Department of Energy
Washington, DC 20585

August 31, 2010

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

Dear Mr. Chairman:

During the past several months, the Department of Energy's (DOE) Office of Environmental Management (EM), Office of River Protection (ORP) and DOE's contractor, Bechtel National Incorporated have conducted an independent review of the implementation of the methodology and criteria used to analyze for Hydrogen in Piping and Ancillary Vessels (HPAV) in the Waste Treatment Plant (WTP) at Hanford. The Defense Nuclear Facility Safety Board was briefed on the results of the Independent Review Team (IRT) evaluations of the HPAV designs criteria and implementation methods on July 8, 2010; at that time EM committed to providing formal responses to the findings and recommendations to HPAV IRT. Since our briefing to you, we have provided the IRT's final report on July 12, 2010, (updated on August 1, 2010) and most recently, on August 24, 2010, we briefed you on our approach to addressing the findings of the IRT.

EM has developed its Plan to address the findings of the IRT (Enclosure 1). As requested by the WTP Federal Project Director, my staff has reviewed and concurred with the approach discussed in the Plan (Enclosure 2). As discussed in our briefing to you, and documented in the attached Plan, this will be a living document that the project team will update monthly, as our implementation of the IRT's findings and recommendations proceeds. The first such revision will occur in September 2010, when the Plan is expanded to address the recommendations of the IRT.

If you have any further questions, please contact me or Dr. Steven L. Krahn, Deputy Assistant Secretary for Safety and Security Program at (202) 586-5151.

Sincerely,

Inés R. Triay
Assistant Secretary for
Environmental Management

Enclosures

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ISSUED BY
RPP-WTP PDC

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Issue status: Approved

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Approver's position: WTP Project Technical Director

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Signature Date

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History Sheet

Rev	Reason for revision	Revised by
0	Initial issue.	SL Lachmann

Contents

Appendices

Tables

Abbreviations

ABAR	Authorization Basis Amendment Request
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BC	Black Cell
BNI	Bechtel National, Inc.
CIT	California Institute of Technology
C-J	Chapman-Jouguet
DDT	Deflagration-to-Detonation Transition
DEI	Dominion Engineering, Inc.
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
EPL	Event Progression Logic
FEA	Finite Element Analysis
GNNA	Global Nuclear Network Associates
HFO	High Frequency Oscillations
HLW	High-Level Waste [Facility]
HPAV	Hydrogen in piping and ancillary vessels
HTR	Hard to Reach
IRT	Independent Review Team
ITS	Important to Safety
MOT	Minimum operating temperature
OFA	Operational Frequency Analysis
ORP	Office of River Protection
PRC	Pressure Reflection Calculation
PRC-DDT	Pressure Reflection Calculation Deflagration-to-Detonation Transition
PSR	Project Service Request
PT	Pretreatment [Facility]
QPRT	QRA Peer Review Team
QRA	Quantitative Risk Analysis
RUD	Run-Up Distance
SQP	Software quality Procedures

SwRI	Southwest Research Institute
SRS	Summary Response Sheet
TR	Topical Report
UHGR	Unit hydrogen generation rate
V&V	Verification and Validation
WTP	Waste Treatment and Immobilization Plant

1 Purpose

The purpose of the Hydrogen in Piping and Ancillary Vessels (HPAV) Implementation and Closure Plan (I&CP) is to manage all outstanding HPAV items to closure supporting finalization of the HPAV engineering design methods and criteria, and the release of the corresponding design changes for construction. This revision of the I&CP only addresses the plan to implement the Findings documented in the HPAV Independent Review Team (IRT) Report, *Hydrogen in Piping and Ancillary Vessels in the Pretreatment Facility of the Hanford Waste Treatment Plant of July 12, 2010* (HPAV IRT Report). Items that address the Findings are mandatory for obtaining final acceptance of the HPAV engineering design methods and criteria. Future revisions of this I&CP will provide the plan to disposition the Recommendations documented in the HPAV IRT Report. For completeness the Recommendations are provided in Appendix B.

This plan also explicitly addresses (Appendix D) the recommendations from the DOE Peer Review Team report, *Peer Review of Waste Treatment Plant Quantitative Risk Assessment of Hydrogen Events in Piping and Vessels*, DOE Draft Final Report, April 28, 2010.

Response approaches for each of the IRT Findings are provided in Appendix A of this document. As these approaches are implemented, the resolution to each Finding will be detailed in a Summary Response Sheet (SRS) for concurrence by the HPAV IRT when proposed disposition is complete. HPAV IRT concurrence is prerequisite to closure which will be tracked on the SRS.

A goal of this plan is to complete all major actions no later than the end of October 2010 with the Verification and Validation of the Quantitative Risk Analysis software completing by January 2011 to support design changes in support of the construction schedule. Actions necessary to support design confirmation are scheduled to complete no later than January 2011. The closure of each of the HPAV IRT findings will be reviewed and agreed to by Dr. Roger Mattson or a designated HPAV IRT member at his direction. HPAV IRT agreement with the closure of the findings will be documented in a letter from Dr. Mattson to the WTP Technical Director, Greg Ashley.

While efforts to support the execution of this plan will be managed under the normal project management approach, this report will be updated monthly to track closure of items and incorporate any updates to the approaches for each Finding and Recommendation to be implemented. Finalized changes to the HPAV analysis and design criteria will be incorporated in Waste Treatment Plant reports and procedures listed in the reference section. Resolutions that require formal approval of proposed Safety Requirements Document (SRD) or Basis of Design Change Notices (BODCN) will be prepared and submitted for approval prior to implementation in accordance with normal engineering design and change procedures.

2 Background

BNI chartered the HPAV IRT in early April 2010 to review the design criteria and methodology developed to address the effects of postulated hydrogen events (deflagration and detonation) in piping and components in the WTP. The HPAV IRT review was commissioned as a panel of industry experts to review all aspects of HPAV engineering analysis and design methods established in references 1 through 6 and as approved by DOE for safety basis inclusion in the safety basis by references 7 and 8. The IRT's review included, but was not limited to, the reports and procedures of the references listed in Section 8 of this report and the supporting references and underlying calculations to these documents that numbers in the hundreds. Their review also included review of responses provided to comments submitted by DOE-EM and the DNFSB staff in previous review sessions.

The B31 Codes, including B31.3, do not provide explicit design guidance for high energy explosive events such as those that may be experienced by the HPAV piping. However, B31.3 does recognize that unique design issues may arise and the Code provides for these situations. The provisions of ASME B31.3 paragraph 300(c)(3) provide for applying more rigorous analysis when the existing Code requirements are not adequate with the provision that validity of such analysis be demonstrated. In addition, the owner must approve the approach and the methodology documented in the engineering design.

Review by the HPAV IRT provides added assurance that the criteria and methodology used is a technically defensible and conservative approach to ensure the safety and reliability of the WTP design, thereby meeting the requirement in the ASME Codes. Given the expertise of the HPAV IRT members, the review provides the additional basis for the owner to accept the validity of the engineering design based on the proposed more rigorous analysis methods allowed by ASME B31.3 paragraph 300(c)(3).

The final IRT charter listed the following items to be reviewed:

- Calculations of the generation rates and lower flammability limits (HGRs and LFLs) for hydrogen and other flammable gases generated in PTF;
- Calculations of the frequency and severity of postulated hydrogen events;
- Modeling of gas pocket formation and hydrogen events (deflagrations and detonations) to provide input to the piping response analysis;
- Calculation of the structural response of piping systems to hydrogen events;
- Qualification of piping systems for hydrogen events;
- Testing used to develop and validate criteria and methods;
- Tools and procedures used to implement criteria and methods; and
- The role and suitability of streamlined HPAV controls in the approved safety basis.

Based on those reviews, the charter required the IRT to answer three primary questions:

1 Will implementation of HPAV criteria and methods provide reasonable assurance that an HPAV event will not prevent systems, structures and components (SSC) from performing their intended safety function?
2 Will implementation of the HPAV criteria and methods provide reasonable assurance that an HPAV event will not significantly affect the WTP mission duration (e.g., by disabling portions of the systems that cannot be repaired in a reasonable time)?
3 Are the gas generation models used for HPAV design suitable for their intended purpose?

To answer these questions the IRT formed three technical area working groups to facilitate the interactions among experts and to focus their reviews. The working groups established by the IRT were 1) quantitative risk assessment, 2) gas phenomena, and 3) structural design. While the topical reports were developed primarily within the corresponding technical working group, all Findings and

Recommendations were reviewed and concurred in by the entire team based on a cross functional team review of each technical area.

3 HPAV IRT Conclusions and Findings

The IRT identified 35 Findings considered essential to improve the models, assumptions and methodology of the HPAV design approach. The IRT concluded, that the design approach for HPAV piping and components is acceptable provided BNI resolves the Findings . The IRT also concluded that they could provide an affirmative response to the three Primary Questions of the IRT Charter when the IRT's Findings are resolved and further stated that there is "*high confidence that*

- *The QRA approach is acceptable for defining loads to be used in design, and there is a low probability of exceeding either their frequency or their magnitude.*
- *The best estimate pipe stresses and strains, computed from the defined loads in the manner proposed by BNI, are not likely to be significantly exceeded.*
- *The combination of QRA load definitions, best estimate piping system response calculations and conservative acceptance criteria developed pursuant to the piping Code B31.3 provides a reasonable balance of probabilistic and deterministic elements appropriate for design of HPAV piping and components.*
- *The net result of this approach to design will be a low probability of pipe failure if hydrogen explosions occur."*

In addition to the 35 Findings, the IRT identified 32 Recommendations for consideration. Although not required for IRT approval of the HPAV design approach, these Recommendations were offered by the IRT as discretionary improvements "that DOE and BNI should consider for making long-term improvements in this risk-informed approach to design." The number of Findings and Recommendations in each technical area is listed in Table 3-1 below.

Table 3-1 Summary of Findings and Recommendations

Technical Area	Findings	Recommendations
QRA	9	5
Gas phenomena	12	11
Structural Design	14	16
Total	35	32

4 Implementation Plan

A response approach for each of the HPAV IRT Findings is provided in Appendix A identifying the actions required to resolve the finding.. Discussion of the plan to complete these actions is provided below. Also a list of the HPAV IRT Recommendations is provided in Appendix B. Formal responses to the Recommendations listing in Appendix B will be completed by September 3, 2010. The schedule for the implementation plan is provided in Appendix C with major milestones summarized in Table 4-1 below.

Table 4-1 Summary of Schedule Milestones

Milestones	Forecast Date
Issue Hydrogen in Piping and Ancillary Vessels (HPAV) Implementation and Closure Plan	August 18, 2010
Complete Preliminary QRA Probability Distribution Review	September 3, 2010
Complete Recommendation Responses	September 3, 2010
Issue Response Plan Update	September 7, 2010
Conduct QRA Peer Review of Final QRA	September 20, 2010
Complete Findings - Close Summary Response Sheets	September 30, 2010
Issue Response Plan Update	October 5, 2010
Revise Project Procedures	October 31, 2010
Revise 24590-WTP-RPT-ENG-10-008	November 9, 2010
Revise 24590-WTP-RPT-ENG-07-011	November 30, 2010
Complete QRA V&V	January 31, 2011

To implement the Findings and Recommendations, the previous HPAV support team of Dominion Engineering Incorporated (DEI), Global Nuclear Network Analysis (GNNA), and the URS SMS will be re-established under new subcontracts. The Quantitative Risk Analysis (QRA) Team is made up of BNI, DEI, and URS personnel. The structural analysis and responses changes will be addressed by BNI and DEI, with GNNA providing expert oversight of integration of the requirements. Resolving and implementing the IRT Findings and Recommendations by the geographically dispersed HPAV team will be managed as it has in the past through daily and weekly conference calls held by the HPAV Project Engineer.

As each IRT Finding or Recommendation is completed a Summary Response Sheet (SRS) will be issued that identifies the original Finding or Recommendation, the response and a listing of all affected calculations and sections of project reports and procedures that have been or will be revised as a result of completing the item. The SRS is designed to provide a succinct summary of the finding disposition sufficient to support review by the IRT and support implementation on changes. A copy of the SRS cover sheet is provided in Appendix E. The actual revised calculations and specific wording changes will be included in the SRS package submitted for IRT concurrence. The SRS and supporting information will be available for viewing the latest versions in an electronic e-room as was establish for the IRT review.

