MITSUBISHI HEAVY INDUSTRIES, LTD.
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TOKYO, JAPAN

December 15, 2010

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffery A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-10335

Subject: MHI's Responses to US-APWR DCD RAI No. 636-4732 (SRP 03.06.02)

Reference: 1) "Request for Additional Information No. 636-4732 Revision 0, SRP Section: 03.06.02 – Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping, Application Section: 3.6.2," dated 9/23/2010.
2) "MHI's Responses to US-APWR DCD RAI No. 636-4732," UAP-HF-10319, dated 11/24/2010.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Responses to Request for Additional Information No. 636-4732, Revision 0."

Enclosed are the revised responses to RAI 636-4732, Questions 40-48 that are contained within Reference 1. These revised responses were prepared to reflect the discussion results at the conference call with NRC held on December 1.

As indicated in the enclosed materials, this document contains information that MHI considers proprietary, and therefore should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential. A non-proprietary version of the document is also being submitted with the information identified as proprietary redacted and replaced by the designation "[ ]".

This letter includes a copy of the proprietary version (Enclosure 2), a copy of the non-proprietary version (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all materials designated as "Proprietary" in Enclosure 2 be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

D081
NRD

Sincerely,

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosures:

1. Affidavit of Yoshiki Ogata

2. Responses to Request for Additional Information No. 636-4732, Revision 0 (Proprietary)

3. Responses to Request for Additional Information No. 636-4732, Revision 0 (Non-Proprietary)

CC: J. A. Ciocco
C. K. Paulson

Contact Information
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Enclosure 1

Docket No. 52-021
MHI Ref: UAP-HF-10335

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, state as follows:

1. I am General Manager, APWR Promoting Department, of Mitsubishi Heavy Industries, LTD ("MHI"), and have been delegated the function of reviewing MHI's US-APWR documentation to determine whether it contains information that should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential.

2. In accordance with my responsibilities, I have reviewed the enclosed document entitled "Responses to Request for Additional Information No. 636-4732, Revision 0," and have determined that portions of the document contain proprietary information that should be withheld from public disclosure. All pages contain proprietary information as identified with the label "Proprietary" on the top of the page, and the proprietary information has been bracketed with an open and closed bracket as shown here "[ ]". The first page of the document indicates that all information identified as "Proprietary" should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

3. The information identified as proprietary in the enclosed documents has in the past been, and will continue to be, held in confidence by MHI and its disclosure outside the company is limited to regulatory bodies, customers and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and is always subject to suitable measures to protect it from unauthorized use or disclosure.

4. The basis for holding the referenced information confidential is that it describes the unique design and methodology developed by MHI for performing the plant design of protection against postulated piping failures.

5. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of information to the NRC staff.

6. The referenced information is not available in public sources and could not be gathered readily from other publicly available information. Other than through the provisions in paragraph 3 above, MHI knows of no way the information could be lawfully acquired by organizations or individuals outside of MHI.

7. Public disclosure of the referenced information would assist competitors of MHI in their design of new nuclear power plants without incurring the costs or risks associated with the design of the subject systems. Therefore, disclosure of the information contained in the referenced document would have the following negative impacts on the competitive position of MHI in the U.S. nuclear plant market:

A. Loss of competitive advantage due to the costs associated with the development of the methodology related to the analysis.

B. Loss of competitive advantage of the US-APWR created by the benefits of the approach to jet expansion modeling that maintains the desired level of conservatism.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information and belief.

Executed on this 15th day of December, 2010.

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure 3

UAP-HF-10335
Docket No. 52-021

Responses to Request for Additional Information No. 636-4732, Revision 0

December, 2010
(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: NO. 636-4732 REVISION 0

SRP SECTION: 03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING

APPLICATION SECTION: 3.6.2

DATE OF RAI ISSUE: 09/23/2010

QUESTION NO. : 03.06.02-40

Follow-up RAI 03.06.02-10 S02

This is the supplemental RAI for RAI 71-986, 03.06.02-10 and RAI 459-3331, 03.06.02-29

In its response to the staff's RAI, the applicant continues to assert that the pressures induced by blast waves on surrounding structures in US-APWR plants will be negligible. In its justification, the applicant ignores the effects of surrounding structures and walls, and the pressure wave reflections they would cause. The applicant also assumed that the blast wave loading time history is a step function, rising from ambient pressure to a peak pressure and remaining at the peak pressure indefinitely. In actuality, blast wave pressure time histories will peak, and then decrease. More importantly, this is generally followed by shock reflections, pressure increases and subsequent expansions, often to pressures below ambient pressure. The applicant also considers only barrier structures, and resonance frequencies below 50 Hz, in their response. The applicant is advised that the staff is concerned about not only barrier structures, but other structures, and safety-related components and systems. The staff is also concerned about all structural resonances which could be strongly excited by blast waves, not only the fundamental modes. The applicant is requested again to provide a rigorous explanation of appropriate and conservative blast wave estimating procedures to be applied to the USAPWR design and to document those procedures in a revised version of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 439-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

Impact on DCD

See Attachment 3 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Add the following subsection at the end of DCD Subsection 3.6.2.4.1:

"3.6.2.4.1.1 Blast Wave Assessing Procedure

Computational Fluid Dynamics (CFD) analysis confirms generation of blast wave from a steam pipe break. Potential effects are assessed on equipment within US-APWR pressurizer compartment. Distance between postulated pipe break locations and components is long enough to attenuate effects. However, if layout in the pressurizer compartment is changed in future, reassessment of blast wave will be conducted.

Blast wave is not considered to occur from sub-cooled water pipe break. This is because velocity of the two-phase flow at break point is slower than speed of sound in atmospheric environments.

Therefore, blast wave does not impact on design. Detailed blast wave assessing procedure is provided in Reference 3.6-32."

- Add the following at the end of DCD Subsection 3.6.5:

"3.6-32 MUAP-10022 Revision 0 "Evaluation on Jet Impingement Issues Associated with Postulated Pipe Rupture."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-41

Follow-up RAI 03.06.02-11(a) S02

This is the supplemental RAI for RAI 71-986, 03.06.02-11(a) and RAI 459-3331, 03.06.02-30

In its response to the staff's RAI, the applicant continues to use ANS 58.2 to assess jet impingement loading on US-APWR structures and components. It should be noted that several inaccuracies in the ANS 58.2 Standard are identified and the Standard is no longer considered universally acceptable for jet impingement loading evaluation by the staff. Although the applicant cites several papers that contain experimental data from tests conducted in Japan, it does not appear that the applicant uses those data to define their jet impingement loads, nor to justify using ANS 58.2 methodology/procedures. The applicant is therefore requested again to substantiate that the use of ANS 58.2 methodology/procedures in US-APWR application is conservative. The applicant may submit different procedures (perhaps using the measurements cited in MHI references 1-6), along with substantiation that those procedures are conservative.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

The jet geometry evaluation is performed with MHI methods while thrust force evaluation is based on ANS 58.2. This clarification will be reflected in Revision 3 of the DCD.

Impact on DCD

See Attachment 3 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- The 2nd paragraph in DCD Subsection 3.6.2.3 will be modified as follows:

  "The analytical methods used for the calculation of the jet thrust for the above described situations are based on SRP 3.6.2 (Reference 3.6-3) and MHI original methodologies based on measurements cited in References 3.6-25, 3.6-26, 3.6-27, 3.6-28, 3.6-29 and 3.6-30."

- The 3rd paragraph in DCD Subsection 3.6.2.4.1 will be modified as follows:

  "The MHI original methodologies (Reference 3.6-25) used to evaluate the jet effects resulting from the postulated breaks in high energy piping are based on measurements cited in References 3.6-26, 3.6-27, 3.6-28, 3.6-29, 3.6-30 and 3.6-31. Figure 3.6-2 depicts jet characteristics for the three fluid states. The short term response evaluates the jet impingement load considering a dynamic load factor of 2 and snubber supports to be active. No dynamic load factor is used and the snubbers are considered inactive for the long-term response."

- Add the following at the end of DCD Subsection 3.6.5:

  "3.6-25 MUAP-10017 Revision 1 "US-APWR Methodology of Pipe Break Hazard Analysis"

  3.6-26 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Study of Pipe Reaction Force and Jet Impingement Load at the Pipe Break, Trans. 5th Int. Conf. on SMiRT, F6/2, 1979.

  3.6-27 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Studies on Transient Water-Steam Impinging Jet, Vol. 22 No. 5, pp. 403-409, Journal of Atomic Energy Society of Japan, 1980 (in Japanese).

  3.6-28 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Studies on Steam Free Jet and Impinging Jet, Vol. 22 No. 9, pp. 634-640, Journal of Atomic Energy Society of Japan, 1980 (in Japanese).

  3.6-29 Masuda, F., Nakatogawa, T., Kawanishi, K. and Isono, M., Experimental Study on an Impingement High-Pressure Steam Jet, Nuclear Engineering and Design 67-2, pgs 273-285, 1982.

  3.6-30 Masuda, F., Nakatogawa, T., Kawanishi, K. and Isono, M., Experimental Study on Jets Formed Under Discharges of High-Pressure Subcooled

Water and Steam-Water Mixture, Trans. 7th Int. Conf. on SMiRT, F1/6, 1983.

3.6-31 Isozaki, T. and Miyazono, S., Experimental Study of Jet Discharging Test Results under BWR and PWR Loss of Coolant Accident Conditions, Nuclear Engineering and Design 96, 1986."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-42

Follow-up RAI 03.06.02-12(a) S02

This is the supplemental RAI for RAI 71-986, 03.06.02-12(a) and RAI 459-3331, 03.06.02-31

In its response to RAI 459-3331, 03.06.02-31, the applicant agrees that the pressure distribution is non-uniform. The applicant also states that it will uniformly use the maximum pressure in their non-uniform pressure distribution, which is conservative. However, the applicant did not include this commitment in a revision to the DCD. The applicant is requested to document their commitment to use the maximum pressure in its assumed uniform pressure distribution in a revised version of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

The 2nd paragraph of DCD Subsection 3.6.2.4.1 will be modified in Revision 3 of the DCD to use the maximum pressure as an assumed uniform pressure distribution.

Impact on DCD

See Attachment 3 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Add the following at end of the 2nd paragraph of DCD Subsection 3.6.2.4.1:

  "The Jet impingement pressure essentially has non-uniform distributions, which varies with distance from the pipe break as shown in References 3.6-26, 3.6-27, 3.6-28, 3.6-29, 3.6-30 and 3.6-31. However, the maximum pressure in the non-uniform distribution is conservatively used as uniform distribution."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-43

Follow-up RAI 03.06.02-12(b) S02

This is the supplemental RAI for RAI 71-986, 03.06.02-12(b) and RAI 459-3331, 03.06.02-32

In RAI 459-3331, 03.06.02-32, the staff requested the applicant to expand on a table provided by the applicant in its previous RAI response to include all postulated pipe break locations, along with internal and external properties and the analysis approach to be used for the jet impingement load evaluation. In its response to this RAI, the applicant provided the requested table. However, the applicant did not include this table in a revision to the DCD. The applicant is therefore requested to include this table in a revised version of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

Table 3.6-2, providing all postulated pipe break locations, internal and external properties and the analysis approach to be used for the jet impingement load evaluation, will be included in Revision 3 of the DCD.

Impact on DCD

See Attachment 4 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Add the Table 3.6-2, "List of High Energy Lines for Pipe Break Hazard Analysis, Including Properties of Internal and External Fluids," behind Table 3.6-1 in DCD Section 3.6.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-44

Follow-up RAI 03.06.02-13 S02

This is the supplemental RAI for RAI 71-986, 03.06.02-13 and RAI 459-3331, 03.06.02-33

In its response to the staff's RAI, the applicant discounts the possibility of feedback amplification of dynamic jet loads on the grounds that the sound speed within the jet plumes of two-phase flows is much smaller than the sound speed outside the plumes. However, the acoustic waves which cause feedback and the amplification of shed vortices from the pipe break propagate outside the jet plume at the sound speed of the external, quiescent fluid (Ho and Nossier, 1981), and are not strongly affected by the sound speed within the jet plume. Thus, even supersonic jets have similar feedback mechanisms. The applicant is therefore requested to provide a conservative methodology for assessing jet impingement loading at resonant jet conditions. The applicant is also requested to provide a conservative methodology for assessing the effects of jet impingement loading oscillations at non-resonant conditions (without strong feedback amplification), and a methodology for assessing the effects of oscillating jet loads on impinged-upon structures. Furthermore, the applicant is requested to document these methodologies in a revision of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

References

2-1 Masuda, F., Nakatogawa, T., Kawanishi, K. and Isono, M., Experimental Study on an Impingement High-Pressure Steam Jet, Nuclear Engineering and Design 67-2, pgs 273-285, 1982.

2-2 F. S. Alvi, J. A. Ladd, W. W. Bower,"Experimental and Computational Investigation of Supersonic Impinging Jets",AIAA JOURNAL, Vol. 40, No. 4, April 2002

2-3 K. Kitade, T. Nakatogawa, H. Nishikawa, K. Kawanishi, T.Tsuruto, "Free Jet and Jet Impingement of High Pressure Steam" , Journal of Atomic Energy Society of Japan, Vol. 22, No.9, pp634-640. (In Japanese)

2-4 H.Ashkenas and F.S. Sherman, "Rarefied Gas Dynamics, Vol II" , Academic press, New York, pp 84-105, 1966.

