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Prediction of Ablation Depths of Lithium Hydride Shield During Reentry, Including a Study of the Effects of Node Size on Calculated Ablation Rates

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ABSTRACT Calculations were made using a one-dimensional thermal model of a section through the lithium hydride shield surrounding the ZrH reactor. It was found that, for a representative reentry trajectory and for an assumed aerodynamic heating factor of 0.535, about 4.8 in. of hydride would ablate before the end of the heating period. The validity of the heating factor used has not yet been established, so these results should be considered to be preliminary. The insensitivity of the calculated ablation rates to node thickness of interest in the thermal model was established.		ORIGINAL ISSUE DATE 11/11/69 GO NO. 7700 S/A NO. 12610 PAGE 1 OF TOTAL PAGES 10 REL. DATE 11/21/69 PREPARED BY <i>R. D. Elliott</i> DATE 11/17/69 DEPT/GRP NO. 731-160 APPROVALS <i>R. B. Paulson</i> 11/18/69 DATE SECURITY CLASSIFICATION (CHECK ONE BOX ONLY) (CHECK ONE BOX ONLY) UNCL. ☒ AEC ☐ DOD ☐ RESTRICTED ☐ CONF. ☐ ☐ ☐ DATA ☐ SECRET ☐ ☐ ☐ DEFENSE INFO. ☐ AUTHORIZED CLASSIFIER <i>E. M. Larson</i> DATE 11/21/69																																													
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I. INTRODUCTION

A study has been made of the ablation rates and total depth of ablation of the lithium hydride shield surrounding the ZrH reactor during reentry from a satellite orbit. The results of this study are considered to be preliminary because they are based on aerodynamic heating rates taken from a representative, but not necessarily the most probable trajectory. Furthermore, the local heating factor, $q_{\text{local}}/q_{\text{ref}}$, was assumed to be 0.535, in order to be consistent with previously-reported data (Ref. 1). The actual heating factor will vary with body shape and with time as the body oscillates and ablates. More nearly accurate heating factors will be obtained in the near future. Nevertheless, it is deemed useful to present these preliminary results at this time.

The principal objectives of this study were:

1. To determine the effect of lithium hydride node thickness on the calculated ablation rates, using a lumped-node network model of the physical system for solution with the TAP-4 program.
2. To compare the results of these calculations with those reported in Reference 1.

II. DESCRIPTION OF SYSTEM ANALYZED

The lithium hydride shield surrounding the ZrH reactor, in the reference design shown in Figure 1, is nominally 8.5 in. thick. It is cast in place between an outer and an inner jacket of 0.1 in. stainless steel (Type 304), with a thermal barrier of Min-K between the inner jacket and the tungsten inner shield.

The four thermal models used in this analysis consisted of one-dimensional strips of nodes representing plugs of unit cross-sectional area through the shield. The models differed only in the node thicknesses and numbers of nodes used to represent the hydride, thicknesses of 0.8, 0.4, 0.2, and 0.1 in. being used. The total thickness of hydride was assumed to be 8.0 in. in each model. The first (outermost) node represented 0.1 in. of steel, receiving aerodynamic heat and losing heat by radiation to space at zero absolute temperature. The innermost node represented 0.1 in. of steel, with no heat flow from its back face. An initial uniform temperature of 0° C was assumed for all nodes.

The thermal models were set up so that each node was assigned a latent heat of fusion. After the first steel node was completely melted it was dropped from the system, and the aerodynamic heating was switched over to the first unmelted hydride node. It was found that some hydride nodes melted before the steel, and these nodes were assumed to blow off immediately after the loss of the steel node. The radiant heat loss was also switched over to the newly exposed surface as the nodes were dropped.

A fifth thermal model was devised with 20 nodes of lithium hydride 0.1 in. thick and 32 nodes behind these, each 0.2 in. thick. No steel outer node was used, so the results show the behavior of bare lithium hydride as an ablator.

The thermal model described in Reference 1, page 22, consisted of lithium hydride nodes of 2.15 in. thickness. One strip of these nodes was recomputed in the present analysis, and the results found to agree with those reported in Reference 1. In this model, no provisions were made for dropping nodes and switching the heat over to the inner nodes. As previously reported, it was found that one hydride node (2.15 in.) ablated completely, and it was surmised that a portion of a second node would have ablated if the first node had been dropped off.

The aerodynamic heating rate history used in this study is shown in Figure 2. It is the same as that used for Reference 1. Thermophysical properties used are given in Table I.

III. PRESENTATION OF RESULTS

The calculated temperature histories of the outer steel jacket and of the lithium hydride at a depth of 1.1 in. are given in Figure 3. Values taken from NAA-SR-TDR-12163 (Reference 1) are given for comparison.

