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MARTIN MARIETTA

THERMAL ANALYSIS OF UF_6 CYLINDER INSIDE A PROTECTIVE OVERPACK

Shin H. Park

Systems and Equipment
Technology Department

Process Support Division

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Prepared by the
Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee 37831
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ABSTRACT

To ensure their safety, cylinders containing reactor grade UF_6 are transported in protective overpacks. An overpack is designed to protect the UF_6 cylinder in a fire at least 1/2 hr in case of an accident. A thermal analysis was performed on a 30-in. diameter cylinder in a protective overpack to simulate various accident cases and compared with available experimental data. The analysis included the thermal performance of both a damaged and an undamaged overpack as well as the effect of moisture in the insulating layer of an overpack. The results indicate that an average cylinder surface temperature inside an overpack, after exposure to a fire for 1 hr, is still below the level where appreciable UF_6 phase change would occur that could cause a cylinder to rupture.

INTRODUCTION

A majority of the commercial nuclear reactors utilize uranium, enriched as uranium hexafluoride (UF_6) to an assay of 3.0%, for fuel. The UF_6 is transported throughout the country in 30-in. diameter cylinders which are encased in protective overpacks. The function of the overpacks is to prevent release of UF_6 by protecting the cylinders from physical damage and providing thermal insulation in case of fire. A cylinder will rupture when the internal pressure exceeds the ultimate hoop stress of the cylinder. Internal pressure, sufficient to rupture a cylinder, can be developed by expansion of liquid UF_6 on heating if the cylinder is completely filled with liquid UF_6 from phase change. The thermal design criteria specify that the overpack must protect the cylinder at least 1/2 hr in an oil fire. The purpose of this study is to verify compliance of the thermal design criteria with numerical models. The study was conducted with a numerical program, TRUMP,[1] developed by Lawrence Livermore National Laboratory. The study also included the effect of moisture contained in the insulation layer of an overpack. Both two- and three-dimensional models of a cylinder inside an overpack are used for the investigation. The exact nature of heat flux from a fire is a very complicated phenomenon involving the nature of fuel (gas or liquid), combustion conditions, and many other factors. Because of this, and in order to determine the effects of geometrical variations of the overpack, the source heat flux was simplified and held constant for all cases.

THERMAL ANALYSIS MODEL

TRUMP is a general purpose, heat transfer computer code capable of handling multidimensional systems with conduction, convection, and radiation heat transfer processes. TRUMP solves sets of nonlinear parabolic partial differential equations for both steady and transient cases. The overpack for a 30-in. diameter UF_6 cylinder is a horizontal loading type having two halves as shown in Fig. 1. A three-dimensional model, shown in Fig. 2, was used to investigate the temperature profiles of a prototype cylinder in cases where flames surrounded the overpack. The solid UF_6 mass inside a cylinder was assumed to be deposited radially in uniform thickness layers inward from the cylinder wall to simplify the analysis. In case of a full cylinder, solid UF_6 occupies more than 60% of the internal surface of a cylinder, which makes this simplification close to the real situation. The heat flux from a fire to an overpack is the sum from the radiation and convective heat transfer processes is expressed as

$$q = A \times [F_{12} \times (T_f^4 - T_s^4) + h_c \times (T_f - T_s)]$$

where F_{12} is the overall exchange factor, h_c is the natural convective heat transfer coefficient, and T_f and T_s, are the temperatures of the

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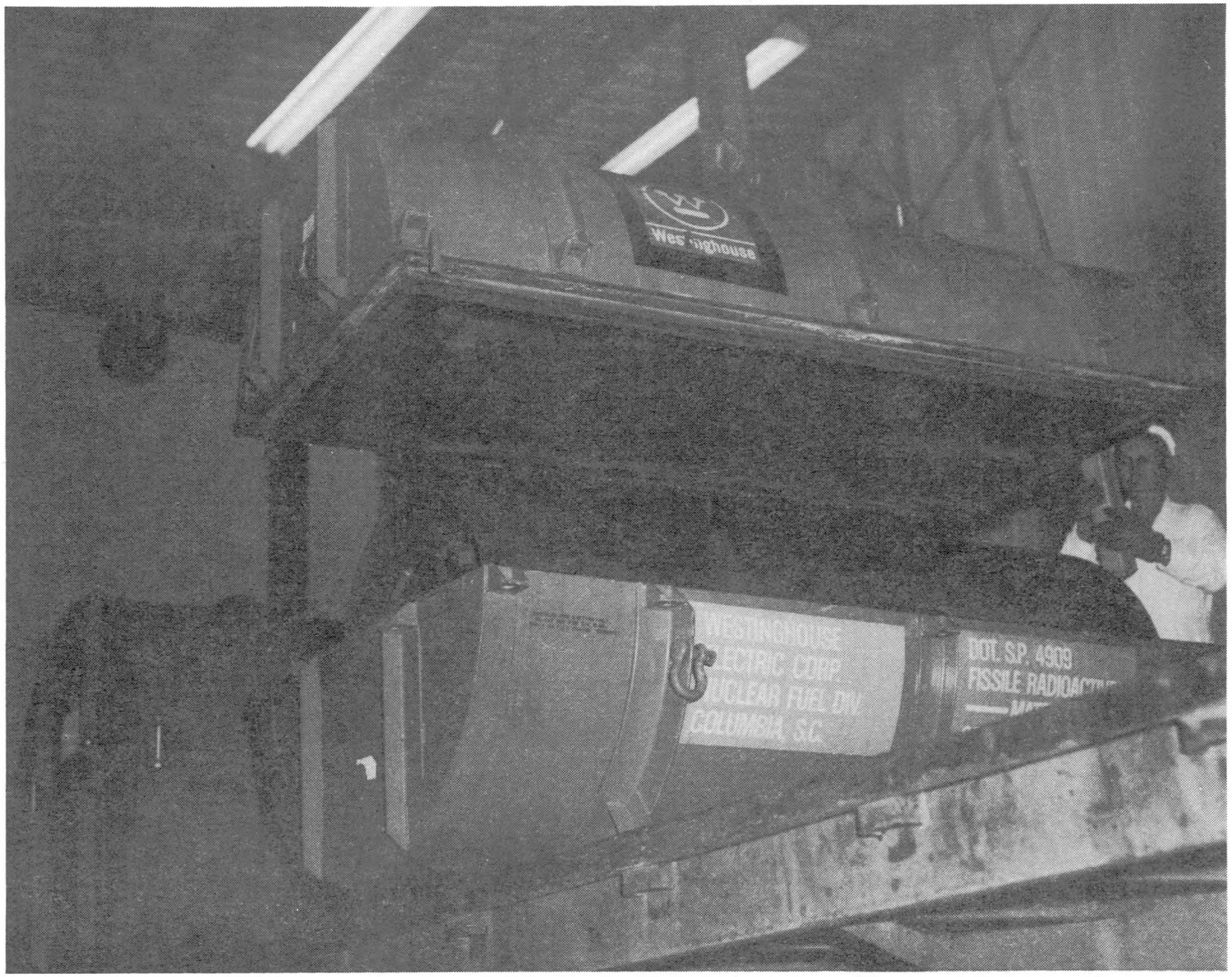

Fig. 1. 2 1/2 ton UF_6 cylinder overpack - horizontal loading type.

