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Your ref: Docket No. 52-006
Our ref: DCP/NRC1642

October 24, 2003

SUBJECT: Transmittal of Revised Responses to AP1000 DSER Open Items

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

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

Very truly yours,

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

/Attachments

1. List of the AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses transmitted with letter DCP/NRC1642
2. Non-Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses dated October 24, 2003

D063

DCP/NRC1642
Docket No. 52-006

October 24, 2003

Attachment 1

List of

Non-Proprietary Responses

Table 1 "List of Westinghouse's Responses to DSER Open Items Transmitted in DCP/NRC1642"	
2.3.4-1 Revision 2 3.8.4.5-2 Revision 2	

DCP/NRC1642
Docket No. 52-006

October 24, 2003

Attachment 2

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: 2.3.4-1 Revision 2

Original RAI Number(s): 451.006, 451.006 Rev. 1

Summary of Issue:

The hypothetical reference control room χ/Q values calculated by the applicant are listed in Table 15.3-9a of this report. A site selected for an AP1000 facility should have control room χ/Q values equal to or less than the hypothetical Reference χ/Q values shown Table 15.3-9a. In the event a site selected for the AP1000 design exceeds the hypothetical reference χ/Q values, the COL applicant should demonstrate that the radiological consequences associated with the design-basis accidents, using its site-specific χ/Q values, continues to meet the dose reference values given in GDC 19 of 10 CFR Part 50. The staff initially asked the applicant if the methodology and all inputs and assumptions would be evaluated as part of the COL review. The applicant provided a detailed response stating that the methodology, inputs and assumptions would be provided by the COL applicant and also provided additional information about the analysis. The staff issued a second RAI to inquire if the applicant was seeking certification of any of the AP1000 design values used as inputs to the control room χ/Q calculations. The applicant subsequently provided certain design-specific information that was used as input to the assessment and for which the applicant was seeking certification. The staff review of this topic is ongoing, and may reveal other concerns with respect to χ/Q. The staff has identified unresolved issues related to adequate justification for assuming a diffuse release, estimation of initial sigma values, other release assumptions, building cross-sectional areas, and distances between release/receptor pairs. This is Open Item 2.3.4-1. This is also COL Action Item 2.3.4-1 since the resultant χ/Q values are also a function of the site-specific meteorology which cannot be reviewed until site selection.

Follow-on Question:

Westinghouse submitted revisions to address this question in DCD Revision 7. The staff had further questions in response to those revisions, particularly relating to the modeling used in the demonstration case control room χ/Q values.

Westinghouse Response:

The AP1000 control room χ/Q values used in the AP1000 dose analyses were based on the calculation performed for the AP600 Design Certification. This calculation examined a wide range of site meteorological data and plant orientations to develop a conservative set of χ/Q values for use in the AP600 dose analyses. However, following the issue of Regulatory Guide 1.194 (which provides specific NRC staff guidance on the use of the ARCON96 code for calculating control room χ/Q) it was determined that the the modeling assumptions used for AP600 did not fully comply with that Regulatory Guide.

An additional issue is whether the control room χ/Q values are being approved for AP1000 as part of Design Certification. Unlike the offsite χ/Q values that were identified as site interface parameters that the COL applicant would later verify for their site, the control room χ/Q values were not identified as a site interface for either the AP600 or AP1000. Westinghouse agrees with the NRC that control room χ/Q values should be identified as a site interface parameter. Thus a COL applicant would verify as part of the COL process that the calculated control room χ/Q values for their site are bounded by those assumed in the DCD dose analysis. However, unlike the site boundary χ/Q values that are based solely on the site meteorological data, the control room χ/Q values are determined based both on site meteorological data and assumptions related to plant design features and layout. Westinghouse believes that the assumptions related to the plant design features are important in ultimately determining acceptable control room doses for design basis accidents, and therefore should be approved as part of Design Certification.

Therefore the following approach is being taken to resolve these issues:

1. Bounding control room χ/Q values will be established for the AP1000. These values will be determined for the various source – receptor locations that are applicable for the various design basis accidents as appropriate. χ/Q values that will still yield doses within the dose acceptance limits will be calculated consistent with the dose analysis methodology and assumptions described in the DCD Chapters 6 and 15. Consistent with the approach of treating the control room χ/Q values as interface parameters, Westinghouse will revise some assumptions described in the current DCD dose analysis to remove excess conservatism to provide the COL applicant greater flexibility in demonstrating acceptability. These changes were incorporated in DCD Revision 7; minor additional changes are provided in the attached DCD markup and will be included in DCD Revision 8.
2. The key control room χ/Q modeling assumptions related to the plant design will be added to DCD Appendix 15A. This was also incorporated in DCD Revision 7, but has been revised in view of revised modeling techniques now applied; changes are shown in the attached pages and are to be incorporated into DCD Revision 8.
3. A set of χ/Q values for typical site meteorology and plant orientation have been calculated in accordance with the guidance set forth in Regulatory Guide 1.194. The purpose of the calculation is to define the modeling assumptions for calculating the control room χ/Q values for AP1000, and will serve as an example of an approved method for the COL applicant to follow to determine the acceptability of their site to meet the control room χ/Q values. Relevant portions of this calculation are now included in DCD Appendix 15A.

