22
2/5/79
4 to MT 15

MASTER

BDX-613-2034 (Rev.)

PREDICTING THE THERMAL RESPONSE OF AN
ENCAPSULATION PROCESS

By J. H. Richardson

Published January 1979

Topical Report

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$3.00
 Paper Copy \$4.50

**PREDICTING THE THERMAL RESPONSE OF AN
ENCAPSULATION PROCESS**

By J. H. Richardson

Published January 1979

Topical Report

J. H. Richardson, Project Leader

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Communications Services

**Kansas City
Division**

PREDICTING THE THERMAL RESPONSE OF AN ENCAPSULATION PROCESS

BDX-613-2034 (Rev.), Topical Report, January 1979

Prepared by J. H. Richardson

An evaluation of the thermal behavior of an electronic component assembly has indicated a need for increasing the temperature-soak time prior to the electrical testing of potted and unpotted assemblies. The preheat time before encapsulation was found adequate, and the internal mold temperature proved to be within desirable limits during encapsulation. Use of the automatic encapsulation system prevents excessive heat loss during the potting operation and provides a 50 percent savings in time. A movie showing the encapsulation of a nonfunctional unit in a clear container revealed the formation of three types of voids. Corrective action to eliminate the voids is described.

CPD-TR8/A

This report was prepared as an account of work sponsored by the United States Government. Neither the United States, nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United States
Department of Energy under Contract Number
DE-AC04-76-DP00613

CONTENTS

Section	Page
SUMMARY.	7
DISCUSSION	8
SCOPE AND PURPOSE.	8
ACTIVITY	8
<u>Background</u>	8
<u>Investigation</u>	8
<u>Data Analysis</u>	10
<u>Encapsulation Movie</u>	20
ACCOMPLISHMENTS.	22
APPENDICES	
A. GRAPHS OF THERMOCOUPLE RESPONSE FROM UNPOTTED ECA.	23
B. GRAPHS OF THERMOCOUPLE RESPONSE FROM POTTED ECA.	32
C. ENCAPSULATION-PROCESS FLOWCHART.	41
DISTRIBUTION	43

ILLUSTRATIONS

Figure		Page
1	Maximum and Minimum Recorded Temperatures During Encapsulation Cycle	16
A-1	Response From Unpotted ECA Thermo- couple 1	24
A-2	Response From Unpotted ECA Thermo- couple 2	25
A-3	Response From Unpotted ECA Thermo- couple 3	26
A-4	Response From Unpotted ECA Thermo- couple 4	27
A-5	Response From Unpotted ECA Thermo- couple 5	28
A-6	Response From Unpotted ECA Thermo- couple 6	29
A-7	Response From Unpotted ECA Thermo- couple 7	30
A-8	Response From Unpotted ECA Thermo- couple 8	31
B-1	Response From Potted ECA Thermo- couple 1	33
B-2	Response From Potted ECA Thermo- couple 2	34
B-3	Response From Potted ECA Thermo- couple 3	35
B-4	Response From Potted ECA Thermo- couple 4	36
B-5	Response From Potted ECA Thermo- couple 5	37
B-6	Response From Potted ECA Thermo- couple 6	38

B-7	Response From Potted ECA Thermo- couple 7	39
B-8	Response From Potted ECA Thermo- couple 8	40
C-1	Encapsulation-Process Flowchart.	42

TABLES

Number		Page
1	Thermocouple Locations.	10
2	Temperature Cycling of Unpotted Electronic Component Assemblies.	10
3	Run-1 Temperature-Cycling Results for Unpotted ECA	11
4	Run-2 Temperature-Cycling Results for Unpotted ECA	12
5	Run-3 Temperature-Cycling Results for Unpotted ECA	13
6	Encapsulation-Cycle Data	14
7	Run-1 Temperature-Cycling Results for Potted ECA	17
8	Run-2 Temperature-Cycling Results for Potted ECA	18
9	Run-3 Temperature-Cycling Results for Potted ECA	19
10	Original Thermal-Cycling Schedule	20

SUMMARY

This study was initiated to verify the basic engineering assumptions that had been made regarding the encapsulation and thermal cycling of an electronic component assembly (ECA). The results of the study then were used in the preparation of a process flowchart to be used as a guide during product development. The study was divided into two parts, each of which was intended to check a specific problem area.

