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NASA TECHNICAL MEMORANDUM

(NASA-TM-82508) INVESTIGATION OF SURFACE TENSION PHENOMENA USING THE KC-135 AIRCRAFT (NASA) 16 p HC A02/MF A01 CSCL 22A

N85-18995

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NASA TM-82508

INVESTIGATION OF SURFACE TENSION PHENOMENA USING THE KC-135 AIRCRAFT

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October 1982

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM -82508		

4. TITLE AND SUBTITLE	5. REPORT DATE
Investigation of Surface Tension Phenomena using the KC-135 Aircraft	October 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W. S. Alter	8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	10. WORK UNIT NO.
	11. CONTRACT OR GRANT NO.
	13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Space Science Laboratory, Science and Engineering Directorate.

16. ABSTRACT

The KC-135 aircraft provides a short-duration, microgravity environment which is useful for performing certain types of experiments. In particular, small-scale, free-format investigations which would otherwise be neglected can be conveniently pursued on the KC-135. Three hand-held experiments were performed during the 1982 May and July flights. The purpose of these experiments was to verify their concepts in order to justify more extensive investigation. These experiments are described, and plans for further research, based on preliminary results, are discussed.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
KC-135 Aircraft Surface Tension Critical Wetting	Unclassified — Unlimited Wendy S. Alter

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	13	NTIS

MSFC - Form 3292 (May 1969)

For sale by National Technical Information Service, Springfield, Virginia 22151

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INTRODUCTION

The KC-135 aircraft, flown in repetitive ballistic trajectories, offers an extremely valuable means of carrying out short-term microgravity tests for modest cost. In addition to several elaborate low-gravity investigations being carried out in this aircraft, other research activities can benefit greatly, such as quick testing of a theory, confirmation of a principle, qualitative work preliminary to a quantitative investigation, and precursory testing of various apparatus. A definite advantage to this method of investigation is the presence of an onboard investigator who can respond rapidly in the event of equipment malfunction, or provide experienced judgement in procedural changes to optimize data yield. Especially valuable is the relatively informal, free-format type of investigation that can be carried out in a low-g environment in the aircraft. This type of approach is not generally possible at this stage of the Space Shuttle program because of the cost and complexities of manned orbital flight. The less formal research environment provided by the KC-135 greatly enhances creativity and spontaneity in the discovery process and allows many interesting small-scale experiments to be conducted which, apriori, may not justify a Shuttle flight, but may well provide a key link to a significant new avenue of thought.

Three such experiments were performed during the May and July flights of 1982. A description of the experiments, their objectives and results, follows.

CRITICAL WETTING EXPERIMENT

Description

An experiment was performed to determine the feasibility of measuring critical wetting temperatures in the KC-135 microgravity environment. This work is important to an on-going investigation of monotectic systems being carried out by Dr. Donald O. Frazier, Space Science Laboratory, Marshall Space Flight Center. These metallic materials could prove to be useful for electrical or superconductive purposes, but the liquid-phase immiscible behavior which gives the systems their desirable properties also makes it formidably difficult to obtain in situ composites directly from the melt. Research has been done using SPAR rockets to investigate the effect of eliminating gravitationally dependent separation due to density differences between the two liquid phases [1,2]. However, phase separation mechanisms unrelated to gravity also exist and this low-gravity work has indicated that they may be very significant.

Critical point wetting appears to be one of the most influential factors in the low-gravity separation of immiscibles [3]. This may manifest itself as wetting of the container wall by one of the phases, or as wetting of the solid growth front preferentially by one of the phases. The former case results, if the minority phase is the wetting phase, in samples with a shell of minority phase material around the outer surface, while the latter effectively prevents steady-state composite growth, since no stable three-phase junction can form [4].

