Department of Energy
Washington, DC 20585

June 18, 2010

The Honorable Peter S. Winokur
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004-2901

Dear Mr. Chairman:

At the June 10, 2010, briefing to the Defense Nuclear Facilities Safety Board, it was requested that I formally transmit a copy of the pilot peer review conducted through the Department's Risk Assessment Technical Experts Working Group (RWG). In response please find a copy of the final *Peer Review of the Waste Treatment Plant Quantitative Risk Assessment of Hydrogen Events in Piping and Vessels*, May 28, 2010. The document will soon be posted at http://www.hss.energy.gov/nuclearsafety/ns/rawg/ on the RWG Web Site.

If you have any questions regarding this document please contact Dr. James O'Brien at (301) 903-1408, or me at (202) 586-4996.

Sincerely,

Andrew Wallo
Deputy Director
Office of Nuclear Safety, Quality Assurance
and Environment
Responsible Manager
for Recommendation 2009-1

Enclosure

Peer Review of Waste Treatment Plant Quantitative Risk Assessment of Hydrogen Events in Piping and Vessels

Final

May 28, 2010

Executive Summary

This report provides the results of a Peer Review of the Hanford Waste Treatment Plant (WTP) December 2009 Draft Quantitative Risk Assessment (QRA) of the impact of potential hydrogen combustion events on WTP pipes and vessels. The WTP project intends to utilize the results of the QRA to support the design of the piping in the WTP.

The purpose of this review was to provide the WTP Project and the Department of Energy's (DOE's) Office of River Protection feedback on:

- QRA and available standards
- Appropriateness of the QRA model including the modeling assumptions
- Adequacy of data utilized in the QRA and treatment of uncertainties
- Adequacy of QRA development process to ensure quality

QRA and Available Standards

The WTP QRA report correctly notes that, presently, no DOE standards or guidance exist that could be followed for this specific application. Rather, the WTP project used best practices and lessons learned from the U.S. Nuclear Regulatory Commission (NRC), the Center for Chemical Process Safety (CCPS), and the National Fire Protection Association (NFPA) as guidance. This, of course is not the same as following an established consensus Standard for performing a risk assessment (the only true consensus standard for probabilistic risk assessment is the ASME/ANS Standard (RA-Sa-2009) which was recently developed explicitly for commercially operating light water power reactors). However, to the extent applicable the WTP QRA logic model appropriately adapted techniques and methods from the light water reactor industry and the chemical process industry including standard practices for utilizing fault trees and event trees to logically model failure likelihoods and event progression. The QRA model used for WTP appears reasonable and well thought out.

QRA Model and Modeling Assumptions

As in all probabilistic risk assessments, the QRA methodology combines probabilistic and deterministic features. Key elements of the QRA model included models to determine (1) Gas Pocket Formation Frequency, (2) Hydrogen Generation, (3) Hydrogen Distribution and Pocket Formation, (4) Hydrogen Ignition, and (5) Hydrogen Combustion. In all of the above models, some parameters are treated probabilistically. For hydrogen ignition, the current QRA model sets this probability to unity.

In general the Peer Review Team concluded that the QRA logic used to estimate the frequency of gas pocket formation was reasonable and in accordance with conventional risk assessment practices. Furthermore, many aspects of the models and assumptions were appropriately based upon physical laws for the phenomena being modeled and on the experimental data. For example the hydrogen combustion model was based upon state of the art mechanistic deflagration and detonation formulations with support from experiments supported by WTP.

However, the Peer Review Team identified several assumptions relative to gas distribution and pocket formation that were made with insufficient justification, leading to concerns that substantial differences between the actual and modeled hydrogen combustion consequences could potentially exist.

QRA Data and Uncertainties

The QRA method includes data inputs for parameters such as initiating events (e.g., human failure, hardware failure, and loss of offsite power); hydrogen distribution and pocketing (e.g., holdup conversion factor and critical angle of pipe inclination); hydrogen generation (e.g., composition and amount of waste); hydrogen combustion (e.g., cell width and run up length).

The Peer Review Team found that the selection of QRA model parameters treated as point estimates versus those treated as uncertainty distributions was not performed systematically in accordance with conventional risk assessment practices. Furthermore, for those parameters selected for uncertainty distribution treatment, the Peer Review Team found that the sources of parameter uncertainty and the construction of the probability distributions were not adequately described. The Peer Review Team understands that a Phenomena Identification and Ranking Table (PIRT) analysis has been performed and is currently being documented. The Peer Review Team further understands that the PIRT analysis will be used to justify the basis for the representation of inputs as distributions or point values in the QRA model going forward, and also guide follow-up sensitivity and uncertainty analyses.

The Peer Review Team also found the QRA document's discussion of the treatment of uncertainties to be brief and the area to be narrowly focused. These factors limit the ability of the reader of the QRA report to understand the uncertainties associated with the QRA results.

QRA Development Process

The QRA report had a very limited discussion of the approach to quality assurance of the product, which consisted of a summary of the NRC approach. The Peer Review Team was unable to conclude whether the QRA was developed in accordance with standard industry quality assurance processes for developing a PRA/QRA. However, the Peer Review Team did conclude that the WTP project members were highly skilled and competent to develop the QRA for the potential hydrogen combustion events on WTP pipes and vessels.

The QRA method has been exercised for some example cases, but apparently there has not yet been a more formal benchmarking of the method against a test facility or other small facility to determine if the predictions of the methodology are consistent with the observable outcomes, or at least conservative.

Summary

In summary, the Peer Review Team concluded that the QRA logic model for estimating gas pocket formation frequency was reasonable and in accordance with conventional risk assessment practices. For the most part, the various models and their assumptions were appropriately based upon physical laws for the phenomena being modeled and on the experimental data. However, some modeling assumptions (most importantly hydrogen distribution and pocketing) lacked sufficient justification. Finally, uncertainty was not systematically treated in accordance with conventional QRA practices and the QRA could document in greater detail how it utilized industry practices for ensuring QRA quality.

These issues limit the usefulness of the QRA as a tool for providing the technical basis for the adequacy of the design of the WTP piping to meet code requirements. The Peer Review Team recognizes that the QRA was developed to prevent unnecessarily complex designs for mitigating hydrogen combustion events. However, without further refinement of the modeling and treatment of uncertainty the WTP runs the risk of making inappropriate design decisions.

The Peer Review Team identified several recommendations for improving the QRA that are included in the body of this report. The Peer Review Team is aware the final QRA was issued in March 24, 2010, and that it addresses some of these issues and recommendations. Draft comments by WTP on the draft final version of this peer review report are included as an appendix to this final report.

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1. PURPOSE AND BACKGROUND

1.1 Purpose of Peer Review

The report provides the results of a Peer Review of the Hanford Waste Treatment Plant (WTP) December 2009 Draft Quantitative Risk Assessment (QRA) of the impact of potential hydrogen combustion events on WTP pipes and vessels.

The purpose of this review was to provide the WTP Project and the Department of Energy's (DOE's) Office of River Protection feedback on:

- QRA and available standards
- Appropriateness of the QRA model including the modeling assumptions
- Adequacy of data input to the QRA and treatment of uncertainties
- Adequacy of QRA development process to ensure quality

1.2 Background and Standards

Background

In late 2008, the Office of River Protection (ORP) chartered a team to investigate how WTP operational complexities and design constraints that result in over-conservatisms in hydrogen event analysis methodology may be reduced. The team recommended implementation of alternative analysis methods and design criteria that could result in a WTP design that is operationally simplified, more reliable, and of reduced construction and operational costs. Use of a QRA was one of the key alternative analysis approaches recommended by the team.

The QRA report states that its purpose is to provide a technical basis for quantifying the demand from a postulated hydrogen event and the associated hydrogen event frequency in order to assess available margin in piping systems at the WTP. The conservative assumptions and acceptance criteria previously used in the design analysis of the WTP led to the need for hydrogen controls for the majority of the WTP piping systems. This resulted in added construction and operational complexity and cost, and significant risk to plant availability.

The WTP project developed a QRA method that (1) determines the likelihood of hydrogen events and the relative importance of event hazards; (2) models gas pocket formation using physically based engineering judgment; (3) takes credit for improved phenomenological understanding and test-informed analytical models for deflagrations and detonations; and (4) guides implementation of the appropriate code-based structural response and acceptance criteria tied to the frequency of postulated hydrogen events. The WTP QRA method is documented in the Dominion Engineering, Inc. report "Quantitative Risk Analysis of Hydrogen Events at WTP: Development of Event Frequency-Severity Analysis Model," R-6916-05-01 Rev 1, December 2009 [DE 2009].

Standards

WTP appropriately takes guidance from process industry developed guidance (i.e., *Guidelines for Chemical Process Quantitative Risk Analysis* from the American Institute of Chemical Engineers) as well as commercial nuclear industry guidance (e.g. Regulatory Guide 1.200, *An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities*). However, the WTP QRA report notes that currently no DOE standard or guidance exist that directly applies to this specific application, i.e., the use of RA for design margin quantification. Rather, they used good practices and lessons learned from the U.S. Nuclear Regulatory Commission (NRC), the Center for Chemical Process Safety (CCPS), and the National Fire Protection Association (NFPA) as guidance for model development. Therefore the WTP project followed conventional risk assessment practices in the development of their tool for assessing piping design margins. This, of course is not the same as following an established consensus Standard for performing a risk assessment. The only true consensus Standard for probabilistic risk assessment is the ASME/ANS Standard (RA-Sa-2009) which has recently been developed explicitly for commercially operating light water power reactors.

It is reasonable for WTP to take guidance from this standard and the above cited sources, as well as NASA guidance for risk assessment. However, their model QRA development cannot be said to meet any specific Standard because there is no specific standard for their situation. See Appendix A for additional discussion.

2. REVIEW METHODOLOGY

The review was conducted in accordance with the Peer Review Project Plan. The Peer Review Team consisted of four engineers/scientists with extensive knowledge in risk assessments and/or multiphase fluid transport and hydrogen combustion phenomena. As discussed in more detail in the Plan, the Peer Review Team, at Brookhaven National Laboratory (J. Lehner, T. Ginsberg and R. Bari) and DOE (R. Nelson), evaluated the QRA against state-of-the-art risk assessment practices.

