Summary of the Fifth Meeting of the
Peer Review Group on the
NRC Source Term Reassessment
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INTRODUCTION

This paper is a summary of the fifth meeting of the Peer Review Group on the NRC Severe Accident Source Term Reassessment. The meeting was held on the 26th and the 27th of January 1984, at the ACRS, 1717 H St. NW. Washington, DC. The page numbers in the text refer to the transcript of the meeting.

ATTENDEES

Peer Reviewers

W. Castleman	Penn State
R. Hilliard	HEDL
C. Johnson	ANL
W. Kastenberg	UCLA
S. Levy	Levy, Assoc.
A. Reynolds	U. of Virginia
R. Ritzman	SAI
D. Rowe	Rowe Assoc.
R. Vogel	EPRI
D. Walker	Westinghouse
L. Zumwalt	NSCU

Battelle Columbus Lab.

C. Cybulskis
J. Gieseke
M. Kuhlman
K. Lee
K. Moore

Sandia

A. Benjamin
D. Bradley
R. Gasser
M. Griesmeyer
C. Leigh
J. Lineburger
D. Powers
A. Taig
J. Walker
D. Williams

Pacific Northwest Lab

P. Owczarski
W. Winegardner

ASTPO

R. Grill
M. Jankowski
R. Meyer
P. Niyogi
W. Pasedag
C. Peabody
C. Ryder
M. Silberberg

Oak Ridge

T. Kress
A. Malinauskas

Consultants

J. Cobble	SDSU
H. Isbin	
S. Loyalka	UMC

Observers*

F. Abbey	UKAEA
R. Audetti	NRC
L. Chan	NRC
K. Holtzclaw	GE
G. Marino	NRC
W. Mims	TVA
S. Niemczky	UCS
G. Petrangeli	ENEA
S. Rosen	GE
C. Thomas	YAE
R. Tripathi	ACRS
E. Warman	SW

* Partial list

SEQUENCE SELECTION

Sequences are selected for an analysis by three criteria: significance of risk, range of phenomena, and comparison with WASH-1400. The source term estimates are influenced by the dimensions of a plant (p52). A source term is calculated given a particular order of events; a variation of a given sequence is considered to be another sequence.

FISSION PRODUCT RELEASE FROM FUEL

Battelle predicts some aerosol clouds near the core to be as concentrated as kilograms per cubic meter. R. Vogel thought that this figure was high. M. Kuhlman speculated that a highly concentrated aerosol could exist, but a kilogram per cubic meter figure seemed too large. R. Vogel mentioned experiments in which a highly concentrated aerosol behaved as a fluidized bed rather than an aerosol per se (p74).

In Battelle's calculations the aerosol particles are assumed to have a homogeneous composition for all particle sizes. Little variation in the aerosol composition is predicted from one sequence to the next (p60).

Aerosol particle size. An initial particle size distribution is assumed for the BMI-2104 calculations (p71). The median diameter is about 0.05 microns. A sensitivity analysis showed that the predicted aerosol behavior is sensitive to the assumed distribution when the aerosol concentration is low. When the aerosol concentration is high, the predicted aerosol behavior is not sensitive to the assumed distribution. This occurs because concentrated aerosols coagulate rapidly; an error in the initial distribution is canceled. Dilute aerosols coagulate slowly; the error in the initial distribution persists. For the Battelle calculations, a partical size under several microns is adequate. Experiments with metal fumes are used to justify the assumed particle size distribution.

E. Warman estimated a large fraction of fission product reevolving because of decay heat (p87). The upper plenum is a forest of structures. A 1/8-inch film of fission products may deposit on the surfaces. About half of the decay energy is beta-energy and about half of the remaining decay energy is gamma energy. The entire plenum does not have to heat up before fission products vaporize. The fission products will vaporize when the film is sufficiently hot. Fission products on the upper plenum will adiabatically heat to about 2000°F within a few minutes. A large fraction of fission product will be transported to the containment (p88, 462, 464).

