Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555

Direct tel: 412-374-4728
Direct fax: 412-374-5005
e-mail: vijukrp@westinghouse.com

Your ref: Docket No. 52-006
Our ref: DCP/NRC1662

December 31, 2003

SUBJECT: Transmittal of Responses to AP1000 DSER Open Items

This letter transmits the Westinghouse responses to Open Items in the AP1000 Design Safety Evaluation Report (DSER). A list of the DSER Open Item responses transmitted with this letter is Attachment 1. The proprietary responses are transmitted as Attachment 2. The non-proprietary responses are provided as Attachment 3 to this letter.

The Westinghouse Electric Company Copyright Notice, Proprietary Information Notice, Application for Withholding, and Affidavit are also enclosed with this submittal letter as Enclosure 1. Attachment 2 contains Westinghouse proprietary information consisting of trade secrets, commercial information or financial information which we consider privileged or confidential pursuant to 10 CFR 2.790. Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosures.

This material is for your internal use only and may be used for the purpose for which it is submitted. It should not be otherwise used, disclosed, duplicated, or disseminated, in whole or in part, to any other person or organization outside the Commission, the Office of Nuclear Reactor Regulation, the Office of Nuclear Regulatory Research and the necessary subcontractors that have signed a proprietary non-disclosure agreement with Westinghouse without the express written approval of Westinghouse.

D063

December 31, 2003

Correspondence with respect to the application for withholding should reference AW-03-1757, and should be addressed to Hank A. Sepp, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company, P.O. Box 355, Pittsburgh, Pennsylvania, 15230-0355.

Please contact me at 412-374-4728 if you have any questions concerning this submittal.

Very truly yours,

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Enclosure

1. Westinghouse Electric Company Copyright Notice, Proprietary Information Notice, Application for Withholding, and Affidavit AW-03-1757.

/Attachments

1. List of the AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses transmitted with letter DCP/NRC1662
2. Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated December 31, 2003
3. Non-Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated December 31, 2003

December 31, 2003

Enclosure 1

Westinghouse Electric Company
Application for Withholding and Affidavit

Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

December 31, 2003

AW-03-1757

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

ATTENTION: Mr. John Segala

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: Transmittal of Westinghouse Proprietary Class 2 Documents Related to AP1000 Design Certification Review Draft Safety Evaluation Report (DSER) Open Item Response

Dear Mr. Segala:

The application for withholding is submitted by Westinghouse Electric Company, LLC ("Westinghouse") pursuant to the provisions of paragraph (b)(1) of Section 2.790 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject documents. In conformance with 10 CFR Section 2.790, Affidavit AW-03-1757 accompanies this application for withholding setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-03-1757 and should be addressed to the undersigned.

Very truly yours,

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Enclosures

AW-03-1757

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Dennis M. Popp, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company, LLC ("Westinghouse"), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief.

Dennis M. Popp, Manager
Regulatory Compliance
Nuclear Services Division

Sworn to and subscribed
before me this 30TH day
of DECEMBER, 2003

Notary Public

Notarial Seal
Jessica L. Gribben, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires June 7, 2004
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory Compliance, of the Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Electric Company, LLC.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company, LLC in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in Attachment 2 as Proprietary Class 2 in the Westinghouse Electric Co., LLC document: (1) "AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Response."

This information is being transmitted by Westinghouse's letter and Application for Withholding Proprietary Information from Public Disclosure, being transmitted by Westinghouse Electric Company letter AW-03-1757 to the Document Control Desk, Attention: John Segala, CIPM/NRLPO, MS O-4D9A.

This information is part of that which will enable Westinghouse to:

(a) Provide documentation supporting determination of APP-GW-GL-700, "AP1000 Design Control Document," analysis on a plant specific basis

(b) Provide the applicable engineering evaluation which establishes the Tier 2 requirements as identified in APP-GW-GL-700.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for Licensing Documentation.

(b) Westinghouse can sell support and defense of AP1000 Design Certification.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar methodologies and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for performing and analyzing tests.

Further the deponent sayeth not.

December 31, 2003

Copyright Notice

December 31, 2003

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

DCP/NRC1662
Docket No. 52-006

December 31, 2003

Attachment 3

AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: 5.2.3-3 Revision 1

Original RAI Number(s): None

Summary of Issue:

The high-chromium nickel-base alloys (e.g., Alloy 690/52/152, as well as 82/182) may be susceptible to a significantly lowered fracture toughness if they have been exposed to high temperature hydrogenated water and then stressed at lower temperature (e.g., < 120°C). This is a known phenomenon and may be of significance during a thermal shock event (i.e., during an accident scenario when there is ingress of large amounts of cold water into the primary system). Address whether this phenomenon could result in the failure of the nozzles between the pressure vessel and main recirculation or direct vessel injection (DVI) piping. If such a failure occurred, what are the consequences?

Westinghouse Response:

Background

The scenario reflected in the open item is that, since it is possible that small subsurface weld flaws such as hot cracks or floaters/stringers may be present in heavy section multipass welds of Alloys 52 and 152, might these flaws serve as sites for the initiation and subsequent growth of cracks. There have been a reported decrease of toughness of these welds in low temperature hydrogenated water environments. Could such degradation occur for an accident scenario in with large amounts of cold water rapidly lowering the temperature before hydrogen is removed from the metal and the reactor coolant?

Under normal plant shutdown conditions such a scenario is not possible since hydrogen is removed by a combination of mechanical and chemical degassing before the water temperature gets below about 180°F.

Essentially all published research on the phenomenon referred to as low temperature crack propagation (LTCP) has been the result of research conducted by Mills and co-workers at Bettis (cf., Refs. 1-4).

Literature

The published research was reviewed and an abbreviated summary of relevant results with the authors' conclusions follow.

The materials that have been studied for susceptibility to the LTCP phenomenon include Alloy X-750, Alloys 600 and 690, and the weld metal Alloys EN82H and EN52. All but Alloy 600 have been found susceptible to varying degrees. The reason for the exception of Alloy 600 is not clear. The general ranking of the alloys found susceptible is (most to least susceptible): Alloy X-750, Alloy EN82H, Alloy EN52, Alloy 690. Each of these alloys exhibits extremely high fracture resistance in air and high temperature water, irrespective of the presence of hydrogen.