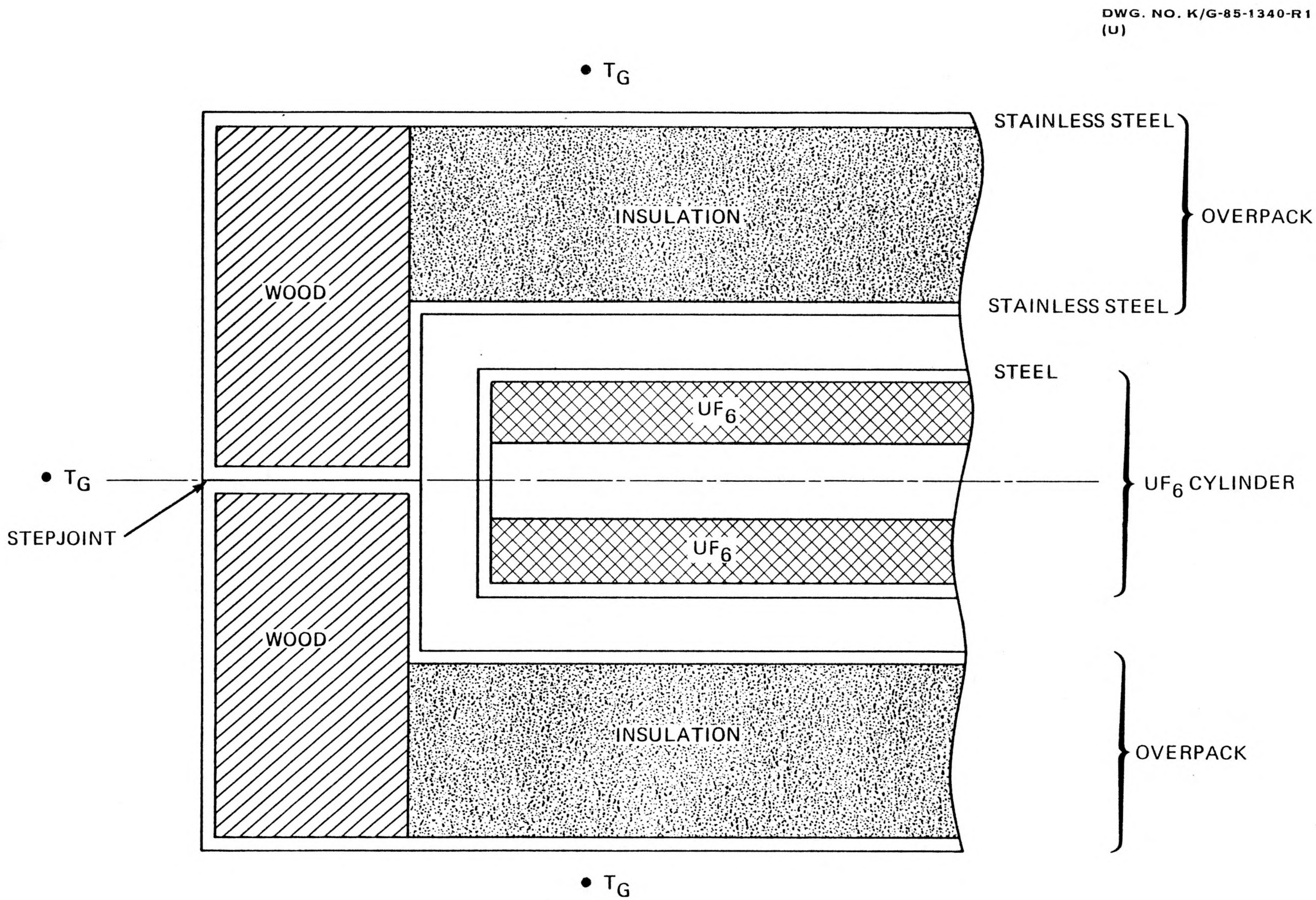

Fig. 2. Model of cylinder and protective overpack.

fire and the surface of the overpack, respectively. The cylinder surface temperature, T_c, will be the main observation point in the analysis. The heat exchange between the inner surface of an overpack and the outer surface of the cylinder is by radiation only. The initial temperature of the overpack system is 80.0°F. To simulate exposure to a fire, the overpack was suddenly exposed to a gas environment with an average temperature of 1,750°F. The gas emissivity used was 0.5. The effect of moisture in the insulating layer was analyzed by assuming that the total moisture content is concentrated in the middle of the insulation layer as shown in Fig. 3. Since the primary purpose of the investigation was to determine the temperatures of the cylinder and UF_6, the assumption did not introduce any gross error into the final analysis. The two-dimensional model, shown in Fig. 4, was used to investigate the cases where an overpack, in both damaged and undamaged conditions, is exposed to a localized fire. The main variables in those analyses are the fire width (L), distance between fire and the overpack (h), and crack size, 2θ. The overpack diameter is 43.30 in. In order to analyze the worst cases with damaged overpack, the damaged sections are exposed to fire in the analysis.

RESULTS

The effectiveness of the overpack to meet the thermal design criteria was investigated with the three-dimensional code. The worst case considered was an infinitely large fire source with the flames surrounding the entire overpack. The results of this case are compared in Fig. 5 with experimental data obtained by the Oak Ridge Gaseous Diffusion Plant (ORGDP) in 1966.[2] The agreement between the analytical and experimental results is fairly good considering the uncertainties that exist in experimental conditions. The cylinder surface temperature at the mid-section by the analysis is approximately 122°F after 1 hr in the fire even though the outside surface of the overpack is 1,742°F. Furthermore, the UF_6 temperature inside the cylinder is below the triple point temperature. Even if the higher values of the experimental data are chosen, the cylinder surface temperature after 1/2 hr in the fire would be below the triple point temperature of UF_6. This indicates that the overpack meets the thermal design criteria of protecting the cylinder for 1/2 hr when exposed to a fire.

