INTERIM REPORT

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INTERIM REPORT

I. Steam Explosions

We have begun the second small scale test series using iron-oxide droplets in water. The purpose of this series is to determine the threshold trigger energy necessary to initiate an explosion for a given set of initial conditions, i.e., water at T = 20°C and an iron-oxide drop ($FeO_{1.3}$) at T = 2000°K with a diameter of ~3 mm. The variation in trigger magnitude is accomplished by varying the distance between the drop and the exploding bridgewire. Preliminary results indicate that a trigger pressure in excess of 0.3 MPa is needed to initiate an explosive interaction. Testing at high ambient pressure is expected to commence this summer.

The first FITS test series is progressing. Two more EXO-FITS experiments MD-17 and MD-18 using 3 kg of iron-alumina thermite were performed to investigate the anamolous behavior observed in the in-vessel test FITS2A. In FITS2A the melt entrance velocity was unexpectedly lowered to 4.5 m/s. This appears to have caused a spontaneous explosion to occur before all the melt was submerged in the water. In the follow-up EXO-FITS test, MD-17, when the melt entrance velocity was increased to 8 m/s the spontaneous explosion was suppressed; when it was decreased to 5 m/s in test MD-18 a spontaneous explosion occurred after the melt was completely submerged in the water. This behavior may be due to the noncondensible gas entrained by the melt as it enters the water. If the velocity is high the entrained gas volume increases and can suppress the spontaneous trigger. Also if the mass of melt is decreased spontaneous triggers may be suppressed because a larger volume fraction of gas would be present. This behavior is consistent with the small scale experiment observations of Nelson and past analysis of Corradini. Further analysis of this effect will continue.

This month analysis efforts have been addressing three areas.

(1) The 1-D transient explosion model is being checked out to verify that no modelling or coding errors remain. The initial conditions from the EXO-FITS tests are being used as the sample problem for this effort.

(2) The MARCH-CORRAL code package was put on the SANDIA computer system and sample calculations have been performed with emphasis on understanding the "steam spike" phenomenon in the ZIP study. The objective of this work is to get a self-consistent calculation of the core meltdown sequence to use as initial conditions in structural analyses both with and without steam explosions.

(3) The small scale and FITS experimental results are being analyzed.

Also during this month Mike Corradini was asked to comment on a steam explosion summary article written by Prof. Conyers Herring for the National Academy of Sciences Report on "Nuclear Power Risks." The letter from Prof. Herring and Mike's reply are enclosed in this letter.

II. Core-Concrete Interactions

CORCON Development

CORCON clean-up and simplification activities continued during May. They included the removal of additional redundant variables, revamping of the common blocks, and finding and eliminating occasional bugs.

The effort to reduce or eliminate problems encountered in the melt/gas-phase chemical equilibrium solution technique achieved considerable success during May. A procedure has been developed which, while not optimum, appears to work satisfactorily. It converges to a true solution for those situations tried to date and, for most of these cases, it does so in a reasonable number of interations. It is anticipated, however, that a set of conditions will be encountered in the future where the solution will fail to converge. In the interest of avoiding this situation, an effort to improve the current procedure will continue. However, as long as the solution continues to converge, it is no longer the limiting problem in CORCON. Consequently, the activity devoted to improving the solution procedure will continue at a lower level of effort.

The code comparison test analysis effort continued during the month. CORCON-MOD 0 was successfully run for almost the full test time ($\sim$ 3000 sec). Although there were no major difficulties, some minor problems were encountered during the initial cool-down before power was applied to sustain the melt. As the temperature of the steel melt decreased to its freezing point, the discontinuity in the enthalpy-temperature relationship corresponding to the latent heat of fusion prevented convergence of the Newton-Raphson iteration in the energy conservation and temperature update routine, ENRCON. A quick fix eliminated the immediate problem for the code comparison test analysis. In order to handle the general problem, a scheme was developed to back-up the Newton-Raphson technique with a bisection procedure. Once this has been tested, it will be incorporated into CORCON and used in later calculations. Further CORCON calculations will be made following inclusion of the improved chemical equilibrium solution procedure (mentioned above) into the code in early June.

Work continued on the development of a fission product decay heat generation model suitable for inclusion in CORCON. The available literature revealed a limited amount of decay heat data in the time frame of interest here. To alleviate this situation, the ORIGEN code will be used to calculate values of decay power at 1/4 day intervals over a 10 day period. For this purpose, the core was conservatively assumed to consist of equal portions (thirds) of: 1-year, 2-year, and 3-year burnup fuel (i.e., the condition at the beginning of standard refueling time). Later in the study, a fresh core will be evaluated and its impact assessed. A simple aerosol generation model was selected for inclusion in CORCON to allow depletion of the condensed fission products and a concomitant reduction in decay heat sources in the melt.

A simple transient model for the penetration of a hot solid mass into concrete has been developed. The model considers the solidified core debris to be represented by a two layer (oxidic and metallic phases) mass, each of which is described in terms of lumped parameters. Energy generated within the solid (e.g., fisson product decay heat) is transferred upwards by radiation and natural convection, and sidewards and downwards by conduction across a mixed gas-molten concrete (slag) layer formed by ablation of the concrete beneath the solidified debris. (There is no ablation of the concrete sidewalls.) Initial results from preliminary calculations for a representative reactor cavity/molten pool geometry indicate the following:

1. The controlling heat transfer resistances are those across the two-phase slag-gas layer and within the solidified core debris.

2. The very low top surface temperature, well below the oxide solidus value, essentially eliminates radiation as an effective heat removal mechanism.