With regard to the present issue, the research reported in Ref. 4 is most relevant. Deeply precracked compact tension specimens of Alloys EN82H, EN52, 690 and 600 were tested at 54°C (130°F), 93°C (200°C), 149°C (300°C) and 338°C (640°F) water containing concentrations of dissolved hydrogen ranging from 15 to 150 cm^3 (STP) H_2/kg H_2O. Limited testing was also performed in 54°C (130°F) and 338°C (640°F) air.

The specimens were tested to fracture using a displacement rate of 4 MPa√m/h at 54°-149°C and 0.4 to 2 MPa√m/h at 338°C to assure sufficient time for environmental cracking. Multiple-specimen heat-treat and single-specimen normalization J-curve test procedures were used to establish J_{IC} and tearing modulus values (Refs. 1, 5). J_{IC} is the fracture toughness at the onset of cracking and the tearing modulus is a dimensionless measure of a material's resistance to cracking after J_{IC} is exceeded (see Ref. 4 for definition of terms).

For the tests in air, all materials exhibited extremely high values of J_{IC} and T. However, in 54° and 93°C water the values were severely reduced. The following table summarizes the J_{IC} and tearing modulus results for the 54°C tests in hydrogenated water.

Material	J_{IC} at 54°C, kJ/m^2/Tearing Modulus		
	15 cm^3 H_2/kg H_2O	50 cm^3 H_2/kg H_2O	150 cm^3 H_2/kg H_2O
Alloy 690 Heat A	150/128	90/72	75/38
Alloy 690 Heat B	120/63	95/58	25/24
EN52 Heat B1	No test	No test	~ 50/38
EN52 Heats C1, C2	100/53	80/59	20/4
EN82H Heat C1	8/3	No test	10/5
Alloy 600 Heat A	285/232	No test	285/232

The authors conclude from these data that, in view of the reasonably high tearing moduli for Alloy 690 (24 to 38 at the highest hydrogen concentration), LTCP is not a concern for that alloy.

For the embrittled welds, the authors calculate equivalent critical stress intensity factors (K_{JC}) from the experimental J_{IC} values, and find good agreement with the maximum stress intensity values (K_{Pmax}) observed in previous rising-load tests. [A thorough description of the testing and data interpretation for the rising load tests is provided in Ref. 3.] This agreement suggests that cracking initiates near maximum load under nearly linear-elastic conditions; as a result, lower-bound K_{Pmax} values can be used as a measure of LTCP resistance.

The resulting lower-bound K_{Pmax} values for EN82H and EN52 are 40 and 53 MPa√m, respectively. [Observe that these are not 'low' stress intensities.]

Additional aspects of the Ref. 4 test program included consideration of the displacement rate and the effect of crack geometry. For displacement rates greater than 1000 MPa√m/h (approximately 12 mm/h per the authors for this geometry), LTCP resistance of both weld metals improves significantly, leading the authors to conclude that this phenomenon "is not an issue for welded components subjected to rapid transients."

The authors also observed (in Ref. 4 and other publications) that intergranular LTCP does not occur from as-machined notches or at free surfaces in the absence of a sharp corrosion-induced crack (or perhaps even a small ductile tear). This is interpreted in terms of the requirement that hydrogen is concentrated at the crack tip, and this requires solid-state diffusion of hydrogen.

Other research (Refs. 1 – 3) by the same authors indicates the following:

- LTCP is due to hydrogen embrittlement of the grain boundary regions adjacent to and immediately ahead of the advancing crack,
- The phenomenon appears only under conditions of rising loads – i.e., not under constant load conditions,
- For Alloy 52, the critical stress intensity must be greater than 50 MPa√m, and
- The effective displacement rate must be quite low.

The latter point has been interpreted as supporting the judgment that solid-state diffusion of hydrogen is rate-controlling. This was further supported by calculations and measurements of the activation energies for LTCP crack growth rates (11.3 kcal/mole) and for hydrogen diffusion at this temperature (11.5 kcal/mole). This is also consistent with the observation that LTCP does not occur in the presence of a notch since the diffusion distance to the peak stress location ahead of a notch is much greater than that for a sharp (SCC) crack.

Relevance to Alloy 52/152 Welds in AP1000

Alloys 52 and 152 will be used for large section, multipass welds such as reactor vessel nozzle-to-safe-end welds in AP1000. It is possible that subsurface flaws such as small hot cracks or oxide "floaters" may be present.

However, based on the preceding review of the literature, there appears to be no technical basis to argue such welded structures will be susceptible to low temperature crack propagation under normal or accident-driven conditions. The basis for this conclusion rests on the conditions under which LTCP has been observed to occur in these materials. These conditions include:

- high loads that are applied slowly, increase with time, and are capable of producing high stress intensities, and
- the presence of sharp intergranular (or ductile) cracks.

Hot cracks or subsurface welding defects are unlikely to be characterized by a sharp, "crack-tip" geometry such that high hydrogen concentrations will develop and promote crack advance. Also, the relatively rapidly applied high loads that may be associated with a surge of low temperature water under accident conditions are not consistent with LTCP occurrence. Moreover, the extremely high resistance of these high chromium alloys to stress corrosion crack initiation in primary water makes it extremely unlikely that in-service cracking will occur; hence, a low probability that a surface crack will exist to serve as the propagation site.

References

1. C. M. Brown and W. J. Mills, "Fracture Toughness of Alloy 690 and EN52 Weld in Air and Water," Bettis Atomic Power Laboratory Report, B-T-3265, June 1999.
2. W. J. Mills and C. M. Brown, "Fracture Toughness of Alloy 600 and an EN82H Weld in Air and Water," Metallurgical and Materials Transactions A, 32A (May 2001) 1161-1174.
3. W. J. Mills, M. R. Lebo and J. J. Kearns, "Hydrogen Embrittlement, Grain Boundary Segregation, and Stress corrosion Cracking of Alloy X-750 in Low- and High-Temperature Water," Metallurgical and Materials Transactions A, 30A (June 1999) 1579-1596.
4. W. J. Mills and C. M. Brown, "Fracture Behavior of Nickel-based Alloys in Water," *Ninth International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors*, TMS, 1999.
5. W. C. Porr and W. J. Mills, "Application of the Normalization Data Analysis Technique for Single Specimen R-Curve Determination," Bettis Atomic Power Laboratory Report B-T-3269, February 1999.