2-5 S. I. Kim, S. O. Park, "Oscillatory Behavior of Super Sonic Impinging Jet Flows Shock Waves", 14(4), pp. 259-272, 2005

2-6 C. Y. Loh,"Computation of Tone Noise From Supersonic Jet Impinging on Flat Plates", NASA CR—2005-213426, AIAA–2005–0418 .March,2005

2-7 A. Krothapalli, E. Rajkuperan, F. Alvi, L.Lourenco, "Flow field and noise characteristics of a supersonic impinging jet", J.Fluid Mech.(1999), vol.392, pp.155-181, 1999

2-8 B. Henderson, "An Experimental Investigation into the Sound Producing Characteristics of Supersonic Impinging Jets", AIAA Paper 2001-2145, 2001

2-9 T. Yasunobu, T. Matsuoka, M. Tagami, "Pressure Fluctuation on Self Induce Flow Oscillation Caused by Under-Expanded Super Sonic Impinging Jet", The japan Society of Mechanical Enjineers,No.028-1,pp.141-142, 2002

2-10 J A. (Wilkes) Inman, P M. Danehy, R J. Nowak, and D W. Alderfer, "Fluorescence Imaging Study of Impinging Underexpanded Jets", Extended abstract to be submitted to:46th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 7-10 January 2008

2-11 Okada, H. and Minato, A., the Japan Nuclear Energy Safety (JNES) paper titled "Application of Compressible Two-Fluid Mode Code to Supersonic Two-Phase Jet Flow Analysis", The 13th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-13) N13P1368 Kanazawa City, Ishikawa Prefecture, Japan, September 27-October 2, 2009.

2-12 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Study of Pipe Reaction Force and Jet Impingement Load at the Pipe Break, Trans. 5th Int. Conf. on SMiRT, F6/2, 1979.

Impact on DCD

See Attachment 3 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Add the following subsection at the end of DCD Subsection 3.6.2.4.1.1:

"3.6.2.4.1.2 Jet Pressure Oscillation Assessing Procedure

Jet pressure oscillation from a steam pipe break is unlikely to occur in high compression ratio like US-APWR. Jet flow expansion is large and Mach Disk is large. This leads the stable downstream after Mach Disk. The flow is so stable that disturbance at impingement wall does not reach back to Mach Disk.

When sub-cooled jet-flow impinges on wall, pressure distributions on wall are not concave type and re-circulation vortex is not generated. It is because flow velocity at jet boundary is lower than that of core region.

Therefore, jet pressure oscillation does not impact on design. Detailed jet pressure oscillation assessing procedure is provided in Reference 3.6-32."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-45

Follow-up RAI 03.06.02-14 S02

This is the supplemental RAI for RAI 71-986, 03.06.02-14 and RAI 459-3331, 03.06.02-34

In its response to the staff's RAI, the applicant stated that jet reflection effects would be "assessed considering the changes in direction and expansion with decaying by distance." This response is vague, and does not constitute a substantiated, conservative approach for assessing the effects of jet reflections. Also, the applicant has not documented an approach for jet reflection assessment in a revision of the DCD.
The applicant is therefore requested to provide a jet reflection assessment approach and to document it in a DCD revision.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

Reference:

3-1 N. Rajaratonam, TUBULENT JETS, Elsevier Scientific Publishing Company, Amsterdam,1976

Impact on DCD

See Attachment 3 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Add the following subsection at the end of DCD Subsection 3.6.2.4.1.2:

"3.6.2.4.1.3 Jet Reflection Assessing Procedure

When jet flow impinges on perpendicular wall, impinged jet flow is redirected and runs along surface of wall. Zone of influence (ZOI) obtained by CFD is enveloped by estimated ZOI from MHI original methodologies (Reference 3.6-25). Inside of ZOI, impingement pressure includes effect of pressure due to flow parallel to impingement wall. Loads due to jet impingement reflection outside of ZOI are considered so small that it is not necessary to be considered.

Therefore, jet reflection does not impact on design. Detailed jet reflection assessing procedure is provided in Reference 3.6-32."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-46

Follow-up RAI 03.06.02-15 S02

This is the supplemental RAI for RAI 71-986, 03.06.02-15 and RAI 459-3331, 03.06.02-35

In its response to the staff's RAI, the applicant references the response to RAI 03.06.02-28. In that response, the applicant discounts the possibility of feedback amplification of dynamic jet loads on the grounds that the sound speed within the jet plumes of two-phase flows is much smaller than the sound speed outside the plumes. However, the acoustic waves which cause feedback and the amplification of shed vortices from the pipe break propagate outside the jet plume at the sound speed of the external, quiescent fluid (Ho and Nossier, 1981), and are not strongly affected by the sound speed within the jet plume. The applicant is therefore requested to provide a conservative methodology for assessing jet impingement loading on shields and barriers at resonant jet conditions and to document the methodology in a revision of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08258; dated November 7, 2008; ML083180225.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

ANSWER:

Refer to the answer the RAI question No. 03.06.02-44.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-47

Follow-up RAI 03.06.02-6 S01

This is the supplemental RAI for RAI 71-986, 03.06.02-6

In its response to the staff's RAI, the applicant stated that the BTP 3-4, Part B, Item B(iii)(1)(b) criterion will be added to Revision 2 of USAPWR DCD Subsection 3.6.2.1.2.2. The staff reviewed this subsection of Revision 2 of DCD and found that the information in the DCD is not consistent with the BTP requirement. Specifically, it should state that leakage cracks are postulated for ASME Code, Section III, Class 1 piping systems, where the stress range calculated by Eq. (10) in NB-3653 is more than (as opposed to "less than" as stated in DCD) 1.2 Sm. The applicant is therefore requested to make this correction in the next revision of the DCD.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08226; dated October 7, 2008; ML082840135.

ANSWER:

The phrase "less than" in the first bullet of the first paragraph of DCD Subsection 3.6.2.1.2.2 will be corrected to "more than" in Revision 3 of the DCD.

Impact on DCD

See Attachment 5 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- Change the first bullet of the first paragraph of DCD Subsection 3.6.2.1.2.2 to:

  "For ASME Code, Section III, Class 1 piping, where the stress range calculated by Eq. (10) in NB-3653 is more than 1.2 S(m)"

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/15/2010

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No.52-021

RAI NO.: **NO. 636-4732 REVISION 0**

SRP SECTION: **03.06.02 - DETERMINATION OF RUPTURE LOCATIONS AND DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING**

APPLICATION SECTION: **3.6.2**

DATE OF RAI ISSUE: **09/23/2010**

QUESTION NO. : 03.06.02-48

Follow-up RAI 03.06.02-39 S01

This is the supplemental RAI for RAI 71-986, 03.06.02-18 and RAI 459-3331, 03.06.02-39

The applicant did not adequately address the staff's concerns included in RAI 459-3331, 03.06.02-39. In that RAI, the applicant was requested to include a description in DCD Tier 2 Section 3.6.2 that clearly outlines the information that will be included in the pipe break hazard analysis report along with its (as-design aspect) closure milestone. The applicant was also requested to clarify that pipe break hazard analysis will be performed for all the piping systems (including the non-safety class piping) that are within the scope of SRP Section 3.6.2.

In its RAI response, the applicant provides a list of information under a proposed new DCD Section 3.6.2.6, Pipe Break Hazard Analysis Methodology. However, the staff found that the title of that DCD subsection, "Pipe Break Hazard Analysis Methodology", is not consistent with the content of that subsection. Specifically, DCD Section 3.6.2.6 outlines the information that will be included in the pipe break hazard analysis report rather than pipe break hazard analysis methodology. In addition, the third bullet, identification of SSCs that are safety-related or required for safe shutdown, included in that list of information needs clarification that for each postulated pipe break/crack location, the applicant will identify (in the pipe break hazard analysis report) all the safety-related or required for safe shutdown that are in close proximity to the postulated pipe rupture. Furthermore, the applicant is again requested to clarify that pipe break hazard analysis will be performed for all the piping systems (including the non-safety class piping) that are within the scope of SRP Section 3.6.2. The applicant is requested to address these staff's concerns.

In its RAI response, the applicant proposed some changes to DCD Tier 1, Section 2.3. Specifically, the applicant proposed changes to Items 4 and 5 in Table 2.3-2 to include both as-designed and as-built aspects of pipe break hazard analysis. However, the applicant referred to "reports" for both aspects of the pipe break hazard analysis report. It does not make it clear that both as-designed and as-built pipe break analysis will contain all the information as outlined in DCD Tier 2 Section 3.6.2.6. As a minimum, the title of Section 3.6.2.6 (after it is revised to address the staff's concern identified in the second paragraph of this RAI) should be used in the ITAAC table. In addition, the ITAAC should make clear that Item 4 is for the as-designed plant while Item 5 is for the as-built reconciliation respectively and for both aspects, the pipe break hazard analysis performed will be clearly documented in the pipe break hazard analysis report. Furthermore, both DCD Section 3.6.2.6 and ITAAC Table 2.3-2 need to make it clear that pipe break hazard analysis will be performed for all the piping systems (including the non-safety class piping) that are within the scope of SRP Section 3.6.2. Finally, the current description of design commitment and acceptance criteria for the as-built aspect of pipe break hazard analysis is not clear. It needs to make it clear that the as-built pipe break analysis is to be reconciled with the as-designed pipe break hazard analysis. Also, the as-built pipe break analysis is to be performed for both high energy and moderate energy piping to ensure that the as-built safety related SSCs are appropriately protected against or qualified to withstand the dynamic and the environmental effects associated with postulated failures for all the piping systems (including the non-safety class piping) that are within the scope of SRP Section 3.6.2. The applicant is requested to address these staff's concerns.

Lastly, the applicant did not clearly address staff's concern concerning the closure milestone for as-designed pipe break hazard analysis report. The applicant is requested to clarify whether the MHI's design completion plan as described in UAP-HF-08123 is still valid. Also, in that plan, the applicant did not include the completion schedule for all the piping systems (including the non-safety class piping) that are within the scope of SRP Section 3.6.2.

References:

MHI's Response to US-APWR DCD RAI No. 71-986; MHI Ref: UAP-HF-08226; dated October 7, 2008; ML082840135.

MHI's Responses to US-APWR DCD RAI No. 459-3331; MHI Ref: UAP-HF-09542; dated December 1, 2009; ML093370091.

Additional Information for Design Completion Plan of US-APWR Piping Systems and Components; MHI Ref: UAP-HF-08123; dated July 14, 2008; ML082030589.

ANSWER:

- Subsection Title

MHI will correct the title of Subsection 3.6.2.6 to "Outline of Pipe Break Hazard Analysis Reports" in Revision 3 of the DCD.

- Identification of SSCs

MHI identifies in the pipe break hazard analysis report all the safety-related components or components required for safe shutdown that are in close proximity to the pipe rupture. This clarification will be added to the third bullet in Subsection 3.6.2.6 in Revision 3 of the DCD.

- Pipe Break Hazard Analysis for All Piping Systems

MHI will clarify in Revision 3 of DCD Subsection 3.6.2.6 and Tier 1 ITAAC, Table 2.3-2, that pipe-break hazard analyses are performed on all piping systems (including the non-safety class piping).

- Analysis Report

MHI will prepare the "as-designed pipe-break analysis report" and "as-built pipe-break analysis report" to contain all the information as outlined in DCD Tier 2, Subsection 3.6.2.6. This clarification will be included in Subsection 3.6.2.6 in Revision 3 of the DCD.

- Moderate Energy Piping

MHI will clarify in Revision 3 of DCD Tier 1 ITAAC, Table 2.3-2, that the as-built pipe break analysis is to be performed for both high energy and moderate energy piping.

- Milestone

The design completion plan described in UAP-HF-08123 is not valid. The updated design completion plan was provided in MHI Letter UAP-HF-10207.

The completion schedule for all piping systems, including the non-safety class piping, that are within the scope of SRP Section 3.6.2, is completed prior to material procurement.

Impact on DCD

See Attachment 6 for the mark-up of DCD Tier 2, Section 3.6, changes to be incorporated:

- The DCD Subsection 3.6.2.6 will be added as follows:

"**3.6.2.6 Outline of Pipe Break Hazard Analysis Report(s)**

The following information is outline of methodology for the pipe break hazard analysis that will be completed for all the piping systems (including the non-safety class piping) in accordance with closure of Inspections, Tests, Analyses and Acceptance Criteria (ITAAC) Tier 1, Table 2.3-2 related to pipe break hazard analysis report:

- Identification of pipe break locations in high energy piping[1]

- Identification of leakage crack locations in high and moderate energy piping
- Identification of SSCs that are safety-related or required for safe shutdown[2]
- Evaluation of consequences of pipe whip and jet impingement
- Evaluation of consequences of spray wetting, flooding, environmental conditions
- Design and location of protective barriers, restraints, and enclosures

Notes

1. Table 3.6-2 shows the list of high energy lines for pipe break hazard analysis, including properties of internal and external fluids.
2. All the SSCs that are safety-related or required for safe shutdown in close proximity to the postulated pipe rupture will be identified."

