This report describes only the mechanics and thermodynamics part of this project coordinate with Dr. Brian Spalding, Oak Ridge National Laboratory.

1. Research Objective:

The main objective of the mechanics and thermodynamics subtask is to develop a powerful computational model to evaluate the effect of the heating regime on the on the contaminated concrete wall or slab.

2. Research Progress and Implications:

After the problems reported last year, which delayed progress and necessitated a no-cost extension of this grant, the research has in this final year of the grant progressed smoothly, without any delays. All the planned work will be completed at the extended termination deadline of 9/14/03.

The proposed scheme of decontamination of radionuclides from concrete structures, in which rapid microwave heating is used to spall off a thin contaminated surface layer, has been analyzed. The analysis is split in two parts:

(1) The hygrothermal part of the problem, which consists in calculating the evolution of the temperature and pore pressure fields, and
(2) the fracturing part, which consists in predicting the stresses, deformations and fracturing. The former is assumed to be independent of the latter, but the latter is coupled to the former.

The heat and moisture transfer governing the temperature and pore pressure fields induced by the decontamination process is analyzed using an improved form of Bazant-Thonguthai model for heat and moisture transfer in concrete at high temperatures. The rate of the distributed source of heat due to the interaction of microwaves with the water contained in concrete is calculated on the basis of the standing wave normally incident to the concrete wall. Since the microwave time period is much shorter than the time a heating front takes to propagate over the length of microwave, and since concrete is heterogeneous, the Ohmic power dissipation rate is averaged over both the time period and the wavelength. The reinforcing bars parallel to the surface are treated as a smeared steel layer. The recently developed microplane model M4 is emplyed as the constitutive model for nonlinear deformation and distributed fracturing of concrete.

Based on this mathematical model, a numerical analysis of the process of decontamination of radionuclides from concrete by microwave heating is conducted. The aim of the analysis is to determine the required microwave power and predict whether and when the contaminated surface layer of concrete spalls off. The finite element method is used for the stress and fracture analysis. However, as a departure from previous studies, the finite volume method is adopted to treat the heat and moisture transfer, in order to prevent spurious numerical oscillations that plagued the finite element response at moving sharp interface between the saturated and unsaturated concrete, and to deal accurately with the jumps in permeability and in sorption isotherm slope across the interface. The effects of wall thickness, reinforcing bars, microwave frequency and power are studied numerically. As a result of this analysis, the mechanism of spalling of rapidly heated concrete typical of microwave heating is clarified.

3. Planned Activities:

During the remaining three months of funding, the importance of short-time viscoelasticity and its effect on prevention of localization of thermal cracking will be studied. Further simulations will be run to elucidate the role of declining pressure of the heated pore water on the spalling. The rate-of-deformationn effect on the spalling will be further examined.

4. Publications:

Main Publications:

1. Bazant, Z.P., and Zi, G. (2003). ``Decontamination of radionuclides from concrete. I. Theory." ASCE J. of Engrg. Mech. , submitted to.

2. Bazant, Z.P., and Zi, G. (2003). ``Decontamination of radionuclides from concrete. II. Computations." ASCE J. of Engrg. Mech. , submitted to.

3. Bazant, Z.P., and Zi, G. (2001). ``Spatial and temporal scaling of concrete response to extreme environments". Concrete Under Severe Conditions (Proc., 3rd Int. Conf., CONSEC'01), N. Banthia, K. Sakai and O.E. Gjorv, eds., University of British Columbia, Vancouver, BC, 3--10.

Related Background Publications:

4. Zi, G., and Bazant, Z.P. (2002). ``Continuous relaxation spectrum for concrete creep and its incorporation into microplane model M4." J. of Engrg. Mech. ASCE 128 (12) 1331--1336.

5. Zi, G., and Bazant, Z.P. (2001). ``Continuous relaxation spectrum of concrete creep and its incorporation into microplane model M4." Creep, Shrinkage and Durability Mechanics of Concrete and Other Quasi-Brittle Materials. (Proc., 6th Intern. Conf., CONCREEP-6, held at MIT, Cambridge), F.-J. Ulm, Z.P. Bazant and F.H. Wittmann, eds., Elsevier, Amsterdam 2001, 239--243.

6. Bazant, Cedolin, L., and Cusatis, G. (2001). ``Temperature effect on concrete creep modeled by microprestress-solidification theory." Creep, Shrinkage and Durability Mechanics of Concrete and Other Quasi-Brittle Materials. (Proc., 6th Intern. Conf., CONCREEP-6, held at MIT, Cambridge), F.-J. Ulm, Z.P. Bazant and F.H. Wittmann, eds., Elsevier, Amsterdam 2001, 197--204.

7. Bazant, Z.P. (2001). ``Prediction of concrete creep and shrinkage: Past, present, future." Nuclear Engrg. and Design 203 (1), Jan., 27--38.

8. Bazant, Z.P., and Kaplan, M.F. (2002). Concrete at High Temperatures: Material Properties and Mathematical Models , 2nd edition, Pearson Education, Edinburg, UK.

9. Carol, I., Jir\' asek, M., and Bazant, Z.P. (2001). ``New thermodynamic framework for microplane model." Fracture Mechanics of Concrete Structures (Proc., FraMCoS-4 Int. Conf., Paris), R. de Borst, J. Mazars, G. Pijaudier-Cabot and J.G.M. van Mier, eds., Swets \& Zeitlinger (A.A. Balkema Publishers), Lisse, 519--524.

10. Cusatis, G., Bazant, Z.P., and Cedolin, L. (2001). ``3D lattice model for dynamic simulations of creep, fracturing and rate effect in concrete." Creep, Shrinkage and Durability Mechanics of Concrete and Other Quasi-Brittle Materials. (Proc., 6th Intern. Conf., CONCREEP-6, held at MIT, Cambridge), F.-J. Ulm, Z.P. Bazant and F.H. Wittmann, eds., Elsevier, Amsterdam 2001, 113--118.

11. Bazant, Z.P., Caner, F.C., Carol, I., Adley, M.D., and Akers, S.A. (2000). ``Microplane model M4 for concrete: I. Formulation." J. of Engrg. Mechanics ASCE 126 (9), 944--953.

12. Caner, F.C., and Bazant, Z.P. (2000). ``Microplane model M4 for concrete: II. Algorithm and Calibration." J. of Engrg. Mechanics ASCE 126 (9), 954--961.

13. Bazant, Z.P., Caner, F.C., Adley, M.D., and Akers, S.A. (2000). ``Fracturing rate effect and creep in microplane model." J. of Engrg. Mechanics ASCE 126 (9), 962--970.