NRC Additional (Nov 10, 2003) Comments:

The staff has reviewed your September 8, 2003, response on lowered fracture toughness of Alloy 690/52/152 materials after exposure to hydrogenated water; low temperature crack propagation (LTCP) issue. For the staff to evaluate this information, the staff needs the following additional information.

a. Provide the H_2 concentration of the reactor coolant at normal plant operating conditions.

b. The LTCP issue is loading rate sensitive. Please indicate what transients could lead to LTCP in reactor coolant pressure boundary welds in the AP1000 and provide the applicable loading rates for those transients. For the limiting transient or transients from that set, what temperature levels would the most susceptible bi-metallic welds reach? What bi-metallic welds in the reactor coolant system would experience the most significant cool down effect (i.e., maximum stress intensity)?

c. Provide a schematic drawing of welds at these locations. For example, describe whether these welds would consist of Alloy 52 material through the entire wall or would consist of Alloy 52 in contact with the reactor coolant and Alloy 82 for the remainder of the wall thickness.

d. Assume a small but credible ID surface breaking flaw in the bi-metallic welds identified in parts b. and c. above. Evaluate what conditions and effects the flaws would see as a result of the limiting transient(s) (i.e., hydrogen concentration, final temperature, loading rate, and failure potential).

Westinghouse Response to NRC Additional (Nov 10, 2003) Comments:

a) The specification for hydrogen concentration of the reactor coolant at normal operating conditions is given in DCD Table 5.2-2 as 25 to 50 cm^3 (STP) H_2/kg H_2O. The normal operating range is expected to be 30 t0 40 cm^3 (STP)/kg H_2O.

b) and d) Please refer to the initial response. The following is offered as additional analysis of this issue.

Synopsis of Previous Submittal:

- In the presence of substantial concentrations of hydrogen in the service environment, reductions in toughness and the resistance to crack propagation have been observed for certain high-chromium nickel-based alloys, including Alloy X-750, Alloy 690 and the weld metal Alloys EN82H and EN52. This mode of degradation is referred to as Low Temperature Crack Propagation (LTCP).
- LTCP has been observed to occur only at low temperatures – most profoundly in the range 54 to 93°C (130 to 200°F) – under conditions of rising, high loads.
- In terms of susceptibility to this phenomenon, the alloys can be ranked from most to least affected as: Alloy X-750, Alloy EN82H, Alloy EN52 and Alloy 690. Alloy 600 does not appear susceptible to this form of environmental degradation.

- The mechanism responsible for LTCP is the stress-assisted accumulation of hydrogen adjacent to and immediately ahead of an advancing crack, leading to a decreased resistance to intergranular crack propagation. As such, the phenomenon can be characterized as time-dependent – i.e., time is required for the diffusion of hydrogen to the crack tip. This feature of LTCP has led the authors [see Refs. 1-5]. To conclude that *" .... (LTCP) is not an issue for welded components subject to rapid transients."*
- LTCP does not occur from as-machined notches or at free surfaces in the absence of a sharp corrosion-induced crack. This reflects the inability of hydrogen to concentrate in the diffuse strain field associated with such features. The potentially undetected defects in Alloy 52/152 welds would be hot cracks. The morphology of hot cracks – rounded interdendritic "pores" – indicates that LTCP would not occur at such defects.
- The authors conclude that, despite the decrease in toughness of Alloy 690, the tearing modulus remains sufficiently high that LTCP is not a concern for that alloy. This is based on the data in the table presented previously, where minimum tearing moduli of 63 and 58 were observed at 54°C in water containing 15 and 50 cm^3 (STP) H_2/kg H_2O, respectively [Ref. 4].

Additional Aspects of the Literature:

- In the same test program referred to above [Ref. 4], Alloy EN52 welds at 54°C exhibited tearing moduli of 53 and 59 in the 15 and 50 cm^3 H_2/kg H_2O environments, respectively. These are comparable to those for Alloy 690, judged by the authors to remove this alloy from concern. In Ref. 6, Mills et al. offer the following categorization of the impact of LTCP on the Ni-based alloys, with respect to measured values of J_{IC} and the Tearing Modulus (T):

Category I:	$J_{IC} < 30$ kJ/m^2 [$K_{IC} < 75$ MPa$\sqrt{m}$]; $T < 10$ Low toughness material where failure can occur below the yield strength for relatively small flaw sizes.
Category II:	$30 < J_{IC} < 150$ kJ/m^2 [$75 < K_{IC} < 150$ MPa$\sqrt{m}$]; $10 < T < 100$ Intermediate toughness material where unstable or stable fracture can occur at approximately yield strength loadings for small to medium flaw sizes.
Category III:	$J_{IC} > 150$ kJ/m^2 [$K_{IC} > 150$ MPa$\sqrt{m}$]; $T > 100$ High toughness material where fracture involves stable tearing at stresses well above the yield strength. Tearing instabilities are unlikely except after gross plastic deformation.

From the data provided in Refs. 4 and 6, Alloy EN52 (and presumably Alloy 152) welds are regarded as Category II materials.

Additional Discussion:

From the literature reviewed here, four conditions must be satisfied simultaneously for the occurrence of LTCP:

1. relatively high concentrations of hydrogen (in the environment and therefore in the metal),
2. low temperatures; typically in the range from 54 to 93°C (130 to 200°F),
3. the presence of a "sharp" crack tip, and
4 the presence of sustained high loads.

A consideration of LTCP as a potential degradation mechanism for Alloy 690-type materials has been published recently in a report prepared for the Materials Reliability Program activities coordinated by EPRI [Ref. 7]. In that assessment, the authors review the Bettis literature referred to here, complemented by the results of French research on cathodically charged (with hydrogen) Alloy 690. The conclusions of that assessment indicate that a minimum hydrogen concentration of 30 wppm is required for intergranular cracking at room temperature. From Sievert's Law estimates, the hydrogen concentration in nickel-base alloys exposed in a "PWR primary water" aqueous environment containing 25 to 50 cm^3 H_2/kg H_2O is on the order of 2 to 3 wppm. Even allowing for localized concentrations due to hydrostatic stress, the hydrogen concentration cannot exceed this by more than a factor of two or so. Hence, ***Condition 1 is not satisfied.***

Condition 2 may be satisfied in the event of an incident which would rapidly lower the temperature from normal operating conditions to the temperature range of concern. This will be explored further below.

