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THERMAL BEHAVIOR OF CONCRETE*#

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The treatment of post accident containment problems requires an understanding of concrete when subjected to high temperatures due to thermal contact with molten core materials and/or coolant. Sodium spills on concrete are of special concern because the resulting chemical reactions are collectively exothermic.[1] Among other possible safety problems, the gas released by the thermal decomposition of concrete has the potential of producing pressures sufficient to endanger the integrity of cell liners.[2]

Insight into these phenomena has been gained by constructing a computer model and performing a series of studies. The code presently calculates the following quantities as functions of space and time: 1) temperature of the cell liner, 2) temperature of the concrete, 3) ablation rate of the heated concrete surface, 4) the water, water vapor, and carbon dioxide evolution rates, 5) the total gas discharged, and 6) the decomposition energy absorption rate for each decomposing species. The code has been used to predict the decomposition of concrete both with and without a containment liner.

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DISCLAIMER

Results of the code compare very well with experimental data measured by Muir.[4] Figure 1 compares measured and calculated temperature profiles. Figure 2 depicts some typical water and carbon dioxide evolution rates as a function of depth in the concrete.

Thermal decomposition of concrete is characterized by loss of structural strength, by melting, and by the release of evaporable water, chemically constituted water, and carbon dioxide. Powers[3] found that the latter processes are well approximated by first order reaction rate equations. For calcareous concrete, we use:

$$d\alpha_1/dt = (1 - \alpha_1)\ \exp(14.07)\ \exp(-5557/U) \tag{1}$$

$$d\alpha_2/dt = (1 - \alpha_2)\ \exp(28.31)\ \exp(-20560/U) \tag{2}$$

$$d\alpha_3/dt = (1 - \alpha_3)\ \exp(16.8)\ \exp(-19362/U) \tag{3}$$

where α is the fraction of reactant decomposed; U is absolute temperature, the constants are empirical parameters, and the subscripts 1,2,3 respectively denote evaporable water, chemically constituted water and carbon dioxide. Each of the above equations is solved by a second order predictor-corrector finite difference scheme.

Careful treatment of the boundary conditions for the heat flow equation,

$$\rho c_p \frac{\partial U}{\partial t} = \kappa \nabla^2 U + \dot{Q} \qquad (4)$$

is required at the ablating melt-concrete interface. This is achieved by transforming to a moving coordinate system defined by

$$x' = x - vt \qquad (5)$$

where v is the velocity of the ablating surface, $x' = 0$. The resulting equation is approximated by a Crank-Nicholson finite difference equation.

The source term for the heat flow equation consists of the endothermic reaction energies from the rate equations (1) through (3) and an exothermic term arising from the condensation of water vapor in the volume of concrete that is just below the boiling point of water. A self consistent solution of the three rate equations and the heat flow equation with sources is obtained.

Conclusions from this study are: 1) The calculated temperature profile agrees well with experimental data. 2) The plateau at 373°K in the temperature profile has been shown by this study to be due to a heat source, not a sink. It is hypothesized that the source is due to the condensation of pressure driven steam. The calculated plateau in Figure 1 was obtained by simulating this effect. 3) The ablation rate calculated by the code falls within the experimental range measured by Muir. 4) The gas evolution rates calculated by the code agree with the experimental work of Powers. 5) The shape of the temperature profile in the concrete is relatively insensitive to the rate of gas evolution due to decomposition. 6) The release rates of H_20 and $C0_2$ are strongly dependent on the shape of the temperature profile.