However, critical point wetting is not fully understood. Obtaining accurate data on critical wetting temperatures is an arduous process. The simplest method is to measure the contact angle of the interface between the two liquid phases with the solid as the critical wetting temperature is approached. However, in 1-g this angle is difficult to measure because large density differences between the two phases force the interface flat (Fig. 1). Although the contact angle approaches 0 deg as the temperature approaches critical wetting temperature, the radius of curvature near the solid surface is so small that it cannot be determined with confidence. By removing gravity, the interface should relax to a shape determined solely by interfacial forces and the contact angle between the two liquid phases and the container wall can easily be measured. Since the KC-135 flies a series of subsequent parabolas, the sample may be slowly heated or cooled so that the contact angle measured during each low-gravity parabola is at a slightly different temperature. In this way the contact angle may be determined as a function of temperature and the critical wetting temperature can be found.

Procedure

The simple hand-held experiments performed aboard the KC-135 were designed as feasibility experiments to show that at microgravity, interfacial free energy effects rather than density effects dominate interface shapes and an easily measured angle will form. These will serve as precursors to a more elaborate experiment with improved photography and temperature control. A metal model system, 55 wt% ethanol in succinonitrile, was enclosed in a flat quartz cuvette and the angle made by the interface between the two liquid phases in contact with the edge of the cuvette was observed. The cuvette was cooled and warmed through the critical wetting temperature: a qualitative measure of temperature was obtained by monitoring calibrated liquid crystals strips on the cuvette face. Variation in interface shape and contact angle were recorded by both still and motion photography.

Results

An initial uncertainty concerning the system was whether a stable interface dominated by interfacial forces would form in the available time. Also there was concern that the transition from microgravity to the 2-g pullout would cause mixing of the two phases. However, this did not occur. The phases maintained a single interface which quickly assumed a characteristic angle as soon as microgravity conditions prevailed. Photographic resolution proved good enough that the liquid crystal indicators could be read from the prints. A dark background with side lighing revealed a contact angle which was easily discernible to the eye, but the lack of contrast made photography difficult (Fig. 2).

Conclusions

Tentative results were obtained from the hand-held cuvettes, but because temperature measurement was imprecise, the results must be viewed as preliminary. However, the experiment showed that the KC-135 provides a suitable environment for acquiring critical wetting temperature data. A more refined version of this experiment is planned for a future KC-135 flight. A primary feature of the experiment will be improved temperature measurement through the presence of thermal sensors within the liquid which will yield a digital readout for precise correlation of temperature with contact angle.

AMPOULE TRANSLATION EXPERIMENT

Description

The challenge of designing crystal growth furnaces which will function effectively on the Space Shuttle has inspired the concept of surrounding the ampoule in the furnace cavity with a low melting point metal. This interface between ampoule and furnace could serve two purposes. First, at ambient temperatures the metal will be solid. This would support the quartz ampoule against the vibrations of takeoff. Then during crystal growth, the metal will become liquid at a relatively low temperature and provide good thermal contact between furnace and ampoule. This could substantially increase the gradient that can be achieved. Also, hot spots caused by a slightly off-center ampoule may be alleviated.

The choice of metal and design of the system requires consideration of a number of factors. Evaporation and corrosion must be avoided. The liquid metal must be retained in the furnace in zero-gravity, although the system must be open to allow the ampoule to be translated out. The level of surrounding metal must be held constant to maintain static thermal profiles. Wicking must be prevented.

The purpose of this hand-held KC-135 experiment was to examine the effectiveness of surface tension as a means of keeping the cushioning heat-transfer liquid in the furnace during ampoule translation. It was proposed that choosing a metal which wets the furnace liner but not the ampoule would result in retention of the liquid within the cavity. A nonspreading barrier around the mouth of the furnace should prevent wicking.

Obviously this concept must be tested before implementation and molten metal in an open system could prove inconvenient to work with initially. As a preliminary investigation, two simple hand-held experiments were designed using water as the cushioning liquid, pyrex to represent the furnace liner, and a teflon rod to simulate the translating ampoule.

