Jupiter

MAY 9 1978

MEMORANDUM FOR: E. G. Case, Acting Director
Office of Nuclear Reactor Regulation

R. B. Minogue, Director
Office of Standards Development

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER #28: MELT/CONCRETE INTERACTIONS

This Research Information Letter describes the INTER-1 code for calculating the effects of interaction between molten materials and concrete and the experimental data base from which it was developed.

Introduction

Programs sponsored by the Division of Reactor Safety Research are helping to characterize phenomena expected to occur during postulated fuel melt accidents in light-water reactors. The principal incentive for such work is to improve the ability to provide quantitative assessments of risks which will assist NRR in making decisions regarding design and siting. Its justification has been documented in the Reactor Safety Study (WASH-1400)[1] and in letters from the Advisory Committee on Reactor Safeguards.[2,3]

In its analysis of physical processes encountered during various meltdown scenarios, the Reactor Safety Study identified the interaction between molten materials and concrete as a significant factor in determining the time and mode of containment failure. Specific questions raised included the rate, direction and mechanism of erosion of the concrete; the rate of release and the chemical forms of decomposition gases and fission products; the effects of the chemical composition of the concrete; and the uncertainties associated with scaling. The scarcity of applicable data necessary to improve the available model led RSR to initiate the research described here.

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1/ W. A. Carbiener, et al, "Physical Processes in Reactor Meltdown (NUREG 75/014), United States Nuclear Regulatory Commission, October 1975.

2/ ACRS Report on Water Reactor Safety Research, W. R. Stratton to D. L. Ray, November 20, 1974.

3/ ACRS letter on Reactor Safety Study, W. Kerr to W. A. Anders, April 8, 1975.

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An improved model based on experiments with prototypical materials is now available as a result.

Results

Results from the research are organized into three groups derived from 1) separate effects experiments, 2) integral experiments, and 3) model development and verification. Results from each of these activities are highlighted below and described in detail in Enclosure 1.[4] Additional work being conducted to complete this program is also identified.

1. Separate effects experiments are those which are designed to differentiate among simultaneous and potentially competitive thermal, mechanical, and chemical phenomena occurring during the interaction.

   The thermal response of several prototypical compositions of concrete has been investigated by various thermoanalytical techniques (e.g., differential thermal analysis and thermogravimetric analysis). Dehydration and decarboxylation of cured specimens occur over the ranges 30-500°C and 550-800°C, respectively. First-order reaction rates accurately describe the two distinct dehydration processes observed. The decarboxylation data fit a reaction rate law of two-thirds order. These data are necessary to quantify the rates at which gases are evolved from concrete during the integral interaction.

   Monolithic specimens of concrete have been subjected to controlled thermal fluxes in order to measure rates of erosion. Erosion is linear with time for a given heat flux, after correction for thermal losses through reflection and radiation (Figure 1). The dominant mode of erosion is quiescent melting of the cement (i.e., the binding material), with no differences observed by varying the composition of the aggregate material. These data are necessary to interpret erosion rates observed in integral experiments.

2. Integral experiments are those in which prototypical molten materials contact concrete.

   In "large-scale" experiments, up to 200 kg of molten steel (~1700C) have been poured into concrete crucibles. Figure 2 indicates the appearance of the ensuing interaction. In "small-scale" experiments,

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4/ D. A. Powers, et al, "Exploratory Study of Molten Core Material/Concrete Interactions, July 1975 - March 1977," SAND-77-2042, Sandia Laboratories, December 1977.