Condition 3 is unlikely to be satisfied except for the possible existence of a "lack-of-fusion" condition arising from welding. In-service (elevated temperature) stress corrosion cracking of Alloy 52 or Alloy 152 is judged to be a non-concern based on all available published data which attests to the extraordinary resistance of these materials to PWSCC crack initiation.

Condition 4 requires the presence of stresses which, according to the categorization of Mills et al. [Ref. 6], must be on the order of the yield strength of the weld metal.

In order to quantify the conditions that could occur at the nozzle safe-end welds that will consist of the Alloy 52/152 weld metal, a review of the primary system was conducted, considering various cold temperature transients. The accident scenario that appears to result in the most aggressive conditions is the inadvertent opening of the isolation valves that separate the large-volume core makeup tanks (CMT) from the reactor vessel. This transient results in a large volume of room temperature water flowing through the Direct Vessel Injection (DVI) nozzle and, in particular, the Alloy 52/152 safe-end butt welds used to connect the nozzle safe-ends to the nozzle body (see Attachment 5.2.3-3 R1-1). For this scenario it is assumed the operators take no corrective action for at least thirty minutes. The temperature of the weld metal would quickly fall to near the temperature of the injection water (assumed to be 50°F). The primary system pressure initially falls due to the cooldown of the primary system, but later rises to the safety valve setpoint as the injected water heats up.

In order to assess the effect of this transient on the safe-end weld, an axisymmetric finite element model of the nozzle-safe end was developed. It was then assumed that the water from the CMT cools the safe-end weld from 550°F to 50°F in 30 seconds. This leads to a rapid spike in the stresses, both on the inside and on the outside of the nozzle. Figure 1 shows the results of the temperature and pressure transients on the axial (top plot) and hoop (bottom plot) stresses. The solid curves are of interest, since they are the stresses acting at the inside, wetted surface.

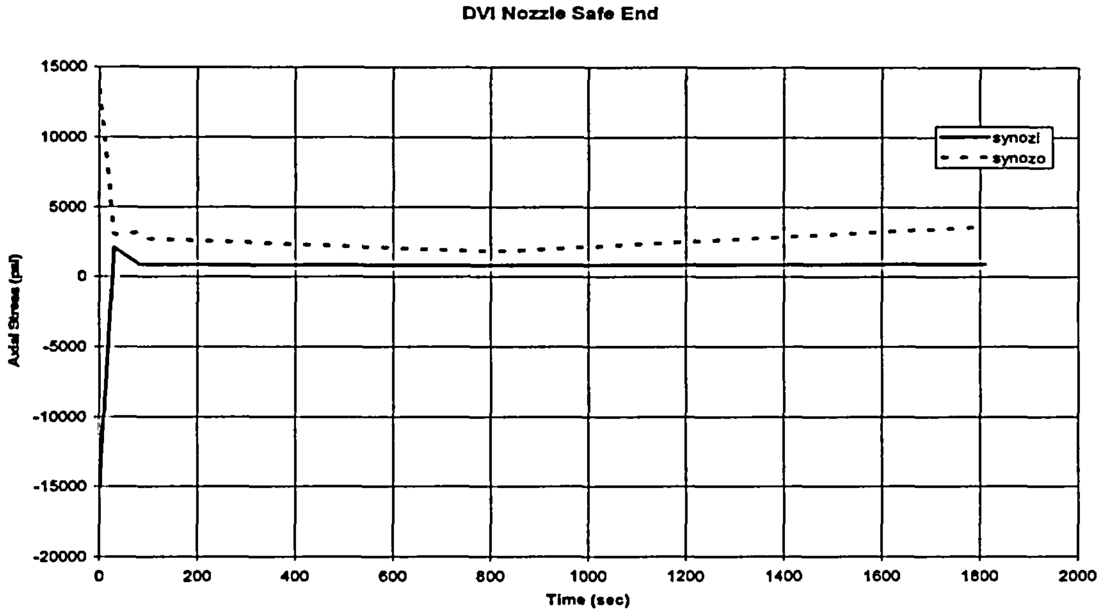
The ID hoop stresses peak at about 9000 psi in 30 seconds, after which the stresses begin to decrease and then slowly rise to approximately 8000 psi at 30 minutes (1800 seconds) when the safety valve pressure is reached. The stresses would not increase further even if the operators took no remedial action at thirty minutes because the safety valve setpoint has been reached. The normal operating stresses at this location due to pressure and thermal loads are 10,000 psi (hoop). Thus, the maximum stresses experienced by the DVI nozzle welds will be on the order of 19,000 psi. The yield strength of the Alloy 52 weld metal can be conservatively estimated as 50,000 psi. Hence, it is concluded that the stresses do not approach the level where LTCP might occur, and ***Condition 4 is not satisfied.***

From the preceding, it is concluded that of the four conditions necessary for LTCP to represent a legitimate concern, the only one that will be met, under postulated accident conditions, is the decreased temperature. Even allowing for the existence of a sharp defect (lack of fusion) in the weld, the hydrogen concentration in the weld metal and the applied stresses are insufficient to cause crack propagation.

Note that the discussion and conclusions presented here apply equally to assumed welding flaws that are surface-breaking or embedded within the weld. Also, although specific LTCP test results are not available for Alloy 152, the similarity in chemical composition and general welding characteristics of Alloy 52 and Alloy 152 argue that the discussion and conclusions presented here apply equally to both weld metals.