The scope of the review was focused on whether the QRA was conducted in accordance with the industry conventions for performing risk assessments and whether the resulting model and data inputs were appropriate to serve the intended purpose of the QRA (i.e., support evaluation of the adequacy of the piping design to meet code requirements). A limited check on selected elements of the calculational model was performed; however, the peer review team did not re-calculate the model. Particular attention was given to the treatment of uncertainty in the modeling and data.

The peer review team did <u>not</u> evaluate the engineering analysis and calculation of pressure increases from the hydrogen events, i.e. the structural analysis. However, the review did include a high level evaluation of the reasonableness of mathematical models of physical processes utilized to calculate the consequences of hydrogen combustion.

In performing the review, the peer review team reviewed the WTP QRA report (December draft) and some of the references mentioned in the report as well as numerous other pertinent WTP Project references, as listed in Section 5 of this report. The peer review was performed over a four week period of time during February and March 2010. Several meetings/conference calls were held with the WTP Project to obtain clarification on the QRA and to request additional information, including supporting reports for the QRA.

3. RESULTS

This section provides a summary of the results from the Peer Review Team review in the areas of modeling, input data and treatment of uncertainty, and quality assurance. Each subsection below includes a brief discussion of the industry approaches and practices, the approach utilized in the QRA, the Peer Review Team evaluation of the QRA relative to industry approaches and practices, and the recommendations. Further details of the Peer Review Team review are included in Appendix A. Draft comments by WTP on the draft final version of this peer review report are included as Appendix B to this final report.

3.1 QRA Model and Modeling Assumptions

3.1.1 Introduction and Discussion of Industry Practice

The WTP QRA is being developed as a design tool to reduce conservatisms while still providing an acceptable structural design of the WTP, given that hydrogen events will occur. The QRA method is an innovative approach to a difficult design problem.

It should be noted that the use of quantitative risk analysis as a design tool is relatively novel. In the nuclear industry probabilistic risk assessment (PRA) has been used mostly to assess vulnerabilities or integrated risk of existing plants or completed designs. Only with the next generation of reactors is PRA expected to be used during the design stage to help in the development of the design. The chemical industry has used HAZOP and other reliability analyses in plant design, but this has generally not extended to a complete quantitative analysis used to demonstrate satisfaction of structural criteria. Therefore, the QRA method is innovative in both the type of facility it is being applied to, as well as its application as a design tool.

As noted (and enumerated) in the QRA report, significant benefits can be obtained from the use of an analysis which is conservatively realistic rather than very conservative. However, a key feature of using a more realistic approach, instead of a conservative one, is a thorough quantification of the uncertainties of the more realistic analysis and the inclusion of the total uncertainty when the comparison of the analysis results with acceptance criteria is made. A well-documented example of such an approach is the best estimate calculation approved by the NRC for demonstrating emergency core cooling system capability during a loss-of-cooling-accident [INL 1989]. That calculation, when uncertainties are properly accounted for, can be used instead of the conservative Appendix K calculation of 10 CFR Part 50

3.1.2 Overview of WTP QRA Model and Assumptions

The QRA method has a logical structure which is used to develop estimates of the frequency of hydrogen combustion events, as well as estimates of the severity of the events. The method uses a conventional fault tree approach for determining the potential frequency of gas pocket formation from a set of initiating events and subsequent failures. Based on an elaborate gas pocket logic model, the type of event and its severity are then determined from a series of event-tree-like questions. The severity of the events is represented by a series of pressures resulting from the various hydrogen combustion events, and these pressures are then used to estimate loadings on the WTP piping system.

3.1.3 Peer Review Team Evaluation

To the extent applicable the WTP QRA logic model appropriately adapted techniques and methods from the light water reactor industry and the chemical process industry including standard practices for utilizing fault trees and event trees to logically model failure likelihoods and event progression. The QRA model used for WTP appears reasonable and well thought out.

The model has multiple strengths. It incorporates a very detailed representation of the piping system in the WTP facility, breaking piping routes down into sectors, portions and segments, whose geometry is faithfully modeled. The method uses Monte Carlo sampling of selected distributed parameters to allow a characterization and propagation of the uncertainty associated with those parameters. Much testing was carried out on simple piping configurations to obtain and justify many of the parameters used in the gas pocket logic model. The model can be easily used to carry out sensitivity and "what-if" type of analyses, including the effect of mitigating devices placed in the routes.

The Peer Review Team identified the following opportunities for improvement in the WTP QRA model:

Modeling of hydrogen pocket formation

In the QRA model the WTP piping routes are broken down into sectors, portions and segments, whose geometry is faithfully modeled. The distribution of hydrogen pockets and their size is highly dependent upon this geometry in the QRA modeling method. The method is not based upon solution of conservation of mass, momentum and energy balance equations applied on a local basis within the pipe network. Instead the method is based upon gas transport rules developed from extensive testing in simple piping configurations and with what the WTP team believes are conservative assumptions. One such assumption is that the mass of gas generated in a route remains in the route piping, despite outflows of gas through pipe segments open to the process building volume.
Although this is a reasonable approach, the Peer Review Team concluded that the method lacks sufficient justification to assure its conservatism relative to how the hydrogen may actually be distributed in the WTP pipes during accumulation conditions. This issue could result in substantial differences between the actual and modeled hydrogen combustion consequences.

The QRA report does not discuss why this modeling approach is justified relative to other modeling approaches, such as those using first principles, i.e., the report does not discuss modeling uncertainty (see Section 3.2 below).

Benchmarking of the Model

The basis for the physical aspects of the QRA model has relied in part on extensive testing in simplified piping configurations, but there has not been a more formal evaluation of the model, as would be expected before application as a design tool. There has been no benchmarking of the physical aspects of the model against a test facility or other small facility with a reasonably complex piping network to determine if the predictions of the model are consistent with the observable outcomes, or at least conservative. This facility would be designed to simulate the transient multiphase processes within the complex WTP piping networks that result in pocket formation. The complexity of a network that would be needed and the choice of fluids that would be used for additional benchmarking could be a subject for a subsequent review.

3.2 QRA Data and Treatment of Uncertainties

This section focuses on the data inputs that the WTP project uses with the QRA logic model structure and then propagates through the model (utilizing tools such as Monte Carlo sampling) to provide calculations of the frequency and magnitude of hydrogen combustion events, along with a measure of the associated uncertainty.

3.2.1 Introduction and Discussion of Industry Practice

Input data into the WTP QRA model includes:

Data Related to Calculation of the Frequency of Hydrogen Pocketing Events (e.g., human failure frequency, equipment failure frequency, seismic events frequency)

Data Related to Hydrogen Generation (e.g., mass and composition of waste material)

Data Related to Combustion Phenomena (e.g., detonation limits, run-up length)

Good practice for these type of input parameters is to include a central value (e.g., mean) with an uncertainty distribution. The central value and distribution is typically determined from physical data, expert judgment, and operating experience.

Regarding the treatment of uncertainty, it is considered good practice (NUREG-1855 [NRC 2009]), to categorize the epistemic uncertainties into those that are associated with the parameter values used and those that involve aspects of models used, because the methods for the characterization and analysis of uncertainty are different for the two types. In addition, a third type of uncertainty exists, namely uncertainty about the completeness of the model. While this type of uncertainty cannot be handled analytically, it needs to be considered when making decisions using the results of an analysis.

Parameter uncertainty is the uncertainty in the values of the parameters of a model given that the mathematical form of that model is satisfactorily established. Conventional practice is to characterize parameter uncertainty using probability distributions on the parameter values.

A model uncertainty can arise because the phenomenon being modeled is not completely understood, and/or while some data or other information about the phenomena may exist, it needs to be interpreted to infer behavior under conditions different from those in which the data were collected. Model uncertainty may occur in the choice of the model itself or as uncertainty about the logic structure of the model. While it is possible to embed a characterization of model uncertainty into a risk assessment by including several alternate models, this approach is not commonly followed. Instead the usual approach is to demonstrate that the key uncertainties, reasonable alternative hypotheses, or modeling methods would not significantly change the assessment.

3.2.2 Overview of WTP QRA Data Input and Uncertainty Analysis

The QRA model is constructed as a probabilistic model to reflect the random nature of some of the constituent basic events such as the initiating events and equipment or human failures. In the QRA report some parameter uncertainty is addressed with the Monte Carlo sampling that is part of the methodology. Considerations of model uncertainty, or compensation for completeness uncertainty, are not explicitly mentioned.

Single values were provided for route and segment specific parameters that reflect geometric or other deterministic features. Furthermore single valued parameters were provided for initiating event frequencies and error rates. Some parameters did include distributions, such as the event duration parameters. Failure rate parameters for equipment failure and human errors were obtained from what appear to be acceptable industry sources. The QRA report identified that the value of some of these parameters had not been finalized.

3.2.3 Peer Review Team Evaluation

The QRA report appropriately references the source of some of the point estimates used (e.g., human failure rates). The Peer Review Team concludes that these were taken from conventional industry sources. However the basis for other input parameters was not clear.

Although the QRA report provides a brief discussion on how it treated input parameter uncertainty it does not provide a comprehensive discussion that demonstrates that uncertainty has been addressed in accordance with best industry practices. While the developers of the QRA methodology obviously attempted to incorporate uncertainty considerations, there is very little discussion in the report as to what process was used to decide which parameters would be treated as distributed, and how the distributions were chosen. There is also little discussion as to what parameters drive the model results. In other words, the treatment of the uncertainties appears to be ad hoc rather than following a systematic process. With respect to parameter uncertainties the Monte Carlo sampling incorporated in the approach is certainly a very useful tool. However, only some parameters are treated as distributed and many others (such as initiating event frequencies, error rates, and gas pocket model parameters) are input as single values when they would be more correctly also treated as distributed. The report notes that some of these single valued parameters may be treated as distributed, but this adds to the impression that the methodology is not quite ready for application at the time of the peer review. In addition, the range and distributions chosen for some of the key distributed parameters should be justified to make the modeling more credible.