Procedure

The first experiment design simulated the ampoule with a large magnetic stirring rod which was inserted into a pyrex test tube, allowing approximately 0.5 cm clearance (Fig. 3). Regularly spaced indentations were made in the outside of the test tube to provide fingers to guide and center the rod in the tube. To discourage the water from wicking out around the edge, a lip of teflon tape was wrapped around the mouth of the tube. A second magnetic stirring rod could be used externally to control the motion of the inner rod through the wall of the tube. Before entering the zero-gravity cycle, the test tube with rod in place was filled with water. The rod was then translated during zero-gravity by means of the external magnet.

This design was upgraded for a second experiment in which the teflon stirring rod was replaced by a 40-cm teflon rod and the tube was open at both ends (Fig. 4). A rubber septum was fitted to the tube at one end, pierced for insertion of the rod, to act as a guide and to constrain the water during the

2-g portion of the flight maneuver, but a syringe without plunger was inserted through the rubber to prevent the formation of an air-tight seal. The teflon rod entered the tube through the septum and was translated out the other end, which was wrapped with a lip of teflon tape.

Results

Because the tube used in the first design was closed on one end, gradual removal of the rod from the tube resulted in a drop in water level, making it necessary to fill continuously during the translation. This proved to be very difficult to coordinate during the KC-135 parabolic maneuver. When the inner rod was held stationary in a position protruding from the tube, and the tube was over-filled with water during low-gravity, the water was held in place through surface tension although it bulged well out from the top of the test tube (Fig. 5). The teflon-taped rim seemed to be effective in constraining the water.

In order to assure that the action of translating the ampoule would not disrupt this stability, the revised design allowed for a constant water level during translation. Wicking did not occur, nor did the water escape freely, but occasional drops did cling to the teflon rod as it was withdrawn from the tube. This may have been a result of marks drawn with indelible pen at regular intervals on the teflon rod to make the translation apparent in motion photography. The wetting characteristics of the ink could differ from that of the teflon, enabling water droplets to cling at those points. The general behavior of the water, however, was to remain within the pyrex tube.

Conclusions

The stability of the water in these configurations shows that a liquid which wets the furnace liner but not the ampoule may be retained in an open furnace even during low-gravity. An experiment involving a low melting point metal is planned to verify that the principles will hold for the materials of interest.

ZERO-GRAVITY NONWETTING EXPERIMENT

Description

A motivation for growing crystals of HgCdTe from the melt under low-gravity conditions is to discover how the absence of buoyancy-driven convection may influence the composition of the crystal. This material is particularly prone to segregation, and natural convection due to density differences in the alloy components is thought to be a factor [5]. A Shuttle experiment may help to determine the extent to which composition is affected, but only if buoyancy-driven convection effects can be isolated.

In low-gravity, however, surface-tension driven flow (Marangoni effects) can become significant. If the molten liquid were to separate from the wall of the quartz ampoule due to the nonwetting tendencies of this mercury compound and to its proximity, at such elevated temperature, to its critical wetting temperature, then a large liquid/vapor interface could exist. This surface would have nonuniformities of both temperature and composition over the length of the ingot as a result of furnace temperature profiles and the crystal growth process. Consequent variations in surface tension would cause Marangoni-type convection to assume significant proportions [6]. Effects of the absence of buoyancy-driven convection could be eclipsed by this flow.

The question of interest, then, is whether a nonwetting fluid would separate from the ampoule wall under low-gravity conditions.

Procedure

Approximately 1 ml of distilled water was placed in a plastic test tube which had a tightly fitting screw cap. The water did not wet the walls of the tube; that is, it exhibited a contact angle greater than 90 deg. Several colored substances were tried to enhance contact angle visibility, but they were found to have a wetting effect, so water alone was used. The behavior of the water on the plastic was observed under low-gravity.

Results

Without the hydrostatic head pushing the interface flat, the contact angle between water and plastic gave the appearance of increasing. Water drops formed a higher dome. Droplets clinging to the walls of the tube could not, however, be dislodged to free-float, even by vigorous shaking and tapping. Thus the area of the water/vapor interface increased, and the area of the water/plastic interface decreased, but separation from the walls of the tube was not complete.

