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PRELIMINARY INVESTIGATION OF FIRE AND EXPLOSION HAZARDS ASSOCIATED WITH S-II INSULATION

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ABSTRACT

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The condensation of LOX/LN_2 mixtures within composite insulations, such as that being considered for the S-II vehicle, would be expected to create a fire and explosion hazard in the event of impact, shock, or other stimuli.

To obtain experimental information on this problem, an investigation was made in which small tanks provided with S-II insulation panels were filled with LH_2, held for varying lengths of time, and impacted. The results confirmed the expectation that catastrophic failures could occur under these conditions but suggested that the probability of such failures is low and should be weighed against other factors to determine if modification of the S-II insulation concept is necessary.

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PRELIMINARY INVESTIGATION OF FIRE AND EXPLOSION HAZARDS ASSOCIATED WITH S-II INSULATION

SUMMARY

The condensation of liquid oxygen/liquid nitrogen (LOX/LN_2) mixtures within composite insulations, such as that being considered for the S-II vehicle, would be expected to create a fire and explosion hazard in the event of impact, shock, or other stimuli. The quantity of condensate and, therefore, the extent of any such hazard would be expected to be increased if the outer vapor barrier of the insulation were damaged.

To obtain experimental information on this problem, an investigation was made in which small tanks provided with S-II insulation panels were filled with LH_2, held for varying lengths of time, and impacted. The results confirmed the expectation that catastrophic failures could occur under these conditions but suggested that the probability of such failures is low and should be weighed against other factors to determine if modification of the S-II insulation concept is necessary.

INTRODUCTION

Many materials in contact with LOX constitute fire and/or explosion hazards when subjected to impact, shock, heat, or other forms of energy. Organic materials are especially hazardous under these conditions. Although the degree of hazard is decreased when LOX/LN_2 mixtures are substituted for LOX, evidence of sensitivity has been noted for mixtures containing 30 percent LOX by weight. Conclusive evidence that no hazard exists even with mixtures containing only 20 percent LOX (liquid air) has not been obtained.

The selection of liquid hydrogen for advanced launch vehicles has necessitated the use of a wide range of new materials. In particular, the low boiling point and heat of vaporization have dictated the use of the most efficient insulations available for flight systems. External insulations currently being considered consist of reinforced rigid closed pore foams, bonded directly to the vehicle skin and covered with an essentially impermeable vapor barrier. In principle, gases, primarily air, contained within the pores of the foam, adjacent or close to the foam/aluminum interface will condense or cryopump. Gases located farther away from the interface will cool and contract. If a leak occurs in the outer vapor barrier, cryopumping at the cold interface will continue, fed by air permeating the leak, until the thickness of the condensate layer provides a sufficient thermal barrier to prevent further condensation.

Inspection of the liquid/vapor equilibrium diagram for LOX/LN_2 mixtures (FIG 1) indicates that the concentration of oxygen in the condensate will exceed that in the vapor phase by an amount which is dependent upon the conditions under which condensation occurs. Similarly, evaporation of the condensed phase during warmup of the insulation will cause a further increase in the concentration of oxygen in the condensate residue remaining at any time after evaporation begins. Since both the quantity of condensate and the concentration of oxygen in the condensate depend on the size of the leak, the permeability of the foam, and other poorly defined variables, it appears evident that conditions could be established under which a significant quantity of condensate containing appreciably more than 20 percent oxygen would accumulate within the foam portion of the insulation. Because the foam materials used for this application are known to be susceptible to impact in LOX/LN_2 mixtures containing more than 20 percent LOX, an investigation was initiated to study the hazards associated with condensate formed within damaged insulation on LH_2 containers. Since the development of an acceptable insulation was considered a schedule pacing item for the S-II stage of the Saturn V vehicle, this study was restricted to the particular insulation concept under consideration for that stage.

PRELIMINARY CONSIDERATION

Figure 2 gives computed steady state temperature profiles for LH_2 containers covered with 0.8 and 1.6 inches of the proposed S-II composite insulation. This insulation consists of polyurethane foam bonded to the aluminum tank surface with an epoxy-type adhesive. Phenolic fiberglass honeycomb is pressed into the foam for reinforcement, and the outer surface is covered with an essentially impermeable vapor barrier.

The approximate boiling point temperature for liquid air is indicated in FIG 2 with the distances from the foam/aluminum interfaces at which this temperature occurs. The indicated thicknesses of the condensate layers (combined solid and liquid) are 0.15 and 0.30 inch, respectively, for the 0.8-inch and 1.6-inch insulations. Assuming a density of 1.1 gm/cm^3, the corresponding weights of condensate are in excess of 300 and 600 gm/ft^2, respectively. Since these weights greatly exceed the weights of air present initially within the composite insulations, they can be realized only if the vapor barrier is inherently permeable, if it contains leaks, or if accumulation of condensate occurs at a specific location within intact insulation. The permeability of typical vapor barrier materials was determined to be of the order of 10^{-10} S. P. U.* For a pressure differential of one atmosphere, the corresponding rate of air permeation per square foot per hour is negligible for this application. The permeability of the polyurethane foam also is relatively low. However, the manner in which the honeycomb reinforcement is applied creates numerous gross leakage paths extending from the surface of the foam to the foam/aluminum interface. Thus, the requirement that a relatively good vacuum be attained within the insulation is solely dependent on the integrity of the vapor barrier.

Consideration of the large areas and complex shapes of the surfaces which must be insulated suggests that leaks in the vapor barrier are extremely probable. Because of the difficulties in predicting either the thickness or the oxygen concentration of condensate layers in damaged insulations and also because of the uncertainties attendant to the initiation of reactions between composite materials and LOX/LN_2

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*One permeability unit (SPU) is defined as the number of cubic centimeters of a gas at STP (0^oC, 1 atma) passing through one square centimeter of material, one centimeter thick, under a pressure gradient of one centimeter Hg (10 torr), in one second. Thus, the equivalent units for $1\ SPU = 1\ cm^3\ (STP) \cdot cm^{-2} \cdot (cm\ Hg)^{-1} \cdot sec^{-1}$.

mixtures, a direct, but limited, experimental investigation of the problem was carried out.