For the first part of the study, a nonfunctional ECA was built, and thermocouples were attached at strategic locations in each molded cavity. This unit was used to determine soak times at temperatures of -54, -40, and +71°C (-65, -40, and +160°F) before electrical testing, and preheat and cool-down times during encapsulation. The unit also was used to monitor the internal heat buildup caused by the exothermic action of the foam during potting.

The second part of the study consisted of filming the encapsulation of a nonfunctional unit assembled inside a special transparent container. The completed film provides a permanent, continuous record that indicates the location of and manner in which voids are formed during encapsulation.

The two ECAs in this study are the first units encapsulated entirely by the automatic encapsulation system (AES). These units confirmed the value of the AES system. Processing time was reduced by approximately 50 percent.

Although unpotted units previously had been thought to attain equilibrium temperature in approximately half the time required for potted units, this study showed the required temperature-soak times to be virtually identical. As a result, all soak times for the ECA were increased from 30 to 200 percent over the original estimates, and the preheat and cool-down times also were extended. As anticipated, the highest internal temperature (97°C, or 207°F) occurred in the largest open area of the unit, thus confirming the mass-dependency of the exothermic action of the foam.

The movie of the encapsulation process showed the formation of air voids in three areas: one was under a curved surface; another occurred beneath the connector; and the third occurred between a component and the wall of the container. These problems were corrected by tilting the unit during encapsulation to remove the bubble under the connector, by adding another vent hole in the curved area, and by increasing the clearance between the component and the wall of the container.

DISCUSSION

SCOPE AND PURPOSE

This study was initiated to characterize the response of an electronic component assembly (ECA) to temperature gradients before, during, and after encapsulation. The data obtained were used to verify temperature-soak times prior to electrical testing, and to predict the value and location of the maximum internal temperature of the unit during encapsulation.

A movie was made of the encapsulation of a nonfunctional unit within a transparent container rather than the specified opaque container. The film provides a permanent record of how each cavity in the container filled.

ACTIVITY

Background

As with the development of most new electronic assemblies, certain basic engineering assumptions were made regarding the encapsulation and thermal cycling of the ECA. Included were assumptions pertaining to the location of fill and vent holes for encapsulation, the temperature-soak times prior to the electrical testing of both potted and unpotted assemblies, the preheat time prior to encapsulation, the cool-down time prior to mold removal after encapsulation, and even the internal temperature of the assembly during encapsulation.

These assumptions, although necessary at the beginning of any new project, represent only an educated guess. Consequently, after the design of an assembly has been fixed, and before full-scale production has begun, engineering assumptions must be verified so that any necessary corrections can be made. A two-part processing study was conducted. The data collected, in addition to specifically characterizing this ECA, were used in the development of an encapsulation process flowchart to be used by both product and process engineers as a guide during the developmental stages of such assemblies.

Investigation

For the first part of the study, eight thermocouples were attached to a nonfunctional unit at strategic locations within each molded cavity to monitor the temperature.

Dummy switches and potted circuit boards without components were used to duplicate, wherever possible, the correct internal volume and material composition of an actual assembly. The locations of the thermocouples are described in Table 1.

This assembly was used to determine soak times for both potted and unpotted units before electrical testing, and the preheat and cooling times during encapsulation. The same unit also was used to monitor the internal heat buildup caused by the exothermic action of the foam during potting. The ECA, potted and unpotted, was subjected to three cycles which consisted of varying the soak times at -43, -54, ambient temperature, and +71°C (-45, -65, ambient temperature, and +160°F) (Table 2). Three different ovens were used to maintain each of the controlled soak temperatures.

Prior to temperature cycling, the lid was installed on the ECA, and the entire unit was put inside a shielded box. Before low-temperature cycling, the shielded box, in turn, was placed inside a large plastic bag which then was sealed and backfilled with dry nitrogen to prevent moisture condensation during warmup. Only the bag was removed before high-temperature cycling. Data obtained from the cycles are in Tables 3 through 5, and plotted graphs of the results are in Appendix A.

After the unpotted assembly had been thermally cycled, it was encapsulated according to the standard production technique, except that the automated encapsulation system was used instead of a hand mix. Data on the encapsulation cycle are in Table 6, and Figure 1 is a plotted graph of the maximum and minimum temperatures recorded during encapsulation.

