ENCLOSURE

WATTS BAR NUCLEAR PLANT (WBN) UNIT 1
LICENSE AMENDMENT REQUEST WBN-TS-03-06

EXCERPTS FROM CALCULATION WBN-OSG4-091
MAXIMUM CONTAINMENT WATER LEVEL

TVAN CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
NEB811005261	calculations(nuclear)	T71 020102 800

Calc Title: **MAXIMUM CONTAINMENT WATER LEVEL**

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	WBN	NTB	WBNOSG4091	R08	R09	Entire calc ☒
NEW	CN	NUC						Selected pages ☐

ACTION					
ACTION	NEW ☐ REVISION ☒	DELETE ☐ RENAME ☐	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
1	271	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
E-50814-A	N/A	E

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
JFLUND	423-365-1460	MEB	DESIGN REVIEW	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
J. F. Lund *John F. Lund*	20DEC2001	D. W. Posey *Don Posey*	12-20-2001
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
D. W. Posey *Don Posey*	12-20-01	*JS Robertson for B.G. Briody*	12/20/01

STATEMENT OF PROBLEM/ABSTRACT

STATEMENT OF PROBLEM

DETERMINE THE MAXIMUM CONTAINMENT WATER LEVEL THAT WILL OCCUR FOLLOWING AN ACCIDENT.

ABSTRACT

THIS CALCULATION DETERMINES THE MAXIMUM CONTAINMENT WATER LEVEL FOR THE BOUNDING CASE OF LBLOCA, SBLOCA, AND MSLB/MFLB. THE LBLOCA RESULTS IN THE MAXIMUM WATER LEVEL. A TRANSIENT WATER LEVEL INSIDE THE CRANE WALL WAS CALCULATED FOR THE LBLOCA. THE EQUILIBRIUM WATER LEVEL WAS CALCULATED FOR THE LBLOCA AND THE MSLB. THIS WAS PERFORMED USING THE METHODOLOGY DISCUSSED IN SECTION 4.0. THE RESULTS ARE SUMMARIZED IN SECTION 9.0.

THE LEVELS ARE SUMMARIZED BELOW:

LBLOCA MAXIMUM TRANSIENT CONTAINMENT WATER LEVEL: ELEVATION 720.0 FEET
LBLOCA MAXIMUM EQUILIBRIUM CONTAINMENT WATER LEVEL: ELEVATION 717.2 FEET
MSLB MAXIMUM EQUILIBRIUM CONTAINMENT WATER LEVEL: ELEVATION 716.0

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: EQB 1M-WBN
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

TVAN CALCULATION RECORD OF REVISION	
CALCULATION IDENTIFIER: **WBNOSG4091**	
Title	**MAXIMUM CONTAINMENT WATER LEVEL**
Revision No.	DESCRIPTION OF REVISION
9	This calculation implements Corrective Action Step 19 of PER 00-007819-000. The revision to this calculation evaluates the effects of potential LOCA induced line breaks in the Component Cooling and Essential Raw Cooling Water Systems on the Containment flooding analysis. This is necessary since the existing calculation did not account for the addition of water from these potential sources. 1. Pages 1 and 1A replaced the existing coversheet. 2. Page 2E added the Revision 9 Revision Log. 3. Page 3 replaced the existing Verification page. 4. Page 5 was revised to change the Revision Log page count. 5. Pages 7 and 9 were replaced to update the Table Of Contents.` 6. Page 13 7. Pages 21 and 22 were revised to consolidate the References and add References 43 through 59. 8. Page 36 was revised to add CCS and ERCW as potential sources of water. 9. Pages 87 through 96 were added to include Appendix C which evaluated the effect of potential CCS and ERCW line breaks. 10. Attachment 3 was added to include a copy of Reference 58. This revision of the calculation does not affect any successor calculations. Pages Added: 2E (new Revision Log), 87 through 96, Attachment 3, page 1 of 1 Pages Revised: 5 Pages Replaced: 1, 1A, 3, 7, 9, 13, 21, 22, 36, Pages Deleted: None Total pages in Calculation: 119, including 1A, 2a, 2b, 2c, 2d, 2E, 4a, and 39.1. The computer files prepared for this revision are stored in the S Drive under S:\Nuc_Eng\Mechanical\Calculations.

Calc Title: MAXIMUM CONTAINMENT WATER LEVEL							WBN Unit 1
	TYPE	PLANT	BRANCH	NUMBER	REV	prepared	J F Lund
CALC ID	CN	WBN	NTB	WBNOSG4091	R09	checked	D W Posey

Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

Two (2) Component Cooling System lines and one (1) Essential Raw Cooling Water System line inside containment are subject to LOCA impingement failure due to LOCAs which could occur in adjacent piping (Reference 59). Each line is subject to a different LOCA. If one of the subject lines breaks, the failure of the outboard containment isolation valve associated with the specific cooling water line to close could result in a flow of cooling water into containment.

The failure of one of the CCS containment isolation valves (1-FCV-070-92 or -100),or the ERCW containment isolation valve (1-FCV-067-107) to close after a LOCA induced line break in the piping associated with that valve can result in the flow of water into containment. This flow can occur because check valves are provided to protect the piping section between the inboard and outboard containment isolation valves (CIVs) from thermal overpressure conditions which can occur when the containment isolation valves are both closed (Refer to Figure C-1). The check valve piping bypasses the inboard CIV and discharges back into the associated piping inside containment. This problem was discovered during the Extent of Condition Review for PER 00-007819-000. This leakage would add to the volume of water inside the containment after a LOCA. Calculations performed in Reference 43 determined that the flow rate through any of the line breaks would be approximately 40 gallons per minute. Due to the rules of single failure criteria, it is only necessary to postulate the limiting failure of one (1) of the valves to close in the condition being evaluated. The valve associated with the broken line is assumed to be the one that fails.

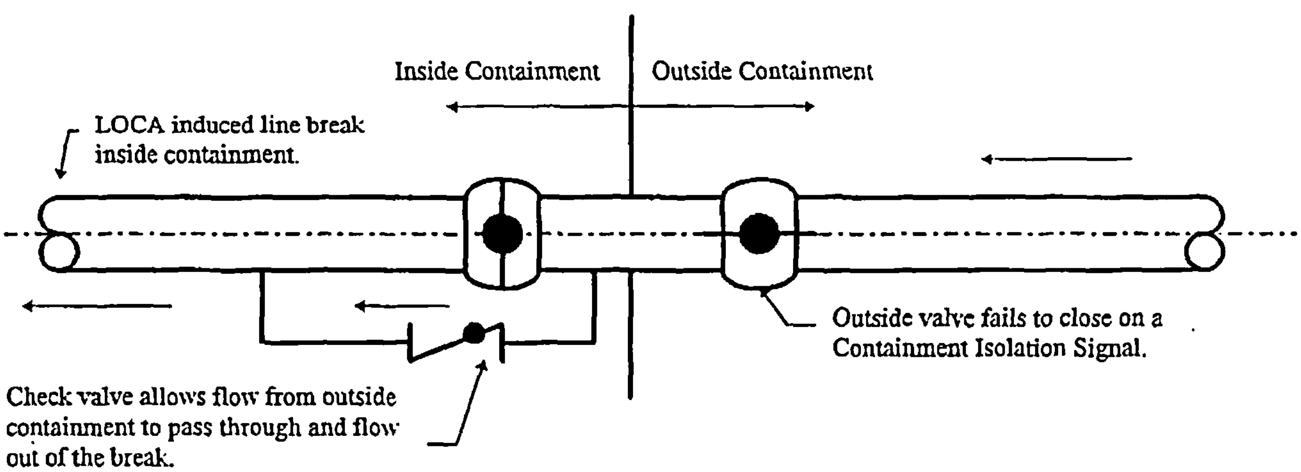

FIGURE C-1
Containment Penetration Detail

Calc Title: MAXIMUM CONTAINMENT WATER LEVEL							WBN Unit 1
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Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

The postulated failure of the outboard containment isolation valve would result in an unintended cooling water flow path into containment. This could affect two areas of concern: the boron concentration of the recirculation water in the containment sump, and the post LOCA flood level inside containment. The effect on boron concentration is evaluated in Reference 43.

Post LOCA Flooding Inside Containment

This calculation (WBNOSG4091) determines the maximum transient and equilibrium flood levels inside containment. Following a large break LOCA, the flood levels are as shown below.

1. The maximum transient level inside the Crane Wall, prior to establishing equilibrium conditions on each side of the Crane Wall, is 720.0 feet.

2. The maximum equilibrium level is 717.2 feet.

The 717.2 elevation is the maximum elevation specified for the raceway between the Crane Wall and Steel Containment Vessel on the Environmental Data drawing 47E235-42 (Reference 34). Flooding above this elevation could impact safety related equipment.

According to page 62 of this calculation, the maximum transient elevation inside the crane wall occurs at approximately 15 minutes after the Safety Injection Signal for a large break LOCA. After this time the maximum transient elevation will decrease due to flow out through the Crane Wall sleeves located above elevation 716.0' into the raceway and also into the reactor cavity. The flow through a CCS or ERCW line break will have negligible impact on the transient flood level during the initial 15 minute time frame following the LOCA. Conservatism in the calculation's assumptions will account for the slight difference in water flow into containment.

