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** PRELIMINARY **

GAS ELEVEN NODE THERMAL MODEL (GEM)

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INTRODUCTION

The Eleven Node Thermal Model (GEM) of the Get Away Special (GAS) container was originally developed based on the results of thermal tests of the GAS container. The model was then used in the thermal analysis and design of several NASA/GSFC GAS experiments, including the Flight Verification Payload (FVP), the Ultra-Violet Experiment (UVX), and the Capillary Pumped Loop (CPL).

The enclosed model description details the five cubic foot container both with and without an insulated end cap. Mass specific heat values are also given so that transient analyses can be performed. A sample problem for each configuration is included as well so that GEM users can verify their computations. The model can be run on most PC size computers with a thermal analyzer solution routine.

CONTAINER WITH THE INSULATED END CAP

The thermal model for the container with the insulated end cap is presented in Figure 1 with a nodal listing given in Table 1. The container cylinder is represented by three nodes, and the top and bottom end plates have one node each. The side insulation is represented by one node and the end caps have two nodes each. The external environment (node 11) represents the boundary condition for the model. This is a fixed (constant) temperature node which is set to a temperature level obtained from the GAS container equilibrium temperature table given on page 67 of the GAS experimenter handbook (Red book - reference 1). These boundary conditions were determined by extensive computer analysis and flight data.

The conduction couplings for the model are given in Table 2. Additional couplings may be added depending on the unique payload configuration being modeled, such as payload couplings to the top mounting plate (node 1). The conductive coupling from the GAS container to the GAS adapter beam is not included in the interest of simplifying the model. Furthermore, fiberglas isolators reduce the thermal conductance to a minimum in this area.

The external radiative couplings are given in Table 3. These values represent the radiative couplings from the container through the insulation system to the external environment. These values stay fixed regardless of the internal payload configuration.

The internal radiative couplings for an empty container with no payload are given in Table 4. These values were determined by the geometrical view factor program contained in the Simplified Shuttle Payload Thermal Analyzer (SSPTA). The calculations were based on GAS container internal dimensions of 20 inches in diameter by 31.25 inches long. The internal surface emittance of the container is 0.80 (anodized aluminum). It should be noted that the internal radiative couplings will change dramatically when a payload is introduced into the container as will be shown in the following example.

EXAMPLE PROBLEM 1

A cylindrical experiment payload is mounted to the experiment mounting plate with conductive isolators. It is 15.5 inches in diameter by 28 inches long and painted black (surface emittance is 0.85). The payload is represented by node 12 in Figure 2 and Table 1. This is the same example payload that was used in the GAS Motorized Door Assembly (MDA) Thermal Design Guide (reference 3).

Since this payload is conductively isolated from the experiment mounting plate, no additional conductive couplings are required. However, there are large modifications to the internal radiative couplings as shown in Table 5, due to the influence of the experiment payload. These couplings replace the radiative couplings given in Table 4. The radiative couplings were again determined using the SSPTA program, although they had to be modified from the MDA thermal analysis to correspond to the nodal breakdown of the GAS Eleven Node Model (GEM). The radiative couplings may be hand calculated or estimated if necessary, however, this can be somewhat tedious and inaccurate depending on the complexity of individual payload thermal models.

Three thermal environment cases were run for the example problem with payload power levels set at 10 watts and 25 watts. Table 6 gives the steady state temperature results for both the average container temperature (Node 3) and the payload temperature (Node 12) for the moderately cold, earth viewing (ZLV), and hot cases. These cases refer to the thermal environments listed on page 67 of the GAS red book for the 5 cubic foot container with the insulated end cap. Temperature levels are also given for the same payload covered with low emittance aluminum tape. For this case, the radiative couplings to node 12, numbers 23 through 27, are reduced to 0.06 times their original value, corresponding to an aluminum tape emittance of 0.05. A substantial payload temperature increase results from this change, even though the container temperature is unaffected.

The average container temperatures listed in Table 6 correspond to node 3, which is an approximate average of nodes 1-5 for this configuration. None of the container temperatures varied by more than 0.5 degrees C in this case. Other payloads having large conductive couplings to the experiment mounting plate (node 1) would yield greater temperature variations within the container.

A comparison between GEM and the 3-node thermal model described in the GAS Thermal Design Summary (reference 2) was also performed. The GAS container temperature curves shown on pages 69 through 72 of the GAS red book were produced utilizing the 3-node model. The GEM average container temperatures from Table 6 are indicated on Figure 3, which is excerpted from page 69 of the red book. Both models agree fairly well, although GEM predicts slightly warmer temperature levels in all cases. This may result from the omission of the conduction coupling from the GAS container to the adapter beam in GEM, which yields a slightly lower overall container heat loss to the environment. Although this conduction coupling is not directly included in the 3-node model, its effect was included in its overall heat transfer coefficient to the environment (effective emittance). It was decided to leave GEM as is rather than increase its thermal coefficients to compensate for the difference. Recent indications such as Dr. Werner Neupert's report (reference 4) suggest that the thermal coefficient (effective emittance) in the 3-node model may be too high. Other flight results tend to confirm this as well. If GEM were reduced to the 3-node model, the effective emittance would be reduced to 0.056 as stated in the Thermal Design Summary (ref. 2). Final resolution of this discrepancy would require additional thermal tests of the GAS container in its latest configuration.

GEM TRANSIENT CONSIDERATIONS

EXAMPLE 2

The mass specific heat values for GEM are given in Table 7. This information is required in order to perform transient thermal analyses with GEM. The experiment payload from the previous example (node 12) is included as a 165 pound payload with a specific heat of 0.21 BTU/LB-deg R. This configuration was run for the cold, earth viewing, and hot-33 cases described in Table 1 of the GAS/MDA thermal design guide (ref. 3). The environment temperature (node 11) was set to the corresponding levels listed in Table 2 of the MDA guide. The conductive and radiative thermal couplings are the same as those from the previous example for a black painted experiment payload. The transient temperature results for a 48 hour no power case are given in Table 8, with average container (node 3) and experiment payload (node 12) temperatures listed. The payload temperatures are then plotted on Figure 4, which is excerpted from the MDA guide. This plot gives a comparison between the GEM container model and the SSPTA closed door MDA model. The two models agree quite well, showing the thermal similarity between the closed GAS/MDA container and the standard container with the insulated end cap. GEM runs slightly warmer than the GAS/MDA model, which may again be due to the omission of the conductance to the adapter beam as discussed previously.