Following encapsulation, the potted assembly was thermally cycled exactly the same as the unpotted assembly, with the following three exceptions:

- To save time, a 4-hour ambient soak was used on Run 3.
- Units were considered stabilized if the temperature was within the predicted tolerance ($\pm 3^{\circ}\text{C}$, or $\pm 5^{\circ}\text{F}$).
- Final cool-down was monitored on Run 2 only.

Data obtained during the temperature cycles of the potted assemblies are in Tables 7 through 9, and plotted graphs of the results are in Appendix B.

Table 1. Thermocouple Locations

Thermocouple Designation	Description of Location
1	Midway down between the inside barrier.
2	Between two switches.
3	Embedded in PWA-3 module foam.
4	Embedded in PWA-4 module transformer.
5	Embedded in tube cavity.
6	Embedded in SA2296 capacitor C1.
7	Located in cavity of a large component.
8	Embedded in PWA-8 module transformer.

Table 2. Temperature Cycling of Unpotted Electronic Component Assemblies

Run	Temperature at Stabilization		Ambient Soak Time (Hours)	Temperature at Stabilization		Cool-Down
	°C	°F		°C	°F	
1	-43	-45	1	71	160	Yes
2	-54	-65	1	71	160	No
3	-54	-65	5	71	160	Yes

Data Analysis

A number of conclusions were drawn from this study regarding the ovens used for thermal cycling, the times required for temperature stabilization, and the location of critical "cold" spots within the assembly. The variation in the time required for stabilization, caused by the ovens, was immediately obvious.

Table 3. Run-1 Temperature-Cycling Results for Unpotted ECA*

Thermo-couple	Time to -40°C** (Hours)	Time From -40 to -42°C** (Hours)	ΔTemperature After 1 Hour at Room Temperature (°C; °F)	Time to 68°C** (Hours)	Time From 68 to 71°C** (Hours)	Time to Room Temp (Hours)
1	7	5	30 (53)	5	3	6
2	7	5		6	3	6
3	5	6	61 (110)	4	3	5
4	6	5	42 (75)	5	3	5
5	7	4	42 (75)	5	3	5
6	7	5	33 (60)	5	3	6
7	6	5	42 (75)	5	3	6
8	5	6	39 (70)	5	2	5
Average	6.3	5.1	41 (74)	5	2.9	5.5

*Run 1: Room temperature to -43°C (-45°F), plus 1-hour room-temperature soak, plus stabilization at 71°C (160°F), plus cool-down to room temperature.

**Temperature equivalents:

-°C	-°F	+°C	+°F
-42	-44	68	155
-40	-40	71	160

Table 4. Run-2 Temperature-Cycling Results for Unpotted ECA*

Thermo- couple	Time to -51°C** (Hours)	Time From -51 to -54°C** (Hours)	ΔTemperature After 1 Hour at Room Temperature (°C; °F)		Time to 68°C** (Hours)	Time From 68 to 71°C** (Hours)
1	6	3	22	(39)	6	3
2	7	3	9	(16)	6	3
3	5	2	49	(88)	4	3
4	5	2.5	31	(56)	5	3
5	6	2.5	32	(58)	5	3
6	6	2.5	25	(45)	6	3
7	6	2.5	31	(55)	5	3
8	5	2	28	(51)	5	2
Average	5.8	2.5	28	(51)	5.3	2.9

*Run 2: Room temperature to -54°C (-65°F), plus 1-hour room-temperature soak, plus stabilization at 71°C (160°F).

**Temperature equivalents:

-°C	-°F	+°C	+°F
-54	-65	68	155
-51	-60	71	160

Table 5. Run-3 Temperature-Cycling Results for Unpotted ECA*

Thermo-couple	Time to -51°C** (Hours)	Time From -51 to -54°C** (Hours)	ΔTemperature After 5 Hours at Room Temperature (°C; °F)	Time to 68°C** (Hours)	Time From 68 to 71°C** (Hours)	Time to Room Temp (Hours)
1	7	5	73 (131)	6	5	8
2	8	4	72 (129)	7	4	9
3	6	4	76 (137)	5	5	8
4	7	4	75 (135)	6	4	8
5	7	4	74 (133)	6	4	10
6	7	4	73 (132)	6	4	10
7	7	4	73 (132)	6	4	10
8	6	5	75 (134)	6	4	9
Average	6.9	4.3	74 (133)	6	4.3	9

*Run 3: Room temperature to -54°C (-65°F), plus 5-hour room-temperature soak, plus stabilization at 71°C (160°F), plus cool-down to room temperature.

