UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 61, MOLTEN SODIUM INTERACTION WITH BASALT CONCRETE

REFERENCES:
1. SAND 79-0938, Molten Sodium Interaction with Basalt Concrete and Siliceous Firebrick (NUREG/CR-0934)
2. Letter E. G. Case to S. Levine, March 7, 1978, Redirection of Confirmatory Research Program to Investigate Inherent Retention Capability for Sodium and Core Debris (RR-NRR-76-2)

Introduction and Summary Conclusions

This memorandum transmits the results of tests conducted at Sandia Laboratories on the interactions of molten sodium with basalt concrete and siliceous fire-brick (Reference 1). This work was carried out in response to Reference 2 which requested redirection of the generic program on sodium-concrete interaction to support the NRR safety review of FFTF. Specifically, emphasis and priority of testing with the FFTF types of concrete aggregate, basalt and magnetite, were requested. Thus, large scale sodium-basalt concrete interaction tests have been carried out and brief reports were forwarded and included in Supplement No. 1 to the FFTF Safety Evaluation Report. Reference 1 documents these tests in detail and includes chemical phenomenology, water release data, and the results of smaller scale separate effects tests.

The results of the basalt concrete tests from Reference 1 provide a firm basis for several conclusions. An exothermic reaction will result from a sodium spill onto concrete under certain conditions of temperature and sodium-concrete contact. The reaction will continue until the sodium is consumed at sustained liner penetration rates of about 2.5 cm per hour. Products of the reaction do not plug defects in liners (test defect was 0.6 x 15 cm) but build up with sufficient force to readily deform the steel liners. The siliceous firebrick also reacted readily with the sodium.

Reference 1, therefore, answers some of the questions and substantiates the staff position in NUREG-0358, August 1978, which questioned the lower sodium-concrete reaction rates and purported self-limiting concrete penetration assumed by the FFTF contractor. The principle results have been forwarded previously and were included as Appendices F through H of NUREG-0358, Supplement 1, May 1979.

Results

The results of the large-scale tests of sodium-basalt concrete interaction are provided in final report form in Reference 1. There are no major corrections to the information supplied previously for Supplement 1 of NUREG-0358, but the more complete evaluation of the test data may show minor numerical differences. Reference 2 also requested tests on magnetite concrete. One such large-scale test has been completed, additional testing is in progress, and the results will be the subject of a future report.

The high temperature sodium-concrete facility used in these tests has a sodium pour capacity of 250 kg and has a data recording system for temperature, pressure, gas identification, gas flow, moisture, strain and concrete penetration rate information. The test crucibles were poured in accord with FFTF specifications with basalt aggregate obtained from FFTF. The firebrick was of FFTF specification and was obtained from the FFTF suppliers for firebrick. Concrete strength was monitored by crushing cylindrical concrete test specimens on the date of the test.

Three large-scale sodium-basalt concrete tests were conducted. The first test was sodium on bare basalt concrete. The test confirmed that an energetic reaction results for basalt as well as limestone aggregate. The second test was a crucible lined with two layers of firebrick and a steel insert to simulate the FFTF cell design. The purpose of this test was to investigate the interaction of sodium and firebrick. Post-test observations of severe concrete cracking in this second test and the possible influence of the crucible test geometry led to the design of the third test. This third test was "one dimensionalized" by insulating the crucible walls with a steel cylindrical liner backed by MgO. This permitted attack only on the bottom of the crucible in the downward direction.

The results of the first test, bare basalt concrete, show that: an energetic reaction results; all the sodium was consumed; the crucible cracked upon heating (not upon cooling); and the walls of the cracks were attacked significantly by the sodium forming a multipointed, star-shaped, cross section in the cylindrical cavity region of the crucible.

The results of the second test, two layers of firebrick and a defected steel liner, show that: the firebricks were consumed by the hot sodium; the concrete was then attacked by the sodium; and the defected liner was not plugged by the products of the sodium-firebrick or concrete in

The third test was one dimensionalized for linear penetration rate measurement by insulating a steel cylindrical liner with MgO from the cylindrical concrete walls of the crucible and by two layers of firebrick below the liner. The bottom of the liner was tack welded in place so the products of the sodium-concrete interaction could break it free and push it upward without destroying the integrity of the cylindrical wall liner. The sodium (239 kg at 973°K) was dumped into the crucible and reheated by immersion heaters. The exothermic sodium-firebrick reaction caused the thermocouple located between the firebrick layers to exceed the sodium pool temperature 110 minutes into the test. The thermocouple located one cm below the concrete surface indicated a rapid excursion at 170 min. A similar excursion 6 cm below the surface followed at 280 minutes. These temperature excursions within the concrete became self-limited at about 1,000°K. The concrete penetration proceeded at a uniform rate, forming layered products of reaction, through 25 cm of concrete. Only 13 cm of concrete remained when gross cracking dropped a small amount (< 5 kg) of sodium out of the crucible and the test was terminated.