Each SRS will require IRT concurrence of actions and results to support closure of the item, and documented concurrence. The goal of the SRS is to allow the closure of items and integration with project procedures and calculations to support work, yet allow revision to major WTP reports, such as a reference 1, to occur following closure without impacting construction. Design will proceed in accordance with the approved Quality Assurance Manual and all approved design control procedures which means that new HPAV designs will not be issued until the supporting analytical tools are in place. HPAV affected piping that has the potential for design change such as increased pipe schedule has been placed on hold. Control lines for active controls are being installed with the intent that they can be removed or abandoned in place if final QRA results and analysis show the active controls are not required.

There are two primary tasks associated with implementation of the HPAV IRT responses that will be worked concurrently as part of this closure plan. The first task is the development of the revised QRA model that will meet Verification and Validation (V&V) requirements defined by Software Quality Procedures (SQP) for use in the confirmed design. In particular, BNI has committed to review and evaluate the selection of the initiating events, the OFA fault tree structure, the Event Progression Logic (EPL), and most of the parameter distributions (see Appendix A, F2-1 - F2-9). The second major task is updating all the calculations for the structural responses, gas generation and gas phenomenology correlations. In addition to the items specific to the QRA, a portion of the other IRT findings will impact the QRA model. Several of the findings require additional work on gas distribution models, the Unit Hydrogen Generation Rates (UHGRs) and the run-up distance correlations used in the model. These items will be complete in the near term to ensure the QRA model is updated with the latest information by late September 2010. Scoping efforts are in progress to define specific changes and establish specific tasks that will be reviewed in detail at a meeting scheduled for August 30 to September 2, 2010 at the DEI office in Reston Virginia.

In addition to the IRT Findings and Recommendations, responses to the DOE-HS sponsored QRA Peer Review Team (PRT) report will be integrated with implementation of the IRT Findings. The responses for these issues are provided in Appendix D. Formal responses to the PRT findings will also be provided on the SRS to provide responses to each of the four main items and a listing of all affected calculations and sections of project reports and procedures that will be revised to close the item. After all the IRT and PRT findings and recommendations are incorporated in the QRA, a team of three probability experts will make the determination that the QRA is ready for design. The team of probability experts will be made up of the HPAV IRT member, a member from the DOE-HS sponsored PRT and one additional, nationally recognized expert that will be retained under subcontracted. This QRA Peer Review Team (QPRT) team will review the changes to the QRA and determine it is ready for use in design. The HPAV IRT findings will be closed once the model changes are agreed to by the WTP QRA team and the QPRT. Once the model is finalized it will be V&V'ed as required by DOE Order 414.1C. After successful completion of the V&V process the QRA will be ready for use in design of the WTP.

5 Quality Assurance

All work will be conducted under NQA-1 2000 requirements and includes implementation of new software quality requirements to enhance compliance with DOE Order 414.1C. The new requirements are detailed in procedure Software Quality Procedure (SQP) 24590-WTP-3PS-G000-T0045, Supplier Design Analysis with Developed Software issued on June 24, 2010. The new SQPs are for managing software used or developed by subcontractors and ensure the appropriate software lifecycle requirements are met. These requirements affect the Quantitative Risk Analysis (QRA) software and the calculations supporting HPAV that used ANSYS, Excel, and other supporting software programs for finite element analysis (FEA) of impulsive loads. These requirements provide specific guidance to Subcontractors under NQA-1 2000, for implementing DOE Order 414.1C to resolve concerns raised by the DNFSB in their letter of 5 May 2010.

6 Plan Budget

The budget for executing this response plan has been documented in Trend Notice 24590-06-04913, Implementation of HPAV IRT Findings, and DOE Order 414.1C, Requirements. Issuing new Project

Support Requests (PSRs) and new subcontracts is in progress and dates of activation and proposed manning plans support the proposed schedule.

7 Records

Closure of the IRT Findings will result in the revision of project calculations, reports, and procedures. The project documents to be revised will be listed on the SRS associated with the Finding as discussed earlier and final design criteria will be incorporated in the WTP Basis of Design.

8 References

1. 24590-WTP-RPT-ENG-07-011, *HPAV Engineering Analysis and Design Methods.*
2. 24590-WTP-RPT-ENG-10-008, *Quantitative Risk Analysis of Hydrogen Events at WTP: Development of Event Frequency-Severity Analysis Model.*
3. 24590-WTP-GPG-M-0065, *Quantitative Risk Analysis Data Collection Process.*
4. 24590-WTP-GPG-ENG-0143, *HPAV Stress Analysis Design Guide.*
5. 24590-WTP-DC-PS-01-001, *Pipe Stress Design Criteria including "Pipe Stress Criteria" and "Span Method Criteria".*
6. 24590-WTP-DB-ENG-01-001, *Basis of Design.*
7. CCN 208458, *Conditional Approval of Pretreatment Authorization Basis Control Strategy Change Package* 09-NSD-044, November 2, 2009
8. CCN 214109, Conditional Approval Of Safety Requirements Document (SRD) Change Adding Hydrogen In Piping and Ancillary Vessels (HPAV) Design Criteria For Pretreatment (PT) Facility, 10-NSD-013, February 15, 2010

Appendix A

List of HPAV IRT Final Report Findings and Responses

Appendix A
List of HPAV IRT Final Report Findings and Responses

A.1 Topical Report TR 02-01: Fleming "Probabilistic Evaluation of QRA"

F2-1 Completeness of Initiating Events and Event Sequences

The systematic search for initiating events and event sequences that were considered and screened out prior to the fault tree and event tree development was not included in the QRA. Rather, it was incorporated by reference to prior studies, which investigated the risks of accidental releases. This systematic search needs to be brought inside the boundary of the QRA to ensure that the different purposes of the supporting studies do not result in risk significant sequences being left out. The fault tree analysis itself does not provide sufficient justification for excluded events. The events that were considered in previous studies need to be reviewed to confirm applicability to the current design and to account for the different purposes of the QRA and those of the previous studies. Justification for screening out any events is an important element of the QRA documentation and needs to be added.

<u>BNI Response:</u>

BNI will document a systematic review of all initiating events and event sequences that are applicable to HPAV-related events. In support of this effort, the following activities will be performed:

- Review of all source documents that formed the basis for the selection of initiating events (IEs) currently considered in the QRA model to identify assumptions which may have led to omitting certain IEs which may now be relevant, given the more advanced state of the WTP design.
- Review of potential additional initiating events (IEs) specifically recommended for consideration in HPAV IRT Topical Report 2-1.
- Revise / update the OFA fault tree structure as appropriate to consider / include any IEs previously omitted in the QRA model and deemed to be relevant based on the above re-evaluation and updated review.

F2-2 Need for Qualitative and Quantitative Screening Criteria

There is a need for further justification for events that were identified in the review that were screened out of the fault tree event tree logic to assure completeness of the QRA. A set of quantitative and qualitative screening criteria should be developed for this purpose. The criteria need to be selected to ensure that the frequency of any screened out event of a given severity potential is an insignificant fraction of the total frequency of unscreened events at the severity level. For example, if an event with a given severity level had a frequency of occurrence less than 0.1% of the total frequency of retained events at that severity level, it is unlikely that the total frequency of screened events would be significant. Such screening criteria are important tools to keep the size and complexity of PRA models manageable. In this QRA, the duration of the event needs to be considered as part of the severity potential and thus included as a parameter for the screening criteria.

<u>BNI Response:</u>

This finding has two parts to it. First, it requires justification for events that were identified but were screened out of the fault tree/event tree logic model to assure completeness. To do this, the Finding recommends that a set of quantitative and qualitative screening criteria should be developed for this purpose. The criteria will ensure that the frequency of any screened out initiating event of a given severity level is an insignificant fraction of the total frequency of events at a specific severity level. Secondly, the finding says that the duration of the event should be considered as part of the severity potential, and thus included as a parameter for the screening criteria. The following actions will be taken:

1. After completing actions of Finding 2-1, the QRA Team will identify candidate quantitative and qualitative criteria, and determine whether they can be used to screen events at the OFA (frequency analysis) or EPL (event progression logic) phase of analysis.
2. As the OFA provides the annual frequency of gas pocket formation to the EPL, the use of event duration will be discussed more fully as an interface point from the OFA to the EPL phenomenological analysis. The event duration is currently considered in the severity portion of QRA in the EPL and consequently will be included as a parameter in the development of the screening criteria.
3. The routes modeled thus far, will be re-run through the updated OFA and their respective severity level outcome will be reviewed to validate that they are representative of the full QRA and span what will be seen in systems throughout HLW and PTF. The results will be compared against the criteria. If the available route models do not fully exercise the fault tree logic, additional routes that would involve untested branches will be identified, modeled, and evaluated for screening. This will be documented and justification provided for not including certain events.
4. The existing QRA documentation will be revised including any new reports developed in support of these actions. The conclusions regarding screening criteria will be documented and justification provided for why the events that will be screened out would not be important for the route designs.

F2-3 De Minimus and Design Basis Accident Frequency Criteria

The QRA needs to adopt a de minimus screening criteria for screening out initiating events and event sequences that have such low frequency of occurrence as to preclude realistic quantification and are outside the capabilities of the current state of the art of PRA technology. Examples of such criteria are found in the ASME/ANS PRA Standard that has been endorsed by the US NRC in Regulatory Guide 1.200. According to this standard, events less likely than 10^{-8} per plant year may be screened out as beyond the de minimus level, and events less than 10^{-6} per plant year may be screened out as long as the capabilities of the (nuclear power plant) containment are not compromised.

In addition, it is not reasonable to impose design basis requirements on the PTF piping system for event sequences less likely than 1×10^{-4} to 1×10^{-5} per plant year (not to be confused with frequencies per pipe route year as currently calculated in the QRA). Event sequences whose total aggregate frequency is less than these values should be regarded as beyond design basis accidents and evaluated accordingly. The IRT's structural subgroup has concluded that fragmentation failures of PTF piping are not credible and that the capabilities of the confinement structures and systems are not affected by pipe failures. Therefore, event sequences involving pipe failures at frequencies below 1×10^{-5} per plant year should be regarded as beyond design basis events. Hence, any event sequences that challenge pipe integrity from a hydrogen event whose aggregated frequency is less than 1×10^{-5} per plant year should also be regarded as beyond design basis events.

<u>BNI Response:</u>

The QRA provides a systematic approach for performing a bounding analysis of the load posed by hydrogen events. The QRA produces pressure load and frequency estimates for all categories of hydrogen combustion phenomena with frequencies ranging from very frequent (multiple times per year) to less than 1 x 10^{-8} per year. In the QRA application, our approach has been to not screen events, regardless of frequency.

This finding states that the QRA needed to adopt screening criteria for initiating events and event sequences to eliminate those below threshold frequencies of occurrence to preclude unrealistic quantification and avoid frequency values that cannot be analyzed using contemporary Probabilistic Risk Assessment (PRA) methodology. The finding references as a suitable approach the screening methods discussed in the ASME/ANS Standard endorsed by the Nuclear Regulatory Commission in Reg Guide 1.200.

The ASME/ANS Standard provides methods applicable to PRA where the focus is on plant-wide risk of commercial nuclear reactor facility operations. The NRC uses PRA to estimate risk by using realistic models and industry-vetted input data to determine what can go wrong, how likely is it, and what are its consequences. Thus, PRA provides insights into the strengths and vulnerabilities of the design and operation of a nuclear power plant. End-point consequences of interest are plant-specific considering severe accidents/sequences comprising multiple plant systems and typically beyond design basis events, and include core damage frequency (CDF), large early release frequency (LERF), and ultimately public dose and health effect risks. In this process, there is a need to include multiple system failures for correctly analyzing core damage and subsequently containment failure. However, to keep the analysis tractable, it is necessary to develop criteria and rules to screen negligibly contributing events and sequences. Key measures of risk are usually evaluated at the mean risk levels and the major uses tend to be as a prioritization tool for existing reactor maintenance management or backfits, and for comparison purposes with respect to newer reactor designs.

The nuclear plant PRA application use is in contrast to the use of the QRA for hydrogen events in the WTP, specifically, to determine the peak pressure loads for evaluating the acceptability of the piping design on a route-by-route basis. The PRA also provides frequency information for differentiating between ASME code defined normal loads (>1000) and occasional loads (<1000) for deflagrations, and for evaluating multiple (i.e., greater or less than 3) events for detonations. Also, the approach for the QRA is route-specific and in this sense it is less meaningful to sum results across routes to determine whether the piping system meets the code-based acceptance criteria.

