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HEAT RADIATION THROUGH STEAM IN DIRECT CONTAINMENT HEATING*

by

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In current discussions of the direct heating of containment atmospheres (DCH) during a hypothetical severe accident in certain PWR's, involving meltdown and discharge via steam blowdown of substantial core materials (corium) from primary into secondary containment, there is concern about the potential for containment loading resulting from the release of large amounts of thermal energy from the airborne corium debris or aerosol directly to the containment atmosphere in sufficient quantities to cause overpressurization.

Calculations applicable to the time scales associated with blowdown and thermal energy release show that the thermal radiation mode of heat transfer plays a role ranging from major to dominant in the heat removal from airborne corium, depending upon exact mechanical and thermal conditions defined by mechanistic studies of the ejection and dispersal processes. Whether this partitioning of the status of heat transfer mechanisms is of major significance to the conversion of thermal to mechanical energy and containment loading, is dependent upon the extent to which emitted radiant heat is transmitted through steam to containment boundaries (walls, etc.) in comparison to that absorbed directly by the steam-air atmosphere. The purpose of this study is to provide some preliminary indications based upon existing correlations, data, models, about transmission of high temperature radiant heat through steam at distances and conditions of significance to DCH.

Figure 1 shows the transmission results determined from modified Hottel emissivity charts,[1] for a black body emission source at several temperatures and steam at 600 K. We can immediately discern three features of the absorption curves. The percentage of the heat emitted which is then absorbed by the steam, (1) is lower for higher temperatures of the corium source, (2) is predominantly absorbed quickly, i.e. at short distances, causing flattening of the curves, (3) is a small percentage of total emission for realistic corium temperatures. These observations can also be deduced from steam infrared spectral considerations, from the locations of windows and intensities of absorption bands. To determine the transmission through distances greater than ~2 ft. from Hottel charts requires extrapolation of Fig. 1 curves; (these curves also do not include a pressure broadening factor of approximately 1.2). Thus, there remains major uncertainties at distances beyond 5 ft.

Some estimates of the long-pass transmission of black body radiation can be made from two sources, (a) atmospheric (humid air) infrared spectral transmission data, (b) correlations based upon absorption bands and associated modeling. Figure 2 shows results based upon digitizing, integrating, and distance adjustment of atmosphere data[2] to equivalent transmission depths at 3 steam atmospheres of pressure. Figure 3 shows corresponding calculated results determined via. the exponential band modeling of Tien.[3]

The disparity of Fig. 2 and Fig. 3 calculated results stem from distinct advantages and disadvantages. While the humid air measurements span the infrared spectrum more completely (to include long distance absorption in the windows) they do not account for pressure broadening, and hence match up better with Fig. 1. They also include absorption by other atmospheric molecular constituents, principally CO_2. Thus these curves are likely to predict too little absorption by steam at short distances, and too much at larger distances. They also cannot account for alternate steam temperatures. Figure 3 more accurately includes the effects of the primary four absorption bands of steam. It includes pressure broadening effects, and so is likely to be more accurate at short distances (~2 ft.). It can be adjusted for alternate steam temperatures. However, it omits all window absorption, and therefore becomes increasingly uncertain as transmission distance and source temperatures increase.