- The DCD Tier 1 ITAAC, Table 2.3-2 will be modified as follows:

Table 2.3-2 Piping Systems and Components Inspections, Tests, Analyses, and Acceptance Criteria (Sheet 2 of 2)

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
4. Safety-related SSCs are designed to be protected against or qualified to withstand the dynamic and environmental effects associated with analyses of postulated failures for all the piping systems (including the non-safety class piping).	4.i Dynamic effect analysis will be performed for the high-energy piping system. The analysis includes the evaluation of pipe whip and jet impingement.	4.i Pipe break hazard analysis report(s) for all high-energy piping system exist and conclude that for each postulated piping failure, the reactor can be shut down safely and maintained in a safe, cold shutdown condition without offsite power. The report confirms whether: (A) piping stresses in the containment penetration area are within allowable stress limits, (B) pipe whip restraints and jet shield designs can mitigate pipe break loads, and (C) loads on safety-related SSCs are within design load limits.
	4.ii Environmental effect analysis will be performed for the high-energy piping and moderate-energy piping systems. The analysis includes the evaluation for spray wetting, flooding, and environmental conditions, as appropriate.	4.ii Pipe break hazard analysis report(s) for all high-energy piping and moderate-energy piping systems exist and conclude that for each postulated piping failure, the reactor can be shut down safely and maintained in a safe, cold shutdown condition without offsite power. The report confirms whether SSCs are protected or qualified to withstand the environmental effects of postulated failures.
5. Safety-related SSCs are reconciled with the analyses results of as-designed pipe break hazard analysis report(s).	5. A reconciliation analysis of the as-built high-energy piping and moderate-energy piping using as-designed pipe break hazard analysis report(s) and as-built information will be performed.	5. Pipe break hazard analysis report(s) exist and conclude that the as-built high-energy piping systems including the protective features and moderate-energy piping systems are installed in the as-built plant as described in the as-designed pipe break hazard analysis report(s).

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

This completes MHI's responses to the NRC's questions.

ATTACHMENT 1
to RAI 636-4732

March 31, 2010

Mr. Anthony Nowinowski, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: NUCLEAR REGULATORY COMMISSION CONCLUSIONS REGARDING PRESSURIZED WATER REACTOR OWNERS GROUP RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION DATED JANUARY 25, 2010 REGARDING LICENSEE DEBRIS GENERATION ASSUMPTIONS FOR GSI-191

Dear Mr. Nowinowski:

As you are aware, the U.S. Nuclear Regulatory Commission (NRC) staff had questions regarding certain assumptions that some licensees have made regarding the generation of debris following a design basis accident. These questions were based on staff review of two industry technical reports referenced by some licensees in submittals to the NRC: WCAP-16710-P, Revision 0, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) of Min-K and NUKON® Insulation for Wolf Creek and Callaway Nuclear Operating Plants," and WCAP-16851-P, Revision 0, "Florida Power and Light (FPL) Jet Impingement Testing of Cal-Sil Insulation." The reports documented jet impingement testing performed at Wyle Laboratories, and were intended to justify a reduced ZOI (volume around a hypothetical reactor coolant system break within which insulation could be damaged and potentially travel to the emergency core cooling system strainer following a loss-of-coolant accident). During a teleconference on February 20, 2009 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML090570671), the Pressurized Water Reactor Owners Group (PWROG), on behalf of affected licensees, requested that the NRC staff's questions regarding these technical reports be resolved generically through the PWROG to the extent feasible. Based on this request, the NRC staff discussed questions regarding the technical reports with the PWROG during the teleconference. Additional detailed technical discussions with the PWROG have been ongoing since February 2009.

As a result of NRC staff questions, on December 11, 2009, Westinghouse identified several locations in the Wyle test loop where the inside diameter of the piping was significantly smaller than the nozzle. For example, the nozzle size used to calculate the jet pressures at most of the jet impingement targets was 3.54 inches in diameter; however the smallest piping diameter was 2.313 inches and was located approximately 26 inches upstream of the nozzle exit. In addition, on February 12, 2010, Westinghouse submitted a letter to the NRC (ADAMS ML100480138) that concluded the following reports had the same or similar small diameter locations upstream of the test nozzle:

- WCAP-16568-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings"

- WCAP-16720-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOIs) for Diablo Canyon Power Plant"
- WCAP-16727-NP, "Evaluation of Jet Impingement and High Temperature Soak Tests of Lead Blankets for Use Inside Containment of Westinghouse Pressurized Water Reactors"
- WCAP-16783-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) of Min-K and 3M® Fire Barrier Insulation for Watts Bar Nuclear Plant"
- WCAP-16836-P, "Arkansas Nuclear One – Jet Impingement Testing of Insulating Materials"

During a public meeting between NRC staff and the PWROG on December 16, 2009, the PWROG agreed to formally respond to the NRC staff concerns regarding the technical reports by March 1, 2010. To facilitate this response, the NRC staff sent a request for additional information (RAI) to the PWROG via letter dated January 25, 2010 (ADAMS ML100060467). The PWROG responded to the RAI via letter dated March 5, 2010 (ADAMS ML100710710). The NRC staff has reviewed the PWROG RAI responses. The purpose of this letter is to transmit the NRC staff's conclusions regarding WCAP-16710-P, WCAP-16851-P, and similar technical reports as listed above.

The NRC staff has concluded that the small diameter locations upstream of the test nozzle constitute significant test design errors, and, absent substantial additional information, render all recommended ZOIs in similar test reports invalid. The NRC staff notes that empirically derived damage pressures (i.e. measured) may be obtained for a target centerline through testing and subsequently used as an input to the American National Standard Institute/American Nuclear Society (ANSI/ANS) 58.2-1988 model for calculating a ZOI. This approach, as long as appropriate test scaling is considered for jacketed insulation, is consistent with the staff safety evaluation (SE) of Nuclear Energy Institute (NEI) guidance report 04-07, "Pressurized Water Reactor Sump Performance Methodology" (ADAMS ML043280007).

While the NRC staff has concluded that the test report ZOIs are not valid based on the available information, the PWROG has resolved some of the staff's RAI questions. A discussion of the PWROG responses to the RAIs, and the NRC staff's conclusions regarding the status of each issue identified in the RAI letter, are provided below.

<u>Issue 1 - Resolved</u>

This issue refers to the potential for formation of a damaging blast wave. Based on the technical references reviewed by the staff, several of which were provided by the PWROG, the NRC staff agrees that a blast wave is not likely to form during a hypothetical loss-of-coolant accident where the fluid upstream of the break location is sub-cooled. In addition, the NRC staff agrees that the PWROG has shown that if a blast wave did form during the initial moments of a sub-cooled pipe break, it would be insignificant compared to the forces exhibited by the subsequent jet blowdown. As such the NRC staff considers Issue 1 resolved for sub-cooled breaks. The NRC staff also agreed with the statements and conclusions made by the PWROG in response to sub-issue 1.d. The staff did not find information provided by the PWROG sufficient to address the details of sub-issues 1.a, 1.b, 1.c, and 1.e. However, the staff's conclusion that a blast wave would be insignificant for a sub-cooled liquid renders these questions irrelevant to resolution of Issue 1.

While the staff agrees that blast waves are not likely to form during breaks involving flashing of sub-cooled jets (hot leg, cold leg, and surge line breaks), this conclusion does not apply to postulated breaks of steam-bearing piping, where blast waves are likely to occur.

Issue 2 and 4 - Unresolved

The NRC staff has grouped Issues 2 and 4 together to maintain clarity when comparing NRC staff positions in this letter to the PWROG responses. In addition, the PWROG RAI response discussed sub-issues 2.c and 2.e prior to the remaining aspects of Issue 2 and 4. The NRC staff has elected to mirror this approach in this letter as well for clarity.

Sub-issue 2.c – Resolved (Plant-specific)

The NRC staff agrees that pressurizer insulation may be excluded as a debris source above a support skirt for a break below the support skirt as long as a licensee has a support skirt that would physically block any jet associated with the break.

Sub-issue 2.e – Resolved

During the WCAP-16710-P tests of jacketed NUKON® on piping, the test target had three latches holding a jacket section in place. During three different tests, at various distances, latches disengaged. However, in all three tests, at least one of the three latches remained engaged and the jacketing remained on the target. Considered as an entire latch system, the staff agrees that this behavior is repeatable for jacketing sections held in place by sets of three latches. Licensees seeking this credit should conduct multiple tests using the number of latches per section applicable to their installation if different from the three latches per section tested in WCAP-16710-P. This conclusion does not imply acceptance of the jacketed NUKON® ZOIs cited in WCAP-16710-P, due to the test loop design error identified by Westinghouse.

The PWROG did not address the remaining questions related to Issue 2 or Issue 4. Instead, the PWROG provided an overall response to these two issues that is intended to provide a framework for addressing the concerns in Issue 2 and Issue 4 under a possible future submittal. As a result, the NRC staff conclusion is that the PWROG has not provided sufficient technical justification to address Issue 2 and Issue 4. The exceptions to this conclusion are sub-issues 2.c and 2.e, as previously discussed.

In addition, the NRC staff has reached the following conclusions with respect to the overall response provided by the PWROG for Issues 2 and 4:

1. The NRC staff agrees that the method described in Appendix B of the NRC's SE of Topical Report NEDO-32686-A, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (ADAMS ML092530482), may be used to scale jacketed insulation test results to larger diameter pipes. The staff notes that target scaling is only required for jacketed insulation systems and would not be required where failure of a material would result from a local force (i.e. tearing of cover) versus a total force on a pipe jacket.

2. The staff does not accept the concept of an "effective jet nozzle diameter." The test design error represents significant uncertainty in attempting to make any comparisons to free jet expansion models, much less refinements.

3. Similarly, the NRC staff does not recognize the Wyle January 2010 instrumented tests as "free-jet expansion tests." This conclusion is a result of the test design error in the test loop.

4. The ANSI/ANS 58.2-1988 model has been accepted in the SE to NEI 04-07 for determining jet volumes at different pressure isobars. The NRC staff acknowledges that the model is expected to over predict axial pressure because jet expansion is artificially constrained within the model. However, this overestimation of axial pressure comes in part at the expense of the jet's radial expansion. Specifically, where the ANSI/ANS 58.2-1988 model over predicts the pressure isobar at a given axial location in the far field due to artificial expansion constraints, it also under predicts the pressure isobar at a given radial location in the near field for the same reason. These model uncertainties may not cancel each other out completely. However, the Westinghouse method discussed in the RAI response of equating an axial target distance to a calculated isobar using the ANSI/ANS 58.2-1988 model removes conservatism axially but does not address non-conservatism radially and is thus likely to under calculate the jet isobar volumes for any given pressure.

5. The NRC staff also acknowledges that the ANSI/ANS 58.2-1988 model will over predict the total isobar volume at very low pressures because the model is unbounded as it approaches ambient pressure. It is in this range of very low pressures where the NRC staff believes refinements to the model would be beneficial in reducing excessive conservatisms in calculated ZOIs for materials with comparatively low destruction pressures.

6. In addition to those criteria listed in the RAI response for a "successful test," the NRC staff position is that a successful test includes no observable liberation of insulation from the test item.

7. The PWROG has not submitted a refinement method for the ANSI/ANS 58.2-1988 model to the NRC staff for review, but the RAI response notes that a possible future submittal is being evaluated. The NRC staff is unable to predict the potential for success of such a submittal, or the likely duration of an NRC review. The NRC staff notes the following items for PWROG consideration prior to any future submittal:

    A. The test loop used for any data obtained for the purpose of free jet model refinements should not include upstream choke locations.
    B. Model refinements should include sufficient spatial pressure measurements to map the actual shape of the jet isobars of pressures that are of interest for debris generation to within a tolerable degree of uncertainty.
    C. Radial pressure measurements should be performed with the instrument oriented normal to the expected direction of flow of the expanding jet at each instrument location.
    D. Model refinements should include measurements that map the boundary of the actual jet radial expansion (i.e. radial measurements about the jet centerline at small axial distances from the nozzle) such that realistic isobar volumes may be obtained for comparison to the free-jet model volumes being refined.
    E. Pressure instruments should be of an appropriate range for the expected measurement.

F. The test setup should be oriented such that the jet expansion isn't artificially altered by a robust structure (e.g. the ground).
G. The PWROG should consider using impingement plates to obtain pressure measurements as they would be deemed more suitable for refinement purposes.

8. As stated in the introduction of this letter, the NRC staff agrees that empirically derived (i.e. measured) damage pressures may be obtained for a target centerline through testing and subsequently used as an input to the ANSI/ANS 58.2-1988 model for calculating a ZOI volume. This approach, as long as appropriate test scaling is considered for jacketed items, is consistent with the staff SE of NEI guidance report 04-07, "Pressurized Water Reactor Sump Performance Methodology" (ADAMS ML043280007).

Issue 3 - Resolved

The NRC staff agrees with the PWROG response to Issue 3 with the addition that a "successful test" includes no observable liberation of insulation from the test item. In addition, the NRC staff does not recognize the ZOIs listed in WCAP-16710-P as valid plant ZOIs. The NRC staff considers Issue 3 resolved in that the PWROG response stated that the referenced test was not considered a successful test.

Issue 5 – Resolved

The PWROG provided a detailed description of the test apparatus. The NRC staff notes that resolution of this question resulted in identification of 13 inches of piping with an internal diameter of 2.9 inches as well as several locations of smaller internal diameters with the smallest location measuring 2.313 inches approximately 26 inches upstream of the 3.54 inch nozzle. The NRC staff considers Issue 5 resolved in the sense that the detailed description of the test apparatus was provided. Issues with the configuration of the test apparatus are addressed in discussions of Issues 2 and 4 above.

Issue 6 - Resolved

The NRC staff agrees with the PWROG response to Issue 6 with the addition that a "successful test" includes no observable liberation of insulation from the test item. In addition, the NRC staff does not recognize the ZOIs listed in WCAP-16710-P as valid plant ZOIs. The NRC staff considers Issue 6 resolved in that the PWROG response stated that the referenced test was not considered a successful test.