EXAMPLE 3

Another comparison was run for the transient cooldown of the GAS/EMP experiment on the STS-61C mission. This time a comparison between GEM and actual flight data was made. The EMP was a 200 pound payload that was conductively isolated from, but radiatively coupled to the GAS container. EMP was modelled in an approximate fashion using the same experiment payload model cited in the previous examples. The radiative and conductive couplings were left unchanged, but the mass specific heat of node 12 was increased to 42.0 BTU/deg R, assuming a payload specific heat of 0.21 BTU/LB-deg R. The first 24 hours of the mission were simulated. The starting temperature was 19.5 C and node 11 was set at -5 C (earth viewing environment) for the first 12 hours and to -50 C (moderately cold condition) for the next 12 hours. Table 9 gives the transient temperature results for the average container (node 3) and the experiment payload (node 12) thermal levels. (Note that this is a no power cooldown condition). The GEM payload temperatures (node 12) are indicated on Figure 5 which is the EMP temperature profile for STS-61C (ref. 5). Excellent agreement between the GEM predictions and actual flight results is demonstrated. Figure 5 also shows that after the EMP reached 7 deg C, its heaters began to cycle to maintain its temperature near 7 C throughout a variety of shuttle thermal conditions. This is an example of the tight thermal control that can be achieved with the use of thermal control heaters and thermostats.

CONTAINER WITHOUT THE INSULATED END CAP

The GAS container without the insulated end cap is easily modelled by making minor modifications to GEM. Nodes 9 and 10 representing the top insulated end cap are removed as shown in Figure 6. GEM now becomes the GAS Nine node Model, or GNM. The conductive and radiative couplings associated with nodes 9 and 10 are also removed, and a radiative coupling between the top mounting plate (node 1) and the environment (node 11) is added. Specifically, conductive couplings #5 and #8 are removed from Table 2 and radiative couplings #1, #2, #11, and #12 are removed from Table 3. A radiative coupling from node 1 to node 11 with a value of 2.34 FT**2 should be added to Table 3. For the transient model, the mass specific heat values for nodes 9 and 10 should be removed from Table 7.

EXAMPLE 4

GNM was run using the same experiment payload model (node 12) that was used for the previous examples. The moderately cold, earth viewing (ZLV), and hot cases were run for experiment power levels of 10, 25, and 50 watts. Node 11 was set to the corresponding boundary temperatures listed on page 67 of the GAS red book for the 5 cubic foot container without the insulated end cap. Steady state temperature results for the container top plate (node 1), the average container temperature (node 3), and the experiment payload (node 12) are listed in Table 10. Much larger gradients are evident throughout the GAS container as compared to the GEM values. The power levels required to maintain a specific payload temperature level are higher too. This shows that a container without the insulated end cap is best suited for those experiments that have high continuous power dissipations and/or desire lower temperature levels.

The average container temperatures (node 3) of GNM were compared to the 3 node model (ref. 2) as well. Figure 7 shows the GNM container temperatures from Table 10 plotted on the temperature curves excerpted from page 71 of the GAS red book for the container without the insulated end cap. GNM, like GEM predicts slightly warmer temperatures that the 3 node model, although reasonable agreement is evident, especially at the lower power levels. The reason for the discrepancy is probably due to the container-to-top-plate thermal gradient, which becomes especially pronounced at higher power levels. The 3 node model does not show this since it gives only an average temperature for the entire container. The effect of the lack of conductance to the adapter beam is very minor in this case due to the large dominant radiative coupling from the container top plate to the environment.

GNM TRANSIENT CONSIDERATIONS

EXAMPLE 5

Transient cooldown cases (no power) were run for the previous example problem for the cold and earth viewing (ZLV) cases. Table 11 gives the transient temperature results for nodes 1, 3 and 12 for a 48 hour cooldown. Node 11 was ARBITRARILY set to the boundary conditions used in Table 8 for the GEM transient case of example 2, so that a comparison could be made between GEM and GNM. Thus, a comparison of the two container configurations was accomplished, showing the different transient thermal behavior of each. For YOUR thermal analysis and design, node 11 should be set to the boundary conditions listed on page 67 of the red book for the 5 cubic foot container without the insulated end cap.

Figure 8 is a plot of the average container temperature (node 3) from GEM and GNM for the cold and earth viewing (ZLV) cases. These curves show that the container without the insulated end cap responds much more quickly to a given thermal environment, further demonstrating the different thermal behavior of the two container configurations. The 2-node transient model described in the GAS Thermal Design Summary (reference 2) was also analyzed for these cases. The results of this analysis are indicated on Figure 8. The agreement with GEM is good, but comparison with GNM shows that with GNM predicts warmer temperatures than the 2-node model. The 2-node model does not include the influence of large thermal gradients within the container that result from the removal of the insulated end cap. GNM should therfore be inherently more accurate than the 2-node model, which only provides a bulk or average container temperature.

CONCLUSIONS

Thermal models of the GAS container both with and without an insulated end cap have been presented. Examples have been provided for each case so that users can verify their thermal computations. This information should assist those GAS users that require more accurate thermal analyses than that previously available from the smaller models. This information is especially pertinent to the container without the insulated end cap, since large thermal gradients can exist within the container.

Users are cautioned that this model is NOT perfect or exact. Unique payload configurations and variations in shuttle orbits can affect the thermal environment substantially. A +/- 10 deg C uncertainity should be applied to the listed temperatures, and payloads should be designed with enough margin to overcome these and other uncertainities.

GOOD LUCK WITH YOUR THERMAL DESIGN

REFERENCES

1. "Get Away Special (GAS) Experimenter Handbook" (Red Book), 1987, NASA/GSFC Special Payloads Division

2. "Get Away Special (GAS) Thermal Design Summary" by Dan Butler, NASA/GSFC X-732-83-8, July 1983

3. "Thermal Design Guide for Get Away Specials/Motorized Door Assembly Users" by Anthony Melak, Swales and Associates and Dan Butler NASA/GSFC, September 1986

4. "Response of GAS Payload (G345 and G347) Temperatures to Various Orbiter Flight Attitudes" by Dr. Werner M. Neupert, NASA/GSFC GAS Symposium, October 1985

5. "Temperature Data from Selected GAS Flights" Dan Butler, NASA/GSFC GAS Symposium, October 1986