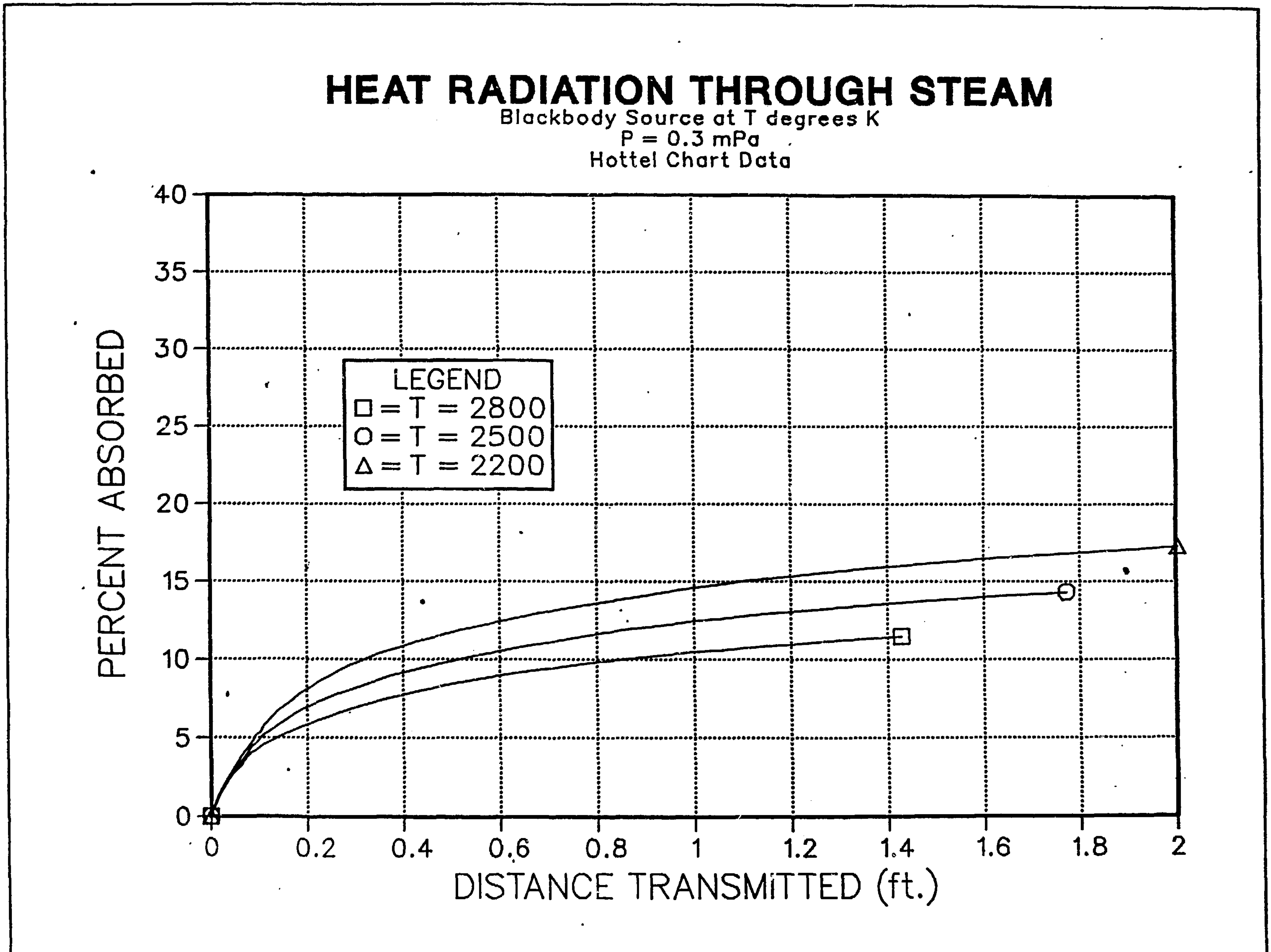
Despite disparities and uncertainties, the calculations presented in Figs. 1-3 suggest that thermal radiation is a major mitigating mechanism for containment loading due to direct containment heating and warrants detailed attention in the interest of ascertaining greater public safety in severe accident scenarios.