Conclusions

The apparent increase in contact angle may have been illusory. Since the radius of curvature of water/vapor interface at the cell wall was quite small in 1-g, the magnitude of the angle was difficult to judge. (This is the rationale for performing critical wetting measurements in microgravity, as described in a previous section.) The increase in liquid/vapor interface area, however, was real and would provide increased opportunity for surface-tension driven convection.

Furthermore, the system was well below its critical wetting temperature, while liquid HgCdTe will be much closer to its T_{cw}. Thus, the alloy will exhibit greater tendency to separate from the ampoule walls, allowing a vapor space to intervene. In order to model this system more closely, a further experiment has been proposed utilizing materials which are near their critical wetting temperatures when at room temperature. This experiment cannot be performed on the KC-135 for safety reasons, as such materials are flammable and have extremely high vapor pressures. A drop-tower experiment is being considered.

SUMMARY

This trio of investigations concerning surface phenomena demonstrates the effectiveness of the KC-135 as a microgravity research environment for small-scale, hand-held experiments. The critical wetting cell has led to the development of precision apparatus for measuring contact angles quantitatively to be tested shortly on the KC-135. Further investigations into the feasibility of a heat-transfer liquid within a furnace cavity are being planned on the strength of results from the water/teflon/pyrex model. The nonwetting investigation raises questions of importance concerning a future Shuttle experiment. By confirming hypotheses through these preliminary experiments within a flexible research environment, more elaborate investigations can now be justified.

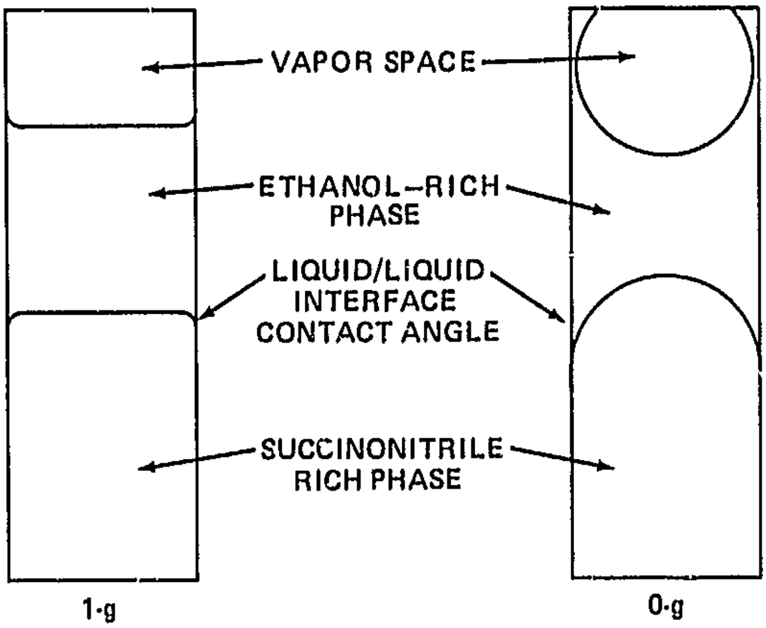

Figure 1. Interface behavior in normal gravity and low-gravity. Contact angle of liquid/liquid interface with wall of cell approaches zero as critical wetting temperature is approached, but flat interface in 1-g makes angle difficult to measure. Interfacial forces dominate in microgravity, so small contact angles are easily measured.

