

THERMAL BEHAVIOR OF CONCRETE*#

Richard L. Knight
Sandia Laboratories
Albuquerque, New Mexico

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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

MASTER

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.

*This work was supported by the United States Nuclear Regulatory Commission.

#This is a summary of a presentation to be made to the American Nuclear Society, San Francisco, November 27-December 2, 1977.

Key

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

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. Powers³ found that the latter processes are well approximated by first order reaction rate equations. For calcareous concrete, we use:

$$d\alpha_1/dt = (1 - \alpha_1) \exp(14.07) \exp(-5557/U) \quad (1)$$

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

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

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,

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

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

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

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^oK 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_2O and CO_2 are strongly dependent on the shape of the temperature profile.

References

1. D. A. Dahlgren, Personal Communication (1977).
2. R. K. Hilliard, "Sodium Concrete Reactions, Linear Response and Sodium Fire Extinguishment", HEDL SA-983, (1975).
3. D. A. Powers, A.N.S. Trans., 26, 400 (1977).
4. J. F. Muir, A.N.S. Trans., 26, 399 (1977).

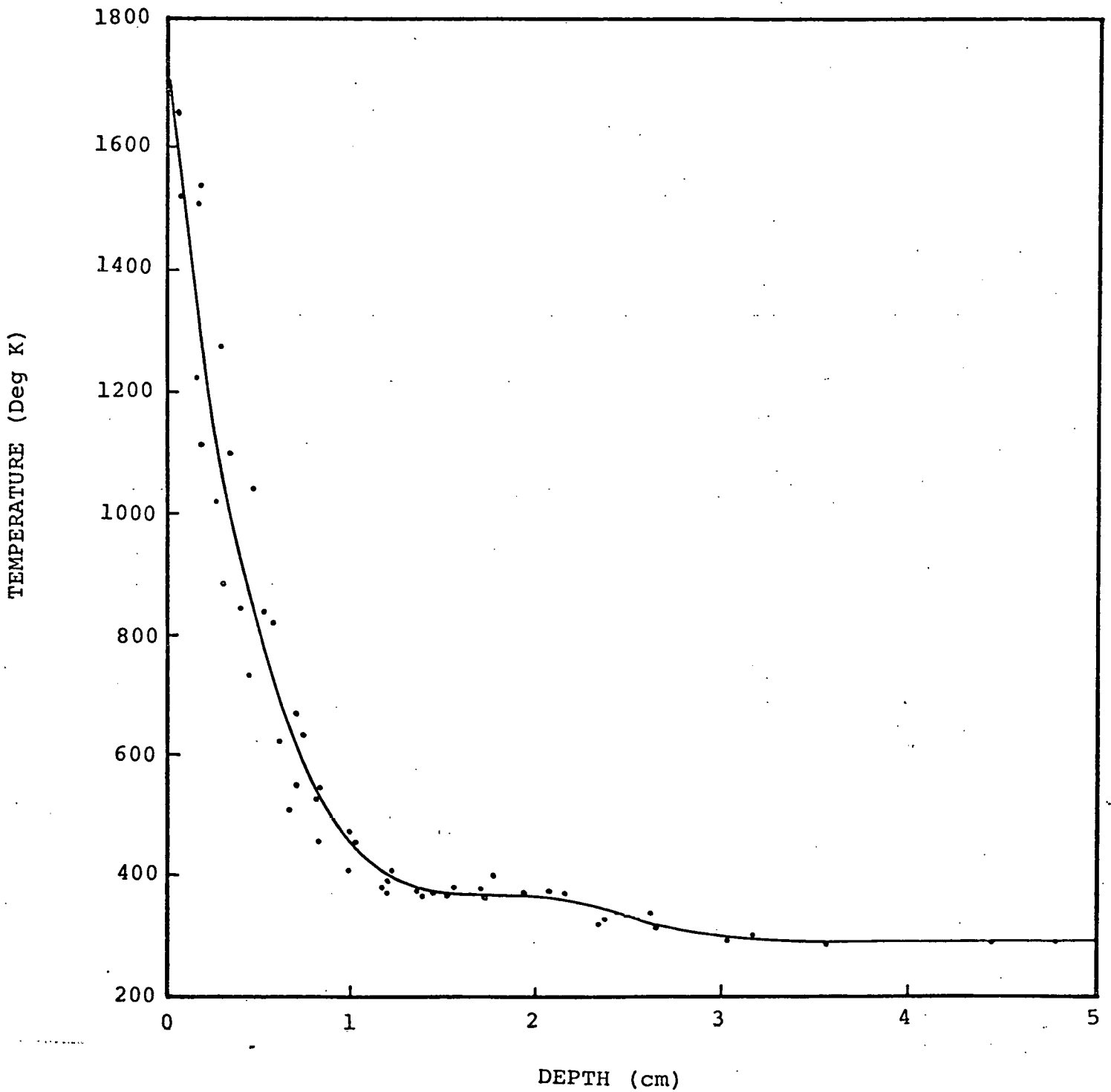


Fig. 1 Temperature vs depth in basaltic concrete at $t = 60$ sec. The solid curve is calculated. The points are Muir's experimental data.