Issue 7 - Resolved

The NRC staff agrees that the test results only apply to Callaway and Wolf Creek Nuclear Plants and that these plants have performed plant-specific evaluations to determine that the Min-K panels cannot be impacted by the jet based on the insulation panel locations in the plant. The PWROG response stated that no credit was taken for jet-ejected insulation panels not being damaged due to subsequent collisions in the plant. The NRC staff considers Issue 7 resolved in that the referenced test was not credited or considered a successful test.

In summary, the PWROG has not provided sufficient technical bases to fully resolve NRC staff concerns with the technical reports. The major unresolved concerns relate to errors in the test loop design and Westinghouse's use of an unaccepted method to determine material-specific damage pressures for calculating a ZOI. As such, the NRC staff has determined that the technical report conclusions have the potential to significantly under predict the quantity of debris that could be generated during a hypothetical loss-of-coolant accident. In light of this, the NRC staff does not accept, and licensees should not credit, the ZOI conclusions made in WCAP-16710-P, WCAP-16851-P, or similar technical reports referenced in this letter.

Empirically derived (i.e. measured) damage pressures may be obtained for a target centerline through testing and subsequently used as an input to the ANSI/ANS 58.2-1988 model for calculating a ZOI. This approach, as long as appropriate test scaling is considered for jacketed insulation, is consistent with the staff SE of NEI guidance report 04-07.

Sincerely,

/RA/

Jonathan Rowley, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

cc: See next page

In summary, the PWROG has not provided sufficient technical bases to fully resolve NRC staff concerns with the technical reports. The major unresolved concerns relate to errors in the test loop design and Westinghouse's use of an unaccepted method to determine material-specific damage pressures for calculating a ZOI. As such, the NRC staff has determined that the technical report conclusions have the potential to significantly under predict the quantity of debris that could be generated during a hypothetical loss-of-coolant accident. In light of this, the NRC staff does not accept, and licensees should not credit, the ZOI conclusions made in WCAP-16710-P, WCAP-16851-P, or similar technical reports referenced in this letter.

Empirically derived (i.e. measured) damage pressures may be obtained for a target centerline through testing and subsequently used as an input to the ANSI/ANS 58.2-1988 model for calculating a ZOI. This approach, as long as appropriate test scaling is considered for jacketed insulation, is consistent with the staff SE of NEI guidance report 04-07.

Sincerely,

/RA/

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Office of Nuclear Reactor Regulation

Project No. 694

cc: See next page

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PWR Owners' Group

Project No. 694

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ATTACHMENT 2
to RAI 636-4732

Application of Compressible Two-Fluid Model Code to Supersonic Two-Phase Jet Flow Analysis

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ABSTRACT

In case of postulated cooling system line break of a light water reactor, high temperature and high pressure coolant may be ejected from the break. For assessing structural loadings by the jet, the ANSI/ANS jet model was developed. It is a semi-empirical correlation based on thermodynamic assumptions and empirical observation of two-phase free jets. The present numerical method is based on a compressible two-fluid model within a finite-volume framework. Numerical simulation results of supersonic two-phase jets from the break were compared with evaluations of the ANSI/ANS jet model. A reasonable agreement between the numerical and theoretical solutions are confirmed for the classic benchmark problems of the Sod's single-phase shock tube and two-phase hydraulic hammer. Two-phase jet impingement tests performed by JAERI were analyzed and the pressure profile and load on the target plate were well predicted. Steam-water two-phase free jets were calculated under actual BWR/PWR thermodynamic conditions using the present model. The predicted distribution of jet pressure, which is a potential damage defined as static pressure plus two-phase momentum flux, was compared with evaluations from the ANSI/ANS jet model, and the JAERI experimental correlation. The initial blast wave is not generated in the two-fluid model calculations. Calculated jet pressure profiles in the jet centerline by these three different methods are similar, while the evaluated area of damage from the ANSI/ANS jet model is the largest. It is concluded that safety assessment by the ANSI/ANS jet model is reliable and conservative.

KEYWORDS

Gas-liquid two-phase flow, Computational fluid dynamics, Supersonic jet, Loss of coolant accident, Coolant suction strainer, Light water reactors

1. INTRODUCTION

It has been reported that there is a possibility of strainers and sump screens clogging both in boiling water reactors (BWRs) and in pressurized water reactors (PWRs) in occurrence of a loss of coolant accident (LOCA). Because debris might be generated by break jet flow and washed down to clog strainers or sump screens.

The ANSI/ANS jet model[1] was developed for a evaluation on debris blockage of the ECC water suction strainer of a sump of the light water reactor (LWR). The ANSI/ANS jet model is based on thermodynamic assumptions and comparisons with empirical observations. The jet pressure due to impingement is defined as static pressure plus momentum flux, and its distribution is estimated by the model in the two-phase free jet.

The ANSI/ANS jet model does not deal with fluid dynamics of a supersonic jet like structure of compression and rarefaction shock waves. The assumed simple thermodynamic behavior in one dimensional consideration is not assured in actual multi dimensional jet fields. It is needed to confirm validity of the ANSI/ANS jet model through comparison with computational fluid analysis of highly compressible and thermal nonequiliblium gas-liquid two-phase flow. Computer codes of single-phase compressible flow may be applied to homogeneous and thermal equilibrium two-phase flow. But the velocity slip and thermal nonequilibrium, which are important for two-phase flow thermal hydraulics, are not able to calculated.

One of the useful numerical methods for gas-liquid two-phase flow is the two-fluid model, which treats local gas and liquid conservation equations simultaneously. Most of conventional programs for transient two-phase flow use incompressible fluid solution methods, where fluid compressibility is treated as a quasi-static change of fluid property with time. This approximation is not available to highly compressible phenomena like supersonic jets. The successful solution method of compressible single-phase flow contains characteristic wave propagation as a factor of primary importance. The existing numerical method[2] of compressible two-fluid model is introduced to the present study. The basic equations and solution procedure are reviewed and the reliability of the results are checked against benchmark problems.

JAERI performed jet discharge and impingement experiments in BWR/PWR conditions[3]. Temperature, pressure and load on the target plate were measured. Simple and practical experimental formulae to estimate the maximum pressure and temperature profiles on the target plate as a function of axial and radial distances. The experiments provided verification data for computer simulation of supersonic two-phase jet dynamics.

2. NUMERICAL METHOD

2.1. Basic Equations

The field equations of the two-fluid model are composed of the following mass, momentum and energy conservation equations of each phase:

$$\frac{\partial}{\partial t}\alpha_k\rho_k + \nabla\cdot\alpha_k\rho_k\boldsymbol{u}_k = \Gamma_{k',k} - \Gamma_{k,k'}, \tag{1}$$

$$\frac{\partial}{\partial t}\alpha_k\rho_k\boldsymbol{u}_k + \nabla\cdot\alpha_k\rho_k\boldsymbol{u}_k\boldsymbol{u}_k + \alpha_k\nabla P = \boldsymbol{F}_{ik} + \boldsymbol{F}_{vk} + \boldsymbol{F}_{wk} + \nabla\varepsilon_k\alpha_k\rho_k\nabla\cdot\boldsymbol{u}_k + \Gamma_{k',k}\boldsymbol{u}_{k'} - \Gamma_{k,k'}\boldsymbol{u}_k, \tag{2}$$

$$\frac{\partial}{\partial t}\alpha_k\rho_k\left(e_k + \frac{u_k^2}{2}\right) + \nabla\cdot\alpha_k\rho_k\left(h_k + \frac{u_k^2}{2}\right)u_k = \Gamma_{k',k}\left(h_{k'} + \frac{u_{k'}^2}{2}\right) - \Gamma_{k,k'}\left(h_k + \frac{u_k^2}{2}\right), \tag{3}$$

where α is the volume fraction, ρ the density, u the velocity, t time, P the pressure, e the specific internal energy and suffix k the phase (g for gas and l for liquid). h is the specific enthalpy defined as ($e+P/\rho$). $\Gamma_{k',k}$ is the phase change rate per unit volume from phase k' to phase k. F_i, F_v and F_w are the interface friction, the virtual mass force and the wall shear, respectively. Heat conduction is neglected because convection transfer dominates in momentum balance in high velocity transient flows considered here. Gravity is negligible because motive forces by pressure gradient are much larger than the gravity force. The work due to the volume fraction change with time is neglected in the energy conservation equation because it is small enough compared with thermal and kinetic energy.

To close the system of equations, constitutive equations are needed to provide the interfacial friction, the wall shear, the phase change rate and the virtual mass force. The interfacial friction is estimated by using the Andersen's model[4] to derive a drag coefficient from a drift velocity, $\overline{V}_{gj}$ [5],

$$\boldsymbol{F}_{ik} = \alpha_g \alpha_\ell \frac{g(\rho_\ell - \rho_g)|\boldsymbol{u}_k - \boldsymbol{u}_{k'}|}{\overline{V}_{gj}^2}(\boldsymbol{u}_k - \boldsymbol{u}_{k'}), \tag{4}$$

Wall shear on each phase at a surface of a computational cell contact to a solid wall is assumed to be proportional to the volume fractions:

$$F_{wk} = \lambda \alpha_k \rho_k |\widehat{u}_k| \widehat{u}_k A_w , \tag{5}$$

where $\widehat{u}$ is the velocity vector component to parallel to the wall. A_w is wall area per unit capacity of the cell. λ is a wall friction coefficient of 0.003 estimated from a wall shear correlation of turbulent single-phase flows[6].

Phase change rate for evaporation and condensation is assumed to be proportional to degree of difference between frozen quality, x, and thermal equilibrium one, x_{eq}.

$$\Gamma_{\ell,g} = \rho_m \frac{x - x_{eq}}{\tau} \quad \text{for} \quad x < x_{eq}, \tag{6a}$$

$$\Gamma_{g,l} = \rho_m \frac{x_{eq} - x}{\tau} \quad \text{for} \quad x > x_{eq}. \tag{6b}$$

Time constant τ is 50 ms referring to estimation of pressure response in nuclear reactor nonequilibrium transients[7].

Virtual mass force is estimated as follows,

$$F_{vk} = c_{vm} \alpha_g \alpha_\ell \rho_m \left\{ \left(\frac{\partial}{\partial t} u_{k'} + u_{k'} \nabla u_{k'} \right) - \left(\frac{\partial}{\partial t} u_k + u_k \nabla u_k \right) \right\}. \tag{7}$$

The virtual mass coefficient c_{vm} is not well known and it is 0.5, that of solid sphere in perfect fluid.

2.2. Solution Method for Compressible Single-Phase Flow

The mass and momentum equations of unsteady compressible single-phase flow are expressed in one dimensional form as follows:

$$\frac{\partial}{\partial t}\rho + u\frac{\partial}{\partial z}\rho + \rho\frac{\partial}{\partial z}u = 0, \tag{8}$$

$$\frac{\partial}{\partial t}u + u\frac{\partial}{\partial z}u + \frac{1}{\rho}\frac{\partial}{\partial z}P = 0, \tag{9}$$

where z is distance. Assuming the process is considered as isentropic, the sound speed can be expressed as $c = 1/\sqrt{\mathrm{d}\rho/\mathrm{d}P}$. These equations are written in a matrix formulation as:

$$\frac{\partial}{\partial t}\begin{pmatrix} P \\ u \end{pmatrix} + \begin{pmatrix} u & \rho c^2 \\ 1/\rho & u \end{pmatrix} \frac{\partial}{\partial z}\begin{pmatrix} P \\ u \end{pmatrix} = 0 . \tag{10}$$

Introducing the traveling wave velocity s, the derivative along the wave, d/dz, is defined:

$$\frac{\mathrm{d}}{\mathrm{d}z} = \frac{1}{s}\frac{\partial}{\partial t} + \frac{\partial}{\partial z} . \tag{11}$$

Equations (10) and (11) are combined together, and we obtain

$$\left\{ \boldsymbol{I} - \frac{1}{s}\begin{pmatrix} u & \rho c^2 \\ 1/\rho & u \end{pmatrix} \right\} \frac{\partial}{\partial t}\begin{pmatrix} P \\ u \end{pmatrix} + \begin{pmatrix} u & \rho c^2 \\ 1/\rho & u \end{pmatrix} \frac{\mathrm{d}}{\mathrm{d}z}\begin{pmatrix} P \\ u \end{pmatrix} = 0 , \tag{12}$$

where $\boldsymbol{I}$ is the unit matrix. By setting the determinant of the matrix inside { } equal to zero, we obtain two characteristic lines expressed as

$$\frac{\mathrm{d}z}{\mathrm{d}t} = u \pm c . \tag{13}$$

Then Eqs. (8) and (9) are reduced to

$$\frac{\mathrm{d}}{\mathrm{d}z}\left(u \pm \frac{1}{\rho c} P \right) = 0 \quad \text{along the characteristic lines} \quad \frac{\mathrm{d}z}{\mathrm{d}t} = u \pm c . \tag{14}$$

Thus we have

$$\mathrm{d}P = \pm(\rho c)\mathrm{d}u \quad \text{along} \quad \frac{\mathrm{d}z}{\mathrm{d}t} = u \pm c . \tag{15}$$

Combination of the above equation along the two characteristic lines gives discrete approximation of the pressure and the velocity at the interface between neighboring computational cells[8] as :

$$P_{n+1/2} = \frac{P_{n+1} + P_n}{2} - \frac{\rho c}{2}\left(u_{n+1} - u_n\right), \tag{16}$$

$$u_{n+1/2} = \frac{u_{n+1} + u_n}{2} - \frac{1}{2\rho c}\left(P_{n+1} - P_n\right), \tag{17}$$

where subscript n+1/2 indicates the interface between the cell n and cell n+1. Eq.(16) and Eq.(17) are used to evaluate the numerical fluxes of the discrete form of the conservation Equations (1)-(3).