References

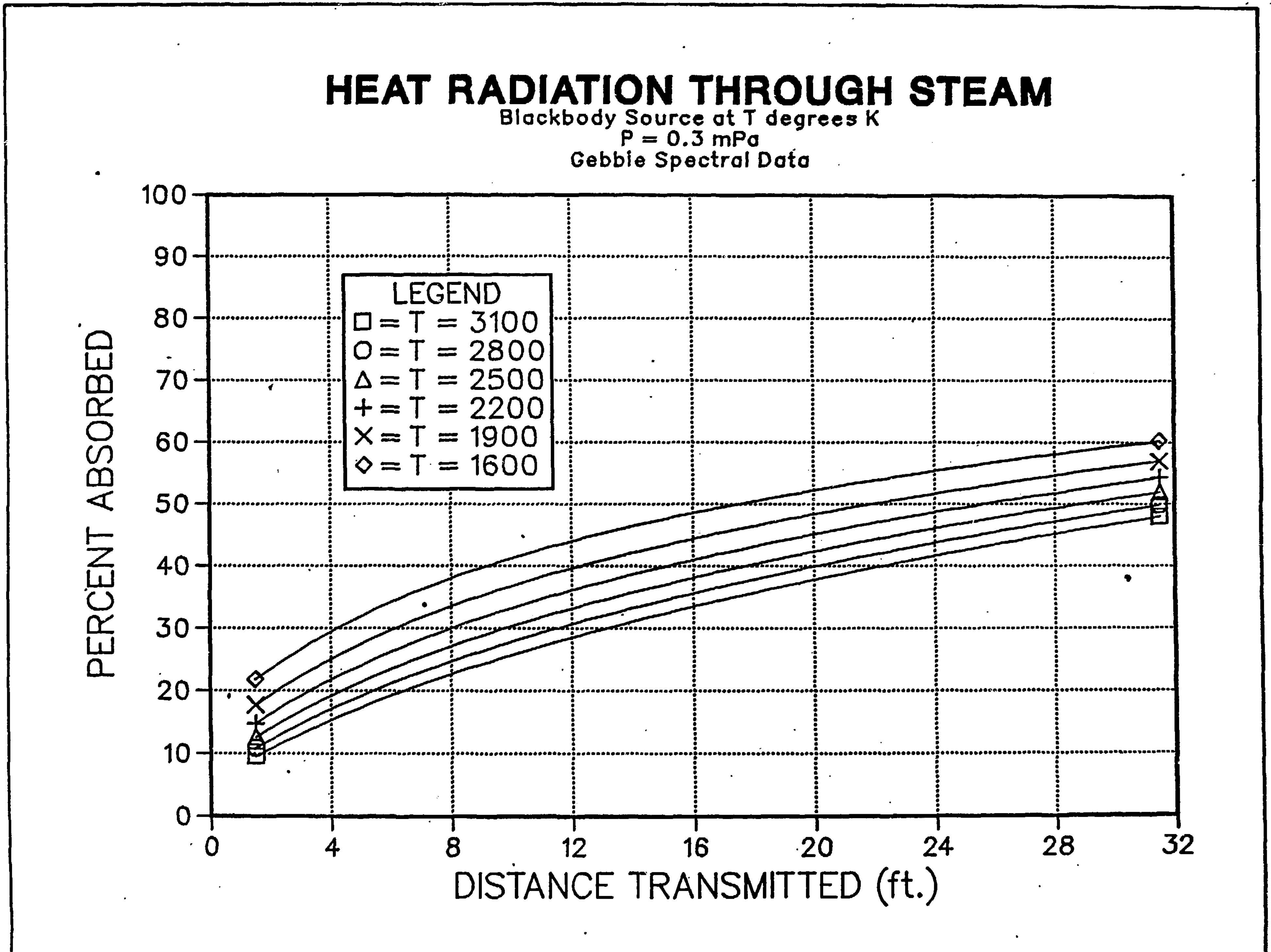
1. H. C. Hottel and A. F. Sarofim, "Radiative Transfer," McGraw-Hill, New York (1967).