EXPERIMENTAL

Standard LOX impact tests were made on samples of the composite insulation and on each of the constituent materials. The results given in Table I indicate that the insulation and its constituents are highly sensitive to impact in LOX. Because the condensate formed within a damaged insulation would be expected to have an oxygen concentration intermediate between that of liquid air and LOX, the tests on the composite insulation were repeated using LOX/LN_2 mixtures.* The results given in FIG 3 indicate a marked decrease in sensitivity with decreasing LOX concentration; samples tested in 20/80 LOX/LN_2 weight mixtures met the standard acceptance criterion of no reactions in 20 tests at 10 kilogram meters.

To obtain a more realistic test configuration, additional tests were made by using flat aluminum test panels, each covered with a 1/2-inch thickness of composite insulation with the vapor barrier either removed or perforated to insure permeation of LOX into the insulation core. These panels, shown in FIG 4, were immersed in LOX/LN_2 mixtures for approximately 15 minutes, removed, and allowed to stand for varying lengths of time before being impacted by approximately 125 #12 lead shot fired from a .22 calibre rifle.** The results of these tests indicated that reactions occurred consistently when the gun was located less than about 50 inches from the target if the concentration of LOX in the LOX/LN_2 mixture exceeded some threshold value, roughly 20 percent. It was noted that the frequency of reactions appeared to increase with increasing hold time (up to approximately 5 minutes) for tests with LOX/LN_2 mixtures containing 20 to 30 percent LOX. This is consistent

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*All LOX/LN_2 mixtures used for this investigation were prepared by weighing the desired quantity of LOX and then adding the necessary quantity of LN_2 to give the desired total weight of mixture.

**Each shot weighed approximately 0.013 gm. Average shot velocity measured between 1 and 3 feet from the gun muzzle was approximately 900 fps. Standard impact tests indicated that the lead shots were not impact sensitive in LOX at 10 kilogram meters.

with the expected increase in concentration of LOX in the liquid residue during warmup of the test specimen. Similar results were obtained in tests using .177 calibre copper-coated pellets fired from an air rifle. Similar results also were obtained using test tanks (instead of flat panels) immersed in LOX/LN_2 mixtures after damaging the insulation by perforating the vapor barrier over each cell or by making saw cuts 1/16 inch wide and approximately 4 inches long across the test section of the tank insulation. These cuts were approximately 1/2 inch deep and extended to the adhesive bond adjacent to the metal tank wall.

The tests discussed above were made with LOX/LN_2 mixtures being introduced in the test specimen by direct immersion beforehand. To obtain a much more realistic simulation, tests were run in which insulated tanks were filled with LH_2 and held for varying lengths of time before impacting to allow natural cryopumping. The test system is shown schematically in FIG 5. Test tanks were constructed and insulated as shown in FIG 6. After the test tanks were filled with LH_2, the samples were impacted with bird shot, fired remotely from a .22 calibre rifle located 18 to 27 inches from the tank surface. The results were recorded photographically.

For the initial tests, the outer vapor barrier was punctured so that air would be liquefied in the sample cells. For the latter tests, four horizontal slots were cut in the sample to the tank skin to simulate damaged or defective insulation.

Instrumentation for all tests, except the third, included two copper-constantan thermocouples. One thermocouple was placed in contact with the tank skin, and the other was placed in the sample core. For the third test, two thermocouples were placed in each of the above mentioned areas. The liquid hydrogen level in the tank was monitored with carbon resistors. Additionally, the tank pressure was monitored as a safety precaution.

Each tank was filled with liquid hydrogen and maintained full for periods varying from 4 to 12 hours, depending on ambient conditions, sample temperature, and the degree of liquid air saturation of the insulation sample. For each impact, the LH_2 supply was shut-off; then, the sample was impacted one or more times.

For the 9 tanks tested, 57 impacts were made. During the tests, liquid air wetting of most of the samples was observed. Generally, impacts were directed at the wetted portions of the samples. Sustained burning occurred 10 minutes and 8 minutes following shut-off of LH_2 supply in Runs No. 3 and 8, respectively. Temperature time curves for these runs are presented in FIG 7 and 8. Photographs of the burned tanks are shown in FIG 9 and 10. The reaction after 10 minutes warmup was much more violent than the reaction after 8 minutes warmup, which suggested either a larger quantity of condensate or a larger percentage of oxygen in the condensate.

CONCLUSIONS

There is a small but finite probability of occurrence of a catastrophic reaction if damaged S-II insulation is subjected to impact, shock, fire, or other stimuli during or subsequent to LH_2 hold. The hazard probably is greatest during warmup of the insulation after testing or detanking operations. This small hazard must be considered with other factors such as reliability, time, weight, cost, etc., to determine whether a purge or other modification is required.

