TECHNICAL SUMMARY OF THE MAY 1983
PEER REVIEW MEETING

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ACCIDENT SEQUENCES AND SYSTEM BEHAVIOR

Sequences

The peer review group discussed how variations in a given accident sequence were taken into account. I feel that the sequence definitions are to be taken in a general sense such that some amount of variation is implicitly understood. However, two examples were cited that go beyond this implicit understanding, namely, containment penetration failure (p. 378) and suppression pool bypass (p. 412).

R. Bernero discussed the consequences of a failure of electrical penetration assemblies. If this occurred prior to a containment failure, a diffuse flow path instead of a concentrated flow path would arise. Most likely, the diffuse flow would go through the auxiliary building because that is where most penetration lead. W. Kastenberg discussed how, even in a MARK-III containment, unidentified bypasses around the suppression pool may exist.

System Behavior

The TC sequence is a model of a failure to scram and to borate. In this model, Battelle has the Peach Bottom BWR core at an equilibrium power level of 30% while covered with water (p. 94). The power level is at the level of decay heat when the core is dry. Battelle feels that the 30% figure is reasonable and says that the 30% figure is from GE literature (p. 401). I checked with the NRC staff and arrived at the same conclusion. For the Grand Gulf core, the equilibrium power level before the core dries out is 16%; the difference between this and the 30% figure arises because of the difference in the flow pattern from the ECC systems in the plants (p. 193).

THERMMAL HYDRAULICS

General

Many concerns were raised about the thermal hydraulic modelling. Example 1: As steam enters a containment, adiabatic expansion should occur such that particle deposition is enhanced (p. 49). Example 2: The standby gas treatment system pulls 25000 cfm when operating; when the system is not operating, it is unclear what makes the gas flow through the blowout panels of the reactor building at the same rate (p. 427). Example 3: The thermal hydraulic characteristics of the reactor coolant system are given much attention but the thermal hydraulic characteristics of other portions of the pathways are given little attention (p. 307). Battelle acknowledges the uncertainties in the thermal hydraulic modelling (p. 99). Many of the analyses are redone as new information comes to light.

Decay Heat

The effect of decay heat from fission products that are deposited in the reactor system was not modelled. However, Battelle estimated the thermal hydraulic influence of decay heat for the S2D sequence in the Surry analysis. The estimate was made by iterating the MERGE code, which predicts flow patterns, and the TRAP-MELT code, which predicts deposition. The codes were iterated once.

Battelle found from their calculations that the decay heat from fission products significantly influences the deposition of fission products (p. 58). The effect is not on the deposition of aerosols but on the deposition of vapors. Their calculations show that in the upper plenum, cessium iodide begins to deposit but is driven off by decay heat (p. 56). Volatile species deposit on aerosol particles instead of on surfaces and the fission products essentially move downstream (p. 67).

Much of the decay heat is from the tellurium and the aerosols (p. 57). Though the thermal hydraulic calculations are influenced by the decay heat data, Battelle does not plan to modify their models because of the complexity of the changes (p. 59).

I find difficulty in believing that the behavior of aerosols is uninfluenced by decay heat. I speculate that convection currents change the flow patterns and modify aerosol deposition. Admittedly though, I have not done any calculations to support my statement. I am surprised that the aerosols pick up the volatile fission products because I speculate that the aerosol particles are hot from emitting decay heat; perhaps the particles stay cool, relative to surfaces, by emitting heat rapidly rather than heating up. Nevertheless, I expect the volatile fission products to remain suspended in the hot areas of the reactor system.

CHEMISTRY

Hydrated Species

At high temperatures and pressures, hydrated molecules form from an inorganic specie and water (p. 140). The vapor pressure of the inorganic specie is modified so that a normally immobile specie is transported. J. Cobble, who has experience in high pressure and high temperature chemistry, raised this point. The phenomenon is seldom recognized and little is known about it. It is not surprising that Battelle did not model the phenomenon.

Chemisorption

No definition of chemisorption was agreed upon. R. Vogel said the chemisoprtion is not a strong interaction and that "reaction" was being confused with "absorption" (p. 133). C. Johnson said that, to a chemist, chemisorption is anything but a chemical reaction (p. 289). Finally, J. Cobble was puzzled by the use of the term, especially under the conditions of high temperatures; cesium hydroxide reacts with the iron in steel forming iron oxide and cesium; the cesium reacts with water to form cesium hydroxide (p 324).