THERMAL ANALYZER PROGRAMS FOR THE PC

1. PC SSPTA — Frederick A. Costello Inc.
   12864 Tewksbury Dr.
   Herndon, VA 22071
   Phone: (703) 620-4942

2. PC SINDA — Jerry GASKI
   Network Analysis Associates
   P.O. Box 8007
   Fountain Valley, CA 92728
   Phone: (714) 557-2080

3. MSC CAL — MacNeal-Schwendler Corp.
   815 Colorado Blvd.
   Los Angeles, CA 90041
   Phone: (213) 259-3888

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TABLE 1

GAS ELEVEN NODE THERMAL MODEL (GEM)

NODAL LISTING

1. Container Top - Experiment Mounting Plate
2. Cylinder Upper Section
3. Cylinder Middle Section
4. Cylinder Lower Section
5. Container Bottom - Interface Equipment Plate
6. Bottom Insulated End Cap Disc
7. Bottom Insulated End Cap Side
8. Container Side Insulation
9. Top Insulated End Cap Side
10. Top Insulated End Cap Disc
11. Thermal Environment
12. Example Experiment Payload

TABLE 2

GEM CONDUCTION COUPLINGS

NUMBER	COUPLING	VALUE (BTU/deg R)
1	1 - 2	10.08
2	2 - 3	6.63
3	3 - 4	6.63
4	4 - 5	10.08
5	1 - 9	0.08
6	5 - 7	0.08
7	6 - 7	0.02
8	9 - 10	0.02

TABLE 3

GEM EXTERNAL RADIATION COUPLINGS

NUMBER	COUPLING	VALUE (FT**2)
1	1 - 9	0.06
2	1 - 10	0.06
3	2 - 8	0.34
4	3 - 8	0.34
5	4 - 8	0.34
6	5 - 6	0.06
7	5 - 7	0.06
8	6 - 11	2.53
9	7 - 11	0.72
10	8 - 11	13.97
11	9 - 11	0.72
12	10 - 11	2.53

TABLE 4

GEM INTERNAL RADIATION COUPLINGS

NO PAYLOAD - EMPTY CONTAINER

NUMBER	COUPLING	VALUE (FT**2)
13	1 - 2	1.17
14	1 - 3	0.29
15	1 - 4	0.16
16	1 - 5	0.15
17	2 - 3	0.67
18	2 - 4	0.31
19	2 - 5	0.16
20	3 - 4	0.67
21	3 - 5	0.29
22	4 - 5	1.17

TABLE 5

GEM INTERNAL RADIATIVE COUPLINGS

EXAMPLE EXPERIMENT PAYLOAD (NODE 12)

NUMBER	COUPLING	VALUE (FT**2)
13	1 - 2	0.61
14	1 - 3	0.06
15	1 - 4	0.01
16	1 - 5	0.01
17	2 - 3	0.10
18	2 - 4	0.02
19	2 - 5	0.01
20	3 - 4	0.10
21	3 - 5	0.05
22	4 - 5	0.62
23	1 - 12	1.18
24	2 - 12	2.39
25	3 - 12	2.39
26	4 - 12	2.39
27	5 - 12	0.88

TABLE 6

GEM STEADY STATE TEMPERATURES (DEG. C)

EXAMPLE 1

	MODERATELY COLD	EARTH VIEWING	HOT
ENVIRONMENT	-50.0	-5.0	40.0
POWER = 10 WATTS			
CONTAINER	-24.1	12.1	51.6
PAYLOAD (BLACK)	-20.8	14.3	53.1
PAYLOAD (AL TAPE)	18.9	43.4	74.1
POWER = 25 WATTS			
CONTAINER	5.0	33.3	66.9
PAYLOAD (BLACK)	10.8	37.6	70.1
PAYLOAD (AL TAPE)	74.2	89.9	111.7

TABLE 7

GEM MASS SPECIFIC HEATS (MCP's)

TRANSIENT MODEL

NODE	MCP (BTU/deg R)
1	5.78
2	4.77
3	4.77
4	3.56
5	7.67
6	1.47
7	0.49
8	0.93
9	0.49
10	1.33
11	N/A
12	34.6

Note: Nodes 2 and 3 contain additional mass due to the GAS container support brackets.

TABLE 8

GEM TRANSIENT TEMPERATURES (DEG C)

EXAMPLE 2

	COLD		EARTH VIEWING		HOT	
ENVIRONMENT	-75.8		-8.9		45.2	
TIME (HRS)	CONTAINER	PAYLOAD	CONTAINER	PAYLOAD	CONTAINER	PAYLOAD
0	20.0	20.0	20.0	20.0	20.0	20.0
8	8.8	13.2	15.4	17.2	25.4	23.6
16	1.0	5.1	12.2	13.8	28.8	27.3
24	-5.8	-1.9	9.5	10.9	31.7	30.5
32	-11.8	-8.0	7.2	8.5	34.1	33.1
40	-17.0	-13.5	5.2	6.3	36.0	35.2
48	-21.7	-18.4	3.5	4.4	37.7	37.0

TABLE 9

GEM TRANSIENT TEMPERATURES (DEG C)

EXAMPLE 3

TIME (HOURS)	CONTAINER	PAYLOAD
0	19.5	19.5
4	17.0	18.7
8	15.4	17.2
12	14.0	15.7
16	9.8	13.4
20	6.8	10.5
24	4.0	7.6

NOTE: The environment temperature (node 11) was held at -5 deg C for hours 0 - 12 and at -50 deg C for hours 12 - 24.

TABLE 10

GNM STEADY STATE TEMPERATURES (DEG C)

EXAMPLE 4

	MODERATELY COLD	EARTH VIEWING	HOT
ENVIRONMENT	-55.0	-10.0	25.0
POWER = 10 WATTS			
TOP PLATE	-43.5	-3.1	29.8
CONTAINER	-41.9	-1.7	31.1
PAYLOAD	-38.1	0.6	32.7
POWER = 25 WATTS			
TOP PLATE	-29.1	6.0	36.3
CONTAINER	-25.3	9.5	39.5
PAYLOAD	-17.8	14.4	43.1
POWER = 50 WATTS			
TOP PLATE	-9.8	19.4	46.3
CONTAINER	-2.6	26.0	52.3
PAYLOAD	8.4	34.1	58.6

TABLE 11

GNM TRANSIENT TEMPERATURES (DEG C)

EXAMPLE 5

	COLD			EARTH VIEWING		
ENVIRONMENT		-75.8			-8.9	
TIME (HRS)	TOP PLATE	CONTAINER	PAYLOAD	TOP PLATE	CONTAINER	PAYLOAD
0	20.0	20.0	20.0	20.0	20.0	20.0
8	-11.2	-2.4	5.4	7.4	10.9	13.8
16	-22.6	-15.7	-8.5	3.2	5.7	8.0
24	-31.3	-25.8	-19.4	0.1	2.0	3.8
32	-38.2	-33.7	-28.0	-2.1	-0.7	0.7
40	-43.8	-40.1	-35.0	-3.7	-2.7	-1.7
48	-48.4	-45.3	-40.7	-5.0	-4.2	-3.4

NOTE: The environment temperature (node 11) was arbitrarily set to the temperatures shown for comparison purposes only. GNM users should set node 11 to the environment temperatures listed on page 67 of the GAS red book for the container without the insulated end cap.