This calculation (WBNOSG4091) assumed the maximum postulated amount of liquid that could be dumped into containment following a LOCA. System descriptions N3-61-4001 "ICE CONDENSER SYSTEM" in subsection 3.2.19.3 (Reference 11), N3-63-4001, "SAFETY INJECTION SYSTEM" in Tables 7 and 9 (Reference 12), and N3-68-4001 "REACTOR COOLANT SYSTEM" on page 26 (Reference 11) provide normal minimum and maximum values for the fluid volumes of the Reactor Coolant System, the Safety Injection System Accumulators, Refueling Water Storage Tank, and the Ice Mass in the Ice Condenser. TABLE C-1 is based calculations performed in Reference 43, and gives a comparison of the values derived from the system descriptions with the values used in this calculation.

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Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

TABLE C-1

System Fluid Volumes					
Component	Volume total Per Ref. 43 gal, minimum	Volume total Per Ref. 43 gal, maximum	Volume per calc WBNOSG4091 gal	Maximum Difference gal	Minimum Difference gal
RCS	51,198	51,198	51,200	2	2
Accumulator	30,897	33,664	40,400	9,503	6,736
RWST	352,644	362,981	380,000	27,356	17,019
Ice Condenser	297,991	371,900	372,000	74,009	100
Total	732,730	819,743	843,600	110,870	23,857

As can be seen from the above table, calculation WBN-OSG4-091 provides conservative volumes for the water contributing to containment flooding. Another difference is that the flooding calculation WBN-OSG4-091 assumed the RWST completely emptied, when in actuality, approximately 28, 800 gallons of water remain in the tank. In addition, it also assumes a complete ice-melt, which may not occur during these LOCA scenarios, due to the location and size of the LOCAs.

With a flow rate of approximately 40 gpm through the check valve (Reference 43), a LOCA induced ERCW or CCS pipe break results in a flow rate of approximately 2,400 gallons per hour. Therefore, under worst case assumptions, there would be anywhere from approximately 10 to 46 hours before the actual flood level reached the equilibrium flood level in calculation WBN-OSG4-091 based on the range of values listed in TABLE C-1. This time span is based on the minimum and maximum values for the quantities of water that are specified in the system descriptions and shown in Table C-1. In actuality, the time to reach design basis equilibrium flood conditions will be longer since the types of LOCAs that would break the ERCW or CCS pipe lines are not the same size as the design basis LOCA evaluated in this calculation.

Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

EVALUATION OF THE CCS LINE BREAK

Description

If the line break was in the CCS system, a dropping level in the CCS Surge Tank would indicate a potential line break. In addition, a rising water level inside containment, caused by the CCS line break, would also be identified by Operations personnel.

According to subsection 3.2.3 of Reference 44, "Each of two surge tanks is divided internally by a baffle to separate the Train A and Train B sides of the surge tanks. This internal division provides redundancy for a passive failure during recirculation following a LOCA." The A Train side of the Surge Tank is associated with the piping that supplies the components in the Reactor Building served by the CCS.

In addition, subsection 3.3.2 of Reference 44 states, "Level indication is provided for each tank in the MCR and ACR. Low and high level alarms in MCR warn of the loss of water, or inleakage of water to the CCS."

Using the water level at which the high level alarm would actuate, it is possible to determine the maximum initial amount of water in the Surge Tank that would be available to drain into the Train A header, if there was a line break inside containment. Normally when the water level in the Surge Tank reaches the low level setpoint, valve 1-LCV-70-63 would open and make-up water would be provided from the Demineralized water system. For the purposes of this calculation, it is assumed the continuing need for makeup would additionally alert the operators to the potential for a line break, and together with the status light for the containment isolation valve showing it was still open, action would be taken to isolate the break in a timely manner. Either the break would be isolated, or the CCS pumps assigned to Train A would be shut down due to low NPSH concerns if makeup water was not available.

Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

Determination Of Time To Empty The CCS Surge Tank If Make-Up Is Not Available.

The following calculation determines the amount of water in the surge tank and the time it would take to drain the tank if there was a CCS line break inside the containment concurrent with a LOCA.

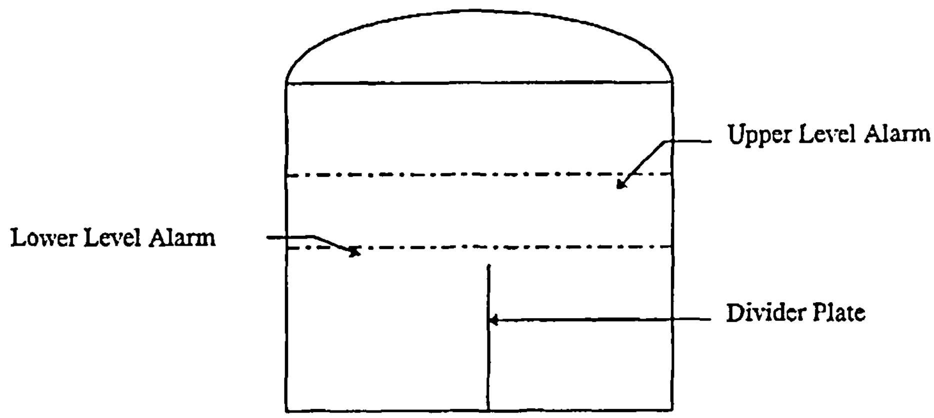

Figure C-2
CCS Surge Tank Outline

Volume of CCS Surge Tank

outside diameter =	12 ft	Ref. 45
outside diameter =	144 inches	Ref. 45
wall thickness =	5/16 inches	Ref. 45
inside diameter =	143.375 inches	
inside radius =	71.688 inches	
inside surface area =	16144.951 sq inches	
inside surface area =	112.118 sq feet	

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Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

volume =	112.118 cu feet/foot of height			
volume =	838.699 gallons/foot of height			
Low level alarm elevation =	769.08 feet			Ref. 46
At height above lower tap	75 inches			Ref. 46
Top of divider plate =	71.81 inches			Ref. 45
Height of water above the divider plate =	3.19 inches			
Volume above divider plate = (below low level alarm)	222.954 gallons			
Volume below divider plate =	2509.4 gallons	plus	790.5 gallons	Ref. 45
Volume below divider plate =	3299.9 gallons			
High level elevation =	770.875 feet			
Height from Low to High level alarms =	1.795 feet			
Volume from Low to High level alarms =	1505.464 gallons			
Total Volume of Water to be drained from the A Train side of the Surge Tank (assuming no make-up) =	5028.318 gallons			
Flow out of break CCS line break equals	40 gpm			Ref. 43
Time to drain from high level to low level alarm =	37.64 minutes			
Time to drain remainder of water, assuming no make-up =	88.07 minutes			
Total time to drain from the high level alarm =	125.71 minutes			

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Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

If valve 1-FCV-070-0092 or 0140 failed to close, and there was a LOCA induced line break inside containment in the piping associated with the open valve, the dropping level in the CCS Surge Tank would provide timely indication that there was a break in the CCS piping pressure boundary. Operator action to isolate the leak, by closing either the containment isolation valve or a manual valve in the piping associated with the containment isolation valve, would isolate the leak well before adversely impacting the maximum containment flood level. The manual valves which could be used to isolate the line break if the containment isolation valve fails to operate are listed below.

Isolation valve 1-ISV-070-501 (1-FCV-070-92)

(Refer to Drawings 1-47W859-1 (Ref. 51), -2 (Ref. 52), and 47W464--9 (Ref. 56)

Isolation valve 1-ISV-070-516 (1-FCV-070-140)

(Drawings 1-47W859-1 (Ref. 51), -2 (Ref. 52), and 47W464-8 (Ref. 55)

Isolation valve 1-ISV-070-700 (1-FCV-070-92)

(Refer to Drawings 1-47W859-(Ref. 51), -2 (Ref. 52), and 47W464-2D (Ref. 53)

Isolation valve 1-ISV-070-789 (1-FCV-070-140)

(Refer to Drawings 1-47W859-(Ref. 51), -2 (Ref. 52), and 47W464-3D (Ref. 54), -11 (Ref. 57)

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Appendix C

Flow Resulting From CCS and ERCW Line Breaks (continued)

Evaluation of the ERCW Line Break

The ERCW line break concern is significantly different from the CCS line breaks. The difference is that the source of the ERCW is the Tennessee River, and therefore, a line break could not be identified due to a loss of inventory in the ERCW system as is the case with the CCS. In the case of the ERCW line break, the only indicators would be indication that the containment isolation valve was open, and there was a rising water level inside containment.

As discussed previously, with a flow rate of approximately 40 gpm out of the line break, the maximum calculated flood level inside containment could be exceeded within 10 to 46 hours depending on the actual volume of fluid contained in each system.

Further evaluation of the Ice Condenser System modifies the minimum time frame. The minimum time frame of 10 hours is based on an Ice Mass of 3,000,000 lbm. The current Technical Specification requirement as defined in SR 3.6.11.2 is that the total weight of stored ice is ≥ 2,403,800 lbm. The as left ice mass after the U1C3 refueling outage was approximately 2,800,000 lbm (Reference 54). As shown on the next page, with an ice mass of 2,900,000 lbm, the minimum time frame for exceeding the maximum flood level inside containment becomes approximately 16 hours. The ice mass in the Ice Condenser is not expected to increase above 2,900,000 lbm mass. A 3,000,000 lbm, that would be the maximum value after the initial fill (or refill) of the Ice Condenser baskets. This value will not be reached by the normal servicing of the Ice Condenser during refueling outages. In addition, ice weight reduction programs that are currently being implemented (Refer to DCN D-50951-A) will further reduce the total amount of ice mass in the Ice Condenser.