The phenolic foam used in overpacks was manufactured based on some physical specifications such as density, porosity, etc., but no thermal property specifications. Since there was no record of a measured thermal conductivity value, a conductivity value that best fit the existing test results was obtained. Hence, a thermal conductivity value of 0.170 Btu/hr ft °F was used in this analysis which was the best fit to the existing data.[2] The validity of the code and other physical properties used in the code are proven in Fig. 6, where the temperature profile through the ends, whose thermal conductivity value is known, agreed well with the experimental value. The thermal conductivity value reported by L. Frazier,[3] however, was one order of magnitude lower than the value

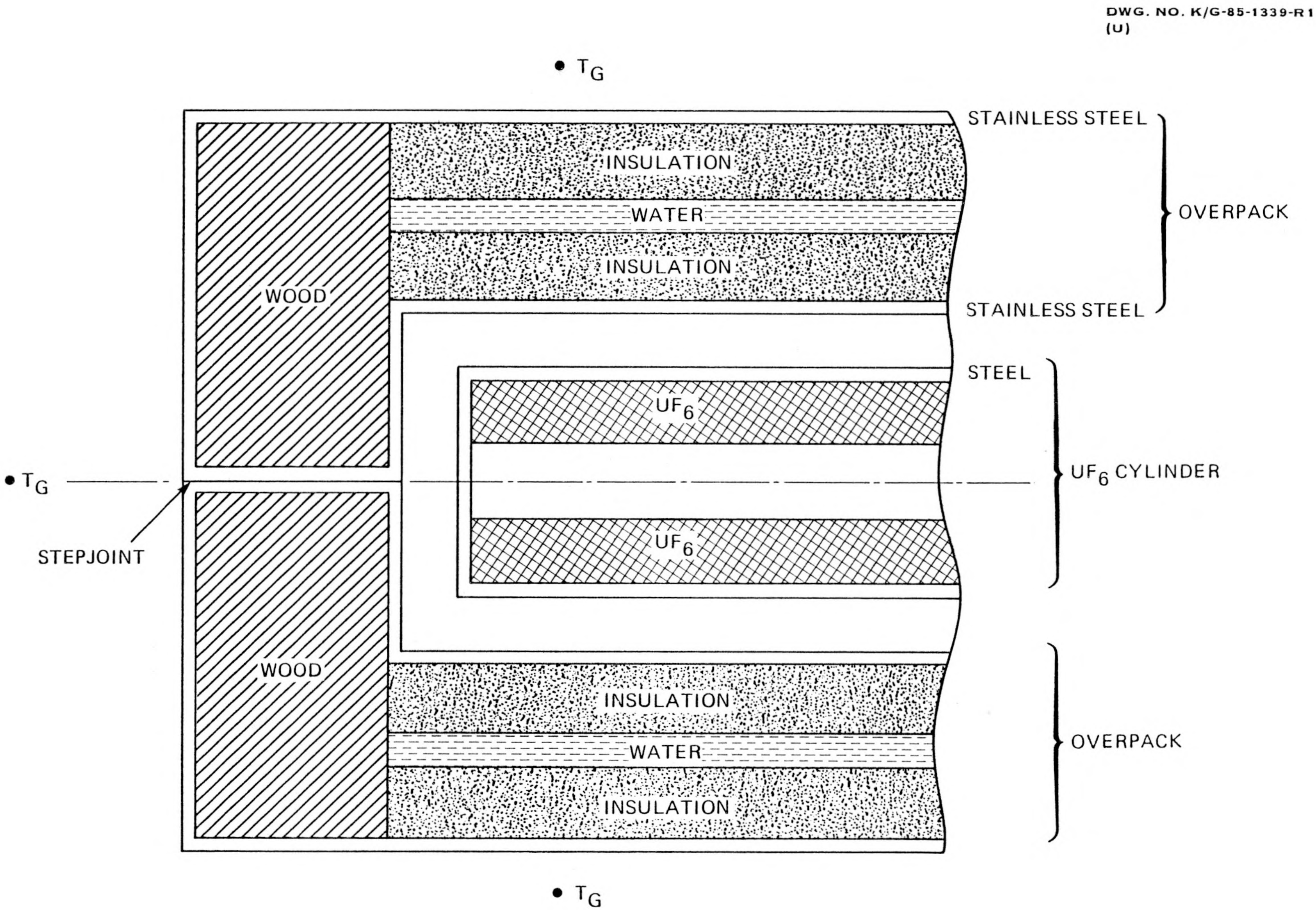

Fig. 3. Model of cylinder and protective overpack with moisture.

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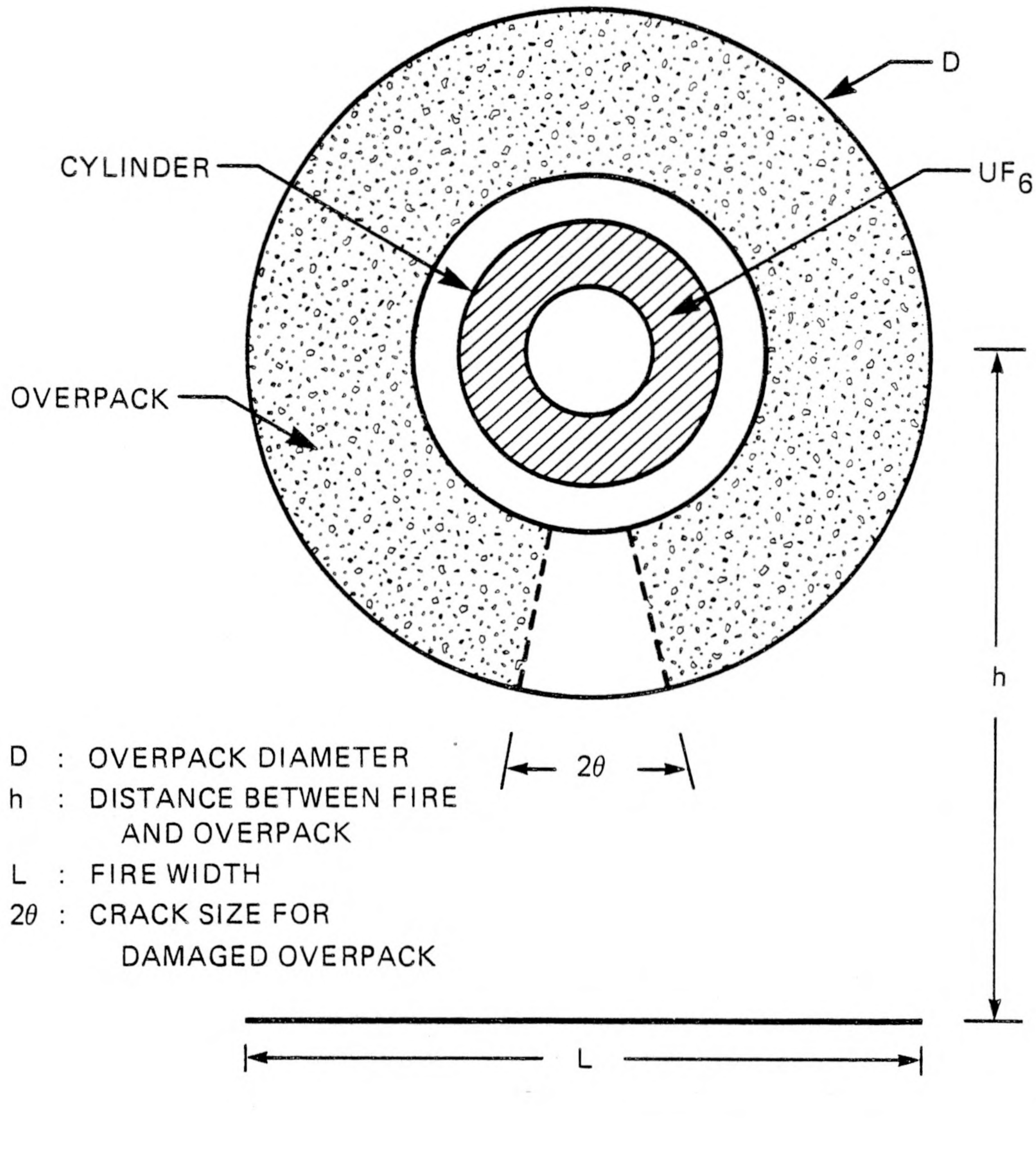

Fig. 4. Two-dimensional model of cylinder and overpack.