THERMAL HYDRAULICS

Ice condenser. An ice condenser reduces the pressure in a containment by removing steam. As a consequence of the tortuous pathways formed by the ice baskets, aerosols may be removed. Fission product aerosols should deposit in the baskets, even after the ice has melted (p190). P. Owczarski calculated a decontamination factor of 10. K. Lee thought that this value was too optimistic, but he did not include gravity settling in his calculations. R. Hilliard cited studies that were done on an aerosol passing upward through a gravel bed; aerosol deposits were found on the top of each piece of gravel (p196). The deposits may be due to gravity settling in a boundary layer or due to eddy currents.

The ice condenser containment at Sequoyah is equipped with a recirculating air fan. Even a low decontamination factor, for fission product removal by the ice baskets, can result in a large removal of fission products (p172).

Calculations were made to determine if water drops, from melting ice, could remove fission product aerosols. The results indicate that the water drops will not remove a significant amount of aerosol particles (p177).*

The water from melting ice may also collect fission products vapors. Only aerosols, no vapors, are assumed to be in the gas entering the ice condenser (p176).**

Hydrogen stratification, D. Rowe asked if hydrogen could stratify in a containment. (p164). Convection current and steam will likely keep the containment atmosphere well mixed. Therefore, a well mixed volume is assumed.

Hydrogen combustion. E. Fuller thought that a rigorous modelling of hydrogen burning was needed. The models of hydrogen production, hydrogen transport, and hydrogen burning are questionable. P. Cybulski replied that the hydrogen burn model in the MARCH code are the state-of-the-art models. The problem is not so much with the hydrogen burn model as it is with the hydrogen generation model (p168)***.

CHEMISTRY

Many chemical systems are not modelled in the VANESA code. But for those chemical species that are in the code, the modelling is reasonably correct. During a core concrete interaction; the chemical environment changes from strongly oxidizing to strongly reducing. In the code, when an oxidizing environment is predicted, the species are in the oxidized form; when a reducing environment is predicted, the species are in the reduced form (p267).

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*A venturi scrubber uses water drops to remove aerosols. The water drops are ejected at a high speed into a gas stream. Because a water drop is moving fast, relative to the aerosol particles, the inertia of the particles causes them to be collected.

**Vapors might be removed to some degree by an ice condenser. An industrial spray scrubber removes vapors from effluent gases. A spray scrubber consists of a column of irregular objects creating a large surface area; gases are forced up the column; liquid spray moves down the column. Rarely can a scrubber be designed to collect both vapors and aerosols efficiently.

***The IDCOR reports present many different hydrogen burn models. Some models are better than other models. Even the "best" model raises questions.

Radiolytic chemical reactions are not modelled in any of the codes. At the Oak Ridge National Laboratory, experiments are being done to determine how radiation influences iodine reactions in aqueous solutions (p279). The influence of radiation on the behavior of an aerosol has been discussed at previous peer review meetings; at present, the charges generated by radiation are thought to have a negligible influence on aerosol behavior.

Isotope decay is not accounted for in any of the codes (p283). The bulk of the fission products seem to be long lived isotopes (p480).

The chemical composition of the aerosols may change during a hydrogen burn. This is being studied at the Sandia National Laboratory. It is not in the models.

J. Cobble explained that the reactions forming ceramic materials are not modelled (p478). Borates of cesium are ceramic-like-materials that are very stable. Vapors pressure data for salts at high temperatures are in the literature; the data have not been tabulated in handbooks as of yet.

Cesium hydroxide. Liquid fission product aerosol deposits that melt and run may be significant because fission products may be dissolved (p83).

MODELLING

General

Many phenomena occur during a severe accident. M. Kuhlman though that Battelle is now in a position to consider many phenomena in their models (p83).

For sequences in which an early containment failure is predicted, a source term estimate is sensitive to the way in which the primary system aerosol is modelled. For sequences in which a delayed containment failure is predicted, a source term estimate is sensitive to the way in which the containment aerosol is modelled (p110).

Specific

Decay heat. Decay heating is not modelled in any of the BMI-2104 codes. Modelling decay heat is important when determining the melting rate of ice in an ice condenser or the reevolution of fission products in the primary system (79, 178).