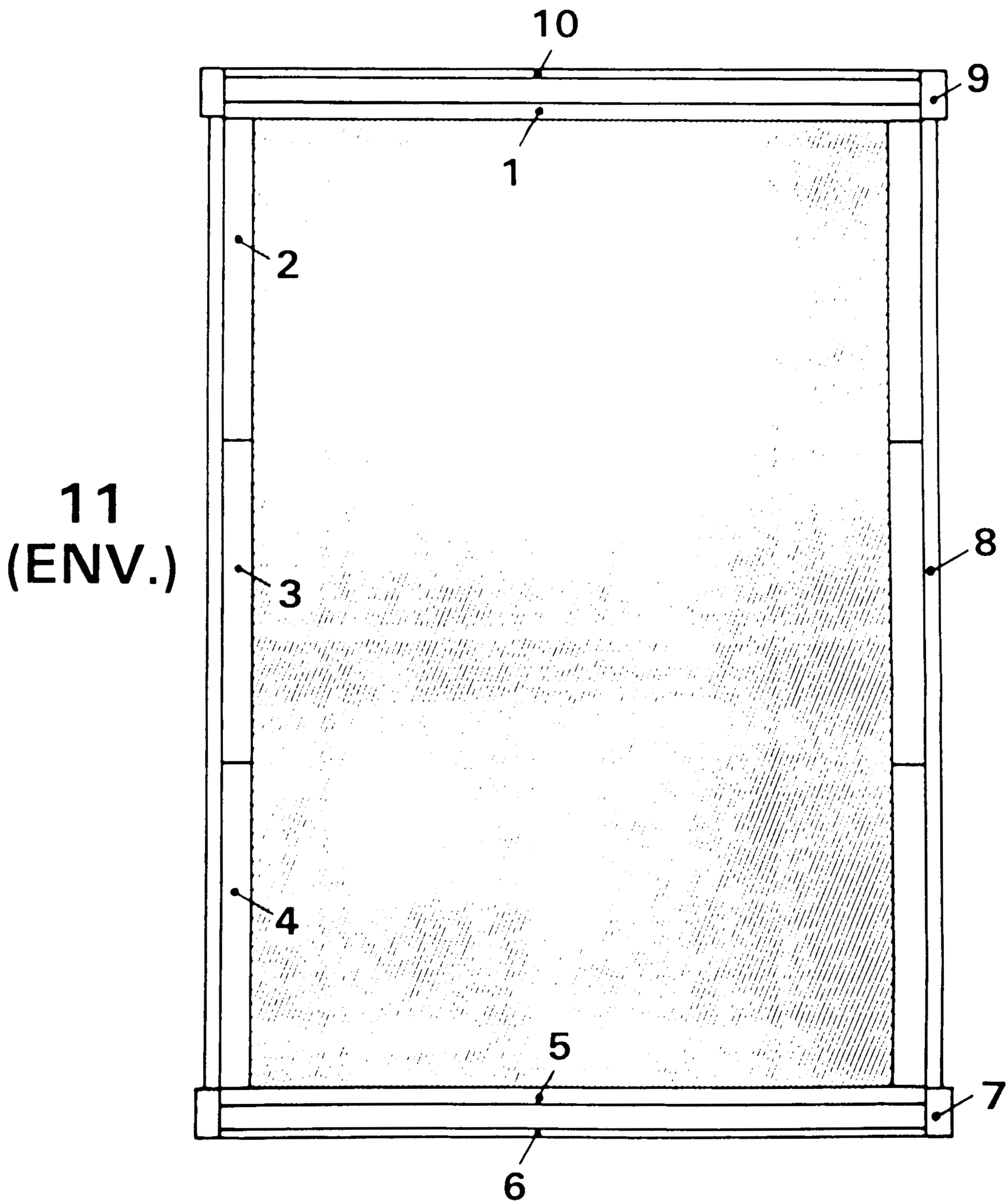

Figure 1. GAS 5 ft^3 Container Thermal Model (with Insulated End Cap)