3. The heat transfer split is roughly 2 to 1 upward-to-downward with negligible sideward heat transfer for the large diameter-to-height ratio (6).

4. The solidified core debris is not a stable configuration. As long as the total heat loss rate is less then the volumetric heat generation rate, the core debris will tend to heat up and remelt. This was found to be the case at an accident time of approximately 6 hours where the total heat loss rate was only about 10% of the decay heat generation rate.

The significance of the last observation is that if these low heat loss rates, about 1-2 MW, are representative of the long term interaction process, the time to freezing of the melt is governed by the time required for the decay heat generation rate to decrease to the heat loss rate. Thus, the ultimate freezing time could be on the order of months as opposed to the few hours predicted by melt/concrete interaction computer codes such as WECHSL and CORCON (which predict much higher heat transfer rates from the melt).

Mr. Vernon Badham, UCLA, visited Germany during the period May 5-16, 1980 to obtain a number of German computer codes which model various aspects of the interaction of molten core materials with reactor structural materials. Computer tapes were obtained containing the codes: WECHSL (KFK); KAVERN and BETZ (KWU); and THEKAR (several versions), HEMIS, BETON, BETSI, TEMBET, and SACRI (Univ. of Hannover). Mr. Badham visited Sandia for the week of May 19-23 to transmit the tapes, code input and operation instructions, and all documentation obtained, and to assist in the set-up and check-out of the codes on the Sandia computer. All have been compiled on the CDC 7600 and some have been checked out on sample problems (those for which sample problem input data were provided.

III. Separate Effects Tests for TRAP Code Development

Additional scoping experiments studying the desorption of tellurium species from stainless steel and nickel surfaces have been performed. There is no vaporization of elemental tellurium (dissociation of surficial tellurides) at temperatures up to 850°C in a nitrogen gas stream. In the same temperature range saturation of the gas stream with water vapor did not induce vaporization of elemental tellurium nor cause the formation of hydrogen telluride gas (H_2T_2) via the reaction: $H_2O + MT_e \rightarrow MO + H_2T_e$.

The measurement of the vapor pressure of cesium hydroxide (CsOH), which is being performed at New Mexico Tech, has encountered experimental difficulties. Apparently there is extreme wetting of crucible surfaces by CsOH; so much so that there has been creepage of CsOH up and over the crucible walls and onto the chamber walls. This creepage has persisted even when the crucible walls have been bent inward and downward. As a result of this migration the thermodynamic state of CsOH (its purity and its vaporization temperature) is somewhat ambiguous.

Design work for the Fission Product Reaction Facility is in its last stages, with emphasis on integrating the laser Raman cell from the interim system with already fabricated components.

Attachment 1

Sandia Laboratories

Albuquerque, New Mexico 87115

May 23, 1980

Prof. Conyers Herring
Dept. of Applied Physics
Stanford University
Stanford, California 94305

Dear Prof. Herring:

I have read your summary on Steam Explosion and found it very well written. I think that you have delineated the essential physics of the process and explained it quite well. However, I do have some specific technical comments about some of the statements you have made. I'll try to briefly describe my ideas on these points and send references where possible.

(1) Page 2, Line 14 -- I think you mean the containment building rather than the pressure vessel.

(2) Page 4, Lines 10-14 -- You suggest that the violence of the explosion is enhanced because the fuel was metallic. This is not true. In experiments at Sandia the oxidic molten materials (e.g., FeO_x, ZrO_x, Al_2O_3) are components. This is because the metallic components generate noncondensible H_2 gas from steam oxidation which can retard the explosion. So, I feel, your statement is too general on this point.

(3) Page 4, 2nd Para. Line 4 -- Your concept of self-quenching during the explosion propagation is quite interesting, but it has not been observed in experiments at Sandia using molten fuel simulants. Rather, a very strong, pressure-propagation wave travels through the steam-fuel-water mixture at a high velocity 300-600 m/s fragmenting the fuel. The two fluids cannot move apart substantially in the associated time frame of a few milliseconds. The particle velocity is too small compared to to this shock velocity.

(4) Page 5, 2nd Para.
Line 7 -- The "incoherence" of the explosion which you describe may not be the only explanation. These pressure records are taken near walls where flow stagnation and pressure amplification can occur. Therefore, you may be observing pressure pulse ringing near a wall, and the explosion's pressures are time-smoothed traces of these records.

(5) Page 9, Line 1 -- This statement about a threshold of pressure and temperature for the explosion is only partially true. For small scale experiments high water temperature can suppress explosions for a fixed trigger magnitude. However, in large scale tests by Buxton or small scale tests by Nelson with a larger trigger energy, boiling water does not suppress the explosion. The temperature suppression effect is therefore trigger and scale dependent. As for pressure, it has been empirically observed that for a given trigger magnitude pressure does suppress the explosion. There are two theories that attempt to explain this. One, by Henry, suggests there is a pressure threshold above which no explosion can occur. The other, supported by Sandia researchers, states that the suppressive effect is a function of the trigger magnitude; i.e., with a larger trigger the explosion can be reinduced. No definitive experiment with reactor materials has been performed, as yet, to resolve this issue.

(6) Page 12, line 4 -- There are three possible ways of imparting energy to the vessel head; liquid water, liquid fuel, or a solid slug (e.g., the upper vessel support plate or the upper core grid plate). Any one of these could be propelled by the expanding high pressure steam, given the multitude of core meltdown accident sequences.

Thank you for allowing me to comment on your work. I think it is a very good effort. I would appreciate it if you could send me a final draft of Chapter 13. If you have any questions concerning my comments, please call me.

Sincerely,

Mike Corradini

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Enclosure