TABLE I

STANDARD LOX IMPACT TEST RESULTS FOR S-II INSULATION

Material	Frequency of Reactions at 10 kgm, percent
Composite Insulation	100.0
Ht 424	100.0
Hexcell 91 LD	100.0
Polyurethane Foam	7.5

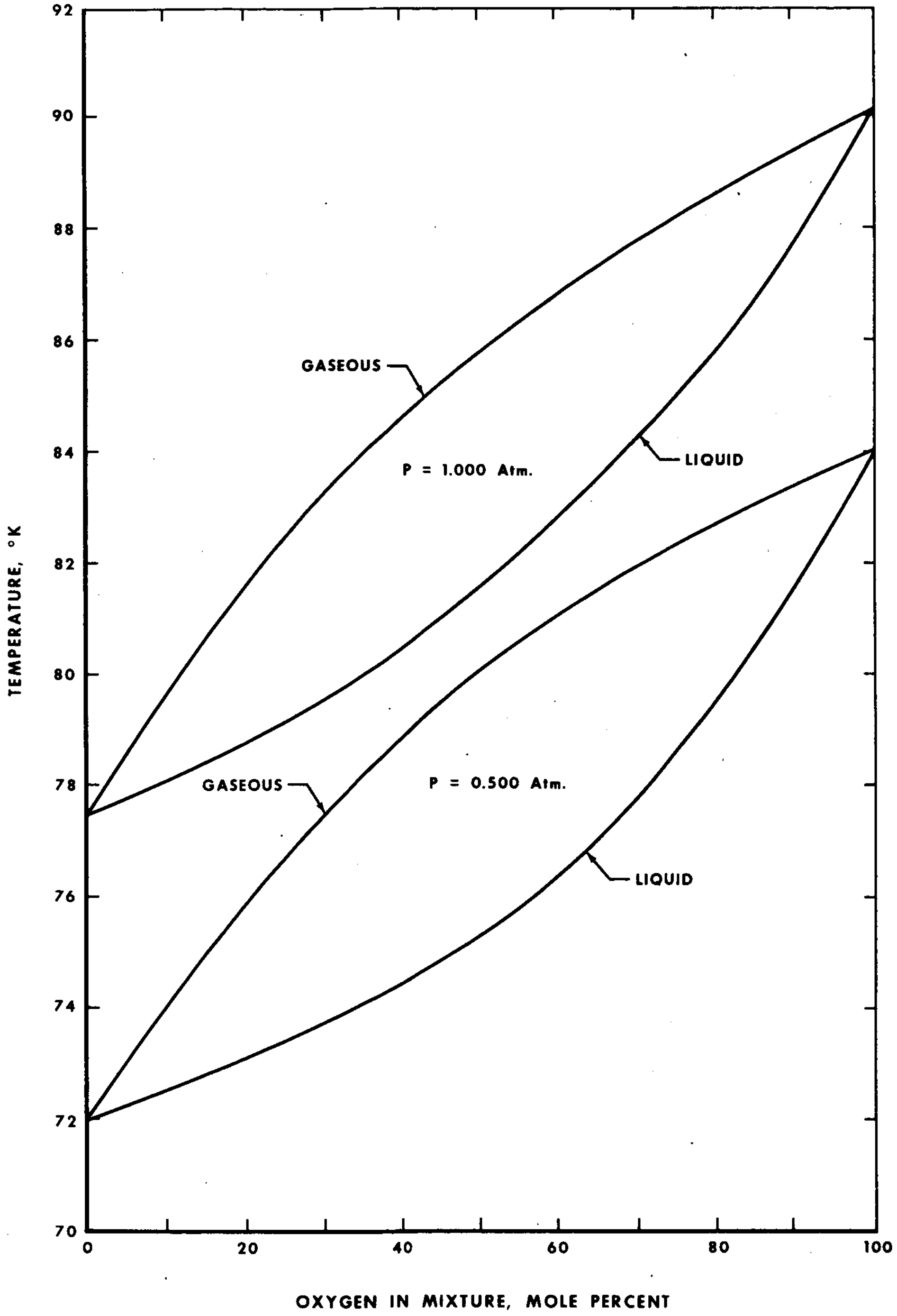

FIGURE 1

O_2/N_2 PHASE DIAGRAM

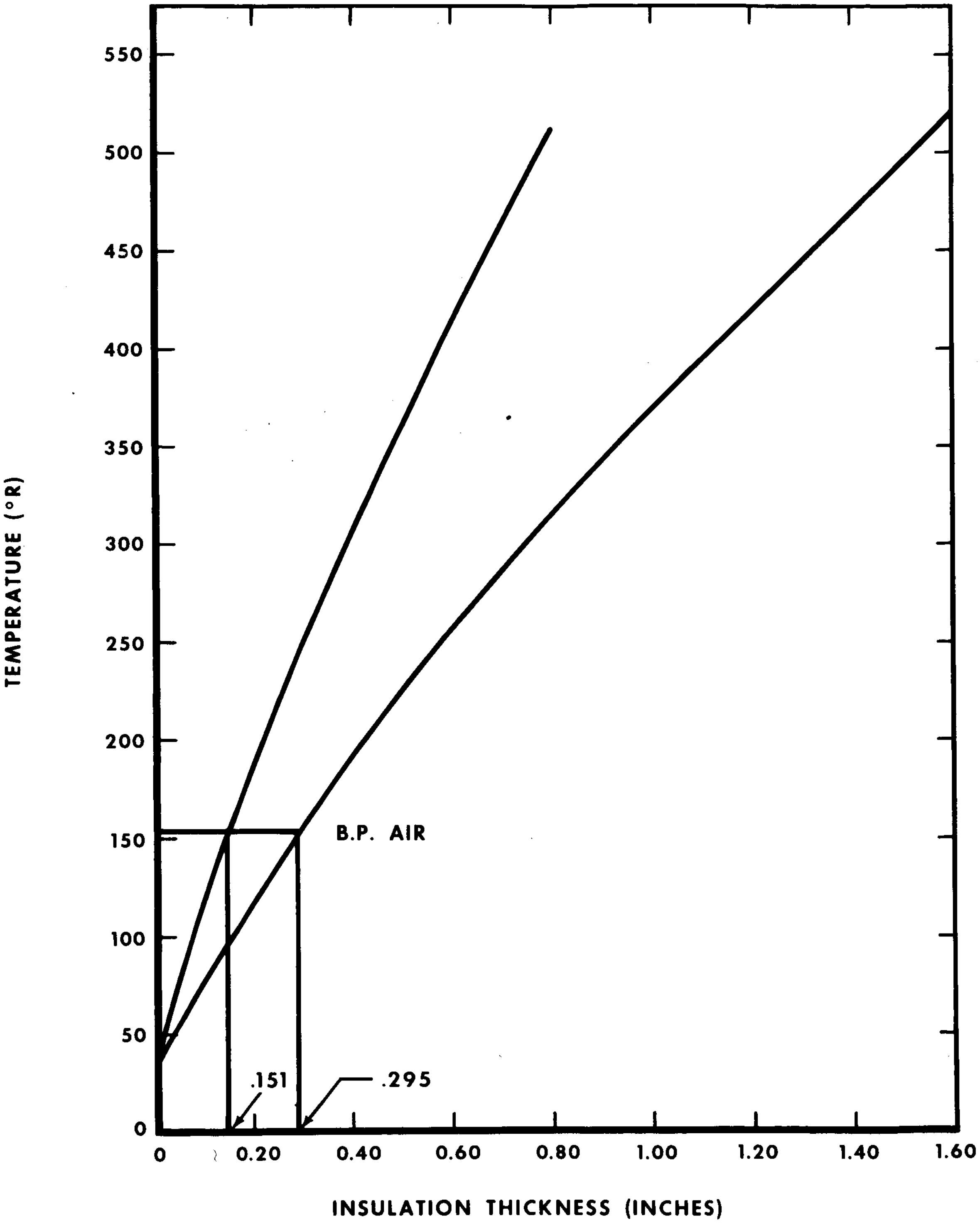

FIGURE 2
CALCULATED TEMPERATURE PROFILES FOR S-II
TYPE INSULATIONS