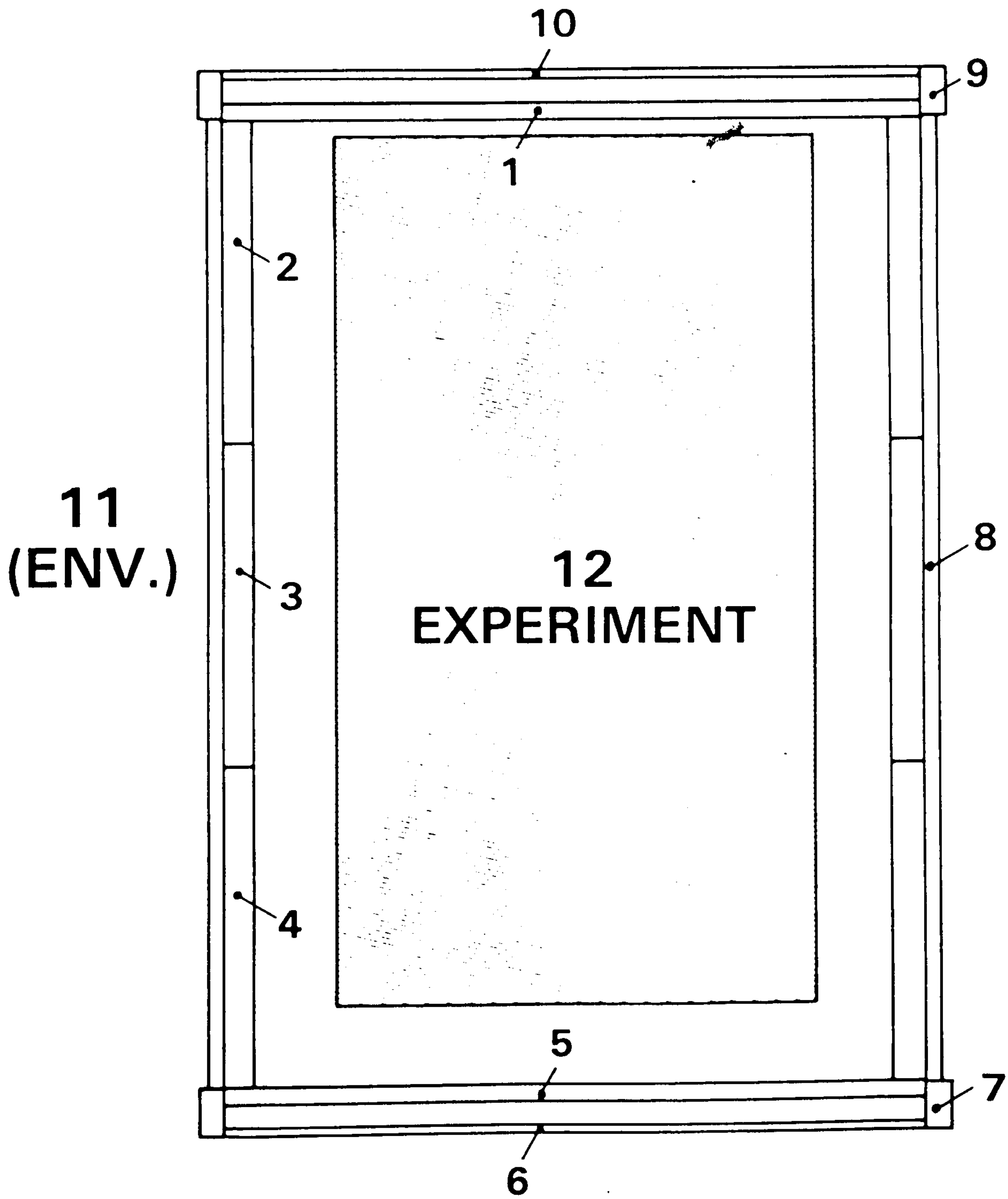

Figure 2. GAS 5 ft^3 Container Thermal Model (with Insulated End Cap)

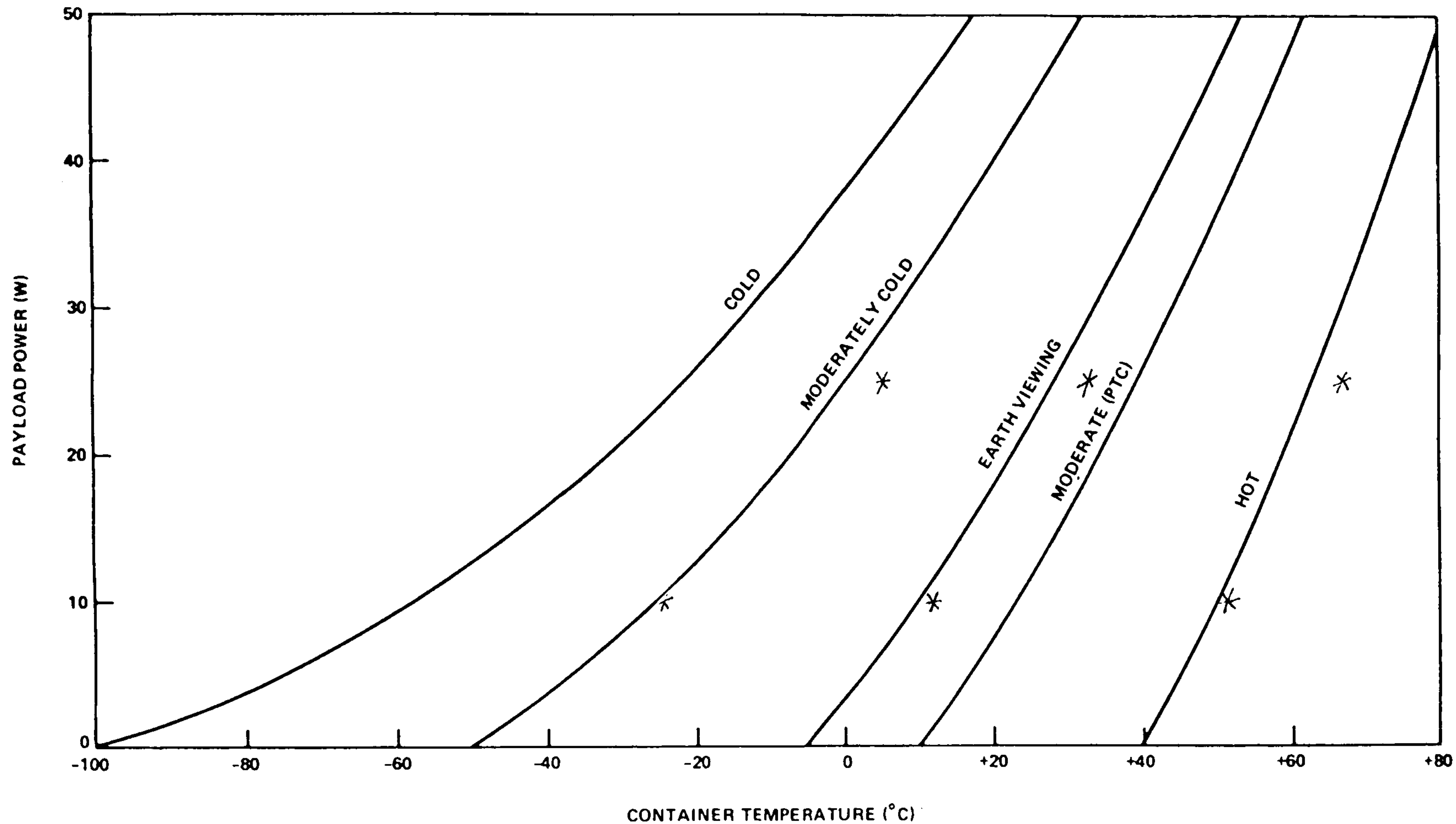

Figure 3. Get Away Special Small Self-contained Payloads (5 ft^3 Container with Insulated End Cap)