**Temperature equivalents:	-°C	-°F	+°C	+°F
	-54	-65	68	155
	-51	-60	71	160

Table 6. Encapsulation-Cycle Data

Thermo- couple	Preheat*		Room-Temperature Soak**			
	Time to 46°C†† (Hours)	Time From 46 to 48°C†† (Hours)	Temperature After 10 min at Room Temperature (°C; °F)		Temperature After 20 min at Room Temperature (°C; °F)	
1	1.5	1.5	61	(142)	62	(144)
2	3	1	61	(141)	63	(146)
3	1.5	1.5	77	(170)	72	(162)
4	2	1	79	(174)	73	(164)
5	3	1	62	(144)	64	(148)
6	3	1	61	(142)	62	(144)
7	3	1	94	(202)	79	(174)
8	2	2	54	(130)	57	(134)
Average	2.4	1.25	68.6	(156)	66	(152)
	Cure***		Cool-Down†			
	Time to 77°C†† (Hours)	Time at Cure Temp (Hours)	Time to 49°C†† (Hours)	Temperature After 1 Hour at Room Temperature (°C; °F)		
1	3	5	2	58	(137)	
2	3	5	2	63	(146)	
3	3	5	2	57	(134)	
4	3	5	2	62	(144)	
5	3	5	2	63	(146)	
6	4	4	3	67	(152)	
7	3	5	2	64	(147)	

Table 6 Continued. Encapsulation-Cycle Data

Thermo-couple	Cure***		Cool-Down†		Temperature After 1 Hour at Room Temperature (°C; °F)
	Time to 77°C†† (Hours)	Time at Cure Temp (Hours)	Time to 49°C†† (Hours)		
8	3	5	2	60	(140)
Average	3.1	4.9	2.1	62	(143)

*Step 1: Preheat to 49 ±3°C (120 ±5°F).

Step 2: Encapsulate (room temperature).

**Step 3: Soak 20 minutes at room temperature.

***Step 4: Cure 8 hours at 79 ±3°C (175 ±5°F).

†Step 5: Cool-down before mold removal.

††Temperature equivalents:		°C	°F	°C	°F
		46	115	49	120
		48	119	77	170

The assembly area has two types of low-temperature chambers or ovens. The basic difference is internal capacity. The large oven required an average of 6.3 hours to attain a temperature within 3°C (5°F) of the -43°C (-45°F) set point, and an additional 5.1 hours to stabilize at -42°C (-44°F). The smaller oven averaged only another 0.4 hour to attain a temperature of -51°C (-60°F) from room temperature, and only 3.5 hours to stabilize at -54°C (-65°F). Although these differences cannot be compared directly because two different temperatures are involved, if the relative temperature drop is considered, the assembly temperature dropped approximately 5.5°C (10°F) per hour in the larger oven versus 8°C (14°F) per hour in the smaller oven.

If use of the large oven is necessary to meet the production schedule, the soak-time requirements should reflect the additional time required for stabilization. If the extra capacity is not needed, consideration should be given to either modifying the oven to make it more efficient or replacing it.

The second problem encountered in the study was that every step of the process took longer than anticipated. The original thermal-cycling schedule is in Table 10. The data that were obtained in

Figure 1. Maximum and Minimum Recorded Temperatures During Encapsulation Cycle

Table 7. Run-1 Temperature-Cycling Results for Potted ECA*

Thermo-couple	Time to -40°C** (Hours)	Time From -40 to -43°C** (Hours)	ΔTemperature After 1 Hour at Room Temperature (°C; °F)	Time to 68°C** (Hours)
1	7	3	15 (27)	5
2	7	3	8 (15)	6
3	5	3	37 (67)	3
4	6	2	37 (66)	5
5	7	2	22 (39)	5
6	7	2	18 (29)	6
7	7	2	20 (36)	6
8	6	2	23 (42)	5
Average	6.5	2.4	22 (40)	5.1

*Run 1: Room temperature to -43°C (-45°F), plus 1-hour room-temperature soak, plus stabilization at 71°C (160°F).

**Temperature equivalents:

°C	°F
-43	-45
-40	-40
71	160

the investigation indicate that the unpotted ECA needs at least 8 hours to stabilize within 3°C (5°F) of a low-temperature set point, and approximately 7 hours to stabilize within 3°C of a high-temperature set point, regardless of the length of the ambient-soak time. Similarly, the potted assembly needs 9 hours at the low temperature and seven hours at the elevated temperature to stabilize within 3°C of the set point.

