the radiator vulnerable to possible meteoroid puncture, various methods for providing protection have been proposed.

The use of protective armor or a meteoroid shield for the ducts have been suggested. Another approach is to use redundant radiators; but because of area limitations this may not be practical in most cases. As modifications, the use of redundant, parallel tubes could be considered, which would involve a completely separate radiator fluid loop.

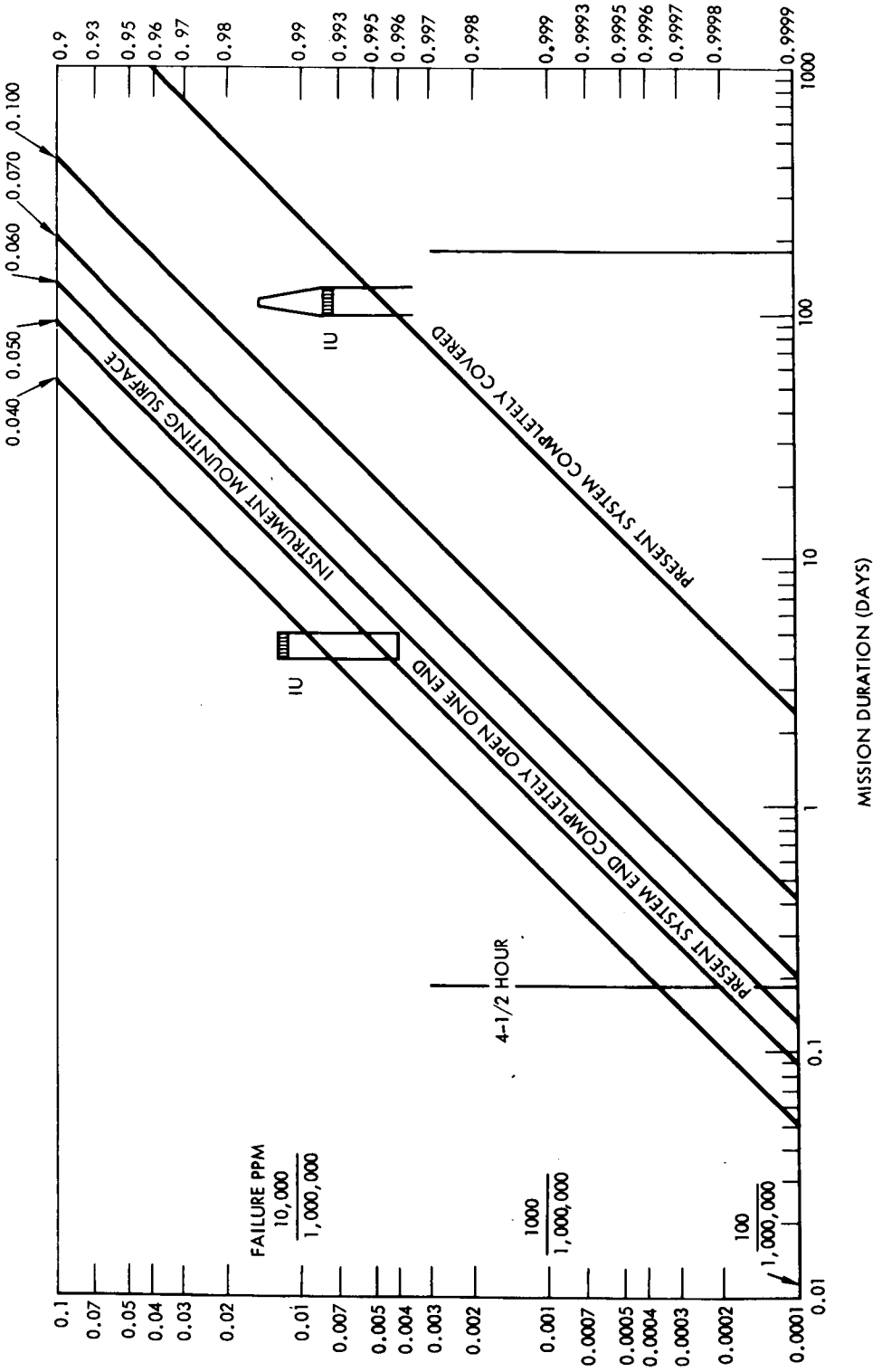

Figure 4C-1. Probability of Meteoroid Penetration of Coldplate

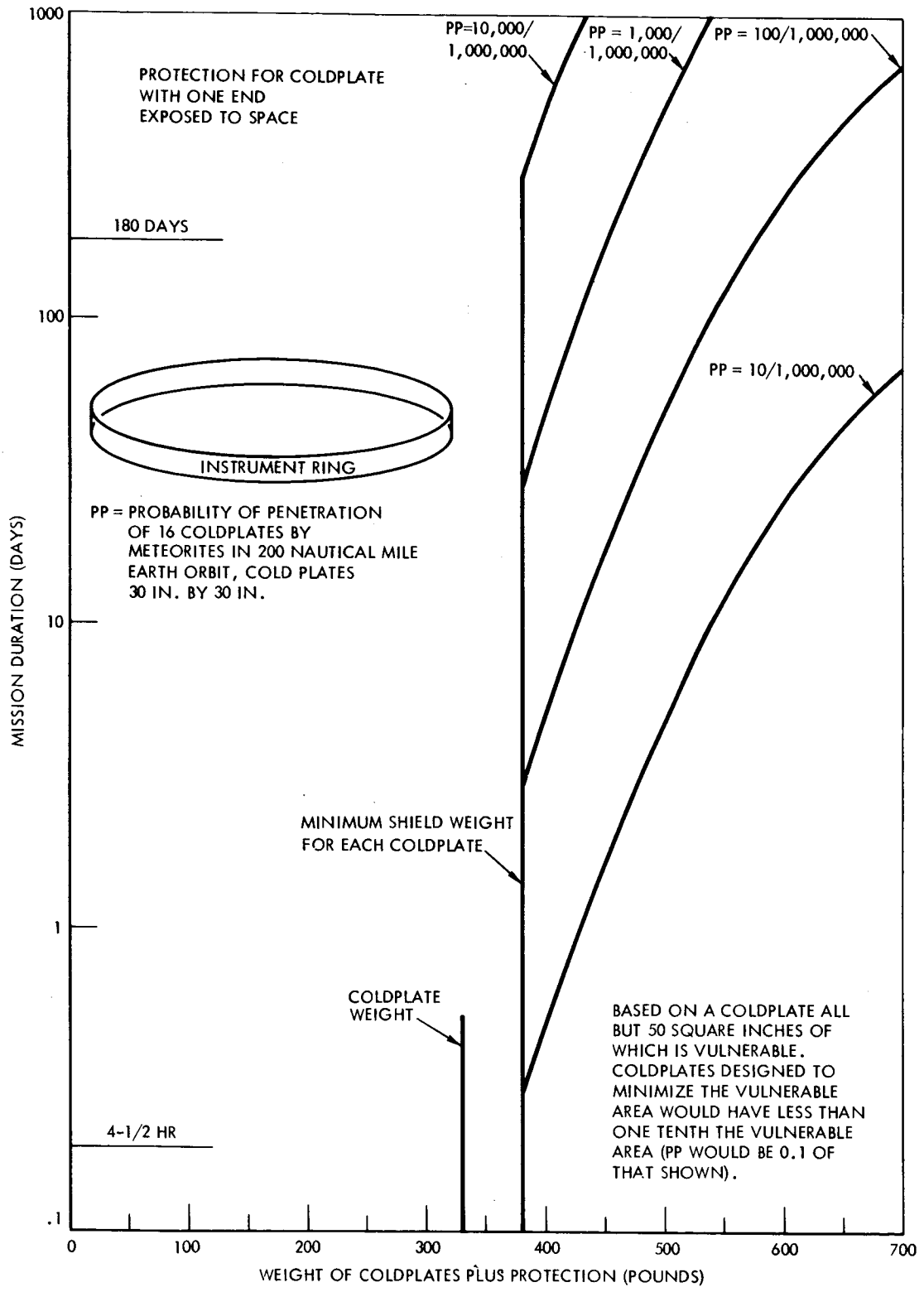

Figure 4C-2. Coldplate Weight With Meteoroid Protection

Figure 4C-3 shows the effect of increasing reliability and mission duration on the weight of the radiator with protective armor. It is important to note that the larger the required heat rejection, the greater the weight per unit heat rejection. This important consideration results from two facts: (1) the heat rejection area is directly proportional to the heat rejection and (2) the probability of penetration is directly related to the area. Even though the radiator weight increases with mission duration, it still results in a minimum weight method for heat rejection.