Initial sets of frequency-severity curves for demonstration purposes have been produced from the QRA using mostly point values in the Operational Frequency Analysis, and with many of the Gas Pocket Logic and Event Progression Logic parameters input in a distributed manner. The resulting frequency-severity curves are characterized as relatively "steep" such that incremental changes to the low-frequency section of the curve will not appreciably change the resulting load. It should be noted however, that if more parameters are input in a distributed manner in updated versions of the QRA model, the characteristics of the frequency-severity curves may change. It will be important to note the relative rate of change of severity with decreasing frequency

The QRA team will propose quantitative screening criteria for route-specific event sequences to propose exclusion from the design model results of those sequences whose quantification is evidently outside the capability of the QRA model. Such criteria will be chosen to ensure that a broad range of sequence frequencies is always retained for the route-specific piping design. The use of a relative probability among event sequences calculated with an ignition probability of one rather than an absolute value (e.g., 10^{-5}) as the threshold will be less sensitive to model uncertainties. After sequences are identified for possible exclusion, they will be presented for engineering review (as discussed in the response to Finding F2-9) to evaluate and disposition them. The engineering review will examine the validity of the model for those sequences to verify that the excluded sequences are not credible or, if they are judged applicable to the route design, to prevent their exclusion. Applying this process to screen event sequences is judged to comply with the SRD requirement that the QRA "*not be used to exclude limiting events such as PRC-DDT that can occur for credible gas configuration conditions.*" in other words, the defined screening process will not eliminate "credible" conditions.

F2-4 Need to Consider Plant Level Events in QRA Models

The QRA method is applied on a pipe route by pipe route basis, which is appropriate for the way in which the results are used to support the design. However there may be "plant level events" that occur that involve stopping flow in multiple lines concurrently, which may lead to longer event durations than those considered when viewed on a pipe route basis. While such plant level events are less likely than many events modeled in the QRA, they can produce unique situations that could increase the duration of a flow stoppage in one or more pipe routes. Since the plant level events have safety implications, the time to recover the processing of waste streams may be significantly delayed by procedures to verify that safety functions have not been adversely compromised.

Examples of plant level events that now lack justification for exclusion include:

- Process pipe leaks and ruptures. A pipe leak or rupture may be difficult to mitigate in terms of route clearing, and the uncertainties in the expected performance of the piping systems are large;
- Internal fires and floods;
- Support system faults, such as loss of confinement HVAC; and
- External events, such as seismic events less severe and more likely than those considered in the model but with potential for a long duration flow stoppage. An example in this category is a seismic event less severe than the design basis event but large enough to cause a need to cease processing of waste streams.

<u>BNI Response:</u>

BNI recognizes that certain plant level events can have plant-wide implications for recovery and lead to different recovery characteristics. Therefore, the team will review the recovery duration distributions associated with route-level and plant-level initiating events to ensure that their shape and extent is representative of expected recovery times from these events including any additional time which may be required to resume waste processing following a plant-level event. It is anticipated that, as part of this review, the following actions will be performed:

- Ensure the initiating event and event sequences as revised for Finding 2-1 appropriately include plant level events, considering the suggested examples in particular.
- Identify key assumptions made on recovery from plant-wide events with respect to the current and expanded set of initiating events.
- Review basis for current recovery duration distributions for IEs currently included in QRA model.
- As appropriate, based on the above review, draw on industry experience / standards and guidance from operations personnel to inform recovery duration distributions for IEs not currently included in the QRA model.

- Request input from operations personnel (based on expected procedures) specifically regarding the expected time to recovery from plant-level initiating events (i.e., seismic, ashfall, LOSP, etc.) across a range of severities associated with these plant-level events.
- Revise, as appropriate, the recovery duration distributions associated with the various IEs considered in the QRA model.
- Appropriate changes will be made to update the fault tree model prior to event screening per Finding 2-1.

F2-5 Need to Enhance Treatment of Event Durations and Uncertainties

The variability and uncertainty in the duration of events modeled in the QRA are treated by binning all the events into 5 categories and then assigning an uncertainty distribution to each category. It is questioned whether these 5 categories are adequate to cover the variability among event types and whether the assigned distributions are wide enough to capture this source of uncertainty. If unique plant level events are added to the model, additional categories are needed. The technical basis for the number of duration bins, the selection of the distribution type, and the parameters of the associated uncertainty distributions needs to be strengthened. For hardware failures, it was questioned during the review whether mean time to repair data provide an adequate coverage of the entire duration of a scenario. It was clarified by BNI that the duration distributions were intended to include all the steps that must be completed in a scenario in addition to the repair time, e.g., time to determine the cause, time to arrange for equipment and personnel to perform the repair and follow-up procedures to restart the process. This commitment needs to be more clearly documented.

<u>BNI Response:</u>

BNI will review all recovery durations to ensure that the type and distribution of recovery durations adequately consider applicable initiating events and are inclusive of all recovery actions required prior to resuming processing of a waste stream. These values were originally evaluated with WTP operational personnel involvement and will be evaluated again to ensure base assumptions are updated as needed and adequately documented. As part of this effort, and as highlighted by the IRT, it is possible that current initiating event categories (LOSP, seismic, equipment failure, human error) will need to be further subdivided to reflect potentially significant differences in the recovery durations associated with subsets of each of these initiating event categories (e.g., a valve failure may be concluded to have a significantly different recovery duration distribution than that applicable to a pipe leak). In addressing this finding, the following activities will be performed:

- Review the basis for the recovery duration distributions for IEs currently included in QRA model.
- Evaluate whether certain IEs and their distributions should be sub-divided based on the frequency and recovery duration associated with subsets of each IE category currently modeled. Conversely, the review may determine that the current set of initiating event categories should be enlarged. As part of our response and if needed, we shall establish the new distributions for these new IE categories.
- As appropriate based on the above review, draw on industry experience / standards and guidance from WTP Operations and URS personnel to inform recovery duration distributions for IE subsets.
- Revise as appropriate, the recovery duration distributions associated with the various IEs currently considered in the QRA model and/or define new recovery duration distributions for subsets of IEs.
- Appropriate changes will be made to update the fault tree model prior to event screening per Finding 2-1.

F2-6 Need to Enhance Treatment of Model and Parameter Uncertainties

The QRA quantification is carried out with a mixture of point estimates, especially on the event frequency part of the analysis, and uncertainty distributions of selected parameters. Many of the parameters quantified with point estimates have large uncertainties. The result is an incomplete treatment of uncertainty. The final production version of the QRA needs to avoid the use of point estimates for uncertain parameters unless it can be shown that such approximation do not have a significant impact on the results.

Given the knowledge gained from applying the QRA models to selected pipe routes, and the insights gained from the HPAV IRT and BNL reviews, the previously developed Phenomena Ranking and Identification Table (PIRT) should be updated and revised. The revision should establish a comprehensive list of sources of uncertainties in each area of the QRA, including the event frequencies and durations, the gas generation phenomena, the gas combustion phenomena and the pipe loading phenomena. Each source of uncertainty should be evaluated for its known or potential impact on the QRA results. This includes an identification of the conservative assumptions currently employed for each source, a quantitative or qualitative evaluation of the sensitivity of the results to the source of uncertainty, and a disposition in terms of whether and how the effects of the uncertainty can be quantified or bounded. Criteria should then be developed and applied to justify the uncertainty distributions that are applied as well as to justify where continued use of point values is sufficient or appropriate.

<u>BNI Response:</u>

This finding notes that the current demonstration QRA model is a mixture of point estimates, especially in the Operational Frequency Analysis, and distributed inputs for many of the Event Progression Logic (EPL) parameters. Additionally, it is noted that many of the parameters that are quantified with point estimates have large uncertainties, and that the current model is an incomplete treatment of uncertainty.

The current QRA model was developed to demonstrate "proof-of-principle" in that it could provide a complete, systematic frequency-severity analysis of hydrogen events in WTP routes using a Monte Carlo-based approach and that subsequent structural analysis could then interface with the outputs in a deterministic, code-compliant manner. To ensure appropriate QRA model features are technically defensible and are used as intended, it is the intent of the effort to run the QRA in two distinct models:

1. The Design tool model will be established with specific input parameter values treated in a conservative, bounding manner as point values with justification, recognizing that sources of data may be sparse or not agreed upon among subject matter experts. This model will be updated to include distributed values in lieu of point values in all other instanced and justified based on industry experience. For this model probability of ignition (POI) of a gas pocket will be set to unity. The results of this model will be used for the actual piping analysis and design.
2. The Informing model will be established for sensitivity and uncertainty analysis, with many key inputs incorporated in the analysis using industry-accepted probability distribution functions (PDFs). In this model, valves for the POI will be a distributed format or numerical point values of less than unity, with the understanding that these are not backed by expert elicitation. This model will be the Project's best estimate of potential hydrogen events in WTP. The Informing model will be used to ensure that the design tool model is not masking any IE or other failure modes that might be overlooked by the use of point values in the Design tool. The Informing model will also provide the best understanding of where to establish the greatest priority of potential risks, but will not be used as the input for piping analysis and design.

The following supporting actions will be performed and resulting changes will be incorporated into the appropriate QRA models:

- Documented quantitative and qualitative criteria will be used to make the selection of the distribution type and distribution parameters for all QRA model input parameters.
- All input parameters to the HPAV QRA model will be distributed in the Informing model unless there is a technical justification for using a point estimate.

The Phenomena Ranking and Identification Table (PIRT) will be revised. The previously developed PIRT document was preliminary and served to facilitate early reviews of the QRA. The updated and revised PIRT document, and related supporting documents will include:

- Documentation of QRA model uncertainties and technical basis for how the uncertainties are modeled
- A sensitivity study to quantify the relative impact of model and input parameter uncertainties on the QRA results
- Net impact of known conservatisms in the QRA model, and
- Comparison of applied distributions with those documented in NRC-approved sources and recently reviewed sources (e.g., Preclosure Safety Analysis for the Yucca Mountain Project which was approved for docket but suspended before final approval).

F2-7 Enhanced Treatment of Phenomenological Uncertainties

Phenomena associated with gas pocket formation and hydrogen combustion within the QRA are being analyzed by a combination of probability distributions to represent uncertainty in key variables, deterministic rules to predict the type and severity of the hydrogen events, and, in some cases, conservative assumptions about individual phenomena. It is questioned whether there are additional sources of uncertainty embedded within the deterministically treated rules and equations, and whether the applied conservatisms are sufficient to bound the effects of these uncertainties. For example, the gas generation subgroup of the IRT, has proposed that current fixed assumptions regarding gas mixtures involving diluents may be better represented by a probabilistic model that considers different discrete batches of waste streams, each with a representative gas mixture of hydrogen, nitrous oxide and nitrogen.

One very important phenomenological uncertainty that is currently treated via a conservative assumption is the likelihood of ignition of combustible gas pockets. While the timing of ignition is treated as a random uncertainty, 1.0 is assumed as the probability of ignition. This area would benefit from a probabilistic treatment. Such probabilistic treatment needs to have a technically sound basis and account for the available evidence that currently exists on the likelihood of a spontaneous ignition when combustible mixtures are known to be present. A technically sound basis would include a review of the experience with formation of combustible gas mixtures in both experimental and industry service conditions, an accounting for the various physical variables, such as gas mixtures, temperatures, configurations, etc., and observed frequency of ignition and non-ignition. Development of ignition probabilities from this evidence would also benefit from an expert elicitation that meets the requirements of the ASME/ANS PRA standard and thereby reflects the range of uncertainty perceived by experts with diverse points of view. The IRT acknowledges that BNI has developed a basis for non-zero ignition probability, but since it was not being used at the time of the review, the IRT did not review it. However, its existence suggests that the some of the groundwork to implement this finding has already been established.

BNI Response:

The QRA Team will identify and document sampled parameter distributions, deterministic rules, and conservative assumptions throughout the QRA and particularly those used for phenomenology in the gas pocket logic (GPL) and event progression logic (EPL) phases of the analysis. This information will clearly delineate what inputs, distributions, rules, and assumptions are used in: (1) the conservative Design Model; (2) the Informing QRA model, or (3) in both the Design and Informing Model. To provide the most understanding of the major sensitivities of the QRA Informing Model, the model earmarked for supporting uncertainty analysis, the QRA team will perform additional review of model and data availability, and may initiate an expert solicitation process in the future for ignition probability and other important input parameters for facility operation support.