   The ARCON96 modeling approach used (as illustrated in attached DCD mark-up, Table 15.A-7 and Figure 15A-1) is fully in compliance with Regulatory Guide 1.194.

Design Control Document (DCD) Revision:
See attached draft markup of the DCD.

PRA Revision:
None

Table 2-1 (Sheet 3 of 3)

SITE PARAMETERS

Control Room Atmospheric Dispersion Factors (χ/Q) for Accident Dose Analysis

χ/Q (s/m^3) at HVAC Intake for the Identified Release Points(1)

	Plant Vent or PCS Air Diffuser(3)	Ground Level Containment Release Points(4)	PORV and Safety Valve Releases(5)	Steam Line Break Releases	Fuel Handling Area(6)
0 - 2 hours	2.5E-3	2.5E-3	2.0E-2	2.4E-2	6.0E-3
2 - 8 hours	1.7E-3	1.7E-3	1.8E-2	2.0E-2	4.0E-3
8 - 24 hours	1.0E-3	1.0E-3	7.0E-3	7.5E-3	2.0E-3
1 - 4 days	8.0E-4	8.0E-4	5.0E-3	5.5E-3	1.5E-3
4 - 30 days	7.0E-4	8.0E-4	4.5E-3	5.0E-3	1.0E-3

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χ/Q (s/m^3) at Control Room Door for the Identified Release Points(2)

	Plant Vent or PCS Air Diffuser(3)	Ground Level Containment Release Points(4)	PORV and Safety Valve Releases(5)	Steam Line Break Releases	Fuel Handling Area(6)
0 - 2 hours	1.0E-3	1.5E-3	4.0E-3	4.0E-3	6.0E-3
2 - 8 hours	8.0E-4	8.0E-4	3.2E-3	3.2E-3	4.0E-3
8 - 24 hours	4.0E-4	4.0E-4	1.2E-3	1.2E-3	2.0E-3
1 - 4 days	3.0E-4	4.0E-4	1.0E-3	1.0E-3	1.5E-3
4 - 30 days	2.5E-4	4.0E-4	8.0E-4	8.0E-4	1.0E-3

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Notes:

1. These dispersion factors are to be used 1) for the time period preceding the isolation of the main control room and actuation of the emergency habitability system, 2) for the time after 72 hours when the compressed air supply in the emergency habitability system would be exhausted and outside air would be drawn into the main control room, and 3) for the determination of control room doses when the non-safety ventilation system is assumed to remain operable such that the emergency habitability system is not actuated.
2. These dispersion factors are to be used when the emergency habitability system is in operation and the only path for outside air to enter the main control room is that due to ingress/egress
3. These dispersion factors are used for analysis of the doses due to a postulated small line break outside of containment. The plant vent and PCS air diffuser are potential release paths for other postulated events (loss-of-coolant accident, rod ejection accident, and fuel handling accident inside the containment), however, the values are bounded by the dispersion factors for ground level releases.
4. The listed values represent modeling the containment shell as a diffuse area source, and are used for evaluating the doses in the main control room for a loss-of-coolant accident, for the containment leakage of activity

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following a rod ejection accident, and for a fuel handling accident occurring inside the containment.

5. The listed values bound the dispersion factors for releases from the steam line safety & power-operated relief valves and the condenser air removal stack. These dispersion factors would be used for evaluating the doses in the main control room for a steam generator tube rupture, a main steam line break, a locked reactor coolant pump rotor, and for the secondary side release from a rod ejection accident. Additionally, these dispersion coefficients are conservative for the small line break outside containment.

6 The listed values bound the dispersion factors for releases from the fuel storage and handling area. The listed values also bound the dispersion factors for releases from the fuel storage area in the event that spent fuel boiling occurs and the fuel building relief panel opens on high temperature. These dispersion factors are used for the fuel handling accident occurring outside containment and for evaluating the impact of releases associated with spent fuel pool boiling.

The emergency air storage tanks are sized to provide the required air flow to the main control room pressure boundary for 72 hours. After 72 hours, the main control room is cooled by drawing in outside air and circulating it through the room, as discussed in subsection 6.4.2.2.

The temperature and humidity in the main control room pressure boundary following a loss of the nuclear island nonradioactive ventilation system remain within limits for reliable human performance (References 2 and 3) over a 72-hour period. The initial values of temperature/relative humidity in the MCR are 75°F/60 percent. At 3 hours, when the non-1E battery heat loads are exhausted, the conditions are 87.2°F/41 percent. At 24 hours, when the 24 hour battery heat loads are terminated, the conditions are 84.4°F/45 percent. At 72 hours, the conditions are 85.8°F/39 percent.

Sufficient thermal mass is provided in the walls and ceiling of the main control room to absorb the heat generated by the equipment, lights, and occupants. The temperature in the instrumentation and control rooms and dc equipment rooms following a loss of the nuclear island nonradioactive ventilation system remains below acceptable limits as discussed in subsection 6.4.4. As in the main control room, sufficient thermal mass is provided surrounding these rooms to absorb the heat generated by the equipment. After 72 hours, the instrumentation and control rooms will be cooled by drawing in outside air and circulating it through the room, as discussed in subsection 6.4.2.2.