It was noted that the calculated temperatures of the steel were lower in the present study than they were in the results from Reference 1. This apparent discrepancy was examined in some detail, and was found to be due mainly to the higher thermal conductivity used for solid lithium hydride in this study. A secondary reason appears to be that a node thickness of 2.15 in. is too great for accurate calculation of the rate of heat flow from the inner face of the steel, although no large differences were found in the results for node thicknesses ranging from 0.1 to 0.8 in.

The calculated temperatures in the hydride show a sudden rise at about 3150 sec, which is caused by the melting of the steel jacket and the sudden loss of some of the molten hydride. In Reference 1, no provisions were made for simulating the loss of nodes, and this sudden rise in temperature is absent.

Figure 4 shows ablation depth in the lithium hydride as a function of time. Two points are plotted for each node, the first point marking the start of the phase change and the second marking the completion of the phase change. It is noted that the results for node thicknesses of 0.1, 0.2, 0.4, and 0.8 in. thicknesses are very nearly alike, except that the difference in time between the start and the completion of the phase change is less for smaller nodes. The maximum depth of ablation was found to be 4.8 in. for all cases.

The computation for node thicknesses of 0.1 in. was terminated at 2 in. depth because the estimated computer time was exceeded. It was not considered to be economic to rerun this case, since the trend of the results was already evident.

The data for the case of bare lithium hydride show a greater rate of ablation during the earlier part of the heating period, but relatively little difference in total ablated depth at the end of the heating period. The maximum ablated depth was calculated to be 5.3 in.

IV. CONCLUSIONS AND RECOMMENDATIONS

The most significant conclusion of this preliminary study is that node thickness used in the thermal model does not have a great effect on the calculated ablation depth, at least up to about 0.8 in. Therefore the next model, which will be three-dimensional, will be made with nodes of about 0.4 in. thickness. This will reduce set-up and computation time, and will allow a model to be made without exceeding the current limit of 100 phase-change nodes in the TAP-4 program.

It is concluded that, for this representative trajectory, and for a location on the shield where the heating factor is 0.535, the maximum depth of ablation during reentry will be about 5 in.

It is recommended that the effects of variations in the trajectories, in the heating factors, and in the initial temperature profile within the shield be studied as soon as possible.

V. REFERENCES

1. L. D. Montgomery, "Thermal Behavior of Manner Orbiting Research Laboratory and Lunar Base Reactor Systems During Atmospheric Entry," NAA-SR-TDR No. 12623, December 14, 1967.
2. J. W. Vogt, "Measurement of Thermal Properties of LiH and LiH-Li Mixtures; Enthalpy, Heat of Fusion, Conductivity," TRW-ER-4809, June, 1962 (Unclassified)

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TABLE I
THERMOPHYSICAL PROPERTIES OF MATERIALS
USED IN ANALYSIS OF STAINLESS STEEL
JACKETED LITHIUM HYDRIDE ABLATION

	USED FOR THIS STUDY	USED IN REF. 1
STAINLESS STEEL (TYPE 304)		
DENSITY LB/IN ³ GM/CM ³	0.286 7.90	0.29 8.02
SPEC. HEAT BTU/LB-°F CAL/GM-°C	0.122 (212)*; 0.160 (2640) 0.122 (100); 0.160 (1450)	0.12 0.12
CONDUCTIVITY BTU/FT-HR-°F CAL/CM-SEC-°C	12.4 0.051	12.4 0.051
EMITTANCE	0.3 (<600°C); 0.7 (≥ 950°C)	0.7
LATENT HEAT BTU/LB OF FUSION } CAL/GM	127 (2640) 70.5 (1450)	NOT USED
LITHIUM HYDRIDE (FROM REF. 2)		
DENSITY LB/IN ³ GM/CM ³	0.0280 (17) 0.775 (25)	0.0277 0.82
SPEC. HEAT BTU/LB-°F CAL/GM-°C	0.714 (32); 1.894 (1270) 0.914 (0); 1.894 (688)	1.00 1.00
CONDUCTIVITY BTU/FT-HR-°F CAL/CM-SEC-°C	3.44 (SOLID); 2.02 (L) 0.0142 (SOLID); 0.0083 (L)	2.0 0.0083
EMITTANCE	0.8	NOT USED
LATENT HEAT BTU/LB OF FUSION } CAL/GM	1250 (1270) 695 (688)	NOT USED

* NUMBERS IN PARENTHESES ARE TEMPERATURES, °F OR °C.

FIGURE 1; CROSS-SECTION THROUGH
SHIELDED E-H REACTOR

SCALE: 1/6.5 SIZE
FROM R-N69613043
SHEET 1

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FIGURE 2: REFERENCE AERO-HEATING RATES FOR REPRESENTATIVE TRAJECTORY

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FIGURE 9: CALCULATED ABLATION DEPTH OF LITHIUM HYDRIDE SHIELD DURING TYPICAL REENTRY FROM ORBIT