An apparent anomaly is visible in Fig. 3d at the point where $t_1 = 5t_0$; the curve takes an uneven jump because of the particular locations of the recovery sites used. These recovery sites generate belts[2] which are almost coincidently overlapping on the fifth waiting orbit. For example, the belts of the fifth waiting orbit of Tachikawa, Hawaii, and Hamilton fall on the belts of the first waiting orbit of Hamilton, Kindley, and Lajes, respectively, thus resulting in a big jump in p and p_{SR} for redundant access.

An assured rescue represents a desired goal of all rescue operations. The required t_1 for this condition is shown in Fig. 4 as a monotonically decreasing function of the increasing search radius. The results of assured rescue for the case of single access and day-night retrieval are given by the lower curve. As shown by the middle curve, the penalty of redundant access is found to be relatively modest, amounting to one or two additional waiting orbits for any search radius larger than 400 naut miles. The penalty of day-only retrieval, on the other hand, is much larger as shown by the upper curve. The day-only retrieval is based on an average December day which imposes the most severe local time constraint among all the months in a year.

Concluding Remarks

The results of this analysis as presented in this Note and the more extensive ones in Refs. 1 and 4, lead to a number of significant observations:

1) Since the reliability of water recovery operations can be expected to be high, the over-all rescue success is very strongly affected by the rescue probability p_{SR} as defined in this analysis.

2) Although the more preferred means of retrieval from the standpoint of astronaut comfort and safety may be with the refueled HH-53 helicopter, a significant reduction in p_{SR} may occur.

3) A significant difference in p_{SR} exists between day-only and day-night recovery. Adverse weather or sea states can reduce the p_{SR} as evidenced by the difference between single and redundant access. For assured rescue, the penalty of redundant access amounts to an additional one or two waiting orbits.

4) The provision for a variable takeoff delay can improve p_{SR}, but only if t_1 is greater than 6 orbital periods. An aircraft takeoff delay, during which the spacecraft is permitted to deorbit, can cause very serious reductions in p_{SR}. A more desirable approach would be to provide for an intentional deorbit lag to compensate for the time of aircraft takeoff delay, t_d.

5) The lower extreme of allowable water immersion time, $t_{w1} = 0$, refers to the case in which the search aircraft must be at the expected splash point before the spacecraft. This is a necessary requirement for a successful rescue being made by the air-pickup mode. Although this condition may not be necessary for the water pickup mode, the chances of personnel on-board the aircraft visually locating the returning spacecraft are improved. The second extreme of $(t_{w1} - t_d) = R/V_a$ hr refers to a t_{w1} that will increase p_{SR} to its maximum. Increasing t_{w1} beyond this point does not increase p_{SR}.

6) Sufficient t_{w1} and t_1 must be provided in the design of spacecraft for an assured rescue ($p_{SR} = 1.0$). In addition, a high p_{SR} for $t_{w1} = 0$ is very desirable.

References

[1] Chu, S. T. and Nagy, A. R., Jr., "Probability of Rescue Success of Emergency Return of Spacecraft," TR-0066(5758-06)-1, (in preparation), Aerospace Corp., El Segundo, Calif.

[2] Chu, S. T. and Davis, K. S., "Multiple Site Return Probability of Spacecraft from Circular and Elliptical Orbits," *Journal of Spacecraft and Rockets*, Vol. 5, No. 4, April 1968, pp. 419–424.

[3] Chu, S. T. and Nagy, Jr., A. R., "Inclusion of Time Constraints and Redundant Access on Spacecraft Return Probabilities by the Concept of Borel Set," *Journal of Spacecraft and Rockets*, Vol. 6, No. 6, June, 1969, pp. 667–772.

[4] Nagy, Jr., A. R., "Orbital Return Probabilities of Escape Spacecraft," TOR-0200(4525-04)-2, Feb. 1969, Aerospace Corp., El Segundo, Calif.

