INTERIM REPORT

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Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

INTERIM REPORT

Sandia Laboratories

Albuquerque, New Mexico 87115

4441/ML-10

May 5, 1980

Mr. Richard Sherry
U. S. Nuclear Regulatory Commission
Fuel Behavior Research Branch
Division of Reactor Safety Research
MS 1130-SS
Washington, DC 20555

Dear Rick,

Enclosed are the status reports for the month of March for the core melt and separate effects programs.

Sincerely,

Marshall

Marshall Berman, Supvr.
Reactor Safety Studies Division, 4441

Enclosures

Copy to: (w/enc.)
NRC Public Document Room (2)
M. Cunningham, NRC, RES
R. Denning, BCL
R. DiSalvo, NRC, RES
J. Gieseke, BCL
W. V. Johnston, NRC, RES
D. Hoatson, NRC, RES
J. Long, NRC, NRR
T. Malinauskas, ORNL
A. Marchese, NRC, NRR
J. Meyer, NRC, NRR
W. Milstead, NRC, NRR
J. Murphy, NRC, RES
J. Norberg, NRC, OSD
W. Pasedag, NRC, NRR
G. Quittschreiber, NRC, ACRS
J. Read, NRC, NRR
M. Silberberg, NRC, RES
T. Speis, NRC, NRR
T. Walker, NRC, RES
R. Wright, NRC, RES

2514 D. E. Mitchell
4400 A. W. Snyder
4414 A. S. Benjamin
4422 R. M. Elrick
4422 D. A. Powers
4440 G. R. Otey
4441 R. K. Cole
4441 M. L. Corradini
4441 J. C. Cummings
4441 J. F. Muir
4442 W. A. VonRiesemann
4442 R. L. Woodfin
5836 L. S. Nelson
5836 R. A. Sallach
4441 M. Berman

I. Steam Explosions

The theory checking single droplet experiments have begun.

The first series consists of a laser melted iron-oxide drop (0.3 gm, 2000K) in water (3.5 kg, 300K), triggered by an exploding bridgewire (1 MPa pressure peak, 20 μsec pulse width @ 3 cm). Reproducible explosions have been triggered. The first parameters to be varied are the ambient pressure and the trigger magnitude. Subsequent parameters include melt mass, temperature and composition.

The Germans have expressed a keen interest in our steam explosion work. I have attached copies of correspondence between L. S. Nelson and L. Caldarola (KfK) concerning small scale experiments.

The first FITS experiment, FITS1A, was conducted and resulted in a mild explosion. The test consisted of dropping 2 kg of Fe-Al_2O_3 into water. The lucite interaction chamber was destroyed and a temperature rise of 25°C and 0.1 MPa overpressure were measured in the vessel. The dynamic pressure, photographic and debris data are currently being reduced. The FITS 2A test is scheduled for April with similar initial conditions. The major change will be to increase the fuel mass to 3 kg and again record the overall vessel response.

The analysis is now concentrating on the EXO-FITS experiments using the transient propagation model and on the fluid-structure interactions during the full scale accident scenario. One question of concern is how the molten core material moves prior to fuel-coolant contact and if it plugs up or flows into the lower plenum. Fuel freezing and streaming models developed for LMFBR core disruptive analysis are being applied to this question. The initial indications are that, similar to the WASH-1400 assumption, the molten material is predicted to freeze and plug the channels allowing a large molten pool to develop.

II. Core-Concrete Interactions

CORCON Development

The initial version of the code, CORCON-MOD 0, which achieved an operational status on February 29, 1980, was transmitted on tape to the NRC (via the Central Scientific Computing Facility at BNL) on March 4th. A partial draft of a topical report/users manual describing the code was subsequently mailed directly to the NRC. CORCON-MOD 0 has a storage requirement of 115K octal. The ratio of problem real time to computation time varies with problem conditions and time step size. For the computations that have been made to date (on the SNLA CDC-7600), the ratio ranges from approximately 10 to 40. The computation time for a 6 hour problem, therefore, can range from about 9 to 36 min.

Activities during March focused on three main areas: (1) continued clean-up and modification of CORCON-MOD 0, (2) initial sample problem calculation, and (3) preparation of a paper and material for three presentations.

