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AN OVERVIEW OF SELECTED SEVERE ACCIDENT RESEARCH AND APPLICATIONS

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ABSTRACT

Severe accident research is being conducted world wide by industry organizations, utilities, and regulatory agencies. As this research is disseminated, it is being applied by utilities when they perform their Individual Plant Examinations (IPEs) and consider the preparation of Accident Management programs. The research is associated with phenomenological assessments of containment challenges and associated uncertainties, severe accident codes and analysis tools, systematic evaluation processes, and accident management planning. The continued advancement of this research and its applications will significantly contribute to the enhanced safety and operation of nuclear power plants.

INTRODUCTION

Following the TMI accident, a new emphasis and significant resources have been focused on severe accident research. The research has resulted in experimental, analytical, and methods development activities. Severe accident research has been conducted by industry organizations, utilities, regulatory agencies, and has been studied internationally. As the body of knowledge continues its significant growth, it is being interpreted and applied by utilities performing Individual Plant Examinations (IPEs) and by the regulatory agencies reviewing those submittals.

Fauske & Associates, Inc. (FAI) and its sponsors (EPRI and Commonwealth Edison Company) have been actively involved with a series of severe accident experiments. These experiments began with an evaluation of the Mark I liner-meltthrough issue associated with BWR containments.[1,2] These experiments were followed by an assessment of the importance of internal containment structures to the potential for high pressure melt ejections causing direct containment heating.[3] Additional tests were conducted following the recognition of the possibility of consequential external flooding of reactor pressure vessels during primary system inventory losses. The ability to remove the fraction of decay heat transmitted through the lower plenum wall was investigated and interpreted in a series of experiments and papers.[4,5] The likelihood of maintaining the integrity of the lower RPV head during external flooding following relocation of core debris depends upon the survivability of the penetrations in the lower plenum wall. EPRI has sponsored research[6] to investigate the response of lower head penetrations (instrument tubes) during such events. As shown in Figure 1, the response of lower head penetrations was investigated such that the importance of the internal heat sink due to the water filled annulus was experimentally investigated. Further consideration of accident management strategies and the potential protection of the RPV lower head by external cooling lead to consideration of reactor configurations that employ RPV support skirts. A presence of a support skirt can influence the ability to continually remove steam generated during ex-vessel cooling (see Figure 2). Experiments were conducted[7] in support of the Commonwealth Edison Company IPE/AM program to investigate the impact of support skirts with and without local venting. Such experimental investigations for a spectrum of reactor coolant system and containment challenges provide a technical basis and direct experimental data to assist in their evaluation and quantification. This is true of all the on-going research being conducted internationally and by regulatory agencies. Direct participation in several experimental activities provides a strong basis for assuring appropriate interpretation and application of the entire spectrum of severe accident research and analyses to plant specific assessments as conducted as part of individual plant examinations (IPEs).

PHENOMENOLOGICAL EVALUATION SUMMARIES

Phenomenological evaluations summaries have been produced as second tier documentation for several IPE submittals in the United States. Phenomenological evaluation summaries are structured to evaluate the plant specific challenge of each postulated containment failure mechanism associated with severe accidents. Several direct applications of severe accident research for IPEs have been employed in these evaluations.