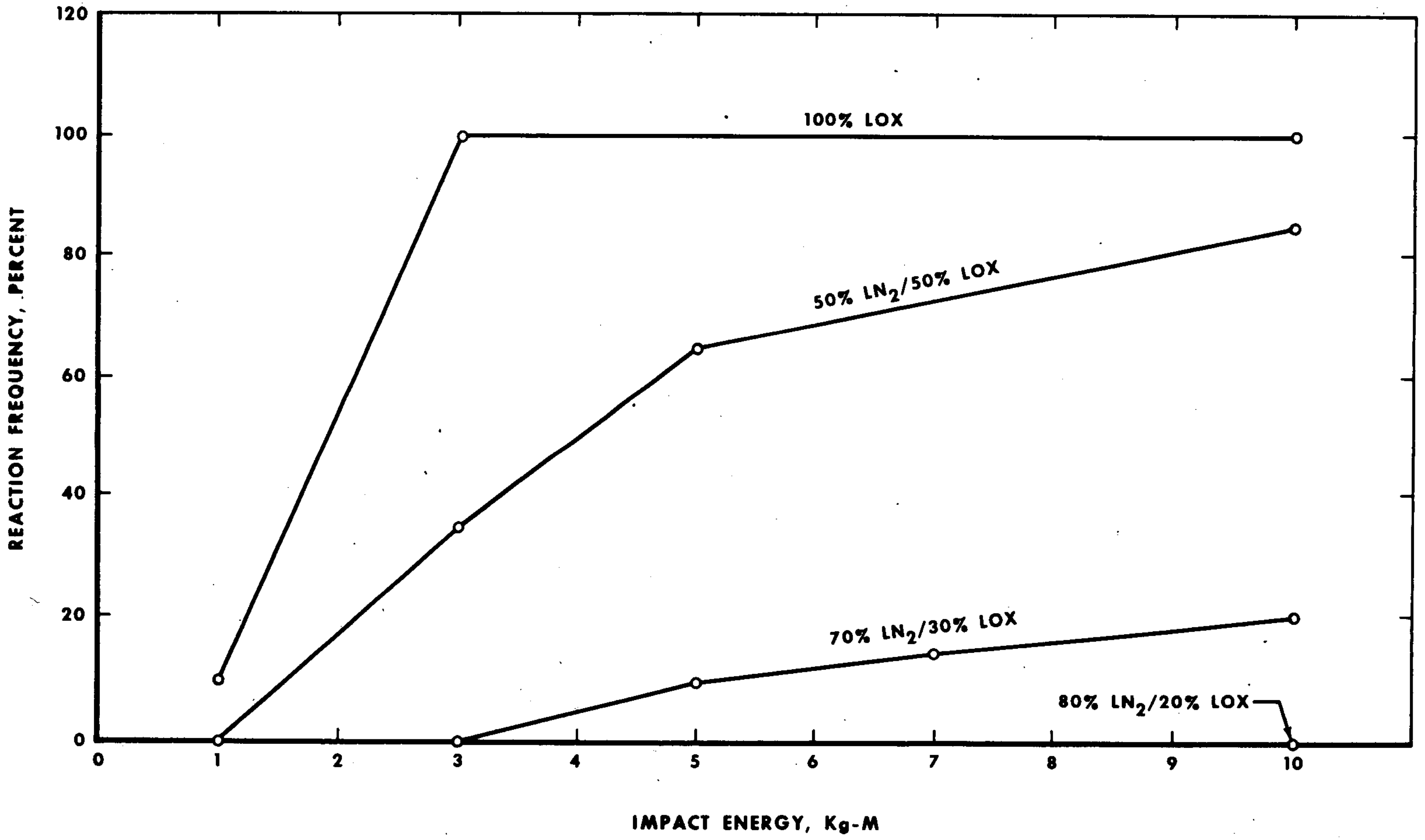

FIGURE 3
LOX IMPACT SENSITIVITY OF S-II COMPOSITE INSULATION

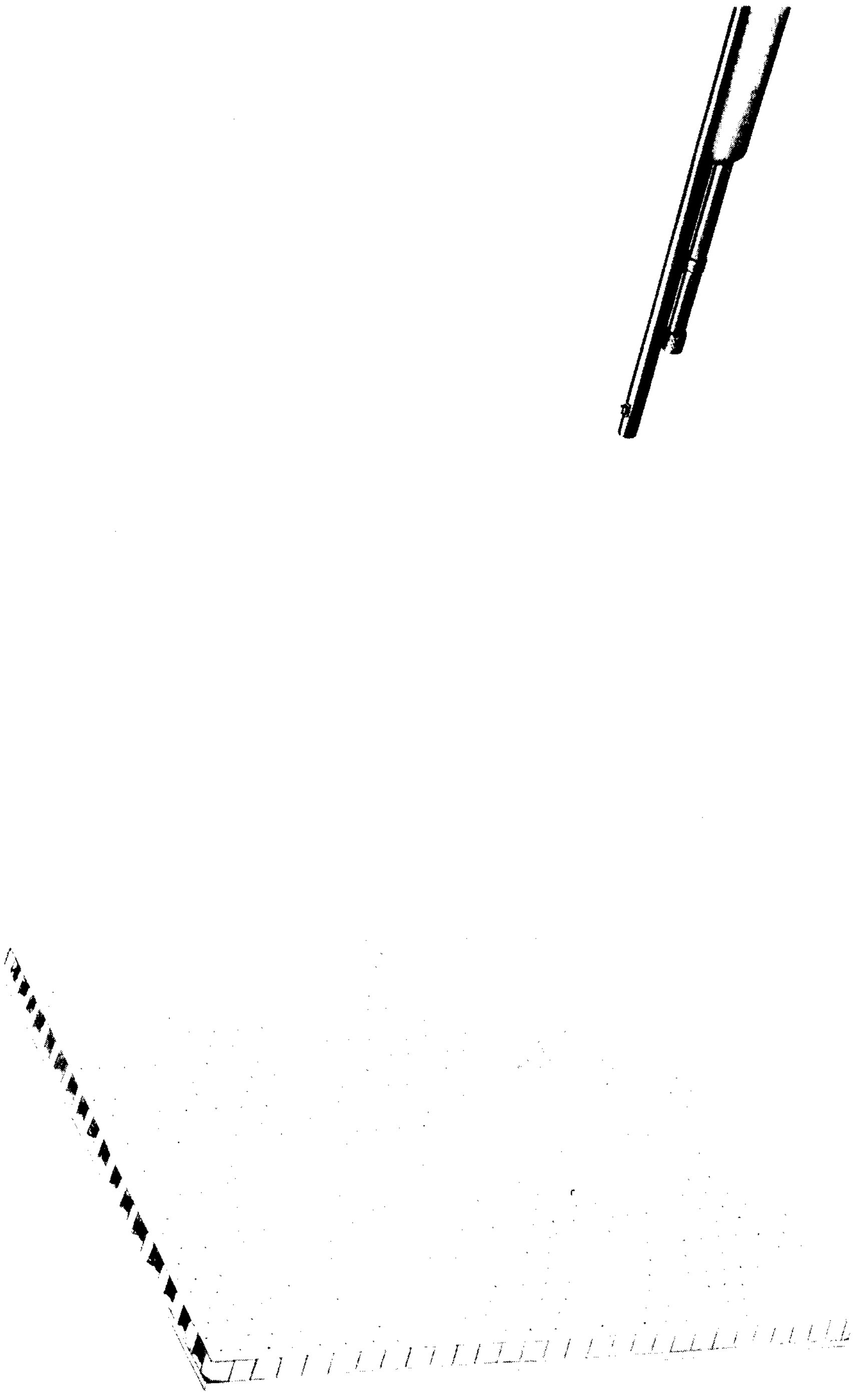

FIGURE 4
TEST SETUP FOR INSULATED
PANELS

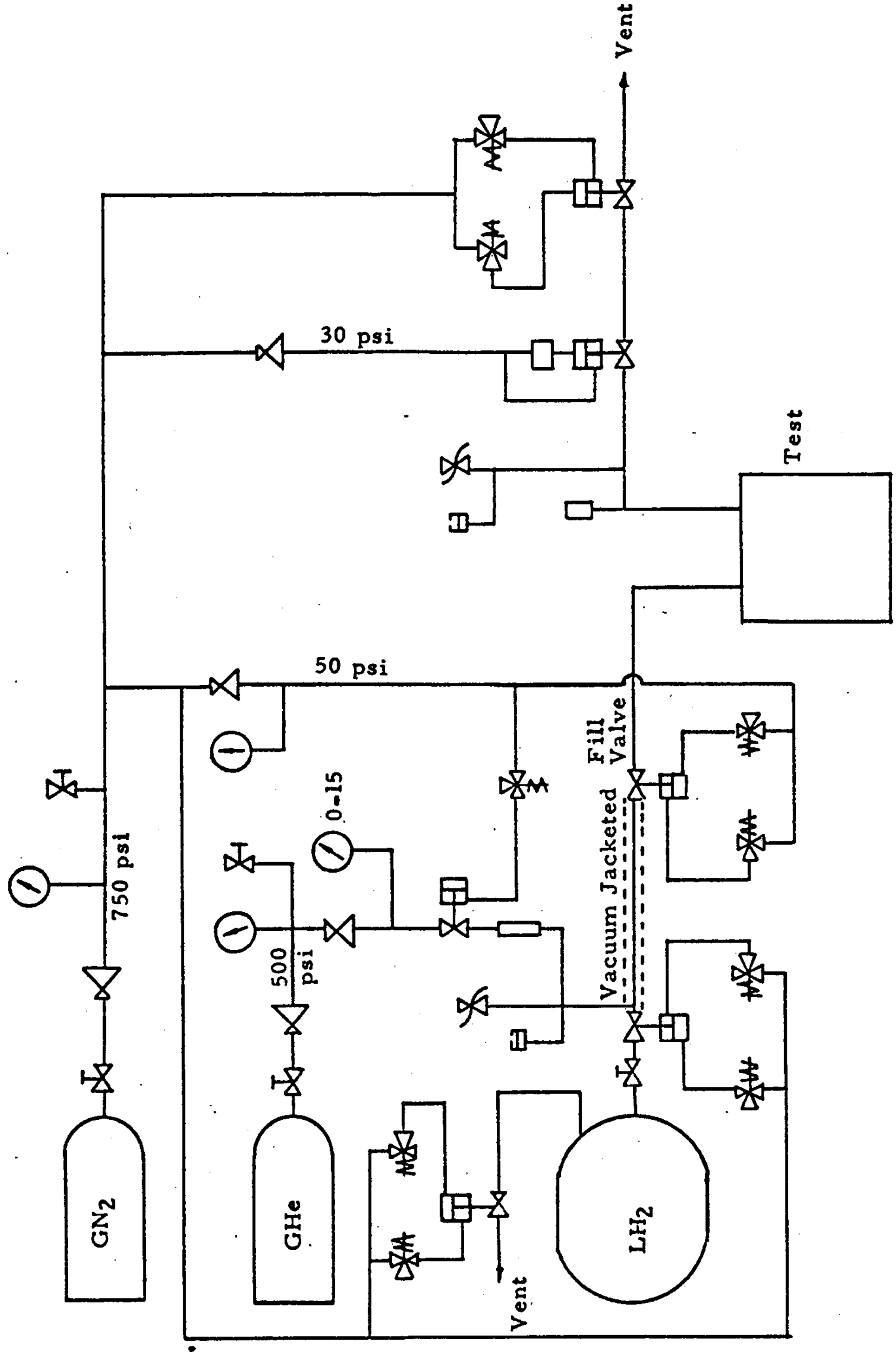