Activities devoted to the clean-up and simplification of CORCON continued in an effort to reduce the storage requirements of the code and to improve the coding. These included changes to the data structure, simplification of existing subroutines, and elimination of unused and redundant variables and subroutines. A major accomplishment was the re-writing of subrouting MASRAT in a much simpler and cleaner form. The original MASRAT routine was part of the Concrete Ablation/Shape Change Evaluation Technique (CASCET) code developed by Acurex Corporation under contract to Sandia. It computed the concrete ablation mass flow rates (gaseous plus condensed phases) at body points around the pool (at the melt/concrete interface). Since the gas flow rates from the concrete are critical to the melt/concrete interaction process and determine its progression, MASRAT is the driving element of the CORCON model. A fatal problem encountered in the original MASRAT was the overflowing of the integration point array as a calculation proceeded. The effort to correct this problem led to a complete re-write of the subroutine. A number of other errors were uncovered and corrected in the process. The re-written routine, therefore, not only has a better structure, i.e., a linear construction that examines the number of integration points at the beginning of the routine, but it is also more accurate.

Other clean-up and simplification activities included: changing the manner in which some of the material property data are stored in the code to improve access to these data, and improving the way in which species input for a calculation are checked, identified, and inserted into the master species list to eliminate superflous arrays.

Sample problem input conditions representative of the Zion and Indian Point nuclear power plants were defined previously. These data were subsequently adjusted slightly to be identical to the input data used for INTER and WECHSL calculations performed as part of the ZIP study. An initial sample problem calculation based on the ZIP input was made using CORCON-MOD 0 out to a time of 1-1/2 hr. The results have been compared with the INTER and WECHSL predictions for the same input conditions. Despite the preliminary nature of the CORCON results (as a consequence of the approximations and simplifications in the initial version), it is significant that the general trends of the CORCON variations are qualitatively quite similar to the WECHSL predictions.

Sample problem calculations were also undertaken as part of a scoping sensitivity study of CORCON. The study was begun by identifying the parameters to be varied and setting up a systematic schedule of calculations based on a factorial design strategy. The six parameters identified as primary variables for the study are: (1) initial core melt composition, (2) concrete composition, (3) decay heat generation in the melt, (4) initial melt temperature, (5) initial cavity radius, and (6) computation time step size. The first two parameters are held constant at their nominal values, i.e., those specified in the ZIP input conditions. Parameters (3)-(5) are evaluated at their nominal values and at upper and lower bounds selected on the basis of plant data and discussions with BCL and Sandia researchers. The last parameter, time step size, is varied over what is believed to be a reasonable range.

The manuscript of a paper entitled "Modelling of Molten Fuel/ Concrete Interactions," coauthored with A. S. Benjamin, 4414, was prepared for presentation at the ANE/ENS Topical Meeting on Thermal Reactor Safety to be held in Knoxville, Tennessee, on April 7-11, 1980. Presentations were also prepared for the FY-1980 Mid-Year Program Review held at the NRC, Silver Spring, Md., on March 27, 1980, and the USA/FRG Fuel Melt Research Program Review and Information Exchange Meeting to be held in Knoxville, Tennessee, on April 11 and 12, 1980.

Experimental Program

In response to the needs of melt/concrete interaction code developers and evaluators, a complete description of the experimental conditions for the two Sandia code comparison tests, CC-1 and CC-2, was prepared. Included are data obtained before and during the tests, a description of the instrumentation and measurement techniques employed, and a discussion of the quality of the various experimental results. Actual test data will be suppressed until after all code comparison calculations have been made.

III. Separate Effects Tests for TRAP Code Development

A. Vapor Pressure Measurements at New Mexico Tech.

The experiments on mass transport of cesium hydroxide in dry nitrogen have been performed. The preliminary results indicate that water vapor may have enhanced the transport of cesium hydroxide by as much as a factor of 3. Further experiments are needed to thoroughly check and verify these preliminary results.

B. Vapor Pressure Measurements at Sandia

Experiments have been started to determine the effect of water vapor on the high temperature reaction of tellurium with stainless steel. Analysis is not yet completed. Concurrently, a copy of a thermodynamic code, FLUEQU, has been obtained from another Sandia division. This code can calculate the range of gas compositions in equilibrium with a given phase within a given quaternary system. It is being evaluated for its applicability to fission product transport.