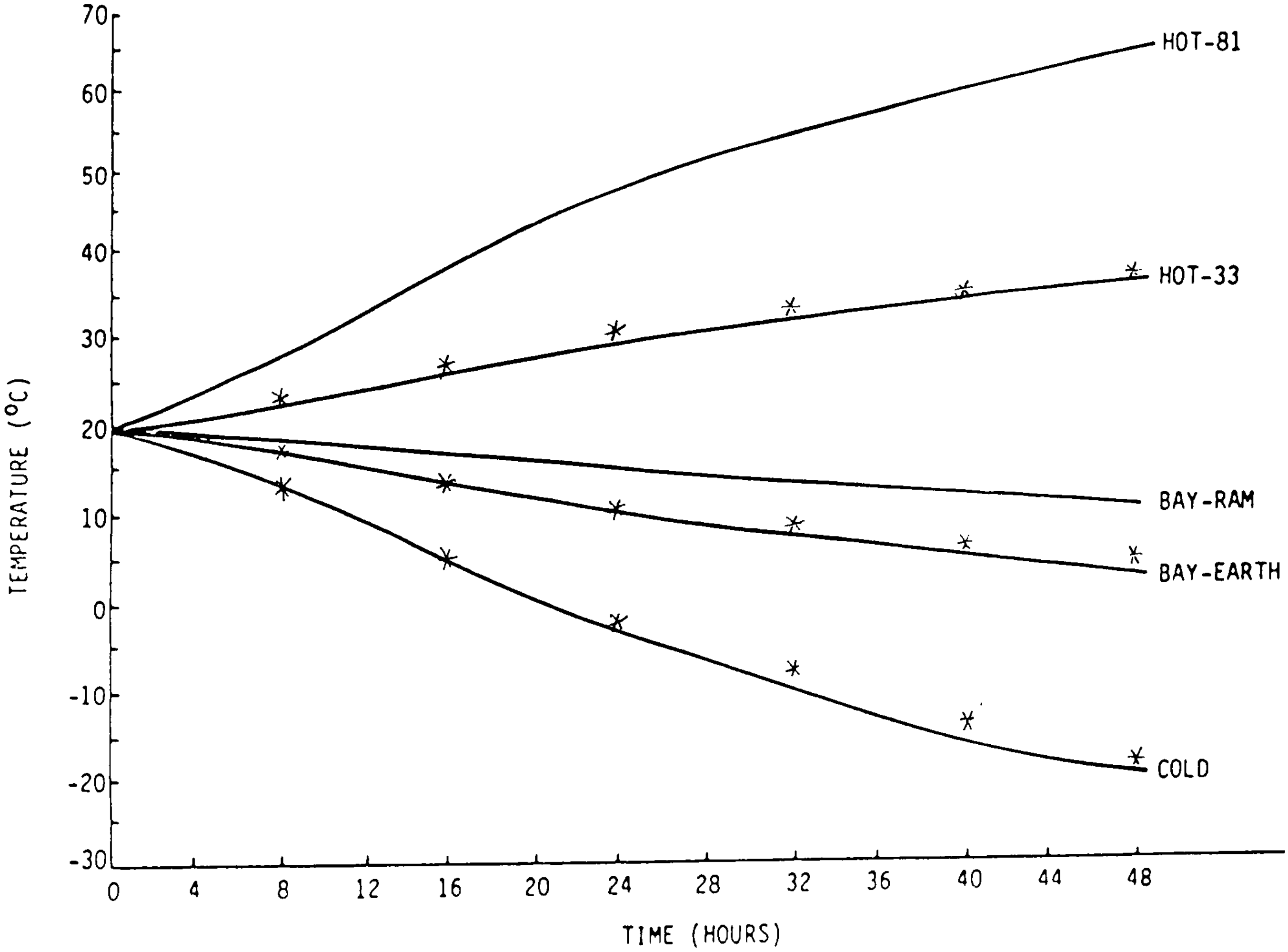

Figure 4. Closed GAS/MDA Experiment Transient Temperature Response for Zero Power