Effects of Simulated Venusian Atmosphere on Polymeric Materials

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POLYMERIC materials (plastics and rubbers) serve as electrical and thermal insulators, protective and structural materials, vibration dampeners, adhesives, etc., on spacecraft and planetary landing probes. In 1967, Venera 4 entered Venus's atmosphere and sent back information about temperature, pressure, and atmospheric composition, as it descended to the surface,[1,2] and Mariner V flew by Venus and reported back atmospheric data, among other information.[3] This Note reports results of exposure of polymeric materials to a simulation of the Venusian atmosphere, which was reported to be composed as follows, in weight percentages: CO_2, 90 ± 10 (probably >90); O_2, 0.4–1.6 (probably ~1); N_2, <7 (probably <2.5); and H_2O, 0.1–0.7. The effects of the simulated "Venus" atmosphere, also are compared with those of air and nitrogen at 550°F and ca. 18 atm.

Experimental

The simulation chamber was a 10-in.-diam by 12-in.-long stainless steel, cylindrical tank. Ports on each side of the cylinder served as gas inlet and outlet. Stainless-steel sheathed, copper-constantan thermocouples were inserted near each port. The front cover plate, as originally supplied by the manufacturer, had an asbestos-graphite gasket seal which proved inadequate and was replaced by a ⅛-in. thick Teflon disk with the same diameter as the cover plate. The disk could be used for several runs at the test conditions, without significant distortion or deterioration. Test specimens of polymeric materials were placed on two stainless steel shelves within the cylindrical tank.

The simulator was placed in a Conrad environmental chamber capable of heating it to the desired temperature and holding the temperature within the specified tolerance. It was then evacuated three successive times and purged with the test gas to eliminate residual air. During the fourth and final purging the gas pressure was brought to 50% of the required value, using the following mixture (wt %): CO_2, 96.7–99.5; H_2O, 0.1–0.7; O_2, 0.4–1.6; and N_2,

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Table 1 Results of preliminary screening[a] tests

No.	Commercial designation	Material type or specific compound	Functional class	Comments
1	DEN 438/amine	Epoxy Novolac/amine	Adhesive	Test samples came apart
2	RTV 891	Silicone	Adhesive	Very low tensile shear strength
3	RTV 140	Silicone	Adhesive	As in No. 1
4	GP-77	Silicone resin	Coating	Pass
5	Pyre-ML, RK 692	Polyimide	Coating	Pass
6	Viton 77-545	Fluorocarbon	Elastomer	Pass
7	Hadbar 5000/50	Fluorosilicone	Elastomer	Melts
8	PMP 6035	Silicone	Elastomer	Embrittlement
9	Sylgard 184	Silicone	Encapsulant	Softens
10	Kapton 100	Polyimide	Film	Pass
11	EG 758	Epoxy/glass	Reinforced plastic	Charring
12	Fiberglas 91LD	Phenolic/glass	Reinforced plastic	Pass
13	Teflon TFE	Fluorocarbon	Plastic	Pass
14	Teflon FEP	Fluorocarbon	Plastic	Melts
15	Unfilled Exp 820	Polybenzimidazole	Plastic	Softens and deforms
16	PPO	Polyphenylene oxide	Filled plastic	Decomposes

[a] Tests performed after 6 hr exposure to the "Venusian" atmosphere.

Table 2 Original properties and percent retained of mechanical properties after exposure to simulated Venusian atmosphere

	Original properties					Tensile strength, % retained after			Elongation, % retained after			Hardness, % retained after		
Material	Tensile strength, psi	Elongation, %	Hardness, Shore or Rockwell	Scrape adhesion, kg	Tear strength, lb/in.	6 hr	24 hr	72 hr	6 hr	24 hr	72 hr	6 hr	24 hr	72 hr
Teflon TFE	3,200	267	55	...	...	105	106	109	102	104	104	105	101	100
Fiberglas	34,300	1.3	50 Rock D	...	...	94	96	91	97	94	94	106	108	103
Kapton 100	19,200	56 –	...	...	3240	92	91	89	91	54	40	...	89[a]	63[a]
Viton 77-545	2,000	150	73A	...	...	92	50	...	91	40	...	93	105	...
GP 77	...	...	...	5	...	...	...	...	...	...	...	80[b]	Peeling started	Not tested
Pyre-ML, RK 692	...	...	...	3	...	...	...	...	...	...	...	70[b]	>20[b]	...
Exp 820	26,880	6.5	80 Rock D	...	...	...	...	...	...	...	...	...	...	...