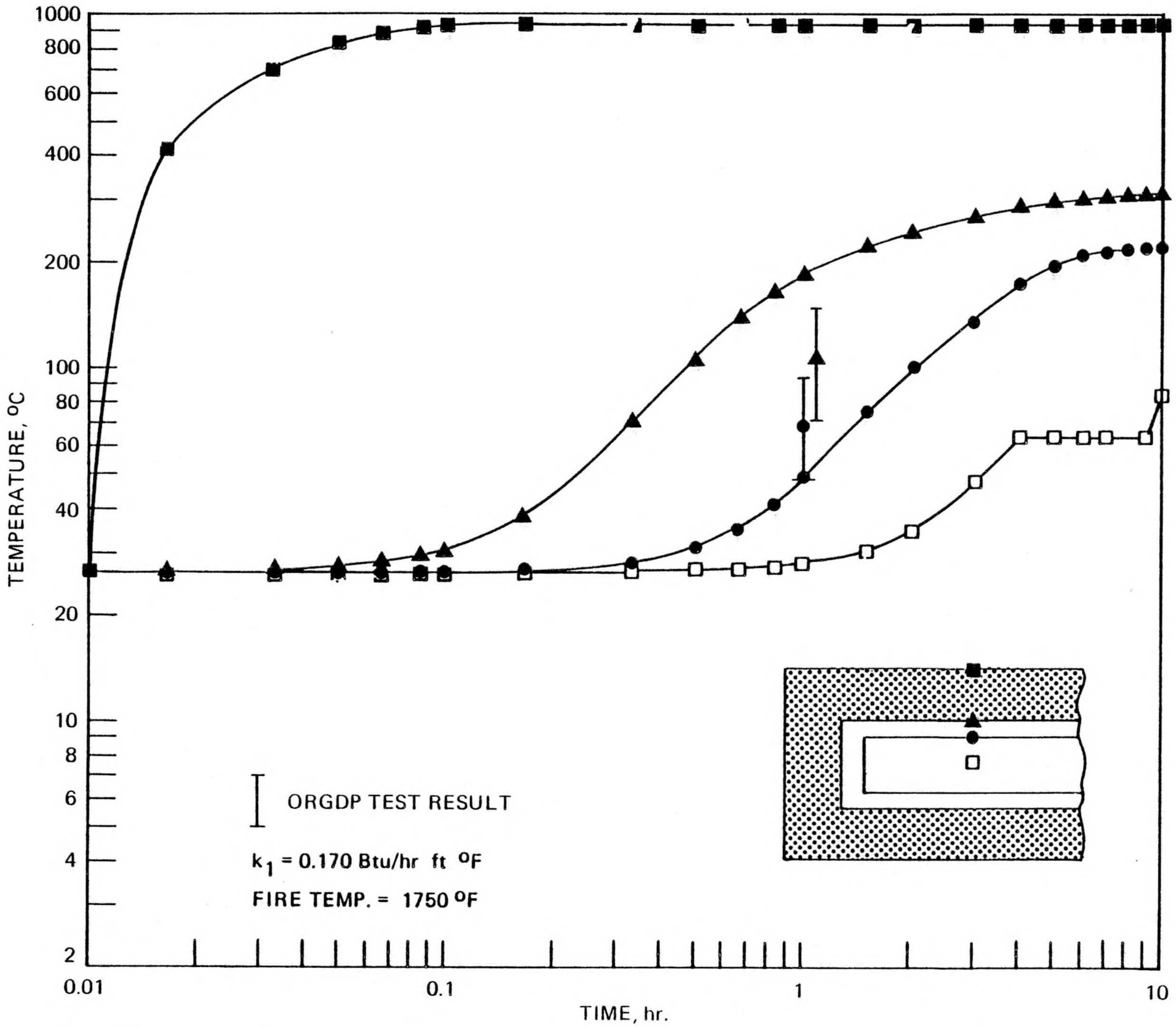

Fig. 5. Radial temperature variation at mid-section of the overpack with time in fire.

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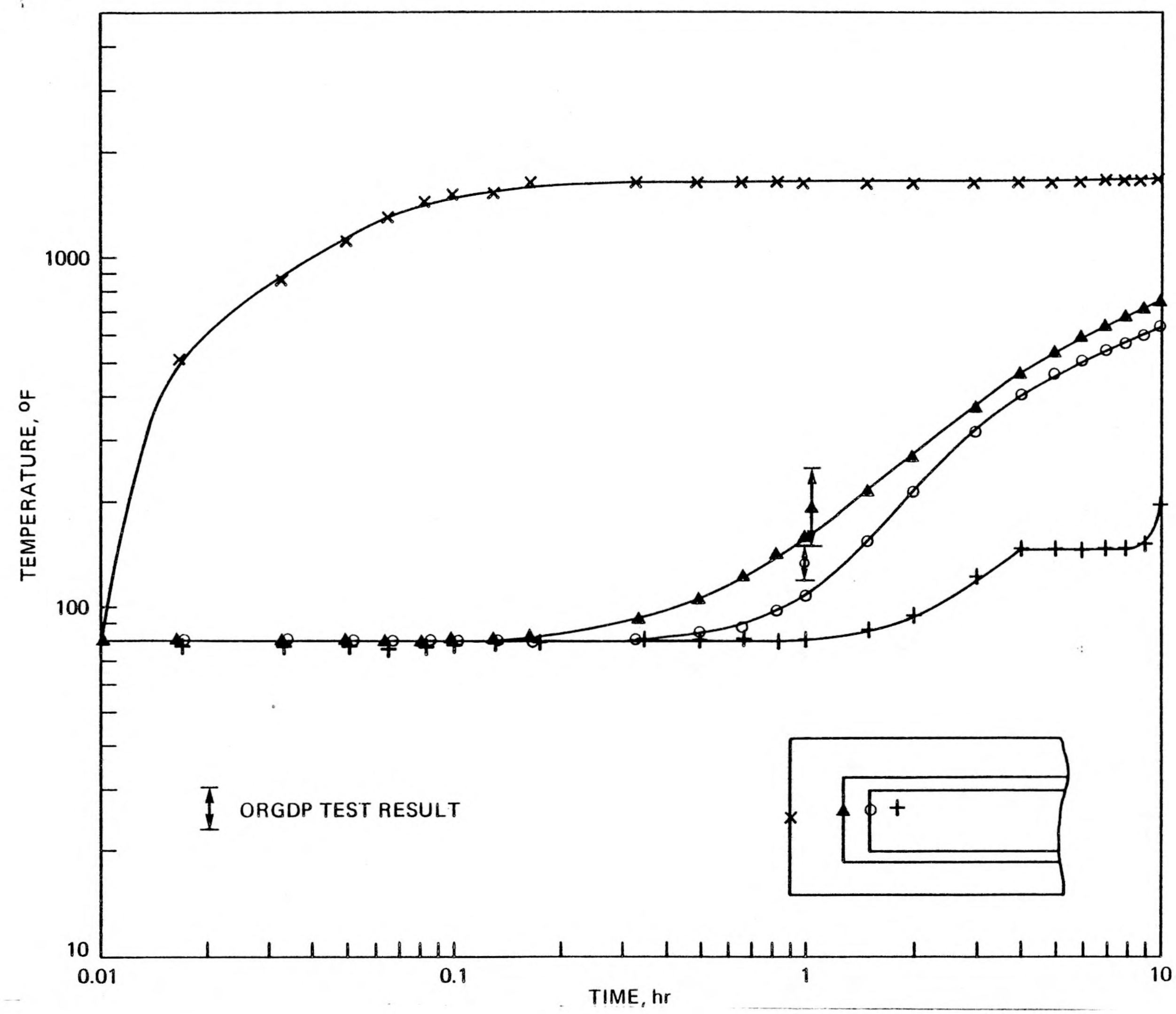