References

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3. D. A. Powers, A.N.S. Trans., 26, 400 (1977).
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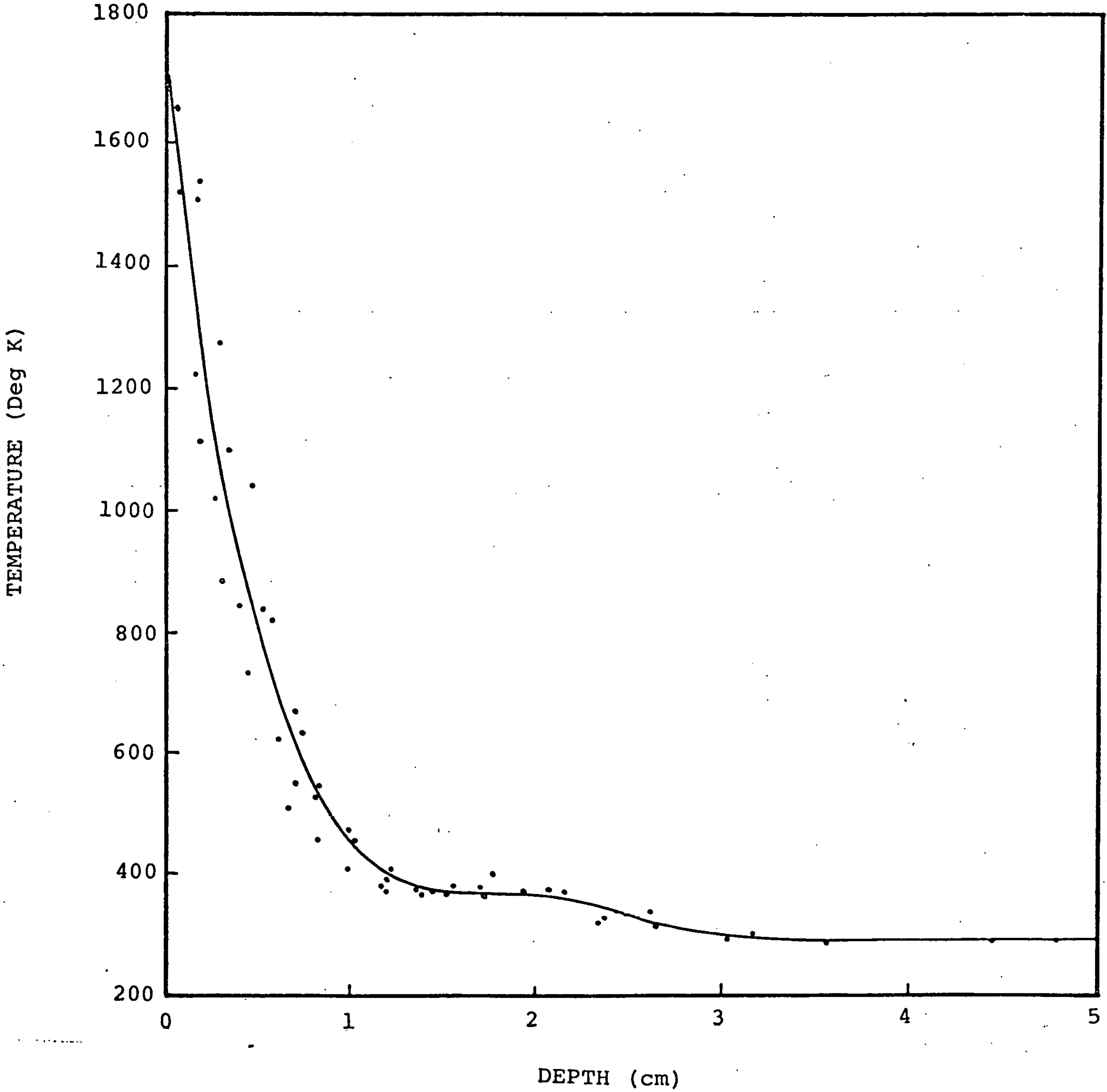

Fig. 1 Temperature vs depth in basaltic concrete at t = 60 sec. The solid curve is calculated. The points are Muir's experimental data.