[a] Property measured was tear strength.
[b] Property measured was scrape-adhesion.

Table 3 Changes in physical and electrical properties after exposure to simulated Venusian atmosphere

	Wt change, %			Dimensional change, %		Volume resistivity, ohm-cms				Dielectric strength, V/mil		
Material	After 6 hr	After 24 hr	After 72 hr	After 6 hr	After 24 hr	After 72 hr	Control	After 24 hr	After 72 hr	Control	After 24 hr	After 72 hr
Teflon TFE	+0.11	+0.19	+0.30	+0.80	+0.814	+1.533	6.3×10^{15}	6.0×10^{15}	1.46×10^{16}	339	320	335
Fiberglas 91LD	−1.40	−0.148	−1.88	−0.290	None	−0.200	1.44×10^{14}	1.03×10^{14}	7.3×10^{14}	411	437	378
Kapton 100	+0.99	+1.95	+0.780	...	...	...	1.24×10^{17}	1.20×10^{17}	1.16×10^{17}	3740	3745	3837
Viton 77-545	−0.67	+2.64	...	−1.91	−3.80	...	...	...	...	...	...	...
GP 77	...	Not tested	...	...	Not tested	...	...	...	...	...	...	...
Pyre-ML, RK 692	...	Not tested	...	...	Not tested	...	...	...	...	...	...	...

Table 4 Retained mechanical properties after 24 hr exposure to various gaseous environments[a]

	Tensile strength, % retained			Elongation, % retained			Hardness unit change (Rockwell E)			Tear strength, % retained		
Material	Air	N_2	"Venus"	Air	N_2	"Venus"	Air	N_2	"Venus"	Air	N_2	"Venus"
Kapton 100 (polyimide film)	99	111	90.6	78.6	127	54	...	...	...	92.7	94.6	89.5
Fiberglas 91LD (glass filled phenolic)	108	122	94	107	113	77	+1.5	+1.5	+2.0	...	...	...
Exp 820 (glass fiber reinforced benzimidazol)	143	115	95	65	60	60	+7	+7	+4	...	...	...

[a] For original properties see Table 3.

Table 5 Change in properties after 24 hr exposure to various gaseous environments

	Volume resistivity, Ω, cm			Weight change, %			Volume change, %			
Material	Control	Air	N_2	"Venus"	Air	N_2	"Venus"	Air	N_2	"Venus"
Kapton 100 (polyimide film)	1.24×10^{17}	5.6×10^{16}	8×10^{16}	1.20×10^{17}	−0.1428	−1.373	+1.950	−0.98	−1.36	...
Fiberglas 91LD (glass filled phenolic)	1.44×10^{14}	1.0×10^{14}	9×10^{14}	1.03×10^{14}	−1.859	−2.389	−0.1488	+1.49	−0.28	0.00
Exp 820 (glass fiber reinforced benzimidazole)	...	...	...	...	−1.671	−1.541	−1.202	0.00	−1.64	−2.52

<1. The steadily rising gas pressure, resulting from heating of the environmental chamber, was adjusted to its desired value (18.5 ± 1 atm) after the test temperature of 550 ± 10°F was reached. A cam-type timer was set to turn off the heat automatically after the required exposure period of 6, 24, or 72 hr. Gas flow through the simulator was carried on during the entire course of an exposure, at the rate of 10 ml/min. Sampling for mass spectrographic analysis was made after externally reducing the pressure in the simulator. The foregoing gas mixture and conditions, first thought to exist on the equatorial surface of Venus, most probably describe the conditions at some distance from the surface. Arguments seem to support the hypothesis that Venera 4 had not reached the planet's surface when it stopped sending information.[4–6]

The materials tested were the commercial products listed in Table 1, and test specimens were prepared in accordance with the sizes and shapes specified in the standard test methods used. Some of the products, for example, the encapsulants and adhesives, required such preliminary handling as mixing and degassing before castings or testing specimens could be prepared. Weight losses were measured to an accuracy of ±0.1 mg and dimensional change measurements were accurate to ±0.1 mil.