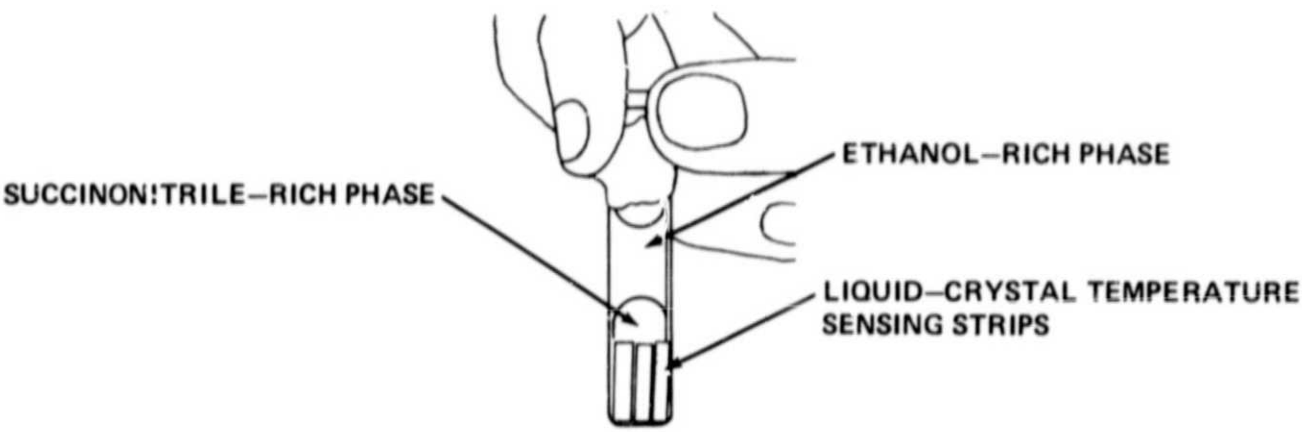

Figure 2. Succinonitrile-ethanol system approaching critical wetting temperature in low-gravity.

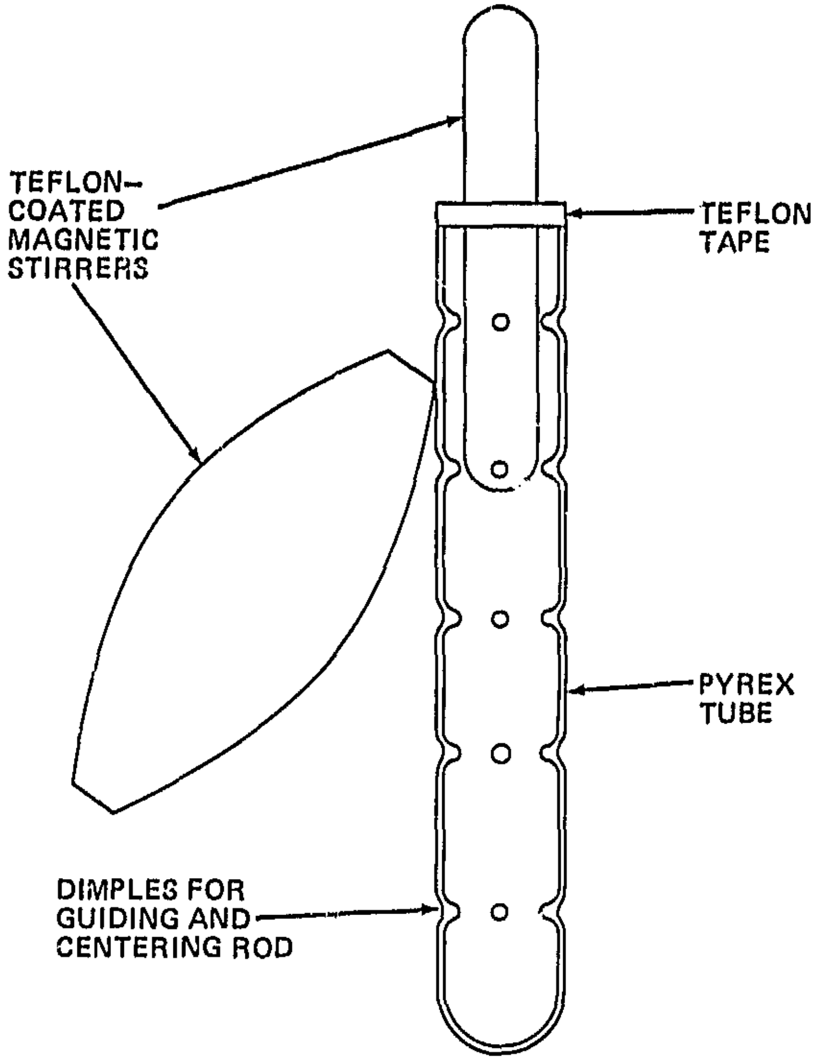

Figure 3. First ampoule translation design.