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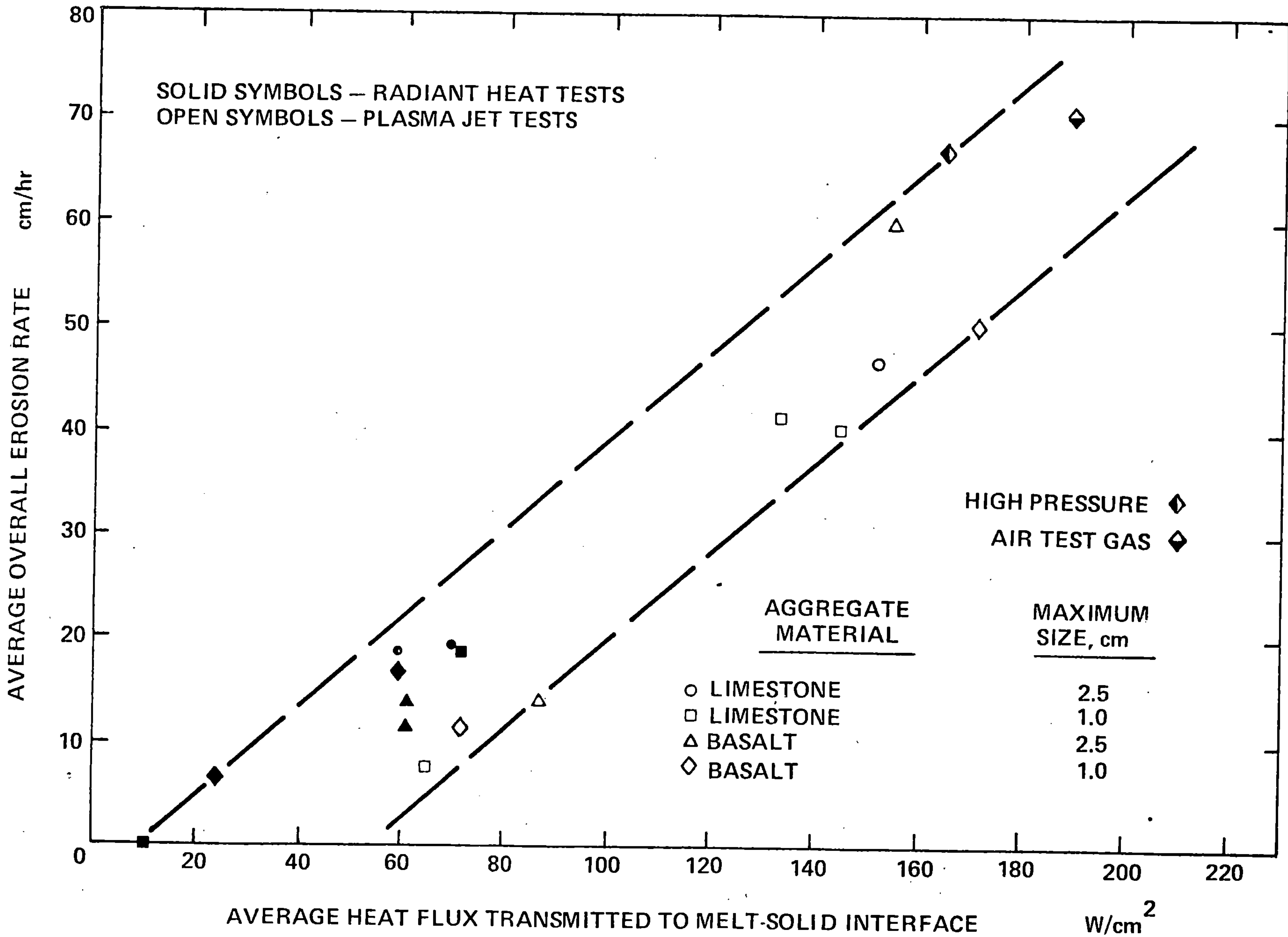
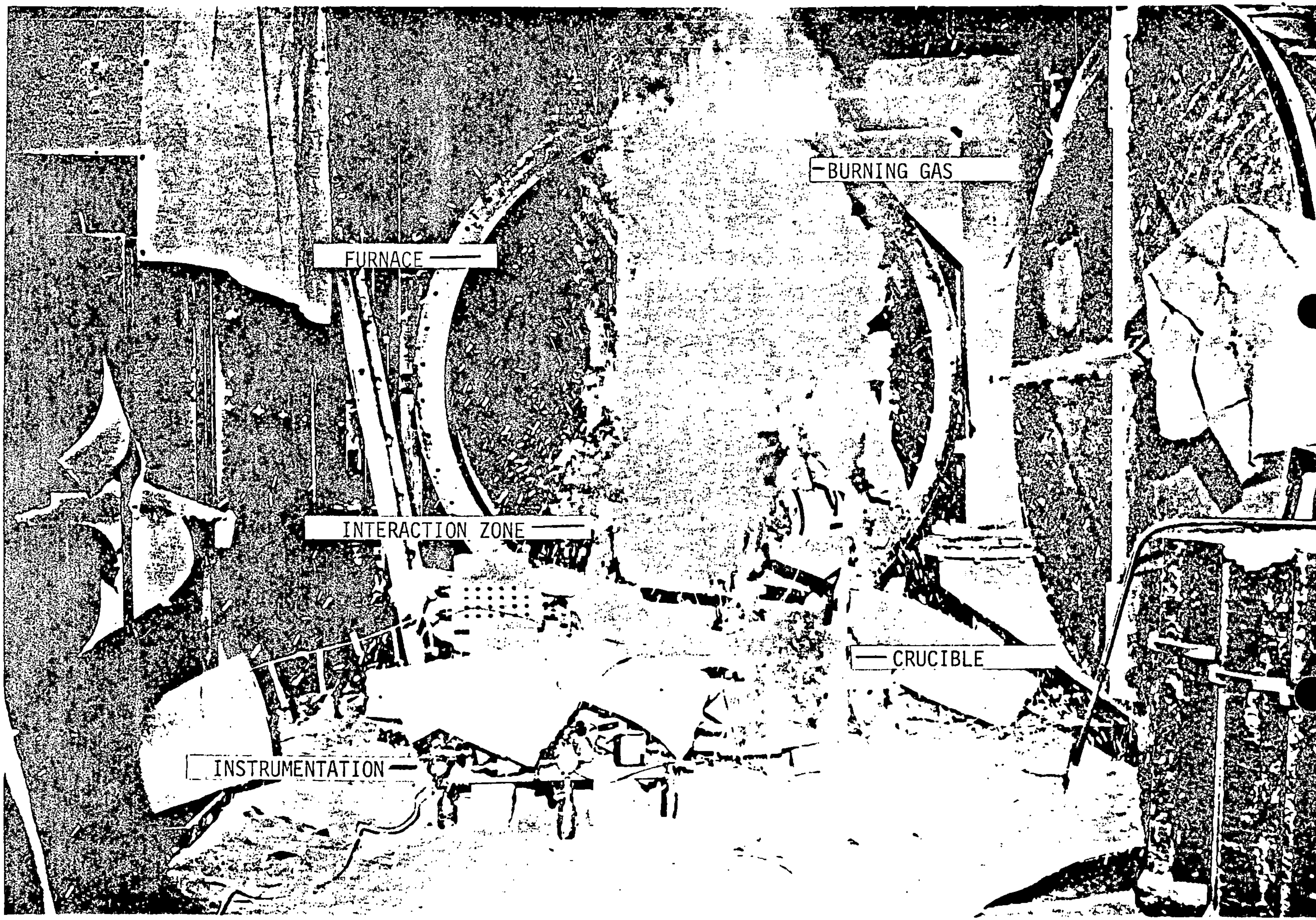