In the event of a loss of ac power, the nuclear island nonradioactive ventilation system isolation valves automatically close and the main control room emergency habitability system isolation valves automatically open. These actions protect the main control room occupants from a potential radiation release. In instances in which there is no radiological source term present, the compressed air storage tanks are refilled via a connection to the breathable quality air compressor in the compressed and instrument air system (CAS). The compressed air storage tanks can also be refilled from portable supplies by an installed connection in the CAS.

6.4.4 System Safety Evaluation

Doses to main control room personnel were calculated for both the situation in which the emergency habitability system (VES) is relied upon to limit the amount of activity the personnel are exposed to and the situation in which the nuclear island nonradioactive ventilation system (VBS) is available to pressurize the main control room with filtered air and provide recirculation cleanup. Doses were calculated for the following accidents:

	VES Operating	VBS Operating
Large Break LOCA	4.8 rem TEDE	~~2.8~~ rem TEDE
Fuel Handling Accident	4.5 rem TEDE	~~2.1~~ rem TEDE
Steam Generator Tube Rupture		
(Pre-existing iodine spike)	4.8 rem TEDE	~~2.1~~ rem TEDE
(Accident-initiated iodine spike)	2.1 rem TEDE	~~1.8~~ rem TEDE
Steam Line Break		
(Pre-existing iodine spike)	3.4 rem TEDE	~~2.1~~ rem TEDE
(Accident-initiated iodine spike)	3.7 rem TEDE	~~4.0~~ rem TEDE
Rod Ejection Accident	2.1 rem TEDE	~~1.2~~ rem TEDE

Comment: "VBS Operating" values have not yet been recalculated and may change, but will be bounded by "VES Operating" case.

	VES Operating	VBS Operating
Locked Rotor Accident		
(Accident without feedwater available)	0.9 rem TEDE	~~0.9~~ rem TEDE
(Accident with feedwater available)	0.7 rem TEDE	~~1.6~~ rem TEDE
Small Line Break Outside Containment	1.2 rem TEDE	~~0.3~~ rem TEDE

Comment: "VBS Operating" values have not yet been recalculated and may change, but will be bounded by "VES Operating" case.

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For all events the dose are within the dose acceptance limit of 5.0 rem TEDE. The details of analysis assumptions for modeling the doses to the main control room personnel are delineated in the LOCA dose analysis discussion in subsection 15.6.5.3.

No radioactive materials are stored or transported near the main control room pressure boundary.

As discussed and evaluated in subsection 9.5.1, the use of noncombustible construction and heat and flame resistant materials throughout the plant reduces the likelihood of fire and consequential impact on the main control room atmosphere. Operation of the nuclear island nonradioactive ventilation system in the event of a fire is discussed in subsection 9.4.1.

The exhaust stacks of the onsite standby power diesel generators are located in excess of 150 feet away from the fresh air intakes of the main control room. The onsite standby power system fuel oil storage tanks are located in excess of 300 feet from the main control room fresh air intakes. These separation distances reduce the possibility that combustion fumes or smoke from an oil fire would be drawn into the main control room.

The protection of the operators in the main control room from offsite toxic gas releases is discussed in Section 2.2. The sources of onsite chemicals are described in Table 6.4-1, and their locations are shown on Figure 1.2-2. Analysis of these sources is in accordance with Regulatory Guide 1.78 (Reference 5) and the methodology in NUREG-0570, "Toxic Vapor Concentrations in the Control Room Following a Postulated Accidental Release" (Reference 6), and the analysis shows that these sources do not represent a toxic hazard to control room personnel.

A supply of protective clothing, respirators, and self-contained breathing apparatus adequate for 11 persons is stored within the main control room pressure boundary.

The main control room emergency habitability system components discussed in subsection 6.4.2.3 are arranged as shown in Figure 6.4-2. The location of components and piping within the main control room pressure boundary provides the required supply of compressed air to the main control room pressure boundary, as shown in Figure 6.4-1.

During emergency operation, the main control room emergency habitability system passive heat sinks are designed to limit the temperature inside the main control room to remain within limits for reliable human performance (References 2 and 3) over 72 hours. The passive heat sinks limit the air temperature inside the instrumentation and control rooms to 120°F and dc equipment rooms to 120°F. The walls and ceilings that act as the passive heat sinks contain sufficient thermal mass to accommodate the heat sources from equipment, personnel, and lighting for 72 hours.