Additional References:

6. W. J. Mills, C. M. Brown and M. G. Burke, "Fracture Behavior of Alloy 600, Alloy 690, EN82H Welds and EN52 Welds in Water," Bettis Atomic Power Laboratory Report, B-T-3303, presented at an EPRI Workshop, July 1999.
7. *Materials Reliability Program (MRP), Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52 and 152 in Pressurized Water Reactors,* Draft Final Report, Dec. 3, 2003.
8. I. Lenartova, "Fragilisation par hydrogène et corrosion sous contrainte d'alliages de nickel et d'un acier inoxydable utilisés dans les générateurs de vapeur: influence de la composition chimique et de la microstructure " [English translation: "Hydrogen embrittlement of nickel base alloys and a stainless steel used in steam generators: influence of chemical composition and microstructure"], PhD Thesis, Ecole Centrale de Paris, 1996.



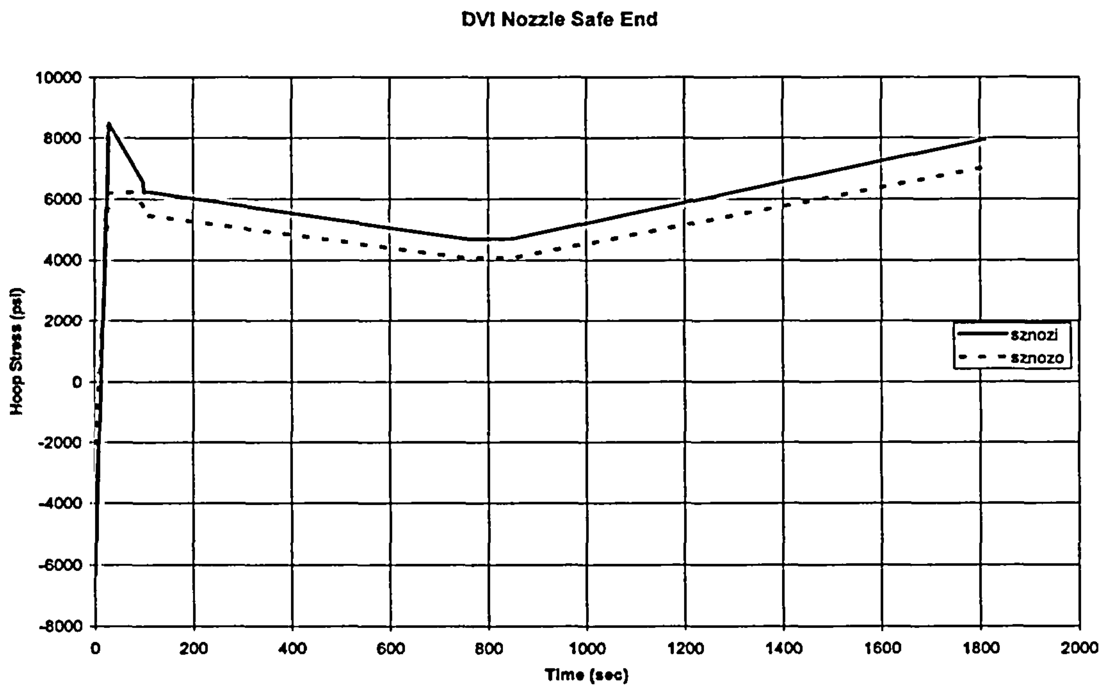
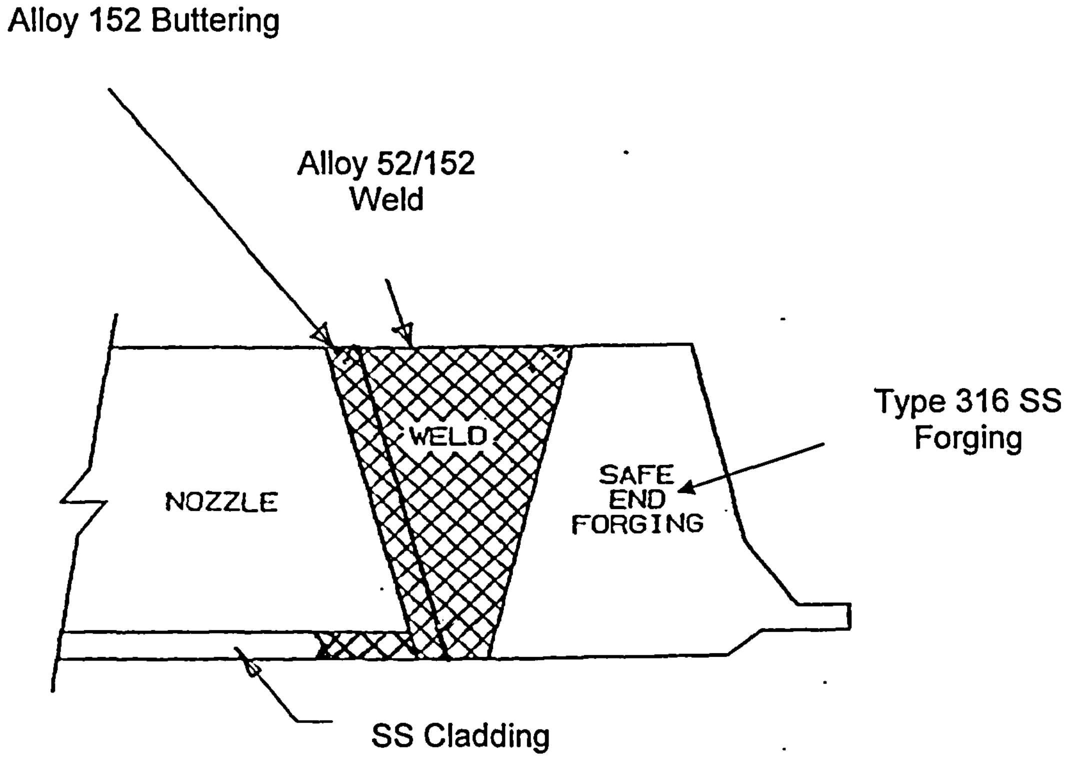


Figure 1 – Axial (top) and hoop (bottom) stresses on the DVI nozzle arising from an accident event in which the nozzle temperature is reduced from 550°F to 50°F in 30 seconds due to failure of the CMT isolation system.

c) Figure 2 provides a sketch of a typical nozzle safe-end butt weld. These welds are composed entirely of Alloy 52 (root and subsequent few passes) and Alloy 152 (later passes).