2.3. Extension to Compressible Two-Phase Flow

This scheme is suitable to the present finite volume framework, but the difficulty is that sound speed and velocity in a finite volume are not unique in two fluid model. The extension of the above technique to two-fluid model requires effective mixture sound speed and velocity corresponding to single-phase flow.

Equation (16) can be understood as the right hand side contains increased pressure due to collision of fluid lumps of the neighboring finite volumes due to velocity difference. Collision of lump of two-phase mixture may occur because of volumetric velocity difference between the finite volumes. Then, the summation of the gas and liquid volumetric velocities can be applied to u in Eqs. (16) and (17),

$$\sum_{k=g,\ell} \alpha_k u_k \Rightarrow u . \tag{18}$$

The following sound speed in two-phase mixture of homogeneous two-phase flow is applied to c,

$$c_{2\phi} = \frac{x v_g + (1-x) v_\ell}{\sqrt{x \frac{v_g^2}{c_g^2} + (1-x) \frac{v_\ell^2}{c_\ell^2}}} \Rightarrow c , \tag{19}$$

Two-phase mixture density is applied to single phase density. These approximations make the Eqs. (16) and (17) applicable to the finite volume formulation of the two-fluid model.

2.4. Benchmark Problems

2.4.1. Sod's Shock Pipe

The Sod problem[9] is a classical initial value problem of an inviscid gas flow in one space dimension which provides a benchmark test of a compressible code's ability to capture shocks and contact discontinuities of fluid. The fluid is initially at rest on both sides of the interface (z=0), and the density and pressure jumps are chosen so that a shock, a contact discontinuity and a rarefaction wave develop. In both sides of the interface in the initial state, the densities and pressures are

Left state : $\rho = 1, \quad P = 1 \qquad (z < 0)$,

Right state : $\rho = 0.125, \quad P = 0.1 \qquad (z > 0)$.

All variables are dimensionless and the ratio of specific heat is 1.4.

Gases in the both sides are treated as fluids having different phase in the present two-fluid model code. Phase 1 exists in the left side and phase 2 in the right side of the discontinuity. The time step is fixed as 0.001 and the cell size is 0.00625 uniformly. The contact discontinuity appears at the interface between the phases. Figure 1 shows calculated profiles of density at time 0.3017. The rarefaction wave and the shock discontinuity are properly reproduced. A slight numerical diffusions are shown around the contact discontinuity and shock front and the shock wave propagation delays a little, but overall results are close to theoretical solution.

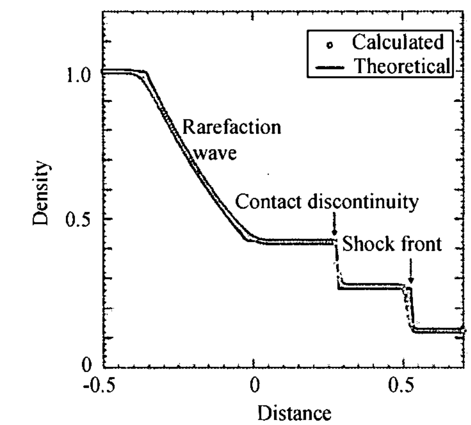

Fig. 1 Density distribution of Sod's shock tube problem (Time: 0.3017)

2.4.2. Two-Phase Hydraulic Hammer

The two-phase hydraulic hammer problem provides a test of a compressible two-phase flow code's ability to estimate generated pressure pulse and wave propagation in two-phase mixture. We construct the initial conditions of a pipe filled with homogeneous two-phase mixture with the left closed end. The right end is pressure boundary. The fluid is initially at velocity of 0.1m/s towards the left closed

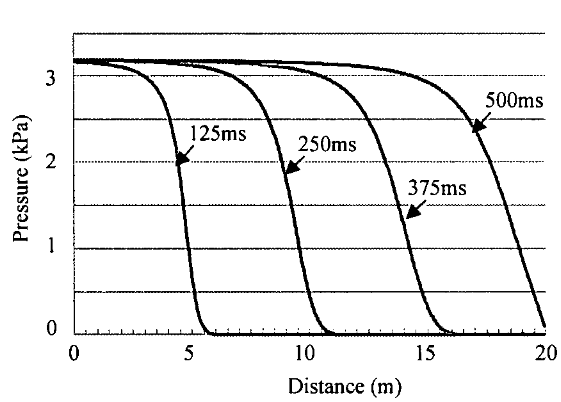

Fig. 2 Calculated pressure distribution of two-phase hammer (Initial void fraction: 10 %)

end. The length of the pipe is 20 m, time step is 2.5 μs and size of finite volume is 0.05 m.

The typical calculated result of pressure profile is shown in Fig. 2 for initial void fraction 10%. The calculated wave propagation velocity compared with the estimation from Eq. (19). Calculated pressure rise is compared with the relationship between pressure and velocity changes from Eq. (15),

$$\Delta P = c_{2\phi}\rho_m u_o . \qquad (20)$$

The deviations between the calculated and the theoretical estimation are 2 % for wave propagation velocity and 4 % for pressure rise. The theoretical estimations are based on infinitesimal change treatment, but the calculation deals with a finite change of pressure, velocity and density. Considering nonlinear effects in the calculation, the result shows a capability for calculating compressible two phase flow dynamics.

3. ANALYSIS OF JAERI EXPERIMENTS

3.1 Test Apparatus

JAERI performed jet discharge and impingement experiments in BWR/PWR conditions[3]. The testing loop was composed of the pressure vessel, pressurizer, discharge pipe and target plate. The discharge pipe attached to the pressure vessel was about 13.4 m long including three elbows. The pipe inner diameter was 0.097 to 0.170 m, and the target plate was circular with diameter 2 m. The volume of the pressure vessel was 4 m^3. A rupture disk was installed at the opening of the pipe. A Distance from the break to the target plate was varied from 1, 2, 5 to 18 times of the pipe diameter. Pressure and temperature were measured on the target plate at several sites. Thrust of the pipe and load on the target plate were also measured. 6 tests were carried out for BWR conditions and 5 tests were carried out for PWR conditions.

3.2 Calculation Conditions

A calculation area extends from the inlet of the pipe to the target plate thorough the pipe opening. The jet field is from the pipe opening to the target plate in axial direction and from the centerline to the fringe of the target plate in radial direction. An axisymetric two-dimensional calculation was performed with an approximation of straight pipe. One side of the centerline is calculated considering field axisymmetry. The number of finite volumes is about 2,000 and time step is 1 μs. An axial finite volume size in the pipe is varied from 0.05m at the opening to 1m at the inlet, where pressure profile is rather smooth. The axial finite volume size is uniform in axial direction 0.038 m in the jet field. A radial finite volume size is about 0.03 m in the pipe and the jet field.

In the initial state, pipe is filled with high temperature and high pressure still water, and saturated steam at atmospheric pressure covers the outside the pipe. The jet field is surrounded by pressure boundaries where the pressure is detemined as averaged value of the atmospheric pressure and the transient pressure of contact finite volumes to the boundary.

The transient flow begins to move due to large pressure difference between inside and outside of the pipe opening. It is equivalent that the rupture disk fully opens in one time step. The calculation continues 0.5 second which is measuring time in the JAERI experiments. The flow is almost quasi-static at that time after initial transients of pressure waves. The pressure history at the inlet of the pipe is from the experimental data under PWR conditions and the RELAP5 results under BWR conditions. It was confirmed that The RELAP5 results are very close to the experimental data under PWR condition.

The typical BWR and PWR condition tests are calculated with the distance between the pipe opening to the target plate about the same as the pipe diameter. Run 5805 was carried out under BWR condition with initial vessel pressure 6.84 MPa and fluid temperature 285 °C. Run 5906 was carried out under PWR condition with initial vessel pressure 15.58 MPa and fluid temperature 325 °C.

3.2 Comparison between Prediction and Experimental Data

Figure 3 shows pressure profile on the target plate under the BWR condition. The calculated result of maximum pressure distribution on the target is compared with experimental correlation of dimensionless profile obtained from the JAERI tests:

$$\frac{P_{max}(r,H)-P_{\infty}}{P_0-P_{\infty}}=0.46\left(\frac{H}{D}\right)^{-2}\exp\left\{-2\left(\frac{r}{H}\right)^2\right\}$$

(for $H/D<5$), (21)

where r is the radial distance, H the distance between the pipe exit to the target plate, D the pipe diameter, P_o the initial vessel pressure and P_{∞} the atmospheric pressure. A total load on the target plate is about 34% overestmated.

Figures 4 shows the calculated result of maximum pressure distribution on the target plate compared with the JAERI correlation. The total load on the target plate is underestmated about 12%. Sensitivity analyses are performed on the time constant related phase change. Change of the time constant from factor 1/100 to 100 does not affect much on the change of pressure distribution on the target plate.

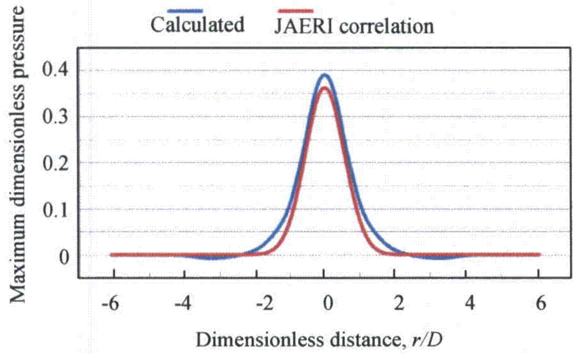

Fig. 3 Pressure distribution on the target plate (BWR condition)

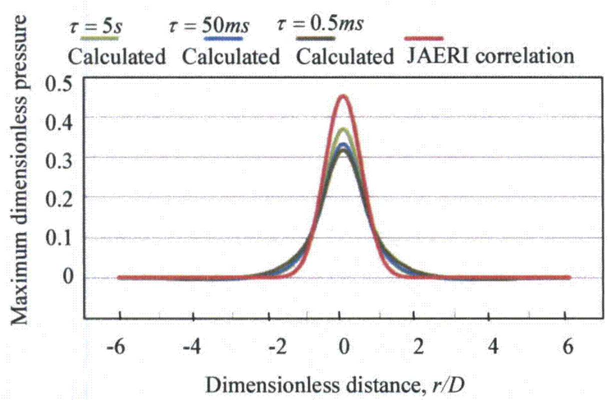

Fig. 4 Pressure distribution on the target plate (PWR condition)

4. ANALYSIS OF FLOW PATTERN FOR LWR CONDITIONS

4.1 Calculation Conditions

A free jet calculation is conservative for load estimation with no perturbation, reflection, or truncation by adjacent structures. The typical BWR and PWR pipe break conditions are calculated. In the BWR condition, vessel pressure is kept 7.5MPa at saturation temperature, while vessel pressure is kept 15.5MPa and subcooling 20 °C in the PWR condition. The inner diameter and length of the discharge pipe is 0.5 m and 1.0 m, respectively. The calculated region is

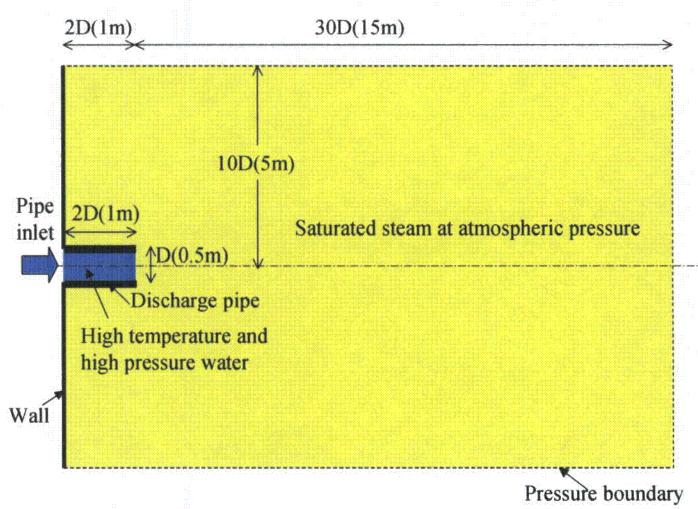

Fig. 5 Free jet calculation area in actual reactor thermal conditions

two- dimentional axisymmetric with 5 m in the radial direction and 16 m in the axial direction large enough for simulating actual cases. The calculated region is depicted in Fig. 5. One side of the centerline is calculated considering its axisymmetry. Calculated contour maps are shown in both sides of the centerline with inversed results of the opposite side.

The number of finite volumes is about 8,000 in the half filed and time step is 10 μs. An axial finite volume size is uniform in axial direction 0.1 m. Radial finite volume size is 0.083 m inside the pipe inner radius and 0.101 m outside the pipe inner radius.

In the initial state, the pipe is filled with high temperature and high pressure still water, and saturated steam at atmospheric pressure covers the ambient field. The left side boundary of the ambient field is rigid wall and surrounded by a mixture of pressure and free boundary. The pressure of the boundary is determined as an average of atmospheric pressure and pressure of contact finite volume.

In the transient calculation, the flow begins to move due to large pressure difference between inside and outside of the pipe opening. Calculation continues 5 seconds which is large enough to achieve a steady discharge flow and the compression/rarefaction shock wave structure of the supersonic jet.