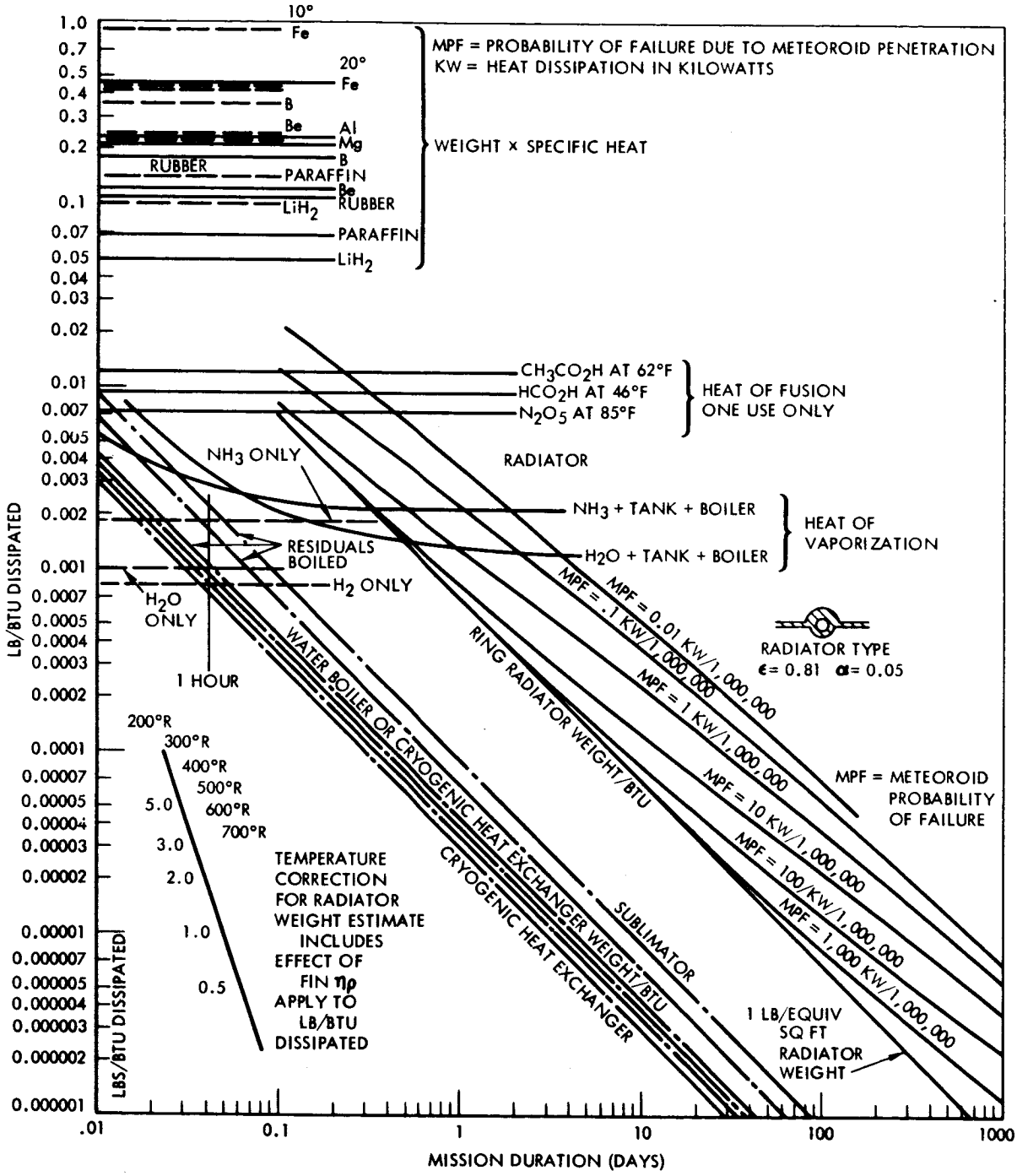

Figure 4C-3. Heat Sink Weight Estimates

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5.0 RECOMMENDED CONCEPTS

Preceding sections of this report have established the environmental control requirements for electronic packages on the IU under various orbital conditions. The selection of applicable TCS concepts to provide the required thermal control must consider not only the permissible equipment temperature range, but also the length of time during which the system is expected to function. To that end, several probable missions have been postulated and are listed in Table 5-1, together with an estimate of respective minimum and maximum durations. Based on these missions, coolant temperature limits (Paragraph 4. 1), and equipment power dissipation-coolant temperature relationships (Figures 4-45 through 4-51), possible environmental system concepts were established and are described in the following paragraphs together with a discussion of their applicability to the postulated missions and durations

Table 5-1. Estimate of Mission Duration

Mission	Duration (hours)	
	Minimum	Maximum
Earth orbit	4-1/2	4320 (180 days)
Synchronous Orbit (19,327 nautical miles)	12	4320 (180 days)
Lunar (Ground Launch)	4-1/2	24
Lunar and Deep Space (Orbital Launch)	720 (30 days)	1440 (60 days)

Examination of the data defining coolant temperature limits and data on the effect of variation in equipment power dissipation on coolant temperature reveals that only a few items of electronic equipment appear to exert an undue influence on thermal control requirements. These specific electronic packages are identified in Table 5-2, in accordance with the coolant temperature limits that they impose on each equipment group. For example, the lower temperature limit for Group I equipment is determined by the 59 F requirement of the accelerometer signal conditioner, based on present NASA

Table 5-2. Coolant Temperature Limits and Critical Electronic Packages

Group	Coolant Temperature Limits (degrees)			
	NASA Specification		NAA Modification	
	Upper Limit (Figure 4-2)	Lower Limit (Figure 4-7)	Upper Limit (Figure 4-3)	Lower Limit (Figure 4-7)
I	80 F ST-124 M Inertial Platform* (70 watts)	59 F (6.5 watts) Accelerometer Signal Conditioner	85 F LVDA* (400 watts)	49 F (6.5 watts) Accelerometer Signal Conditioner
II	87 F Azusa Transponder and Filter (270 watts)	30 F (35 watts) Telemeter Assembly, S1	119 F RF Assembly-P1 (177 watts)	-5 F Telemeter Assembly, S1 (35 watts)
III	100 F Minstram Transponder (140 watts)	-5 F Remote Digital Multiplexer (4 watts)	130 F Minstram Transponder (140 watts)	-60 F Remote Digital Multiplexer (4 watts)

*Internal or integrally thermal-conditioned equipment

specifications. The upper temperature limit for Group I equipment is determined by the 80 F requirement of the ST-124M inertial platform assembly. Hence, if the thermal conditioning system were required to satisfy these temperature limits for Group I electronic packages without active removal or addition of heat, the equipment power dissipation of all equipment would have to be such that the 59 to 80 F coolant temperature range at coldplate inlet is achieved by purely passive means. Allowable equipment power dissipation rates are listed in Table 4-10 for the different mission parameters under consideration. This tabulation shows that, if coolant temperature requirements for equipment in Group I are met, Group II and Group III equipment is also satisfied without any additional control system. Table 4-10 also indicates that the present instrument unit total power dissipation of 3.9 kilowatts falls within permissible Group I limits for all listed missions and vehicle orientations except the synchronous orbit and lunar and deep space injection periods under minimum environmental heating conditions (x axis sun-oriented).

If a separate provision were to be made for thermal control of the ST-124M inertial platform assembly, the 80 F upper coolant temperature limit for Group I equipment would be extended to the 85 F requirement of the launch vehicle data adapter (LVDA). Similarly, if the accelerometer signal conditioner, the platform AC power supply, and the ST-124 electronics were to be provided with a means of preventing them from being overcooled, the lower coolant temperature limit for Group I equipment could be decreased to 40 F. (The foregoing is based on the assumption that the separate thermal control for the ST-124M inertial platform assembly is capable of maintaining the temperature of this assembly at or above its present 50 F lower limit.) The resultant band of permissible coolant temperatures (40 F to 85 F) could be maintained over a wider range of equipment power dissipation and mission profiles without the requirement of active heat rejection or addition. The permissible power dissipation rates, as well as those resulting from a widening of the permissible coolant temperature range that is possible through equipment modifications, discussed in Section 4.0, are summarized in Table 5-3.