Alloy 152 Buttering
Alloy 52/152
Weld
Type 316 SS
Forging
WELD
NOZZLE
SAFE
END
FORGING
SS Cladding

Figure 2

Design Control Document (DCD) Revision:

None

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: **15.2.7-1 Item ADS4 Line Resistance**

Original RAI Number(s): **None**

Summary of Issue:

In a telecon with the NRC staff on 12/18/03 to discuss DSER OI 15.2.7-1 the reviewer requested additional information related to the calculation of line resistance for the Stage 4 ADS lines.

Westinghouse Response:

The ADS valves are discussed in DCD Tier 2 information in Sections 5.1.3.7, 5.4.6, and 6.3.2.2.8.5. The line resistance for the Stage 4 ADS lines are provided in DCD Tier 1 information in Table 2.1.2-4, Item 8.d)

The approach to calculate the Stage 4 ADS line resistances used in the plant safety analysis and in the ITAACs is:

- Divide the line into sections of the same size and schedule
- Pipe routing information for each section is determined from plant line routing drawings
- Conservative maximum resistance for each line segment is calculated using conservative loss factors (L/D's) for the components in each segment
- Individual line segment resistances are added together to determine the total line resistance.

a,c

a,c

Attachment 1 provides the detailed line resistance calculation for the Stage 4 ADS line segments and a summary table that compiles the individual line resistances. This information has been taken from the AP1000 calculation note.

Each table identifies the line segment, the associated line size and schedule, line ID, and friction factor used in the resistance calculation. The table then lists the number of each type of component in the line, including margins as discussed previously, and calculates a conservative total loss factor for the line. The total loss factor is then used to calculate the maximum line resistance for the segment, along with minimum and best estimate resistances.

The total maximum resistance without single failure for each Stage 4 ADS line is used for the ITAAC acceptance criteria in Table 2.1.2-4 of the DCD Tier 1 information. The calculated maximum line resistance value is rounded down to two significant figures so that the ITAAC acceptance criteria bounds the maximum line resistances used in the safety analysis.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Attachment 1 - ADS Line Resistance Calculation Note Tables

ADS 4 th Stage (Loop 1)

40-41 HL to ADS A,C Tee

a,c

41-42 Tee to ADS A Reducer

a,c

42-43 Reducer to V-004A

a,c

41-44 ADS A,C Tee to V-004C

a,c

ADS 4th Stage (Loop2)

40-41 HL to ADS B,D Tee

a,c

41-42 Tee to ADS B Reducer

a,c

42-43 Reducer to V-004B

a,c

41-44 ADS B,D Tee to V-004D

a,c

Total Maximum ADS 4 Line Resistances

a,c

Isometric for Stage 4 ADS Valves RCS-014A/C and -004A/C

a,c

Isometric for Stage 4 ADS Valves RCS-014B/D and -004B/D

a,c

[ ]

ADS Line Routing for Stage 4 ADS Valves RCS-014A/C and –004A/C

a,c

ADS Line Routing for Stage 4 ADS Valves RCS-014B/D and -004B/D

a,c

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: 21.5-1 Item 16 Revision 1

Original RAI Number(s): None

Summary of Issue:

For the comparison of the integrated liquid discharge through ADS-4 between the base DCD case and the revised noding model, Figure 21.5-1.12 on DSER OI 21.5-1P Page 11 has an inconsistency in that the heading states "ADS-4 Liquid Discharge Comparison" whereas the actual figure is for ADS-4 integrated vapor discharge.

Please clarify.

Westinghouse Response:

Figure 21.2.1-12 was intended to be a plot of ADS-4 Liquid Discharge Comparison. However the figure that was included was ADS-4 integrated vapor discharge as t he Item states. The attached figure is the corrected Figure 21.5-1.12 that shows ADS-4 Liquid Discharge Comparison.

NRC Comment from 12/17/03 Status meeting:

Revise WCAP-15644, Rev. 1, in the following areas (per Items 16, 17, and 29):

Correct Figure F-12 (i.e., Figure 21.5-1.12) for ADS-4 Liquid Discharge Comparison.

Correct text and Figure F-14 (i.e., Figure 21.5-1.14) to show Downcomer Pressure Comparison.

Correct the equation for critical bubble radius R-bcr of the Cunningham-Yeh correlation on Pp G-4.

Westinghouse Response (Revision 1):

WCAP-15644 Revision 1 will be revised as shown in open item response 21.5-2P Item 29 Revision 1, and issued as WCAP-15644 Revision 2.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

