LETTERS TO THE EDITOR

COMMENTS ON "REALISTIC ESTIMATES OF THE CONSEQUENCES OF NUCLEAR ACCIDENTS"

We would like to respond to some issues raised by Levenson and Rahn.[1] We should make it clear at the outset that we do not argue with the importance of the issues raised by the authors or that more effort is needed in obtaining a better understanding of fission product behavior in reactor accidents. However, we would like to make some observations on their paper and clarify what we feel are misunderstandings about the WASH-1400 analyses.[2] In addition, we believe that the authors leave the impression that there is a body of evidence that indicates that the fission product release estimates are greatly overstated. We disagree with this position. Since the completion of WASH-1400, we have been involved in the development of methods for the analysis of core meltdown accidents (the MARCH code describing the physical processes of core meltdown accidents, the TRAP code describing radionuclide retention in the primary system, and several containment transport codes) in which the sensitivities of results have been tested as functions of modeling and data uncertainties. We have concluded that the uncertainties in predicting fission product release from containment are quite large. The degree of optimism of the authors that the WASH-1400 values are greatly overestimated is not warranted, however.

Some specific comments follow.

1. The authors assert that "... the probabilistic models have been developed to the point where their usefulness is not limited by their technique, but by the validity of the data used in evaluation part 2, the consequences," and "... WASH-1400 has a tendency to greatly overestimate consequences." We disagree with these assertions. The authors do not discuss the uncertainties associated with the prediction of the probabilities of the occurrence of reactor accidents; we feel that the latter are at least comparable to those associated with the prediction of accident consequences. As will be noted in subsequent comments, it appears that the authors' impression that WASH-1400 greatly overestimates consequences stems from some misunderstanding of WASH-1400 analyses.

2. The authors make a major point regarding the solubility of CsI and the existence of moisture in light water reactor (LWR) core meltdown accidents. It is important to consider the behavior of core meltdown accidents mechanistically. For most sequences of interest, the pathway from the core region to the containment would be filled with superheated steam and hydrogen, and not water. Carryover of the water droplets as observed in emergency core cooling tests would not occur during core melting. Transport of CsI through the reactor coolant system would initially be as a vapor that would condense to form an aerosol as it is cooled in the reactor coolant system or containment. Water condensation on these aerosols would be expected to occur in the containment atmosphere, which would tend to enhance aerosol deposition. This effect is included empirically in the CORRAL code (used in WASH-1400), which was based on Containment Systems Experiment data. Furthermore, preliminary comparative analyses with the NAUA code, which includes consideration of condensation on aerosol behavior, have indicated that this effect is not dramatic.

3. The authors reference a number of old experiments regarding fission product release from fuel and containment deposition as evidence of effects not included in the WASH-1400 analyses. These data were not only recognized by the authors of WASH-1400 and used in forming the fission product release models, but in many cases the data have been collected by the authors of WASH-1400 themselves (e.g., G. Parker and A. Postma). The CORRAL code developed for the Reactor Safety Study was based primarily on large-scale containment tests noted in Sec. III.B of Ref. 1.

4. The unqualified statement that the mode of containment failure would involve long irregular cracks through concrete cannot be supported. While such failure modes are possible, they would imply localized failures (probably in the containment liner) at internal pressures close to design levels. Such failure modes are not consistent with internal pressures several times the design level that challenge the gross structural integrity of the containment, as have been considered in WASH-1400 as well as a number of subsequent studies. One cannot discount, with any degree of assurance, the possibility of gross containment failure.

5. In contrast to the comments by the authors regarding "models ... assume that any melting of the reactor core will within minutes lead in all cases to a catastrophic failure of the reactor pressure vessel and containment building," models in WASH-1400 were used to *predict* the failure of the pressure vessel and containment building. The timing of these events relative to core melting was found to be sequence dependent and had a major influence on the predicted consequences. Although the models that are currently being used to predict the physical processes of core meltdown accidents are significantly improved over those used in WASH-1400, our current perception of the timing and mode of these events has not been substantially altered.