Fig. 6. Radial temperature variation with time--end section.

used in this report but in accordance with some other known insulating materials. Figure 7 compares the temperature profiles with the two thermal conductivity values of insulation mentioned along with the ORGDP experimental data. The thermal conductivity value used in this analysis, therefore, represents a conservative case compared to the measured value.

The effect of moisture in the insulation layer of the overpack was investigated with the model shown in Fig. 3. A total of 200 lb of moisture* was assumed to be absorbed in the insulation layer in this analysis. The moisture effects should result in a reduction of cylinder temperature with latent heat, thereby reducing the amount of sensible heat for temperature rise. This is evident in Fig. 8 where the radial temperature profiles from the outer surface of the overpack to UF_6 are plotted with and without moisture in the insulation layer of the overpack. The figure shows that the internal temperature of the overpack decreased by 50% with 200 lb of moisture, and the average water temperature was still below its boiling point.

Other cases analyzed in this report are with localized exposure to a fire in both damaged and undamaged overpacks. Figure 9 shows the surface temperature profiles of the overpack and the cylinder when an undamaged overpack is exposed to a fire whose width is equal to the diameter of the overpack. Varying the distance between the fire and the overpack does not change significantly the temperatures of the surfaces facing the fire. The larger deviation in T_s/T_c for the positions not facing the fire may have resulted from the ambient temperature variation, which was inversely proportional to the distance, h, from the fire. The effect of varying the fire width shown in Fig. 10 is more significant on the temperature profiles than the distance variation. The highest cylinder surface temperature obtained was 118°F with L/D=5, while temperatures at the backside of the overpack were around 86°F for both cases. This may indicate that the circumferential heat transfer is minimal compared to the radial heat exchange. The cases of damaged overpacks exposed in a fire are analyzed in Figs. 11 and 12. The worst case results when the damaged side is exposed directly to the fire. Figure 11 indicates the effect of a 20° opening in the overpack. The cylinder surface temperature at the exposed side increased to approximately 572°F, but the back side remained around 140°F. The convective heat flux due to the opening in the overpack for the nodes not directly exposed to the fire was not included in the analysis. Hence, the temperatures obtained in the analysis may be lower than that including the convection. Varying the L/D from 10 to 1 decreases the temperatures roughly 20%. Figure 12 shows the cylinder surface temperature profiles as a function of crack sizes. The comparison of crack sizes demonstrates the dominance of the radial heat exchange compared to circumferential heat transfer. The case of undamaged overpack is included to show the effect of crack on the temperature profile. Even with a 20° crack, the

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*The maximum amount of moisture absorbed by the phenolic foam varied widely. The 200 lb used in this analysis is based on actual measurement of overpack weight at saturation condition.

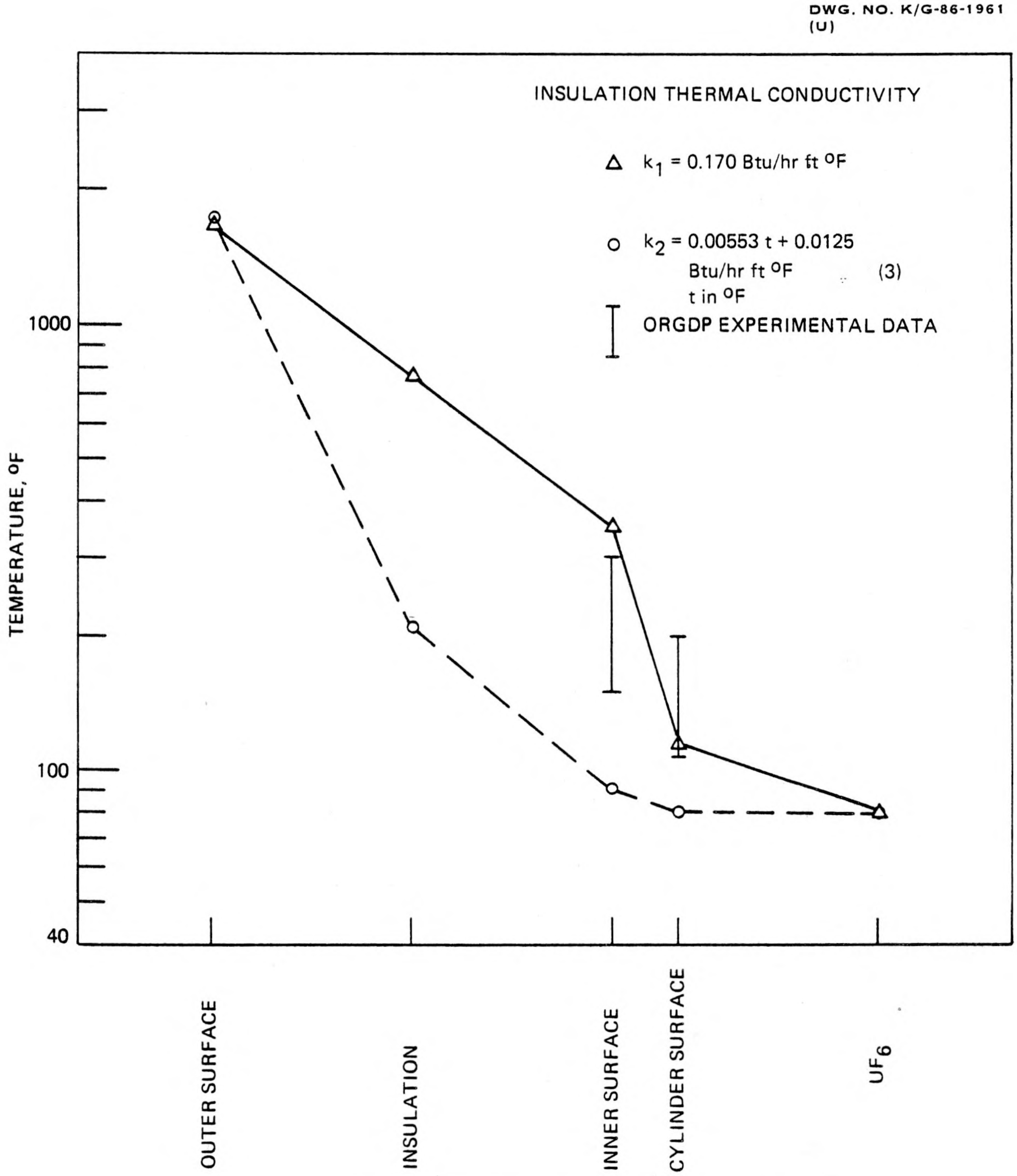

Fig. 7. Variation of temperature profile with thermal conductivity of insulating material.