Figure 1. Experimentally measured rates of erosion of two types of concrete as a function of heat flux. The range of heat fluxes encompasses those anticipated for a postulated fuel melt accident.



EARLY STAGES OF INTERACTION IN WHICH 200KG OF MOLTEN STEEL IS POURED INTO A CONCRETE CRUCIBLE. AS THE MELT COOLS, RATES OF GAS GENERATION DECREASE AND THE FLAMES EMANATING FROM THE SURFACE OF THE MELT SUBSIDE.

up to 15 kg of molten refractory oxides (~2800°C) have been generated via a thermite reaction within concrete crucibles.

The principal parameters investigated include composition of the concrete; mass, temperature and composition of the molten material; and the geometry of the interfacial contact area. In addition to qualitative identification of phenomena by visual observations during the experiment, quantitative results are provided by instrumentation and post-test examination.

The conclusions drawn from these experiments include the following:

- Erosion of concrete is thermally dominated, with insignificant contributions from mechanical and chemical effects.

- The principal mechanism of erosion is melting of the binding material, with no significant qualitative differences caused by changing the composition of the aggregate.

- The composition of the concrete determines the composition and masses of gases released at the interface of the melt and concrete.

- Turbulence and essentially isothermal conditions are induced in the melt by the passage of decomposition gases.

- Hydrogen and carbon monoxide are among the gases evolved from the surface of the melt and they burn upon contacting air. This indicates that the H_2O and CO_2 released from the decomposing concrete are reduced chemically, most likely by oxidizing the metallic constituents of the melt.

3. Model development and verification.

The experiments have culminated in an analytical model (INTER-1) of the melt/concrete interaction which can help extend their range of applicability. INTER-1 is a phenomenological model containing several empirically derived constants such as the heat transfer coefficient at the melt/concrete interface. The code's principal outputs are the rates of axial and radial penetration, the temperature of the melt, and the generation and chemical reactions of gases formed by the decomposition of concrete. Among the phenomena considered are convective stirring of the melt by evolved gases, segregation of molten components into oxidic and metallic layers, dissolution of decomposition products of concrete into the melt, chemical reactions, radiative heat loss from the surface of the melt, and heat transfer at the melt/concrete interface. The code is described in more detail in Enclosure 1.

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Discussion

The first of two phases of this research has been completed. Both qualitative and quantitative data have been generated. Table 1 summarizes the resulting enhancement of the state-of-the-art.

