RHODE ISLAND NUCLEAR SCIENCE CENTER
PROPOSED 3 MW OR HIGHER
EMERGENCY CORE COOLING SYSTEM PLAN

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INTRODUCTION

The Rhode Island Nuclear Science Center research reactor has a design capability of 5 MW (thermal) power level. The current license and power level of operation is 2 MW. The recent conversion to the LEU fuel necessitated a Safety Analysis Review (SAR) which addressed a postulated loss of coolant. The Nuclear Regulatory Commission approved the SAR and related information for the 2 MW case.

This report addresses the 3 MW situation and the proposed emergency core cooling required. Since the original GE reactor design did not include provisions for emergency cooling, it was necessary to originate a design plan which would incorporate some of the positive features available at the site.

LOSS OF COOLANT REVIEW

The SAR (Part B, Section X) calculated that the loss of coolant from the pool could occur through a 1/2" diameter hole in a beam port experiment and the 1" beam tube vent/drain line. The calculation from Section XIII, Appendix C of the SAR showed that a minimum of 3.76 gpm was needed to keep the core box full (assuming water was directly flowing into the core box).

A typical calculation to determine what flow rate would be required to keep the pool full while the maximum draining is taking place is shown below:

$$F = .61A\left[2gH\right]^{1/2} = .61(.00682)\left[2x32.2x(139.417-114.130)\right]^{1/2}$$

$$F = .1679 \times 7.48 \times 60 = 75.35 \text{ gal/min}$$

Using this equation, A "flow rate vs. elevation" table was developed (see Table A of this report). In addition to the normal make-up water system, the proposed ECCS is basically a "redundant" water supply line, a 1 1/4" line which serves as a deluge type of discharge to the pool (thereby eliminating an expensive piping system fabrication to the suspension frame and down to the core).

To further reduce the consequence of a LOCA, the 1" beam tube vents will be fitted with a 1/2" orifice. This will reduce the leakage flow rate* to:

$$F = 0.61a\left[2gH\right]^{1/2} = 0.61 \times 2.727 \times 10^{-3}(2 \times 32.2 \times 25.278)$$

$$F = 0.067 \times 7.8 \times 60 = 30 \text{ gpm}$$

*See Appendix E for details

3 MW DECAY HEAT

The SAR (December 1992) for the 2 MW LEU core shows calculations for decay heat generation (Section X) during a LOCA such that it would take 10 1/2 hours to expose the core and that melting would not occur.

Applying the decay heat curve to the 3 MW situation and knowing that the core must have sufficient cooling until such time that the decay heat has reduced to .049 BTU/sec.

For 3 MW $Po = \frac{3}{2} \times 6.187 = 9.28$ BTU/sec (plate)

$$\frac{P(ts)}{Po} = \frac{.049}{9.28} = .00528$$

From the decay curve (Table 5.1), the time after shutdown to reduce the decay heat to below 0.049 is about 7.25×10^4 seconds or 20.19 hours.

By reducing the leakage rate to the equivalent of two 1/2" diameter holes the Drain time* is:

$$T = \frac{2A\left[(h_1)^{1/2} - (h_2)^{1/2}\right]}{Ca(2g)^{1/2}}$$

$$T = \frac{2 \times 150 \times (25.287)^{1/2}}{0.61 \times 2.727 \times 10^{-3} \times (2 \times 32.2)^{1/2}}$$

T = 31.39 hours

resulting in a drain time safety factor of 155% without adding water to the pool.

*See Appendix E for details

[illegible]

The Ratio, $P(t_s) / P_o$, of the Fission Product Decay Power to Reactor Operating Power as a Function of Time, t_s, After Shutdown (ANS, 1966)

Time After Shutdown, t_s (seconds)	Power Ratio $P(t_s) / P_o$	Time After Shutdown, t_s (seconds)	Power Ratio $P(t_s) / P_o$
1×10^{-1}	0.0675	6×10^{4}	0.00566
1×10^{0}	0.0625	8	0.00505
2	0.0590	1×10^{5}	0.00475
4	0.0552	2	0.00400
6	0.0533	4	0.00339
8	0.0512	6	0.00310
1×10^{1}	0.0500	8	0.00282
2	0.0450	1×10^{6}	0.00267
4	0.0396	2	0.00215
6	0.0365	4	0.00166
8	0.0346	6	0.00143
1×10^{2}	0.0331	8	0.00130
2	0.0275	1×10^{7}	0.00117
4	0.0235	2	0.00089
6	0.0211	4	0.00068
8	0.0196	6	0.00062
1×10^{3}	0.0185	8	0.00057
2	0.0157	1×10^{8}	0.000550
4	0.0128	2	0.000485
6	0.0112	4	0.000415
8	0.0105	6	0.000360
1×10^{4}	0.00965	8	0.000303
2	0.00795	1×10^{9}	0.000267
4	0.00625		

FACILITY WATER SUPPLY

The Wakefield Water Supply Company provides water to the University of Rhode Island Bay Campus. The Rhode Island Nuclear Science Center facility is located on the Bay Campus.