The main control room emergency habitability system nominally provides 65 scfm of ventilation air to the main control room from the compressed air storage tanks. Sixty scfm of ventilation flow is sufficient to pressurize the control room to at least positive 1/8-inch water gauge differential

Table 15A-6

CONTROL ROOM ATMOSPHERIC DISPERSION FACTORS (χ/Q) FOR ACCIDENT DOSE ANALYSIS

χ/Q (s/m³) at HVAC Intake for the Identified Release Points[1]

	Plant Vent or PCS Air Diffuser[3]	Ground Level Containment Release Points[4]	PORV and Safety Valve Releases[5]	Steam Line Break Releases	Fuel Handling Area[6]
0 - 2 hours	2.5E-3	2.5E-3	2.0E-2	2.4E-2	6.0E-3
2 - 8 hours	1.7E-3	1.7E-3	1.8E-2	2.0E-2	4.0E-3
8 - 24 hours	1.0E-3	1.0E-3	7.0E-3	7.5E-3	2.0E-3
1 - 4 days	8.0E-4	8.0E-4	5.0E-3	5.5E-3	1.5E-3
4 - 30 days	7.0E-4	8.0E-4	4.5E-3	5.0E-3	1.0E-3

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χ/Q (s/m³) at Control Room Door for the Identified Release Points[2]

	Plant Vent or PCS Air Diffuser[3]	Ground Level Containment Release Points[4]	PORV and Safety Valve Releases[5]	Steam Line Break Releases	Fuel Handling Area[6]
0 - 2 hours	1.0E-3	1.5E-3	4.0E-3	4.0E-3	6.0E-3
2 - 8 hours	8.0E-4	8.0E-4	3.2E-3	3.2E-3	4.0E-3
8 - 24 hours	4.0E-4	4.0E-4	1.2E-3	1.2E-3	2.0E-3
1 - 4 days	3.0E-4	4.0E-4	1.0E-3	1.0E-3	1.5E-3
4 - 30 days	2.5E-4	4.0E-4	8.0E-4	8.0E-4	1.0E-3

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Notes:

1. These dispersion factors are to be used 1) for the time period preceding the isolation of the main control room and actuation of the emergency habitability system, 2) for the time after 72 hours when the compressed air supply in the emergency habitability system would be exhausted and outside air would be drawn into the main control room, and 3) for the determination of control room doses when the non-safety ventilation system is assumed to remain operable such that the emergency habitability system is not actuated.
2. These dispersion factors are to be used when the emergency habitability system is in operation and the only path for outside air to enter the main control room is that due to ingress/egress.
3. These dispersion factors are used for analysis of the doses due to a postulated small line break outside of containment. The plant vent and PCS air diffuser are potential release paths for other postulated events (loss-of-coolant accident, rod ejection accident, and fuel handling accident inside the containment), however, the values are bounded by the dispersion factors for ground level releases.
4. The listed values represent modeling the containment shell as a diffuse area source, and are used for evaluating the doses in the main control room for a loss-of-coolant accident, for the containment leakage of activity following a rod ejection accident, and for a fuel handling accident occurring inside the containment.

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5. The listed values bound the dispersion factors for releases from the steam line safety & power-operated relief valves and the condenser air removal stack. These dispersion factors would be used for evaluating the doses in the main control room for a steam generator tube rupture, a main steam line break, a locked reactor coolant pump rotor, and for the secondary side release from a rod ejection accident. Additionally, these dispersion coefficients are conservative for the small line break outside containment.
6. The listed values bound the dispersion factors for releases from the fuel storage and handling area The listed values also bound the dispersion factors for releases from the fuel storage area in the event that spent fuel boiling occurs and the fuel building relief panel opens on high temperature. These dispersion factors are used for the fuel handling accident occurring outside containment and for evaluating the impact of releases associated with spent fuel pool boiling.

Table 15A-7

CONTROL ROOM SOURCE/RECEPTOR DATA FOR DETERMINATION OF ATMOSPHERIC DISPERSION FACTORS

Source Description	Release Elevation Note 1 (m)	Straight-Line Distance to Receptor (m)		
		Control Room HVAC Intake (Elevation 19.9 m)	Annex Building Access (Elevation 1.5 m)	Comment
Plant Vent	55.7	53.4	94.0	
PCS Air Diffuser	71.3	60.7	98.1	
Containment Shell (Diffuse Area Source)	Same as receptor elevation (19.9 m or 1.5 m)	11.0	47.2	Note 2
Fuel Building Blowout Panel	17.4	50	89.7	Note 3
Fuel Building Rail Bay Door	1.5	52.4	92.1	Note 3
Steam Vent	17.1	18.3	48.8	
PORV/Safety Valves	19.2	19.8	44.1	
Condenser Air Removal Stack	7.6	63	59.9	Note 3

Notes:
1. All elevations relative to grade at 0.0 m
2. For calculating distance, the source is defined as the point on the containment shell closest to receptor
3. Vertical distance traveled is conservatively neglected.

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Deleted: Releases from these sources must travel over a building to reach the HVAC intake. Therefore, the "taut string" length over the obstruction to the source is used as the source-to-receptor distance and the source elevation is used for both source and receptor when input into ARCON96. ¶
4.. The staging area hatch doors are located such that any release would be into the auxiliary building. The release would then be required to pass through doors into the annex building and travel through the annex building before reaching the ultimate release point. The ultimate release point for the staging area hatch is considered to be the sliding door in the east wall of the annex building between columns 4 and 4.1 at elevation 107'-6" (see Figure 15A-1). Therefore the horizontal distance of 101 ft traveled inside the annex building was included in the source to receptor distance. For conservatism, the vertical distance traveled inside the buildings is not included ¶
5..