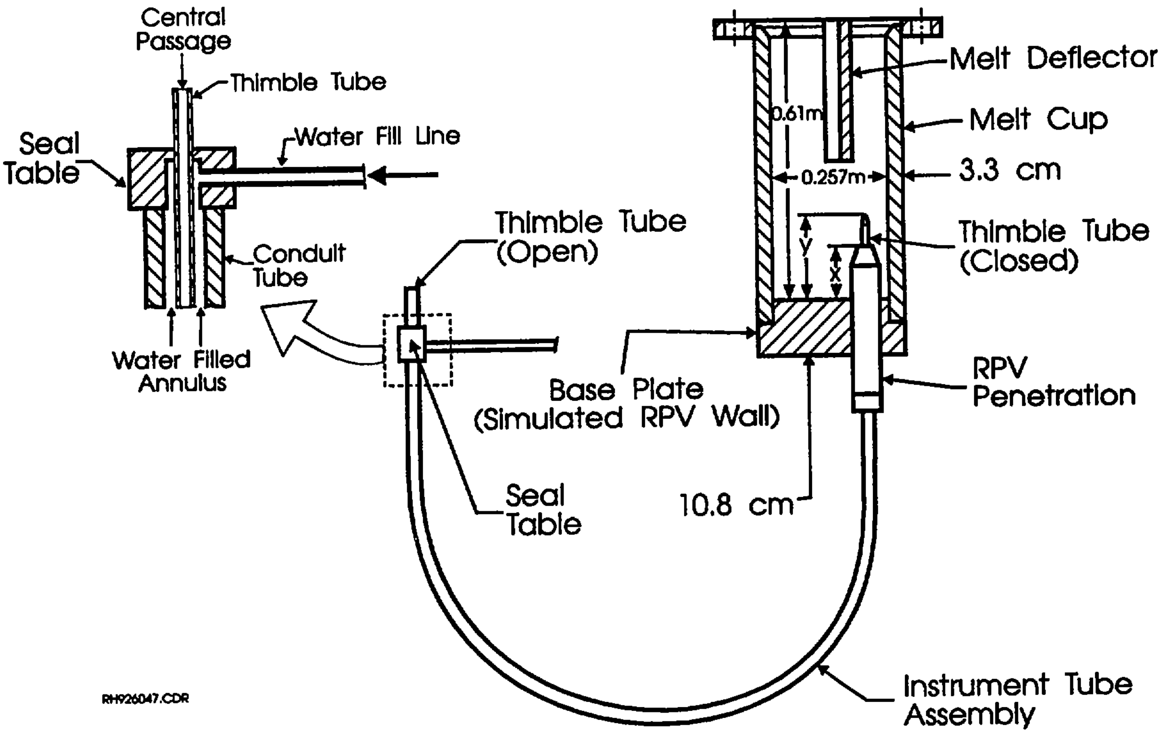

Figure 1 - Simulated Lower Plenum, Penetration, and Instrument Tubes

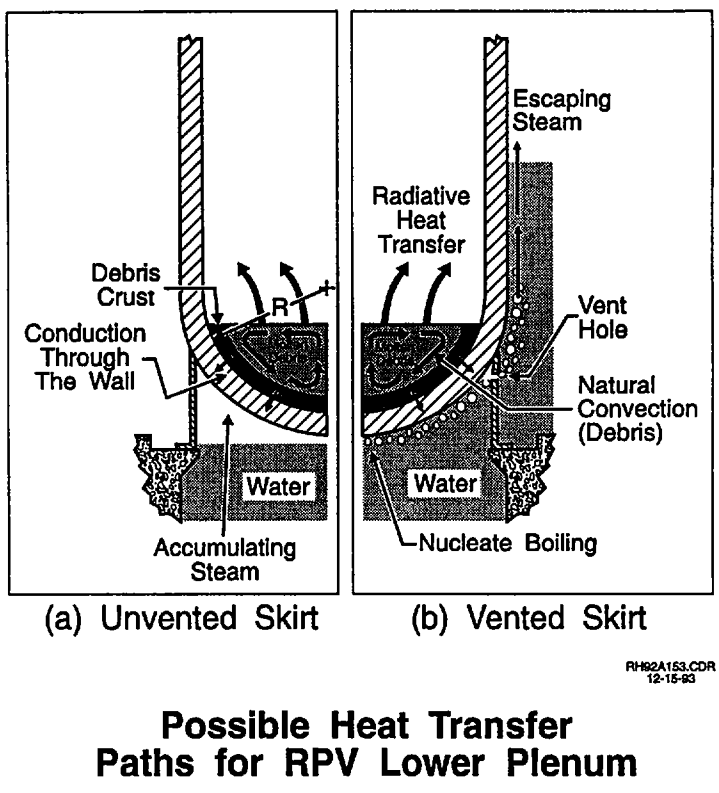

Figure 2 - Possible Heat Transfer Paths for RPV Lower Plenum With Support Skirt During Ex-Vessel Cooling