Battelle estimated the effect of decay heat on aerosol deposits that are vaporizing. Calculations were made with the MARCH code, the MERGE code, and the TRAP-MELT code. Given the amount of aerosols predicted by the TRAP-MELT code, an estimate of the decay heat in the primary system was made. These estimates were entered into the MERGE code and used to modify the estimate of deposited aerosols (p79). At Surry, for the TMLB-prime sequence and prior to vessel failure, the predicted fission product behavior was 90% without considering decay heat and 85% considering decay heat.

By neglecting to calculate the amount of decay heat, the source terms can be underestimated. If the fission products are revaporized from the primary system while aerosols are in containment, the aerosol may act as condensation nuclei and remove fission products. If the fission products revaporize after the aerosol have settled, the fission products may remain suspended in the containment (p82).

Flooding. From the V-sequence, aerosol scrubbing by water in a flooded compartment was not addressed in the modelling. E. Warman analyzed the stress on a large diameter pipe and showed that a break would likely occur in a section of Surry ECCS the pipe surrounded by a compartment. Approximately 3 feet of water would cover the break and scrub fission products. This construction is probably found in many plants because the water tight compartment is required by the NRC regulations (p218-35).

Steam generator. The fission product retention by a steam generator at Surry was not considered in the V-sequence analysis (p234). The steam generators are built for 3000 megawatts of heat. During the hypothetical accident, they are receiving 4 to 5 megawatts of heat. The steam generators should be acting as infinite heat sinks. The calculated thermal hydraulic conditions should be influenced by including the steam generators in the calculations. D. Rowe was concerned that natural circulation may eventually carry fission products into the steam generators and other components. P. Cybulskis thought that the steam generators would not receive fission products, at least in some of the sequences (p34).

Debris. Battelle assumed that the interaction between core debris and water results in an efficient heat transfer. R. Ritzman was concerned that the heat transfer was assumed to be perfect. Thermal resistance is included in the quenching models. Quenching experiments indicate that the heat transfer is efficient (p28).

Concrete. For the models of the reactor cavity at the Surry plant, Battelle assumed that the concrete had a limestone composition. The concrete has a basalt composition. The models were corrected. The models now predict less evolved gas from the concrete but faster penetration by corium into the concrete (p27).

Aerosol density. The bulk density of an aerosol particle is assumed to be 3 g/cc. Because of the uncertainty in the figure, shape factors were not used in the models (p67).

Upper reactor vessel region. The upper dome region of the reactor vessel at the Surry plant is considered to be inaccessible to fission products. Battelle was told by Westinghouse that about 1/2% of the primary coolant flow enters the upper dome. However, a greater flow may occur in reactors made by other manufacturers (p27).

Upper plenum. The upper plenum of the reactor at Surry is modelled in the MERGE code as a well mixed volume with three regions, the top support plate, the control rod guide tubes, and the core barrel (p32). Drawings of the upper

plenum are proprietary. Westinghouse described the upper plenum to Battelle in terms of surface areas, flow areas, and structure thicknesses. This information is sufficient for the Battelle analyses.

Ice condenser. The ice condenser containment is modelled using two control volumes. The first control volume is used for the lower containment. The second control volume is used for the upper containment. The junction of the control volumes represent the ice condenser (p153). Models using four control volumes were also tried. The manner in which the containment is modelled has an influence on the predicted pressure due to hydrogen burning (p156). W. Kastenberg asked if the modelling, done under BMI-2104, is in agreement with the calculations for designing hydrogen igniters. P. Cybulskis explained that in some cases, their modelling agrees with the design calculations.

The criteria for hydrogen burning in the Battelle models are as follows; complete burning occurs at 8% by volume and above of hydrogen; partial combustion occurs at 6% to 8% by volume of hydrogen; no combustion occurs when the hydrogen concentration is less than 4% by volume (162).

CODE VALIDITY AND UNCERTAINTY

Validity

The validity of the codes was assessed at the Oak Ridge National Laboratory by T. Kress. The validation study is not a direct comparison of the predicted source terms with experimental data. Rather, the study both assesses the completeness of predictive models and correlates individually modelled phenomenon with experimental data. In general, the codes are supported by at least some data (p252). Nevertheless, additional experiments are necessary. Some of the strengths and weaknesses in the codes are discussed in the following paragraphs.