Results and Discussion

Only six products (4–6, 10, 12, and 13 in Table 1) met the compatibility criteria set for the screening program. Two materials, Teflon FEP and Exp 820, had melted at the exposure temperature, and therefore, the test specimens were deformed. However, the mechanical properties seemed intact, after the specimens were brought to room conditions, and the small weight loss indicated that chemical degradation was practically absent. If these two plastics were reinforced by fibrous materials, they probably would have been dimensionally stable. Later on, a glass-cloth-reinforced polybenzimidazole showed adequate resistance to the test conditions and was rated compatible with the environment.

The six products were then exposed for 24 hr to the "Venusian" atmosphere. Three of these, Viton 77-545, GP-77, and Pyre-ML-RK 692, failed to meet the compatibility criteria, which consisted essentially of retaining at least 70% of the original mechanical, physical, and electrical properties, and losing less than 2% weight (see Tables 2 and 3). The three remaining materials, Teflon TFE, Fiberglas 91 LD, and Kapton 100 were exposed 72 hr to the simulated conditions. Kapton 100 retained 40% of its original elongation and 63% of its original tear strength after this treatment. Its tensile strength was well retained. The other two compounds were affected very little by the 72-hr exposure.

Kapton 100, Fiberglas 91LD, and Exp 820 also were exposed to N_2 and air, as well as again to the "Venus" atmosphere, at 550° ± 10°F and 18.5 ± 1 atm for 24 hr. Some of the values obtained (averages of at least three tests) are given in Tables 4 and 5. Table 4 indicates that the "Venus" atmosphere reduced the mechanical properties of the materials more than did air or N_2; however, with the exception of percent elongation, the mechanical properties were not reduced more than 10%. The improvement in the tensile strength of Kapton and Fiberglas 91LD in nitrogen is worthy of notice, as is the tensile property of Exp 820 after exposure to air.

No dramatic changes in the volume resistivity of Kapton and Fiberglas 91LD were encountered after any of the exposures. There was not sufficient amount of Exp 820 to perform the volume resistivity measurement. The weight of Kapton increased after the "Venus" exposure. Also the weight loss of the other two materials was less after exposure to this atmosphere. Absorption or an actual chemical combination between the imide nitrogen of the Kapton and the acidic CO_2 is a possibility. Although the "Venus" atmosphere affected the properties of the tested materials more than nitrogen or air did, its affect was not severe enough to rate these materials to be incompatible with this atmosphere for the duration of the test.

References

[1] Davydov, V. D., "New View of Venus," *Science and Technology*, Vol. 73, Jan. 1968, pp. 49–54.

[2] Vinogradov, A. P., Surkov, U. A., and Florensky, C. P., "The Chemical Composition of the Venus Atmosphere," *Journal of the Atmospheric Sciences*, Vol. 25, No. 5, July 1968, pp. 535–536.

[3] Snyder, C. W., "Mariner V Flight Past Venus," *Science*, Vol. 158, No. 3809, Dec. 1967, pp. 1665–1668.

[4] Johnson, F. S., "The Atmosphere of Venus: A Conference Review," *Journal of the Atmospheric Sciences*, Vol. 25, No. 4, July 1968, pp. 658–662.

[5] Jastrow, R., "The Planet Venus," *Science*, Vol. 160, No. 3835, June 1968, pp. 1403–1410.

[6] Eshelman, V. R. "The Atmosphere of Mars and Venus," *Scientific American*, Vol. 220, No. 3, March 1969, pp. 79–88.

Assessment of the Explosive Hazards of Large Solid Rocket Motors

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THE conventional sensitivity tests for the hazard classification of propellants and explosives are generally arbitrary in nature and based on previous experience. With 260-in.-diam motors containing over 4 million pounds of propel-

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