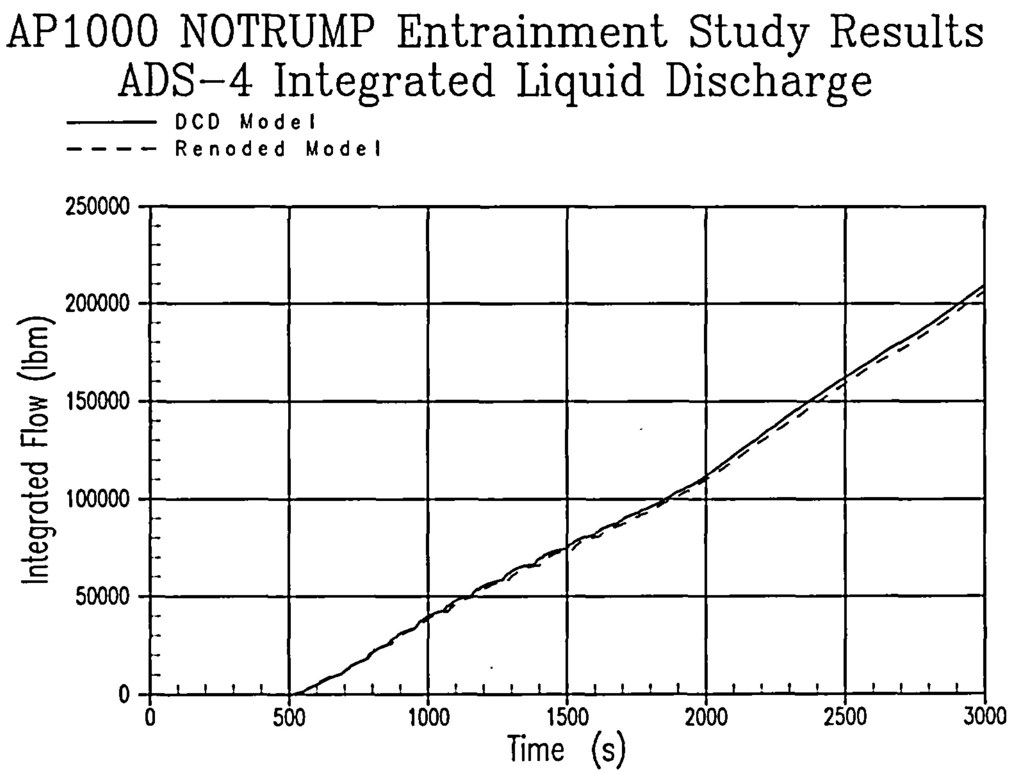


Figure 21.5-1.12 ADS-4 Liquid Discharge Comparison

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: **21.5-1 Item 17 Revision 1**

Original RAI Number(s): **None**

Summary of Issue:

The text on DSER OI 21.5-1P Page 3 states that Figure 21.5-1.14 presents a comparison of the upper downcomer pressure between the base case and the sensitivity case, but the actual figure is for pressurizer pressure (except for the heading). The text also states that the pressurizer mixture level response (Figure 21.5-1.25) reflects the change in pressure response (Figure 21.5-1.14) observed in the model.

Clarify the discrepancy regarding Figure 21.5-1.14.

Westinghouse Response:

Figure 21.5-1.14 was intended to show the upper downcomer pressure between the base case and the sensitivity case, but the actual figure is incorrect as stated in Item 17 above. The attached figure provides the corrected Figure 21.5-1.14. The plot of Pressurizer pressure is also provided as 21.5-1.26 and the text should refer to this figure for pressurizer pressure. No update to the previous response is intended.

NRC Comment from 12/17/03 Status meeting:

Revise WCAP-15644, Rev. 1, in the following areas (per Items 16, 17, and 29):

Correct Figure F-12 (i.e., Figure 21.5-1.12) for ADS-4 Liquid Discharge Comparison.

Correct text and Figure F-14 (i.e., Figure 21.5-1.14) to show Downcomer Pressure Comparison.

Correct the equation for critical bubble radius R-bcr of the Cunningham-Yeh correlation on Pp G-4.

Westinghouse Response (Revision 1):

WCAP-15644 Revision 1 will be revised as shown in open item response 21.5-2 Item 29 R1, and issued as WCAP-15644 Revision 2.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