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Main Equipment Hatch	1.5	106.2	106.1	Notes 2, 3
Staging Area Hatch	4.6	89.4	101.6	Notes 3, 4

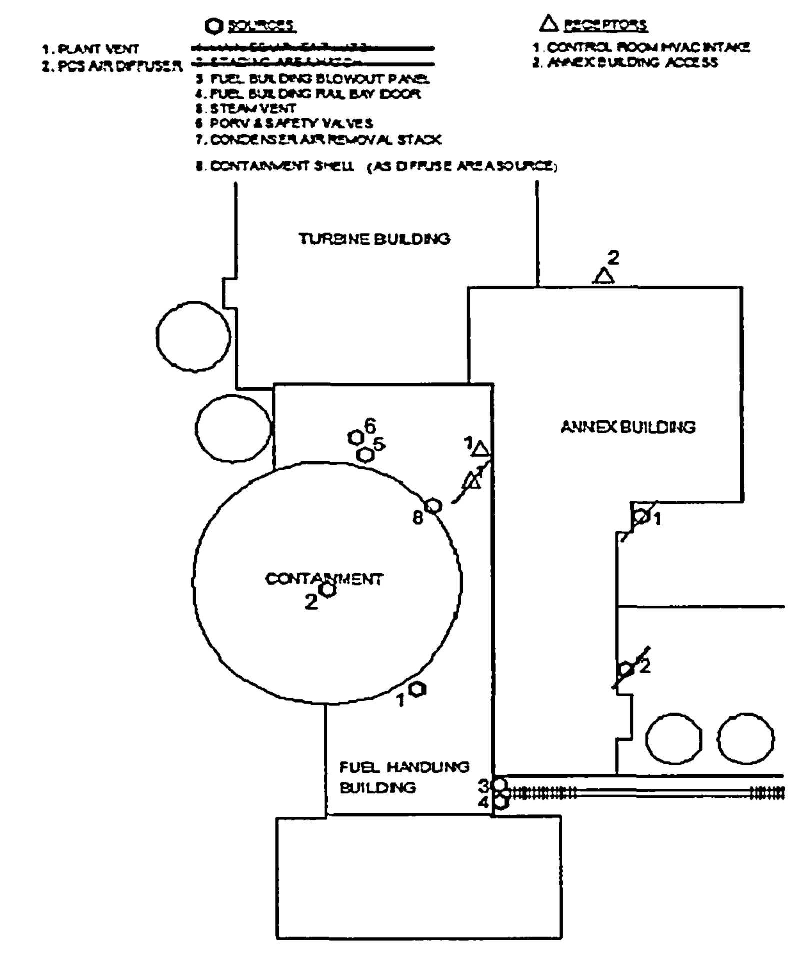


Figure 15A-1

Site Plan with Release and Intake Locations

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: 3.8.4.5-2 (Response Revision 2)

Original RAI Number(s): None (April 3, 2003, meeting summary)

Summary of Issue:

During the course of its review of the Wall 7.3 design calculation, the staff noted that the applicant had previously identified and corrected an error in the equation used by INITEC to calculate the required positive reinforcement for a section subjected to both bending moment and axial load. The staff could not conclude during the audit that the corrected equation accurately calculates required positive reinforcement. Therefore, the applicant was requested to submit the derivation of the equation currently used to calculate the required reinforcement. The applicant was also requested to submit a sample verification calculation for the computer algorithm, and verify that the corrected equation has been utilized in all calculations. This is Open Item 3.8.4.5-2.

NRC discussion during telephone call on August 22, 2003

The Revision 0 response only showed development of equation for one case (axial plus bending with both tension and compression steel at yield). Clarify how range of applicability is checked and what other cases are used in the macro or explain how design engineer is told that the case is out of range of applicability.

NRC meeting, October 6-10, 2003

Confirm that the guidance described in revision 1 of this response has been implemented in the design of the critical sections.

Westinghouse Response:

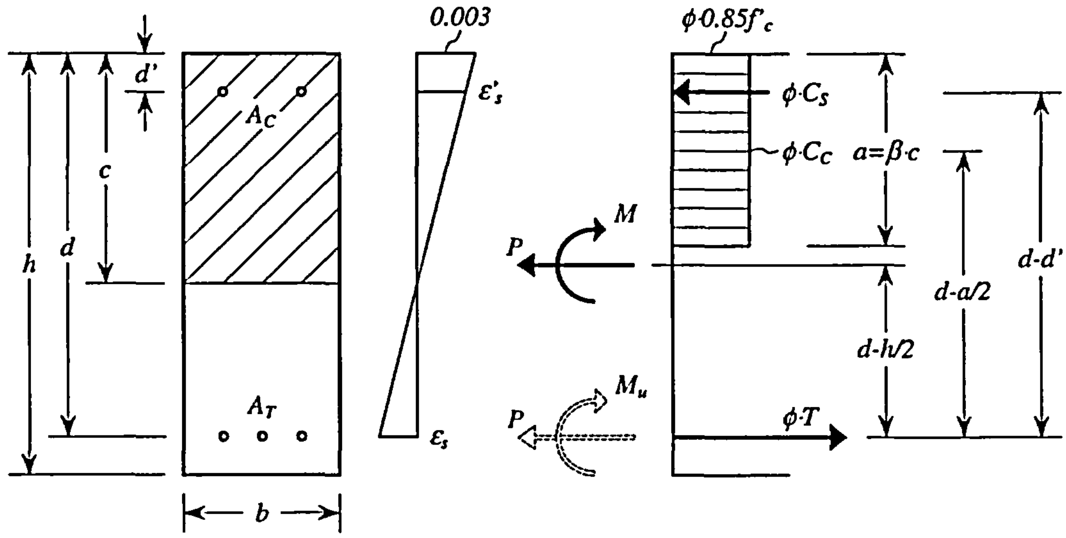
The development of the equation for sizing the required reinforcement for a section subject to bending moment and axial load is shown in this response. This equation is applicable when the strength of the section is controlled by yielding of the tension steel and both tension and compression steel, if any, are at yield. Loads and internal forces are shown in the following figures. The design loads P and M act at the centroid of the section, where:

P = Design Axial Load (P is positive in tension)
M = Design Moment

These loads are then converted to loads P and M_u relative to the plane of tension reinforcement.

The strength reduction factor ϕ is applied to both the steel and concrete strengths to obtain the design strength as shown in the figures.

Compression reinforcement is calculated such that the portion of tension reinforcement not equalized by compression reinforcement (A_T - A_C) does not exceed 75% of the A_b that would produce balanced strain conditions.



Transfer design loads P and M to the plane of tension reinforcement as P and M_u:

$$M_u \equiv M - P\left(d - \frac{h}{2}\right) \tag{1}$$

From equilibrium of forces and moments:

$$T = C_C + C_S + \frac{P}{\phi} \tag{2}$$

$$M_u = \phi \cdot C_C\left(d - \frac{a}{2}\right) + \phi \cdot C_S\left(d - d'\right) \tag{3}$$

Where, the concrete stress block is defined in 10.2.7 of ACI 349 as follows:

$$C_C = b \cdot \beta \cdot c \cdot 0.85 f'_c \tag{4}$$

$$\beta = 0.85 \qquad (\because f'_c \leq 4000 psi) \tag{5}$$

For tension controlled failure with both tension and compression reinforcement strain at or greater than yield:

$$T = A_T \cdot f_y$$

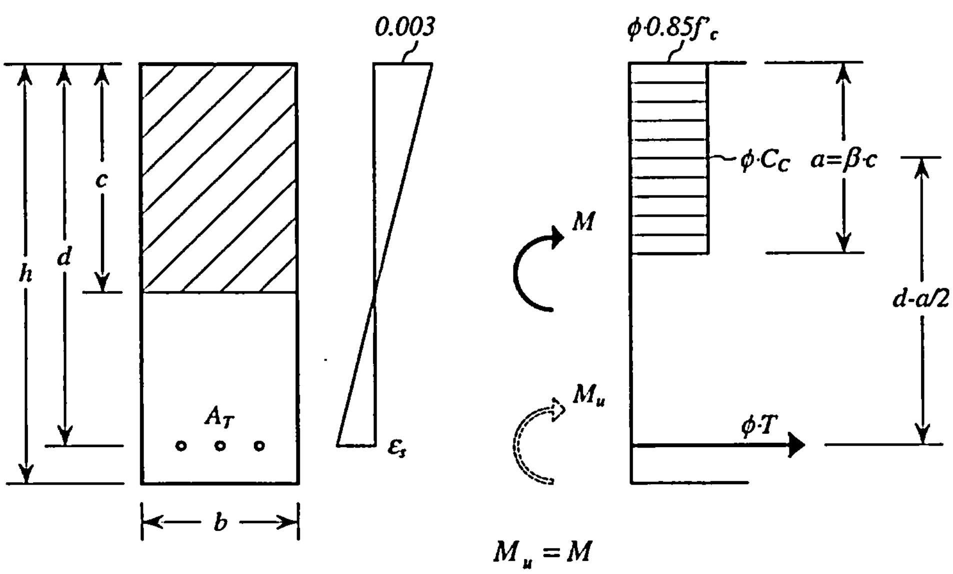
(6)

$$C_S = A_C \cdot f_y \tag{7}$$

From equations (2), (6) and (7), the required reinforcement is given as follows:

$$A_T = \frac{C_C}{f_y} + A_C + \frac{P}{\phi \cdot f_y} \tag{8}$$

The third term on the right side can be calculated directly. The other terms are calculated to satisfy the limit of 75% of balanced strain conditions as described below:



From equilibrium of forces and moments:

$$T = C_C \tag{9}$$

$$M_u = \phi \cdot C_C \left(d - \frac{a}{2} \right) \tag{10}$$

From equations (4), (6) and (9):

$$A_T = \frac{b \cdot \beta \cdot c \cdot 0.85 f'_c}{f_y} \tag{11}$$

From equation (4):

$$a=\beta\cdot c=\frac{C_C}{b\cdot 0.85f'_c} \tag{12}$$

From equations (6), (9), (10) and (12):

$$M_u=\phi\cdot C_C\left(d-\frac{C_C}{2\cdot b\cdot 0.85f'_c}\right)=\phi\cdot A_T\cdot f_y\left(d-\frac{A_T\cdot f_y}{2\cdot b\cdot 0.85f'_c}\right) \tag{13}$$