Based on available relevant test data as well as theoretical understanding of the physics governing relevant phenomena, this will be used to determine if specific phenomena would be better represented by technically justifiable, alternative distributions. Finding F3-9 is a good example of how uncertainties in gas phenomena will be incorporated. Other means of sensitivity study for the gas pocket logic model, for example, may be developed in place of the baseline parameter inputs. Revisions to deterministic rules and / or assumptions will be documented in the comprehensive documentation package referenced in the response to Finding F2-6.

F2-8 Incorporate Applicable Elements of the ASME/ANS PRA Standard

Incorporate the applicable technical requirements from the ASME/ANS PRA standard into the quality program elements of the QRA.

BNI Response:

BNI is currently reviewing and updating the quality assurance program elements governing the development of the QRA for HPAV events. BNI will review the ASME/ANS PRA standard and incorporate applicable technical / quality requirements on the development of the model. As stated above, there is no plan to apply the expert elicitation process at this time, but this standard would be applied if the process was to be implemented for operation.

F2-9 Use of Engineering Expertise in Approving QRA Results

BNI plans to use teams of subject matter experts to define the input variables for analysis of individual pipe routes using the QRA model. These experts are to exercise judgment based on science in selecting the input parameters. A similar if not the same group of experts should be used to judge the output of individual pipe route analyses to assure that they do not result from idiosyncratic aspects of the analysis or would change dramatically with small changes in the analysis process.

BNI Response:

There will be consistent BNI oversight in both definition of the QRA model inputs and review of the QRA results and application to piping design. The team of project subject matter experts that will be established the inputs for the QRA is modeled after the Integrated Safety Management System (ISMS) system by using the same functional involvement. As explicitly stated in the WTP QRA report (24590-WTP-RPT-ENG-10-008) not only does the QRA provide an integrated analysis of design requirements, expected operational configurations, and vulnerabilities to hazards, the

> *"QRA application is supported by in-depth review of hydrogen event-affected systems conducted by an interdisciplinary team of system engineers, process engineers, plant operations modelers, operators, and safety personnel to ensure facility ownership of the overall process."*

This statement specifically refers to the production team providing inputs, which is the same team that will review the QRA results, with emphasis on event and event sequence screening; uncertainty analysis; piping response and structural supports. After reviewing the analytic results and their basis, the team will be responsible for approving the final design basis for each piping route. In some instances, the team will instead determine that structural analysis of the route will not be performed, if event frequency and severity make success sufficiently improbable that active preventive safety controls should be maintained. These requirements for the team members and the documentation and approval process are provided in WTP procedure 24590-WTP-GPG-M-0065, *Quantitative Risk Analysis Data Collection Process.*

In addition, BNI has committed to developing a documentation package of the QRA development process, technical bases for the inputs and implicit models, quality assurance of the process and model, and model sensitivity. Much of this information is required as part of the documentation when developing the software under NQA-1 as enhanced by DOE Order 414.1C. The evolving QRA documentation package will be provided to facilitate the subject matter expert team review.

The subject matter expert (review) team will meet on an as-needed basis to review updates and revisions to the QRA documentation package and other related information. In particular, the review team will look at input data and parameter selection in light of QRA results that are obtained in applying these inputs to:

- ensure consistency of results
- identify non-physical or idiosyncratic model behavior and sources of discrepancy, and
- develop model response and trending insights.

A.2 Topical Report TR 3-01: Kubic - Hydrogen Gas Generation Rate and Gas Composition

F3-1

The conclusion that methane can be neglected in the HPAV QRA is based on a preliminary review by the IRT of a limited set of data. A more comprehensive evaluation is needed to demonstrate that data showing high methane to hydrogen ratios in the gas are not applicable to PTF. This evaluation must address data pertinent to Tanks C-101, C-102, C-103, U-103, S-102, and S-106. (See TR 3-1.)

<u>BNI Response:</u>

BNI will issue a report addressing methane to hydrogen ratios in the WTP waste feed. The evaluation performed by Dr. Kubic involved Tank Farm data from ~up to 10 years ago. These data will be obtained from Dr. Kubic. With this data and any more recent project data, the BNI Process and Engineering Technology (PET) group will conduct a review to focus on values representative of the range of WTP chemistry. PET will draw conclusions about methane and document the findings in a report that will be referenced in the QRA report. If high methane to hydrogen ratios are unexpectedly found to be applicable for WTP, appropriate model changes will be developed.

F3-2

The assumed distribution for the hydrogen to nitrous oxide ratio must be replaced by a distribution that can be justified on the basis of gas composition data and process knowledge. (See TR 3-1.)

BNI Response:

BNI will perform an Aspen Process Performance Simulation (APPS) run to update the stream chemical compositions. Using the APPS run and other available data (feed receipt relative to nitrous oxide) BNI's PET Group will conduct a review by mid-August to determine the gaps in information and the actions necessary to bound the expected range and uncertainty in the hydrogen to nitrous oxide ratio and close this finding.

F3-3

A stoichiometric hydrogen-oxygen mixture, or appropriate distribution of hydrogen-oxygen ratio, must be used in areas of the process where the mixture contains insufficient nitrite ions or soluble organic compounds for nitrous oxide production. These areas include piping for washed solids from UF. (See TR 3-1.)

BNI Response:

BNI will perform an Aspen Process Performance Simulation (APPS) run to update the stream chemical compositions. BNI will then develop an empirical model to determine where the nitrate/nitrite and organics are relative to potential gas generation. Early model runs can be accomplished to validate current expectations with verified results being included in a final report to be issued by BNI by October 19, 2010.

F3-4

The impact of nitrogen on the HPAV QRA must be determined. Additional analysis and sensitivity studies are needed to determine whether neglecting nitrogen is a conservative assumption. (See TR 3-1.)

BNI Response:

BNI will evaluate the competing effects of combustible gas mixture dilution due to nitrogen generation and the increased bubble size/run-up length (discussed below) due to total gas generation. Once these two effects are understood and documented in a study, supported by calculations as necessary, a closure strategy will be finalized. If the effect is important and a new model is needed, BNI will determine if any additional research, in the form of additional APPS model runs, is required to update the HPAV methods and criteria. The competing effects may essentially cancel each other and the existing model would then be adequate.

The effect of nitrogen dilution is being considered by developing a DDT run-up distance model consistent with the methodology advanced in IRT finding F3-9 and recommendation R3-7. A common relationship between normalized run-up distance, cell size, and reaction zone length is being relied upon for developing the model. The QRA results using the run-up distance model that accounts for nitrogen dilution will be compared to the results using the run-up distance model for hydrogen and nitrous oxide only mixtures. This effort will also require developing correlations for gas generation of nitrogen/nitrous oxide in addition to the hydrogen generation rate correlation.

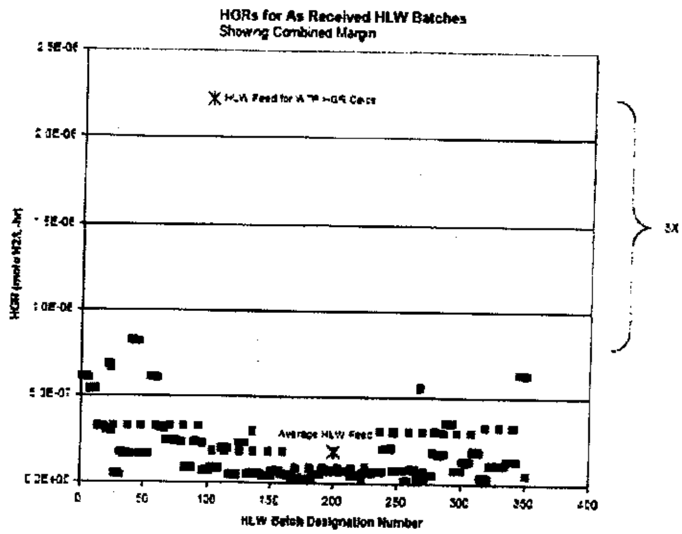
F3-5

Additional analysis is needed to demonstrate the enveloping feeds result in conservative estimates of the hydrogen generation rate at all locations in the process. (See TR 3-1.)

<u>BNI Response:</u>

BNI will perform an Aspen Process Performance Simulation (APPS) run to update the stream chemical compositions and hydrogen generation information. APPS is the mass balance model used at WTP. As related to hydrogen calculations, it is used to develop complete sets of chemical composition data for each main waste stream in the three WTP facilities (pretreatment, and the two vitrification facilities). This finding is partially answered by CCN 142843, which shows that for WTP receipt batches the feed selected for the design basis provides measurable margin in excess of the correlation uncertainty (factor of 2X)..

Figure 2



BNI will expand on this and document an evaluation that shows that other key points in the plant representative of the impact of planned processing on the hydrogen generation rate calculation margin have at least the factor of two margin required to bound the correlation uncertainty. To a significant extent this has already been done in the margin, leach, and AN waste analyses (Attachments M, K, and L or 24590-WTP-M4C-V11T-00004), but some results in Table L-5 do not demonstrate adequate margin, additional documentation is required, and some new runs must be performed with the current mass balance, and current feeds. BNI will revise the Hydrogen Generation Rate Calculation with the results of this work.

In addition, in conjunction with Finding 2-6, a distributed HGR will be developed in lieu of the conservative, point estimate currently established by project calculations. BNI will issue an HPAV HGR calculation that will provide the UHGR that spans the expected temperatures ranges of minimum, normal operating, and maximum operating for each system in support of preprocessing for each route . These temperatures will be used to develop HGR distributions for QRA input. In addition, for select systems, cool down times will be calculated for the piping to more realistically model total H2 generation in long duration events. These UHGRs will be developed using the correlations, and stream composition data, that are currently developed in the vessel HGR calculations (24590-WTP-M4C-V11T-00011, and 24590-WTP-M4C-V11T-00004), with the exception that temperatures appropriate to the pipe section (at the expected range of plant operating temperatures) will be used as a new input. In addition, this calculation will document the reduction in the radiolysis contribution due to the gamma energy that is allowed to escape and is not deposited into the waste. This gamma correction will only be developed for streams with a significant radiolysis term.

A.3 Topical Report TR 03-02: Sacz - Rheological Aspects of Gas Pockets

F3-6 and F3-7: Justification Regarding Simulant Selection

The justifications regarding the simulant selection for the gas testing performed by DEI and the QRA are not appropriately documented. The most important parameter affecting the formation and geometry of gas pockets is the yield strength of the waste. The range of yield stresses used both in the gas testing and the QRA calculations must be either revised or justified in terms of the expected behavior of the waste. Specifically, two related aspects of the waste properties need to be addressed:

F3-6

After a period of static conditions, particles in the waste will settle, potentially forming regions in the pipe system where concentrations of solids can be substantially higher than in the original waste. Such settling could be especially important in vertical pipes, where a region of high yield stress at the bottom might affect gas pocket mobility. Evidence should be gathered on the possibility of settling and the resulting yield stress of the concentrated waste. This could be done by looking at previous studies that have addressed simulant selection or by testing. The main possible consequence of this analysis will be the need to widen the yield stress range used in the QRA. Alternatively, an evaluation of results could be made (sensitivity study) by assuming high yield stress regions to determine the impact of higher yield stresses on QRA calculations. (See TR 3-2.)

F3-7

The variability of waste composition through the life of the PTF should be documented. It is important to make sure that the yield stress range used in the QRA conforms to possible changes in the waste characterization. Aside from solids content, the ionic strength of the liquid should be considered. Variations in ionic strength may affect interparticle interaction and thus impact the yield stress of the waste. (See TR 3-2.)

<u>BNI Response:</u>

In responding to these two related findings, the following activities are anticipated to be performed:

- The technical basis for the expected waste composition and resulting waste properties in a given route will be documented. The QRA model inputs that define the waste properties will be consistent with the documented properties for the route being evaluated.
- Variation in the yield stress of waste streams will be considered as part of the documented sensitivity study. Specifically, although the QRA model does not currently permit temporal and spatial variations in waste stream properties (e.g., resulting from particulate settling), sensitivity studies will be evaluated to bound the expected effects of these variations.

- Based on results of the above actions, if it is deemed necessary to conduct additional modeling, some small scale confirmatory gas bubble testing may also be considered to augment the analyses. If the testing is consider prudent, these are two dimensional tests that can be accomplished in time to support the closure of the findings based on preliminary, informal 2 dimensional studies.