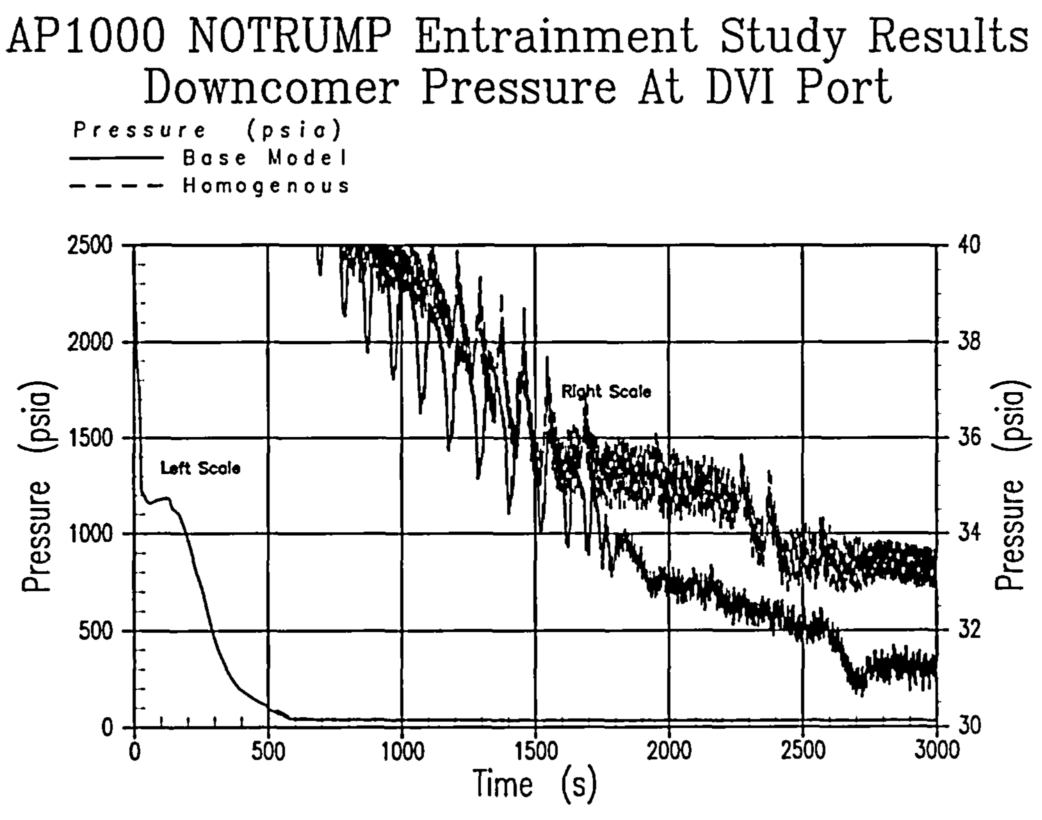


Figure 21.5-1.14 Downcomer Pressure Comparison

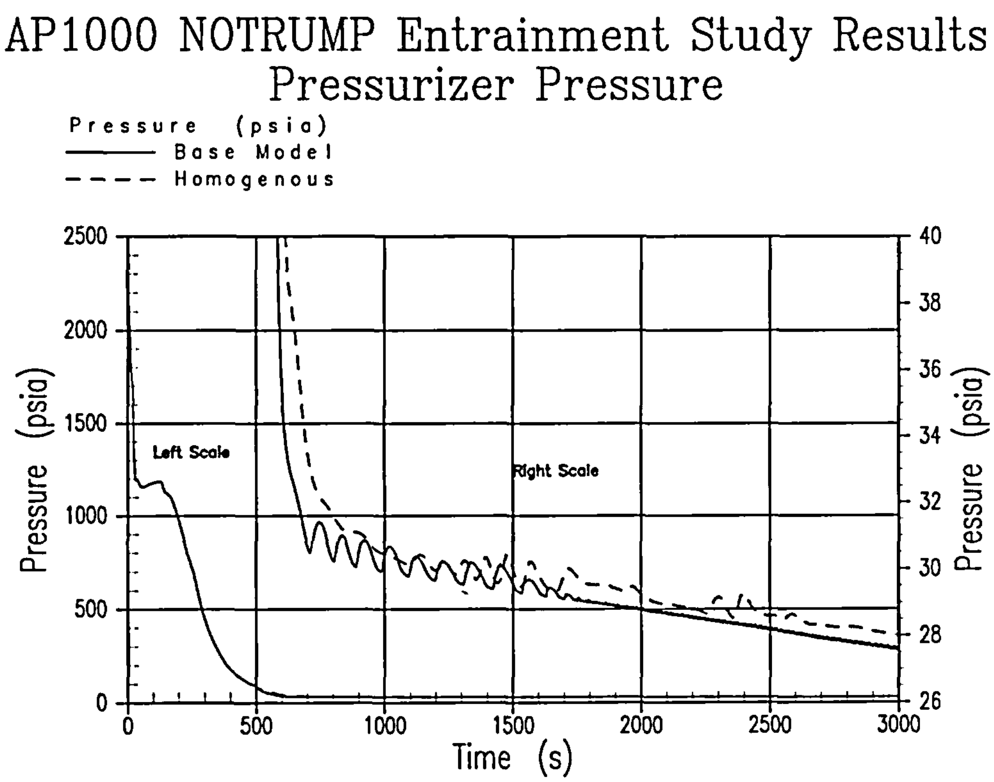


Figure 21.5-1.26 Pressurizer Pressure Comparison

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: 21.5-2 Item 25 Revision 1

Original RAI Number(s): None

Summary of Issue:

For the test DBA-04, 2-inch cold leg break simulation (Test Acceptance Report OSU-AP1000-04), Table 4-1 indicates that the assumed single failure is failure of 1 of 2 lines in one ADS-4 train on the pressurizer side, whereas Section 5.0, "Test Procedure," states that the 100-percent flow nozzle was installed in the ADS 4-2 (on hot leg 2) and the 50-percent flow nozzle was installed in ADS 4-1 (on hot leg 1). Since the pressurizer is on hot leg 2, the use of 50-percent flow nozzle on hot leg 1 appears to simulate a single failure of ADS-4 on the non-pressurizer side, contradictory to Table 4-1.

A. Please clarify this inconsistency

B. The results of the DBA-02 and DBA-03 tests simulating DVI line break indicate that the single failure of ADS-4 valve on the non-pressurizer side is limiting. Please explain why a single failure of ADS-4 valve on the pressurizer side was simulated for the DBA-4 2-inch cold leg break test.

NRC Comment from 12/17/03 Status meeting:

Provide errata on Test Acceptance Reports OSU-AP1000-04 and -05 (Items 25 & 26):

In OSU-AP1000-04, Table 4-1, assumed single failure of one ADS-4 valve on the non-pressurizer side.

In OSU-AP1000-05, Table 4-1, ADS-1, 2, and 3 valves were open during the test.

Westinghouse Response (Revision 1) :

There is an error in the report. For DBA-04, Table 4-1 should indicate that the assumed single failure of 1 of 2 lines in one ADS-4 train is on the non-pressurizer side. The information is correct in Section 5.0.

Attached is an errata sheet for Test Acceptance Report OSU-AP1000-04.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

ERRATA SHEET

for

Oregon State University, *Test Acceptance Report*

OSU-AP1000-04
(Revision 0)

(for Proprietary Class 2 and Class 3)

Page	Location	Correction
4-2	Table 4-1, Fourth entry: DBA-04-D	Last column – change: "pressurizer" to "non-pressurizer"
4-2	Table 4-1, Fifth entry: TR-02-D	Last column –delete: (No ADS 1-3)
4-2	Table 4-1, Sixth entry: TR-03-D	Last column –delete: (No ADS 1-3)
4-2	Table 4-1, Seventh entry: TR-04-D	Last column –delete: (No ADS 1-3)

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: **21.5-2 Item 26 Revision 1**

Original RAI Number(s): **None**

Summary of Issue:

For the test TR-02-D, a 2-inch cold leg break simulation with ADS-4 actuation at plant-prototypic pressure conditions (Test Acceptance Report OSU-AP1000-05), Table 4-1 indicates the assumed failure of one ADS-4 train and no ADS 1-3. However, Section 5, ATest Procedure,@ of the report indicates that flow nozzles that simulate full flow for ADS-1, 2, and 3 were installed.

Please clarify whether the ADS-1, 2, and 3 valves were open during the test, and whether this is consistent with Table 4-1, which indicates no ADS-1, 2, and 3 for the test.

NRC Comment from 12/17/03 Status meeting:

Provide errata on Test Acceptance Reports OSU-AP1000-04 and -05 (Items 25 & 26):

> In OSU-AP1000-04, Table 4-1, assumed single failure of one ADS-4 valve on the non-pressurizer side.
>
> In OSU-AP1000-05, Table 4-1, ADS-1, 2, and 3 valves were open during the test.

Westinghouse Response (Revision 1):

There is an error in the report. ADS-1, 2, and 3 valves were open during test TR-02-D.

Attached is an errata sheet for Test Acceptance Report OSU-AP1000-05.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

ERRATA SHEET

for

Oregon State University, *Test Acceptance Report*

OSU-AP1000-05
(Revision 0)

(for Proprietary Class 2 and Class 3)

Page	Location	Correction
4-2	Table 4-1, Fourth entry: DBA-04-D	Last column – change: "pressurizer" to "non-pressurizer"
4-2	Table 4-1, Fifth entry: TR-02-D	Last column –delete: (No ADS 1-3)
4-2	Table 4-1, Sixth entry: TR-03-D	Last column –delete: (No ADS 1-3)
4-2	Table 4-1, Seventh entry: TR-04-D	Last column –delete: (No ADS 1-3)