Water at 40 psi is supplied from the Wakefield Water Supply Company to a 300,000 gallon tank located the Bay Campus. The tank booster pump delivers water at 55 psi to the Campus distribution system. If pressure drops or more flow is needed a standby fire pump energizes maintaining system flow rate and pressure. The 3 fire pumps in the system have emergency generator backup. The Bay Campus demand (1992 records) is about 83 gallons/minute. The ECCS flow rate will be set at 50 gpm to provide a safety margin (30 gpm is required). The total Campus demand will be 133 gpm (83 gpm + 50 gpm) . This provides a reserve supply in the 300,000 gallon tank to maintain both the Bay Campus demand and the pool filling requirements for 37.59 hours.

Since the actual drain rate is 30 gpm, this is an additional safety factor of 67%.

A copy of the fire pump test results conducted for the system by Keily Associates, the design firm, is enclosed.

The reliability of the system was discussed in the SAR dated December 1992 in Section B, IX.

Refer to the plans in the appendix for the system piping.

The URI 300,000 gallon tank* can be cross connected to the Wakefield Water Company who also has a 300,000 gallon tank about 1 mile away providing additional reserve capacity.

*See Appendix F - Administrative Controls

KIELY ASSOCIATES LTD.

LOUISQUISSET FREEWAY • MINERAL SPRING INTERCHANGE • P.O. BOX 6644, PROVIDENCE, RHODE ISLAND 02940 • TELEPHONE 724-8850

January 30, 1985

Otis C. Wyatt Jr., Chief
Narragansett Fire Department
40 Caswell Street
Narragansett, Rhode Island 02882

Re: Fire Pump Test
Graduate School of Oceanography
University of Rhode Island
Narragansett Bay CAmpus

Dear Chief Wyatt:

We would like to acknowledge and thank you and the members of your staff for their attendance and interest during the January 29, 1985 fire pump test at Narragansett Bay Campus, University of Rhode Island.

The Peerless fire pump, Model 8AF20B, nominal capacity of 2000 GPM vs 85 psi, 1775 RPM, 125 HP, 3P, 60C, equipped with a Firetrol Model FTA 1500/FTA 900 Controller, was discharged thru a Dieterich Model ANR permanent flowmeter and produced the following results:

2000 GPM - 2200 GPM at 85 psi
3000 GPM - 3200 GPM at 55 psi

It would be appreciated if you would attest to the observed results, by countersigning this correspondence and returning to our office at the above address.

We have enclosed, for your record and file, a copy of results of Test #169248, as performed by the Peerless Pump Company, manufacturer of the fire pump.

Very truly yours,

KIELY ASSOCIATES LTD

Daniel J Kiely
DJK/fa
enclosure
cc: Mr. Richard McGannon, GSO, URI
Mr George Urban, GSO, URI
Mr. Robert Stewart, URI

Attest:

Otis C. Wyatt., Chief
Narragansett Fire
Department

PRESENT POOL FILL SYSTEM OPERATION

The existing pool is filled from the make-up demineralizer system. The pool fill system has an automatic electrically operated valve which opens when the pool level float switch is activated for a nominal one inch drop in pool water level. The pool fill system has a manual by-pass valve in case the automatic valve fails. Measurements reflect that the make-up system can provide 25 gpm to the pool.

PROPOSED EMERGENCY CORE COOLING SYSTEM OPERATION

(Refer to the Emergency Core Cooling System (ECCS) Schematics in the Appendix)

The ECCS will operate under AC power with emergency power backup from the emergency generator. This assures operation of electrical components with loss of AC power.

At present the RINSC emergency generator has 1600 watts of excess capacity. The solenoid valve and flow measuring instrument would require about 100 watts and would be insignificant.

The reactor control system will be provided with two alarm circuits to be used for 3 MW or higher. The first is an ECCS water line pressure sensor located between the pressure regulator and AV which monitors the water supply line pressure. A drop in normal water pressure below a preset value will alarm in the Control Room. The second alarm function would be that of the automatic (AV) ECCS water line valve opening. If the AV is energized (opened) al alarm will sound in the control room.