A.4 Topical Report TR 3-3: Lee/Ciccarelli "De minimus Gas Bubble"

F3-8

The accuracy of the analysis is difficult to comment on because the approach is imperfectly represented as an availability analysis. The revised report should be written to accurately describe the approach taken, e.g., the expansion work method currently used or an actual standard availability analysis, as outlined in the foregoing discussion section. The calculated de minimus bubble size is very conservative, but it meets the needs of the QRA analysis in eliminating the need to analyze insignificantly small gas pockets.

BNI Response:

The De Minimus calculation (C-6916-00-16, R0) will continue to be an "expansion work method" analysis. However, the calculation will be revised to properly describe and document the analysis that was performed and ensure that it does not proclaim to be a thermodynamic availability analysis. Additional guidance for application to non-stoichiometric and nitrogen-diluted mixtures will also be added, so that the QRA may reference established relationships for mixtures of various H_2, N_2O, and N_2 composition, and various initial pressures. (See also related comment R3-6.). The following actions will be accomplished.

- Revise C-6916-00-16, R0
- Revise Section 6.3.2.1 in 07-011

A.5 Topical Report TR 3-4: Ciccarelli/Lee "DDT Run-up Correlations"

F3-9

The DDT run-up distance data must be properly used in the QRA analysis. The inherent irreproducibility of the phenomenon, and the resulting scatter in the data, has to be captured in the model used to predict the DDT run-up distance. The DDT run-up distance should not come from curve fitting the SwRI experimental data or using a linear cell size correlation where data is available. The run-up distance data should be divided into three zones encompassing the fuel lean, stoichiometric and fuel rich regions. Each zone should include data showing an equal amount of scatter at a given mixture composition. Within each zone, the DDT run-up distance for a given mixture would be obtained by using a random number generator to select a value between the assigned minimum and maximum value for the zone. Such an approach would ensure that the stochastic nature of the DDT phenomenon is retained in the modeling.

BNI Response:

The run-up distance model in the QRA Monte Carlo simulation will be revised to be consistent with the three zone model proposed in the finding. The concentration bounds of each zone will be informed by the available run-up distance data and cell size based or experimentally determined detonability limits. Maximum run-up distances for each zone will be based on measured run-up distances in smooth pipe without closed-end effects. Minimum run-up distances will be based on available run-up distance data with blockages (spirals) and closed-ends. In the absence of available data, minimum run-up distances may be taken to be as short as 7λ.

- Investigate models that capture the RUD dependence on pipe diameter and cover all ranges of mixtures of N_2 or mixtures with equal concentrations of N_2 and N_2O and determine if there is opportunity to improve the model by using reaction zone lengths.
- Determine bounds for three zone run-up distance model for H_2-N_2O and H_2-N_2 mixtures using available test data from HPAV testing at Southwest Research Institute (SwRI) and California Institute of Technology (CIT).
- Implement model in QRA Monte Carlo Simulation.
- Revise Section 5.4.5.2 in 24590-WTP-RPT-ENG-07-011 to eliminate run-up distance cell-size correlation and include new section on three zone run-up distance model.

A.6 Topical Report TR 3-5: Ciccarelli/Lee "Pressure Load Correlations"

F3-10.1

The tests that used a spiral and the location of the spiral must be identified in the BNI report 24590-WTP-RPT-ENG 07-011.

<u>BNI Response:</u>

A column will be added to Table A-7 in BNI Report 24590-WTP-RPT-ENG 07-011 designating whether a spiral was used in the experiment and where it was placed.

F3-10.2

The second paragraph in DEI report C-6916-00-04 page 23 must be completely rewritten because it does not properly describe the PRC-DDT model used to develop the pressure-time correlation that includes a time dependent expansion tail pressure.

<u>BNI Response:</u>

One of the primary conclusions of this topical report (see Recommendation R3-8 below) is that the PRC-DDT pressure correlation must be modified to either (1) better capture the unsteady expansion behavior behind the detonation front, or (2) use a simple bounding exponential decay curve fit to the experimental data. As part of this revision, the text describing the correlation will also be revised as required.

F3-10.3

The initial pressure and temperature conditions that U_{CJ}, γ_2, and C_3 in equation 7 are based on needs to be provided.

<u>BNI Response:</u>

As documented in the DEI factual review provided on 7/8/2010, C-6916-00-04, R1 Section 5.2 refers to Table 6, which tabulates the initial pressure, temperature, and other properties of the gas mixture considered in the calculation. Additional references to Table 6 will be added following the equations where gas-specific variables are introduced.

F3-11.1

The DDT correlation (equation 6) needs to take into account pre-compression leading up to DDT.

BNI Response:

Equation 6 does not explicitly account for pre-compression, but pre-compression was a key component in developing Equation 6 in C-6916-00-05. It was stated in Summary and Conclusions that pre-compression must be included in determining the initial pressure for Equation 6 but it was not explicitly included in the equations. Calculations C-6916-00-05 and C-6916-00-15 and ENG 07-011 will be revised appropriately to make this requirement clear.

F3-11.2

The PRC-DDT model is based on incorrect physics and needs to be changed.

BNI Response:

The PRC-DDT model will be revised to capture more of the physics of the expanding gas behind the detonation front, while maintaining the pre-compression and Taylor wave expansion physics which are currently included in the model. If accurately modeling the behavior of the expanding gas proves to be overly complicated, a simplified bounding curve fit, similar to the DDT correlation, will be used instead. The revised PRC-DDT correlation will be documented in C-6916-00-04, Revision 1. This also applies to Recommendation R3-8.

F3-12

The DDT correlation consists of an exponential decay with the peak pressure and two time constants as fitting parameters. Due to the nature of the pipe hoop response to short duration DDT loading it is not necessarily appropriate to choose the fitting parameters to match the pressure time history. It is perhaps more appropriate to choose the peak pressure and time constants to match the measured and computed peak strains for a given size of pipe. However BNI chooses to proceed, this is an important aspect of the analysis, and its basis must be documented.

BNI Response:

Calculation C-6916-00-05 used experimental strain data to validate the DDT pressure-time correlation for elastic strains. However, during the HPAV IRT meetings in early June 2010 in Reston, VA, IRT members questioned whether the DDT pressure correlation would remain valid for larger (~3%) plastic strain events, where, due to the longer time required for the pipe to reach maximum strain, the pipe's response would be driven more by the integrated impulse than the peak pressure. Preliminary calculations performed following the HPAV IRT Team's meeting show that the DDT pressure correlations conservatively bound the impulse of the experimental pressure traces for integration times required to reach large (~3%) plastic strains. Therefore, the correlations should be bounding (from an integrated impulse standpoint) for all smaller strain events, which occur over a much shorter time than the 3% strain events. These calculations will be added to DEI Calculation C-6916-00-05 in order to demonstrate that the DDT pressure correlations bounds the impulse of the experimental pressure traces over an appropriate integration time.

A.7 Topical Report TR 4-01: Short/Kennedy - HPAV Piping Dynamic Response

F4-1 Comparison of Test and Finite Element Pipe Dynamic Response

The differences between global pipe response analyses and tests must be resolved and accounted for in the analytical procedure employed for HPAV production piping analyses. BNI has draft calculations demonstrating that local through-wall bending and thermal transients are the reason for the observed differences between analyses and tests. Both of these effects are only considered in fatigue analyses as discussed in Sections 6.2.2.3 and 6.7 of ENG 07-011. Hence, BNI proposes to use the ME101 computed pipe stresses without adjustment for these effects for piping design. BNI must adequately justify that its proposed design approach is not unconservative as is indicated by the comparisons of analysis and test results. Based on work performed to date, it is our judgment that adequate justification can be provided. If such justification cannot be developed, an acceptable method to account for the difference in analysis and test results would be to scale the ME101 analysis results for longitudinal pipe stresses by a factor of 1.25. (See TR 4-1.)

<u>BNI Response:</u>

BNI has developed, and will submit, revision B to Calculation 24590-WTP-P6C-P40T-00021, which shows that adding HFO and thermal strains to the ME101 strains results in an average strain slightly higher than the test average strains. The following actions will be taken:

- Submit Revision B to 24590-WTP-P6C-P40T-00021
- Incorporate results into Section 6.2.2.1 of 07-011 to discuss the revised correlation

F4-2 Effect of the Initial Detonation Location on Piping System Dynamic Response

To assure that an appropriate range of detonation locations is considered in computing dynamic response of the pipe and of pipe supports, several detonation location cases should be considered for each piping run being designed. (See TR 4-1.)

<u>BNI Response:</u>

BNI has developed, and will submit, revision B to Calculation 24590-WTP-P6C-P40T-00021, which shows that multiple detonation locations do need to be considered when evaluating HPAV affected systems. The following actions will be taken:

- Submit Revision B to 24590-WTP-P6C-P40T-00021
- Revise Design Guide 24590-WTP-GPG-ENG-0143
- Incorporate discussion into Section 6.2.2.1 of 07-011

F4-3 Behavior of Pipes with Gas and Liquid

The approach for treatment of slug loads should be clearly stated in Chapter 6. Perhaps they are not explicitly considered because the detonation traveling wave case for a gas-filled system is judged to be adequate. If so, this should be stated. There is a need to benchmark ME101 analysis of the SSR system with water in the pipe against the cases considered by DEI. If slug loads are explicitly considered in pipe response analyses, it would be desirable to benchmark ME101 analyses including slug loads against test data. (See TR 4-1.)

BNI Response:

BNI will revise 6.1.3.2 of 07-011 to document the approach and will include provide more detail as discussed below. BNI will also formally issue DEI Calculation C-6916-00-18, which documents the method used to evaluate multiple slugs and was provided to the IRT as a draft version. Finally, in response to the comment on ME101 and SSR, BNI has developed, and will issue, revision B to Calculation 24590-WTP-P6C-P40T-00021, which shows that the ME101 SSR "partial fluid" model adequately matches the ANSYS predicted loads in the water filled region. The basis for this conclusion will be documented. The following actions will be taken:

- Complete and issue DEI calculation C-6916-00-18
- Issue Revision B to 24590-WTP-P6C-P40T-00021
- A series of sample analyses will be conducted to determine if slugs effects are generally enveloped by a traveling reflected detonation (due to the reflection in the fluid) wave load. Therefore, BNI/DEI will perform studies on actual WTP piping system geometries to show reflected detonation loads bound slug loading.
- Revise Design Guide 24590-WTP-GPG-ENG-0143 to include the following:
  - The pressure wave does not transfer from the first slug to the next pocket at the free surface; it simply reflects at the surface.
  - A detonation event in each pocket will be analyzed for local affects on the system, but recognizing that only the slug effects transfer from slug to slug.
- If a line is determined to only be subjected to slow speed deflagrations and no detonation, then the slug loads do need to be evaluated.
  - DEI Calculation C-6916-00-18 provides a method for developing slug loads for a pressurized pocket.
  - BNI will develop a spreadsheet or Mathcad sheet to develop force-time histories at bends, reducers, and tees due to deflagration induced slug loading.
  - The force time histories will be based on sample geometries for deflagration condition to establish typical slug loading.
  - Update Design Guide to incorporate the method and spreadsheet.

F4-4 Local Pipe Response Analyses using ANSYS

To assure that dynamic response of the pipe is conservative, the thickness of pipe modeled in ANSYS finite element analyses should consider the manufacturer's minus tolerance of 12.5 percent. It is our judgment that the thin region of the pipe under internal pressure load will experience larger stresses than a pipe with uniform wall thickness. Thus, the pipe cross section for hoop stress evaluation should be based on a 12.5% offset between the pipe inside and outside diameter and the corrosion allowance should be included around the pipe circumference. Hence, the resulting pipe cross section will be thinner by 12.5% on one side and thicker by 12.5% on the opposite side. (See TR 4-1 & TR 4-9.)

BNI Response:

BNI will modify its methods to incorporate Manufacturer's minus tolerance in computing the 0.2% equivalent through wall strain for dynamic HPAV events for straight pipe. The methodology will consider an offset center, such that one side is 12.5% thinner and the opposite side is 12.5% thicker. 3D bends, which experience additional thinning due to the bending process, will be based on a 20%

thinning/thickening at the center of the bend, which a sample of 1" to 4" NPS piping has shown to be a valid input (Reference 24590-WTP-FIR-CON-10-00136). The sample results will be documented in DEI Calculation C-6916-00-15 and discussed in 24590-WTP-ENG-07-011.