In the literature, chemisorption is defined as binding forces of the magnitude of chemical bonds.* Physical absorption is defined as binding forces of the magnitude of Van der Waals forces.* These definitions are convenient definitions of extremes. As J. Cobble implies, at high temperatures, the distinction between binding forces and bonds may not exist.

Release of CsI and CsOH

For the BWR analysis of the AE sequences, Battelle has CsI and CsOH release to the environment in equal fractions (p. 125). This is surprising because CsOH is much more reactive than CsI. One would expect little CsOH and much CsI to be released. Battelle offered no explanation at the meeting because, at the time, the calculations were not thoroughly studied.

Battelle explained that they studied the kinetics of the CsI and the CsOH reactions. An equilibrium between the two species is reached. Furthermore, the removal of CsOH as a deposit on the hardware surfaces does not significantly influence the amount of CsI in the reactor system. This was questioned by C. Johnson (p. 221). Battelle feels that the deposition of CsOH is somewhat reversible though just how much so was not mentioned. Two aspects of CsOH chemistry were of concern when modelling irreversible bonding and reversible processes (p. 124). Battelle felt that irreversible bonding dominated the reversible processes.

* Carberry, Chemical and Catalytic Reactions, p. 364.

Tellurium Chemistry

The chemistry of tellurium is being investigated by Oak Ridge National Laboratory. Tellurium reacts with zirconium, chromium, nickel, and iron. Zirconium telluride is the most stable specie of these four compounds. In steel, tellurium reacts with chromium first and nickel second. As the chromium oxidizes, nickel telluride and iron telluride form. Much work is still needed in this area.

FISSION PRODUCT RELEASE FROM FUEL

Core Concrete Interaction

The composition of concrete used in the reactor cavity varies from one reactor to the next (p. 153). Sometimes the concrete has a high limestone content and other times it has a low limestone content. The limestone content is important because limestone generates carbon dioxide during a core concrete interaction. The evolving gas ejects fission products as aerosols. The importance of this is illustrated with an example of tellurium behavior. Experiments at Oak Ridge indicate that tellurium will remain in a core melt, but tellurium may be released from a melt by evolving gases. R. Vogel points out the behavior of tellurium is an extrapolation of the behavior of sulfur; statements about tellurium behavior should be made with caution (p. 164).

Release from Fuel

Oak Ridge is doing research directly with tellurium release rates from fuel (p. 332). Three approaches are taken to determine release rates. The first approach is to classify past experiments. These experiments show conflicting results. In some experiments, the release rate of tellurium is similar to the release rate of iodine, cesium, and noble gases. In other experiments, the release rate of tellurium is either greater than or less than the release rates of iodine, cesium, and noble gases. Oak Ridge is determining the reason for the conflicting results. The second approach is a look at TMI-2 data. This data is conflicting. The third approach is to conduct exeriments in high temperature chemistry.

The fission products modelled most often are the volatile ones, namely, cesium, iodine, and tellurium. Less volatile fission products, such as barium and strontium, also are modelled, but these fission products are of secondary importance (p. 393).

REACTOR SYSTEM-TRANSPORT, DEPOSITION, AND REENTRAINMENT OF AEROSOLS

Four features of Battelle's model of the aerosols in the Peach Bottom reactor system are as follows:

1. Vapors are deposited on equipment and hardware surfaces. As the surfaces heat up from hot gases, the vapor resuspends and deposits downstream. Vapors are resuspended. Aerosols are not resuspended (p. 118).

2. Decay heating is not modelled. Decay heat is expected to influence the deposition of vapors, not the deposition of aerosols (see thermal hydraulic section).

3. In the Peach Bottom analysis some of the low retention factors for CsI and CsOH in the coolant system are due to a rapid flow of steam. The steam flow results from the way in which the core slump is modelled, either as a coherent slump or as a gradual slump (p. 128).

4. The core slumping model also influences the aerosol emission rate. The coherent slump model causes a higher rate than the gradual slump model.

CONTAINMMENT - TRANSPORT, DEPOSITION, AND REENTRAINMENT OF AEROSOLS

Many of the mechanisms that govern the behavior of aerosols are in Battelle's models. Some of the mechanisms built into the models are gravity settling, diffusional deposition, agglomeration, and steam condensation (p. 142). Two mechanisms that are not in the models are diffusiophoresis and aerosol charging.