The flow path(s) can be isolated as described below.

Isolation valve 1-ISV-067-523B (1-FCV-067-107)

If Containment Isolation Valve (CIV) 1-FCV-067-107 can not be closed and a line break in the associated piping inside containment needs to be isolated, valve 1-ISV-067-523B is the only valve available for isolation. This will isolate flow to both the 1B and 1D containment cooler groups and Reactor Coolant Pumps 2 and 4. Flow to these components would already have been isolated by the closure of the other associated CIVs; therefore, it is acceptable to shut this valve. Valve 1-ISV-067-523B is located at elevation 709'-6" and near column lines A2 and U (47W450-2D), and is the isolation valve for the connection to the 24" supply header.

(Refer to Drawings 1-47W845-2 (Ref. 48) and -3 (Ref. 49), 47W450-2D (Ref. 50).

WBNOSG4091, Rev. 9
WATTS BAR NUCLEAR PLANT, UNIT 1

Flow Resulting From
CCS and ERCW Line Breaks

Prepared by J. F. Lund
Checked by D. W. Posey

INPUT DATA

	Volume each min	Volume each max			Density of water lbm/cu ft	References
Reactor Coolant System Spillage	413,000	413,000	lbm			Design Input Item D
Cold Leg Accumulators	1,005	1,095	cu ft at	100 (F)	61.999051	Ref. 12, Table 7
Refueling Water Storage Tank Total Volume	370,000	380,000	gallons at	60 (F)	62.373587	Ref. 12, Table 9
Refueling Water Storage Tank Unused Volume						
O. D. = 43.5 ft						Ref. 60
wt = 5/16 inches						Ref. 60
lo to level = 31.2 inches						
Ice Condenser (Required)	2,403,800	2,900,000 lbm				Ref. 14, Section 3.2.19.3

CALCULATION OF ALLOWABLE CCS/ERCW FLOW INTO CONTAINMENT

Component		Mass lbm min	Mass lbm max	Density lbm/cu ft	Volume each cu ft min	Volume each cu ft max	Volume each gal min	Volume each gal max	Quantity
				190 (F)					
Reactor Coolant System		413,000	413,000	60.34302332	6,844	6,844	51,198	51,108	1
		lbm	lbm	lbm/cu ft	cu ft	cu ft	gallons	gallons	
Cold Leg Accumulators		62,309	67,889	60.34302332	1,033	1,125	7,724	8,410	4
		lbm	lbm	lbm/cu ft	cu ft	cu ft	gallons	gallons	
Refueling Water Storage Tank Total Volume							370,000	380,000	
Refueling Water Storage Tank Unused Volume									
O. D. =	43.5 ft								
wt =	5/16 inches								
I.D. =	43.45 ft								
Height =	31.2 inches =			2.600 feet					
Volume =	3,855 cu ft				3,855		28,836	28,836	
RWST Volume Transferred at		60 F					341,164	351 164 cu ft	
RWST Volume Transferred at		60 F					2,844,673	2,928,054 lbm	
RWST Transferred at	190 F	2,844,673	2,928,054	60.34302332	47,142	48,523	352,644	362,981	1
		lbm	lbm	lbm/cu ft	cu ft	cu ft	gallons	gallons	
Ice Condenser (Required)		2,403,800	2,900,000	60.34302332	39,836	48,059	297,991	359 503	1
		lbm	lbm	lbm/cu ft	cu ft	cu ft	gallons	gallons	
			2 781,373	lbm as of Apr 1999					

Component	Volume total gal min	Volume each gal max	Volume per calc gal	Maximum Difference gal	Minimum Difference gal
Reactor Coolant System	51,198	51,198	51,200	2	2
Cold Leg Accumulators	30,897	33,664	40,400	9,503	6,736
RWST Transferred at 190 F	352,644	362,981	380,000	27,356	17,019
Ice Condenser (Required)	297,991	359,503	372,000	74,009	12,497
	732,730	807,346	843,600	110,870	36,254
			daily flow rate	54,720	gal/day
	days to reach equilibrium flood elevation			2.03	0.66
	hours to reach equilibrium flood elevation			48.63	15.90

Page Added by Revision 9

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Appendix C (Continued)

Flow Resulting From CCS and ERCW Line Breaks (continued)

SUMMARY

If one of the subject valves fails to close, remedial action should be taken to minimize the effects on the water level inside containment.

In the cases of the Component Cooling Systems, valve position indication lights and a dropping inventory in the CCS Surge Tank, or the requirement to frequently add make-up water to the Surge Tank would ensure remedial actions are taken well within the 16 hour time frame before the water from the line break affects the water level inside containment.

In the case of an ERCW line break the valve position indication lights and an increasing water level inside containment would be the indications that there is the possibility ERCW was getting into the post-LOCA containment water inventory. As long as the flow into containment is isolated within the 10 to 16 hour time frame, there are no adverse consequences to the containment flooding analysis flood levels.

WALKDOWN DATA REQUEST FORM (Example)

Page 1 of 4

Walkdown Identification No. WBN-OSG4-071-ISC

Walkdown Title Inside Containment Evaluation of Free Volume for RHR Containment Sump Level (elevation vs gallons)

Walkdown Initiating Document WBN-OSG4-071

Affected Documents (Attach if Required) NR   References: 47W470-4, 41N710, 41N716, 41N726, 47W200

Estimated Walkdown Manhours 40

PWL Code WJ

Walkdown Location	1 RB	702.8'	0-360	LOWER CONTAINMENT
	Unit & Bldg	Elev.	Azimuth/Col. lines	Room/Area

Walkdown Scope

- Walkdown Unit 1 Lower Containment in conjunction with the ~~[illegible]~~ concrete outline drawings (see references ~~[illegible]~~ 4/27/92) to calculate the amount of Lower containment (ft³) space occupied by concrete. (Volume vs Elev)
- Determine the amount of Lower Containment free space occupied by misc equipment (structural steel, supports, etc).
- The above to be done for Inside Crane Wall and Outside Crane Wall from floor elevation to just above the elevation of the crane wall unsealed penetrations (neglect Rx Cavity). Roughly from 702.8' to 716' to 720' (this higher elevation needed for input to OSG4-091 sump level).

Data Tolerance Requirements Field Measurements ± ½"

- ID all penetrations thru crane wall that are unsealed between elev 702.8 and 721.

John Henry Sullivan Jr	4/27/92	3274	[signature]	4/27/92
Data Requester (Print)	Date	Tel. No.	Supervisor Signature	Date

WALKDOWN DOCUMENTATION FORM (Example)

Page 2 of 9

Walkdown Identification No. WBN-0S64-071-1SC

Actual Walkdown Manhours ~18

Walkdown Documentation

This following is a itemized list of items found outside crane wall from az 11° to az 23° and from el. 702.78′ to el. 714.0′. Piping and conduits in this area <2 1/2" and support steel were not identified.

1. 3" pipe x 9′-0 1/2" lg. (CVCS)
2. 4" pipe x 9′-1 1/2" lg. (CVCS)
3. 3" pipe x 9′-0 1/2" lg. (CCS)
4. 3" pipe x 9′-0 1/2" lg. (CCS)
5. 6" pipe x 9′-0 1/2" lg. (CCS)
6. 6" pipe x 9′-0 1/2" lg. (CCS)
7. 6" pipe x 12′-9 1/2" lg. (CCS)
8. 6" pipe x 14′-10" lg. (CCS)
9. 4" pipe x 10′-10" lg. (S.G. BLOWDOWN)
10. 4" pipe x 17′-4 1/2" lg. (S.G. BLOWDOWN)
11. 3" conduit x 3′-6" lg. (1VC-2580A)
12. 3" conduit x 11′-3" lg. (PLC-1072A)
13. Junction box - 6" x 6" x 6" (1-JB-293-392A)
14. Junction box - 12" x 14" x 6" (1-JB-293-2516)

DENNIS REIFFER
Data Taker (Print)

[signature]
Data Taker Signature

6-1-92
Date

GEORGE M. HERRON
Data Verifier (Print)

George M. Herron
Data Verifier Signature

6-4-92
Date

WALKDOWN DOCUMENTATION FORM (Example)

Page 3 of 4

Walkdown Identification No. WBN-0SG4-071-ISC

Actual Walkdown Manhours ~20

Walkdown Documentation

This following is a itemized list of items found inside crane wall from az 0° to az 15° and from el. 702.78' to el. 708.78'. Piping and conduits in this area <2 1/2" were not identified.