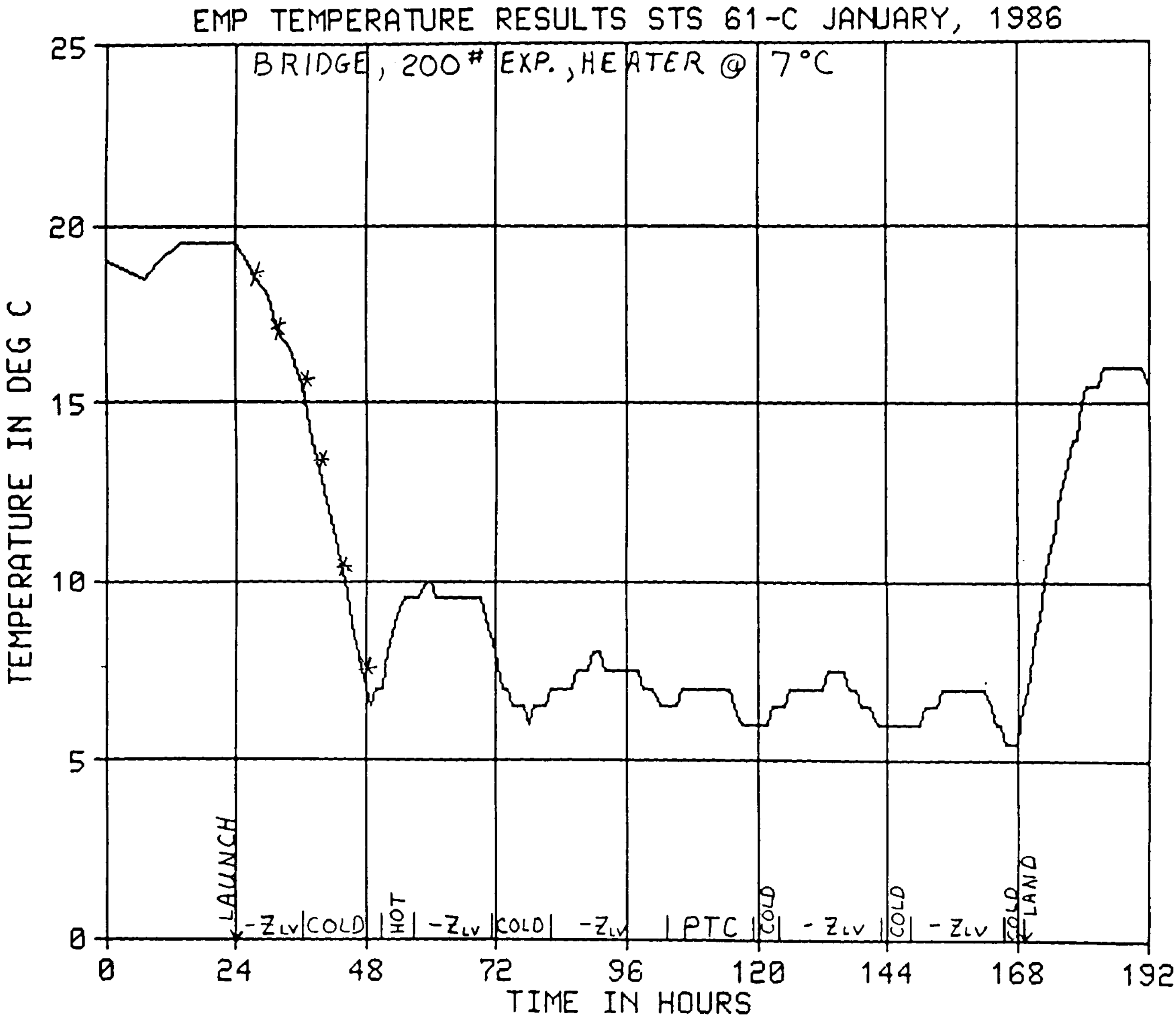

Figure 5. EMP Temperature Results STS 61-C, January, 1986

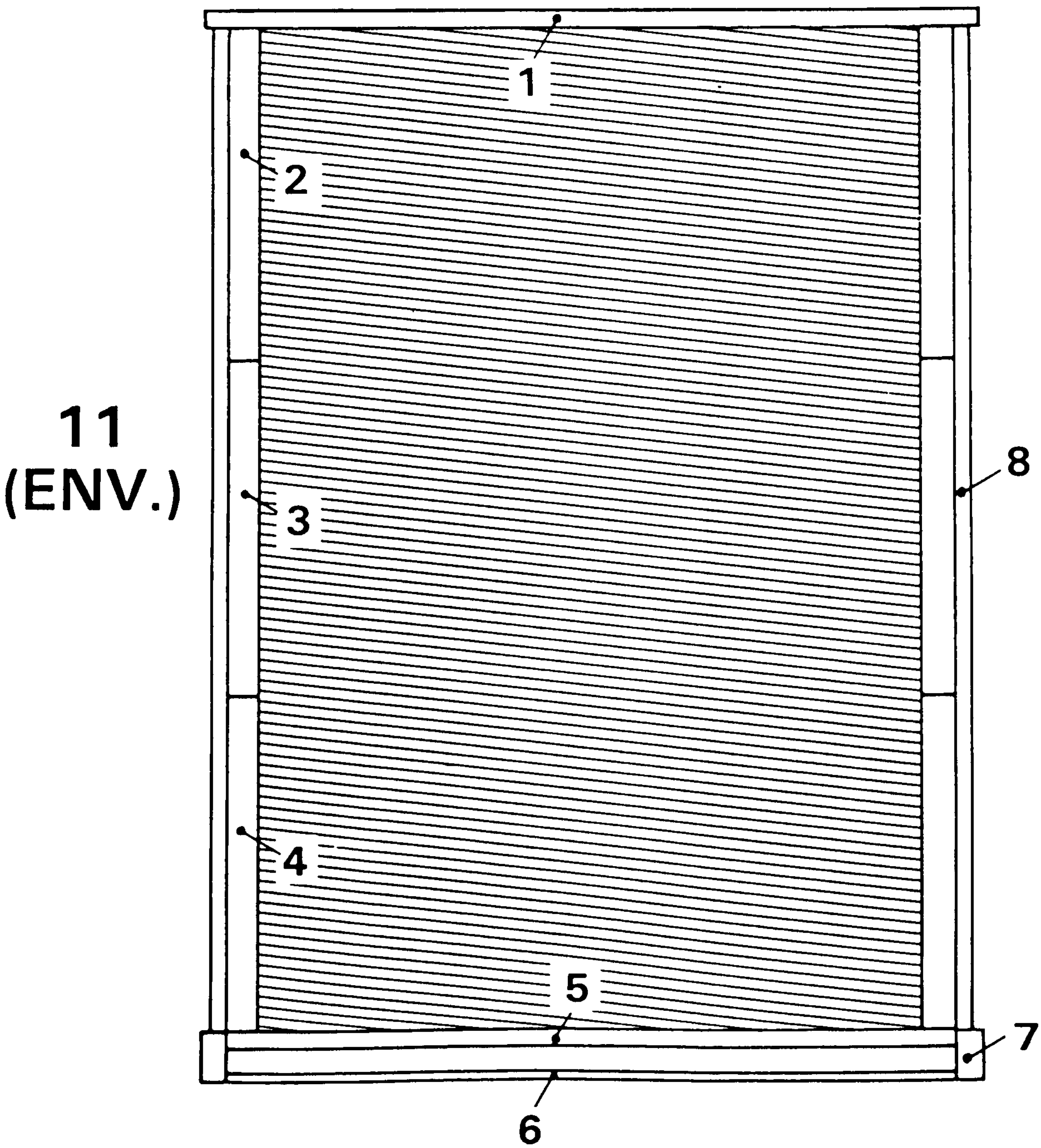

Figure 6. GAS 5 ft^3 Container Thermal Model (without Insulated End Cap)