These evaluation summaries assess potential containment challenges from the entire set of severe accident phenomena as identified in U.S. NRC Generic Letter 88-20[8] and other documents.[9] Summaries have been prepared for topics that address both BWR and PWR design currently in operation around the world. Additionally, summaries have been prepared for the AP600 design. Table 1 lists the set of topics considered by preparing phenomenological evaluation summaries. Phenomenological evaluation summaries incorporate a description of the severe accident phenomena including the associated physical processes, the relationship to potential containment failure mechanisms and modes, and their relationship to environmental source terms.

Table 1 - List of Phenomenological Evaluation Summary Topics

Phenomenological Evaluation Summary Topics:

- containment bypass/failure to isolate,
- core-concrete interactions,
- vessel blowdown/thrust loads,
- high pressure melt ejection/direct containment heating,
- steam explosions,
- hydrogen deflagration/detonation,
- containment overpressurization,
- thermal attack of penetrations,
- ex-vessel cooling,
- fission product retention,
- liner attack and melt-through.

Evaluation summaries identify and discuss related severe accident experiments and analyses. A simplified methodology for assessing the potential containment challenge associated with each selected severe accident phenomena is described and applied to the specific plant's IPE. Uncertainties in phenomena and methodologies are identified and discussed. Lastly, accident management implications of such an evaluation are identified and discussed for each severe accident phenomena. Figure 3 provides a topical outline of the content of an evaluation summary. Such a structured assessment has proved to be a useful means of synthesizing current research results and applying them to a given plant's IPE. Furthermore, the structure of such an evaluation summary provides a direct mechanism for incorporating additional severe accident results as they become available. This is a useful feature when addressing "living" PRAs and the maintenance of each utility's IPE. On-going severe accident research will likely provide additional experimental data that can be used to assess and confirm the simplified methodology included in such evaluation summaries. Plant modifications and enhanced credit for the plant's total capability as exploited by recovery actions and accident management strategies can be reflected in the plant specific application of the simplified methodology. Future experimental results can also be used to assess potential reductions in key uncertainties. Thus, the upgrading of an IPE can be facilitated by this structured approach as more severe accident experimental research becomes available.

DECOMPOSITION EVENT TREE QUANTIFICATION

An additional direct application of severe accident research involves the generation and quantification of decomposition event trees. Decomposition event trees identify the sub-phenomena and their chronological relationship associated with each selected severe accident phenomenon or containment failure mode. Results from severe accident experiments and analyses provide perspective for selecting and ordering the key sub-phenomena and uncertainties. Decomposition event trees have been used in IPE's for light water reactor plants, in certification documentation for advanced light water reactor plants, and in regulatory assessments of selected containment failure modes such as the Mark I containment liner melt-through and direct containment heating issues. These two topics have been treated by application of the risk-oriented accident analysis methodology - ROAAM[10] which provides alternate probabilistic framework for representing major uncertainties in core melt progression. Severe accident research results have been applied to set ranges in key parameters assessed in the related sensitivity and uncertainty studies.

SEVERE ACCIDENT TOOLS

Several indirect applications of severe accident research in IPEs have also been formulated. The development of severe accident tools (including computer codes) and their benchmarking is a principal indirect application of such research. The MAAP and MELCOR codes are examples of tools being used for IPE's. Severe accident research, particularly in the areas of core melt progression, hydrogen generation, fission product release rates, aerosol behavior, high pressure melt ejection and direct containment heating, debris coolability (in-vessel and ex-vessel), and containment mixing are examples of the topics direct assessed by severe accident research. The results of this research is used to define and describe models for incorporation in severe accident computer codes and for benchmarking the behavior of such models once they have been implemented.