- Requires revision of DEI Calculation C-6916-00-15.
- Revise Section 7.1.4.1 of 24590-WTP-ENG-07-011.

A.8 Topical Report TR 4-02: Short/Kennedy - HPAV Piping Capacity

F4-5 Pipe Strain Limits

BNI should modify the criterion applied to piping outside BC/HTR areas that permits pressure equal to 1.5 times the initial pressure required to achieve a straight pipe equivalent through wall average strain of 0.2% plastic strain for no more than three HPAV events. If there can be multiple detonations at a single pipe location, an improved criterion would be to limit each event to the pressure loading which results in no more than 2.8% plastic strain per event and to allow no more than three such events. In our judgment, this improved criterion is easier to understand than the existing criterion and, thus, more defensible. In addition, the uncertainty in the plastic strain level reached is eliminated for different pressure time histories. (See TR 4-2.)

<u>BNI Response:</u>

This finding does not result in any change in results of analysis performed in accordance with the HPAV analysis and design criteria. This finding strictly provides an improved method of stating allowable strain limits. BNI will incorporate the recommended change obtaining DOE ORP approval of the necessary change to the PDSA Addendum, SRD, and BOD to revise the criteria. In addition, BNI will limit the number of events such that the average through wall equivalent strain, as determined using the straight pipe and 3D bend models in DEI Calculation C-6916-00-15, does not exceed 8.4% (=3*2.8%).

- Revise Design Guide 24590-WTP-GPG-ENG-0143
- Revise Section 7.1.4.1 of 07-011

Valve manufacturers should be consulted for appropriate strain limits for valves. (See TR 4-11.)

<u>BNI Response:</u>

As part of the equipment procurement specification and component analysis or test program, manufacturers will be consulted on the appropriate strain limits expected for the component service life as discussed in section 7.4 of 07-011. Testing or analysis will qualify the valve for it intended use, however, routine equipment maintenance or repairs is expected of hot cell process equipment. In the event of component repairs, dimensional inspections of seating and sealing surfaces would be accomplished that would reveal if any permanent deformation of the valve body and or bonnet assembly exists that would indicate if any strain limits were exceeded.

F4-6 Combination of Stresses from Simultaneous Explosion Effects

Further justification must be provided to support the BNI position that DDT SigE effects need not be combined with beam longitudinal effects. (See TR 4-2.)

BNI Response:

BNI will revise DEI calculation C-6916-00-05 to provide additional justification for not combining DDT and beam longitudinal effects. The justification will rely upon high resolution finite element modeling as recommended by Dr. Shepherd to address both through wall and axial effects, consistent with elastic shell theory. The combination of DDT hoop "SigE" stresses with the longitudinal "traveling wave" stresses are proposed to be addressed by performing detailed finite-element analysis of a DDT occurring upstream of a piping feature such as a bend. The DDT location will be varied to determine if the maximum stresses increase as the DDT occurs closer to the bend, where system excitation and longitudinal stresses would originate. The maximum DDT stresses will also be compared to the "SigE" stress calculated using the spatially invariant model discussed in DEI Calculation C-6916-00-15. It is acknowledged that PRC-DDT occurring at a closed valve would itself generate longitudinal stresses. Therefore, BNI is considering modifying the modeling methodology to include applying the axial thrust load from the PRC-DDT pressure to the model such that adding the longitudinal stresses separately would not be necessary.

F4-7 Combination of Stresses from Simultaneous Explosion Effects

The combination of the high frequency oscillations (HFO) and the low frequency beam response for fatigue analysis by SRSS (square root of the sum of the squares) in Section 7.1.5.1 requires further justification. After a telephone conversation between Bob Kennedy and John Minichiello on June 15th, we now agree that SRSS combination of HFO and beam response is reasonable and probably somewhat conservative. However, the existing Section 7.1.5.1 does not adequately provide the basis for this approach and should be revised to provide a better, more convincing explanation of the basis for SRSS combination as discussed in the telephone conversation. (See TR 4-2.)

BNI Response:

BNI will revise Section 7.1.5.1 of 07-011 and add an Appendix to incorporate the basis for this conclusion as discussed with the IRT members (Dr. Kennedy and Mr. Short) at the final IRT meeting on June 22-23, 2010. The following actions will be taken:

- Incorporate into new calculation C-6916-00-17 the discussion showing that the fatigue damage due to HFO occurs early in the event.
- Add an appendix to 07-011 incorporating the basis for this conclusion.

F4-10 Acceptance Criteria for Pipe Supports

The entire pipe support code, such as AISC N690 for outside BC/HTR areas and an equivalent provision for inside BC/HTR areas, should be used for pipe stress criteria rather than a single scale factor. (See TR 4-2.)

BNI Response:

BNI will modify its documentation to show the appropriate limits for each design code for pipe supports. BNI may do this via reference to the Pipe Support Design Criteria (24590-WTP-DC-PS-01-002) or by incorporating the appropriate excerpts into an appendix to the 07-011 report.

F4-11 Acceptance Criteria for Pipe Support Anchorage

Pipe support anchorage criteria must be provided. Such criteria exist within the BNI civil/structural group and those criteria should be included in ENG 07-011. If expansion anchors are used, only "undercut" anchors should be allowed (e.g., Maxi-Bolts). (See TR 4-2.)

BNI Response:

For concrete and embeds, BNI will revise the Civil-Structural Design Criteria (24590-WTP-ST-DC-01-001), Section 5.4.1, which provides the factored load combinations (reinforced concrete) and AISC N690 load combinations and limits (structural steel) that have been used for Safety Class structures, such as the Pretreatment Facility. BNI will revise its pipe support design criteria to indicate that when expansion anchors are used for an HPAV affected support, only maxi-bolts will be permitted.

- Revise 24590-WTP-ST-DC-01-001 to incorporate a discussion of HPAV loads and how they are to be treated (BNI-CSA)
  - Pipe Loads on structures due to high speed deflagration will be treated as operating pipe reactions.
  - Pipe loads on structures due to detonation loading will be treated like seismic loads. Neither deflagration nor detonation loads will be combined with actual seismic loading however.
  - Effects from HPAV loads from the same piping system on civil structures will be combined absolutely.
  - Effects from HPAV loads from different piping systems will not be combined
- Revise 24590-WTP-DC-PS-01-002 to state that only maxi-bolts are permitted, when expansion anchors are used on HPAV affected supports (BNI-PD).
- Revise 07-011 to add appendices discussing supports and anchorage.

A.9 Topical Report TR 4-09: Koves - Application of ASME B31.3 Code to HPAV

F4-12 Effective Stress under Deflagration

For the BC/HTR piping, a combined effective stress calculation of the average through the thickness sum of hoop, radial, axial and torsion stresses shall be performed for the deflagration case and limited to yield (0.2% strain). (See TR 4-9.)

BNI Response:

BNI will modify its methods to incorporate this evaluation for deflagrations that occur less than 1000 times over the life of the plant. The following actions will be taken:

- If deflagration occurs more than 1000 times, it is a normal condition, and will be treated the same as any normal pressure condition, using Code Case 178, with no increase in allowable.
- An ME101 report writer module will be developed to support this change (similar to what was done for incorporating corrosion effects) - (BNI-PD)
- Modify Design Guide 24590-WTP-GPG-ENG-0143
- Revise Section 7.1.4.3 of 07-011
- Revisions will also include information regarding the impact of thermal affects. Specifically, thermal effects from deflagration (skin stress effects) will continue to be considered as part of the fatigue analysis, as documented in Appendix C of the Basis of Design, Section 2.4, and 07-011, Section 7.1.5. As discussed in 07-011, Section 6.7, and DEI Calculation C-6916-00-12, the increase in the piping bulk temperature due to deflagration is about 10oF, which results in negligible stresses in the piping system.

A.10 Topical Report TR 4-11: Koves - Fatigue Evaluation of HPAV Piping

F4-8 Fatigue

Weld Strength Reduction Factors (WSRFs) are not currently applied to the high frequency oscillations. Weldments are known to have a reduced fatigue life compared with the base metal. Fatigue Strength Reduction Factors should be applied at all weld locations in the piping. Reference 117, HPAV Detailed Analysis Example, Calculation C-6916-00-14 section 5.2.2, equations (5-8) and (5-9) should be corrected. (See TR 4-11.)

<u>BNI Response:</u>

In addition to the visual and volumetric exams already in place, BNI will institute full external surface exam on all HPAV affected welds, without grinding smooth. This extends the current practice for Black Cell piping to HPAV affected piping in the Hot Cell, as well. BNI will apply the appropriate Section III, NB-3600, "K" indices for as-welded surfaces when performing the fatigue analysis, consistent with the Section III, NB method that BNI has proposed. The following actions will be taken:

- Revise Specifications 24590-WTP-3PS-PS02-T0001 (*Shop Fabrication of Piping*) and 24590-WTP-3PS-PS02-T0003 (*Field Fabrication of Piping*) - BNI-MET and Construction
- DEI revise Calculation C-6916-00-14, Section 5.2.2, equation 5-8 and 5-9, and the subsequent fatigue analysis to incorporate the Code correction published in 2009 and to incorporate an FSRF at weld locations.
- Revise Section 6.9 and 7.1.7 of 07-011
- BNI will issue a new section to ENG 07-011 on materials and quality of construction to address welds, fittings, bending of pipe, etc.

These new requirements are in addition to commitments made from earlier reviews with DOE-EM Subject Matter Expert, which resulted in incorporating in 07-011 "weld-on" branch weld connection details related to weld configuration.

F4-13 Fatigue

The stresses due to HFOs must not be treated as skin stresses and must include the application of fatigue strength reduction factors in the fatigue analysis, unless otherwise justified. (See TR 4-11.)

<u>BNI Response:</u>

As indicated above, in addition to the visual and volumetric exams already in place, BNI will institute full external surface exam on all HPAV affected welds, without grinding smooth. BNI will apply the "ΔT_1" Section III, NB-3600, "K" index ($K_3 = 1.7$) for as-welded surfaces when performing the fatigue analysis, consistent with the Section III, NB method that BNI has proposed. The following actions will be taken:

- Revise Specifications 24590-WTP-3PS-PS02-T0001 (Shop Fabrication of Piping) and 24590-WTP-3PS-PS02-T0003 (Field Fabrication of Piping) (BNI-MET and Construction).
- Revise 7.1.5 of 07-011.

F4-14 Fatigue

BNI should assess the need for an environmental effect adjustment for the fatigue curves used for analysis of HPAV piping and address this subject in ENG 07-011. Recognizing that environmental effects on fatigue behavior are a subject of concern in the nuclear power industry, it is appropriate that the subject be acknowledged, along with BNI's plan to deal with the issue (or to explain why it does not need to be factored into the fatigue analysis of HPAV piping). (See Topical Report TR 4-7.)

BNI Response:

BNI presented information to Dick Moen related to the environmental effect on HPAV dynamic events and temperature on stainless steel in water environments, plus information on corrosive tests done on the stainless material. As indicated in the Topical report "Environmental Effects on Fatigue" by Dick Moen:

> "BNI will revise ENG 07-011, Paragraph 6.4.3.2 to address NUREG/CR-6909. The primary factors affecting any environmental adjustments for the fatigue curves used for HPAV design would be that temperatures in HPAV piping are well below those in LWR applications and at strain rates above 0.4% per second, environmental effects are relatively small in austenitic stainless steels. BNI has also conducted modified ASTM G-123 corrosion tests on cold-worked pipe bend materials and has evidence that the worst-case corrosive substances will not corrosively attack the HPAV materials. That information will be useful in assessing the need for an environmental effect adjustment for the fatigue curves used for analysis of HPAV piping."

The final fatigue curves will be documented together with the basis for their selection.

A.11 Topical Report TR 4-16: Koves - Code Design Issues for Vessels and Flanges

F4-9 Flanges

Bolted Flange Joint Qualifications and Procedures should be added for the assembly of all flange joints. (See TR 4-16.)

BNI Response:

For HPAV affected flanges, ASME PCC-1 Guidance for Flange Assembly will be incorporated into the Piping Installation Procedure (24590-WTP-GPP-CON-3503) (BNI-Construction).

Appendix B

List of HPAV IRT Final Report Recommendations

Appendix B
List of HPAV IRT Final Report Recommendations and Responses

This Appendix is reserved for responses to the findings that will be provided at the next update of this report.