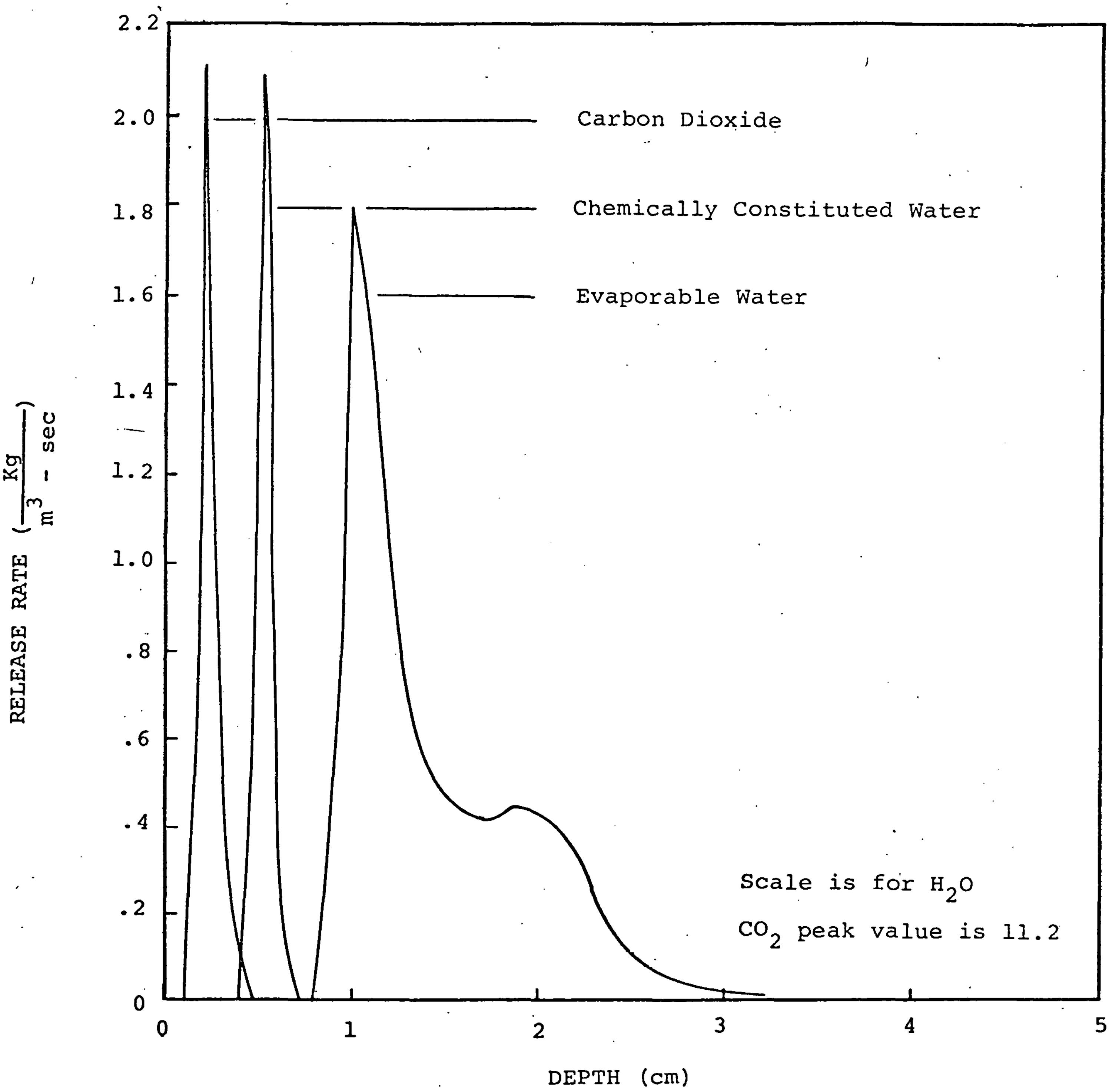

Fig. 2 Release rates of carbon dioxide, chemically constituted water, and evaporable water vs depth in calcareous concrete for the temperature profile of Fig. 1.