Benchmarking can also be conducted by comparing the relative performance of different severe accident tools. This approach further extends the application of both the experimental and analytical research and enhances the understanding of the current state-of-the-art. For example, the comparison of the two different solution techniques employed by the NAUAHYGROS and MAAP4 codes to solve the integro-differential equation for aerosol behavior in a closed

PHENOMENOLOGICAL EVALUATION SUMMARY
(General Outline)

I. ABSTRACT
Summary of evaluation of potential containment challenge or failure mechanism.

II. PURPOSE AND BACKGROUND
Statement of summary's objectives and related regulatory requirements or positions.

III. PHENOMENA
III.1 DESCRIPTION: Description of phenomena and its physical processes, its relationship to containment failure mechanisms and modes, and its relationship to the source term.
III.2 EXPERIMENTS: Listing, summary, and assessment of applicability of regulatory, international, and industry severe accident experiments for given phenomena.
III.3 ANALYSES: Listing, summary, and assessment of applicability of regulatory, international, and industry severe accident analyses for given phenomena and plant configuration.

IV. METHODOLOGY
Description of simplified or bounding estimate methodology for assessing potential for containment challenge or fission product release.

V. APPLICATION OF METHODOLOGY
A plant specific application of the methodology described in Section IV is performed and documented.

VI. ACCIDENT MANAGEMENT IMPLICATIONS
Accident management activities (strategies, training, tools, information needs, organization enhancements) are identified and highlighted for the assessed phenomena.

VII. UNCERTAINTIES
Key phenomenological uncertainties are identified and assessed.

VIII. SUMMARY
Summaries phenomenological evaluation and key observations or insights.

IX. REFERENCES
Serves as a bibliography of severe accident research included in the phenomenological evaluation.

Figure 3 - Topical Outline for Phenomenological Evaluation Summary

container has been performed.[11] This comparison demonstrated the degree of agreement obtained from solutions based on a sectional approach and an approach that used a non-dimensional correlation based on similarity arguments. This is useful as it expands the technical basis and confidence in using these codes to assess the effectiveness of passive aerosol removal mechanisms and their impact of fission product release fractions. On-going tool development and benchmarking via international standard problems is another important aspect of severe accident research that impacts IPEs.

SYSTEMATIC EVALUATION OF IPE RESULTS

The systematic evaluation of IPE results during or after their generation is an important feature of developing an accident management program. Research[12,13] has been performed to develop review processes for developing insights regarding the selected plant's behavior. Such systematic evaluations are useful in developing details regarding potential plant vulnerabilities, plant design strengths and good features, and plant capabilities that can be exploited as part of accident management strategies. Cost effective implementations of selected insights can significantly increase a plant's ability to prevent and mitigate a severe accident.

ACCIDENT MANAGEMENT PLANNING

Several continuing applications for the on-going and past severe accident research apply to accident management planning. These include the identification and preparation of technical bases for accident management strategies. In the United States the several reactor vendor Owner's Group are developing generic accident management programs that address the five elements associated with accident management planning, i.e., strategies, training, tools, information needs, or organization. Furthermore, the development of specialized and sophisticated accident management tools to assist utilities and regulators in the diagnosis and response to severe accidents is an active research area. Instrumentation behavior and requirements during severe accident events and their subsequent mitigation and termination is another area of severe accident research whose application is continuing to evolve. The survivability, continued validity, and interpretation of readings under severe accident conditions is of key interest.

CONCLUSION

The examples provided and discussed in this paper provide an overview of the techniques currently being employed to effectively include the severe accident research results in Individual Plant Examinations. These applications will also evolve accident management plans and capabilities. It is important to strive to continue international exchanges of experimental and analytical results and their applications to maximize the global safety of nuclear power plants.

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