From these results, it is apparent that there is little difference in the time required for temperature stabilization of potted and unpotted assemblies and that the existing soak times are insufficient. Only the mold-preheat time has proven to be adequate.

Table 8. Run-2 Temperature-Cycling Results for Potted ECA*

Thermo- couple	Time to -51°C** (Hours)	Time From -51 to -54°C** (Hours)	ΔTemperature After 1 Hour at Room Temperature (°C; °F)		Time to 68°C** (Hours)	Time to Room Temp (Hours)
1	7	3	37	(67)	5	6
2	7	3	19	(34)	7	7
3	5	2	62	(112)	4	5
4	6	2	42	(76)	5	6
5	6	3	42	(75)	6	6
6	7	2	31	(56)	6	7
7	6	4	40	(72)	6	7
8	5	3	42	(75)	5	5
Average	6.1	2.8	39	(70.9)	5.5	6.5

*Run 2: Room temperature to -54°C (-65°F), plus 1-hour room-temperature soak, plus stabilization at 71°C (160°F), plus cool-down to room temperature.

**Temperature equivalents:

°C	°F
-54	-65
-51	-60
68	155

The last major conclusion that was drawn from the study involved the location of the thermocouples. In placing the thermocouples, an attempt was made to identify areas where temperature response might pose a specific kind of problem. For example, three switches in the ECA represent large metallic masses, whereas the PWA-3s, -4s, and -8s, foamed as subassemblies, are well insulated against temperature change. The open area for the cavity in a large component was chosen as the location for a thermocouple because it represented the largest mass of foam.

The fastest response to temperature change was indicated by Thermocouple 3, followed by Thermocouples 8 and 4. All three of these thermocouples were embedded in printed wiring assemblies,

Table 9. Run-3 Temperature-Cycling Results for Potted ECA*

Thermo-couple	Time to -51°C** (Hours)	Time From -51 to -54°C** (Hours)	ΔTemperature After 4 Hours at Room Temperature (°C; °F)	Time to 68°C** (Hours)
1	9	4	66 (118)	3
2	9	4	62 (111)	4
3	7	5	72 (129)	2
4	7	5	68 (123)	3
5	8	4	66 (118)	4
6	8	4	63 (114)	4
7	8	4	66 (118)	4
8	7	5	70 (126)	3
Average	7.9	4.4	67 (119.6)	3.4

*Run 3: Room temperature to -54°C (-65°F), plus 4-hour room-temperature soak, plus stabilization at 71°C (160°F).

**Temperature equivalents: °C °F

-54	-65
-51	-60
68	155

and they were relatively close to the outside of the container. Thermocouple 2, located in the center area of the assembly between the switches, had the slowest response to both heating and cooling.

The highest exothermic temperature, which occurred within 10 minutes after the filling of the unit, was indicated by Thermocouple 7, in the component cavity. This reading confirmed the mass-dependency of the exothermic action of foam encapsulants. The next two highest temperatures were recorded by Thermocouples 3 and 4, which correspond to Printed Wiring Assemblies 3 and 4. The maximum temperature increase was 39°C (70°F). The minimum change was recorded by Thermocouple 8 in PWA-8 transformer.

Table 10. Original Thermal-Cycling Schedule

ECA	Thermal-Cycle Step	Time (Hours)
Unpotted	-43°C (-45°F) Soak	4
	71°C (160°F) Soak	2
Encapsulation	Mold Preheat at 49°C (120°F)	2
	Internal Temperature Rise	
	Cool-Down to Below 66°C (150°F)	1
Potted Final	-43°C (-45°F) Soak	6
	71°C (160°F) Soak	6

Excessive exothermic action is undesirable because of possible damage to heat-sensitive components, while insufficient action may indicate inadequate cure or reduced physical properties of the foam. Because the exothermic action is both mass- and temperature-dependent, the time required to fill a unit is important. If the mold cools too much before the filling is completed, it acts as a heat sink and draws heat away from the encapsulant. The viscosity of the foam then increases, and the material does not flow properly into constricted areas.

A hand-mix-and-fill for this ECA normally requires approximately 1 hour; because the automatic encapsulation system was used to fill the unit used in the investigation, the entire operation was completed within 1/2 hour. Not only did this represent a 50-percent savings in flow time, but none of the cavities cooled enough to prevent proper foaming.