Model uncertainty is not discussed in the report. In this respect it would be reassuring, especially for the gas pocket modeling, to have a discussion in the report of what other modeling methods were considered and why the one chosen was preferred. Further discussion could address whether alternative models were likely or not to lead to similar results.

With regard to completeness there is some discussion of perceived conservatisms retained in the modeling, but there is no discussion as to the margins that can be appealed to or the defense-in-depth provisions that could mitigate unforeseen load aggravating phenomena or events.

Adding to the overall uncertainty is the fact that one had the impression from the report, as well as from discussion with the modelers, that the model and the parameter choices are still in somewhat of a state of flux at the time of the peer review.

3.3 Adequacy of QRA Development Process to Ensure Quality

3.3.1 Introduction and Discussion of Industry Practice

Standard industry quality assurance processes for development of QRAs/PRAs involve development of an internal protocol that is implemented to assure the quality of the product before it undergoes peer review. Typical topics would be qualification of personnel, review of technical correctness of the model, review of computer model development and implementation, sanity check of the results, and documentation.

3.3.2 Overview of WTP QRA Development Process to Ensure Quality

The WTP QRA report notes that there is not an existing standard or model that could be followed for this specific application. To ensure the quality of the QRA processes in the absence of approved DOE policy, the report states that: "…the WTP project has used the guidance and best practices of other agencies that have formalized the use of QRA through relevant standards. In particular, the WTP project is using lessons learned from the U.S. Nuclear Regulatory Commission (NRC), the Center for Chemical Process Safety (CCPS), and the National Fire Protection Association (NFPA) as guidance. In addition, personnel with experience in use of probabilistic analysis are supporting the development of the HPAV QRA tool to ensure its quality and completeness."

3.3.3 Peer Review Team Evaluation

The discussion of the development process appropriately indicated that conventional quality practices from other industries were used, to the extent applicable, to guide the WTP project. The QRA report did not discuss what internal protocols were used to assure quality in the development of the model and its results.

However, the Peer Review Team did conclude that the WTP QRA was developed by risk assessment experts with support of experts in hydrogen combustion phenomenology and the design of the WTP.

4. SUMMARY

In summary, the Peer Review Team concluded that the QRA logic model was reasonable and used conventional risk assessment practices to estimate hydrogen event frequencies. Some of the modeling assumptions were appropriately based upon physical laws for the phenomena being modeled and on the experimental data. However, a number of concerns were identified:

- Some modeling assumptions (most importantly aspects of hydrogen distribution and pocketing) lacked sufficient justification;
- Uncertainty was not systematically treated in accordance with good QRA practices.
- The QRA report did not document in sufficient detail what protocol the project team developed for ensuring QRA quality.

These concerns should be addressed before using the QRA as a tool for providing the technical basis for the adequacy of the design of the WTP piping to meet code requirements. The PRT recognizes that the QRA was developed to prevent unnecessarily complex designs for mitigating hydrogen combustion events. However, without further refinement of the modeling and treatment of uncertainty the WTP runs the risk of making inappropriate design decisions.

The Peer Review Team is aware the final QRA was issued in March 24, 2010, and that it addresses some of these issues and some of the following recommendations. The Peer Review Team understands from WTP that, subsequent to the March 24 report, there will be follow-up PIRT and sensitivity studies.

5. RECOMMENDATIONS

The Peer Review Team recommends the following actions be taking to improve the QRA to where it could serve as a design tool:

Benchmarking the QRA

Benchmark the QRA results (i.e., frequency and magnitude of hydrogen combustion events) against a test facility or other small facility to determine if the predictions agree with observable outcomes, or are at least conservative. More complex simulant experiments than have been performed would be especially useful.

The development of the WTP QRA is being supported by an extensive experimental program in a number of areas. It is recommended that the Project demonstrate that the models that are developed to describe phenomena in the prototypic WTP system are based on an interpretation of the experimental data that accounts for any potential scaling distortions. The processes and time scales of the phenomena that are expected to occur in prototype systems should be described and compared with those observed in the experimental systems.

Sensitivity Analysis

It is recommended that the integrated QRA be used for sensitivity calculations to test the effect of specific variables on calculated results. In particular, the ratio of run-up length to cell width is assigned a very large range that reflects the considerable uncertainty in understanding of flame acceleration phenomena. A uniform probability distribution between the selected end points is used in the QRA for the shape of the distribution. The PRT is unclear as to whether this is a conservative assumption or not. It is recommended that the sensitivity of the shape of the distribution and its end points on the computed results of the QRA be computed to determine if the results are particularly sensitive to these uncertainties.

As noted above, the Peer Review Team understands that a sensitivity analysis of the QRA model is planned to be performed in the near term.

Uncertainty Analysis

A systematic, robust estimate of the uncertainties inherent in the QRA methodology should be conducted. This should include:

- A phenomena identification and ranking tables (PIRT) type process that systematically lists the phenomena involved and their ranking relative to their importance on the results by a group of subject experts. Such a ranking scheme would then allow defensible judgments to be made as to which phenomena and associated uncertainties need to be included and addressed in the model, and how well the uncertainties in each case need to be addressed. The Peer Review Team understands that a PIRT analysis has been performed and is currently being documented and that this is intended to guide subsequent uncertainty analysis.

- The parameters treated as distributed should be expanded based on the PIRT.

- For those parameters that are represented by distributions, such as the event duration parameters, the choice of distribution type and range should be justified.

- Model uncertainty, especially for the gas pocket modeling, should be addressed with discussion of what other modeling methods were considered and why the one chosen was preferred.

- With regard to completeness a more complete discussion as to the margins that can be appealed to or the defense-in-depth provisions that could mitigate unforeseen load-aggravating phenomena or events would be helpful.

Discussion of Remaining Conservatisms

The report would also benefit from a thorough discussion of the conservatisms remaining in the WTP QRA method, and why they outweigh any non-conservatisms or incompleteness in the analysis. A discussion as to what parameters and model features drive the model results would be informative. This discussion would include information on which conservatisms were reduced by the QRA methodology, and by how much.

6. REFERENCES

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APPENDIX A
DETAILS OF PEER REVIEW

A.1 INTRODUCTION

The peer review team reviewed the WTP QRA and some of the references mentioned in the report as well as numerous other pertinent WTP Project references, as listed in Section 6 of this report. The peer review team level of detail of review was limited due to the short-term schedule for the review and due to the level of resources applied. The basic idea of the review was to form some high-level judgments about the overall method proposed in the QRA model and to give feedback to the WTP for improvement of its modeling for the intended application.

One meeting and three conference calls were held with the WTP Project to obtain clarification on the QRA. Several email exchanges occurred between the WTP Project and the peer review team for purposes of obtaining additional information, including supporting reports for the QRA.

This appendix provides material that expands on Sections 3.1 and 3.2 of the Main Report. There is no further discussion of Section 3.3 of the Main Report because that section is brief and self-explanatory.

A.1.1 QRA and Available Standards

WTP takes guidance from process industry developed guidance (i.e., *Guidelines for Chemical Process Quantitative Risk Analysis* from the American Institute of Chemical Engineers) as well as commercial nuclear industry guidance (e.g. Regulatory Guide 1.200, *An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities*). However, the WTP QRA report notes that currently no DOE standards or guidance exist that could be followed for this specific application of using QRA for design margin quantification. Rather, they used good practices and lessons learned from the U.S. Nuclear Regulatory Commission (NRC), the Center for Chemical Process Safety (CCPS), and the National Fire Protection Association (NFPA) as guidance. Therefore the WTP project followed conventional risk assessment practices in the development of their novel tool for assessing piping design margins. This, of course is not the same as following an established consensus Standard for performing a risk assessment. The only true consensus Standard for probabilistic risk assessment is the ASME/ANS Standard (RA-Sa-2009) which was developed explicitly for commercially operating light water power reactors.

The light water reactor standard applies to operating power reactors. It notes that for plants under design or construction, for advanced LWRs, or for other reactor designs, revised or additional requirements may be needed. A new risk standard is being developed for that application. It does not apply to the next generation gas-cooled reactor or to sodium-cooled reactors. Risk standards will be developed for those applications. Consensus standards for the portions of risk assessments that deal with physical phenomena and offsite consequences for operating light water reactors are still in development. The development of nuclear risk standards by consensus standards organizations is coordinated by a Nuclear Risk Management Coordinating Committee (NRMCC or "Committee") has been established by the American

Nuclear Society (ANS) and the ASME (American Society of Mechanical Engineers). Attachment 1 to this Appendix is an excerpt from the current strategic plan of the NRMCC. It clearly shows that the Level 1 (events leading to core damage in operating light water reactors) plus Large Early Release Frequency (LERF) is the only currently approved consensus standard. It also provides the planning for future standards that go beyond this first standard. (Note that in the long range, NRMCC plans to address risk assessment for other nuclear facilities, transportation and storage of nuclear materials, and related activities, including design of such facilities)

The AIChE CCPS *"Guidelines for Chemical Process Quantitative Risk Analysis" (Second Edition, 2000)* is a guide and not a consensus standard; while it focuses on chemical hazards and their offsite consequences, it does not provided guidance on the details of combustion modeling and potential loading on piping. According to the WTP, however, the AIChE document did guide their thinking on setting up a fault tree and event tree framework, on finding appropriate data, and on approaches to quality assurance.

While it is reasonable for the WTP project to take guidance from the ASME/ANS consensus Standard and the above cited sources, as well as NASA guidance for risk assessment, their model QRA development cannot be said to meet a Standard because there is no specific standard for their situation. The WTP is creating a methodology for risk assessment of a new facility and addressing physical phenomena (hydrogen distribution and combustion) that are not addressed in current risk assessment standards.

In subsequent work, the WTP could provide, if possible, specific discussions of what they drew from each standard or guide and how it was used in their model development.

Appendix B contains the draft responses to this report by WTP and discusses their plans for future work in that regard.

A.2 REVIEW OF PHYSICAL MODELING AND MODELING ASSUMPTIONS

The WTP developed models in the following areas: 1) Gas Pocket Formation Frequency, 2) piping route modeling, 3) hydrogen generation, 4) pocketing of hydrogen in piping, 5) ignition and 6) combustion. Each subsection below provides the observations of the PRT in the specific area.