The addition of separate controls for critical items of equipment will increase the complexity of the TCS, which may not be justified for short-duration missions. Therefore, assuming that it is desirable to restrict the number of modifications to the present IU thermal conditioning system to a minimum, it is suggested that only a means for adding heat to the coolant circuit be incorporated into the present system for mission durations of less than 24 hours. This suggestion applies to near-earth orbital missions, synchronous orbit missions, and the earth-orbit phase of ground-launched lunar missions. The justification for this suggestion is that appreciable radiation heat transfer takes place from the IU to the S-IVB dome during the first few hours of orbit time, when the dome is still at cryogenic

Table 5-3. Equipment Power Dissipation Limits for Zero Net Heat Gain or Loss

Case No.	Mission	Equipment Power Dissipation Limits (kw)							
		Based on NASA Specification Temperature Limits				Based on NAA Modified Temperature Limits			
		Without Coolant Flow Restriction		With Coolant Flow Restriction		Without Coolant Flow Restriction		With Coolant Flow Restriction	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
IU-1b-2	200-n. mi. circular earth orbit 29-deg inclination X axis sun-oriented	3.4	4.7	2.1	4.7	2.7	5.1	1.3	5.1
IU-1c-3	200-n. mi. circular earth orbit 29-deg inclination Y axis sun-oriented	2.8	4.2	1.6	4.2	2.1	4.6	0.8	4.6
IU-3b-5	200-n. mi. polar earth orbit 90-deg inclination X axis sun-oriented	3.4	4.7	2.1	4.7	2.7	5.0	1.3	5.0
IU-3c-6	200-n. mi. polar earth orbit 90-deg inclination Y axis sun-oriented	2.5	3.9	1.3	3.9	1.9	4.2	0.5	4.2
IU-6a-8	Synchronous earth orbit 0-deg inclination Y axis sun-oriented	3.3	4.7	2.1	4.7	2.6	5.0	1.3	5.0
IU-6b-9	Synchronous earth orbit 0-deg inclination X axis sun-oriented	4.2	5.6	3.0	5.6	3.5	5.9	2.2	5.9

temperatures, unless the IU is thermally isolated from the dome. Such thermal isolation may be achieved by covering the S-IVB dome with a low emissivity shield such as aluminized mylar. In the event that the IU is not thermally isolated from the S-IVB dome, a quantity of heat must be supplied at a rate decreasing with orbit time in order to maintain the nominal 60 F coolant temperature at coldplate inlet during the initial orbit period. The required amount of heating could be furnished by electrical resistance heating elements incorporated in the coolant inlet manifold; and when heat removal from the system becomes necessary, the existing heat sink (sublimator) could be utilized. Of course, the weight of expendables (water) for a 24-hour mission will have to be evaluated against possible alternatives. It is also suggested that coolant flow can be restricted to a rate of 60 pounds per hour per coldplate. This rate was used for the major portion of the thermal analysis and was found to be satisfactory.

The separate thermal control for the ST-124-M inertial platform assembly, briefly mentioned above, can be achieved most conveniently by using a thermoelectric device that supplies heating as well as cooling. In the event that the coolant temperature at the inlet of the inertial platform assembly exceeds the maximum permissible for the assembly, the thermoelectric device serves to lower the temperature of the portion of the coolant that flows through the assembly. Implied in this situation is an arrangement, similar to that shown in Figure 5-1, in which the coolant passes over the cold surface of the thermoelectric device before it enters the assembly. The heat removed from the coolant by the thermoelectric device, plus the heat equivalent of the device power input, is rejected to the main coolant supply through suitable routing of some coolant flow past the hot surface of the device. When the coolant temperature at platform assembly inlet is below the minimum permissible for the assembly, the heat flow direction across the thermoelectric device is reversed. The main coolant supply then serves as a source of heat for the portion of coolant flow into the assembly, and both the heat extracted from the main coolant supply and the power input to the thermoelectric device are absorbed by the coolant for the inertial platform assembly.

One advantage of thermoelectric devices is their high degree of reliability because of the lack of moving parts. Another advantage inherent in the system, as described above, is that it requires no separate means for producing coolant flow through the critical component. The main supply pumps are used to propel the coolant through all parts of the system. A disadvantage in using thermoelectric devices is the fact that they require a constant power input, even when no heat is pumped across the device. The cost of supplying this power would have to be compared with alternate means for providing the required thermal control. To aid in this comparison, Figure 5-2 shows the performance of a typical thermoelectric device. Input power requirements are those for a 70-watt heat load, which is the power