MARCH. The MARCH code is better than its reputation. The major weakness is the non-mechanistic model of a melting core. The output is dependent on how the core is predicted to melt. At the same time, the flexibility of the code can be used to determine the uncertainty in the code (254).

CORSOR. The CORSOR code is criticized because it lacks many factors that influence fission product releases. Chemical reactions are not modelled even though there reaction influence tellurium releases (p256). Neither is fuel liquification modelled (280). But the CORSOR code appears to be sufficient for most of the appropriate calculations. Considering the deficiencies in the other codes, an analagous code more sophisticated than CORSOR is likely unjustified (256).

MERGE. The merge code does not have features to describe natural circulation in the upper plenum. Neither does the code accommodate decay heat from the fission products (p257).

TRAP-MELT. Some of the deficiencies of the TRAP-MELT are as follows:

p257-9

- The code is coupled to the MERGE code and inherits deficiencies as inputs.

- The model of irreversible deposition is based on insufficient data.
- The model of particle collision and rebounding is neglected.
- The decay heat from fission products is neglected.

To model natural convection in the upper plenum, control volumes, in addition to those that the code currently has, would be needed. Also, TRAP-MELT uses an effective aerosol density for particles; this implies that the aerosol particles are porous. Cesium iodide transport and cesium hydroxide transport are based on chemical equilibrium calculation (276). Reactions of cesium hydroxide with the primary system are not modelled (276). Resuspension mechanism are not modelled (p277).

CORCON, VANESA. Together, these code calculate the thermal hydraulic conditions at a core-concrete interaction and predict the release of fission product gases and aerosols. Data are needed to improve the model of a heat transfer through a metallic layer and an oxide layer in a melt. A hot aerosol cloud above a corium melt was modelled. This reduces the predicted heat loss from the melt and increases the predicted aerosol generation. Many questions still remain about modelling the heat transfer between the corium layers as bubbles pass through the interface of the layers (p265).

The core concrete interaction is based on Green's model. A problem found in the CORCON code is the model of heat transfer between the corium layers. A low viscosity is predicted; this error causes the models to predict a slow heat transfer. Consequently, the predicted corium temperature is erroneously high. Correcting this results in a uniform gas production and a reduced peak aerosol production (p421-7).

The effects of bubbling through a corium melt is supposedly accounted for as a heat flux model in the CORCON code and a void fraction in the VANESA code. These calculations are done by assuming that the bubbles come to a rapid thermal equilibrium.

NAUA. The NAUA code lacks the features to distinguish aerosol particles with varying chemical composition. The code cannot predict the effects of turbulence on agglomeration. Even with these deficiencies, the NAUA code is considered to be adaquate (p274).

Inconsistencies arise when the codes are used together to predict source terms. Four inconsistencies are as follows (p271):

(1) Even though the MARCH code is used to calculate the thermal hydraulic conditions in the reactor coolant system, some other estimates of the thermal hydraulic conditions come from WASH-1400.

(2) Individual fission products species are taken into account in the MARCH code but not in the MERGE code.

(3) The MARCH model is different than the CORCON and VANESA models in calculating the thermal hydraulic loads in a containment.

(4) The MARCH model is different than the SPARC code and the ICDEF code in calculating the thermal hydraulic conditions in a suppression pool and in an ice condenser.

Data

Few comparisons have been made between the predicted fission products behavior and experimental data. Data are scarce. The codes have been compared to their counterpart codes (p285). Even though many of the individual mechanisms are based on experiments, the final predictions from the codes should be compared to some experiments. D. Powers pointed out that some disciplines outside of the nuclear field have relevant data; the VANESA code may be verified with data from the carbon blows in steel mills.