A.2.1 Gas Pocket Formation Frequency

The modeling to estimate the annual frequency of hydrogen pocketing, termed Operational Frequency Analysis (OFA) in the report, is carried out using a conventional fault tree approach. In the OFA various initiating events are propagated through the Boolean logic of the fault tree structure which includes the equipment and human failures that can influence the development of the initiator. The commonly used program CAFTA is used to generate minimum cut sets, whose frequency is added to obtain the frequency of the top event.

The types of initiating events analyzed seem reasonable, and the logic structure of the fault trees seems sound. The OFA model appears reasonable.

A.2.2 Piping Route Modeling

The modeling of the piping routes within the WTP is based on the plant drawings. The modeling seems to be carried out in detail and with great fidelity. The use of the piping modeling for estimating gas pocket formation is discussed in Section 2.4 in this appendix to the review report.

A.2.3 Hydrogen Generation

The objective of this element of the WTP model is to predict the rates of combustible gas generation that lead to a combustible gas pocket within a pipe segment. WTP assumes that hydrogen is generated volumetrically by thermolysis and radiolysis in the waste and that nitrous oxide is present as an oxidizing agent that would support combustion. The WTP currently assumes that there are no other gases present.

The gas generation rate from the Hanford wastes has been extensively studied and rate equations have been developed to characterize various waste types. The rate equations are based upon what appears to be a very extensive survey of the Hanford tanks in which gas generation was measured from waste samples, tank surveillance data and waste characterization data. Separate rate equations are presented for thermolysis and for radiolysis. At least two formulations are discussed, and reflect different levels of conservatism in terms of correlating the data. The experimental errors have been quantified. DE 2007b defines the specific WTP model being used, and presents the uncertainty distribution.

In addition to H_2 and N_2O other gases are present in the waste stream. These include inert gases that could potentially reduce the severity of combustion events. These other gases are not currently accounted for in the QRA analysis. This is clearly a conservative assumption, since the presence of inert gas would decrease the mixture reactivity and would decrease resulting combustion pressures. Since the effect of inert gas is a real physical phenomenon whose influence is readily calculated, the rationale for not taking credit for the inert gas is not apparent to the PRT. It is recommended that inert gases be included in the QRA analysis.

The hydrogen generation modeling is based on empirical fit of a rate equation to experimental data and the PRT concludes that approach is reasonable. DE 2009 presents a triangular uncertainty distribution for the hydrogen generation rate. The PRT has not reviewed the arguments used to justify this distribution.

A.2.4 Piping Segmentation and Pocketing of Hydrogen

The objective of this element of the WTP model is to identify the location, geometry and mass of combustible gases in the gas pockets that develop in the waste contained in a WTP pipe segment. The previous hydrogen combustion analysis conservatively assumed that combustible gases would accumulate at one location in a piping network. In the revised WTP model it is recognized that gas generation would take place within all of the waste found in the piping system, and that gas pockets could develop at many locations. A combustion event at one such location could conceivably involve less combustible mixture than previously assumed. The development of the revised WTP model is supported by an extensive simulant experimental program [DE 2010].

The phenomenon of hydrogen pocketing in the WTP complex involves gas generation and transport within the piping network of the WTP. The physical scenario constitutes a typical problem in the area of transient multiphase flow and transport. Such problems are typically analyzed using computer models involving solution of transient, one-dimensional conservation equations. In the case of the WTP facility, two phases would be considered. Conservation of mass, momentum and energy equations would be solved in conjunction with boundary and initial conditions. A set of constitutive relations would be developed for material properties and flow regime transition phenomena. Solution of such equations would provide the transient distribution of gas (and liquid) within the piping system which could be tracked as a function of time. The solution of the equations could be used by the QRA analysts to identify the locations and dimensions of gas pockets as a function of time since the start of the gas generation within the liquid. The WTP system is complicated by the fact that the liquid being considered is non-Newtonian and the constitutive relationships may not be readily available. Typically, analysis of complex problems such as this will be accompanied by simulation experiments, sometimes using real materials, in order to verify the prediction results in suitably complex and prototypic test facilities. This process was not totally followed in the WTP program.

Elements of the WTP gas pocket logic model are based upon observations of the transport phenomena made in the simulant experimental program. However, considerable uncertainties exist in the phenomena of pocket generation and transport. The basic assumption that the gas generated will attempt to be transported to higher elevations under buoyant force is physically reasonable. And, while the rule-based approach to tracking the gas through the maze of junctions has some physical sense, it is not clear that the assumed motion of the fluids satisfies conservation of mass, momentum and energy principles generally used to approach such problems. The gas pocket model is non-mechanistic in the sense that it is not based upon solution of conservation of mass, momentum and energy balance equations applied on a local basis within the pipe network. The WTP model does, however, conservatively assume that the mass of gas generated in a route remains in the route piping, despite outflows of gas through pipe segments open to the building volume.

The Project assumes that “vertical segments which are not part of a local high point are assumed to retain no gas in the form of pockets.” This assumption seemingly would limit the lengthwise extent of gas pockets between neighboring segments. As a result the PRT believes that it may be possible for pocket lengths to be larger than the model would predict. Furthermore, considering that the experimental program was carried out using simplified idealized piping configurations and simulant fluids, the PRT cannot conclude that the gas pocket dimensions that would be predicted by the model are not non-conservative. This aspect of the WTP model requires more in-depth review. Largely because the WTP pocketing model is not based upon first principles; therefore, on the basis of its limited review effort, the PRT cannot conclude at this time that the pocket model predictions would be either realistic or conservative.

As discussed above, the PRT believes that there is significant modeling uncertainty associated with prediction of the pocket dimensions and mass of combustible gas in a pocket beyond the uncertainties associated with the current model parameters. It is recommended that WTP consider inclusion of model uncertainty in the pocket length formulation. One possibility is to use a pocket length multiplier with a probability distribution that is developed based upon physically-based engineering judgment.

A.2.5 Ignition

The objective of this element of the WTP analysis is to predict the likelihood of ignition and the likely location of ignition within a gas pocket.

The likelihood of ignition of combustible gas in a gas pocket is treated by WTP using an ignition source logic model [DE 2009, Appendix B, and Table B-1]. Three types of ignition sources are identified: mechanical, thermal and discharge, each characterized with its own probability. Finally, each source type is assigned a probability of packing sufficient energy to ignite the gas mixture. Combining these probabilities the probability of ignition by any of the sources is 0.32. The Project staff, however, has related that they are currently assuming a probability of ignition somewhere within a pocket of unity. Within its limited scope of review, the PRT has not reviewed the literature dealing with ignition and its applicability to the WTP. The PRT accepts this assumption as suitably conservative.

The current Project assumption is that the probability of ignition of a gas bubble is one. Given that the project assumes that ignition sources may be present, it is reasonable to assume that any bubble may ignite and the consequences must be determined. It is also reasonable to assume that ignition could occur anywhere along the length of a gas pocket with no bias since a plausible physical argument that would bias the ignition location has not been identified by the PRT.

A.2.6 Combustion Phenomenology

The objective of this portion of the WTP model is to identify conditions within a gas pocket likely to support combustion, to predict the mode of combustion, whether deflagration or DDT or PRC-DDT, and to predict the dynamic pressures developed within the combustible gas and transmitted to the remainder of the pipe network.

The Project treats the combustion phenomenology of H_2-N_2O mixtures with mechanistic methods that have been developed over the past 25 years, and has pursued a vigorous research program to acquire the combustion data and develop advanced models required for combustion analysis of the specific mixtures and specific geometries of interest to the WTP facility. These experiments have been performed in prototypic pipe sizes using gaseous mixtures covering a wide range of compositions. A substantial database has been developed. In the work reported here, only combustion in the facility piping network was considered. The potential for hydrogen combustion in any of the facility vessels was not reviewed.

The Project assumes that any ignition source that might be present at the facility would be of insufficient strength to directly initiate a detonation. Based upon previous experience, this is a reasonable assumption for initiating a gaseous detonation with low energy density sources of the type likely to be found at a chemical plant. As a result, the assumed ignition source would, if mixture stoichiometry were within the flammability limits of the mixture, ignite the mixture to initiate a deflagration which might, or might not, accelerate and develop into a transition to a detonation.

The Project combustion model begins with identification of the hydrogen event type and then proceeds to compute the characteristics of the pressure-time history of the event. The event types are (1) no event if the mixture composition renders it not flammable, (2) a deflagration, or (3) a deflagration-to-detonation transition (DDT) and (4) the pressure-reflection event PRC-DDT. The Project logic model for the combustion analysis is presented in Figure 2- 7 and Section 2.4.2.1 of [DE 2009]. This logic model is based upon several basic ideas concerning gaseous combustion developed over the last few decades: Flammability limit data are used to determine if a mixture will ignite, mixture cell size compared with pocket diameter is used as a measure of detonability, and run-up length compared with pocket length is used as a measure of the ability of a deflagration to rapidly accelerate to a detonation within the length of a gas pocket. The general concepts described here were reviewed and some of the data that have been developed to support the evaluations were also reviewed.

If an event is a deflagration with no transition to detonation, the pressure event is computed using standard methods as an adiabatic, constant-volume deflagration characterized by a quasi-static load on the piping network. This is a reasonable and conservative approach for slow deflagrations. For fast deflagrations, where the flame front is moving at a speed approaching the speed of sound, it is not clear if dynamic events are considered. The Project should consider if such events can generate dynamic pressures that can contribute significantly to the load analysis of the pipe network.

The cell width is used in the WTP combustion modeling as a measure of mixture detonability when compared with the lateral dimension of a confining pipe, and is also used as the scaling parameter for the run-up distance. For this reason, as well as others, it is an important parameter. The cell width, a function of mixture composition, is an empirical quantity, and has been measured as part of the WTP experimental program. These experiments have not been reviewed as part of the current review effort. However, it is known, and the data for H_2 and N_2O mixtures confirm, that measured cell widths for a given mixture composition can vary by a factor of two or more from experiment to experiment. There is a significant experimental uncertainty associated with the cell width variable associated with any specific mixture composition. WTP should consider converting the cell width into a variable with an uncertainty distribution for the analysis, where the distribution represents the experimental uncertainty.