C. Fission Product Reaction Facility

Some difficulty has been encountered in welding the nickel crucible of the interim laser cell; our shops are now trying another technique. Other fabrication and design work are on schedule.

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Institut für
Reaktorentwicklung

Mr. L.S. Nelson
Enviromental Research
Division 5333
Sandia Laboratories
Albuquerque, New Mexiko 87115
.U S A

Datum: 7.3.1980
Bearbeiter: Dr. Caldarola
Telefon: 07247/82-3974
Ihre Mitteilung:

Dear Mr. Nelson,

After my visit last summer in Albuquerque we have started to prepare some experiments similar to yours (small drops into water with trigger). We have bought an high speed camera which can make a total of 500 pictures at a maximum rate of 10^5 pictures/sec. The experiments are being done now and they look very promising. I hope to have some interesting results to show to you already starting from September.
We are also planning small drop experiments with oxyde into sodium, and we want to use the combustion method which you described during my last visit in Albuquerque.
I have some questions and I would be very grateful if you could reply them. The questions are

1. How do the Uranium drops behave during the combustion process at 2400 K? Do they remain compact or do they squirt into small pieces? There is formation of large or of small volumes of aerosols?
2. What other metal would you suggest to use instead of Uranium? We have many safety restrictions in handling also small quantities of Uranium. For this reason it could be more convenient to use a simulant material.
3. What do you think about using a tube having a diameter of 15mm as a combustion chamber? Is this diameter to small? What is the smallest diameter you would suggest us to use?
4. Why do you use an "high speed valve" in your experiments with water? Do you want to avoid that the combustion starts when the drop is in the levitation coil?

Thanking you in advance, please accept my best regards.

Yours sincerely

L. Caldarola

-L. Caldarola-

Sandia Laboratories

Albuquerque, New Mexico 87115

April 4, 1980

Dr. L. Caldarola
Kernforschungszentrum Karlsruhe
Institüt für Reactorenturicklung
D7500 Karlsruhe 1
Federal Republic of Germany

Dear Dr. Caldarola:

This is in reply to your letter of 7 March 1980 in which you request information about our single drop steam explosion experiments.

I have collected several reports and publications that describe our previous single drop studies; these documents are enclosed for your information. In particular, I have included the manuscript which will be contained in the proceedings of the joint American and European Nuclear Society meeting on thermal reactor safety; I will present this paper in Knoxville, Tennessee on 8 April 1980.

Let me summarize the scoping work we have done in the past year on triggered single drop experiments for the study of steam explosions. We have used three basic techniques to produce these drops:

(1) Drop formation by melting with a carbon dioxide laser. Here the laser is used to provide the entire heat to produce a pendant drop. The laser can operate continuously at various levels up to a maximum of 350 W at a wavelength of 10.6 µm. This laser has been used to melt several oxidic materials with melting temperatures up to and including zirconia.

In order to prepare pendant drops of refractory materials, it is necessary to use some sort of non-reactive support material. In the molten iron oxide studies, we use iridium wire which reacts only slowly with the melt at temperatures up to about 2000 K. We have also melted aluminum oxide on aluminum oxide fiber supports, but this requires that the interface between the fiber and the melt remain at the melting temperature of the oxide. This prevents significant superheating of the melt.

Studies have also been performed in our laboratory in which various yttria-zirconia mixtures have been melted on alumina supports, but this was a compromise in which strong thermal and compositional gradients existed. Melt temperatures near 3000 K were routinely studied this way.

(2) Levitation melting has been used to prepare iron drops. We have done only a few experiments this way, having discovered that a drop of molten iron immediately becomes surrounded with a thick blanket of noncondensing gas, probably hydrogen due to the metal-water reaction; this gas seriously interferes with the ability to trigger the steam explosion. Levitation is sensitive to a number of parameters, and only a relatively narrow range of particle diameters may be studied (≈ 5 mm diameter in our apparatus). The technique is applicable only to materials which conduct electrically at high temperatures, usually metals. Under certain circumstances, however, molten iron sulfides can be studied by levitation (Roberts et al, Trans. Met. Soc. AIME 245, 2413 (1969)). Also, Professor John Margrave at Rice University has stated that his people have levitated molten zirconia (stoichiometry unknown to me) by starting with a levitated drop of molten zirconium, and slowly adding oxygen to the chamber. Levitation parameters such as power and cooling with gas flow were regulated carefully to keep the drop levitated during oxidation. It is possible that some of the oxidic Corium-related melts could be studied this way.