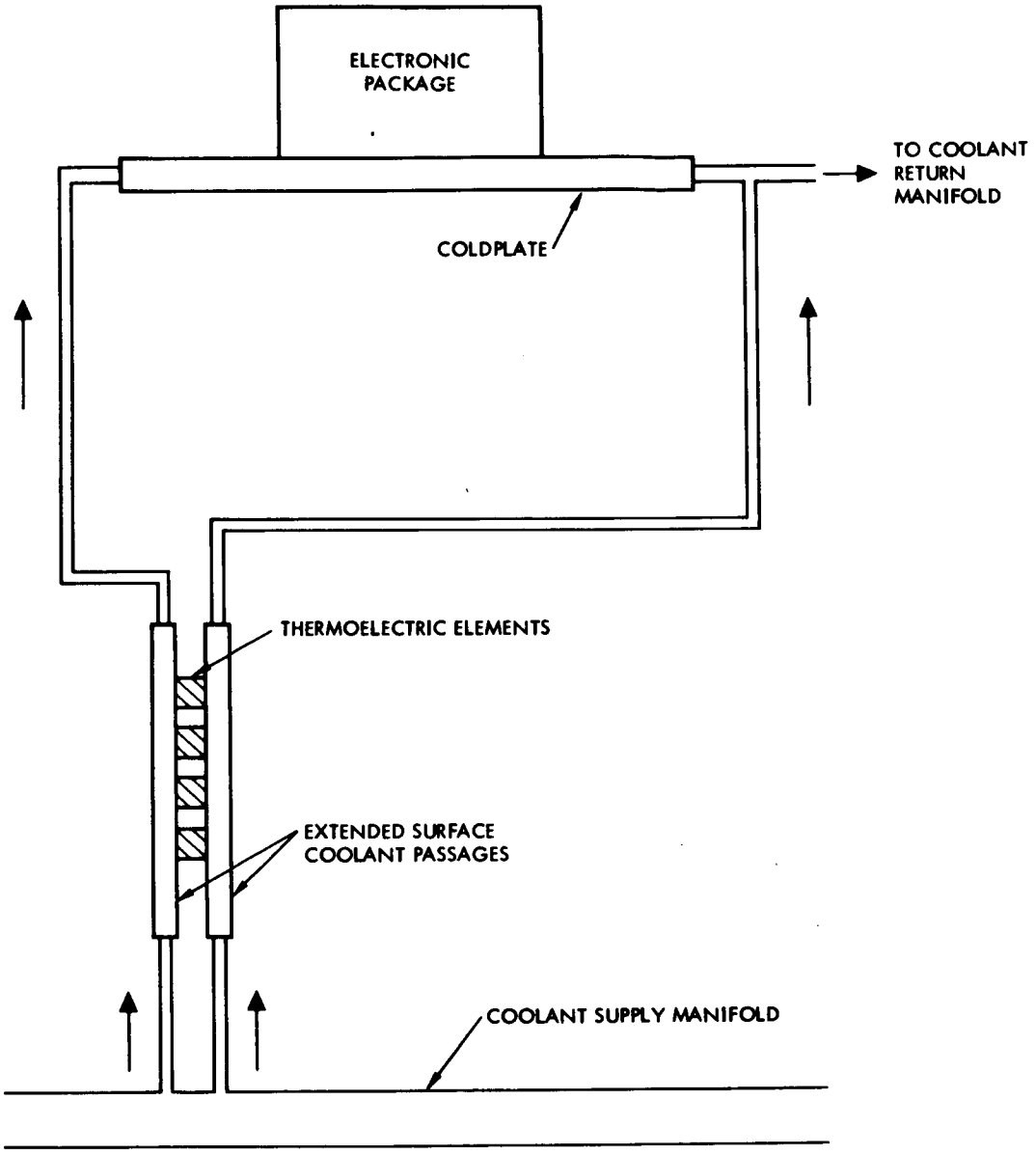


Figure 5-1. Thermoelectric Module Installation Schematic

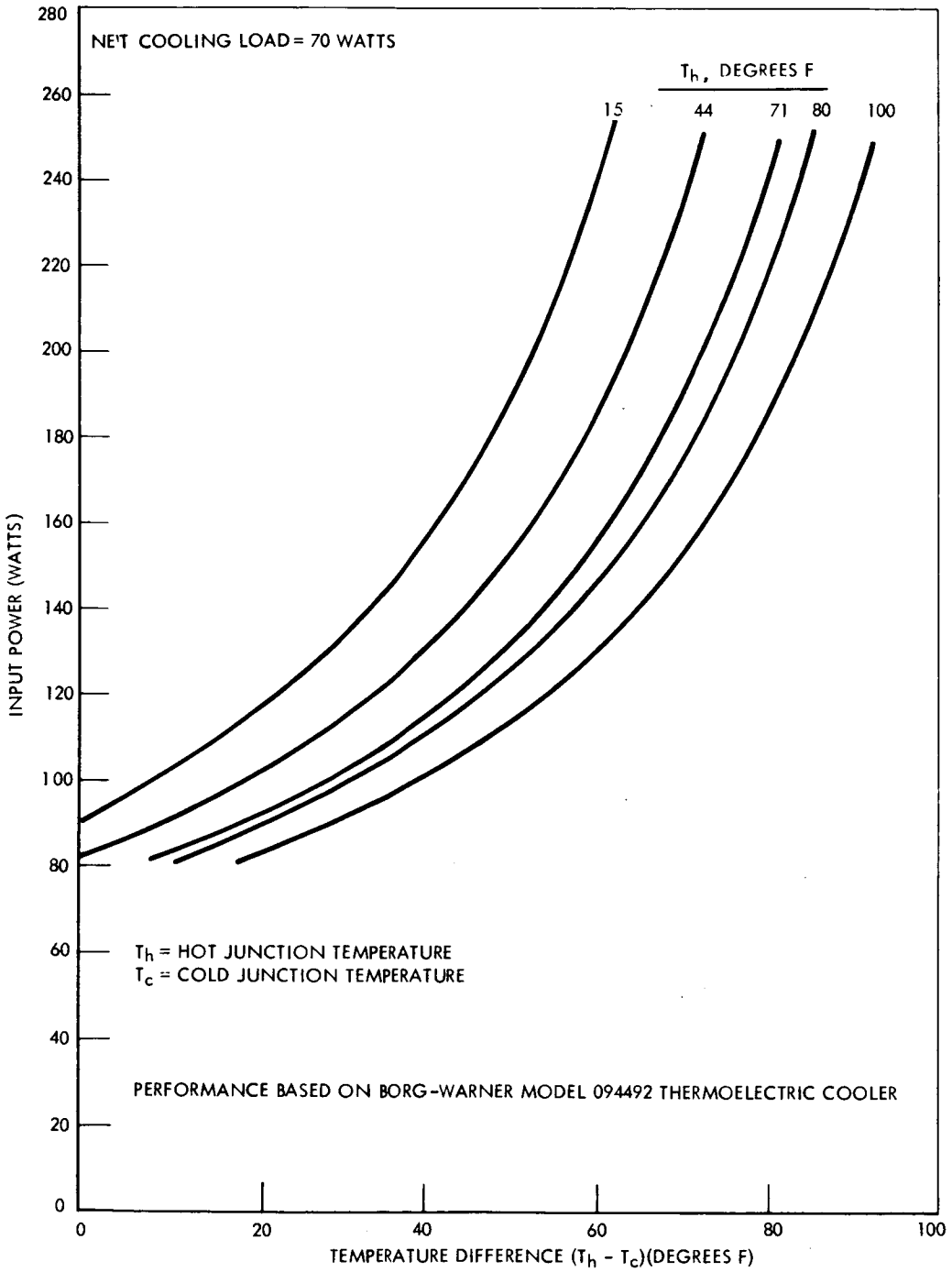


Figure 5-2. Thermoelectric Cooler Performance

dissipation rate of the ST-124-M inertial platform assembly. The performance characteristics shown indicate the rapid increase in input power requirements with the increase in the difference between hot junction and cold junction temperatures at constant hot junction temperature. Additional performance characteristics of thermoelectric devices may be found in Appendix 5A.

The significant approach to extending the Group I (including the accelerometer signal conditioner) lower temperature limit from 59 F to 30 F (the lower limit of Group II) would be to provide a thermally actuated flow control valve at the outlet of each of the coldplates on which the Group I equipment is mounted. For the current equipment layout, this would include coldplates at IU locations 4, 5, and 20. Since only the Group I equipment is mounted on these coldplates, this appears to be an effective and convenient method.

For the internal or integrally cooled equipment, the ST-124-M inertial platform assembly and the LVDC would require a thermally actuated flow control valve at the coolant outlet to limit the flow when the coolant temperature drops to the 30 F value.

Based on the foregoing discussion relating to thermal conditioning system modifications, recommended thermal conditioning system concepts for the missions postulated in Table 5-1 have been summarized in Table 5-4. Mission durations cover the range specified in Table 5-1, and electronic equipment heat loads are those shown in Figure 2-9 for specific mission durations. Use of a sublimator as a heat sink during the initial powered flight phase is recommended for all missions and durations. Flow control valves are suggested for critical items of equipment in instances where the listed electronic equipment heat load (full-on) results in coolant temperature at coldplate inlet below the minimum permissible for the equipment, based on NASA specification temperature limits. A space radiator is recommended whenever active heat removal is required beyond the initial powered flight phase of a mission. Table 5-4 indicates that such active heat removal is required only for mission durations in excess of 24 hours, for which the weight of an expendable heat sink becomes excessive.

Coolant heaters are recommended for mission durations that include periods of operation under standby conditions. Whether or not such heaters are necessary in each and every case depends on the lowest permissible coolant temperature for operating equipment and/or the lowest permissible storage temperature for nonoperating equipment. The ST-124-M inertial platform assembly, for example, requires a minimum 50 F coolant temperature under operating conditions and a minimum 30 F temperature under nonoperating conditions. Hence, if this item of equipment is turned on during standby operation, heat must be supplied to the coolant because coolant equilibrium temperature will be below 50 F. If the inertial platform

Table 5-4. Recommended Thermal Conditioning Systems

Mission Profile			Electronic Equipment Heat Load (kw)		Physical Condition of Instrument Unit		Recommended Thermal Conditioning System
Orbit	Orientation	Duration	Full-On	Standby	Outer Shell	S-IVB Dome	
Near earth (200-n. mi)	X axis sun-oriented	10 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Flow control valve for accelerometer signal conditioner
		24 hours	3.2	0.8	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Flow control valve for accelerometer signal conditioner (Coolant heaters to operate during standby condition)
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
		180 days	5.3	1.0	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
	Y axis sun-oriented	10 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight
		24 hours	3.2	0.8	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby operation)
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight (Coolant heaters to operate during standby operation)
		180 days	5.3	1.0	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight (Coolant heaters to operate during standby operation)
Synchronous	X axis sun-oriented	24 hours	3.2	0.8	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Coolant heaters for ST-124-M inertial platform assembly (and to operate during standby condition) Flow control valves for accelerometer signal conditioner, platform AC power supply, and ST-124 electronics
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
		180 days	5.3	1.0	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
	Y axis sun-oriented	24 hours	3.2	0.8	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Flow control valve for accelerometer signal conditioner (Coolant heaters to operate during standby condition)
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
		180 days	5.3	1.0	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
Lunar mission (ground launch)	X axis sun-oriented	10 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Coolant heater for ST-124-M inertial platform assembly Flow control valves for accelerometer signal conditioner, platform AC power supply, and ST-124 electronics
		24 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Coolant heater for ST-124-M inertial platform assembly Flow control valves for accelerometer signal conditioner, platform AC power supply, and ST-124 electronics
	Y axis sun-oriented	10 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Flow control valve for accelerometer signal conditioner
		24 hours	3.1	-	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight Flow control valve for accelerometer signal conditioner
Lunar and deep space mission (orbital launch)	X axis sun-oriented	30 days	4.4	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Sublimator for initial powered flight (Coolant heaters to operate during standby condition)
	Y axis sun-oriented	30 days	4.4	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight and peak power loads (Coolant heaters to operate during standby condition)
		60 days	4.6	0.9	$\alpha_s/\epsilon = 0.20$	$\epsilon = 0.05$	Space radiator Sublimator for initial powered flight and peak power loads (Coolant heaters to operate during standby condition)

assembly has been supplied with a separate coolant temperature control system, such as a thermoelectric device, then the requirement for active heat addition to the main coolant supply will be determined by the temperature requirements of other equipment.

The applicability of the recommended TCS concepts rests upon the following assumptions with regard to a basic system and its properties:

1. The basic system consists of 16 coldplates through which a water-methanol coolant is circulated.

2. A sublimator or similar device is available for reducing the temperature of the coolant through heat transfer to an expendable heat sink (stored water).

3. Means are provided for separate control of critical electronic packages so that the resulting permissible coolant temperature range is 30 F to 80 F. This modification to the present IU ECS is assumed to be incorporated for missions in excess of 10 hours.

4. The coolant flow rate is a nominal 60 pounds per hour per cold coldplate.

5. The infrared emissivities of the coldplates and the electronic packages mounted on them are 0.18 and 0.90, respectively.

6. A value of 0.18 is preferable for the solar absorptivity of the IU outer skin to minimize the varying effects of solar radiation as a function of orbital position. However, when the IU is in a minimum solar heating orientation, higher values of δ_s may be desirable under conditions of low equipment power dissipation levels. Therefore, the value of δ_s to be used is not unique but will depend on orbital altitude, vehicle orientation, and the level of equipment power dissipation.