The WTP combustion analysis makes use of the run-up distance concept to quantitatively capture the likelihood of the physical processes of flame acceleration, DDT and PRC-DDT within the piping network. This is being accomplished by comparison of the run-up distance with the axial extent of the combustible gas mixture within a WTP pipe segment. While the run-up concept has been a part of the combustion literature for decades, its current use by the Project to predict the combustion regime within a gas bubble and, hence, to determine the severity of the associated dynamic pressure event, is an advance in the state-of-the art. While the concept is a useful one, methods of predicting the actual quantitative value of the parameter is still in its early stages [Ciccarelli 2008]. Using available experimental data, the Project has chosen to use a probability distribution function to represent the range of the variable defined by the ratio of the run-up distance to cell size. They have used a very large range of the parameter to capture the uncertainties. The ratio of run-up distance to cell size was assumed to be in the range of 50 to 500, with a uniform probability distribution. It is the PRT's judgment that the direction taken to quantify the run-up concept is reasonable. The shape of the probability distribution is based, in part, on engineering judgment. It is recommended, therefore, that sensitivity analyses be performed using alternative characteristics of the probability distribution to determine the sensitivity of the QRA results to the particular assumptions regarding the shape of the distribution function.

If there is a DDT event, then the possibility of pre-compression effects and reflected pressure, PRC-DDT, is considered. These pressure events are among the largest that are encountered when considering detonations. The logic for the further analysis of the potential for these events is presented on p. 2-16 of [DE 2009]. Additional DDT severities are defined here, including the PRC-DDT. While the motivation to more finely subdivide the detonation severity is reasonable, it is not clear that available experimental data support this division. The Project should present the analysis of the available experimental data that supports this portion of the combustion logic model. It is recommended that the sensitivity of the QRA results to these assumptions should be determined.

The DDT and PRC-DDT events are dynamic and time-dependent. For the DDT events the peak pressure is taken as three times the Chapman-Jouget pressure and is combined with a function of space and time to reflect the fact that the detonation wave travels down the pipe and decays as it travels. The PRC-DDT events are treated similarly, except that the peak pressures may be larger than for a DDT event, and were shown by a limited number of experiments to vary with run-up distance. These pressure-time functions are provided as input to the structural loading calculations. The data reports supporting these developments were only briefly reviewed. The analytical approach, however, is judged reasonable.

The peak pressures associated with DDT and PRC-DDT are considerably larger than the theoretical Chapman-Jouget (CJ) pressures. For DDT the peak pressures are taken as three times the CJ values, while for the PRC-DDT events the peak pressures are represented as functions of the run-up distance. The pressures can be up to nearly 10 times the CJ values according to the correlation for pressure vs. run-up distance that was developed. It is unclear to the PRT how large the uncertainties are in the CJ pressure multipliers that are presented in the reports. The Project should consider these uncertainties and consider if the multipliers should be represented as uncertainty parameters.

A detailed review of the bulk of experimental and analytical work performed in support of the combustion analyses was not possible in the available time frame for review. The basic combustion modeling approach is judged to make use of accepted concepts, and the research program that has provided a sound basis for development of the combustion modeling adopted by the project. The basic approach to the modeling of the combustion phenomenology is judged reasonable.

A.3 Treatment of Uncertainties

When a more realistic method is used in place of a conservative approach it is important to have a good estimate of the total uncertainty involved in the more realistic method and to include the uncertainty in any comparison with acceptance criteria. Under the best of circumstances rigorous estimation of risk using a quantitative risk assessment is subject to many uncertainties for a one of a kind facility. For analysis of the WTP facility, where several unique, complex, and not fully understood processes occur, a robust uncertainty estimate is essential.

The QRA model is constructed as a probabilistic model to reflect the random nature of some of the constituent basic events such as the initiating events and equipment or human failures. The QRA report provides a brief discussion on input parameter uncertainty versus variability, where it is pointed out that the Monte Carlo simulation used in the approach does not distinguish between aleatory and epistemic uncertainty, and this seems acceptable for the purposes of the report. However, since uncertainty is such an important topic for the application of the QRA methodology, it is worthwhile to discuss the various sources of epistemic uncertainty that should be considered.

As discussed in the literature, for example NUREG-1855 [NRC 2009], it is helpful to categorize the epistemic uncertainties into those that are associated with the parameter values used and those that involve aspects of models used, because the methods for the characterization and analysis of uncertainty are different for the two types. In addition, a third type of uncertainty exists, namely uncertainty about the completeness of the model. While this type of uncertainty cannot be handled analytically, it needs to be considered when making decisions using the results of an analysis.

Parameter uncertainty is the uncertainty in the values of the parameters of a model given that the mathematical form of that model is satisfactorily established. Conventional practice is to characterize parameter uncertainty using probability distributions on the parameter values, and that is the case for some of the parameters used in the QRA model. A model uncertainty can arise because the phenomenon being modeled is not completely understood, and/or while some data or other information about the phenomena may exist, it needs to be interpreted to infer behavior under conditions different from those in which the data were collected. Model uncertainty may occur in the choice of the model itself or as uncertainty about the logic structure of the model. While it is possible to embed a characterization of model uncertainty into a risk assessment by including several alternate models, this approach is not commonly followed. Instead the usual approach is to demonstrate that the key uncertainties, reasonable alternative hypotheses, or modeling methods would not significantly change the assessment.

While lack of completeness is not in itself an uncertainty, but rather recognition of the limitations in the scope of the model, the result is an uncertainty about where the true risk lies. Incompleteness in the modeling can arise in two different ways: (1) some contributors/effects may be knowingly left out of the model for a number of reasons (lack of methods of analysis, can be screened as unimportant, cost, etc.), and (2) some phenomena or failure mechanisms may be omitted because their potential existence has not been recognized. These latter true unknowns cannot be addressed analytically. However, often such unknowns are addressed through the use of safety margins and defense in depth.

In the QRA report some parameter uncertainty is addressed with the Monte Carlo sampling that is part of the methodology. Considerations of model uncertainty, or compensation for completeness uncertainty, are not explicitly mentioned. To come to a good estimate of the total uncertainty involved in the modeling, the methodology would greatly benefit from a process like that used to establish phenomena identification and ranking tables (PIRT), illustrated for example in [ORNL 2008]. Such a process would consist of the systematic listing of the phenomena involved and their ranking relative to their importance on the results by a group of subject experts. Such a ranking scheme would then allow defensible judgments to be made as to which phenomena and associated uncertainties need to be included and addressed in the model, and how well the uncertainties in each case need to be addressed. The Peer Review Team understands from the WTP that a PIRT has been done recently and is currently being documented.

While the developers of the QRA methodology obviously attempted to incorporate uncertainty considerations, there is very little discussion in the report as to what process was used to decide which parameters would be treated as distributed, and how the distributions were chosen. There is also little discussion as to what parameters drive the model results. In other words, the treatment of the uncertainties appears to be ad hoc rather than following a systematic process. It is recommended that a more systematic and robust estimate of the uncertainties inherent in the QRA methodology be conducted, starting with a PIRT type of ranking of the significance of the phenomena involved. With respect to parameter uncertainties the Monte Carlo sampling incorporated in the approach is certainly a very useful tool. However, only some parameters are treated as distributed and many others (such as initiating event frequencies, error rates, and gas pocket model parameters) are input as single values when they would be more correctly also treated as distributed. The report notes that some of these single valued parameters may be treated as distributed, but this gives the impression that the choice of parameter values has not been finalized for applications. In addition, the range and distributions chosen for some of the key distributed parameters should be justified to make the modeling more credible. It should be noted that the PIRT type process, recommended above, could be used here to justify using only single (but conservative) values for some parameters that rank low in importance for the analysis results.

Model uncertainty is not discussed in the report. In this respect it would be reassuring, especially for the gas pocket modeling, to have a discussion in the report of what other modeling methods were considered and why the one chosen was preferred. Further discussion could address whether alternative models were likely or not to lead to similar results.

With regard to completeness there is some discussion of perceived conservatisms retained in the modeling, but there is no discussion as to the margins that can be appealed to or the defense-in-depth provisions that could mitigate unforeseen load aggravating phenomena or events. The formulators of the QRA method are convinced that the method is still a conservative one for use in the design of the WTP facility. A more detailed and thorough discussion of the conservatisms that remain in the QRA WTP method would be helpful to justify that this is the case and that uncertainties, including the completeness issue, have been adequately addressed.

Adding to the overall uncertainty is the fact that one had the impression from the report, as well as from discussion with the modelers, that the model and the parameter choices are still in somewhat of a state of flux at the time of the review.

ATTACHMENT 1: Status of ANS/ASME Risk Standards

(excerpted from the Strategic Plan of Nuclear Risk Management Coordinating Committee, Rev. 0, November 2009)

Current Status of Operating LWR Projects

The ASME Committee on Nuclear Risk Management (CNRM) and the ANS Risk-Informed Standards Committee (RISC) have the responsibility for development of consensus standards. Guidance can also be provided. However, such actions should be discussed with the NRMCC prior to ASME or ANS doing this work. ASME CNRM has accepted the overall responsibility to develop and maintain a new ASME/ANS Standard that incorporates the requirements to determine the technical adequacy to support risk-informed applications using a Level 1/LERF PRA (estimating core damage frequency CDF)) supplemented by an estimation of large early release frequency (LERF) for three plant operating conditions (power, low power, and shutdown), and for accidents initiated by internal hazards (including internal events, internal floods and internal fires), and external hazards (including external flood, seismic events, and wind). ANS RISC has accepted the overall responsibility to develop and maintain new ASME/ANS Standards to ascertain Level 2 PRA and Level 3 PRA technical adequacy to support risk-informed applications.

• An ASME/ANS PRA Standard has been issued as ASME/ANS RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications" (this is Addendum A to Revision 1). Revision 1, Addendum A of the PRA Standard has been endorsed by the NRC via Regulatory Guide (RG) 1.200, Revision 2, issued in March 2009.