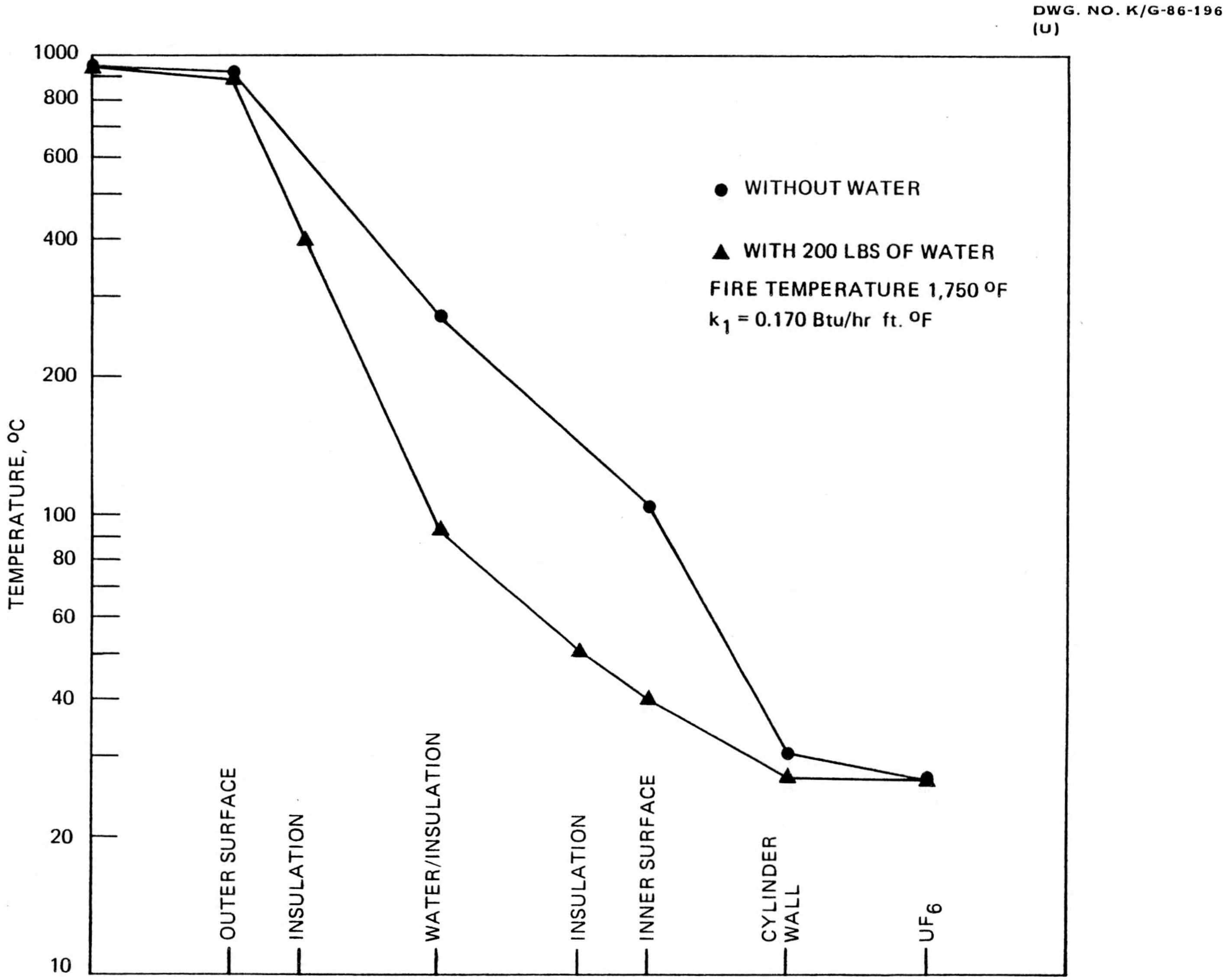

Fig. 8. Radial temperature variation with moisture content in insulation at 1/2 hour in fire.

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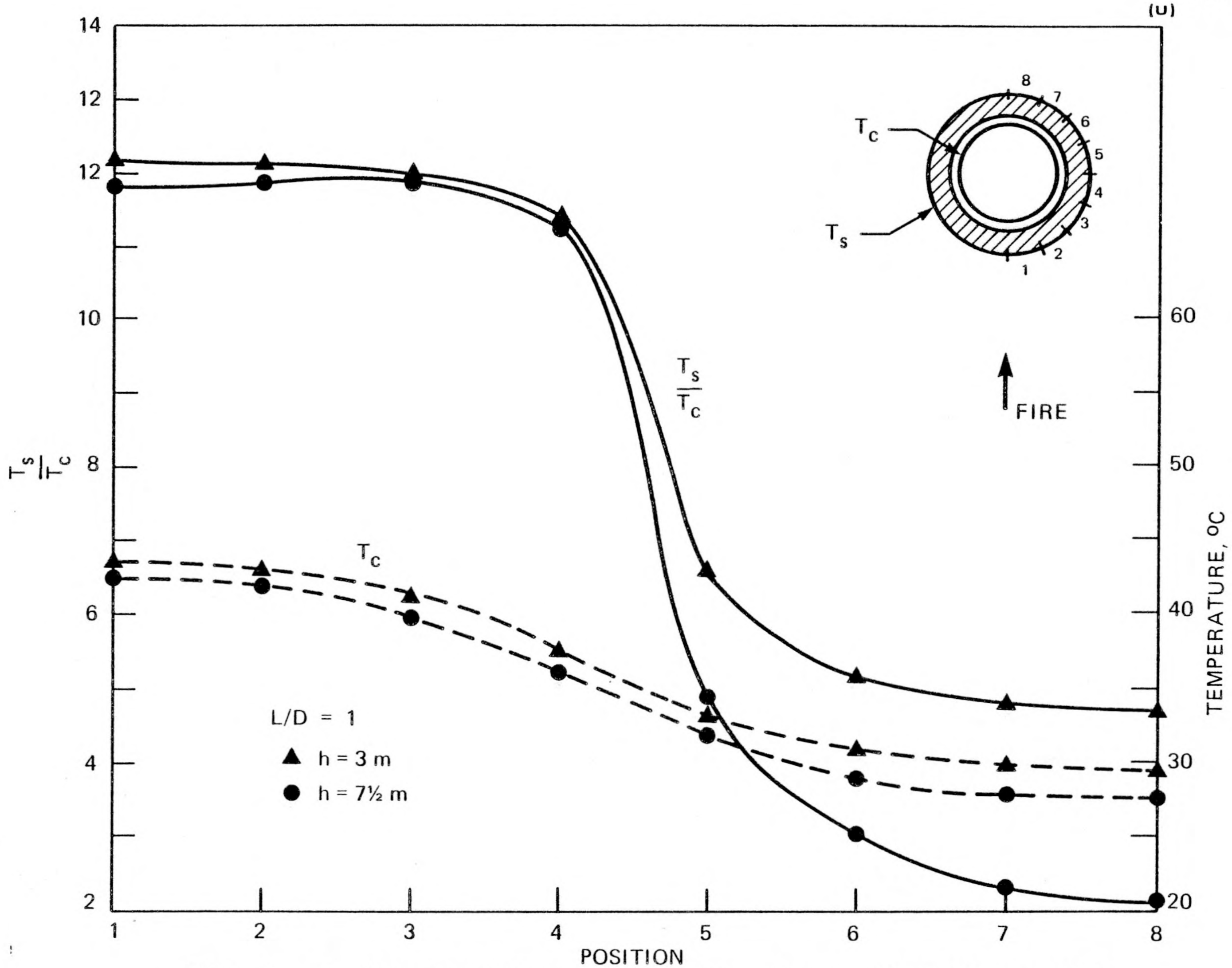