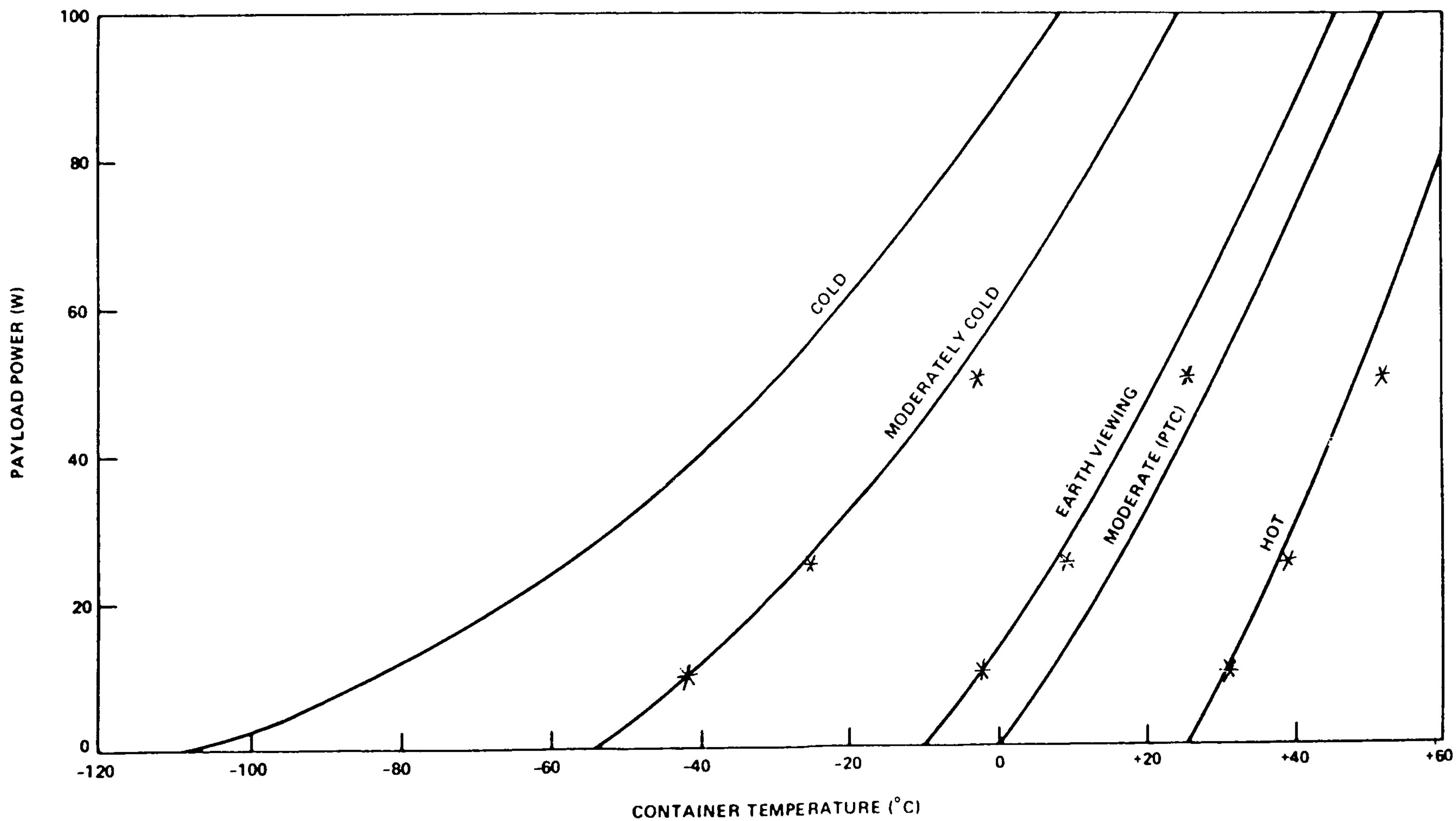

Figure 7. Get Away Special Small Self-contained Payloads (5 ft^3 Container without Insulated End Cap)

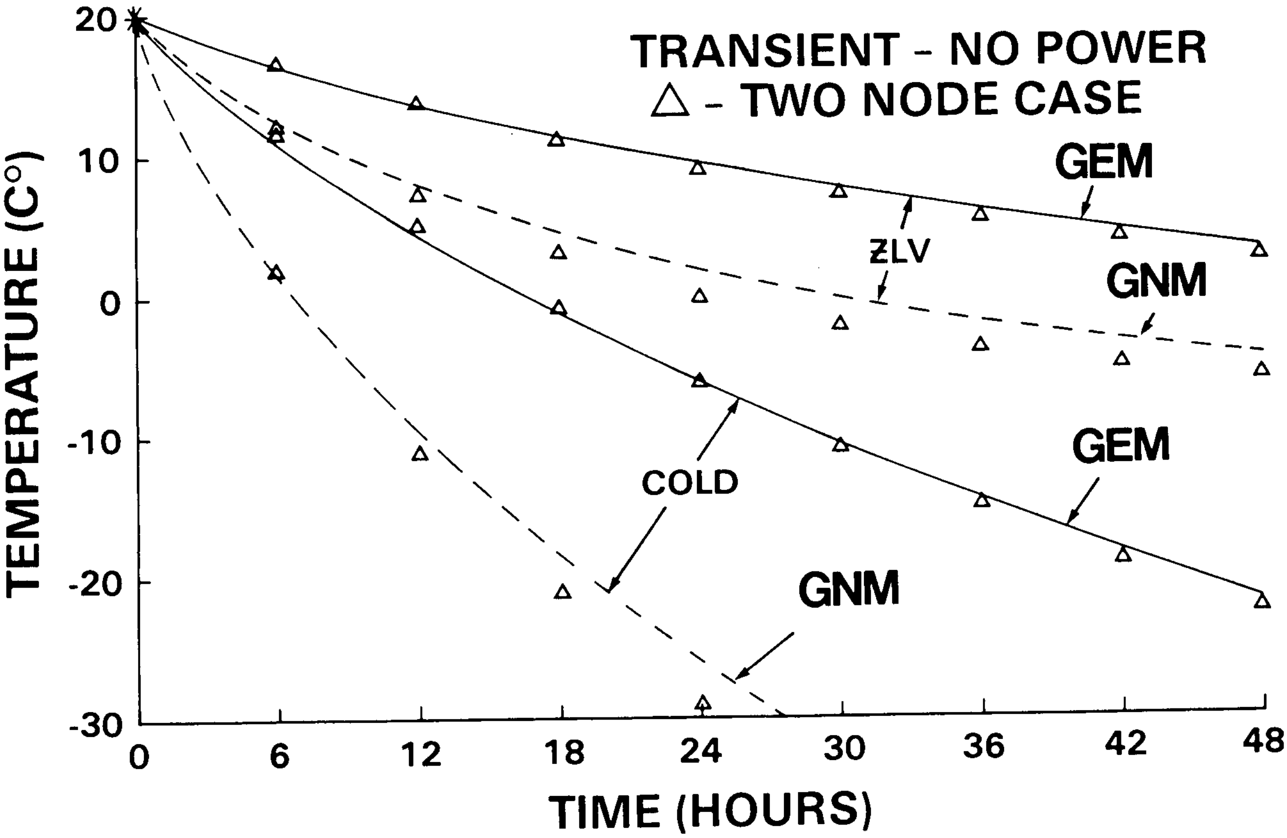

Figure 8. GAS Models with 165# Payload Container Temperatures