Additional efforts in each of the areas indicated are continuing. The emphasis during the remainder of this program is on developing better models for directional partitioning of the heat flux during the interaction and on providing an independent data base against which INTER-1 and subsequent improved versions can be verified. Auxilliary activities, all of which require improved quantitative characterization, will examine release of fission products, chemical interactions among gases and components of the melt, and heat transfer at the melt/concrete interface.

The results reported here have been widely exposed to expert review through extensive interim documentation and through numerous domestic and foreign technical meetings (e.g., ANS, topical conferences, ACRS, international safety information exchanges). RSR's Fuel Melt Review Group concluded that the work was sufficiently mature, timely, inventive and technically sound that this Research Information Letter be prepared.[5] The group also noted that "while the exact impact of this work on current licensing practice remains to be evaluated, it is felt that there are immediate applications involving the evaluation of ...(advanced reactors)... and realistic assessment of risk for LWR's."

Since then, information from the program has been incorporated into integral models of meltdown scenarios in LWR's for current RES-sponsored analyses comparable to those in the Reactor Safety Study. NRR has also used INTER-1 to evaluate the inherent retention concept for proposed designs of advanced reactors. Sensitivity studies performed with the code by RSR are helping to establish priorities for further research. Finally, the results of the program are applicable to questions raised regarding the comparability of consequences of postulated meltdown accidents at land-based and floating nuclear plants.

RES concludes that this research has achieved most of its initial objectives and that the major safety-related phenomena during the melt/concrete interaction have been identified.

5/ Minutes of the WRSR Fuel Melt Review Group Meeting, March 7, 1977, Albuquerque, New Mexico, issued April 6, 1977.

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TABLE 1

CHARACTERIZATION AND QUANTIFICATION OF MELT-CONCRETE INTERACTION

	Assumed in Wash-1400	Post-Wash-1400
Concrete Aggregate	Limestone	Limestone and Basalt
Significant Spalling Upon Initial Contact	Yes	No
Initial Penetration Rate (30 minutes)	7.5-15.2 cm/min (15-30 ft/hr)	Function of Heat Flux
Steady State Penetration Rate	$\sim$3 cm/min	Function of Heat Flux
Agitation of Melt	Yes	Yes
Solid Crust	Yes	No
Fission Product Release	Function of Gas Generation	UNDER INVESTIGATION
H_2O and CO_2 Generation	Yes	Yes
H_2 and CO Generation	No	Yes
H_2 and CO Burning	No	Yes
Partitioning of Heat Flux (i.e., Direction of Attack)	3 Models	UNDER INVESTIGATION
Effect of Rebar on Penetration Rate	Not Significant	Not Significant
Time to Melt Through	18(+10,−5)hr	UNDER INVESTIGATION
Scale	Based on Bench Scale	Up to 200 kg Melt So Far

While direct extrapolation of the data to prototypical conditions must always be made cautiously, enough confidence has been developed so that no fundamental differences in behavior are anticipated in scaling to full-size systems. Reservations exist regarding the application of INTER-1 to predict such variables as the time of containment meltthrough or overpressurization. Additional planned experiments to verify the code are expected to provide more confidence in its use. The model can best be utilized in its current form to estimate the relative significance of variations in parameters such as materials, properties and compositions, interface heat transfer coefficients, geometry, etc. The above conclusions will continue to be evaluated as new information becomes available in the final stages of the program.

Recommendations

The above results and discussion are offered for user office consideration for application to the identified regulatory need. The primary significance of the work described is the improved understanding of physical phenomena. RES recognizes that the results are unlikely to have significant near-term impact on current licensing procedures. It should, however, provide additional background information useful in analyzing regulatory issues involving accidents beyond design basis events. The RES contact for any further clarification or evaluation of these results is Dr. Raymond DiSalvo of the Probabilistic Analysis Staff.

Original Signed by
Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

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RECORD NOTE: Comments on drafts of this letter were received from Tong, Jupiter, Levine, Johnson, Johnston, Beach, Silberberg and the contractor personnel. All comments were considered and the appropriate changes made. Action completes Buff Book node #39200.

*see previous yellow for concurrence

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Saul Levine, Director
Office of Nuclear Regulatory Research

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RECORD NOTE: Comments on drafts of this letter were received from Tong, Jupiter, Levine, Johnson, Johnston, Beach, Silberberg and the contractor personnel. All comments were considered and the appropriate changes made. Action completes Buff Book node #39200. ~~A draft of the enclosure is available for your information. The published version will accompany this letter when dispatched.~~

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See correction on draft

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