• Low Power/Shutdown (LP/SD) – ANS RISC is preparing a LP/SD PRA Standard for incorporation into the above mentioned ASME/ANS PRA Standard.

• Extend PRA to full Level 2 PRA and Level 3 PRA – ANS RISC has established two writing groups to prepare these new standards.

Risk-Informed Developments for New LWRs

Identify needs, priorities and timing for development of new or modification of existing Standard(s) to address unique PRA requirements for new LWRs.
Action Plan:

- The NRMCC will assign a New Reactor Task Group to develop recommendations in this area.
- The committee works with industry, NSSS vendors and NRC on risk initiatives needed to support 10CFR52 licensing for new LWRs.
- ASME CNRM has established a project team to address changes in the existing LWR standards to treat new plant licensing, design and construction phases as well as unique requirements for advanced LWRs.
- ANS RISC will support the standard, providing expertise in Low Power/Shutdown and Level 2 and Level 3 PRA.
- Pending formation of a joint ANS/ASME committee and new agreements that may result, both societies will ballot this standard.

Risk-Informed Developments for Advanced Non-LWRs

Determine the need for a Standard to assess the technical adequacy of a PRA to support risk-informed applications and risk-informed safety classification scheme, to assist the advanced non-LWR designs.
Action Plan:

- ANS is addressing safety classification requirements for high temperature gas-cooled reactors (HTGRs). ASME is developing complementary risk-informed safety classification requirements for pressure boundary systems and components.
- ASME CNRM has established a project team to address the PRA standards needs for the advanced non-LWRs, such as HTGRs. This standard includes development of PRAs to be used in the design and construction stage. In addition, the ASME/ANS PRA Standard is being reviewed in detail for applicability for future reactors and identification of missing needed guidance.
- ANS RISC will support the standard, providing expertise in Low Power/Shutdown and Source Term and Consequence Analysis, as appropriate.
- Pending formation of a joint ANS/ASME committee and new agreements that may result, both societies will ballot this standard.

PROPOSED LONG TERM PROJECTS

- Assign a Task Group to investigate approaches for the development of a Life Cycle, Risk-Informed Nuclear Code.
- Determine need for, and, if appropriate, develop standards for Qualification of RISC-3 items (Safety-Related, Low Safety Significant SSCs).
- Address PRA for other nuclear facilities, transportation and storage of nuclear materials, and related activities.
- Develop risk methodology to address terrorism threats at nuclear power plants.
- Promote use of risk-informed approaches in the design, safety review, licensing and operation of nuclear facilities.

The Member Organizations of the Nuclear Risk Management Coordinating Committee are:

American Nuclear Society
American Society of Mechanical Engineers
Institute of Electrical and Electronic Engineers
U. S. Nuclear Regulatory Commission
U. S. Department of Energy
Nuclear Energy Institute
Electric Power Research Institute
Nuclear Steam Supply Systems Owners Groups

#	Page	Section	Action Item / Comment	Responsible	Proposed QRA Team Response (DRAFT)
1	iv	QRA Data and Uncertainties	"The Peer Review Team also found the QRA document's discussion of the treatment of uncertainties to be brief and the area to be narrowly focused. These factors limit the ability of the reader of the QRA report to understand the uncertainties associated with the QRA results.		A more thorough discussion on the treatment of uncertainty in the QRA model will be provided as part of a follow-up report / calculation documenting the details of the QRA model including the latest modifications to the model based on feedback from the HPAV Independent Review Team (HIRT) as well as results of sensitivity studies.
2	iv	QRA Development Process	"The QRA report had a very limited discussion of the approach to quality assurance of the product, which consisted of a summary of the NRC approach. The Peer Review Team was unable to conclude whether the QRA was developed in accordance with standard industry quality assurance processes for developing a PRA/QRA."		The "For Information Only" report [DE 2009] was intended to document the methodology employed in the WTP hydrogen event QRA model. Because the model is being developed in a rapid application development (RAD) environment, the documentation supporting the development of the model is being advanced in parallel with the model itself. This documentation will be made available as part of final documentation of the QRA model. An explanation of how the QRA development process is compliant will be provided in the next report revision.
3	iv	QRA Development Process	"The QRA method has been exercised for some example cases, but apparently there has not yet been a more formal benchmarking of the method against a test facility or other small facility to determine if the predictions of the methodology are consistent with the observable outcomes, or at least conservative."		Two sets of benchmarking cases are currently being performed. The first set is intended to test the model against results generated during hydrogen event testing at SwRI. Specifically, the model will be used to probabilistically determine the resulting hydrogen events for various initial (pre-ignition) test conditions within a piping system of a geometry consistent with that tested at SwRI. These benchmark cases will be used to determine if the QRA model's Event Progression Logic (EPL) module produces results consistent with the SwRI test results. The EPL module is responsible for the calculation of the frequency of the various event types (deflagrations, DDTs, PRC-DDTs) given a pocket as well as their severity. The second set of benchmark cases is intended to test the QRA model's Gas Pocket Logic (GPL) module against results generated during gas pocket retention and formation testing performed at DEI. The testing was performed by injecting nitrogen gas in a static test fluid in a representative piping system. Experiments were conducted for multiple values of fluid yield stress as well as at various system configurations. The QRA model will be tested against these experiments by calculating the location and dimensions of gas pockets for the same fluid rheology and piping system configuration as simulated during several of the gas pocket formation tests. Results of this benchmarking are expected to support the modeling approach used in the GPL module by showing that the model predictions are consistent with the experimental results.
4	v	Summary	"The Peer Review Team recognizes that the QRA was developed to prevent unnecessarily complex designs for mitigating hydrogen combustion events. However, without further refinement of the modeling and treatment of uncertainty the WTP runs the risk of making inappropriate design decisions."		A detailed sensitivity analysis is being performed which entails approximately 100 cases in which the uncertainty associated with the selection of specific distributions for key parameters as well as key assumptions will be quantified. When not readily quantifiable through the use of a sensitivity case, the effect of other parameters, distributions, or assumptions will be discussed and arguments made as to their appropriateness and / or conservative treatment with regards to the QRA model results.

5	1	1.2 Background	"The WTP project developed a QRA method that (1) determines the likelihood of hydrogen events and the relative importance of event hazards; (2) models gas pocket formation using physically based engineering judgment; (3) takes credit for improved phenomenological understanding and test-informed analytical models for deflagrations and detonations; and (4) guides implementation of the appropriate code-based structural response and acceptance criteria tied to the frequency of postulated hydrogen events. The WTP QRA method is documented in the Dominion Engineering, Inc. report "Quantitative Risk Analysis of Hydrogen Events at WTP: Development of Event Frequency-Severity Analysis Model," R-6916-05-01 Rev 1, December 2009 [DE 2009]."		It should be noted that [DE 2009] is a "For Information Only" report intended to document the approach used in the QRA model and is therefore not inclusive of a complete description of the various data flows in the model nor of the latest improvements / adjustments made to the model since the report's issuance. Specifically, the information contained in this report is not considered sufficient to "re-calculate" the model in its entirety. The complete QRA model will be documented in detail in a separate report following incorporation of the latest recommendations made by the HPAV Independent Review Team.
6	4	3.1.3 Peer Review Team Evaluation	"Much testing was carried out on simple piping configurations to obtain and justify many of the parameters used in the gas pocket logic model."		The test program used to support the development of relevant input parameters and correlations used in the gas pocket logic model was performed in a transparent piping system of representative diameter which included piping features commonly found in WTP piping systems. These included two test rigs of 2 and 4 inch diameter piping sizes with inverted U-bends (used to model gas accumulation at system high points), multiple dead legs in close proximity (representative of jumper headers in the hot cell), inclined horizontal piping (commonly used throughout WTP), and stair step piping. Although the length of typical WTP waste transfer routes exceeds that of the piping system used in testing, the results generated during the test program are scalable to longer piping systems. Gas pocket behavior in the vicinity and / or within piping features such as dead legs and local high points is dependent only on the presence of these features and therefore can be readily applied to these same features in WTP waste transfer piping systems.
7	4	3.1.3 Peer Review Team Evaluation	"In the QRA model the WTP piping routes are broken down into sectors, portions and segments, whose geometry is faithfully modeled. The distribution of hydrogen pockets and their size is highly dependent upon this geometry in the QRA modeling method. The method is not based upon solution of conservation of mass, momentum and energy balance equations applied on a local basis within the pipe network. Instead the method is based upon gas transport rules developed from extensive testing in simple piping configurations and with what the WTP team believes are conservative assumptions. One such assumption is that the mass of gas generated in a route remains in the route piping, despite outflows of gas through pipe segments open to the process building volume. Although this is a reasonable approach, the Peer Review Team concluded that the method lacks sufficient justification to assure its conservatism relative to how the hydrogen may actually be distributed in the WTP pipes during accumulation conditions. This issue could result in substantial differences between the actual and modeled hydrogen combustion consequences. The QRA report does not discuss why this modeling approach is justified relative to other modeling approaches, such as those using first principles, i.e., the report does not discuss modeling uncertainty (see Section 3.2 below)."		The gas pocket logic model is based on the principle of conservation of mass of gas evolved from the waste located in the waste transfer piping system at the initiation of the hydrogen accumulation event. Once the event duration is determined (as part of OFA calculations), the amount (mass) of gas evolved from the waste is fully defined. From this point, the gas pocket logic model performs conservation of mass on the gas evolved from the waste and distributes it throughout the system based on observations made during Gas Pocket Formation testing. The gas pocket logic model does not perform conservation of mass on the waste itself meaning that the reduction in evolved gas which would result from waste being displaced out of the open piping system by expanding gas bubbles is conservatively neglected. The amount of waste displaced from the system by expanding gas bubbles is not tracked as it was concluded to not impact the determination of hydrogen event types. Conservation of momentum is not considered as the systems are considered quasi-static and stationary (i.e., the actual velocity of bubbles moving in the system are not considered critical to the determination of event types). The form of the gas pocket logic (GPL) model discussed above lent itself to its implementation in an Excel workbook space for integration with the remainder of the QRA model. It is acknowledged that a differential model incorporating the gas transfer rules currently implemented in the existing gas pocket logic model may have provided the user with additional flexibility but given the Rapid Application Development (RAD) environment in which the QRA model was developed, the currently employed approach was deemed most likely to yield the necessary data in the