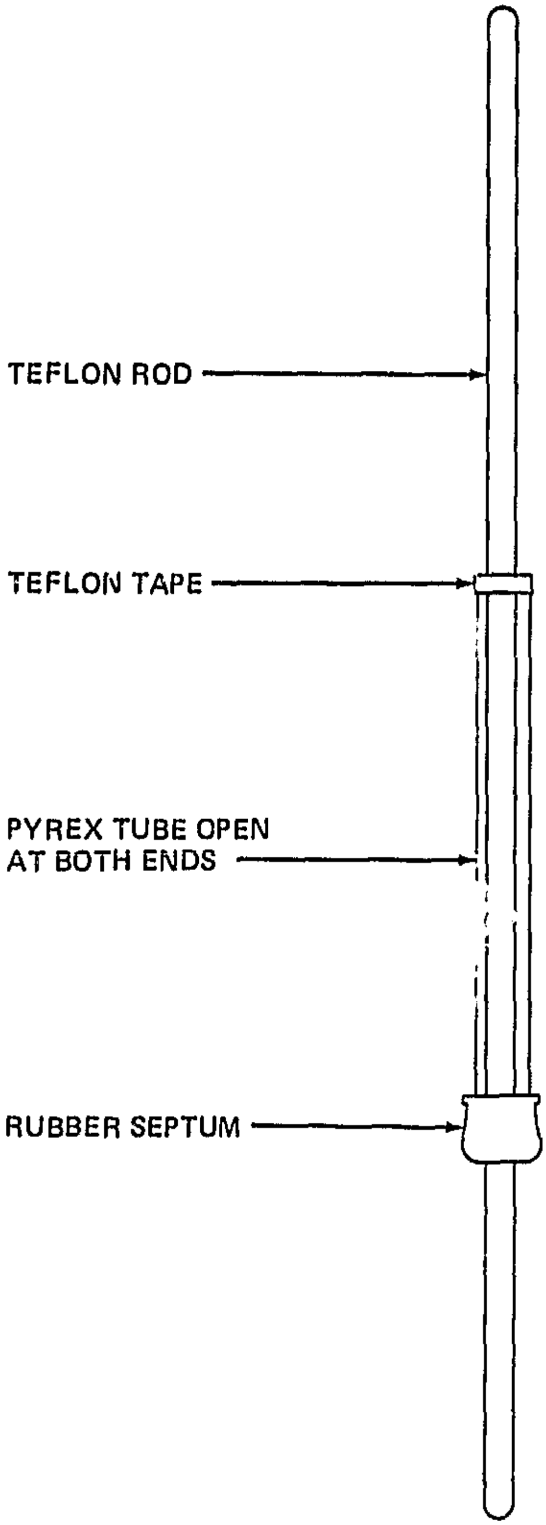

Figure 4. Second ampoule translation design.

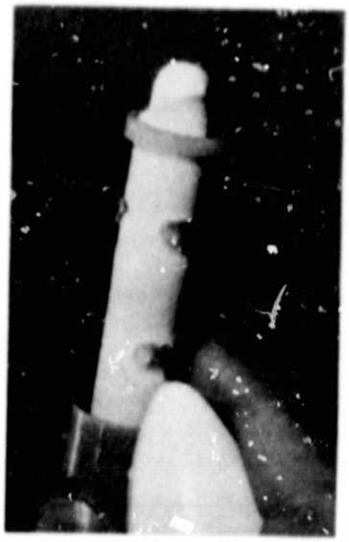

Figure 5. Ampoule translation experiment in low-gravity. Tube has been overfilled with water.

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APPROVAL

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By W. S. Alter

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1983—646-058/119