Encapsulation Movie

Voids in encapsulated assemblies may be caused by three basic problems.

- Flat surfaces such as printed circuit boards or connectors prevent air bubbles from rising to the top.
- Constricted areas prevent the flow of the viscous foam.
- Fill and vent holes are improperly located.

Voids in an assembly are a particularly troublesome problem since they represent areas that are unprotected from thermal and mechanical shock. In addition, voids in high-voltage areas can cause arcing failures. Because the foam is not visible, there is no way to check each production unit for the presence of voids. For this reason, an assembly sometimes may be encapsulated in a transparent container to identify any problem areas.

The second part of this study consisted of making a movie showing the encapsulation of a unit assembled inside a special, clear container. Although units other than this have been encapsulated in clear containers at Bendix Kansas City, this is the first time that a movie has been made of the entire encapsulation process. Normally, the potting of a clear container is observed by the process engineer and possibly the product engineer who then check the cured unit for voids and other problems. With no visual record of the encapsulation, justifying requests for changes in design, assembly, or encapsulation procedures often has been difficult.

The film provided a continuous, permanent record of the encapsulation while showing the location and manner in which voids may form in this assembly. The film also can be used as a guide for the development of future assemblies.

Similar to the unit used for the thermal-response study, the ECA used for the movie contained dummy switches and printed circuit boards without components. To maximize visibility of the internal parts, the encapsulated printed circuit boards were coated with a dark blue-tinted epoxy.

Although no encapsulation problems had been anticipated, several did occur. Although from a production standpoint these problems were undesirable, they proved beneficial in attaining the objectives of this study by providing visual evidence of the void-formation mechanism. A study of the entire movie sequence reveals various stages in the formation of all three previously described types of voids. The void under the connector was caused by the entrapment of an air bubble under the flat part of the connector; the voids along the potting dam on a large component were caused by interference between the dam and the container walls; and finally, a void which would have occurred under the curved portion of the switch cavity because of improper placement of the vent holes was anticipated and avoided by changing the vent-hole location before this test was conducted.

All of the problems revealed in the movie have been corrected. Tilting the mold during filling helped to alleviate voids under the flat surfaces; more accurate placement of the dam with respect to the container wall helped eliminate the voids in that area; and relocating the vent hole prevented the void in the switch cavity.

As a result of this study, a flowchart (Appendix C) of the encapsulation process was prepared to serve as a guide for interaction between the product and process engineers during both the development of the assembly and the establishment, by drawing, of the encapsulation procedure. Because considerable feedback is required at each intermediate step, the flowchart does not represent a straight-line course from design, through development, to production. Encouragement of necessary feedback is one of the primary intents of the flowchart.

ACCOMPLISHMENTS

Probably the most important of several major accomplishments achieved through this study was the obtaining of precise data on the thermal response of this ECA. Without exception, the estimated thermal-soak times prior to electrical testing were shown to be inadequate. In response to this finding, all soak times have been increased from 30 to 200 percent to ensure an accurate electrical test environment.

The study also confirmed the acceptability of the encapsulation procedure. Preheat times were proven adequate, and the internal mold temperature was shown to be within desirable limits during encapsulation. A secondary benefit was realized through the demonstrated effectiveness of the automatic encapsulation system. Encapsulation time was cut in half, thereby reducing the detrimental effect of mold cool-down on product reliability.

The second major accomplishment of this study was the filming of an ECA encapsulation. Three previously unknown problem areas involving air voids were identified, and suitable processing corrections have been made. The movie also has been effective in educating product and processing engineers about design problems that affect encapsulation.

The last major accomplishment of this study was the development of an encapsulation process flowchart. Through the use of this flowchart, product and process engineers now have a guide for ensuring that the encapsulation process has been properly developed and thoroughly evaluated.