Battelle considered the phenomenon of diffusiophoresis insignificant because the containment surface area is small compared to the containment volume and the temperature gradients are small (p. 44). D. Cooper thought that the issue should be reexamined; he cited calculations for Surry which show a large amount of collection from condensing steam (p. 48). S. Beal, from the ACRS, also thought that diffusiophoresis is an important phenomenon. I spoke with Beal outside of the review meeting; he pointed out that diffusiophoresis is driven by three gradients, a temperature gradient, a pressure gradient, and a temperature gradient. A small temperature gradient alone does not mean that diffusiophoresis is insignificant. Apparently, because the temperature gradient is small, Battelle does not model steam condensation on walls.

Aerosol charging is another mechanism that is not in the models (p. 371). J. Gieseki cited studies where radiation fields created a small amount of both positive and negative ion. He did not know how the differences in ion mobility would effect the behavior of an aerosol cloud. D. Cooper stated that the effect may be important for highly concentrated aerosols.

A spray system, whether it is in a containment or in a reactor building is an effective way of removing aerosols. The influence of drop size on the collection efficiency is dramatic. Battelle made calculations using several drop sizes in the range of 400 microns to 1000 microns. The calculations are being redone for several reasons. Impaction was assumed to be unimportant because Stoke's Law was assumed valid for large water drops. This may not be the case. Also, D. Cooper thought that the calculations should include an initial water drop velocity that arises from ejecting water drops out of the spray system under pressure. The initial velocity might carry through a significant height of the containment before the terminal settling velocity is reached (p. 461). It is interesting to note that a single drop size and not a distribution of drop size is used. Battelle says that using a distribution of drop sizes is tedious, complex, and unnecessary (p. 51). The same reason is cited for using a single size distribution for the aerosol particles instead of a multinodal distribution. One would suspect that a multinodal distribution to arise from a uninodal distribution as a result of aerosol aging and circulating currents (p. 173).

CONTAINMENT LOADS AND FAILURES

One of the weakest and most controversial areas of the source term modelling is the containment loads and failure modelling. Because data are scarce, many assumptions are necessary for the calculation. These assumptions continue to be a source of debate. Battelle has made attempts to look at the sensitivity of the source term to some of the modelling assumptions.

Czybulskis described a sensitivity study on the peak steam pressure that is predicted in BWR containments. The study was done with the MARCH 2 code. Battelle varied the heat transfer assumptions and models for a series of core debris particle sizes. Two models were used; a quenching model, where the code has particles binding reactor water until either particles or water quantities are exhausted; a levitation model, where a bed of debris forms in relation to the heat that is evolved. Battelle found that the peak pressure reached in a containment is insensitive to the modelling assumptions (p. 35).

Particle Diameter (inches)	Peak Pressure Quench Model	(psi) Levitation Model
1.00	76	74
0.20	84	82
0.04	96	-

Reference p. 33.

A steam spike is just one of several causes of a containment failure. Hydrogen can also cause a failure of a containment. This can happen in two ways, depending on a particular sequence. First, a reaction between water and zirconium can generate enough hydrogen to build up excess pressure. When a containment is inerted, either with a noble gas or with steam, this pressure is from accumulating hydrogen, not from burning hydrogen. Second, hydrogen may burn causing a large pressure spike. R. Sehgal questioned the severity of such a spike; he claims that hydrogen coming from a suppression pool will ignite as a diffusion flame burns (p. 305). This issue is still unresolved.

Much of the modelling of the steam spike is also unresolved. Battelle pointed to three problems (p. 403); uncertainty in the amount of water available; uncertainty in the amount of core debris available; uncertainty in the temperature of the core debris. W. Kastenberg was concerned that only selected failures were being examined (p. 283). In his opinion, containment failures should be looked at in a more general way.

SUPPRESSION POOL

For the BWR sequences, the capability of the suppression pool to remove fission products was questioned. The questions can be divided into two categories; one, the modelling of the removal mechanisms given that fission products are entering the pool, two, the possibility of bypassing the pool. The first category has questions that are well focussed and more or less easily answered. The second category has few questions.

The SPARC code is used to model the removal of aerosols by the suppression pool. A. Postma described the major phenomena that he modelled:

1. pool temperature,
2. pool depth,
3. bubble shape,
4. bubble stability,
5. steam condensation,
6. growth of soluble particles,
7. centrifugal deposition, and
8. diffusion deposition.

Phenomena that are not modelled include the following:

1. virtual wind from evaporating water, and
2. particle ejection from bubble bursting.

An insignificant amount of aerosols is expected to deposit in the pipes leading to the suppression pool because of the high flow rates and the small particle sizes. Frothing is considered an insignificant phenomenon (p. 326).