FIGURE 5
GENERAL TEST SETUP FOR INSULATED TANKS

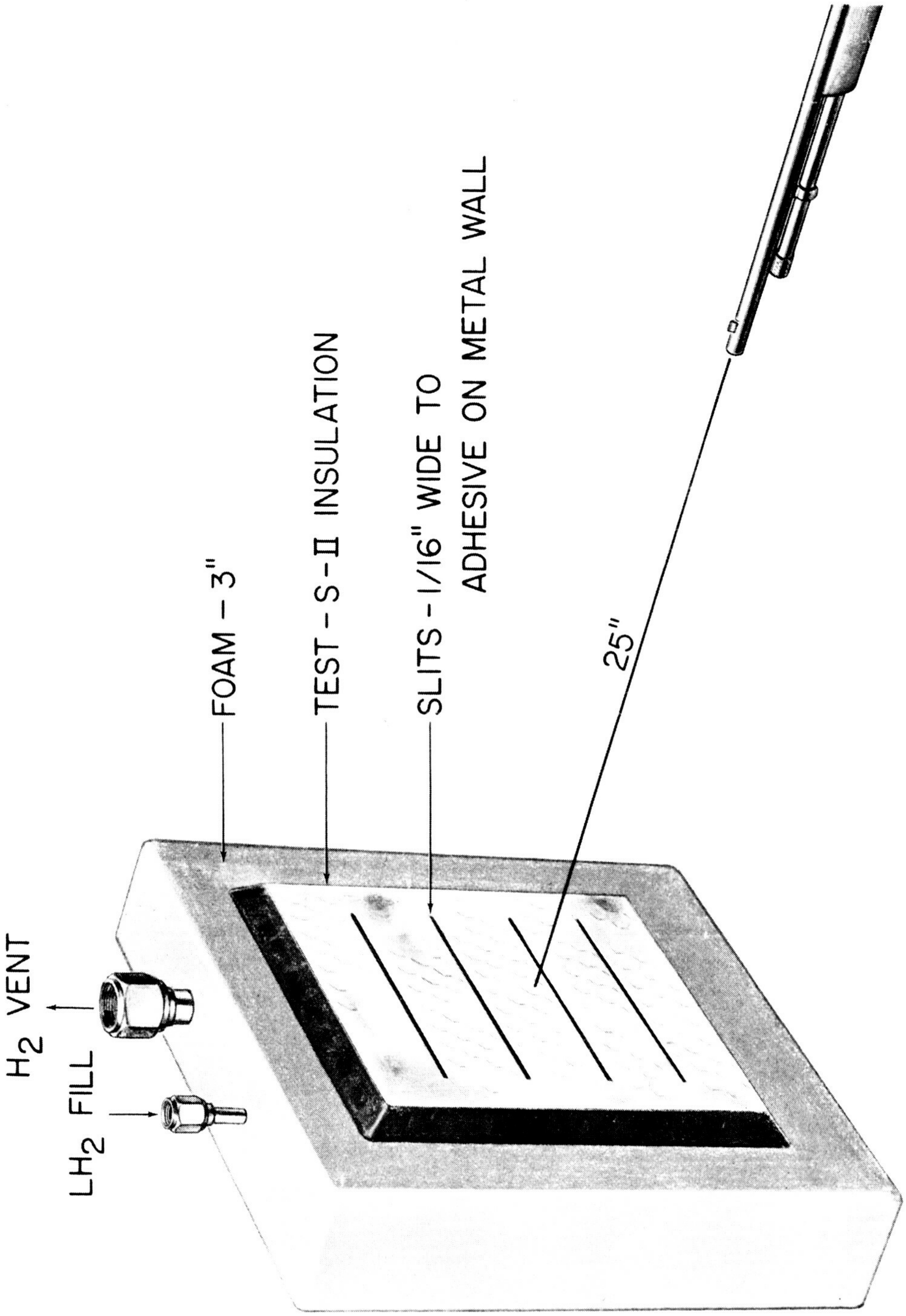

FIGURE 6
DETAILED TEST SETUP FOR INSULATED TANKS

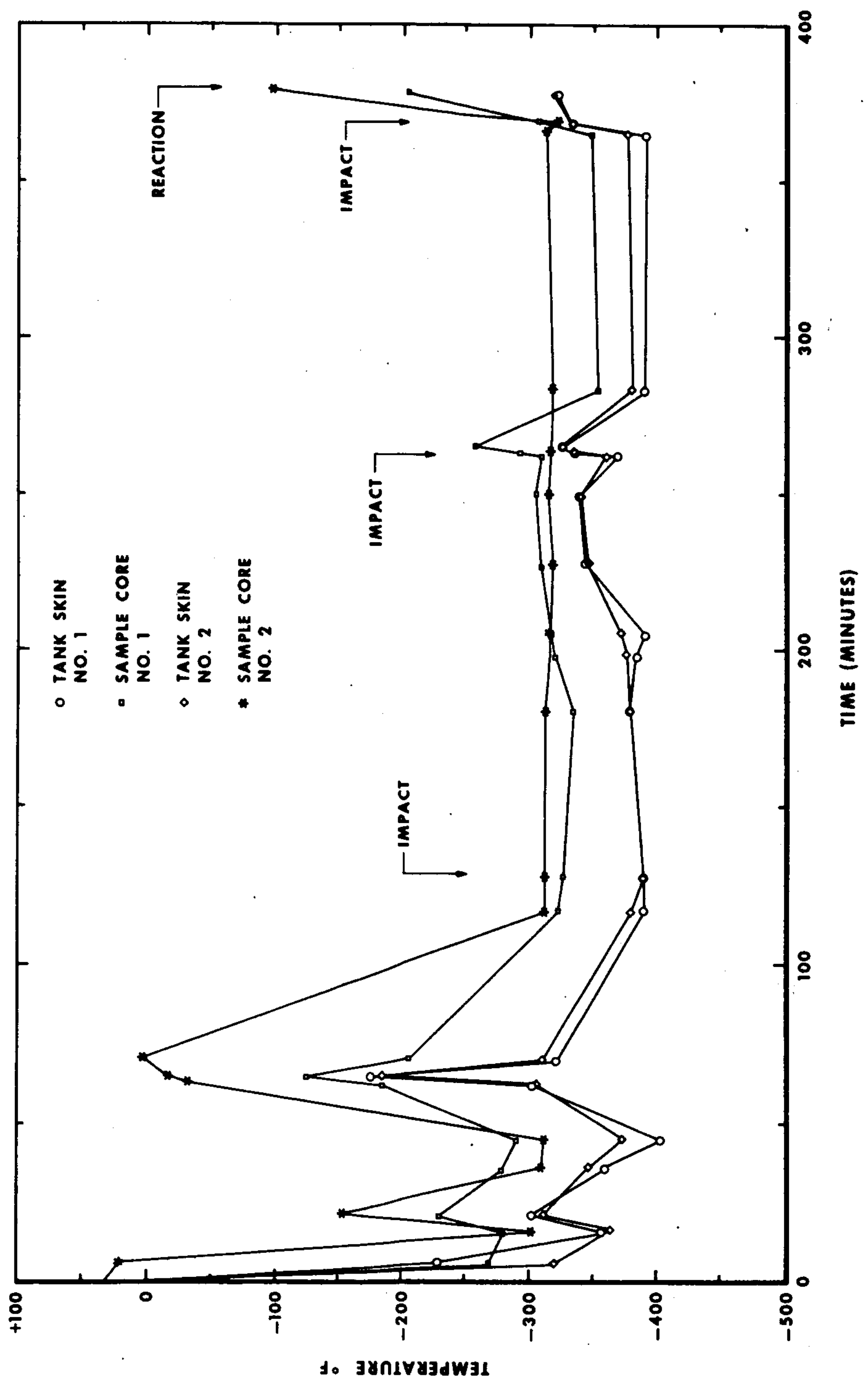