4.2 Calculated Jet Flow

Figures 6 and 7 show the calculated pressure, mixture volumetric velocity distribution under the BWR condition and Figs. 8 and 9 the PWR condition. Structure of steady shock waves appear in the jet region. The pressure waves envelop in longer distance for the PWR condition than the BWR condition. The volumetric velocity changes depend on the shock wave configuration. The volumetric velocity distributions show jet configuration expanding rapidly near the pipe opening and spreading moderately at small angle in the downstream region. The result is consistent with the assumption of ANSI/ANS jet model. Most region of inside jet is supersonic, and the largest Mach numbers are 2.2 and 3.5 for the BWR and PWR conditions respectively. The Mach number is calculated as the ratio of the two-phase mixture volumetric velocity to the sound speed in two-phase flow.

The initial blast wave, which is generated occasionally and travels at supersonic velocity in a spherical form due to break of high pressure pipes or vessels, does not appear in the calculated results. It is because high density water in the pipe is not easily accelerated and high pressure steam by flashing is limited in a short period.

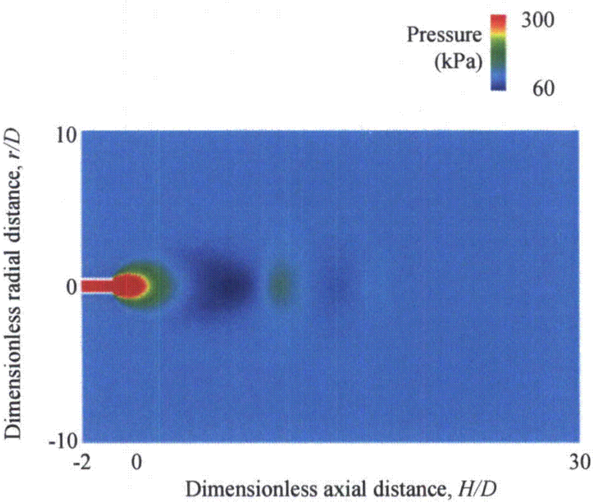

Fig. 6 Calculated pressure contour in free jet (BWR condition)

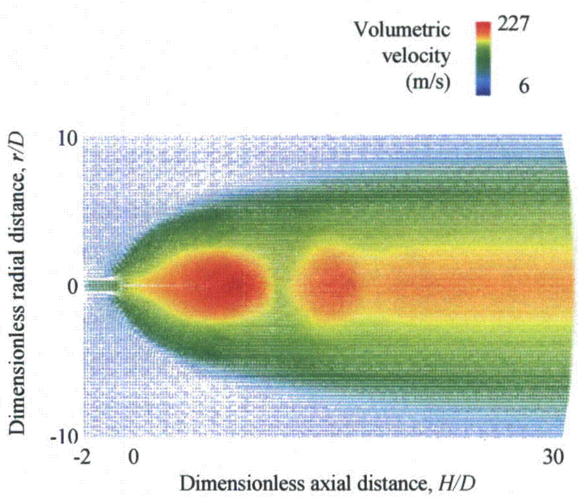

Fig. 7 Calculated volumetric velocity in free jet (BWR condition)

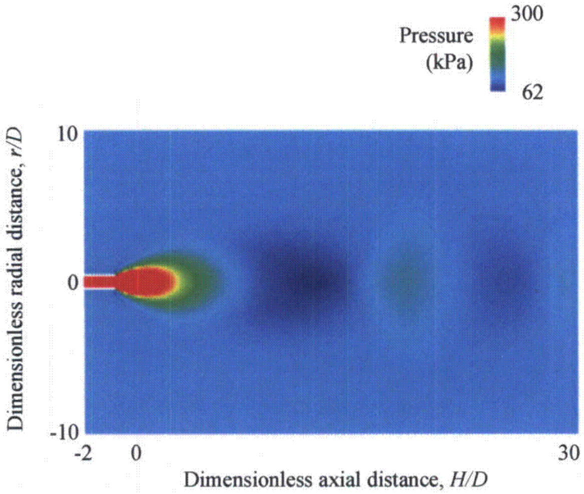

Fig. 8 Calculated pressure contour in free jet (PWR condition)

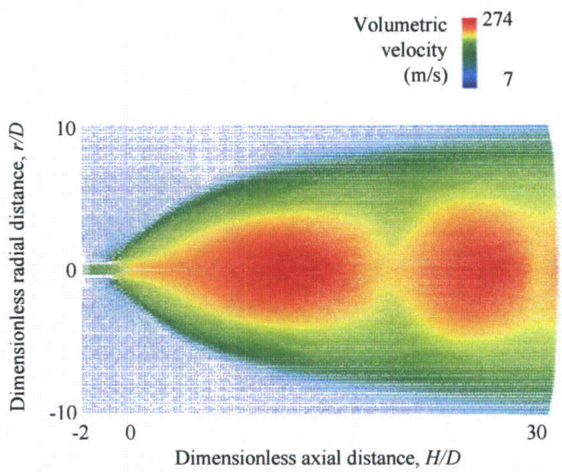

Fig. 9 Calculated volumetric velocity in free jet (PWR condition)

4.3 Jet Pressure

Jet pressures provided by the ANSI/ANS jet model indicates local stagnant pressures due to impingement. The jet pressure is defined as,

$$P_{jet} = P + \left\{ \alpha \rho_g \boldsymbol{u}_g^2 + (1-\alpha)\rho_\ell \boldsymbol{u}_\ell^2 \right\}. \qquad (22)$$

The ANSI/ANS jet model gives the jet pressure distribution as a function of vessel pressure, discharge flow rate and quality, axial and radial distances. Critical flow models are employed by Moody[10] and Ogasawara[11] hear for estimation of critical flow rate and quality.

The jet pressure by the ANSI/ANS jet model and the two-fluid model calculations are compared in Figs. 10 and 11 for the BWR and PWR conditions respectivery. The target pressure from the JAERI correlation $P_{max}(r,H)$ in Eq. (20) is also compared with the jet pressure estimations. The ANSI/ANS jet model gives conservative results in longer distance beyond 5 times as large as the pipe diameter. Very similar features are obtained in the vicinity of the break for BWR condition, while higher jet pressure appears in two-fluid model calculation than the other estimations for PWR condition.

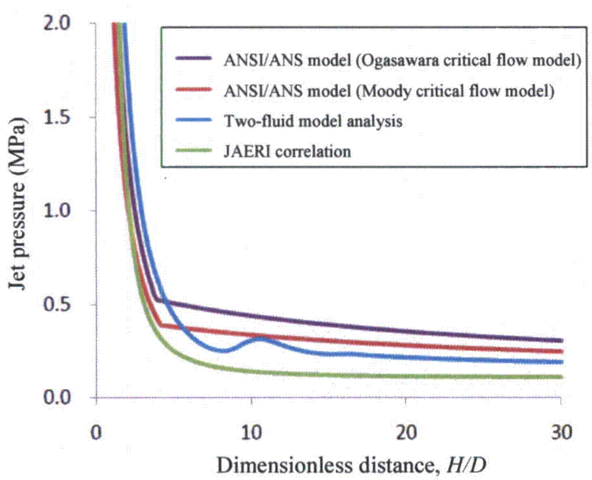

Fig. 10 Jet pressure distribution (BWR condition)

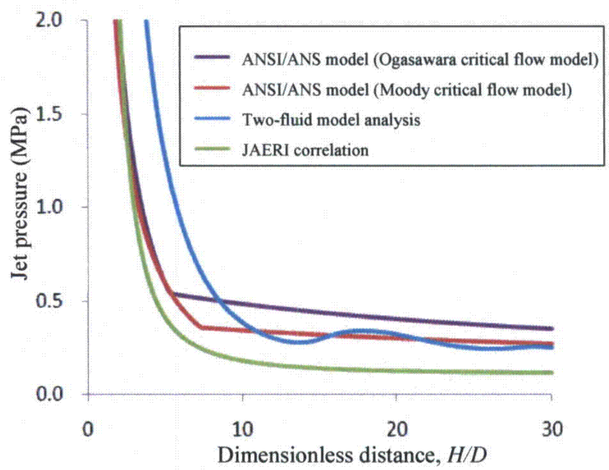

Fig. 11 Jet pressure distribution (PWR condition)

4.4 Zone of Influence (ZOI)

Spatial volumes of local jet pressure can then be integrated over the free-jet conditions and remapped into convenient spherical geometries. Zone of Influence (ZOI) is convenient to evaluate damage area around the break. It denotes relationship between pressure and equivalent radius. The spherical volume with the equivalent radius is equal to the volume in which jet pressure surplus to the ambient pressure is greater or equal to *P*.

$$R_{eq}(P)=\left(\frac{3}{4\pi}\int_{P_{jet}-P_{\infty}>P} dV\right)^{1/3} . \tag{23}$$

Usually, a dimensionless equivalent radius is used based on the pipe diameter, and jet pressure is counted in the psi (pounds per square inch) unit.

Figures 12 and 13 show ZOI results under the BWR and PWR conditions. In the BWR condition, the ANSI/ANS jet model and two-fluid model calculation are very similar for jet pressure higher than 50 psi (0.34 MPa). The ANSI/ANS jet model is conservative for lower jet pressure region. In the PWR condition, the two-fluid model gives equivalent radius larger than the ANSI/ANS jet model, but smaller in low jet pressure region. The JAERI correlation gives the lower limit in ZOI assessment.

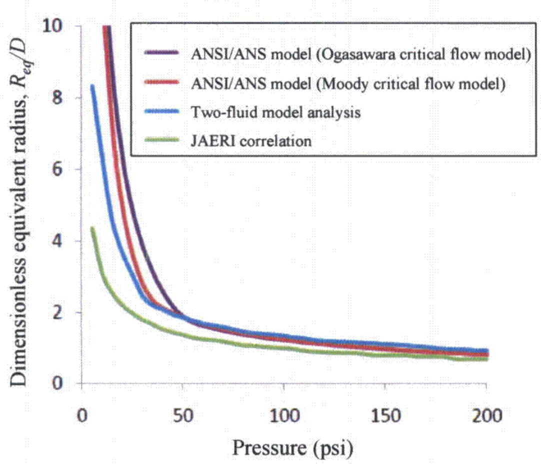

Fig. 12 Zone of influence (ZOI) assessment (BWR condition)

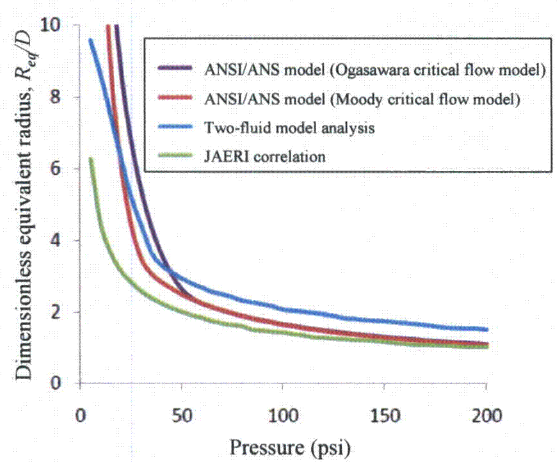

Fig. 13 Zone of influence (ZOI) assessment (PWR condition)

5. CONCLUSIONS

The present study aims at establishing a safety evaluation method for blockage of strainer of ECCS sump due to debris generated by supersonic two-phase jet loading during loss of coolant accidents. A numerical method of a highly compressible two-fluid model are reviewed and verified thorough analysis of benchmark problems of the Sod's single-phase shock pipe and two-phase hydraulic hammer. The pressure profiles on the target plate in the JAERI experiments are predicted well by the two-fluid model calculations.

Loads by free jets of the typical BWR and PWR pipe break conditions are estimated using the ANSI/ANS jet model, the JAERI correlation and the two-fluid model. The obtained jet pressure profiles are similar to each other and the JAERI correlation is comparable in its lower limit near the break. The initial blast wave is not generated in the two-fluid model calculations.

Regarding estimation of ZOI (zone of influence), the two-fluid model and the ANSI/ANS standard model agree well in high jet pressure, while the latter is conservative in a low jet pressure region. The JAERI correlation results in a smaller ZOI. The ANSI/ANS jet model gives conservative and reasonable results in comparison with the computational fluid code which takes critical flow and shock wave structure into account.

The analysis by a semi-empirical correlation of the ANSI/ANS jet model, a computational fluid dynamics of compressible two-phase flow and a pure experimental correlation give close results of jet pressure profile and ZOI relationship. The agreement shows these estimations are reliable and the ANSI/ANS jet model is appropriate to nuclear safety assessment.

REFERENCES

1. "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture, " *American National Standard, ANSI/ANS-58.2-1988* (1988)
2. Minato, A., "Numerical Analysis of Gas-Liquid Two-Phase Flow by Using Compressible Two-Fluid Model," *Kikai-Gakkai-Ronbunshu (JSME Journal)*, Ser. B, 68[673], pp. 2489-2495 (2002) (in Japanese)
3. Isozaki, T., Miyazono, S., "Experimental Study of Jet Discharge Test Results under BWR/PWR Loss of Coolant Accident Conditions," *Nucl. Eng. Design*, 96, pp.1-9 (1988)
4. Andersen, J.G.M., "Interface Shear Model of Two-Fluid Model," *Transactions of American Nuclear Society*, 41, pp.669-671 (1982)
5. Ishii, M., "One-Dimensional Drift Flux Model and Constitutive Equations for Relative Motion Between Phases in Various Two-Phase Flow Regimes," *ANL-77-47* (1977)
6. Clauser, F. H., "The Turbulent Boundary Layer," *Advances in Applied Mechanics*, Vol. 4, pp. 1-51, Academic Press, New York (1956)
7. Akiyama, M., "*Nuclear Thermal Engineering*," University of Tokyo Press, Tokyo, (1978) (in Japanese)
8. Holt, M., *Numerical Methods in Fluid Dynamics (2nd Ed.)*, Springer-Verlag (1984)
9. Sod, G. A., "A Survey of Several Finite Difference Methods for Systems of Nonlinear Hyperbolic Conservation Laws," *J. Comput. Phys.* 27: 1–31 (1978)
10. Moody, F. J., Maximum Flow Rate of a Single Component, Two-phase Mixture, *Trans. ASME, Ser. C*, Vol. 87, pp. 134-142 (1965)
11. Ogasawara, H., A Theoretical Approach to Two-Phase Critical Flow (3rd Report, The Critical Conditions Including Interphasic Slip), *Trans. JSME*, 12, pp. 827-823 (1969)

ACKNOWLEDGMENTS

The authors are grateful to Dr. Fumio Kasahara of JNES and Dr. Masanori Naitoh of IAE for their support and guidance to the present study. The authors thank to Ms. Sayuri Oshima of Advancesoft Corp. for computer running and graphical outputs.