Item	Number	Recommendation
1	R2-1	Role of QRA as a Design Optimization Tool: BNI could use the QRA as a design optimization tool to evaluate all the various design options including passive and active approaches to minimize the risks of hydrogen explosions. Previously, designs relying on more active controls were evaluated without the benefit for information about hydrogen explosion risks. Active controls may change the explosion risk, but such controls do not completely eliminate the potential for explosions. The merits of the QRA should not be judged solely as a means of justifying a more passive design approach.
2	R2-2	Adopt an Expert Elicitation Process to Address Uncertainties: BNI could adopt the expert elicitation process that is used in the nuclear power industry pursuant to Section 1-4.3 of the ASME/ANS PRA Standard to address sources of uncertainty identified in the HPAV IRT review that are not already explicitly modeled in the current QRA models. This approach would apply to areas in the QRA where there is significant reliance on expert opinion and engineering judgment that is not directly supported by available data. One such area is the use of a panel of experts to review the inputs to the QRA evaluation of each pipe route as well as the review of the output to ensure consistency of the approach.
3	R2-3	Separate Treatment of Epistemic and Aleatory Uncertainties: As the treatment of uncertainties matures, consideration should be given to separating the quantification of epistemic and aleatory uncertainties. Currently these types of uncertainties are combined without distinguishing their separate contributions. A separate treatment would provide results that are easier to interpret.
4	R2-4	Perform a Limited Scope Piping Fragility Analysis: BNI should consider the performance of a parallel study to extend the QRA on a selected set of pipe routes to include the probability of pipe failure, pipe fragility, identification of the most likely failure modes, and sources of uncertainty not currently addressed, such as the unknown level of service-induced pipe degradation. Such a study would provide useful insights about the extent of design margins inherent in the piping design approach supported by the QRA.
5	R2-5	Plant Level Aggregation for New Risk Metrics: The current QRA results are aggregated on a pipe route basis, which is appropriate for providing information useful to design of the piping systems. The frequency of each category of events should be aggregated on a plant level basis (i.e., aggregated over all the pipe routes) so the total frequency of the design basis events for the piping system can be determined. This approach would then enable evaluation of beyond design basis events separately from design basis events.

Item	Number	Recommendation
6	R3-1	Use of a distribution of waste compositions instead of a single set of enveloping feeds could eliminate excessive conservatism in the hydrogen generation rate. A reasonable distribution could be constructed by defining feed vector characteristics, e.g., high, medium, and low hydrogen generation rates for the HLW and LAW. A probability could be assigned to each combination of feed vector based on the batch frequencies. (See TR 3-1.)
7	R3-2	Some of the conservatism in the hydrogen generation rate could be eliminated by accounting for cooling of the waste while operations are interrupted. (See TR 3-1.)
8	R3-3	Some additional conservatism could be eliminated by accounting for Cs-137 and Sr-90 decay over the life of the facility. (See TR 3-1.)
9	R3-4 (Main Body)	Nitrogen dilution of the hydrogen-nitrous oxide mixture should be considered. This change could be accomplished by using a joint probability distribution for the nitrous oxide-hydrogen ratio and nitrogen-hydrogen ratio. The joint distribution would account for the correlation that exists between nitrous oxide and nitrogen. (See TR 3-1.)
10	R3-4 (TR 3-1)	A hydrogen-nitrous oxide-nitrogen mixture could be used as a flammable gas surrogate instead of a hydrogen-nitrous oxide mixture. This change could be accomplished by using a joint probability distribution for the nitrous oxide-hydrogen ratio and nitrogen-hydrogen ratio. The joint distribution would account for the correlation that exists between nitrous oxide and nitrogen.
11	RDEI-1	Obtain raw data used by IRT member (B. Kubic) in support of TR 3-1 for analysis to provide the basis for the gas mixture distributions.
12	R3-5	In the analysis of gas pocket geometry in the DEI report [1], plots of pocket width, W, vs. yield stress, τ_y, should be prepared for the original data. Since the yield stress must be proportional to a characteristic length, it would not seem appropriate to use the length ratios AR1 and AR2 as independent variables in correlations. A possible dimensionless variable to use in correlations of the data would be $\Delta\rho g\xi/\tau_y$, where ξ=Ac/D. Even though the empirical approach used by DEI could be adequate for the type of calculations performed in the QRA, an analysis based on a more physical description of force balances, such as that presented in the topical report "Rheological Aspects of Gas Pockets," TR 3-2, will make the calculations more robust and credible. (See TR 3-2.)
13	R3-6	Currently the de minimus bubble size based on a stoichiometric hydrogen-nitrous oxide mixture is used by the QRA to screen out the gas pockets that form in the pipe route under analysis that do not have to be analyzed for explosion phenomena and pipe response. The de minimus bubble size should be used as an integral part of the QRA process if a more realistic model to estimate the de minimus bubble is developed. (See TR 3-3.)

Item	Number	Recommendation
14	R3-7	As discussed in Section 3.1, the hydrogen-nitrous oxide mixture will have significant nitrogen dilution, especially for hydrogen rich mixtures. A DDT run-up distance correlation is not available for such a gas mixture because almost all the experiments performed at SwRI were with hydrogen-nitrous oxide mixtures. In the absence of such data, a DDT run-up distance versus cell size correlation could be developed from the existing hydrogen-nitrous oxide data. This correlation could then be used with either cell size data for nitrogen-diluted hydrogen-nitrous oxide mixtures, or the ZND detonation model could be used to predict the cell size. (See TR 3-4.)
15	R3-8	The PRC-DDT model should be revised to take into account the unsteady expansion that takes place. That is, BNI should take into account the expansion behind the detonation that drives the retonation wave back towards the ignition-end of the tube or replace the entire PRC-DDT model with a simple bounding exponential decay that is curve-fit to the experimental data, similar to that used for the DDT correlation. (See TR 3-5.)
16	R3-9	The control volume analysis of the detonation propagation through the bend shows that the details of the detonation interactions within the bend are not critical to estimating the overall loading of the piping via the bend force. A similar control volume analysis should be performed for all the pipe fittings to lend credibility to the amplification factor approach currently used. The project should consider using the control volume models (ignoring unsteady effects) in place of the AF correlations for all the pipe fittings. (See TR 3-5.)
17	R3-10	The term "pressure reflected calculation-DDT or PRC-DDT" does not accurately represent the phenomenon. DEI should use a new more representative term in the future. (See TR 3-5.)
18	R3-11	The lenticular pocket shape has a larger surface area per unit cross-sectional area compared to a cylindrical volume. The larger surface area increases turbulence ahead of the flame, which leads to reduced run-up distance. This effect was observed in the CIT experiments. For shallow lenticular pockets, the height of the pocket may be a more relevant scaling parameter than the effective cylinder diameter. When the lenticular pocket height is smaller than the detonation cell size, DDT is not possible. For very shallow lenticular pockets, with a corresponding large surface area to volume ratio, heat loss to the pipe wall and waste surface will become very important such that flame acceleration will be severely impeded. In the limit, when the height of the lenticular pocket is smaller than the quenching distance, heat loss will quench the flame. BNI should consider using the lenticular pocket height as the effective diameter in the DDT run-up distance correlation. (There is no topical report addressing lenticular pockets.)
19	R4-1	Chapter 6 of ENG 07-011 should provide a detailed description of the modeling of pipe supports, including the assumptions at support gaps and the use and stiffness evaluation of support springs. (See TR 4-1.)

Item	Number	Recommendation
20	R4-2	BNI has proposed that production piping analyses be performed for a run time of twice the fundamental period of the system even though benchmark analyses were run to three times the fundamental period. Preliminary calculations by BNI demonstrate that there is no significant difference in response between these analyses run times. The effect of analysis run time should be added to ENG 07-011, and, if acceptable, analysis run times of twice the fundamental period may be used. (See TR 4-1.)
21	R4-3	All the local analysis cases that need to be run should be explicitly defined in Section 6.2.2.2 of ENG 07-011. Our recommended cases are the following: • C-J detonation, DDT, and PRC-DDT for run-up lengths established by the QRA; • Straight pipe and 3D bend models; • 1-, 2-, 3-, and 4-inch pipe diameters & three pipe schedules, 40, 80, 160; • Corrosion allowances: for low & high solid waste, 0.040 & 0.093 inches; and • All cases with different AF values. (See TR 4-1.)
22	TR 4-1	Recommended Modifications or Edits to Chapter 6 of 07-011 • On Page 6-14, last sentence of the last paragraph "The wave starts at the jumper connection at node 405 and moves through the piping to the auto sampler connection at node 474 (see Figure 6-11)." The auto sampler connection and node 474 are not shown on Figure 6-11. • On the first line of the only paragraph on Page 6-27, there is a reference to Figure 6-18. That reference should be to Figure 6-19. • On Sheet 18 of 07-011, Reference 67, the parameters heading the columns for ME101 to ANSYS Percentage Difference are Fa/Mx, Fb/My, and Fc/Mz. These parameters should be Fa/Fx, Fb/Fy, and Fc/Fz.
23	TR 4-2	Recommended Modifications or Edits to Chapter 7 of 07-011 • On Page 7-1, the terms BC/HTR and non-BC/HTR are introduced. It is recommended that these terms be defined and a figure illustrating these areas be added. It should be made obvious that a BC/HTR region could be within the hot cell. • Equation (4) for stress due to dead load, Sdw on Page 7-11 should not include the term "SigE." Section 7.1.4.6 on Pages 7-12 and 7-13 provides discussion of the conservatism of Equation (3) that is on Page 7-11 in Section 7.1.4.4. • Section 7.1.4.4 should provide the path forward to Section 7.1.4.6 that covers the equation in the earlier section. In addition, Section 7.1.4.6 should be modified to make it more clear as to the purpose of the section (i.e., to demonstrate that Equation (3) is conservative, but not excessively conservative).