The results of this third test clearly indicate: an energetic reaction results from the sodium-basalt concrete interaction; the sodium-firebrick reaction is not inhibited by a defected steel liner; the penetration rate into the firebrick is as large as the penetration rate into concrete; the penetration rate into the basalt concrete is very linear and is not diminished by layered products of the reaction; the reaction continues until the sodium is consumed; and the basalt concrete exhibited no significant spalling under the conditions of the test.

Reference 1 also summarizes studies of the chemical phenomenology involved. The process involves temperature, constituent concentrations and kinetics of the reactions. Separate effects tests on small and intermediate scales are continuing to define the processes for basalt, limestone and magnetite concretes.

From the results of the three large-scale tests, however, the following appear to be substantiated by chemical analysis of the products of reaction, the observed exothermic reactions, and the gas evolution. The initial response of the concrete to the hot sodium is the migration of water. This water migrates down the thermal gradient from the heated concrete surface and simultaneously down the concentration gradient toward the hot surface. The water reacts (at temperatures of 750 to 1,000°K) with sodium forming sodium hydroxide and free hydrogen. The hydrogen formation has been confirmed by the composition measurement of the evolved gases. However, the sodium hydroxide is very soluble in sodium metal at 800° to 1,000°K and does not react with the concrete until the sodium has become saturated with sodium hydroxide. Additional formation of sodium hydroxide results in the precipitation of a liquid layer. This liquid layer of sodium hydroxide reacts with the silica and alumina components of the concrete. Water is released and reacts rapidly with the sodium to continue the production of sodium hydroxide and hydrogen at the reacting interface.

Evaluation

The test results show that the sodium-basalt concrete reaction does occur at temperatures of 750° to 1,000°K. Thus, a sodium spill must be isolated from basalt concrete or provision made for accommodating the products of the reaction. Defects of the order of 10 cm^2 in a steel liner provide adequate access to the concrete for continued sodium-concrete interaction. The interaction is self limiting with respect to temperature. This self limiting effect may be responsible for the very uniform rate of penetration which results. The penetration rate is $\sim$ 1.5 cm/hr for basalt under the defected liner and appeared to be less for the single bare basalt test. The total concrete penetration is about 40% to 50% of the initial sodium pool depth. Thus, the reaction could be terminated by providing sufficient sacrificial concrete. On the other hand, very deep pools of sodium may not become saturated with sodium hydroxide before the pool temperature drops to a value (apparently about 700°K) where the reaction will not occur. The understanding of this chemical phenomenology is incomplete and continued effort is required in this area. The concept of the saturation requirement for sodium hydroxide appears well founded from the longer time required for the exothermic reaction to initiate when the whole pool is in contact with the concrete. The overall reactions for limestone, basalt and magnetite indicate similar chemistry. Only one magnetite test has been run, but the penetration was similar. The most significant difference in the magnetite test was the greater structural integrity of the crucible after the test. Only very fine cracks in the walls were apparent. In addition to the basic chemistry and intermediate scale separate effects tests, the large scale magnetite tests will be completed and the generic program resumed. Since the 10 cm^2 defect provides full access for the sodium to the concrete, tests are planned using a series of smaller more realistic defects which would simulate various crack sizes in cell liner plates. The NRR staff has noted the desirability of the resolution of this crack size effect.

The crucible does not simulate an actual reactor cell; however, crucibles with insulated walls do provide very satisfactory tests for the determination of one dimensional penetration rates. Comparative structural analyses of cell geometries and possible test geometries are now in progress.

The work reported in the enclosure documents the information on the sodium-basalt concrete interaction in sufficient detail to evaluate the bounding behavior of bare concrete or concrete with a steel liner and a defect large enough (10 cm^2) to assure sodium-concrete contact. Finer cracks, which simulate poor welds, will be evaluated in the future, but such tests will require analysis and design to assure that deformations of the liner will not increase the crack areas beyond the test size. Generic studies of other concrete aggregates will also be continued.

For further information on these results, their use, and the continuing research in this area, please contact Dr. T. J. Walker of my staff.

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