Leakage cracks are not postulated in 1-inch nominal diameter and smaller piping.

Leakage cracks are postulated in those circumferential directions that result in the most severe environmental, spray wetting, and flooding consequences.

Fluid flow from leakage cracks is based on a circular orifice with a cross-sectional area equal to that of a rectangle one-half the pipe inside diameter in length and one-half the pipe wall thickness in width. The flow from the crack opening is assumed to result in an environment that wets all unprotected components within the compartment, with consequent flooding in the compartment and communicating compartments based on conservatively estimated time period to effect corrective actions.

3.6.2.2 Guard Pipe Assembly Design Criteria

Piping penetrations are an integral part of the PCCV pressure boundary. The annular space of the US-APWR consists of multiple compartments encircling the PCCV. These compartments segregate the PCCV electrical and mechanical penetrations into their own isolated compartments; specifically, electrical penetration rooms and mechanical penetration rooms. By virtue of the plant configuration, as piping crosses from inside to outside the PCCV, it emerges into piping penetration compartments. These compartments are designed to address postulated piping failures and the effect there of, as such, guard pipe assemblies are not required.

3.6.2.3 Analytic Methods to Define Forcing Functions and Response Models

The rupture of a pressurized pipe causes the flow characteristics of the system to change, creating reaction forces that can dynamically excite the piping system. To determine the forcing function for breaks postulated based on the criteria in Subsection 3.6.2.1, the fluid conditions at the upstream source and at the break exit determine the analytical approach. For most applications, one of the following situations exists.

- Superheated or saturated steam
- Saturated or sub-cooled water
- Cold water (non-flashing)

The analytical methods used for the calculation of the jet thrust for the above described situations are based on SRP 3.6.2 (Reference 3.6-3) and MHI original methodologies (Reference 3.6-25) based on measurements cited in References 3.6-26, 3.6-27, 3.6-28, 3.6-29, 3.6-30 and 3.6-31 ~~ANSI/ANS 58.2-1988 (Reference 3.6-14)~~.

The time dependent forcing function is effected by the thrust pulse resulting from the sudden pressure drop at the initial moment of pipe rupture, the thrust transient resulting from wave propagation and reflection, and the blowdown thrust resulting from the buildup of the discharge flow rate, which may reach a steady state if there is fluid energy reservoir having sufficient capacity to develop a steady jet for a significant interval.

Alternatively, a steady state jet thrust function may be used as outlined in Subsection 3.6.2.3.1.

A rise time of one millisecond is used for the initial pulse.

streamline force node orientation in the system. The flow areas and projection coefficients are described along the three axes of the global coordinate system. Each node is described by one or two flow apertures as a separate control volume. Forces are broken down orthogonally into x, y, and z components. The summation of the total number of apertures results in orthogonal thrust forces F_x, F_y, and F_z. These thrust forces are applied as input in dynamic analyses of piping and restraints.

3.6.2.4 Dynamic Analysis Methods to Verify Integrity and Operability

Time dependent and steady state thrust reaction loads caused by saturated or superheated steam, saturated or sub-cooled water, and cold water (non-flashing) fluid from a ruptured pipe are used in the analyses of dynamic effects of pipe breaks.

3.6.2.4.1 Jet Impingement Loading on Safety-Related Components

Structural integrity of safety-related SSCs against jet impingement load caused by pipe break is evaluated based on steady state jet force from Subsection 3.6.2.3.

Jet impingement loading is a suddenly applied constant load which can have significant energy content. These loads are generally treated as statically applied loads. The Jet impingement pressure essentially has non-uniform distributions, which varies with distance from the pipe break as shown in References 3.6-26, 3.6-27, 3.6-28, 3.6-29, 3.6-30 and 3.6-31. However, the maximum pressure in the non-uniform distribution is conservatively used as uniform distribution.

The MHI original methodologies (Reference 3.6-25) ~~methods~~ used to evaluate the jet effects resulting from the postulated breaks in high energy piping are based on measurements cited in References 3.6-26, 3.6-27, 3.6-28, 3.6-29, 3.6-30 and 3.6-31~~described in Appendices C and D of ANSI/ANS 58.2 (Reference 3.6-14)~~. Figure 3.6-2 depicts jet characteristics for the three fluid states. The short term response evaluates the jet impingement load considering a dynamic load factor of 2 and snubber supports to be active. No dynamic load factor is used and the snubbers are considered inactive for the long-term response.

3.6.2.4.1.1 Blast Wave Assessing Procedure

Computational Fluid Dynamics (CFD) analysis confirms generation of blast wave from a steam pipe break. Potential effects are assessed on equipment within US-APWR pressurizer compartment. Distance between postulated pipe break locations and components is long enough to attenuate effects. However, if layout in the pressurizer compartment is changed in future, reassessment of blast wave will be conducted.

Blast wave is not considered to occur from sub-cooled water pipe break. This is because velocity of the two-phase flow at break point is slower than speed of sound in atmospheric environments.

Therefore, blast wave does not impact on design. Detailed blast wave assessing procedure is provided in Reference 3.6-32.

3.6.2.4.1.2 Jet Pressure Oscillation Assessing Procedure

Jet pressure oscillation from a steam pipe break is unlikely to occur in high compression ratio like US-APWR. Jet flow expansion is large and Mach Disk is large. This leads the stable downstream after Mach Disk. The flow is so stable that disturbance at impingement wall does not reach back to Mach Disk.

When sub-cooled jet-flow impinges on wall, pressure distributions on wall are not concave type and re-circulation vortex is not generated. It is because flow velocity at jet boundary is lower than that of core region.

Therefore, jet pressure oscillation does not impact on design. Detailed jet pressure oscillation assessing procedure is provided in Reference 3.6-32.

3.6.2.4.1.3 Jet Reflection Assessing Procedure

When jet flow impinges on perpendicular wall, impinged jet flow is redirected and runs along surface of wall. Zone of influence (ZOI) obtained by CFD is enveloped by estimated ZOI from MHI original methodologies (Reference 3.6-25). Inside of ZOI, impingement pressure includes effect of pressure due to flow parallel to impingement wall. Loads due to jet impingement reflection outside of ZOI are considered so small that it is not necessary to be considered.

Therefore, jet reflection does not impact on design. Detailed jet reflection assessing procedure is provided in Reference 3.6-32.

3.6.2.4.2 Dynamic Analysis for Piping Systems

3.6.2.4.2.1 RCL Piping

Appendix 3C provides analysis details for RCL piping. Loads generated by postulated breaks from branch lines are applied to determine structural response of RCL piping.

3.6.2.4.2.2 Piping Other Than RCL Piping

In evaluating the dynamic effects of breaks in high-energy-fluid system piping other than RCL piping, possible break locations and break configurations are first established based on Subsection 3.6.2.1 and the effects of pipe whipping are then evaluated based on Subsection 3.6.2.4.5.

If the above evaluation determines that no safety-related SSCs are damaged, then dynamic analysis is not necessary. If the above evaluation determines that the structural integrity of safety-related SSCs is impaired, pipe whip restraints are incorporated in the high-energy-fluid system piping of concern and dynamic analysis is conducted for the system including the piping and the pipe whip restraints.

In general, a gap is provided between a pipe whip restraint and pipe so as not to restrict thermal movement in the pipe. In the event of a pipe-break accident, the pipe accelerates in the gap due to the jet force and collides with the pipe whip restraint. The

3.6-20 Report of the ASCE Committee on Impactive and Impulsive Loads. Second ASCE Conference on Civil Engineering and Nuclear Power, Volume V, 1980.

3.6-21 Reactor Coolant Pressure Boundary Leakage Detection Systems. Regulatory Guide 1.45, U.S. Nuclear Regulatory Commission, Washington, DC, May 1973.

3.6-22 Control of the Use of Sensitized Stainless Steel. Regulatory Guide 1.44, U.S. Nuclear Regulatory Commission, Washington, DC, May 1973.

3.6-23 Evaluation of Potential Pipe Breaks, NUREG-1061, Vol. 3, U.S. Nuclear Regulatory Commission Piping Review Committee, November 1984.

3.6-24 US-APWR Leak-Before-Break Evaluation. MHI Technical Report, Later.

3.6-25 MUAP-10017 Revision 1 "US-APWR Methodology of Pipe Break Hazard Analysis"

3.6-26 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Study of Pipe Reaction Force and Jet Impingement Load at the Pipe Break, Trans. 5th Int. Conf. on SMiRT, F6/2, 1979.

3.6-27 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Studies on Transient Water-Steam Impinging Jet, Vol. 22 No. 5, pp. 403-409, Journal of Atomic Energy Society of Japan, 1980 (in Japanese).

3.6-28 Kitade, K., Nakatogawa, T., Nishikawa, H., Kawanishi, K., and Tsuruto, C., Experimental Studies on Steam Free Jet and Impinging Jet, Vol. 22 No. 9, pp. 634-640, Journal of Atomic Energy Society of Japan, 1980 (in Japanese).

3.6-29 Masuda, F., Nakatogawa, T., Kawanishi, K. and Isono, M., Experimental Study on an Impingement High-Pressure Steam Jet, Nuclear Engineering and Design 67-2, pgs 273-285, 1982.

3.6-30 Masuda, F., Nakatogawa, T., Kawanishi, K. and Isono, M., Experimental Study on Jets Formed Under Discharges of High-Pressure Subcooled Water and Steam-Water Mixture, Trans. 7th Int. Conf. on SMiRT, F1/6, 1983.

3.6-31 Isozaki, T. and Miyazono, S., Experimental Study of Jet Discharging Test Results under BWR and PWR Loss of Coolant Accident Conditions, Nuclear Engineering and Design 96, 1986.

3.6-32 MUAP-10022 Revision 0 "Evaluation on Jet Impingement Issues Associated with Postulated Pipe Rupture.

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Table 3.6-2

List of High Energy Lines for Pipe Break Hazard Analysis, Including Properties of Internal and External Fluids

No.	System	Subsystem	Line No(s)	Nominal Diameter (Inches)	Outside Diameter (Inches)	Thickness (Inches)	Material	Temp (°F)	Pressure (psig)	Inside Pipe	Outside Pipe (°F , psig)
1	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	617	2235	Subcooled liquid	Air (120, 0)
1	RCS	Primary Loop Hot Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	617	2235	Subcooled liquid	Air (120, 0)
2	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	550.6	2235	Subcooled liquid	Air (120, 0)
3	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316	550.6	2235	Subcooled liquid	
2	RCS	Primary Loop Crossover Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	550.6	2235	Subcooled liquid	Air (120, 0)
3	RCS	Primary Loop Cold Leg	31"ID-RCS-2501R A,B,C,D	31ID	37.12	3.06	SA182 F316LN	550.6	2235	Subcooled liquid	
4	RCS	Surge Line	16"-RCS-2501R B	16	16	1.594	SA-312 TP316	653	2235	Saturated liquid	Air (120, 0)
5	RCS	Surge Line	16"-RCS-2501R A	16	16	1.594	SA-312 TP316	449	400	Saturated liquid	Air (120, 0)
6	RCS	Residual Heat Removal System (RHRS) Hot Leg Branch Line off RCS	10"-RCS-2501R A,B,C,D, Hot Leg Side	10	10.75	1.125	SA-312 TP316	617	2235	Subcooled liquid	Air (120, 0)
7	RCS	RHRS Cold Leg Branch Line off RCS	8"- RCS -2501R A,B,C,D (COLD LEG)	8	8.625	0.906	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
8	SIS	Accumulator System	14"-RCS-2501R A,B,C,D	14	14	1.406	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
9	RCS	Pressurizer Spray Line	6"-RCS-2501R B,C	6	6.625	0.719	SA-312 TP316	550.6	2235	Subcooled liquid	Air (120, 0)
10	MSS	Main Steam Line	32"-MSS-1532N A,B,C,D	32	32	1.496	SA333 Gr.6	535	907	Saturated steam	Air (130, 0)
11	CVS	Aux. Spray Line	3"-RCS-2501	3	3.5	0.438	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
12	CVS	Aux. Spray Line	3"-CVS-2561	3	3.5	0.438	SA-312 TP316	554.6	2366	Subcooled liquid	Air (120, 0)
13	CVS	Charging Line	4"-CVS-2501	4	4.5	0.531	SA-312 TP316	554.6	2366	Subcooled liquid	Air (120, 0)