					allowable time frame. It is possible that limited studies be conducted as part of sensitivity analyses to quantify the impact of certain assumptions made in the gas pocket logic model and that this be performed using a different formulation for the accumulation and transfer of gas within a piping system.
8	5	3.1.3 Peer Review Team Evaluation	"The basis for the physical aspects of the QRA model has relied in part on extensive testing in simplified piping configurations, but there has not been a more formal evaluation of the model, as would be expected before application as a design tool. There has been no benchmarking of the physical aspects of the model against a test facility or other small facility with a reasonably complex piping network to determine if the predictions of the model are consistent with the observable outcomes, or at least conservative. This facility would be designed to simulate the transient multiphase processes within the complex WTP piping networks that result in pocket formation. The complexity of a network that would be needed and the choice of fluids that would be used for additional benchmarking could be a subject for a subsequent review."		See Response 6 regarding Gas Pocket Formation test program. See Response 3 regarding model benchmarking.
9	6	3.2.2 Overview of WTP QRA Data Input and Uncertainty Analysis	"The QRA model is constructed as a probabilistic model to reflect the random nature of some of the constituent basic events such as the initiating events and equipment or human failures. In the QRA report some parameter uncertainty is addressed with the Monte Carlo sampling that is part of the methodology. Considerations of model uncertainty, or compensation for completeness uncertainty, are not explicitly mentioned."		See Response 1.
10	6	3.2.2 Overview of WTP QRA Data Input and Uncertainty Analysis	"Single values were provided for route and segment specific parameters that reflect geometric or other deterministic features. Furthermore single valued parameters were provided for initiating event frequencies and error rates. Some parameters did include distributions, such as the event duration parameters. Failure rate parameters for equipment failure and human errors were obtained from what appear to be acceptable industry sources. The QRA report identified that the value of some of these parameters had not been finalized."		Indeed, at the time of the PRT review, some of the QRA model inputs had not been finalized and are currently being refined. Given the level of knowledge associated with route geometry and the presence (or absence) of certain components in a waste transfer route (i.e., pumps, valves, heat exchangers, etc.) the QRA team maintains that it is appropriate to represent these inputs as point values. Although some of the initiating event frequencies and error rates were represented with point values, it is expected that the results of the PIRT analysis being documented in parallel with the model development will help inform whether some of these point value inputs would be better represented as distributed inputs. Additionally, a sensitivity analysis will be performed in which the effect of uncertainty in input parameters otherwise modeled as point values is quantified.
11	6	3.2.3 Peer Review Team Evaluation	"The QRA report appropriately references the source of some of the point estimates used (e.g., human failure rates). The Peer Review Team concludes that these were taken from conventional industry sources. However the basis for other input parameters was not clear."		The basis for all input parameters, their value, and their distribution (if applicable) will be provided as part of a comprehensive report following the incorporation of the latest modifications to the QRA model based on feedback from the HPAV Independent Review Team.
12	6	3.2.3 Peer Review Team Evaluation	"Although the QRA report provides a brief discussion on how it treated input parameter uncertainty it does not provide a comprehensive discussion that demonstrates that uncertainty has been addressed in accordance with best industry practices. While the developers of the QRA methodology obviously attempted to incorporate uncertainty considerations, there is very little discussion in the report as to what process was used to decide which parameters would be treated as distributed, and how the distributions were chosen. There is also little discussion as to what parameters drive the model results. In other words, the treatment of the uncertainties appears to be ad hoc rather than following a systematic process. With respect to parameter uncertainties the Monte Carlo sampling incorporated in the approach is certainly a very useful tool. However, only some parameters are treated as distributed and many others (such as initiating event frequencies, error rates, and gas pocket model parameters) are input as single values when they would be more correctly also treated as distributed. The report notes that some of these single valued		See Response 10 regarding status of input definitions at the time of the PRT review. See Response 4 regarding sensitivity analysis. See Response 1 regarding uncertainty.

			parameters may be treated as distributed, but this adds to the impression that the methodology is not quite ready for application at the time of the peer review. In addition, the range and distributions chosen for some of the key distributed parameters should be justified to make the modeling more credible."		
13	7	3.2.3 Peer Review Team Evaluation	"Model uncertainty is not discussed in the report. In this respect it would be reassuring, especially for the gas pocket modeling, to have a discussion in the report of what other modeling methods were considered and why the one chosen was preferred. Further discussion could address whether alternative models were likely or not to lead to similar results."		See Response 1 regarding uncertainty.
14	7	3.2.3 Peer Review Team Evaluation	"With regard to completeness there is some discussion of perceived conservatisms retained in the modeling, but there is no discussion as to the margins that can be appealed to or the defense-in-depth provisions that could mitigate unforeseen load aggravating phenomena or events."		The conservatisms reduced by the QRA model and how the remaining conservatisms still outweigh any non-conservatisms introduced by selected models and / or modeling approaches will be discussed as part of comprehensive report following finalization of latest model modifications based on HIRT recommendations.
15	7	3.2.3 Peer Review Team Evaluation	"Adding to the overall uncertainty is the fact that one had the impression from the report, as well as from discussion with the modelers, that the model and the parameter choices are still in somewhat of a state of flux at the time of the peer review."		At the time of the peer review, some of the QRA model inputs as well as some of the constituent models remained in a state of development. Updates to both have been made since the "For Information Only" report [DE 2009] was issued. These updates and a more detailed description of the QRA model, including all data flows within the model, will be covered as a part of a comprehensive report to be issued following the latest updates to the model resulting from HPAV Independent Review Team recommendations later this summer.
16	7	3.3.3 Peer Review Team Evaluation	"The discussion of the development process appropriately indicated that conventional quality practices from other industries were used, to the extent applicable, to guide the WTP project. The QRA report did not discuss what internal protocols were used to assure quality in the development of the model and its results."		See Response 2 regarding the parallel development of the documentation supporting model development and development of the model itself.
17	8	5 Recommendations	"Benchmark the QRA results (i.e., frequency and magnitude of hydrogen combustion events) against a test facility or other small facility to determine if the predictions agree with observable outcomes, or are at least conservative. More complex simulant experiments than have been performed would be especially useful."		See Response 6 regarding Gas Pocket Formation test program. See Response 3 regarding model benchmarking.
18	8	5 Recommendations	"The development of the WTP QRA is being supported by an extensive experimental program in a number of areas. It is recommended that the Project demonstrate that the models that are developed to describe phenomena in the prototypic WTP system are based on an interpretation of the experimental data that accounts for any potential scaling distortions. The processes and time scales of the phenomena that are expected to occur in prototype systems should be described and compared with those observed in the experimental systems."		See Response 5 regarding issuance of a comprehensive report documenting all of the model inputs and their justification.
19	9	5 Recommendations	"It is recommended that the integrated QRA be used for sensitivity calculations to test the effect of specific variables on calculated results. In particular, the ratio of run-up length to cell width is assigned a very large range that reflects the considerable uncertainty in understanding of flame acceleration phenomena. A uniform probability distribution between the selected end points is used in the QRA for the shape of the distribution. The PRT is unclear as to whether this is a conservative assumption or not. It is recommended that the sensitivity of the shape of the distribution and its end points on the computed results of the QRA be computed to determine of the results are particularly sensitive to these uncertainties."		See Response 4 regarding performance of detailed sensitivity study.

20	9	5 Recommendations	"• The parameters treated as distributed should be expanded based on the PIRT. • For those parameters that are represented by distributions, such as the event duration parameters, the choice of distribution type and range should be justified. • Model uncertainty, especially for the gas pocket modeling, should be addressed with discussion of what other modeling methods were considered and why the one chosen was preferred. • With regard to completeness a more complete discussion as to the margins that can be appealed to or the defense-in-depth provisions that could mitigate unforeseen load-aggravating phenomena or events would be helpful."		See Response 1 regarding uncertainty. See Response 5 regarding issuance of a comprehensive report documenting all of the model inputs and their justification.
21	9	5 Recommendations	"The report would also benefit from a thorough discussion of the conservatisms remaining in the WTP QRA method, and why they outweigh any non-conservatisms or incompleteness in the analysis. A discussion as to what parameters and model features drive the model results would be informative. This discussion would include information on which conservatisms were reduced by the QRA methodology, and by how much."		See Response 14 regarding remaining conservatisms.
22	A-2	A.1.1 QRA and Available Standards	"In subsequent work, the WTP could provide, if possible, specific discussions of what they drew from each standard or guide and how it was used in their model development."	URS / DEI	No additional discussion will be provided except for the planned revisions in response 2.
23	A-3	A.2.3 Hydrogen Generation	"In addition to H2 and N2O other gases are present in the waste stream. These include inert gases that could potentially reduce the severity of combustion events. These other gases are not currently accounted for in the QRA analysis. This is clearly a conservative assumption, since the presence of inert gas would decrease the mixture reactivity and would decrease resulting combustion pressures. Since the effect of inert gas is a real physical phenomenon whose influence is readily calculated, the rationale for not taking credit for the inert gas is not apparent to the PRT. It is recommended that inert gases be included in the QRA analysis. "		The effect of other gases was investigated and it was concluded that these other gases act as diluents. Neglecting other gases is a known conservative assumption. Due to the uncertainty associated with the concentration of these other gases in the WTP waste streams, it has been imposed on the QRA modeling that negligible credit will be taken for the presence of diluents. The correlation currently used to determine the pressure associated with a deflagration and a CJ detonation requires a non-zero input for the concentration of diluents. These correlations conservatively predict a maximum peak pressure greater than the theoretical maximum when the triangular distribution used for percent diluents is specified with an upper bound of 3%. In reality, it is expected that diluent concentrations will often significantly exceed these negligible values.
24	A-4	A.2.4 Piping Segmentation and Pocketing of Hydrogen	"Elements of the WTP gas pocket logic model are based upon observations of the transport phenomena made in the simulant experimental program. However, considerable uncertainties exist in the phenomena of pocket generation and transport. The basic assumption that the gas generated will attempt to be transported to higher elevations under buoyant force is physically reasonable. And, while the rule-based approach to tracking the gas through the maze of junctions has some physical sense, it is not clear that the assumed motion of the fluids satisfies conservation of mass, momentum and energy principles generally used to approach such problems. The gas pocket model is non-mechanistic in the sense that it is not based upon solution of conservation of mass, momentum and energy balance equations applied on a local basis within the pipe network. The WTP model does, however, conservatively assume that the mass of gas generated in a route remains in the route piping, despite outflows of gas through pipe segments open to the building volume."		See Response 7 on the Gas Pocket Logic model.