Arciers, from NUS, thought that the suppression pool might flash during a TC sequence. He postulated an injection by HPCI during an ATWS. The suppression pool temperature would rise to 347 degrees. When the containment failed, the suppression pool would depressurize and flash. His concern is that the core melting period and the pool flashing period might overlap; the flashing would effect the bubble characteristics. Battelle did not model suppression pool flashing.

A. Postma's discussion of the SPARC code was very thorough. One of the mechanisms that he described brought several questions. This was centrifugal deposition: the motion of water around a bubble creates air currents that cause aerosol particles to impinge on the bubble surfaces (p. 242). A. Postma assumed that the concentration of aerosol particles is homogeneous in a bubble, even with this phenomenon. I speculate that the center axis may be somewhat depleted of particles because the gas carried to the bottom of the bubble at the bubble surface will have been cleaned before it wells up in the center. I talked with Postma after the meeting about this and he agreed; he added that bubble oscillations would destroy the rising central column of clean air and keep the concentration homogeneous.

CODE VALIDITY, SENSITIVITY, AND UNCERTAINTY

Validity

Battelle cited a number of instances where the modelling is improved. One, the core melt is modelled as a slump instead of a coherent drop; this change was intuitive more than it was factual (p. 64). Two, the period that the melted core is in the lower plenum seems to be more realistic than in earlier models; the melt is held up in support structures (p. 63). Three, water and energy balances are maintained (p. 101). Four, decay heat from heavy elements is modelled.

Czybulskis was concerned about modelling the core power distribution because the modelling techniques strongly influence the calculated core behavior. In a core, according to Czybulskis, the power distribution is always changing. This makes modelling difficult. R. Sehgal disagreed, saying that the power distribution can be known very accurately, even though the levels are changing.

Warman questioned the 0.1 second time allowed for the melted core to travel from the vessel to the reactor cavity. He said that the control rod drive mechanisms and between the vessel and the concrete (p. 312).

Sensitivity

Battelle did sensitivity studies on the containment pressure and reactor coolant system deposition. Differences in the results of the Grand Gulf analysis and the Peach Bottom analysis are due to the way that the cores were divided into node regions for modelling; this indicates that the modelling may leave artifacts in the results. The location of the node regions are very important as D. Cooper pointed out (p. 205). The node regions influence the core temperature; vapor pressure has a strong dependence on temperature. Hence, the release of fission products is strongly influenced by the core nodes. Thus, the apparent holdings of cesium iodide and cesium hydroxide in the Grand Gulf analysis relative to the Peach Bottom analysis may be due to differences in assigning nodes in the core (p. 217). Battelle acknowledges this. The core nodes are based on the information that is available for modelling; the importance of sound modelling practices can not be overemphasized.

Uncertainty

Two areas of uncertainty are the scaling up of experimental results and the failing of the containment. Battelle is updating their models as experimental data becomes available. The experiments are gradually being scaled up but this is no trivial matter. The experiments are costly and use state-of-the-art technology. Containment failure uncertainty is also being addressed. The containment is a complex structure that is very costly and difficult to analyze.

D. Walker is concerned that an event tree was not done for the MARK-I containment (p. 183). Each PRA has a containment event tree which is based on WASH-1400. The Zion plant, a PWR, has the most elaborate containment failure tree described. No BWR plant has a similar analysis.

Representativeness

Many critics of the source term work cite a need to compare the results of the model with the data from the TMI accident. R. Vogel is concerned about using this data (p. 349); he said that the core was reflooded after it was damaged. This caused leaching.

Kastenberg emphasized a need to compare schematic diagrams to the plant itself since "as-built" and "as-drawn" are frequently different (p. 414). Vogel went one step further in stating that a given analysis is specific to the plant that was studied. The results from one analysis cannot be generalized to another plant (p. 327).

I agree with Kastenberg's statement; an as-built plant and an as-drawn plant are frequently different. Battelle said that this is true but there are limits to what can be done in a study. I take issue with Vogel's statement; the results of an analysis cannot be generalized to other plants. The issue is not whether or not plants are identical. To generalize results, the issue is whether or not the plants have relevant common characteristics. I believe that Vogel meant to say that results must be generalized with caution.

REPORT ORGANIZATION

The report needs to be written in a constant way. Time begins either at the onset of a sequence or at the onset of a particular computer code. Time is expressed in seconds, minutes, hours, and days. Temperature is expressed in both Celcius and Fahrenheit degrees. Also, the discussion of the report should be in the terms of the physical processes, not in the terms of the computer codes.