(3) Metal combustion has also been used to produce molten drops of oxidic materials at very high temperatures ($T > 3000$ K). In a few of these experiments, we used the uranium levitation technique which we discussed when you were in Albuquerque. The technique works excellently, provided the melting and preparation of the initial molten uranium sample is done in high purity argon or other inert atmospheres. Again, the size restrictions are troublesome; oxidation of ≈ 5 mm diameter drops requires a very long fall path. Instead, we have turned to carbon dioxide laser ignition of cubes of metal supported at the top of a combustion chamber. The cube is ignited by ≈ 50 W of carbon dioxide laser radiation (a smaller laser than that described in (1)). In this way we have been able to produce 2.7 mm diameter drops of $ZrO_{0.9}$ with a 2 m fall path at temperatures above 3000 K.

We have observed moderate steam explosions with these melts. Initially, upon immersion in the water, the molten drops become blanketed with noncondensing gas, as in the molten iron studies described in (2). We feel that there are two sources of gas generation here: the substoichiometric oxide-water reaction to produce hydrogen, and the thermal dissociation of water at temperatures greater than 3000 K. Later on, when both gas generation and temperatures decrease somewhat, it is possible to initiate the explosions.

To put the three techniques into perspective, the carbon dioxide laser melting is by far the simplest experiment to perform, but the need for a support material is a serious limitation. The levitation experiment is very clean both for the study of metals and for initiation of combustion; however, it does not offer a wide range of compositions and drop diameters. The metal combustion technique is an excellent one and should be usable to produce a wide range of partially oxidic materials which could very accurately simulate core melt materials. (Various alloys of uranium-zirconium-iron and fission product metals could probably be used as starting materials here). But considerable auxiliary information is required, for example, the relationship between stoichiometry of the molten drop and the fall distance.

I shall try to answer your specific questions:

(1) Our experience has indicated that uranium remains as compact drops during combustion at diameters up to 5 mm, provided that the purity of the metal is reasonably high. After very long combustion times, at stoichiometries near O/Me = 1.7, many of these metals will explode as the result of the release of gaseous impurities during the combustion. There will be considerable aerosol produced in the uranium combustion, perhaps several percent of the total metal droplet weight.

(2) I suggest zirconium as a material which would closely simulate uranium in the combustion and also would have significance from the reactor safety standpoint because of the use of Zircaloy as cladding. Both uranium and zirconium dioxides have melting and boiling temperatures which are close. The boiling temperatures of the oxide seems to govern the conditions of drop combustion for many metals. There should be much less aerosol produced in the combustion of zirconium drops than with uranium drops.

(3) I feel that 15 mm diameter tubing is perhaps too small for doing the sort of experiments I would envision. First, the drop combustion might seriously deplete the oxygen supply in the fall chamber, and, secondly, the problem of slight variations in fall direction might become serious over fall paths of several meters. I feel that perhaps 50 mm diameter would be a resonable minimum; larger diameters would be better still.

(4) You are correct in assuming that the high speed valve is used to separate the upper levitation and lower combustion chambers during the levitation melting of uranium. The uranium in our equipment is melted in purified argon and brought to a measured temperature before release into the combustion chamber.

We wish you success in these experiments, and look forward to comparing results. I hope it will be possible to talk with you or your colleagues at the Knoxville meeting.

Very truly yours,

Lloyd S. Nelson

Lloyd S. Nelson
Pyrometallurgy
Division 5836

P.S. We also have plans for dropping molten oxide into liquid sodium.

Enclosures: Adv. High Temp. Sci. (1971)
High Temp. Sci (1970), (1973)
Health Phys. (1978)
Knoxville paper (1980)

Copy to:
2514 D. E. Mitchell
4441 M. L. Corradini
4441 M. Berman
5836 J. L. Ledman
5836 L. S. Nelson (2)