Fig. 9. Surface temperature variations of an undamaged overpack with distance between fire and overpack at 1 hour in fire.

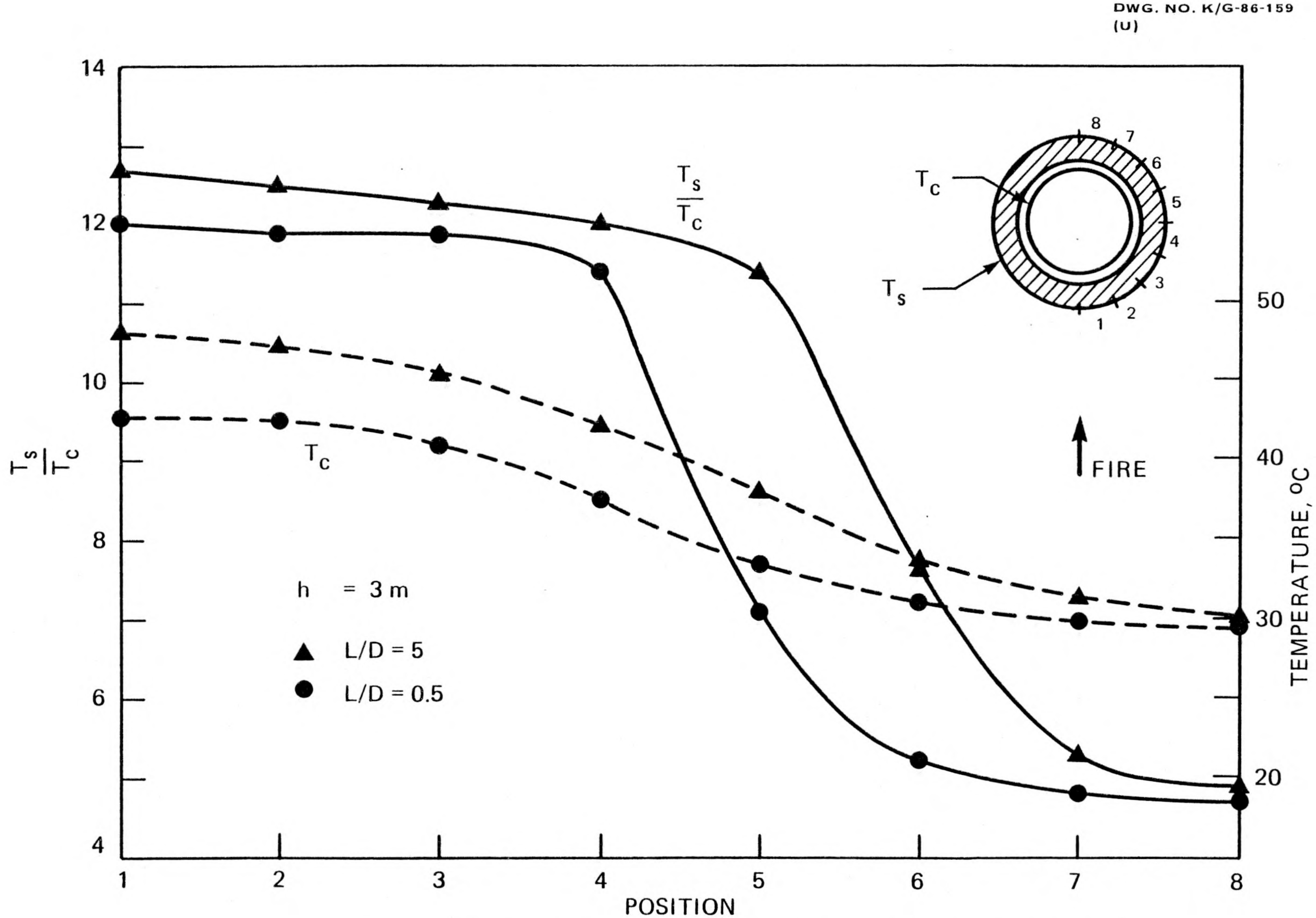

Fig. 10. Surface temperature variations of an undamaged overpack with fire width at 1 hour in fire.