1. 3" Pipe x 5'-6" lg. (Station Drain)
2. 3" Pipe x 10'-6" lg. (WDS)
3. 4" Pipe x 10'-6" lg. (Fire Protection)
4. 4" Pipe x 5'-0" lg. (WDS)
5. 8" Pipe x 1'-3" lg. (HVAC Support)
6. Junction box - 6" x 4" x 4" (1-JB-293-1025)
7. Junction box - 6" x 6" x 6" (1-JB-293-798)
8. Junction box - 12" x 14" x 6" (1-JB-293-585)
9. TS 3" x 3" x 6'-6" lg. (Pipe Support - ERCW)
10. TS 4" x 4" x 3'-6" lg. (Platform Support)
11. TS 4" x 4" x 6'-0" lg. (Pipe Support - ERCW)

DENNIS REIFFER	[signature]	6-1-92
Data Taker (Print)	Data Taker Signature	Date
GEORGE M. HERRON	George M. Herron	6-5-92
Data Verifier (Print)	Data Verifier Signature	Date

WALKDOWN DOCUMENTATION FORM (Example)
Continuation Sheet

Page 4 of 4

Walkdown Identification No. WBN-0564-071-1SC

This following is a list of sleeves found between elevations 716.0' and 721.0' that were not sealed (RB1 crane wall)

Room	Elev. (ft.)	Sleeve Size	Pipe Size	Qty
Acc. Rm. 1	716.3	4"	1"	1
Acc. Rm. 2	716.3	4"	1"	1
Acc. Rm. 2	718.5	8"	Empty	1
Acc. Rm. 3	716.3	4"	1"	1
Acc. Rm. 3	718.5	8"	Empty	1
Acc. Rm. 4	716.3	4"	1"	1
Acc. Rm. 4	717.0	4"	1 - 3/8" tube	1
Acc. Rm. 4	718.0	24"	14" (2" ins)	1
Acc. Rm. 4	718.5	8"	2 - 3/8" tubes	1
Acc. Rm. 4	721.0	18"	2 - 3/8" tubes	1
Excess Letdown Hx.	721.0	4"	Empty	1
Excess Letdown Hx.	Bot. el. 716.0'	1.66' x 1.5'	Empty	1

/R1 /R1

Note: There were no openings in Cooling Rm. 1 & 2.

DENNIS REIFFER / R1 J.H. Sullivan	[signature] R1 [signature]	12/3/92 6-4-92	
Data Taker (Print)	Data Taker Signature	Date	
GEORGE M. HERRON R1 GEORGE M. HERRON	George M. Herron R1 George M. Herron	12/3/92 6-10-92	/R1
Data Verifier (Print)	Data Verifier Signature	Date	

Physical Properties of Water

Temperature of Water t Degrees Fahrenheit	Saturation Pressure P' Pounds per Square Inch Absolute	Specific Volume $\bar{V}$ Cubic Feet Per Pound	Weight Density ρ Pounds per Cubic Foot	Weight Pounds Per Gallon
32	0.08859	0.016022	62.414	8.3436
40	0.12163	0.016019	62.426	8.3451
50	0.17796	0.016023	62.410	8.3430
60	0.25611	0.016033	62.371	8.3378
70	0.36292	0.016050	62.305	8.3290
80	0.50683	0.016072	62.220	8.3176
90	0.69813	0.016099	62.116	8.3037
100	0.94924	0.016130	61.996	8.2877
110	1.2750	0.016165	61.862	8.2698
120	1.6927	0.016204	61.7132	8.2498
130	2.2230	0.016247	61.550	8.2280
140	2.8892	0.016293	61.376	8.2048
150	3.7184	0.016343	61.188	8.1797
160	4.7414	0.016395	60.994	8.1537
170	5.9926	0.016451	60.787	8.1260
180	7.5110	0.016510	60.569	8.0969
190	9.340	0.016572	60.343	8.0667
200	11.526	0.016637	60.107	8.0351
210	14.123	0.016705	59.862	8.0024
212	14.696	0.016719	59.812	7.9957
220	17.186	0.016775	59.613	7.9690
240	24.968	0.016926	59.081	7.8979
260	35.427	0.017089	58.517	7.8226
280	49.200	0.017264	57.924	7.7433
300	67.005	0.01745	57.307	7.6608
350	134.604	0.01799	55.586	7.4308
400	247.259	0.01864	53.648	7.1717
450	422.55	0.01943	51.467	6.8801
500	680.86	0.02043	48.948	6.5433
550	1045.43	0.02176	45.956	6.1434
600	1543.2	0.02364	42.301	5.6548
650	2208.4	0.02674	37.397	4.9993
700	3094.3	0.03662	27.307	3.6505

Specific gravity of water at 60 F = 1.00

Weight per gallon is based on 7.48052 gallons per cubic foot.

All data on volume and pressure are abstracted from ASME Steam Tables (1967), with permission of publisher, The American Society of Mechanical Engineers, 345 East 47th Street, New York, N.Y. 10017.

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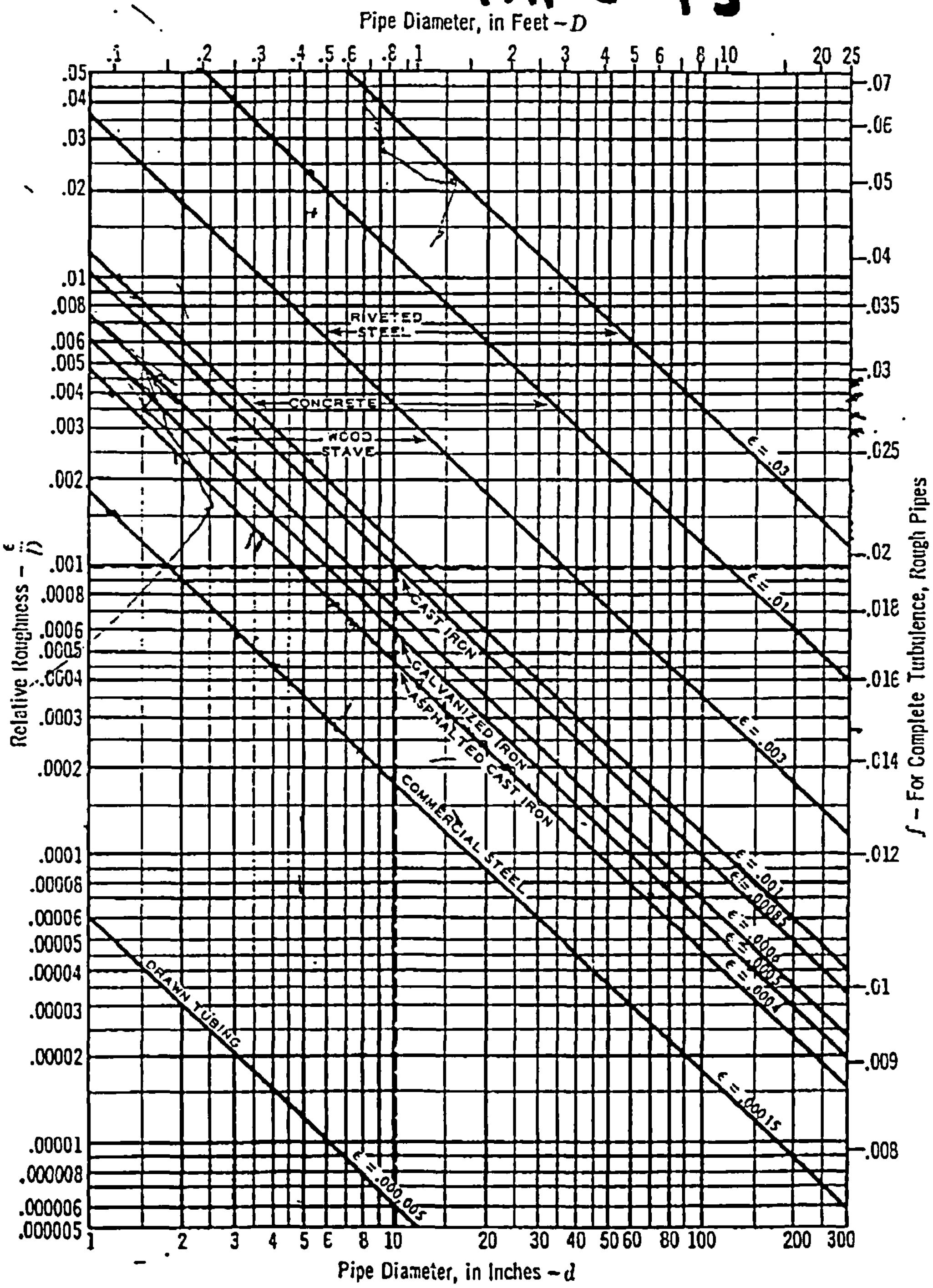
WBN-0SQ-4-091

Relative Roughness of Pipe Materials and Friction Factors For Complete Turbulence[18]

Att 2 pg 2 of 10



Data extracted from *Friction Factors for Pipe Flow* by L.F. Moody, with permission of the publisher, The American Society of Mechanical Engineers, 29 West 39th Street, New York.

Problem: Determine absolute and relative roughness, and friction factor, for fully turbulent flow in 10-inch cast iron pipe (I.D. = 10.16").

Solution: Absolute roughness (ε) = 0.00085.....Relative roughness (ε/D) = 0.001.....Friction factor at fully turbulent flow (f) = 0.0196.