In the balanced strain condition, the neutral axis is calculated as follows:

$$\frac{c_b}{d}=\frac{0.003}{0.003+f_y/E_s}=\frac{87000}{87000+f_y} \tag{14}$$

Substituting the above c_b for c in equation (11), the balanced tensile steel A_b is given as follows:

$$A_b=\frac{b\cdot\beta\cdot 0.85f'_c}{f_y}\cdot\frac{87000}{87000+f_y}\cdot d \tag{15}$$

If M_u requires more reinforcement than 75% of A_b, compression reinforcement A_C is needed as 10.3.3 of ACI 349. Define M_{75} corresponding to 75% of balanced conditions as equation (13):

$$M_{75}\equiv\phi\cdot 0.75A_b\cdot f_y\left(d-\frac{0.75A_b\cdot f_y}{2\cdot b\cdot 0.85f'_c}\right) \tag{16}$$

The area of required reinforcement is calculated using the moment M_{75} as follows:

1) $M_u\leq M_{75}$ (thus, compression reinforcement A_C is not required)

   Solving equation (13) for C_C:

$$\frac{C_C}{f_y}=\frac{0.85f'_c}{f_y}\left\{1-\sqrt{1-\frac{2\cdot M_u}{\phi\cdot b\cdot d^2\cdot 0.85f'_c}}\right\}\cdot b\cdot d \tag{17}$$

2) $M_u>M_{75}$ (thus, compression reinforcement A_C is required)

$$\frac{C_C}{f_y}=0.75A_b \tag{18}$$

$$M_u - M_{75} = \phi \cdot C_S (d - d') \tag{19}$$

From equation (7) and (19):

$$A_c = \frac{M_u - M_{75}}{\phi \cdot f_y (d - d')} \tag{20}$$

The equation has been verified against the following sample problems in the ACI Design Handbook (ACI 340.1R-91):

ACI Design Handbook		This Equation	Ratio
Flexure Example	A_S (in^2)	A_T (in^2)	A_T / A_S
3	1.11	1.10	0.99
10	17.7	18.0	1.02
17	1.84	1.84	1.00

- Flexure Example 3 – Determination of tension reinforcement area for rectangular beam subject to small axial load; no compression reinforcement
- Flexure Example 10 – Design of rectangular beam subject to simple bending; compression reinforcement found to be required
- Flexure Example 17 – Determination of tension reinforcement area for rectangular beam subject to bending and axial tensile load; top fiber found to be in compression

The corrected equation as developed herein has been used in all AP1000 calculations of reinforcement using the ANSYS post processors and EXCEL macros.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Westinghouse Response (Revision 1):

The macro is intended for design of reinforcement in walls and slabs where the strength of the section is controlled by yield of the reinforcement in tension. It calculates the required reinforcement for axial plus bending. One case covers reinforcement on one face in tension with the other face in compression. The other case covers both faces of reinforcement in tension. The macro is not intended or used for design of reinforcement in columns where the strength of the section may be controlled by concrete compression. The documentation states the macros "... are not applicable to walls or columns that are in compression across the complete section".

Additional guidance is being provided to the engineer to confirm the design as described below.

Figure 3.8.4.5-2-1 shows a typical interaction diagram defining the strength of a concrete section under combined axial force (P) and bending moment (M). It shows the nominal strength interaction as well as a simplified nominal interaction based on straight lines connecting the following key points:

- Pure Compression (P_o)
- Balanced Strain Condition (P_b, M_b)
- Pure Flexure (M_n)
- Pure Tension (P_t)

The simplified design interaction diagram is also shown. This is obtained by applying the code specified strength reduction factor (ϕ) to the simplified nominal strength diagram.

The nominal axial load strength at balanced strain conditions, P_b, provides a convenient division point between compression and tension failures (Ferguson "Reinforced Concrete Fundamentals"). This strength is based on the reinforcement provided. When the nominal axial compressive forces are less than P_b, the tension reinforcement is at yield and the compression reinforcement is at or close to yield. Hence the results of the macro are accurate for design axial member forces less than P_b. The macro is used for multiple load combinations and the controlling cases for reinforcement demand are those with axial tension (or smallest compression).

Guidance is being provided to the engineer to perform an additional check when the axial compressive forces are greater than ϕP_b. In this additional check the axial load-moment interaction diagram is calculated for the reinforcement that has been selected based on use of the macro. Combinations of design moments with axial forces greater than ϕP_b are reviewed and confirmed to be bounded by the interaction diagram.

The ACI code imposes a maximum reinforcement limit of 0.08 times the gross area of the section for compression members. There is no maximum limit on members subject to combined flexure and low axial load since ductility is assured by limiting the reinforcement to 75% of the balanced reinforcement ratio. Typical quantities of reinforcement in the AP1000 design are well below the 8% maximum permitted by the code for compression members. For example, the

maximum reinforcement ratio in the cylindrical shield wall is less than 5% (10.74 sq.in/ft on each face).