FIGURE 7
RESULTS FOR INSULATED TANK TEST
NO. 3

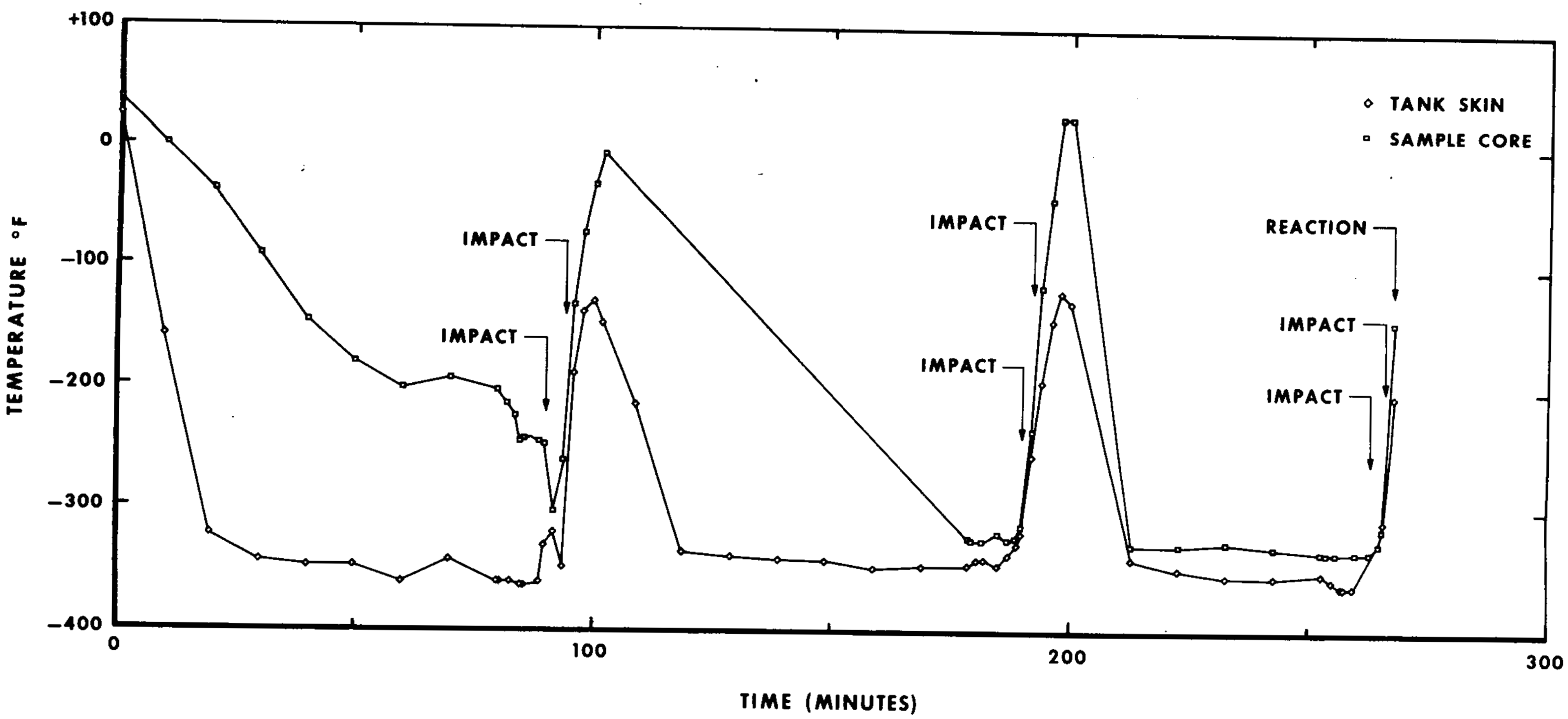

FIGURE 8
RESULTS FOR INSULATED TANK
TEST NO. 8

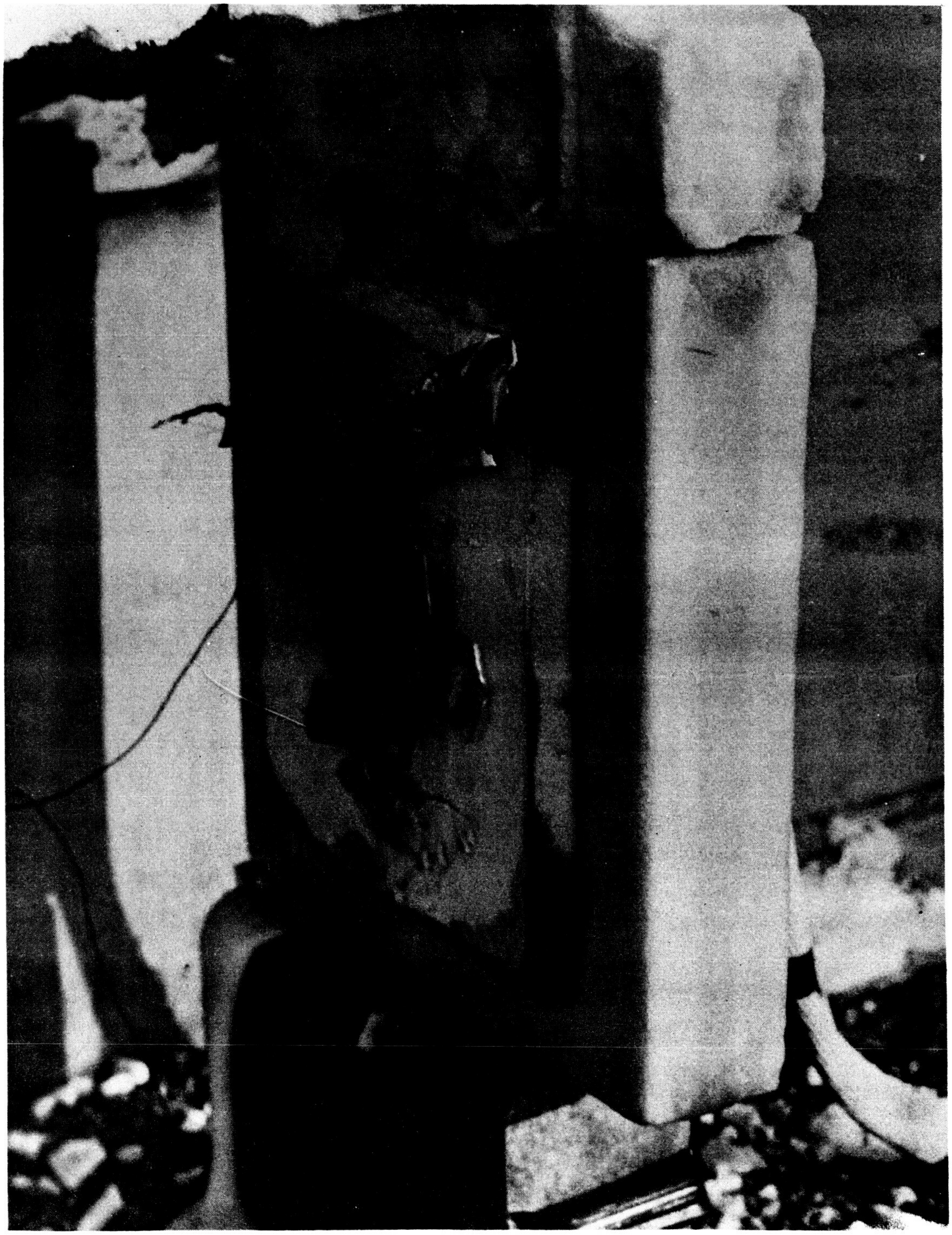

FIGURE 9
PHOTOGRAPH OF DAMAGED TANK AFTER TEST
NO. 8

FIGURE 10
PHOTOGRAPH OF DAMAGED TANK AFTER TEST NO. 3

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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