WBN-0504-091
Att 2 pg 3 of 10

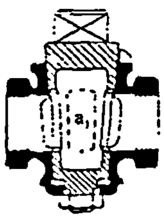
"K" FACTOR TABLE—SHEET 4 of 4

Representative Resistance Coefficients (K) for Valves and Fittings

(for formulas and friction data, see page A-26)

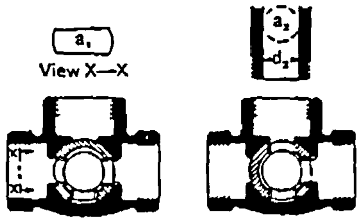
PLUG VALVES AND COCKS

Straight-Way



If: $\beta = 1$, $K_1 = 18\, f_T$

3-Way

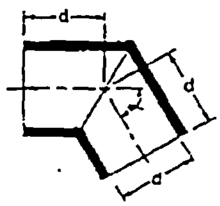


If: $\beta = 1$, $K_1 = 30\, f_T$

If: $\beta = 1$, $K_1 = 90\, f_T$

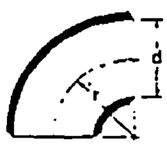
If: $\beta < 1 \ldots K_2$ = Formula 6

MITRE BENDS



∝	K
0°	2 f_T
15°	4 f_T
30°	8 f_T
45°	15 f_T
60°	25 f_T
75°	40 f_T
90°	60 f_T

90° PIPE BENDS AND FLANGED OR BUTT-WELDING 90° ELBOWS



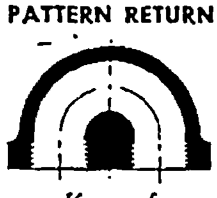
r/d	K	r/d	K
1	20 f_T	10	30 f_T
2	12 f_T	12	34 f_T
3	12 f_T	14	38 f_T
4	14 f_T	16	42 f_T
6	17 f_T	18	46 f_T
8	24 f_T	20	50 f_T

The resistance coefficient, K_B, for pipe bends other than 90° may be determined as follows:

$$K_B = (n-1)\left(0.25\,\pi f_T \frac{r}{d} + 0.5\,K\right) + K$$

n = number of 90° bends
K = resistance coefficient for one 90° bend (per table)

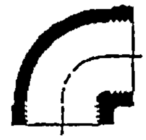
CLOSE PATTERN RETURN BENDS



$K = 50\, f_T$

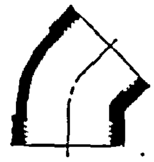
STANDARD ELBOWS

90°



$K = 30\, f_T$

45°



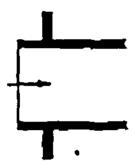
$K = 16\, f_T$

STANDARD TEES

Flow thru run.......$K = 20\, f_T$
Flow thru branch....$K = 60\, f_T$

PIPE ENTRANCE

Inward Projecting

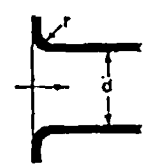


$K = 0.78$

r/d	K
0.00*	0.5
0.02	0.28
0.04	0.24
0.06	0.15
0.10	0.09
0.15 & up	0.04

*Sharp-edged

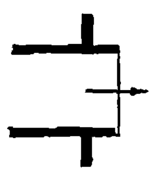
Flush



For K, see table

PIPE EXIT

Projecting

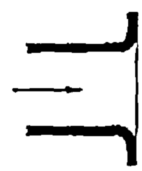


$K = 1.0$

Sharp-Edged

$K = 1.0$

Rounded



$K = 1.0$

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Summary of Formulas

Att 2 pg 4 of 10

To eliminate needless duplication, formulas have been written in terms of either specific volume $\bar{V}$ or weight density ρ, but not in terms of both, since one is the reciprocal of the other.

$$\bar{V} = \frac{1}{\rho} \qquad \rho = \frac{1}{\bar{V}}$$

These equations may be substituted in any of the formulas shown in this paper whenever necessary.

● **Bernoulli's theorem:** *Equation 3-1*

$$Z + \frac{144\,P}{\rho} + \frac{v^2}{2g} = H$$

$$Z_1 + \frac{144\,P_1}{\rho_1} + \frac{v_1^2}{2g} = Z_2 + \frac{144\,P_2}{\rho_2} + \frac{v_2^2}{2g} + h_L$$

● **Mean velocity of flow in pipe:**
(Continuity Equation) *Equation 3-2*

$$v = \frac{q}{A} = 183.3\,\frac{q}{d^2} = 0.408\,\frac{Q}{d^2}$$

$$v = 0.286\,\frac{B}{d^2} = 183.3\,\frac{w\bar{V}}{d^2} = 0.0509\,\frac{W\bar{V}}{d^2}$$

$$v = 0.001\,44\,\frac{q'_h T}{P' d^2} = 0.003\,89\,\frac{q'_h S_g}{\rho d^2}$$

$$V = \frac{q_m}{A} = 2.40\,\frac{W\bar{V}}{a} = 3.06\,\frac{W\bar{V}}{d^2}$$

$$V = 0.0865\,\frac{q'_h T}{P' d^2} = 0.233\,\frac{q'_h S_g}{\rho d^2}$$

● **Reynolds number of flow in pipe:** *Equation 3-3*

$$R_e = \frac{Dv\rho}{\mu_e} = \frac{Dv\rho}{32.2\mu'_e} = 123.9\,\frac{dv\rho}{\mu}$$

$$R_e = 22\,700\,\frac{q\rho}{d\mu} = \frac{473\,q\rho}{R_H\mu} = 50.6\,\frac{Q\rho}{d\mu}$$

$$R_e = 6.31\,\frac{W}{d\mu} = 0.482\,\frac{q'_h S_g}{d\mu} = 35.4\,\frac{B\rho}{d\mu}$$

$$R_e = \frac{Dv}{\nu'} = \frac{dv}{12\nu'} = 7740\,\frac{dv}{\nu}$$

$$R_e = 1\,419\,000\,\frac{q}{\nu d} = 3160\,\frac{Q}{\nu d} = 394\,\frac{W\bar{V}}{\nu d}$$

● **Viscosity equivalents:** *Equation 3-4*

$$\nu = \frac{\mu}{\rho'} = \frac{\mu}{S}$$

● **Head loss and pressure drop in straight pipe:**

Pressure loss due to flow is the same in a sloping, vertical, or horizontal pipe. However, the difference in pressure due to the difference in head must be considered in pressure drop calculations; see page 1-5.

Darcy's formula: *Equation 3-5*

$$h_L = f\,\frac{L}{D}\,\frac{v^2}{2g} = 0.1863\,\frac{fLv^2}{d}$$

$$h_L = 6260\,\frac{fLq^2}{d^5} = 0.0311\,\frac{fLQ^2}{d^5}$$

$$h_L = 0.015\,24\,\frac{fLB^2}{d^5} = 0.000\,483\,\frac{fLW^2\bar{V}^2}{d^5}$$

$$\Delta P = 0.001\,294\,\frac{fL\rho v^2}{d} = 0.000\,000\,359\,\frac{fL\rho V^2}{d}$$

$$\Delta P = 43.5\,\frac{fL\rho q^2}{d^5} = 0.000\,216\,\frac{fL\rho Q^2}{d^5}$$

$$\Delta P = 0.000\,1058\,\frac{fL\rho B^2}{d^5} = 0.000\,003\,36\,\frac{fLW^2\bar{V}}{d^5}$$

$$\Delta P = 0.000\,000\,007\,26\,\frac{fLT(q'_h)^2 S_g}{d^5 P'}$$

$$\Delta P = 0.000\,000\,019\,59\,\frac{fL(q'_h)^2 S_g^2}{d^5\rho}$$

For simplified compressible fluid formula, see page 3-22.

● **Head loss and pressure drop with laminar flow in straight pipe:**

For laminar flow conditions ($R_e < 2000$), the friction factor is a direct mathematical function of the Reynolds number only, and can be expressed by the formula: $f = 64/R_e$. Substituting this value of f in the Darcy formula, it can be rewritten:

Equation 3-6

$$h_L = 0.0962\,\frac{\mu L v}{d^2\rho}$$

$$h_L = 17.65\,\frac{\mu L q}{d^4\rho} = 0.0393\,\frac{\mu L Q}{d^4\rho}$$

$$h_L = 0.0275\,\frac{\mu L B}{d^4\rho} = 0.004\,90\,\frac{\mu L W}{d^4\rho^2}$$

$$\Delta P = 0.000\,668\,\frac{\mu L v}{d^2} = 0.1225\,\frac{\mu L q}{d^4}$$

$$\Delta P = 0.000\,273\,\frac{\mu L Q}{d^4} = 0.000\,191\,\frac{\mu L B}{d^4}$$

$$\Delta P = 0.000\,0340\,\frac{\mu L W}{d^4\rho}$$

Summary of Formulas — continued

Att 2 pg 5 of 10

Limitations of Darcy formula

Non-compressible flow; liquids:

The Darcy formula may be used without restriction for the flow of water, oil, and other liquids in pipe. However, when extreme velocities occurring in pipe cause the downstream pressure to fall to the vapor pressure of the liquid, cavitation occurs and calculated flow rates are inaccurate.

Compressible flow; gases and vapors:

When pressure drop is less than 10% of P_1, use ρ or $\bar{V}$ based on either inlet or outlet conditions.

When pressure drop is greater than 10% of P_1 but less than 40% of P_1, use the average of ρ or $\bar{V}$ based on inlet and outlet conditions, or use Equation 3-20.

When pressure drop is greater than 40% of P_1, use the rational or empirical formulas given on this page for compressible flow, or use Equation 3-20 (for theory, see page 1-9).