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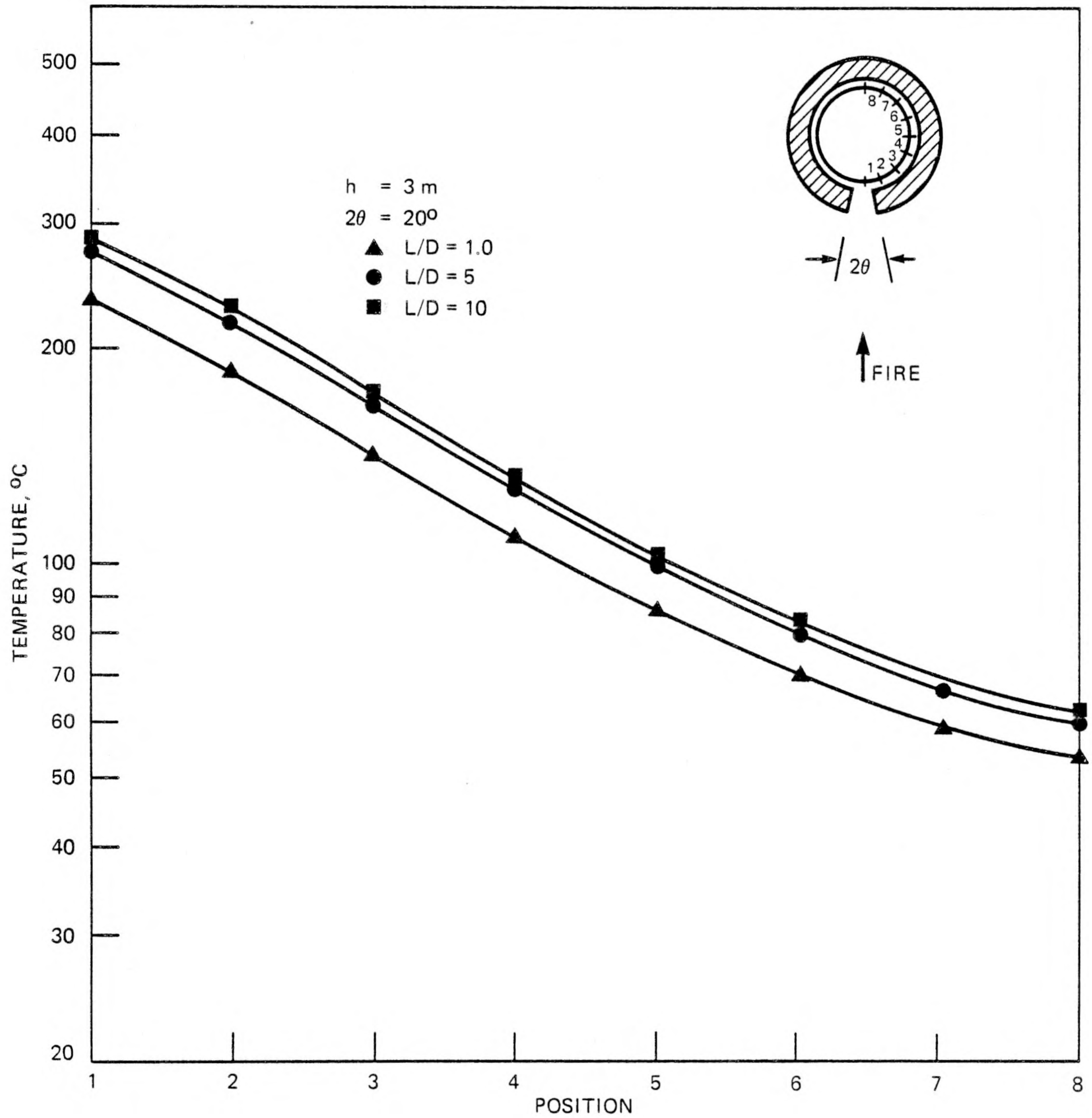

Fig. 11. Cylinder surface temperature variation of a damaged overpack with fire width at 1 hour in fire.

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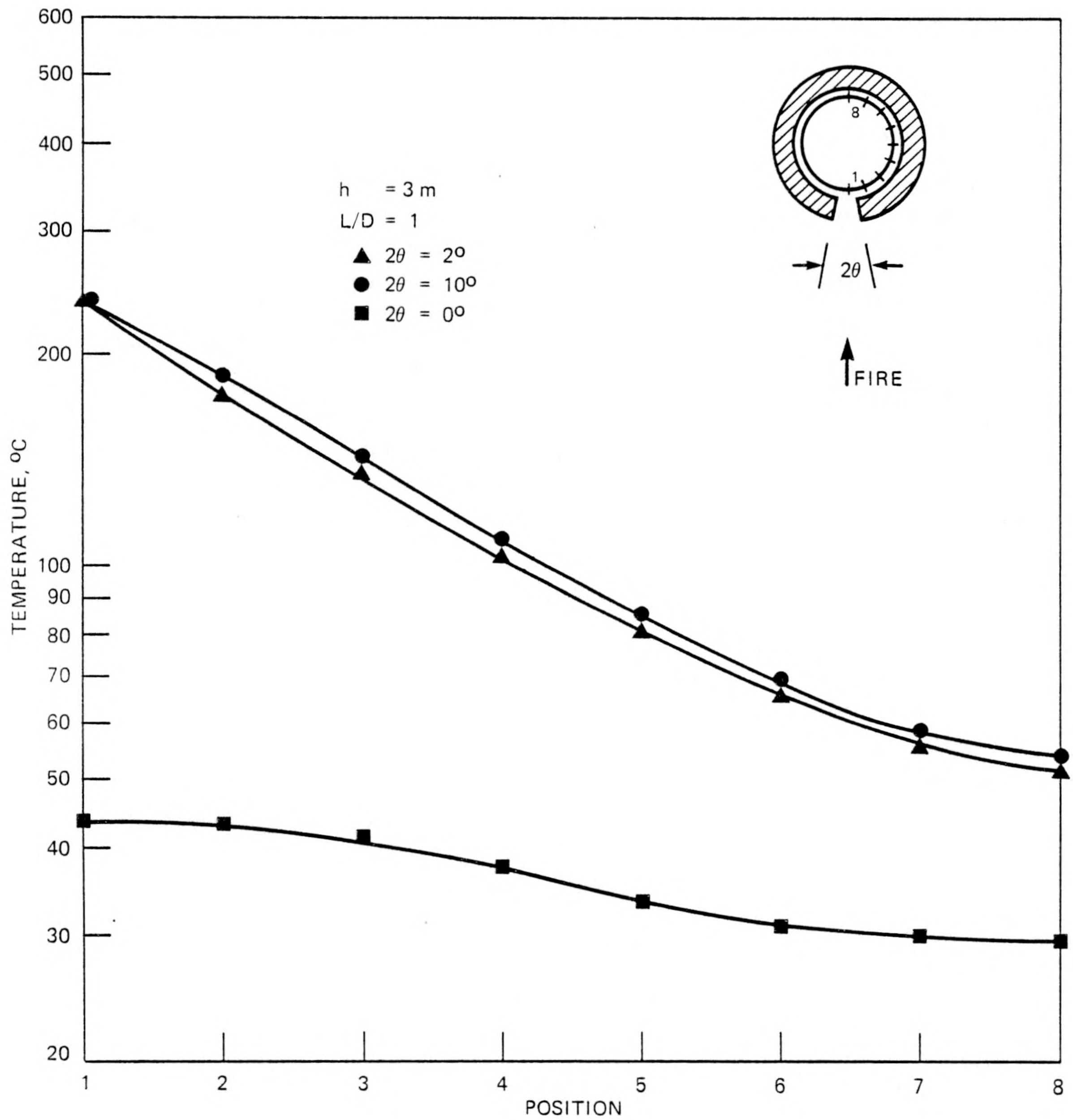

Fig. 12. Cylinder surface temperature variation of a damaged overpack with crack sizes at 1 hour in fire.

average UF_6 temperature in a cylinder was below the triple point after 1 hr in the fire. In an actual situation, there would be a temperature gradient in the UF_6 and localized liquification would occur. The real hazard occurs if the solid UF_6 melts and fills the entire cylinder.

CONCLUSIONS

The cylinder with overpack which is used to transport 3.0% U^{235} enriched uranium has been investigated. The study proves that the overpack is capable of protecting the cylinder at least 1/2 hr in a fire at an average temperature of 1,750°F. The effect of moisture inside the insulation layer acts as a heat sink to reduce heat flux to the cylinder. Cases analyzed involving damaged cylinders with the damaged area directly exposed to the fire suggest that a cylinder is still safe after 1 hr in a fire. Actual cases may differ from this analysis due to complications involved in the nature of the fire, damage conditions, and other factors which are more complicated than the simplified model used in this report. However, if the overpack is not damaged, it will meet the thermal design criteria.

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