14	CVS	Charging Line	4"-CVS-2561	4	4.5	0.531	SA-312 TP316	554.6	2366	Subcooled liquid	Air (120, 0)
15	CVS	Charging Line	4"-CVS-2511 (Inside CV)	4	4.5	0.531	SA-312 TP304	130	2600	Subcooled liquid	Air (120, 0)
16	CVS	Charging Line	4"-CVS-2511 (Outside CV)	4	4.5	0.531	SA-312 TP304	130	2600	Subcooled liquid	Air (105, 0)
17	CVS	Charging Line	3"-CVS-2511	3	3.5	0.438	SA-312 TP304	130	2600	Subcooled liquid	Air (105, 0)
18	CVS	Charging Line	2"-CVS-25B1	2	-	-	-	130	2600	Subcooled liquid	Air (105, 0)
19	RCS	MCP Drain	2"-RCS-2501	2	2.375	0.344	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
20	CVS	Letdown Line	2"-RCS-2501	2	2.375	0.344	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
21	CVS	Letdown Line	3"-RCS-2501	3	3.5	0.438	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
22	CVS	Letdown Line	3"-CVS-2501	3	3.5	0.438	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
23	CVS	Letdown Line	3"-CVS-2561	3	3.5	0.438	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
24	CVS	Letdown Line	3"-CVS-0601	3	3.5	0.216	SA-312 TP304	380	350	Subcooled liquid	Air (120, 0)
25	CVS	Letdown Line	4"-CVS-0601	4	4.5	0.237	SA-312 TP304	380	350	Subcooled liquid	Air (120, 0)
26	CVS	Letdown Line	4"-CVS-06A1	4	-	-	-	200	350	Subcooled liquid	Air (105, 0)
27	SIS	Emergency Letdown Line	2"-RCS-2501	2	2.375	0.344	SA-312 TP316	621	2266	Subcooled liquid	Air (120, 0)
28	SIS	DVI Line	4"-RCS-2501	4	4.5	0.531	SA-312 TP316	554.6	2266	Subcooled liquid	Air (120, 0)
29	SIS	SI Pump Line	4"-RCS-2501	4	4.5	0.531	SA-312 TP316	621	2266	Subcooled liquid	Air (120, 0)
30	SIS	SI Pump Line	4"-SIS-2501	4	4.5	0.531	SA-312 TP316	621	2266	Subcooled liquid	Air (120, 0)
31	RCS	Pressurizer Safety Valve Line	6"-RCS-2501	6	6.625	0.719	SA-312 TP316	657	2266	Saturated steam	Air (120, 0)
31	RCS	Pressurizer Safety Depressurization Valve Line	4"-RCS-2501	4	4.5	0.531	SA-312 TP316	657	2266	Saturated steam	Air (120, 0)
32	RCS	Pressurizer Safety Depressurization Valve Line	6"-RCS-2501	6	6.625	0.719	SA-312 TP316	657	2266	Saturated steam	Air (120, 0)
33	RCS	Pressurizer Safety Depressurization Valve Line	8"-RCS-2501	8	8.625	0.906	SA-312 TP316	657	2266	Saturated steam	Air (120, 0)

34	CVS	Seal Injection Line	1-1/2"-CVS-2501	1-1/2	1.9	0.281	SA-312 TP316	130	2266	Subcooled liquid	Air (120, 0)
35	CVS	Seal Injection Line	1-1/2"-CVS-2511	1-1/2	1.9	0.281	SA-312 TP304	130	2600	Subcooled liquid	Air (105, 0)
36	CVS	Seal Injection Line	1-1/2"-CVS-25B1	1-1/2	-	-	-	130	2600	Subcooled liquid	Air (105, 0)
37	CVS	Seal Injection Line	1"-CVS-2511	1	1.315	0.250	SA-312 TP304	130	2600	Subcooled liquid	Air (105, 0)
38	CVS	Seal Injection Line	2"-CVS-2511	2	2.375	0.344	SA-312 TP304	130	2600	Subcooled liquid	Air (105, 0)
39	CVS	Seal Injection Line	2"-CVS-25B1	2	-	-	-	130	2600	Subcooled liquid	Air (105, 0)
40	SIS	Accumulator Tank Drain Line	2"-SIS-06A1	2	-	-	-	300	700	Subcooled liquid	Air (120, 0)
41	SIS	Accumulator Tank Line	14"-SIS-2511	14	14	1.406	SA-312 TP304	300	2485	Subcooled liquid	Air (120, 0)
42	SIS	Accumulator Tank Line	14"-SIS-0601	14	14	0.500	SA-312 TP304	300	700	Subcooled liquid	Air (120, 0)
43	EFS	Emergency Feedwater Pump Line	3"-FWS-1522	3	3.5	0.300	SA-106 Gr.B	471	1185	Subcooled liquid	Air (130, 0)
44	EFS	Emergency Feedwater Pump Turbine Line	6"-EFS-1532	6	6.625	0.432	SA-106 Gr.B	539	938	Subcooled liquid	Air (130, 0)
45	EFS	Emergency Feedwater Pump Turbine Line	6"-MSS-1532	6	6.625	0.432	SA-106 Gr.B	539	938	Subcooled liquid	Air (130, 0)
46	FWS	Feedwater Line	18"-FWS-1805	18	18	1.375	SA-335 Gr.P22	471	1850	Subcooled liquid	Air (130, 0)
47	FWS	Feedwater Line	6"-FWS-1805	6	6.625	0.562	SA-335 Gr.P22	471	1850	Subcooled liquid	Air (130, 0)
48	FWS	Feedwater Line	16"-FWS-1525	16	16	0.844	SA-335 Gr.P22	471	1185	Subcooled liquid	Air (130, 0)
49	FWS	Feedwater Line	3"-FWS-1802	3	3.5	0.438	SA-106 Gr.B	471	1850	Subcooled liquid	Air (130, 0)
50	MSS	Main Steam Line	32"-MSS-1532	32	32	1.500	SA-333 Gr.6	539	938	Saturated steam	Air (130, 0)
51	MSS	Main Steam Line	6"-MSS-1532	6	6.625	0.432	SA-106 Gr.B	539	938	Saturated steam	Air (130, 0)
52	MSS	Main Steam Drain Line	2"-MSS-1532	2	2.375	0.218	SA-106 Gr.B	539	938	Saturated liquid	Air (130, 0)
53	MSS	Main Steam Drain Line	4"-MSS-1532	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (130, 0)
54	SGS	SGBD Line	3"-SGS-1532	3	3.5	0.300	SA-106 Gr.B	539	938	Saturated liquid	Air (120, 0)

55	SGS	SGBD Line	4"-SGS-1532 (Inside CV)	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (120, 0)
56	SGS	SGBD Line	4"-SGS-1532 (Outside CV)	4	4.5	0.337	SA-106 Gr.B	539	938	Saturated liquid	Air (105, 0)
57	SGS	SGBD Line	3/8"-SGS-2521	3/8	-	-	-	539	938	Saturated liquid	Air (120, 0)
58	SGS	SGBD Line	3/8"-SGS-25CA	3/8	-	-	-	539	938	Saturated liquid	Air (105, 0)

break. If the effects of breaks of moderate-energy fluid system piping are more severe than those of high-energy fluid system piping, then the provision of this Subsection 3.6.2.1.2.2 is applied.

Through-wall leakage cracks instead of breaks may be postulated in the piping of those fluid systems that qualify as high-energy fluid systems for about 2% of the operational period but qualify as moderate-energy fluid systems for the major operational period.

3.6.2.1.2.1 Moderate-Energy Fluid System Piping in PCCV Penetration Areas

Leakage cracks are not postulated in those portion of the piping from PCCV wall to and including the inboard and outboard isolation valves provided that the PCCV penetration meets the requirements of ASME Code, Section III (Reference 3.6-10), Subarticle NE-1120 and the piping is designed so that the maximum stress range based on the sum of Equations (9) and (10) in Subarticle NC/ND-3653 of the ASME Code, Section III (Reference 3.6-9) does not exceed 0.4 times the sum of the stress limits given in NC/ND-3653.

3.6.2.1.2.2 Moderate-Energy Fluid System Piping in Areas Other than PCCV Penetrations

Leakage cracks are postulated in the following piping systems located adjacent to SSCs important to safety.

- For ASME Code, Section III, Class 1 piping, where the stress range calculated by Eq. (10) in NB-3653 is ~~less~~more than 1.2 S(m)
- For ASME Code, Section III (Reference 3.6-9), Class 2 and 3 and non-safety class piping, at axial locations where calculated stress by the sum of Equations 9 and 10 in NC/ND-3653 exceed 0.4 times the sum of the stress limits given in NC/ND-3653.
- For non-safety class piping, which has not been evaluated to obtain stress information, leakage cracks are postulated at axial locations that produce the most severe environmental effects.

3.6.2.1.3 Types of Break/Cracks Postulated

3.6.2.1.3.1 Circumferential Pipe Breaks

Circumferential breaks are postulated in high-energy fluid system piping and branch runs exceeding a nominal pipe size of 1 inch at locations identified by the criteria in Subsection 3.6.2.1.1.2

No breaks are postulated in piping having a nominal diameter less than 1 inch, including instrument lines that are designed in accordance with RG 1.11 (Reference 3.6-13).

If the maximum stress range exceeds the limits specified in Subsection 3.6.2.1.1.2 and the circumferential stress range is greater than 1.5 times the axial stress range, no circumferential break is postulated; only a longitudinal break (Subsection 3.6.2.1.3.2) is postulated.

expected range of impact energies demonstrate the capability to withstand the impact without rupture. Effects on environment and shutdown logics associated with the failure of the impacted pipe are considered.

3.6.2.5 Placement of essential SSCs in segregated areas, which are not subject to the Implementation of Criteria Dealing with Special Features

Special features such as pipe whip restraints, barriers, and shields are discussed in Subsection 3.6.2.4.4.

3.6.2.6 Outline of Pipe Break Hazard Analysis Report(s)

The following information is outline of methodology for the pipe break hazard analysis that will be completed for all the piping systems (including the non-safety class piping) in accordance with closure of Inspections, Tests, Analyses and Acceptance Criteria (ITAAC) Tier 1, Table 2.3-2 related to pipe break hazard analysis report:

- Identification of pipe break locations in high energy piping[1]
- Identification of leakage crack locations in high and moderate energy piping
- Identification of SSCs that are safety-related or required for safe shutdown[2]
- Evaluation of consequences of pipe whip and jet impingement
- Evaluation of consequences of spray wetting, flooding, environmental conditions
- Design and location of protective barriers, restraints, and enclosures

Notes

1. Table 3.6-2 shows the list of high energy lines for pipe break hazard analysis, including properties of internal and external fluids.
2. All the SSCs that are safety-related or required for safe shutdown in close proximity to the postulated pipe rupture will be identified.

3.6.3 LBB Evaluation Procedures

This subsection describes the design basis to eliminate the dynamic effects of pipe rupture (Subsection 3.6.2) for the selected high-energy piping systems of RCL piping, RCL branch piping, and main steam piping. GDC 4 of Appendix A to 10 CFR 50 (Reference 3.6-1) allows exclusion of dynamic effects associated with pipe rupture from the design basis, when analyses demonstrate that the probability of pipe rupture is extremely low for the applied loading resulting from normal conditions, anticipated transients and a postulated SSE. The LBB evaluation is performed in accordance with SRP 3.6.3 (Reference 3.6-4).

The LBB analysis combines normal and abnormal (including seismic) loads to determine a critical crack size for a postulated pipe break. The critical crack size is compared to the size of a leakage crack for which detection is certain. If the leakage crack size is sufficiently smaller than the critical crack size, the LBB requirements are satisfied.

Table 2.3-2 Piping Systems and Components Inspections, Tests, Analyses, and Acceptance Criteria (Sheet 2 of 2)

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
4. Safety-related SSCs have adequate high-energy pipe break mitigation features. are designed to be protected against or qualified to withstand the dynamic and environmental effects associated with analyses of postulated failures for all the piping systems (including the non-safety class piping).	4.i A pipe break analysis of the as-built high-energy line will be performed. Dynamic effect analysis will be performed for the high-energy piping system. The analysis includes the evaluation of pipe whip and jet impingement.	4.i The reconciliation of the as-built configuration of high-energy pipe lines concludes that, Pipe break hazard analysis report(s) for all high-energy piping system exist and conclude that for each postulated piping failure, the reactor can be shut down safely and maintained in a safe, cold shutdown condition without offsite power. For postulated pipe breaks, tThe report confirms whether: (A) piping stresses in the containment penetration area are within allowable stress limits, (B) pipe whip restraints and jet shield designs can mitigate pipe break loads, and (C) loads on safety-related SSCs are within design load limits and (D) SSCs are protected or qualified to withstand the environmental effects of postulated failures.
	4.ii Environmental effect analysis will be performed for the high-energy piping and moderate-energy piping systems. The analysis includes the evaluation for spray wetting, flooding, and environmental conditions, as appropriate.	4.ii Pipe break hazard analysis report(s) for all high-energy piping and moderate-energy piping systems exist and conclude that for each postulated piping failure, the reactor can be shut down safely and maintained in a safe, cold shutdown condition without offsite power. The report confirms whether SSCs are protected or qualified to withstand the environmental effects of postulated failures.
5. Safety-related SSCs are reconciled with the analyses results of as-designed pipe break hazard analysis report(s).	5. A reconciliation analysis of the as-built high-energy piping and moderate-energy piping using as-designed pipe break hazard analysis report(s) and as-built information will be performed.	5. Pipe break hazard analysis report(s) exist and conclude that the as-built high-energy piping systems including the protective features and moderate-energy piping systems are installed in the as-built plant as described in the as-designed pipe break hazard analysis report(s).