Appendix A

GRAPHS OF THERMOCOUPLE RESPONSE FROM UNPOTTED
ECA

Figure A-1. Response From Unpotted ECA Thermocouple 1

Figure A-2. Response From Unpotted ECA Thermocouple 2

Figure A-3. Response From Unpotted ECA Thermocouple 3

Figure A-4. Response From Unpotted ECA Thermocouple 4

Figure A-5. Response From Unpotted ECA Thermocouple 5

Figure A-6. Response From Unpotted ECA Thermocouple 6

Figure A-7. Response From Unpotted ECA Thermocouple 7

Figure A-8. Response From Unpotted ECA Thermocouple 8

Appendix B

GRAPHS OF THERMOCOUPLE RESPONSE FROM POTTED ECA

Figure B-1. Response From Potted ECA Thermocouple 1

Figure B-2. Response From Potted ECA Thermocouple 2

Figure B-3. Response From Potted ECA Thermocouple 3

Figure B-4. Response From Potted ECA Thermocouple 4

Figure B-5. Response From Potted ECA Thermocouple 5

Figure B-6. Response From Potted ECA Thermocouple 6

Figure B-7. Response From Potted ECA Thermocouple 7

Figure B-8. Response From Potted ECA Thermocouple 8

Appendix C

ENCAPSULATION-PROCESS FLOWCHART

Figure C-1. Encapsulation-Process Flowchart

DISTRIBUTION

	Copy
R. Bulcock, DOE-KCAO, 1D49	1
H. M. Barnett, SLA	2
D. Carnicom, SLA	3
G. L. Cessac, SLA	4
J. G. Curro, SLA	5
G. E. Easley, SLA	6
C. B. McCampbell, SLA	7
A. J. Quant, SLA	8
P. B. Rand, SLA	9
T. J. Williams, SLA	10
J. E. Long, D/531, 1B46	11
H. T. Barnes, D/554, BD50	12-13
L. Stratton, D/554, 2C44	14-16
R. P. Frohmberg, D/800, 2A41	17
W. H. Deterding, D/814, 2C43	18
R. L. Sadler, D/814, 2C43	19
C. H. Smith, Jr., D/814, XD43	20
J. W. Steele, D/814, 2C43	21
T. A. Wiley, D/842, MD40	22
Q. S. Bastin, D/846, MF39	23
J. J. Mosakowski, D/846, MF39	24
W. J. Harte, D/862, 2D39	25
R. E. Kessler, D/865, 2C40	26
E. R. Brown, D/867, MF39	27
R. C. Douglas, D/867, MF39	28
R. J. Powell, D/867, MF39	29
D. K. Rasmussen, D/867, MF39	30
J. H. Richardson, D/867, MF39	31-35
W. R. Sprague, D/867, MF39	36

BDX-613-2034 (Rev.)

PREDICTING THE THERMAL RESPONSE OF AN ENCAP-
SULATION PROCESS, J. H. Richardson, Topical,
January 1979.

An evaluation of the thermal behavior of an electronic component assembly has indicated a need for increasing the temperature-soak time prior to the electrical testing of potted and unpotted assemblies. The preheat time before encapsulation was found adequate, and the internal mold temperature proved to be within desirable limits during encapsulation. Use of the automatic encapsulation system prevents

PLASTICS: Thermal Response of Urethane Foam

PREDICTING THE THERMAL RESPONSE OF AN ENCAP-
SULATION PROCESS, J. H. Richardson, Topical,
BDX-613-2034 (Rev.), January 1979.

An evaluation of the thermal behavior of an electronic component assembly has indicated a need for increasing the temperature-soak time prior to the electrical testing of potted and unpotted assemblies. The preheat time before encapsulation was found adequate, and the internal mold temperature proved to be within desirable limits during encapsulation. Use of the automatic encapsulation system prevents

PREDICTING THE THERMAL RESPONSE OF AN ENCAP-
SULATION PROCESS, J. H. Richardson, Topical,
BDX-613-2034 (Rev.), January 1979.

An evaluation of the thermal behavior of an electronic component assembly has indicated a need for increasing the temperature-soak time prior to the electrical testing of potted and unpotted assemblies. The preheat time before encapsulation was found adequate, and the internal mold temperature proved to be within desirable limits during encapsulation. Use of the automatic encapsulation system prevents

excessive heat loss during the potting operation and provides a 50 percent savings in time. A movie showing the encapsulation of a nonfunctional unit in a clear container revealed the formation of three types of voids. Corrective action to eliminate the voids is described.

excessive heat loss during the potting operation and provides a 50 percent savings in time. A movie showing the encapsulation of a nonfunctional unit in a clear container revealed the formation of three types of voids. Corrective action to eliminate the voids is described.

excessive heat loss during the potting operation and provides a 50 percent savings in time. A movie showing the encapsulation of a nonfunctional unit in a clear container revealed the formation of three types of voids. Corrective action to eliminate the voids is described.