Enclosure 1

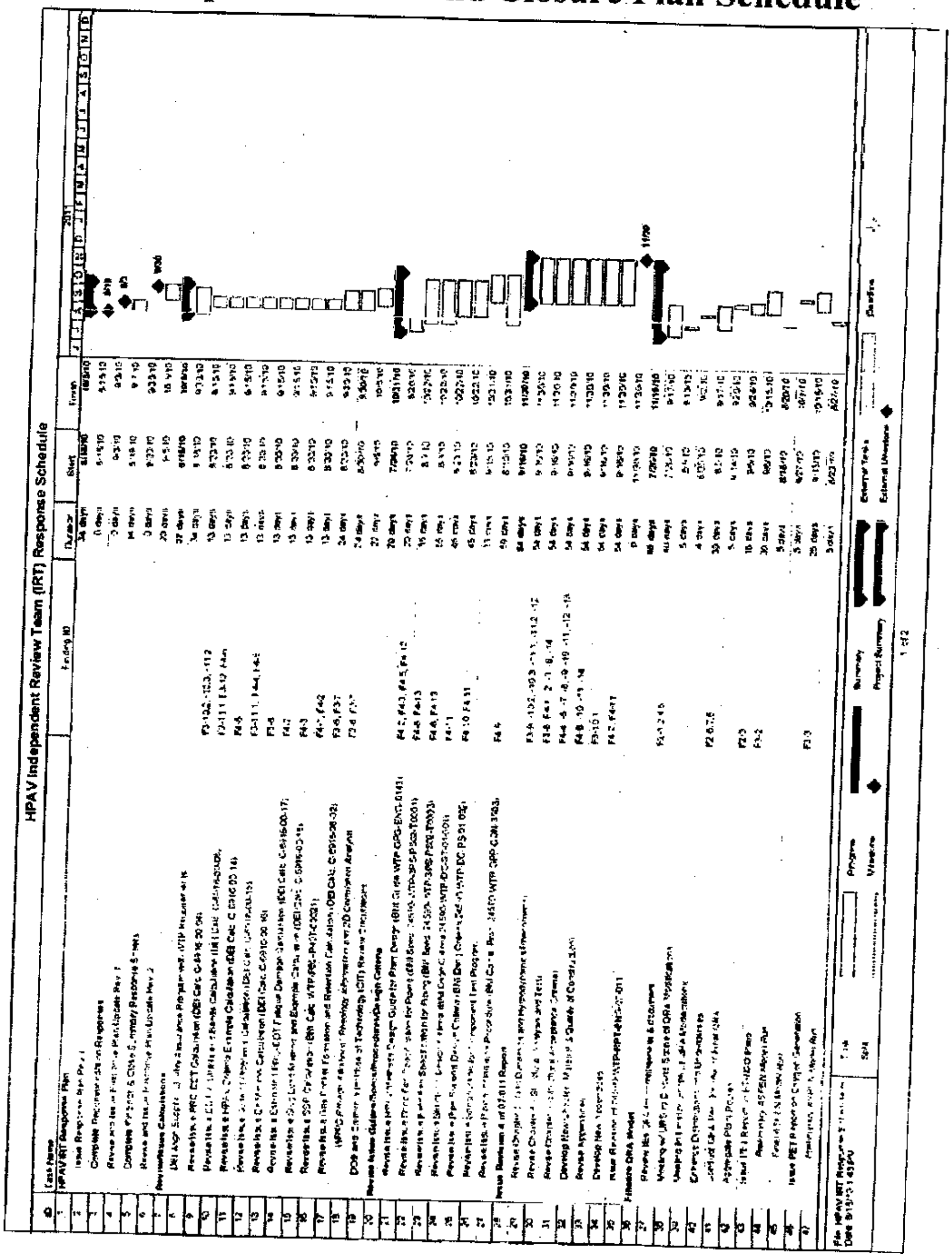
Item	Number	Recommendation
24	R4-4	The testing at SwRI provides actual detonation data in prototypical pipe, and the current state of the pipe is a good indicator of the fatigue resistance to the design events for PTF. BNI should examine the piping tested to provide validation of the fatigue analysis methodology, including thermal skin stresses. (See TR 4-11.)
25	R4-5	Additional justification of the thermal skin stress calculations in ENG 07-011 would improve the confidence level of the fatigue analysis. High rate heat transfer processes are difficult to model, and any additional testing representing the service application would be of great value. Fatigue tests on coupons from the field piping subjected to the detonations would be of value. (See TR 4-11.)
26	R4-6	The fatigue methodology, including damage estimates from testing and the combination of stress needs some clarification. A step-by-step procedure would be helpful. (See TR 4-11.)
27	R4-7	Clarify the discussion on Section 7.22 of ENG 07-011 concerning excluding certain low cycle events in accordance with Section III practice. Since fatigue is a limiting design issue, all significant cycles should be considered and the text revised to so state. (See TR 4-11.)
28	R4-13	The latest edition of ASME PTC 19.3 should be used as a resource in the fatigue evaluation of thermowells in addition to the specified edition. (See TR 4-11.)
29	R4-8	BNI could establish plastic collapse design margins by testing representative piping and components to failure or by analytical calculations to failure or both. (See TR 4-12.)
30	R4-9	A new section should be developed for ENG 07-011 explaining why BNI opted to use pipe bends rather than welded elbows in HPAV piping. Information provided by BNI answers IRT questions and this information needs to be documented in ENG 07-011.
31	R4-10	A new paragraph should be developed for ENG 07-011 Section 7.1.3 discussing use of the modified ASTM testing to qualify the 3D pipe bends for use in the PTF environment. In particular, BNI needs to explain why stress corrosion cracking will not be a concern in HPAV piping (particularly the bend areas) for the 40-year life of the plant.
32	R4-11	All analyses performed for HPAV piping use the steel strength for straight pipe for the entire piping run. In fact, 3D cold worked bends have substantially higher yield strength. This source of conservatism should be acknowledged in ENG 07-011. (See TR 4-6.)
33	R4-14	ENG 07-011 should address the increased potential for stress corrosion cracking in 3D cold worked bends. (See TR 4-6.)
34	R4-12	The information in ENG 07-011 on Dual Certification should be clarified to show that only 304L and 316L stainless steels are used in HPAV piping. (See TR 4-6.)

Item	Number	Recommendation
35	TR 4-6	A number of editorial improvements need to be made in ENG 07-011, including the following: • Clarify on page 7-1 that the first Follansbee reference covering 304/304L stainless steel is also appropriate for 316/316L stainless steel per Ref. 104. • Clarify on page 7-9 that the yield strength value of 22.7 ksi at 150F applies only to 304L and 316L stainless steel and the source of that information is ASME B&PV Code Section II, Part D, Table Y-1. • Clarify on page 7-20 the "Reference 7.4.c" associated with modulus of elasticity and mean coefficient of thermal expansion really comes from Ref. 107 (in ENG 07-011). • Clarify on page 7-32 that 35% is a Code minimum elongation, rather than a "typical minimum." In addition, it would be appropriate to state that as-received 304/304L stainless steel will show elongations well above the 35% minimum value. • On page 7-4 of ENG 07-011 where corrosion allowances are discussed, there needs to be a better explanation of the relationship between what is in Ref. 138, "Preparation of Corrosion Evaluations" by S. Vail, and what is described in ENG 07-011.
36	R4-15	Where available, modal survey results from swept sine testing should be used in preference to impact hammer test results for "benchmarking" analyses using the SwRI SSR global piping responses. As for any empirical approach to experimental investigation, care should be taken in extrapolating the results beyond the bounds of parameters investigated. (See TR 4-15.)
37	R4-16	Possible applications of future modal testing include: 1) Modal surveys of the installed PTF piping could be a useful diagnostic tool if operational vibrations are evident under comprehensive testing during commissioning; and 2) Modal surveys could be used as part of the process for qualification of HPAV in-line mechanical equipment (valves, etc). (See TR 4-15.)
38	TR 4-13.1	As the proposed qualification procedure is based primarily on an empirical approach to validation, care should be taken in extrapolating the results beyond the bounds of parameters investigated. If further analyses result in better correlations with test results for those cases where correlation is not good at the present time, then use of the updated models may allow reductions in conservative assumptions.
39	TR 4-13.2	Certain test specimens (short runs of pipe) have experienced multiple explosions. Material testing of available test pipe samples should be conducted to assess material degradation. Documenting the history of these explosions in the vicinity of the samples could provide useful "proof test" information.

Appendix C

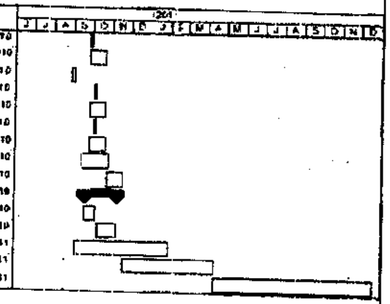
HPAV Implementation and Closure Plan Schedule

Appendix C
HPAV Implementation and Closure Plan Schedule



HPAV Independent Review Team (IRT) Response Schedule

ID	Task Name	Finding ID	Duration	Start	Finish
48	Final ASPEN Model Run		5 days	9/27/10	10/1/10
49	Issue PET Report on Nitrogen Generator	F3-4	20 days	9/27/10	10/27/10
50	Preliminary ASPEN Model Run		5 days	8/26/10	8/31/10
51	Final ASPEN Model Run		5 days	10/4/10	10/8/10
52	Revise HGR Calc	F3-5	20 days	9/27/10	10/22/10
53	Final ASPEN Model Run		5 days	10/4/10	10/8/10
54	Revise Gamma Loss Calc		20 days	9/27/10	10/22/10
55	Update logic with Dominos and DDT Run-up	F3-8, 9	30 days	9/16/10	10/27/10
56	Revise HPAV HGR Calc		20 days	10/26/10	11/18/10
57	Issue Revision 2 of the QRA Report		37 days	9/20/10	11/9/10
58	Enhance Distributions and Uncertainties	F2-6 7 8	15 days	9/20/10	10/8/10
59	Issue Revision 2 of the QRA Report (24590-WTP-RPT-ENG-10-005)		22 days	10/11/10	11/9/10
60	V&V QRA Model		106 days	9/6/10	1/31/11
61	Issue Committed HPAV Calculations		101 days	11/22/10	4/13/11
62	Issue Confirmed HPAV Calculations		180 days	4/14/11	12/21/11



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Date: 6/16/10 1:41 PM

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

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Appendix D

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

Appendix D
Responses to Peer Review of Waste Treatment Plant Quantitative Risk Assessment of Hydrogen Events in Piping and Vessels

1 Background / Introduction

This Appendix provides initial responses to the four primary recommendations identified in the DOE Peer Review Team report (*Peer Review of Waste Treatment Plant Quantitative Risk Assessment of Hydrogen Events in Piping and Vessels*, May 28, 2010) regarding the Hanford Waste Treatment Plant (WTP) Quantitative Risk Assessment (QRA) model for hydrogen events in piping.

Below are responses to four primary PRT recommendations. Responses or clarifications to other items in the PRT report that were not identified as recommendations will also be addressed. The initial responses to those items were included as Appendix B of the PRT report. Some of those earlier responses will be revised based on the HPAV IRT Findings and will be revised appropriately in conjunction with the Finding resolutions.

2 Primary Recommendation and Responses

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

A. 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.

<u>BNI Response</u>:

- 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 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.

B. 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 of 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.

<u>BNI Response</u>:
A detailed sensitivity analysis will be 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.

C. 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.

BNI Response:
At the time of the PRT review, some of the QRA model inputs had not been finalized. 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.

D. 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.

BNI Response:
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 a comprehensive report following completion of the latest model modifications based on HPAV IRT recommendations.

Appendix E

HPAV Independent Review Team Finding Summary Response Sheet

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HPAV Independent Review Team Finding Summary Response Sheet

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HPAV IRT Finding Number:	SRS No.	Rev.
Finding Description:		
Response Provided by	Phone	Date
Detailed Finding Response (attach additional pages as necessary)		
Documents Affected (list all documents affected by this Finding Response):		
Document	**Section Affected**	**Attachments**

Response Approved by (BNI)	Print type name	Signature	Date
Response Approved by (HPAV IRT)	Print type name	Signature	Date
HPAV IRT Finding Summary Response Sheet Closed			Date
HPAV Project Engineer	Print type name	Signature	Date

Department of Energy
Washington, DC 20585

AUG 2 5 2010

MEMORANDUM FOR DALE E. KNUTSON
FEDERAL PROJECT DIRECTOR
WASTE TREATMENT PLANT

FROM: DR. STEVEN L. KRAHN
DEPUTY ASSISTANT SECRETARY FOR
SAFETY AND SECURITY PROGRAM
ENVIRONMENTAL MANAGEMENT

SUBJECT: Review of Hydrogen on Piping and Ancillary Vessels Implementation and Closure Plan

In your memorandum dated August 20, 2010, you requested Environmental Management (EM) review of the subject plan, which presently addresses the findings of the Hydrogen on Piping and Ancillary Vessels (HPAV) Independent Review Team (IRT). It is noted that the IRT differentiated between its findings and recommendations; their report stated, "The IRT has differentiated between its Findings and Recommendations. Findings are things that must be done… if the new design approach is to meet its objectives and satisfy the safety and mission requirements of the piping and components… Recommendations are discretionary opportunities for improvement…" Thus, the subject plan logically focused on addressing findings first. The initial monthly revision of the plan will expand its coverage to address the recommendations of the HPAV IRT.

I have reviewed the structure, process and content of the subject plan and concur with it, subject to the following comment:

> It is my understanding, developed in several conversations with your staff and your contractor, Bechtel National Incorporated, that the Waste Treatment Plant (WTP) Quantitative Risk Analysis (QRA) is not used in the DOE-STD-3009 safety analysis process for either the unmitigated event consequence (which assumes piping system failure) nor in the mitigated analyses that rely upon secondary confinement (C5 cells and HVAC with HEPA filtration). Instead, the WTP QRA supports implementation of the design code, (ASME B31.3) for unconventional loads that may be imposed by combustion events within piping systems. Its use for that purpose is governed by the project's Safety Requirements Document (SRD).
>
> Subject to the SRD requirements, the QRA was approved as suitable for that purpose and accepted by Department of Energy (DOE)-Office of River Protection (ORP) in February 15, 2010. Use of the HPAV QRA as a code implementation tool was reviewed and determined to be acceptable by the HPAV IRT in their July 12, 2010, report, subject to several findings.

However, questions have been raised occasionally regarding the relationship of the QRA to STD-DOE-3009, and this has not been clearly discussed and documented in DOE–ORP and project technical documents. DOE-ORP should clearly define and document the role of the QRA relative to STD-3009 and provide this information to EM for review.

I look forward to continuing to work with you and your project team on issues of safety significance. If you have any further questions, please contact me at (202) 586-5151.

cc: I. Triay, EM-1
D. Chung, EM-2
M. Gilbertson, EM-3 (Acting)
G. Riner, EM-10 (Acting)