7. A value of 0.9 is desirable for the infrared emissivity of the IU outer skin when the IU is in a maximum solar heating orientation and the equipment power dissipation level is high. For other orientations and equipment power dissipation levels, this emissivity value may result in coolant temperatures that are too low. Therefore, the value of IU outer skin emissivity to be used will have to be determined on the basis of the amount of absorbed incident radiation and equipment power dissipation level.

8. The emissivity of the S-IVB dome is assumed to vary between 0.05 and 0.9, depending on the dome temperature profile and the desired effect on the IU temperature level.

Based on these assumptions, the recommended control system concepts may be applied to the postulated missions on the basis of required operating time and equipment power dissipation level. The relationship between these variables is summarized in Table 5-4. It is to be noted that the suitability of the recommended concepts is generally insensitive to mission profile, but depends primarily on mission duration and equipment power dissipation profile.

Operating times up to 10 hours have been assumed to be applicable only to the 200-nautical-mile earth orbital mission and to the lunar mission with ground launch. For these missions, constant levels of equipment power dissipation have been postulated. Any cooling requirement that results can be met most conveniently by the use of an expendable coolant (water) on a demand basis. A possible alternate means of heat rejection exists in terms of the relatively low temperature of the S-IVB dome, which may be of use in IU thermal control through selection of an appropriate value of dome infrared emissivity.

Operating times up to 24 hours have been assumed to be applicable to all postulated missions except the lunar and deep space mission with orbital launch. For this duration, the recommended primary heat sink is still the present expendable coolant system, although different equipment power dissipation profiles are considered possible. An alternate source of heat sink capacity is hydrogen vent gas from the S-IVB stage, which could be used on a demand basis.

For operating times up to 60 days, which have been assumed to be applicable to all postulated missions except the lunar mission with ground launch, hydrogen vent gas from the S-IVB stage cannot be relied upon as a possible alternate heat sink because it is considered to be unavailable after the first 24 hours. Also, the use of an expendable heat sink over this length of time will result in prohibitive weight penalties. Therefore, the recommended primary heat sink is a space radiator, if the equipment power dissipation level is such that continuous heat rejection is required. If the equipment power dissipation is such that passive control is adequate, the space radiator and/or an expendable coolant could serve to provide heat sink capacity during peak power periods. An alternate source of heat sink capacity is considered to be the expendable coolant system if water is available as a fuel cell by-product.

For operating times in excess of 60 days, which have been assumed to be applicable only to the two earth orbital missions, it is assumed that a power source other than fuel cells will be employed. Hence, the heat sink capacity of by-product water will not be available, and only the primary concept (space radiator) can be considered applicable. A limited quantity of expendable coolant could be employed during peak power periods if the thermal lag in the system is insufficient.

The primary and alternate heat sinks are listed in Table 5-5 for the four assumed operating time periods.

Table 5-5. Recommended Heat Sinks

Operating Time	Heat Sinks	
	Primary	Alternate
Up to 10 hours	Expendable coolant: Stored water on demand basis	S-IVB Dome
Up to 24 hours	Expendable coolant: Stored water on demand basis	Expendable coolant: S-IVB hydrogen vent gas on demand basis
Up to 60 days	Space radiator plus expendable coolant: Stored water on demand basis	Expendable coolant: Fuel cell by-product water
Over 60 days	Space radiator plus expendable coolant: Stored water on demand basis.	None

Note: Electrical heaters or another heat source may be required on a demand basis during part of the ascent and orbital phases. The duration is dictated by the S-IVB dome temperature. Radiation from IU outer skin to deep space heat sink is utilized for all operating times.

One alternate source of available heat capacity indicated in Table 5-5 is the hydrogen vent gas from the S-IVB stage. The sensible heat capacity of this cryogenic gas could be used to absorb heat rejected from the environmental control system when such heat rejection is required. However, the availability of hydrogen vent gas is a function of S-IVB propellant utilization and may not be predictable with sufficient certainty. Therefore, the use of hydrogen vent gas as a heat sink is recommended only as an alternative of less than prime desirability.

In the thermal analysis section of the report (Paragraph 4.2), it was shown that thermal control of the IU is possible under zero coolant flow conditions. To take advantage of this condition, it would be necessary to provide separate thermal control for the critical items of equipment mentioned earlier. In addition to providing this equipment with thermoelectric devices or other active systems, it would be necessary to have a completely separate coolant circuit for this equipment to have a source of coolant flow. It should be apparent that a system designed to operate with no coolant flow to most of the coldplates will have compensating features, such as added complexity, which might be less desirable than those of other systems. Hence, the zero coolant flow system is recommended only as an alternative, especially for the cases of loss of coolant through leakage and loss of flow through pump failure.

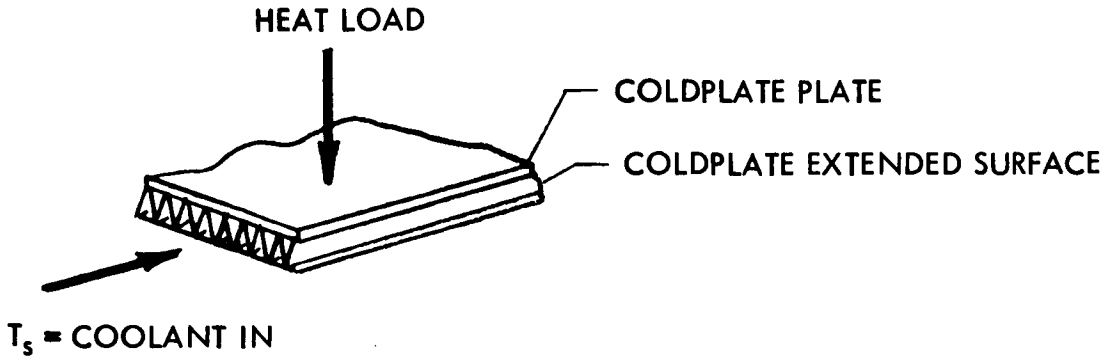
APPENDIX 5.0 THERMOELECTRICS

APPENDIX 5A. THERMOELECTRIC COOLING

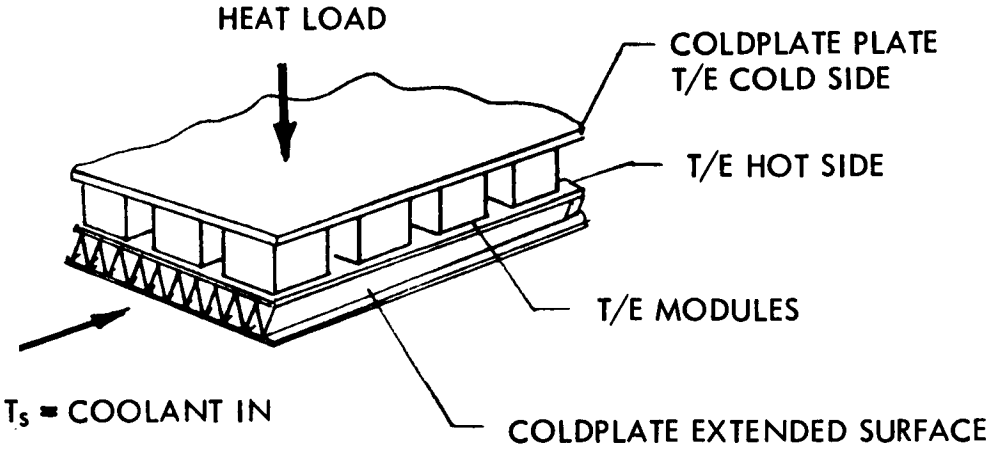
Thermoelectric devices represent ideal, effective means for providing supplemental cooling or heating, whichever is required from time to time, for the modern and future astrionic units. Supplemental cooling is required when the coolant supply from the vehicle ECS is inadequate—i.e., when the coolant supply temperature is higher than the maximum permissible by the particular instrument package. Supplemental heating is required when the main coolant supply is colder than desired.

Since there are no moving parts, thermoelectric devices are inherently very reliable. They are easily controlled to provide as close a temperature regulation as desired, but they do not have the drawback of heater controllers of a wasteful high control point temperature. They are completely and easily reversible to provide auxiliary heating that is more effective than that provided by conventional electrical resistance heaters. They do not generate audible or RF noise. Most importantly, their performance capabilities do not degrade with smaller cooling load capacities or size. This divisibility feature of thermoelectric devices permits the incorporation of the provisions for supplemental cooling and heating for a given instrument package within that package.