Isothermal flow of gas in pipe lines

Equation 3-7

$$w = \sqrt{\frac{144 g A^2}{\bar{V}_1\left(f\frac{L}{D} + 2\log_e\frac{P'_1}{P'_2}\right)}\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$w = 0.371\sqrt{\frac{d^4}{\bar{V}_1\left(f\frac{L}{D} + 2\log_e\frac{P'_1}{P'_2}\right)}\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

Simplified compressible flow for long pipe lines

Equation 3-7a

$$w = \sqrt{\left(\frac{144 g A^2}{\bar{V}_1 f \frac{L}{D}}\right)\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$w = 0.1072\sqrt{\left(\frac{d^5}{\bar{V}_1 f L}\right)\left(\frac{(P'_1)^2 - (P'_2)^2}{P'_1}\right)}$$

$$q'_h = 114.2\sqrt{\left(\frac{(P'_1)^2 - (P'_2)^2}{f L_m T S_g}\right) d^5}$$

Maximum (sonic) velocity of compressible fluids in pipe

The maximum possible velocity of a compressible fluid in a pipe is equivalent to the speed of sound in the fluid; this is expressed as:

Equation 3-8

$$v_s = \sqrt{k g R T}$$

$$v_s = \sqrt{k g\, 144 P' \bar{V}}$$

$$v_s = 68.1\sqrt{k P' \bar{V}}$$

Empirical formulas for the flow of water, steam, and gas

Although the rational method (using Darcy's formula) for solving flow problems has been recommended in this paper, some engineers prefer to use empirical formulas.

Hazen and Williams formula for flow of water: *Equation 3-9*

$$Q = 0.442\, d^{2.63}\, c\left(\frac{P_1 - P_2}{L}\right)^{0.54}$$

where:
- c = 140 for new steel pipe
- c = 130 for new cast iron pipe
- c = 110 for riveted pipe

Babcock formula for steam flow: *Equation 3-10*

$$\Delta P = 0.000\,000\,0363\left(\frac{d + 3.6}{d^6}\right) W^2 L \bar{V}$$

$$\Delta P = 0.470\left(\frac{d + 3.6}{d^6}\right) w^2 L \bar{V}$$

Spitzglass formula for low pressure gas: (pressure less than one pound gauge) *Equation 3-11*

$$q'_h = 3550\sqrt{\frac{\Delta h_w d^5}{S_g L\left(1 + \frac{3.6}{d} + 0.03\, d\right)}}$$

Flowing temperature is 60 F.

Weymouth formula for high pressure gas: *Equation 3-12*

$$q'_h = 28.0\, d^{2.667}\sqrt{\left(\frac{(P'_1)^2 - (P'_2)^2}{S_g L_m}\right)\left(\frac{520}{T}\right)}$$

Panhandle formula[3] for natural gas pipe lines 6 to 24-inch diameter and R_e = (5 x 10⁶) to (14 x 10⁶): *Equation 3-13*

$$q'_h = 36.8E\, d^{2.6182}\left(\frac{(P'_1)^2 - (P'_2)^2}{L_m}\right)^{0.5394}$$

where: gas temperature = 60 F
- S_g = 0.6
- E = flow efficiency
- E = 1.00 (100%) for brand new pipe without any bends, elbows, valves, and change of pipe diameter or elevation
- E = 0.95 for very good operating conditions
- E = 0.92 for average operating conditions
- E = 0.85 for unusually unfavorable operating conditions

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Summary of Formulas — continued

Att 2 pg 6 of 10

Head loss and pressure drop through valves and fittings

Head loss through valves and fittings is generally given in terms of resistance coefficient K which indicates static head loss through a valve in terms of "velocity head", or, equivalent length in pipe diameters L/D that will cause the same head loss as the valve.

From Darcy's formula, head loss through a pipe is:

$$h_L = f\frac{L}{D}\frac{v^2}{2g} \qquad \text{Equation 3-5}$$

and head loss through a valve is:

$$h_L = K\frac{v^2}{2g} \qquad \text{Equation 3-14}$$

therefore:

$$K = f\frac{L}{D} \qquad \text{Equation 3-15}$$

To eliminate needless duplication of formulas, the following are all given in terms of K. Whenever necessary, substitute $(f\,L/D)$ for (K).

$$h_L = \frac{522\,Kq^2}{d^4} = 0.002\,59\,\frac{KQ^2}{d^4} \qquad \text{Equation 3-14}$$

$$h_L = 0.001\,270\,\frac{KB^2}{d^4} = 0.000\,0403\,\frac{KW^2\bar{V}^2}{d^4}$$

$$\Delta P = 0.000\,1078\,K\rho v^2 = 0.000\,000\,0300\,K\rho V^2$$

$$\Delta P = 3.62\,\frac{K\rho q^2}{d^4} = 0.000\,017\,99\,\frac{K\rho Q^2}{d^4}$$

$$\Delta P = 0.000\,008\,82\,\frac{K\rho B^2}{d^4}$$

$$\Delta P = 0.000\,000\,280\,\frac{KW^2\bar{V}}{d^4}$$

$$\Delta P = 0.000\,000\,000\,605\,\frac{K(q'_h)^2\,T\,S_g}{d^4\,P'}$$

$$\Delta P = 0.000\,000\,001\,633\,\frac{K\,(q'_h)^2\,S_g^2}{d^4\,\rho}$$

For compressible flow with h_L or ΔP greater than approximately 10% of inlet absolute pressure, the denominator should be multiplied by Y^2. For values of Y, see page A-21.

Pressure drop and flow of liquids, using flow coefficient

$$\Delta P = \left(\frac{Q}{C_v}\right)^2\frac{\rho}{62.4} \qquad \text{Equation 3-16}$$

$$Q = C_v\sqrt{\Delta P\frac{62.4}{\rho}} = 7.90\,C_v\sqrt{\frac{\Delta P}{\rho}}$$

$$C_v = Q\sqrt{\frac{\rho}{\Delta P\,(62.4)}} = \frac{29.9\,d^2}{\sqrt{f\,L/D}} = \frac{29.9\,d^2}{\sqrt{K}}$$

$$K = \frac{891\,d^4}{(C_v)^2}$$

Resistance coefficient, K, for sudden and gradual enlargements in pipes

If, $\theta \leq 45°$,

$$K = 2.6\sin\frac{\theta}{2}\,(1-\beta^2)^2 \qquad \text{*Equation 3-17}$$

If, $45° < \theta \leq 180°$,

$$K = (1-\beta^2)^2 \qquad \text{*Equation 3-17.1}$$

Resistance coefficient, K, for sudden and gradual contractions in pipes

If, $\theta \leq 45°$,

$$K = 0.8\sin\frac{\theta}{2}\,(1-\beta^2) \qquad \text{*Equation 3-18}$$

If, $45° < \theta \leq 180°$,

$$K = 0.5\sqrt{\sin\frac{\theta}{2}}\,(1-\beta^2) \qquad \text{*Equation 3-18.1}$$

**Note:* The values of the resistance coefficients (K) in equations 3-17, 3-17.1, 3-18, and 3-18.1 are based on the velocity in the small pipe. To determine K values in terms of the greater diameter, divide the equations by β^4.

Discharge of fluid through valves, fittings, and pipe; Darcy's formula

Liquid flow: Equation 3-19

$$q = 0.0438\,d^2\sqrt{\frac{h_L}{K}} = 0.525\,d^2\sqrt{\frac{\Delta P}{K\rho}}$$

$$Q = 19.65\,d^2\sqrt{\frac{h_L}{K}} = 236\,d^2\sqrt{\frac{\Delta P}{K\rho}}$$

$$w = 0.0438\,\rho d^2\sqrt{\frac{h_L}{K}} = 0.525\,d^2\sqrt{\frac{\Delta P\rho}{K}}$$

$$W = 157.6\,\rho d^2\sqrt{\frac{h_L}{K}} = 1891\,d^2\sqrt{\frac{\Delta P\rho}{K}}$$

Compressible flow:

$$q'_h = 40\,700\,Yd^2\sqrt{\frac{\Delta P\,P'_1}{KT_1\,S_g}} \qquad \text{Equation 3-20}$$

$$q'_h = 24\,700\,\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\,\rho_1}{K}}$$

$$q'_m = 678\,Yd^2\sqrt{\frac{\Delta P\,P'_1}{KT_1\,S_g}} = 412\,\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\,\rho_1}{K}}$$

$$q' = 11.30\,Yd^2\sqrt{\frac{\Delta P P'_1}{KT_1\,S_g}} = 6.87\,\frac{Yd^2}{S_g}\sqrt{\frac{\Delta P\rho_1}{K}}$$

$$w = 0.525\,Yd^2\sqrt{\frac{\Delta P}{K\bar{V}_1}} \qquad W = 1891\,Yd^2\sqrt{\frac{\Delta P}{K\bar{V}_1}}$$

Values of Y are shown on page A-22. For K, Y, and ΔP determination, see examples on pages 4-13 and 4-14.