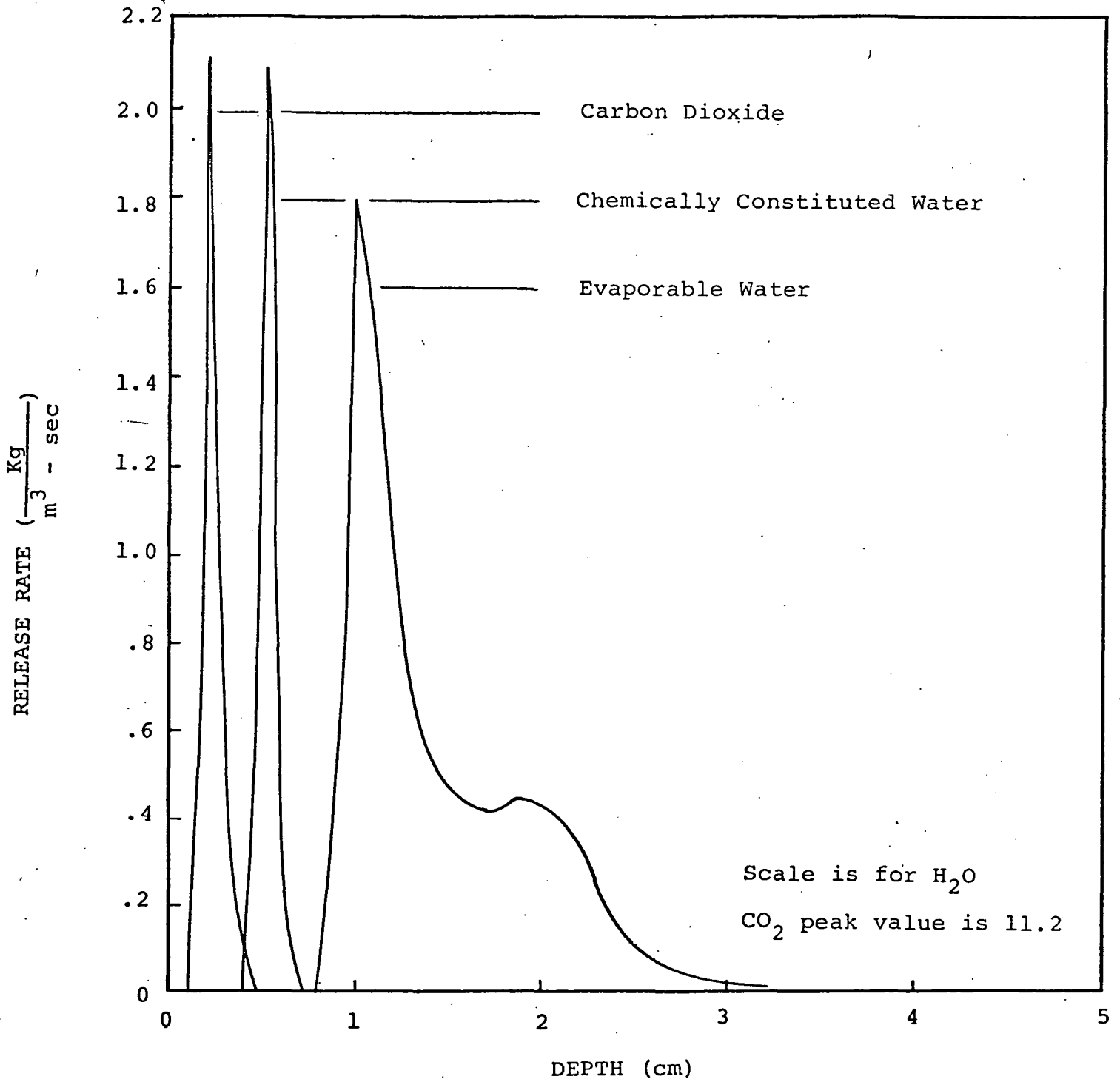


Fig. 2 Release rates of carbon dioxide, chemically constituted water, and evaporable water vs depth in calcareous concrete for the temperature profile of Fig. 1.