25	A-4	A.2.4 Piping Segmentation and Pocketing of Hydrogen	"The Project assumes that "vertical segments which are not part of a local high point are assumed to retain no gas in the form of pockets." This assumption seemingly would limit the lengthwise extent of gas pockets between neighboring segments. As a result the PRT believes that it may be possible for pocket lengths to be larger than the model would predict. Furthermore, considering that the experimental program was carried out using simplified idealized piping configurations and simulant fluids, the PRT cannot conclude that the gas pocket dimensions that would be predicted by the model are not non-conservative. This aspect of the WTP model requires more in-depth review."		The test fluid used in the Gas Pocket Formation test program was fabricated so as to have representative yield strength and viscosity. The piping systems in which the testing was performed included representative piping features and configurations (i.e., not simplified). Despite the fact that actual waste transferring piping systems at WTP are typically longer than the piping used in the test program, the testing and test program was designed such that the results could be applied to systems of greater length. In the Gas Pocket Logic model, pockets are actually not necessarily restricted to be at most as long as the segment they are in. In fact, if a pocket forms at a local high point, it can extend all the way back to the beginning of the sector in which its initiating segment is located.
26	A-5	A.2.4 Piping Segmentation and Pocketing of Hydrogen	"As discussed above, the PRT believes that there is significant modeling uncertainty associated with prediction of the pocket dimensions and mass of combustible gas in a pocket beyond the uncertainties associated with the current model parameters. It is recommended that WTP consider inclusion of model uncertainty in the pocket length formulation. One possibility is to use a pocket length multiplier with a probability distribution that is developed based upon physically-based engineering judgment."		Pockets are not restricted to be of a certain length. Rather, they are assumed to grow in length assuming a fixed cross-sectional area (as a function of simulant yield stress). Depending on the location of the pocket in the piping system, the pocket can either grow to the full length of the sector in which its initiating segment is located (if pocket is predicted to occur at a local high point) or the full length of the segment in which it is located (e.g., if the segment is located somewhere in the middle of a multi-segment sector). It should be noted that, during the Gas Pocket Formation test program, very few gas pockets in non-Newtonian waste were observed to extend beyond more than a few pipe diameters in length, irrespective of the length of the straight pipe segment in which they formed. It is acknowledged that if these observations were taken into account in the Gas Pocket Logic model, a greater number of shorter pockets would be predicted to exist. However, given the typical event durations and the fact that the worst hydrogen events require a certain minimum length of gas pocket to occur, it was concluded to be more conservative to not limit the length of gas pockets based on observations made during Gas Pocket Formation testing but rather, let them grow potentially to the required lengths to support the more severe hydrogen events in each piping segment.
27	A-5	A.2.5 Ignition	The likelihood of ignition of combustible gas in a gas pocket is treated by WTP using an ignition source logic model [DE 2009, Appendix B, and Table B-1]. Three types of ignition sources are identified: mechanical, thermal and discharge, each characterized with its own probability. Finally, each source type is assigned a probability of packing sufficient energy to ignite the gas mixture. Combining these probabilities the probability of ignition by any of the sources is 0.32. The Project staff, however, has related that they are currently assuming a probability of ignition somewhere within a pocket of unity. Within its limited scope of review, the PRT has not reviewed the literature dealing with ignition and its applicability to the WTP. The PRT accepts this assumption as suitably conservative.		The QRA model currently assumes a probability of ignition of one in all modeled gas pockets. A segment-specific parameter has been added to the inputs so as to specify whether a different probability of ignition should be computed based on a combination of physical (geometric) arguments, available test data, and location of a given pipe segment. This relatively new optional input to the QRA model will be documented in detail in the comprehensive report documenting the model.
28	A-6	A.2.6 Combustion Phenomenology	"If an event is a deflagration with no transition to detonation, the pressure event is computed using standard methods as an adiabatic, constant-volume deflagration characterized by a quasi-static load on the piping network. This is a reasonable and conservative approach for slow deflagrations. For fast deflagrations, where the flame front is moving at a speed approaching the speed of sound, it is not clear if dynamic events are considered. The Project should consider if such events can generate dynamic pressures that can contribute significantly to the load analysis of the pipe network. "	TCL	The potential for prolonged fast speed deflarations is low and this is documented in calulation 6916-00-13. The dynamic affects of fast speed deflagrations affects have been provided in the HPAV Analysis and Design Criteria Report, 07-011.

29	A-6	A.2.6 Combustion Phenomenology	"The cell width is used in the WTP combustion modeling as a measure of mixture detonability when compared with the lateral dimension of a confining pipe, and is also used as the scaling parameter for the run-up distance. For this reason, as well as others, it is an important parameter. The cell width, a function of mixture composition, is an empirical quantity, and has been measured as part of the WTP experimental program. These experiments have not been reviewed as part of the current review effort. However, it is known, and the data for H2 and N2O mixtures confirm, that measured cell widths for a given mixture composition can vary by a factor of two or more from experiment to experiment. There is a significant experimental uncertainty associated with the cell width variable associated with any specific mixture composition. WTP should consider converting the cell width into a variable with an uncertainty distribution for the analysis, where the distribution represents the experimental uncertainty. "	TCL	
30	A-6	A.2.6 Combustion Phenomenology	"The WTP combustion analysis makes use of the run-up distance concept to quantitatively capture the likelihood of the physical processes of flame acceleration, DDT and PRC-DDT within the piping network. This is being accomplished by comparison of the run-up distance with the axial extent of the combustible gas mixture within a WTP pipe segment. While the run-up concept has been a part of the combustion literature for decades, its current use by the Project to predict the combustion regime within a gas bubble and, hence, to determine the severity of the associated dynamic pressure event, is an advance in the state-of-the art. While the concept is a useful one, methods of predicting the actual quantitative value of the parameter is still in its early stages [Ciccarelli 2008]. Using available experimental data, the Project has chosen to use a probability distribution function to represent the range of the variable defined by the ratio of the run-up distance to cell size. They have used a very large range of the parameter to capture the uncertainties. The ratio of run-up distance to cell size was assumed to be in the range of 50 to 500, with a uniform probability distribution. It is the PRT's judgment that the direction taken to quantify the run-up concept is reasonable. The shape of the probability distribution is based, in part, on engineering judgment. It is recommended, therefore, that sensitivity analyses be performed using alternative characteristics of the probability distribution to determine the sensitivity of the QRA results to the particular assumptions regarding the shape of the distribution function."	TCL	The proposed recommendation has merit and will be analyzed as part of the sensitivity analysis and changes made accordingly.
31	A-7	A.2.6 Combustion Phenomenology	"If there is a DDT event, then the possibility of pre-compression effects and reflected pressure, PRC-DDT, is considered. These pressure events are among the largest that are encountered when considering detonations. The logic for the further analysis of the potential for these events is presented on p. 2-16 of [DE 2009]. Additional DDT severities are defined here, including the PRC-DDT. While the motivation to more finely subdivide the detonation severity is reasonable, it is not clear that available experimental data support this division. The Project should present the analysis of the available experimental data that supports this portion of the combustion logic model. It is recommended that the sensitivity of the QRA results to these assumptions should be determined. "	TCL / REJ / JEC	The proposed recommendation has merit and will be analyzed as part of the sensitivity analysis and changes made accordingly. The severity of events is discussed in more detail in the HPAV Analysis and Design Criteria Report, 07-011.
32	A-7	A.2.6 Combustion Phenomenology	"The peak pressures associated with DDT and PRC-DDT are considerably larger than the theoretical Chapman-Jouget (CJ) pressures. For DDT the peak pressures are taken as three times the CJ values, while for the PRC-DDT events the peak pressures are represented as functions of the run-up distance. The pressures can be up to nearly 10 times the CJ values according to the correlation for pressure vs. run-up distance that was developed. It is unclear to the PRT how large the uncertainties are in the CJ pressure multipliers that are presented in the reports. The Project should consider these uncertainties and consider if the multipliers should be represented as uncertainty parameters. "	TCL / REJ / JEC	The appropriate multipliers are addressed in the time history calculations that are discusseed in more detail in the HPAV Analysis and Design Criteria Report, 07-011.

33	A-9	A.3 Treatment of Uncertainties	"However, only some parameters are treated as distributed and many others (such as initiating event frequencies, error rates, and gas pocket model parameters) are input as single values when they would be more correctly also treated as distributed. The report notes that some of these single valued parameters may be treated as distributed, but this gives the impression that the choice of parameter values has not been finalized for applications. In addition, the range and distributions chosen for some of the key distributed parameters should be justified to make the modeling more credible. It should be noted that the PIRT type process, recommended above, could be used here to justify using only single (but conservative) values for some parameters that rank low in importance for the analysis results. "		See Response 10 regarding status of input definitions at the time of the PRT review and use of PIRT analysis to confirm or update inputs and their distributions.
34	A-9	A.3 Treatment of Uncertainties	"Model uncertainty is not discussed in the report. In this respect it would be reassuring, especially for the gas pocket modeling, to have a discussion in the report of what other modeling methods were considered and why the one chosen was preferred. Further discussion could address whether alternative models were likely or not to lead to similar results."		See Reponse 1 on uncertainty.
35	A-9	A.3 Treatment of Uncertainties	Page A-10 (Section A.3). "The formulators of the QRA method are convinced that the method is still a conservative one for use in the design of the WTP facility. A more detailed and thorough discussion of the conservatisms that remain in the QRA WTP method would be helpful to justify that this is the case and that uncertainties, including the completeness issue, have been adequately addressed."		See Response 14 regarding remaining conservatisms.