Conceptually, and in practice, the best place to locate the thermoelectric elements is between the electronic package and its coldplate. This arrangement is illustrated in Figure 5A-1. One advantage of locating the thermoelectric elements as shown is that the existing coolant circuit does not have to be altered, although an additional component of thermal contact resistance is introduced between the package and the coolant. A drawback of placing the thermoelectric elements between the package and the coldplate is that power must be supplied to the elements continuously. This power supply is necessary because the thermoelectric elements must transfer the heat equivalent of the package electric power dissipation from the package to the coolant even when the coolant temperature is at or below the maximum permissible. If the power supply were to be turned off, the package temperature would rise until a large enough temperature differential was established to transfer the package power dissipation by conduction through the thermoelectric elements. This temperature differential is large and will cause the maximum permissible package temperature to be exceeded. In order to prevent this situation, the thermoelectric elements must function continuously.



A. CONVENTIONAL COLDPLATE



B. THERMOELECTRIC COLDPLATE

Figure 5A-1. Cross Sections of Conventional and Thermoelectric Coldplates

However, the necessary input power to the elements can be minimized by operating without a temperature difference across the elements whenever the coolant temperature permits.

An alternate location for the thermoelectric elements is between two coolant passages (Figure 5-1). In this arrangement, the thermoelectric elements serve to lower the temperature of the portion of the coolant supply flowing through a coldplate on which a critical piece of electronic equipment is mounted. Cooling is provided only when the coolant temperature in the supply manifold exceeds the maximum permissible for the critical item of equipment. The heat removed from the coldplate coolant supply is transferred at the hot surface of the thermoelectric elements to another portion of the coolant, which is bypassed around the coldplate. When the coolant temperature in the supply manifold is below the minimum permitted by the critical item of equipment, the flow of heat across the thermoelectric elements is reversed. Heat is removed from the bypass coolant flow and is used to raise the temperature of the coldplate supply flow. One advantage of the illustrated arrangement is that no power is supplied to the thermoelectric elements when the coolant temperature in the supply manifold is within the range permitted by the critical item of equipment. A disadvantage, on the other hand, is the fact the required routing of coolant will add several plumbing connections to the system. Since leakage of coolant at such connections is a potential source of difficulty, the possibility of such leakage occurring will have to be evaluated against the alternative of a constant supply of power when the thermoelectric elements are between the package and its coldplate. This latter arrangement, however, offers a number of advantages if the thermoelectric elements are combined with the coldplate in an integral design:

1. Thermal contact resistances can be minimized.

2. Extended heat transfer surfaces can be integrally designed.

3 Weight and size are minimized by elimination of common structural members.

4. Analysis and design of both coldplate and thermoelectric device are handled by the same group.

5. The combination of coldplate plus thermoelectric modules is less susceptible to installation and handling damage than are separate thermoelectric modules.

6. The combination is capable of being tested functionally and is less subject to performance degradation due to manner of installation.

7. The heating/cooling element is closer to the surface to be temperature controlled (the case of the electronic package).

8. Heating or cooling is applied where needed.

9. The thermoelectric power supply circuitry may be integrated with the circuitry for the electronic package.

Once it is determined that thermoelectric cooling (or heating) is within the scope of the design requirement for a given mission, it is necessary to establish the thermoelectric requirements, such as the number and type of modules and the current and operating power to satisfy these design requirements. Both experimental and analytical investigations have been conducted concerning the characteristics of thermoelectric devices. These studies have resulted in an experimental parameter determination method, which outlines a parametric procedure for determining the performance of thermoelectric devices in conjunction with integral coldplates and heat exchangers of the equipment package. The method is discussed in the following paragraphs; for further definitions and background data on thermoelecric effects, equipment cooling reference books and design guides such as NavWep 16-1-532, "Methods of Cooling Electronic Equipment," are recommended.

Experimental Parameter Determination Method

(a) The Seebeck coefficient, α, the electrical resistance, R, and the thermal conductance, K, of various commercially available modules are determined by separate, simple experimental tests within the temperature range of interest. These properties are then expressed as functions of the average temperature, $\overline{T}$, so that

$\alpha = \alpha(\overline{T})$ = Seebeck parameter
$R = R(\overline{T})$ = Electrical resistance parameter
$K = K(\overline{T})$ = Thermal conductance parameter

(b) Starting with the basic thermoelectric equation

$$Q_{net} = \alpha I T_c - K \Delta T - 1/2 I^2 R \qquad (1)$$

where

Q_{net} = Heat pumped per module

I = Supply current

T_c = Cold side temperature, F

$\Delta T = T_h - T_c$

(T_h = Hot side temperature)

and using the relationship

$$T_s = T_h - Q_{total} \; R_f \tag{2}$$

where

T_s = Coolant supply temperature, F

R_f = Heat dissipator equivalent thermal resistance (including thermal contact resistance on hot side)

$Q_{total} = (EI + Q_{net})\, N$, watts

N = Number of modules

EI = Electrical input power, watts

E = Voltage across one module,

Equation 1 may be expressed explicitly as

$$T_h = \frac{I \alpha T_c - 1/2\, I^2 R - Q_{net}}{K} + T_c \tag{3}$$

(c) Substitution of Equation 3 into Equation 2 yields

$$T_s = \frac{I \alpha T_c - 1/2\, I^2 R - Q_{net}}{K} - R_f N (EI + Q_{net}) + T_c \tag{4}$$

(d) Next, substitution of the parametric relationships for α, K, and R into Equation 4 and use of the expression $E = \alpha(\overline{T})\Delta T + IR(\overline{T})$ for the thermoelectric input voltage per module results in

$$T_s = \frac{\alpha(\overline{T})\ T_c\ I - 1/2\ I^2\ R\ (\overline{T}) - Q_{net}}{K(\overline{T})} - NR_f \left[Q_{net} + I^2\ R(\overline{T}) + \alpha(\overline{T})\ I\ \Delta T\right] + T_c \qquad (5)$$

(e) The iterative solution of Equation 5 produces T_s versus I plots for various values of R_f. As used above, R_f is related to the coldplate thermal design as follows:

$$R_f = \frac{1}{\epsilon_D W\ C_p} = \frac{T_h - T_s}{Q_{total}}$$

where

ϵ_D = Dissipator effectiveness $\qquad D = \dfrac{(T_{out} - T_s}{(T_h - T_s)}$

C_p = Coolant specific heat, Btu/(hr)(F)

W_s = Coolant mass flow rate, lb/hr

T_{out} = Coolant exit temperature, F

A typical plot of thermoelectric input power (EI) versus coolant supply temperature (T_s) is shown in Figure 5A-2 for three values of nominal coldplate temperature (T_c). The curves shown are applicable to a value of R_f = 0.08°C/watt, which is obtainable now with reasonable package thermal design. At a coolant flow rate of 60 lb/hr and a specific heat value of 0.737 Btu/lb-°F, this value of R_f corresponds to a dissipator effectiveness (ϵ) of 0.535, which is considered reasonable since it takes into account the thermal contact resistance between the thermoelectric modules and the dissipator. It should be noted, however, that the curves in Figure 5A-2 represent performance based on experimental values of Seebeck coefficient, electrical resistance, and thermal conductance of the modules.

Application of the performance characteristics in Figure 5A-2 to the requirements of the RF Assembly P1 is illustrated in Figure 5A-3. The curves shown in this figure represent the variation in thermoelectric module input power requirements as a function of coolant supply temperature for