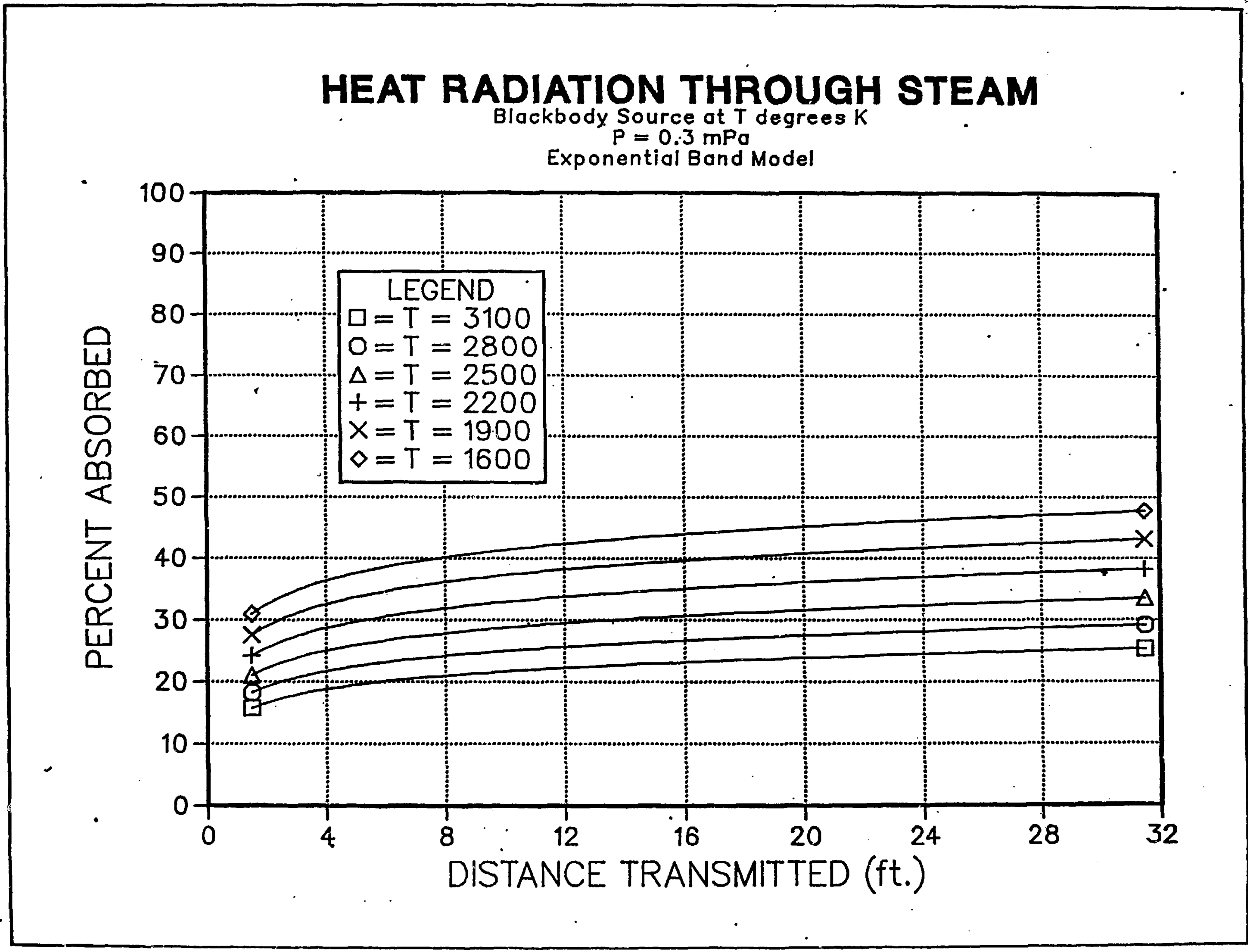
2. H. A. Gebbie, W. R. Harding, C. Hilsum, A. W. Pryce, and V. Roberts, Proc. Roy. Soc. (London) A206, 87 (1951).

3. C. L. Tien in "Advances in Heat Transfer," Vol. 5, T. F. Irvine, Jr. and J. P. Hartnett eds., Acad. Press, New York (1968).



HEAT RADIATION THROUGH STEAM
Blackbody Source at T degrees K
P = 0.3 mPa
Hottel Chart Data
LEGEND
□ = T = 2800
O = T = 2500
Δ = T = 2200
PERCENT ABSORBED
DISTANCE TRANSMITTED (ft.)
0
5
10
15
20
25
30
35
40
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


HEAT RADIATION THROUGH STEAM
Blackbody Source at T degrees K
P = 0.3 mPa
Gebbie Spectral Data
LEGEND
□ = T = 3100
○ = T = 2800
△ = T = 2500
+ = T = 2200
× = T = 1900
◇ = T = 1600
PERCENT ABSORBED
DISTANCE TRANSMITTED (ft.)
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32



HEAT RADIATION THROUGH STEAM
Blackbody Source at T degrees K
P = 0.3 mPa
Exponential Band Model
LEGEND
□ = T = 3100
○ = T = 2800
△ = T = 2500
+ = T = 2200
× = T = 1900
◇ = T = 1600
PERCENT ABSORBED
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32
DISTANCE TRANSMITTED (ft.)