Uncertainty

Uncertainty in the codes was studied at the Sandia National Laboratory in a program called QUEST - Quantitative Uncertainty Estimates for the Source Term (p322). Two types of uncertainty were defined; delta-c is the uncertainty in the inputs; delta-p is the uncertainty in the phenomena. The method to calculate delta-c consists of varying the inputs of the codes to find the ones that strongly influence the output from the codes. Delta-p calculations are analagous. The range over which the inputs are varied is based on data in the literature or alternate models. An extremely wide range of the inputs is avoided (p330). When asked if this method was just a modified sensitivity study, C. Leigh explained that the method was an uncertainty study because the changes in the inputs are not arbitrary changes, they are carefully studied changes (p337).

W. Kastenberg asked if any confidence levels were assigned to the ranges of the inputs and/or outputs (p394). D. Walker wanted to know how the uncertainty bands that were calculated in the QUEST analyses could be used (p446, 448). Because confidence levels were not assigned to the ranges, W. Kastenberg stated that the QUEST analyses were sensitivity studies, not uncertainty studies. R. Lipinski thought that this is a matter of definitions (p449). D. Williams emphasized that these analyses are uncertainty studies because the input changes were justified (p449).

Some of the findings of the QUEST analyses are as follows:

C. Leigh discussed the major uncertainty in the NAUA code (p343-9):

Strong influence on the output	Little influence on the output
Dynamic shape factor. Mean particle diameter. Source rate. Particle density.	Agglomeration shape factor. Number of classes in the particle size distribution.

The dynamic shape factor is based on the premise that the containment atmosphere is dry; a range of 1.0 to 2.3 is used in the analyses. Thermal hydraulic calculations support the premise (347). J. Gieseke speculated that a containment atomsphere would be moist; condensation would occur. To him, a more appropriate range is from 1.1 to 1.2 (p347, 389). R. Lipinski stated that the way to study this factor during late times in a severe accident is by assuming dry conditions.

The use of a log-normal distribution to describe the particle sizes was discussed (p350). C. Leigh explained that the criticisms are focused not on the log-normal distribution but on the Method of Moments using the log-normal distribution. A discrete treatment of the log-normal distribution describes the particle size distribution reasonably well (p350).

D. Powers discussed the results of the QUEST analyses on the VANESA code (p350-8).

Strong influence on the output	Little influence on the output
Steel content of the corium.	Reactor cavity flow area.
Zircalloy content of the corium.	Concrete composition.
	Water content of the concrete.
	Corium temperature.

A. Reynolds pointed out that the concrete compositions may have little influence on the source term but it has a significant influence on the containment loading.

M. Griesmeyer discussed the QUEST analyses on the MARCH code. The MARCH code has a strong influence on the predicted radial penetration into the concrete of the reactor cavity (p379). The predicted temperature in the reactor containment is also influenced by the MARCH code. Large amounts of oxidizing steel in a reactor cavity lead to high pressures in a containment (p379).

CONTAINMENT LOADS AND FAILURES

Events external to a plant, such as an earthquake, were not taken into account in any of the analyses done by Battelle (p130). Such external events could cause a containment to fail. External events can be considered in two ways, as a source term analysis or as a part of the regulatory process.

In the Battelle analyses, the TMLB-prime sequence for Zion results in normal containment leakage; for Surry, it results in a early containment failure. The difference is due to the type of containment at each plant. The containment failure pressure is higher at Zion than at Surry. The predicted pressure, 80 psi to 100 psi, in the containment is based on an energetic core debris-water interaction.

REPORT

Volume 5 of the BMI-2104 reports is considered more reliable than volume 1. In volume 5, the source term calculations for the Surry plant are redone. The difficult question to answer is what is causing the results to differ. Many changes were made including improvements in the computer codes, in the description of the plants, and in the description of the phenomena (p114). Volume 5 may be an improvement for the Surry plant but the volume 1 analysis may represent other plants accurately (p296).

Many cross references are in the current reports (p119). When the BMI-2104 reports are finished, each report will stand by itself.

D. Rowe thought that the assumptions should be better supported. Many times, unqualified assumptions are made (p291).

The BMI-2104 reports will not reflect the uncertainty analyses done at the Sandia National Laboratory (p453). This is due to the NRC schedule.