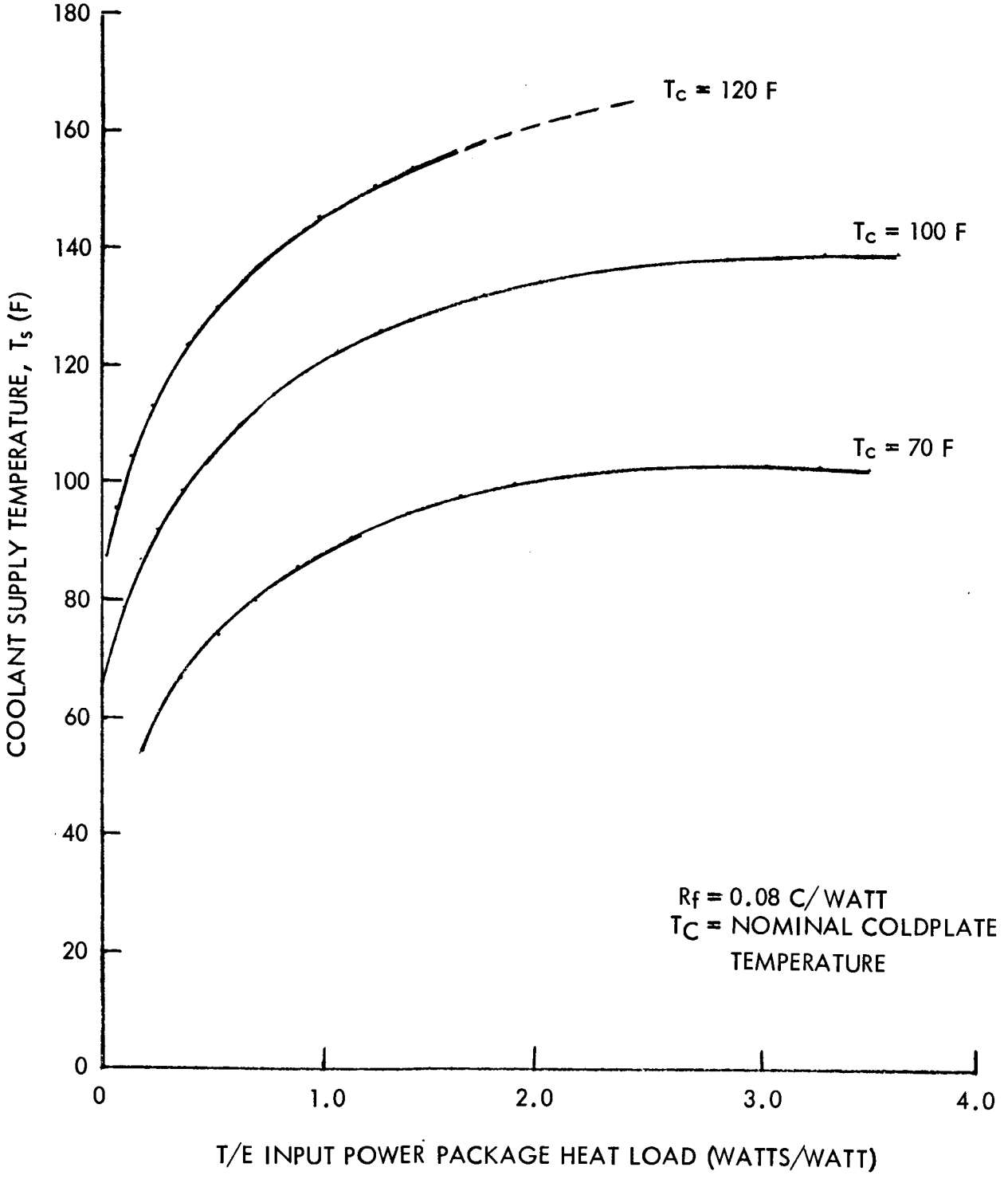


Figure 5A-2. Coolant Temperature Versus Thermoelectric Input Power/Package Heat Load

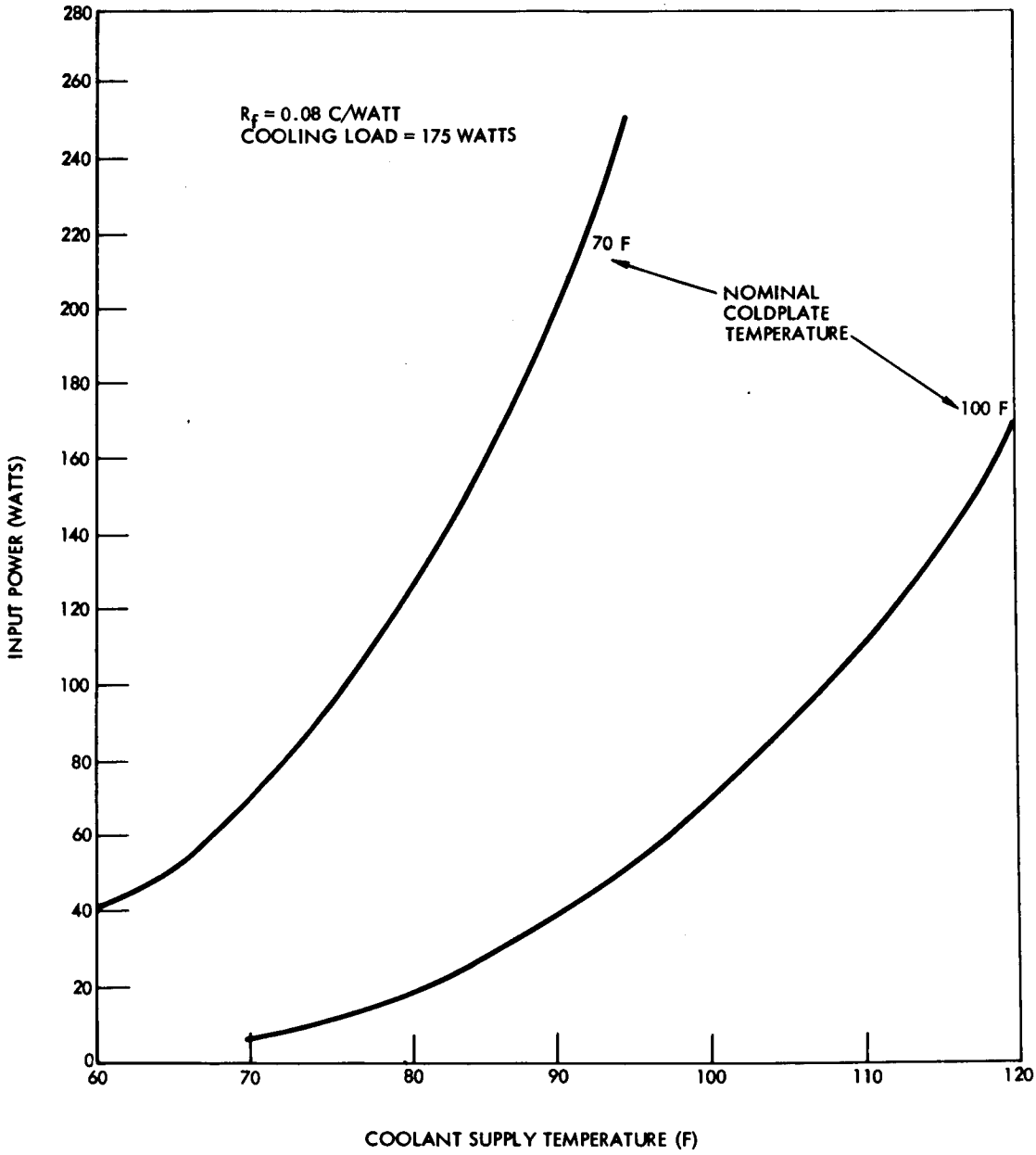


Figure 5A-3. Input Power Requirement Versus Coolant Supply Temperature

nominal coldplate temperatures of 70 and 100 F. The cooling load is the power dissipation equivalent of the RF Assembly P1 (175 watts), and a combination coldplate/thermoelectric cooler has been assumed. The required coldplate temperature will be a function of the joint thermal resistance between the RF Assembly P1 and the coldplate, as discussed in Section 4.1. These data were derived by multiplying input power values in Figure 5A-2 by the 175 watts of power dissipation, and by assuming a joint thermal resistance of 0.5 F/watt.

For the case of a thermoelectric module installation as shown in Figure 5-1, a different method was employed to obtain an estimate of required thermoelectric input power. The coolant flow rate to the coldplate was assumed constant at 60 lb/hr, coolant specific heat was calculated to average 0.737 Btu/lb-°F over the temperature range of interest, and the thermoelectric input power required to maintain a given coolant coldplate inlet temperature was obtained over a range of supply manifold temperatures. The results of these calculations are shown in Figure 5A-4 for coolant coldplate supply temperatures of 30, 40, 50, and 60 F. The input power requirements shown in Figure 5A-4 were derived from published performance data for the Borg-Warner Model 094492 thermoelectric cooler module, which operates at an input power level of 2.8 watts per module. It may be seen that 330 watts are required to maintain a coldplate supply temperature of 60 F when the manifold temperature is 80 F, and that 235 watts are required to maintain a coldplate supply temperature of 60 F when the manifold temperature is 30 F. Of course, if temperatures below 60 F, or any other maximum permissible temperature, are satisfactory for thermal control of a particular piece of equipment, then no power will be required by the thermoelectric device when the manifold temperature is below the permissible maximum. The curves in Figure 5A-4 are also applicable to items of internally cooled equipment, such as the ST-124-M inertial platform assembly, as long as the coolant flow rate is 60 lb/hr. For these pieces of equipment, the coldplate supply temperature in Figure 5A-4 becomes the coolant temperature at package inlet. No attempt should be made to compare the power requirements of Figure 5A-4 with those of Figure 5A-3 because they do not represent the same type of thermoelectric module. The curves shown are intended only to give an indication of the general level of performance obtainable.