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Westinghouse Response (Revision 2):

The macro described above was used in the design of the following critical sections:

Structural Wall Modules inside containment

- **South west wall of the refueling cavity (4′ 0″ thick)**
- **South wall of west steam generator cavity (2′ 6″ thick)**
- **North east wall of in-containment refueling water storage tank (2′ 6″ thick)**

Auxiliary Building Walls and Floors

- **South wall of auxiliary building (column line 1), elevation 66′-6″ to elevation 180′-0″**
- **Shield building cylinder, elevation 160′-6″ to elevation 200′-0″**
- **Roof slab at elevation 180′-0″ adjacent to shield building cylinder**
- **Finned floor in the main control room at elevation 135′-3″**

Nuclear island basemat

- **Basemat between column lines 9.1 and 11 and column lines K and L**
- **Basemat between column lines 1 and 2 and column lines K-2 and N**

The guidance applies when axial forces are greater than ϕP_b. For the typical sections of the nuclear island with equal reinforcement on each face, the design axial stress at balanced strain conditions, ϕP_b, is about 0.25 f_c' and is almost independent of the reinforcement provided. The axial member forces in each of the critical sections have been reviewed. Detailed evaluation of the interaction diagrams has been performed for the shield building cylinder where the vertical axial stresses exceed 0.25 f_c'. In all cases, the reinforcement calculated by the macro was sufficient. In a few local areas of the other walls and floors, there were elements at discontinuities with high stress concentrations whereand the axial forces exceeded ϕP_b. The stresses at these locations redistribute to adjacent elements~~have also been evaluated and the required reinforcement was correctly~~

~~calculated.~~ These reviews of each critical wall and floor is~~have been~~ documented in a revision to the reconciliation report reviewed during the meeting.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

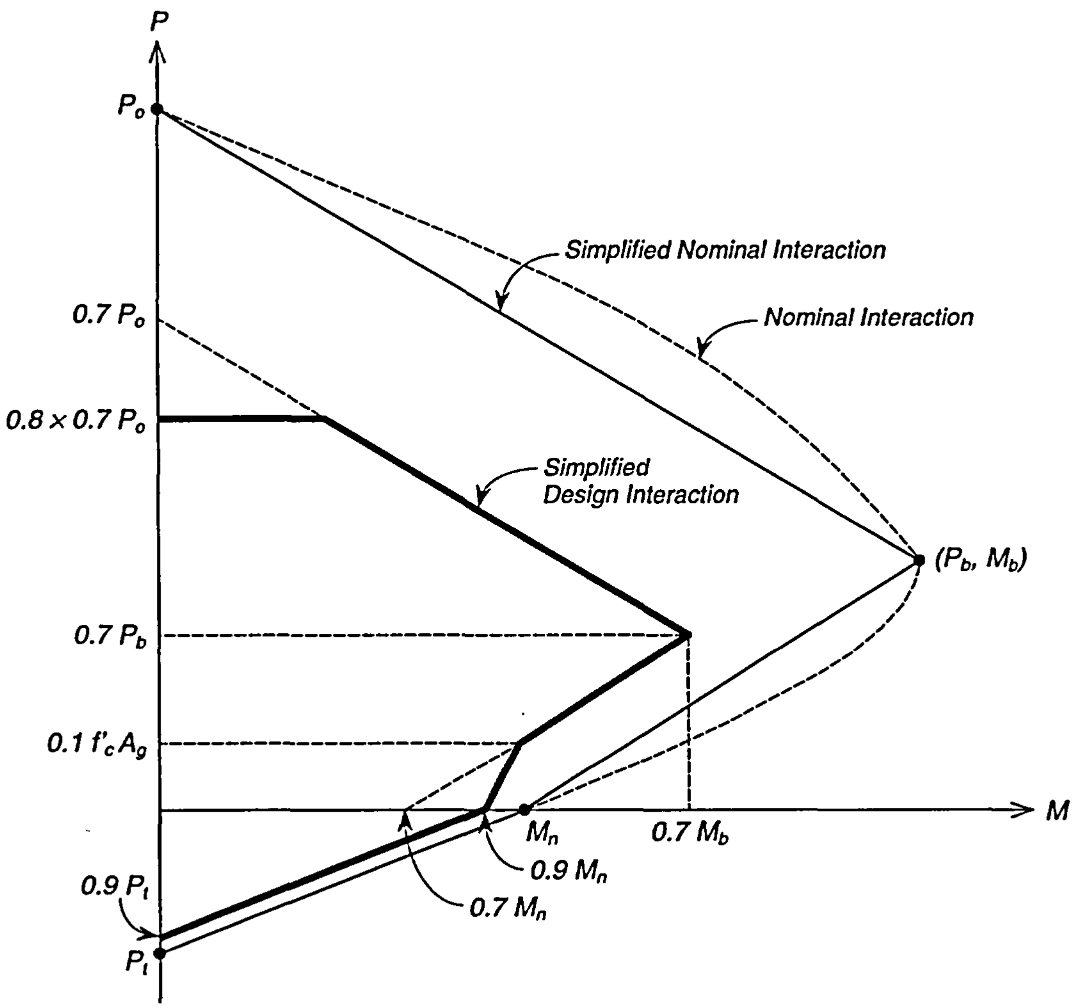


Figure 3.8.4.5-2-1
Axial Load-Moment Interaction Diagram