6. The discussion in Ref. 1 of the WASH-1400 containment failure modes and consequences is erroneous. Large radioactivity releases were not always predicted; depending on the details of the physical phenomena occurring, a very broad range of radioactivity releases was calculated. WASH-1400 predicted that in all core meltdown sequences the containment basemat would be penetrated. If the internal

containment pressure was high enough, some of the airborne radioactive material was released to the ground where it was scrubbed (DF of 1000 except for noble gases) before escaping to the air. In the most probable core meltdown sequences in the pressurized water reactor above-ground failure was predicted to be unlikely. (It is not clear from where the authors' <2% came.) For sequences in which above-ground failure of the containment is averted, the release of radioactive material to the environment is much less (by a factor of 10^4 to 10^5) than for the more severe accidents. In fact, using indices of relative hazard for different radionuclides, the predicted consequences of the most likely core meltdown sequences in WASH-1400 are less than the actual off-site population exposure of the Three Mile Island (TMI) Unit 2 accident. In contrast, the Mark I boiling water reactor (BWR) containment design was predicted to have an atmospheric failure for all core meltdown sequences. Again, a broad range of potential consequences was obtained in WASH-1400, ranging from little deposition for direct releases to the atmosphere to substantial retention due to the effectiveness of the suppression pool in scrubbing fission products and because of the credit taken in the analysis for deposition external to the primary containment along the pathway of the release to the environment.

7. The authors base much of their argument on the history of reactor accidents and the results of destructive experiments. They fail to take note of the fact that neither the reactor designs nor the scenarios in these accidents and experiments resemble the accident sequences that have been found to be important in WASH-1400 as well as a number of subsequent risk studies. The reader should recognize that the types of accidents at issue (those predicted to dominate risk) are believed to be very rare events (e.g., 1:200 000 reactor years); statistically they represent only a small fraction of all possible core meltdown accidents. In these events, combinations of failures of engineered safety features are predicted to result in early above-ground failure of the containment building. Despite their very low probability, but because of their potentially high consequences, these sequences were predicted to dominate public risk in WASH-1400 as well as other more recent studies. The magnitude of possible retention mechanisms must be evaluated for the specific conditions expected in these sequences. Accidents that have occurred in 400 reactor years of LWR operation have had little similarity to the behavior expected in these rare events. In particular, the TMI accident is quite unlike the risk-dominant accidents of WASH-1400 and a direct comparison is inappropriate.

8. Table I of Ref. 1 misrepresents the WASH-1400 assumptions concerning fission product release to the environment. Specific examples of apparent misunderstandings are:

a. Significant washout of released fission products by water in the primary system was indeed considered when the release path was through water, particularly in the BWR analyses.

b. Deposition of released radioactivity within the containment as well as external to it, where appropriate, was specifically considered; deposition external to the primary containment was found to significantly reduce releases to the environment in many BWR accident sequences.

c. Fission product removal due to flow through suppression pools was explicitly considered.

d. Aerosol behavior was evaluated by means of the CORRAL code, which is based on large-scale containment experiments.

9. No basis is given to support the iodine attenuation factors assumed in Table III of Ref. 1.

As stated at the outset, we agree that more effort is needed in obtaining a better understanding of fission product behavior in reactor accidents to serve as the basis of safety judgments as well as improved risk assessments. While risk assessments should be conducted as realistically as possible, care must be taken that the assumed realism can be well supported. Due note must be taken of the uncertainties associated with the prediction of both the probabilities and the consequences of reactor accidents. Since these uncertainties are large, the formulation of safety judgments must err on the side of safety by taking into account all possible outcomes at some high level of confidence. A "realistic" or "best estimate" evaluation would, after all, underpredict reactor accident consequences much of the time. Only if the uncertainties associated with such a "best estimate" or "realistic" evaluation are small, would such an approach be acceptable. The concept of "upper limit of possible attenuation factors" as used in Ref. 1 has meaning only insofar as it may help to define the range of uncertainties. Clearly, a safety judgment or meaningful risk assessment cannot be made on the basis of possible attenuation factors that may, in fact, be unavailable most of the time.

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REFERENCES

1. M. LEVENSON and F. RAHN, "Realistic Estimates of the Consequences of Nuclear Accidents," *Nucl. Technol.*, **53**, 99 (1981).

2. "Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400 (NUREG-75/014), U.S. Atomic Energy Commission (1975).

REPLY TO "COMMENTS ON 'REALISTIC ESTIMATES OF THE CONSEQUENCES OF NUCLEAR ACCIDENTS' "

Cybulskis et al.[1] call us[2] to task for leaving "the impression that there is a body of evidence that indicates that fission product release estimates are greatly overestimated." That was exactly our intention. All the empirical evidence to date suggests that the predicted consequences of reactor accidents are too high. On the other hand, there is no accident or *integral* experiment that shows the computer models they advocate give accurate results.

It appears from reading their last paragraph that they did not appreciate a major point of our paper. Calculations