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Summary of Formulas — concluded

● **Flow through nozzles and orifices**
(h_L and ΔP measured across taps at 1 diameter and 0.5 diameter)

Liquid: *Equation 3-21*

$$q = AC\sqrt{2g\,h_L}$$

$$q = 0.0438\,d_1^2\,C\sqrt{h_L} = 0.525\,d_1^2\,C\sqrt{\frac{\Delta P}{\rho}}$$

$$Q = 19.65\,d_1^2\,C\sqrt{h_L} = 236\,d_1^2\,C\sqrt{\frac{\Delta P}{\rho}}$$

$$w = 0.0438\,d_1^2\,C\sqrt{h_L\,\rho^2} = 0.525\,d_1^2\,C\sqrt{\Delta P\rho}$$

$$W = 157.6\,d_1^2\,C\sqrt{h_L\,\rho^2} = 1891\,d_1^2\,C\sqrt{\Delta P\rho}$$

Values of C are shown on page A-20

Compressible fluids: *Equation 3-22*

$$q'_h = 40\,700\,Y\,d_1^2\,C\sqrt{\frac{\Delta P\,P'_1}{T_1\,S_g}}$$

$$q'_h = 24\,700\,\frac{Y\,d_1^2\,C}{S_g}\sqrt{\Delta P\,\rho_1}$$

$$q'_m = 678\,Y\,d_1^2\,C\sqrt{\frac{\Delta P\,P'_1}{T_1\,S_g}}$$

$$q'_m = 412\,\frac{Y\,d_1^2\,C}{S_g}\sqrt{\Delta P\rho_1}$$

$$q' = 11.30\,Y\,d_1^2\,C\sqrt{\frac{\Delta P\,P'_1}{T_1\,S_g}}$$

$$q' = 6.87\,\frac{Y\,d_1^2\,C}{S_g}\sqrt{\Delta P\rho_1}$$

$$w = 0.525\,Y\,d_1^2\,C\sqrt{\frac{\Delta P}{\bar{V}_1}}$$

$$W = 1891\,Y\,d_1^2\,C\sqrt{\frac{\Delta P}{\bar{V}_1}}$$

Values of C are shown on page A-20
Values of Y are shown on page A-21

● **Equivalents of head loss and pressure drop** *Equation 3-23*

$$h_L = \frac{144\,\Delta P}{\rho} \qquad \Delta P = \frac{h_L\,\rho}{144}$$

● **Changes in resistance coefficient, K, required to compensate for different pipe I. D.** *Equation 3-24*

$$K_a = K_b\left(\frac{d_a}{d_b}\right)^4$$

(see page A-30)

Subscript a refers to pipe in which valve will be installed.
Subscript b refers to pipe for which the resistance coefficient K was established.

● **Specific gravity of liquids**

Any liquid: *Equation 3-25*

$$s = \frac{\rho\ \left(\text{any liquid at 60 F, unless otherwise specified}\right)}{\rho\ (\text{water at 60 F})}$$

Oils: *Equation 3-26*

$$S\,(60\text{ F}/60\text{ F}) = \frac{141.5}{131.5 + \text{Deg API}}$$

Liquids lighter than water: *Equation 3-27*

$$S\,(60\text{ F}/60\text{ F}) = \frac{140}{130 + \text{Deg Baumé}}$$

Liquids heavier than water: *Equation 3-28*

$$S\,(60\text{ F}/60\text{ F}) = \frac{145}{145 - \text{Deg Baumé}}$$

● **Specific gravity of gases** *Equation 3-29*

$$S_g = \frac{R\,(\text{air})}{R\,(\text{gas})} = \frac{53.3}{R\,(\text{gas})}$$

$$S_g = \frac{M\,(\text{gas})}{M\,(\text{air})} = \frac{M\,(\text{gas})}{29}$$

● **General gas laws for perfect gases**

$$p'V_a = w_a\,RT$$ *Equation 3-30*

$$\rho = \frac{w_a}{V_a} = \frac{p'}{RT} = \frac{144\,P'}{RT}$$ *Equation 3-31*

$$R = \frac{1544}{M} = \frac{144\,P'}{\rho T}$$ *Equation 3-32*

Equation 3-33

$$p'V_a = n_a MRT = n_a\,1544\,T = \frac{w_a}{M}\,1544\,T$$

Equation 3-34

$$\rho = \frac{w_a}{V_a} = \frac{p'M}{1544\,T} = \frac{P'M}{10.72\,T} = \frac{2.70\,P'S_g}{T}$$

where:
$n_a = w_a/M$ = number of mols of a gas

● **Hydraulic radius*** *Equation 3-35*

$$R_H = \frac{\text{cross sectional flow area (sq. feet)}}{\text{wetted perimeter (feet)}}$$

Equivalent diameter relationship:
$D = 4R_H$
$d = 48R_H$

*See page 1-4 for limitations.

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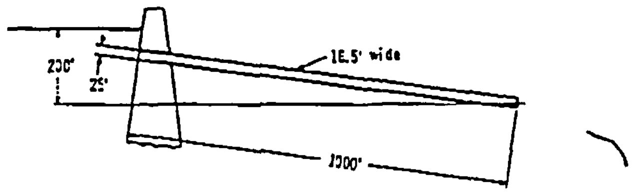
Application of Hydraulic Radius to Flow Problems

Att 2 pg 8 of 10

Example 4-25... Rectangular Duct

Given: A rectangular concrete overflow aqueduct, 25 feet high and 16.5 feet wide, has an absolute roughness (ϵ) of 0.01 foot.



Find: The discharge rate in cubic feet per second when the liquid in the reservoir has reached the maximum height indicated in the above sketch. Assume the average temperature of the water is 60 F.

Solution:

1. $h_L = \frac{v^2}{2g}(K_e + K_a) = \frac{v^2}{2g}\left(K_e + \frac{fL}{4R_H}\right)$

2. $v = \frac{q}{A}$

3. $q = 0.0438\, d^2 \sqrt{\frac{h_L}{K_e + K_a}}$ ....page 3-4

$q = 8.05 A \sqrt{\frac{h_L}{K_e + K_c}}$

$q = 8.05 A \sqrt{\frac{h_L}{K_e + f\frac{L}{4R_H}}}$

$\frac{.0438 \times 144}{0.785} = 8.05$

where: K_e = resistance of entrance and exit
K_a = resistance of aqueduct

To determine the friction factor from the Moody diagram, an equivalent diameter four times the hydraulic radius is used; refer to page 3-5.

$R_H = \frac{\text{cross sectional flow area}}{\text{wetted perimeter}}$

$R_e = \frac{473 q \rho}{R_H \mu}$ ....page 3-2

4. Assuming a sharp edged entrance,
$K = 0.5$ .... page A-29
Assuming a sharp edged exit to atmosphere,
$K = 1.0$ .... page A-29
Then, resistance of entrance and exit,
$K_e = 0.5 + 1.0 = 1.5$

5. $R_H = \frac{16.5 \times 25}{2\,(16.5 + 25)} = 4.97$ ft.

6. Equivalent diameter relationship:
$D = 4R_H = 4 \times 4.97 = 19.88$ ....page 3-5
$d = 48R_H = 48 \times 4.97 = 239$ ....page 3-5

7. Relative roughness, $\epsilon/D = 0.0005$ ..page A-23

8. $f = 0.017$ ....fully turbulent flow assumed; page A-23

9. $q = 8.05 \times 25 \times 16.5 \sqrt{\frac{200}{1.5 + \frac{0.017 \times 1000}{19.88}}}$

$q = 30\,500$

10. Calculate R_e and check, $f = 0.017$ for $q = 30\,500$ cfs flow.

11. $\rho = 62.371$ ....page A-6

12. $\mu = 1.1$ .... page A-3

13. $R_e = \frac{473 \times 30\,500 \times 62.371}{4.97 \times 1.1}$
$R_e = 164\,000\,000$ or 1.64×10^8

14. $f = 0.017$ ......for calculated R_e; page A-24

15. Since the friction factor assumed in Step *8* and that determined in Step *14* are in agreement, the discharge flow will be 30 500 cfs.

16. If the assumed friction factor and the friction factor based on the calculated Reynolds number were not in reasonable agreement, the former should be adjusted and calculations repeated until reasonable agreement is reached.

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Application of Hydraulic Radius to Flow Problems — continued

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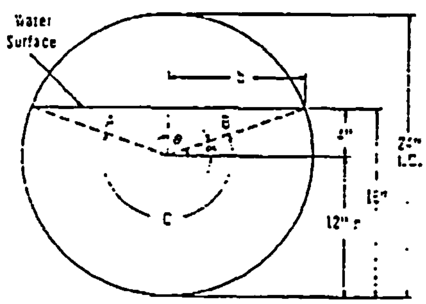
Example 4-26...Pipe Partially Filled With Flowing Water

Given: A cast iron pipe is two-thirds full of steady, uniform flowing water (60 F). The pipe has an inside diameter of 24 inches and a slope of ¾-inch per foot. Note the sketch that follows.



Find: The flow rate in gallons per minute.

Solution:

1. $Q = 19.65\, d^2 \sqrt{\frac{h_L D}{f L}}$ .... page 3-4

Since pipe is flowing partially full an equivalent diameter based upon hydraulic radius is substituted for D in Equation 1 (see page 1-4).

$D = 4R_H$ .... page 3-5

2. $Q = 19.65\, d^2 \sqrt{\frac{h_L 4R_H}{f L}} = 39.3\, d^2 \sqrt{\frac{h_L R_H}{f L}}$

3. $R_H = \frac{\text{cross sectional flow area}}{\text{wetted perimeter}}$ .... page 3-5

4. $R_e = \frac{4739 Q\rho}{R_H \mu} = 1.054 \frac{Q\rho}{R_H \mu}$ .... page 3-2

5. Depth of flowing water equals:

$\frac{2}{3}(24) = 16$ in.

6. $\text{Cos}\ \theta = \frac{4}{r} = \frac{4}{12} = 0.333$

$\theta = 70°32'$

$\alpha = 90° - 70°32' = 19°28' = 19.47°$

7. $\text{Area C} = \frac{\pi d^2}{4}\left[\frac{180 + (2 \times 19.47)}{360}\right]$

$\text{Area C} = \frac{\pi 24^2}{4}\left(\frac{218.94}{360}\right) = 275 \text{ in}^2$

8. $b = \sqrt{r^2 - 4^2} = \sqrt{12^2 - 16} = 11.31$ in.