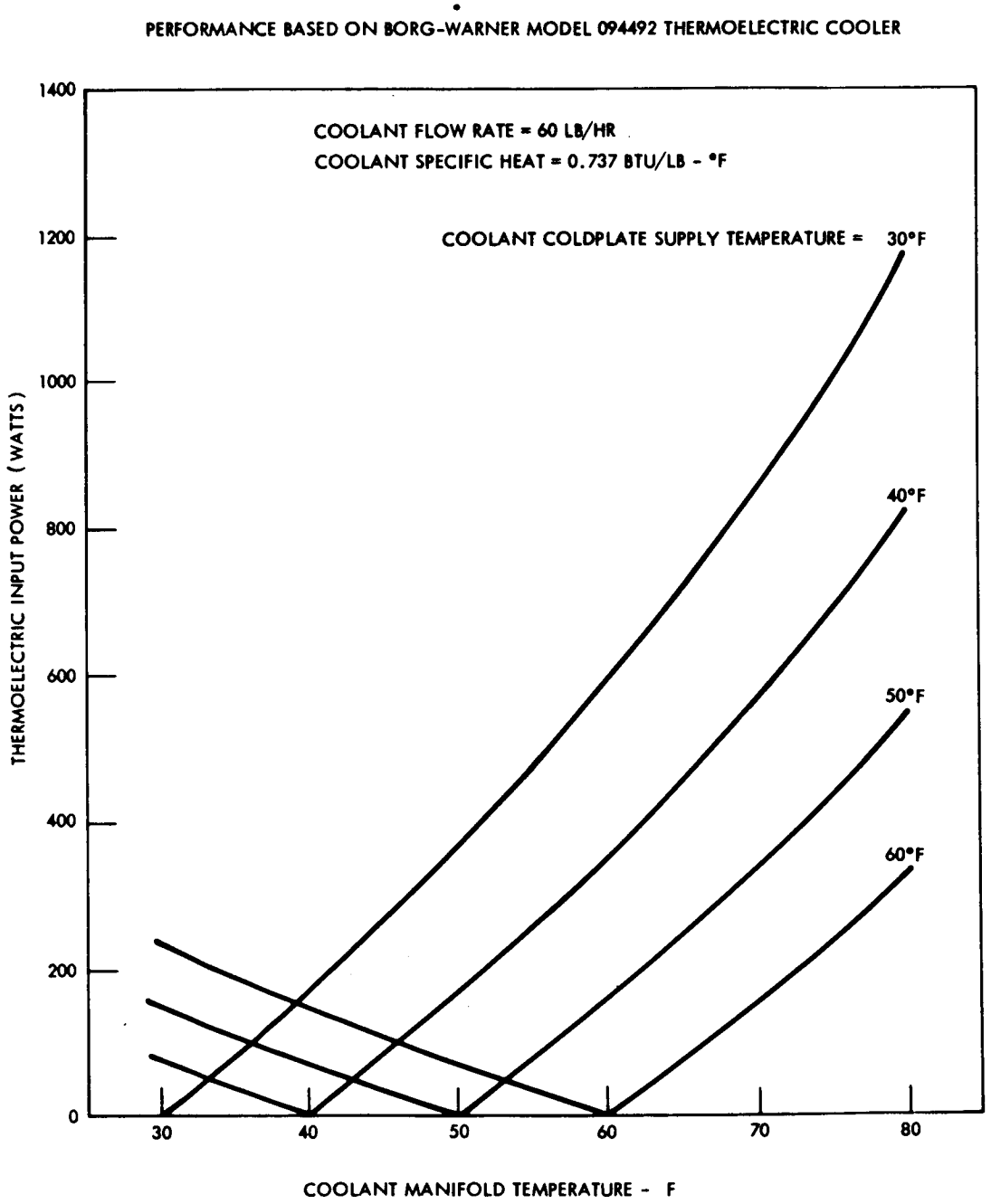


Figure 5A-4. Input Power Requirement Versus Coolant Temperature

6.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of the study, several conclusions can be made with regard to extending the operational life and decreasing the mission sensitivity of the current ECS. Based on possible modifications to the current system, recommended system concepts have been made. The conclusions, recommended concepts, and recommendations for further investigation are as follows:

For the various orbits, vehicle orientations, and astrionic equipment considered in this study, the operational life of the current ECS can be extended, with modifications, as long as the equipment power dissipation rate is within limits for which no heat rejection or addition is required. The minimum modifications for the current configuration of 16 coldplates and integrally cooled equipment with coolant flow consists of (1) maximizing the heat rejection capability of the coldplate and the IU outer skin surface by selection of proper surface coatings (Table 5-4) and (2) extending the tolerable coolant temperature range by providing individual thermal control for each of the few critical pieces of equipment. These modifications can be readily incorporated into the present configuration. Once thermal equilibrium has been established following powered flight, there is a range of power dissipation levels within which the three categories of IU equipment noted may be operated in a passive mode (no active heating or cooling of the circulating fluid in the coldplates) for an indefinite period. Within these power dissipation levels, the IU thermal control system is insensitive to mission duration.

Based on the minimum modifications indicated in the previous paragraph, there is a narrower range of total IU equipment operating power dissipation levels over which the IU thermal control system design is insensitive to the earth orbital mission change. Within this range of power dissipation levels, the IU may be operated on changed earth orbital missions without a redesign of the thermal control system.

Based on the minimum modifications indicated in the first paragraph, there is a range of total IU equipment operating power dissipation values (much narrower than those indicated in the second paragraph) over which the IU thermal control system design is insensitive to the missions and orbits considered in this study. This possibility of a single design for all missions has been indicated, but the power dissipation range may be too narrow to be practical.

The effect of vehicle axial orientation on the allowable power dissipation levels is sensitive to the α_s/ϵ of the IU outer skin. For a α_s/ϵ of 0.20, the allowable power dissipation levels vary moderately between the axial orientation for maximum solar heat and minimum solar heat. For a α_s/ϵ approaching the value of 1.0, the allowable power dissipation levels should vary considerably for different vehicle orientation. In addition, for orbital conditions that have earth shadow periods, α_s/ϵ, as it approaches the value of 1.0, results in a wide swing from the maximum to minimum net heat load on thermal conditioning systems on a per-orbit basis. Thus, it would be desirable to select a value for the α_s/ϵ ratio to minimize or dampen the variation in the net heat load (near the 0.2 value).

For the short-duration missions (less than 24 hours), it appears possible that the S-IVB dome could be used as the heat sink by selection of the proper dome surface properties.

The results of the study for the S-IVB dome emissivity approaching 0.90 indicate that heat addition appears necessary to maintain the coolant temperature above the minimum allowable value. Thus, a lower value for the S-IVB dome emissivity should minimize the requirement for heating or cooling. The selection of the emissivity value will depend upon the S-IVB dome temperature-time profile and expected heat load.

For an emergency mode, with coolant flow, a change in vehicle orientation from maximum to minimum solar heat (or vice versa) may provide some benefit, depending on whether cooling or heating is required.

A purely passive approach (no coolant flow) may be possible for the case of low power dissipation and with provisions for individual thermal control for the critical components. This approach should be investigated further, particularly since it may be used during an emergency due to coolant circulation failure resulting from pump failure or complete loss of coolant.

For the short-duration peak or spike equipment power dissipation, the system thermal mass may be sufficient to absorb the transient heat load. A brief analysis indicates that, for a peak equipment heat load of less than two hours, the system thermal mass appears sufficient. As the duration of the peak or spike heat load increases and approaches ten hours, the system mass is not sufficient and so heat rejection by an appropriate means must be used.

For the missions and postulated heat load profiles, various system concepts and alternatives have been presented. For the short-duration missions (less than 24 hours), a possible approach would be to utilize the thermal capacity of the S-IVB dome to provide the necessary heat sink, thus avoiding additional heat rejection provisions. As the mission time increases

and after the S-IVB dome temperature reaches an assumed equilibrium level condition (60 F), one approach would be to incorporate a space radiator, particularly for a sustained heat load condition above the power dissipation level which requires no active cooling of the circulating fluid. Thus, as the mission time increases and the heat load remains at a relatively high level, requiring heat rejection, the system complexity increases.

For the heat load profile that has peak or spike heat loads, the recommended approach has been based on the duration of the peak or spike heat load.

The thermal analysis performed during this study has provided the necessary data from which to establish the system concepts applicable to the type of missions described in this report. There are several areas for which a more detailed thermal analysis should be performed, using a more refined or detailed thermal model than the one used in this study. From a reliability standpoint, a no-flow condition, a purely passive method, should be investigated further to simulate the condition of pump failure or loss of coolant due to leakage in the coolant lines or coldplates. Failure of this type may be critical for only a few of the electronic packages, so the overall instrument unit may be able to function on a degraded basis. Another area for further investigation is the heat transfer between the S-IVB dome and the thermal conditioning system for various combinations of S-IVB dome temperature profiles and dome surface properties. The analysis presented in this report suggests the possibility of utilizing the S-IVB dome as a heat sink for the short-duration missions.

A better understanding of the system thermal lag is required if it is to be fully utilized for transient or peak equipment power dissipation cases. In addition, the advantages of using heat storage materials (particularly those with high heat of fusion at or near the system temperature) should be investigated as a means of dampening the effects of variation in orbital heat loads.