9. $\text{Area A} = \text{Area B} = \frac{1}{2}(4\,b) = \frac{1}{2}(4 \times 11.31)$

Area A or B = 22.6 in²

10. The cross sectional flow area equals:

$A + B + C = 22.6 + 22.6 + 275 = 320.2 \text{ in}^2$

$A + B + C = \frac{320.2}{144} = 2.22 \text{ ft}^2$

11. $d^2 = \frac{4a}{\pi} = \frac{4 \times 320.2}{\pi} = 408$

$d_{eff} = \left(\frac{\text{cross sec flow area}}{.785}\right)^{\frac{1}{2}}$

12. $h_L = \Delta h = \frac{0.75}{12} = 0.0625$ ft per ft

13. The wetted perimeter equals:

$\pi d\left(\frac{218.94}{360}\right)$

$= \pi 24\left(\frac{218.94}{360}\right) = 45.9$ in.

$\frac{45.9}{12} = 3.83$ ft.

14. $R_H = \frac{2.22}{3.83} = 0.580$

15. Equivalent diameter $d = 48R_H$ .... page 3-5

$d = 48(0.580) = 27.8$

16. Relative roughness $\frac{\epsilon}{D} = 0.00036$ ..... page A-23

17. $f = 0.0155$ .... assuming fully turbulent flow; page A-23

18. $Q = 39.3 \times 408 \sqrt{\frac{0.0625 \times 0.580}{0.0155 \times 1}}$

$Q = 24\,500$ gpm

19. Calculate the Reynolds number to check the friction factor assumed in Step 17.

20. $\rho = 62.371$ .... page A-6

21. $\mu = 1.1$ .... page A-3

22. $R_e = \frac{1.054 \times 24\,500 \times 62.371}{0.580 \times 1.1}$

$R_e = 2\,520\,000$ or 2.52×10^6

23. $f = 0.0155$ .... page A-24

24. Since the friction factor assumed in Step 17 and that determined in Step 23 are in agreement, the flow rate will be 24 500 gpm.

25. If the assumed friction factor and the friction factor based on the calculated Reynolds number were not in reasonable agreement, the former should be adjusted and calculations repeated until reasonable agreement is reached.

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Nature of Flow in Pipe — Laminar and Turbulent

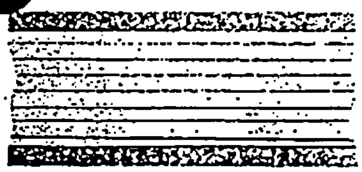

Figure 1-1
Laminar Flow
Actual photograph of colored filaments being carried along undisturbed by a stream of water.

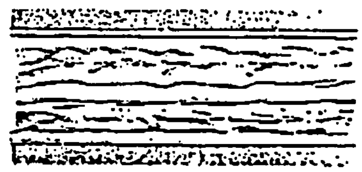

Figure 1-2
Flow in Critical Zone, Between Laminar and Transition Zones
At the critical velocity, the filaments begin to break up, indicating flow is becoming turbulent.

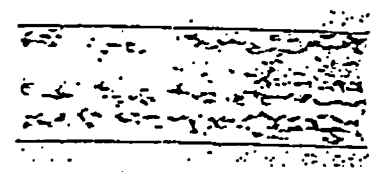

Figure 1-3
Turbulent Flow
This illustration shows the turbulence in the stream completely dispersing the colored filaments a short distance downstream from the point of injection.

A simple experiment (illustrated above) will readily show there are two entirely different types of flow in pipe. The experiment consists of injecting small streams of a colored fluid into a liquid flowing in a glass pipe and observing the behavior of these colored streams at different sections downstream from their points of injection.

If the discharge or average velocity is small, the streaks of colored fluid flow in straight lines, as shown in Figure 1-1. As the flow rate is gradually increased, these streaks will continue to flow in straight lines until a velocity is reached when the streaks will waver and suddenly break into diffused patterns, as shown in Figure 1-2. The velocity at which this occurs is called the "critical velocity". At velocities higher than "critical", the filaments are dispersed at random throughout the main body of the fluid, as shown in Figure 1-3.

The type of flow which exists at velocities lower than "critical" is known as laminar flow and, sometimes, as viscous or streamline flow. Flow of this nature is characterized by the gliding of concentric cylindrical layers past one another in orderly fashion. Velocity of the fluid is at its maximum at the pipe axis and decreases sharply to zero at the wall.

At velocities greater than "critical", the flow is turbulent. In turbulent flow, there is an irregular random motion of fluid particles in directions transverse to the direction of the main flow. The velocity distribution in turbulent flow is more uniform across the pipe diameter than in laminar flow. Even though a turbulent motion exists throughout the greater portion of the pipe diameter, there is always a thin layer of fluid at the pipe wall . . . . known as the "boundary layer" or "laminar sub-layer" . . . . which is moving in laminar flow.

Mean velocity of flow: The term "velocity", unless otherwise stated, refers to the mean, or average, velocity at a given cross section, as determined by the continuity equation for steady state flow:

$$v = \frac{q}{A} = \frac{w}{A\rho} = \frac{w\bar{V}}{A} \qquad \textit{Equation 1-1}$$

(For nomenclature, see page preceding Chapter 1)

"Reasonable" velocities for use in design work are given on pages 3-6 and 3-16.

Reynolds number: The work of Osborne Reynolds has shown that the nature of flow in pipe . . . . that is, whether it is laminar or turbulent . . . . depends on the pipe diameter, the density and viscosity of the flowing fluid, and the velocity of flow. The numerical value of a dimensionless combination of these four variables, known as the Reynolds number, may be considered to be the ratio of the dynamic forces of mass flow to the shear stress due to viscosity. Reynolds number is:

$$R_e = \frac{Dv\rho}{\mu_e} \qquad \textit{Equation 1-2}$$

(other forms of this equation: page 3-2.)

For engineering purposes, flow in pipes is usually considered to be laminar if the Reynolds number is less than 2000, and turbulent if the Reynolds number is greater than 4000. Between these two values lies the "critical zone" where the flow . . . . being laminar, turbulent, or in the process of change, depending upon many possible varying conditions . . . . is unpredictable. Careful experimentation has shown that the laminar zone may be made to terminate at a Reynolds number as low as 1200 or extended as high as 40,000, but these conditions are not expected to be realized in ordinary practice.

Hydraulic radius: Occasionally a conduit of non-circular cross section is encountered. In calculating the Reynolds number for this condition, the equivalent diameter (four times the hydraulic radius) is substituted for the circular diameter. Use friction factors given on pages A-24 and A-25.

$$R_H = \frac{\text{cross sectional flow area}}{\text{wetted perimeter}}$$

This applies to any ordinary conduit (circular conduit not flowing full, oval, square or rectangular) but not to extremely narrow shapes such as annular or elongated openings, where width is small relative to length. In such cases, the hydraulic radius is approximately equal to one-half the width of the passage.

To determine quantity of flow in following formula:

$$q = 0.0438 d^2 \sqrt{\frac{h_L D}{fL}}$$

the value of d^2 is based upon an equivalent diameter of actual flow area and $4R_H$ is substituted for D.

Calculation WBNOSG4091
MAXIMUM CONTAINMENT WATER LEVEL
Attachment 3

From: Jordan, Gary T.
Sent: Monday, December 03, 2001 10:14 AM
To: Lund, John F.
Subject: RE: Ice Mass

John,

We weigh our ice baskets during each RFO. During each RFO, we perform a 100% as-found weighing and then service any basket below our established administrative limit on net ice weight. The baskets that we service, we re-weigh to establish an as-left net ice weight. Any basket that we don't service, we assume maintains the as-found ice weight. All of these weights are documented in the MI-61.06 data package that is maintained in the vault. I also keep all ice weights in my ICEMAN program plus I maintain an Excel spreadsheet that allows me to cut the ice bed in any number of different looks to see just what's going on at any point. The number provided to you is based upon the as-left net ice weight of all baskets (either re-weighed or assumed) and totaled by the Excel spreadsheet. That number for total as-left ice mass at the conclusion of RFO2 was 2.78E6 pounds and does not credit any ice weight maintained in 14 baskets that were unweighable in either the as-found or as-left condition. These 14 baskets could provide you with approximately another 21,000 pounds (assuming 1500/basket). Final assumed as-left net ice weight in the Ice Condenser at the conclusion of RFO2 would have been approximately 2.8E6 pounds.

If you need anything else on this, please let me know and we'll discuss.

Thanks.

Gary T. Jordan
NSSS System Engineer
System 61 - Ice Condenser
System 84 - Flood Mode Boration
EQB-1F, Watts Bar Nuclear Plant
Phone: (423) 365-1454
Pager: (Onsite) 450, then 40607
(Offsite) (800) 323-4853, then 40607
Fax: (423) 365-7845
E-mail: gtjordan@tva.gov

-----Original Message-----
From: Lund, John F.
Sent: Friday, November 30, 2001 2:57 PM
To: Jordan, Gary T.
Subject: Ice Mass

Gary,

When I discussed this subject with you earlier this year, I got information that said the ice mass was 2,781,373 lbm as of Apr 1999. Could you provide me a reference for this information?

John