The line also contains a flow meter indicating ECCS water flow during testing* or a pool fill event. This unit will read out locally in the Demineralizer Room.

The AV has a manual bypass valve* in case of the failure of the electrical activator. The manual valves #3 and #4 are used for a system by-pass flow test.

Manual valve #1 is used to isolate the system. It will be locked open. The four inch supply gate valve to the fire main and the ECCS system will be locked in the open position.

Activation of the AV is from a low level pool switch. The unit will have a low pool level limit of 24 inches below the suspension frame base plate. The ECCS system will cycle (on and off) to maintain the pool water level at the 24 inch limit. This prevents a pool overflow situation.

The reactor is scrammed on a low pool water level limit of 16 inches below the suspension frame base plate from a separate low water level sensor. (Tech. Spec. Table 3.1).

The ECCS will automatically initiate flow to maintain pool level at a minimum level of 24 inches below the suspension frame base plate.

*See Appendix F - Administrative Controls

ECCS WATER SUPPLY ANALYSIS

An analysis of the 4" supply with the proposed 1 1/4" line supply to the core.

The pressure (supply) at the 4" pipe entering the building is based on the accompanying fire test report. Due to high pump pressure available, the proposed 1 1/4" line (ECCS) should have a pressure reducing value. A 55 psi setting is more than adequate for expected demand. The valve would prevent excessive line pressures when the Bay Campus fire pumps are in use.

The analysis was performed with a 55 psi supply pressure.

Assumptions:

Flow through a 1.25 inch smooth pipe

Friction loss 1.25in., 50psi = 21psi/100ft of pipe*

Equivalent loss (pipe lengths) for fittings:

1 Press. reducing valve		1ft
3 valves @ 1 ft/valve		3ft
7 tees @ 3 ft/tee		21ft
7 elbows @ 4 ft/elbow		28ft
	Total	53ft
Actual pipe length		68ft
Equivalent loss		121ft

Friction head loss = 121ft/100ft * 21psi = 25.4psi

Elevation head loss = 32ft * 0.43psi/ft = 13.8psi

Total head losses = 25.4psi + 13.8psi = 39.2psi

Demand Flow = Supply - Head losses

= 50gpm @ 55psi - 39.2psi = 50gpm @ 15.8psi

TABLE A

HEAD ABOVE INVERT OF BEAM PORT	CALCULATED MAXIMUM FLOW RATE (GPM) FROM BEAM PORT
25.29	30.13
24.29	29.53
23.29	28.91
22.29	28.28
21.19	27.64
20.29	26.98
19.29	26.31
18.29	25.62
17.29	24.91
16.29	24.18
15.29	23.42
14.29	22.65
13.29	21.84
12.29	21.00
11.29	20.13
10.29	19.22
9.29	18.26
8.29	17.25
7.29	16.17
6.29	15.02
5.29	13.78
4.29	12.40
3.29	10.86
2.29	9.06
1.29	6.80
0.79	5.31
0.00	0.00

It is assumed that (1) the diaphragm valve to the beamport vent line is OPEN
(2) The beamport "shutter" is in the full OPEN position

CONCLUSIONS

A postulated "Loss of Coolant" accident for power levels above the existing 2 MW licensed power level would lead to possible reactor core damage due to heat generation. The decay analysis defines the need for additional emergency cooling water during decay times up to 20 hours after shutdown at 3 MW. The existing pool fill system is capable of supplying about 25 gpm, enough water to maintain the entire reactor pool at about 17 feet above the core box (see Table A). The proposed emergency core cooling system could provide about 50 gpm, enough water to maintain the pool water level at 24.5 feet above the core box with maximum water loss.

The above analysis is conservative in a number of areas. The LOCA assumes maximum drainage times with no operator actions to close the beamport shutter, close the vent/drain line, etc. The proposed ECCS will be safeguarded from electrical power loss with emergency power backup.

It is our conclusion that the proposed system can sustain the proper level of cooling required and maintain acceptable levels of reliability within minimum risk.

ECCS EQUIPMENT AND COMPONENTS

(1) Pressure Switch

(2) Level Switch

(3) Flow Meter System

(4) Manual Valve

(5) Automatic Valve

(6) Pressure Reducing Valve

(7) Piping and Fittings

(8) Miscellaneous

(9) Pressure Gage

PLANS

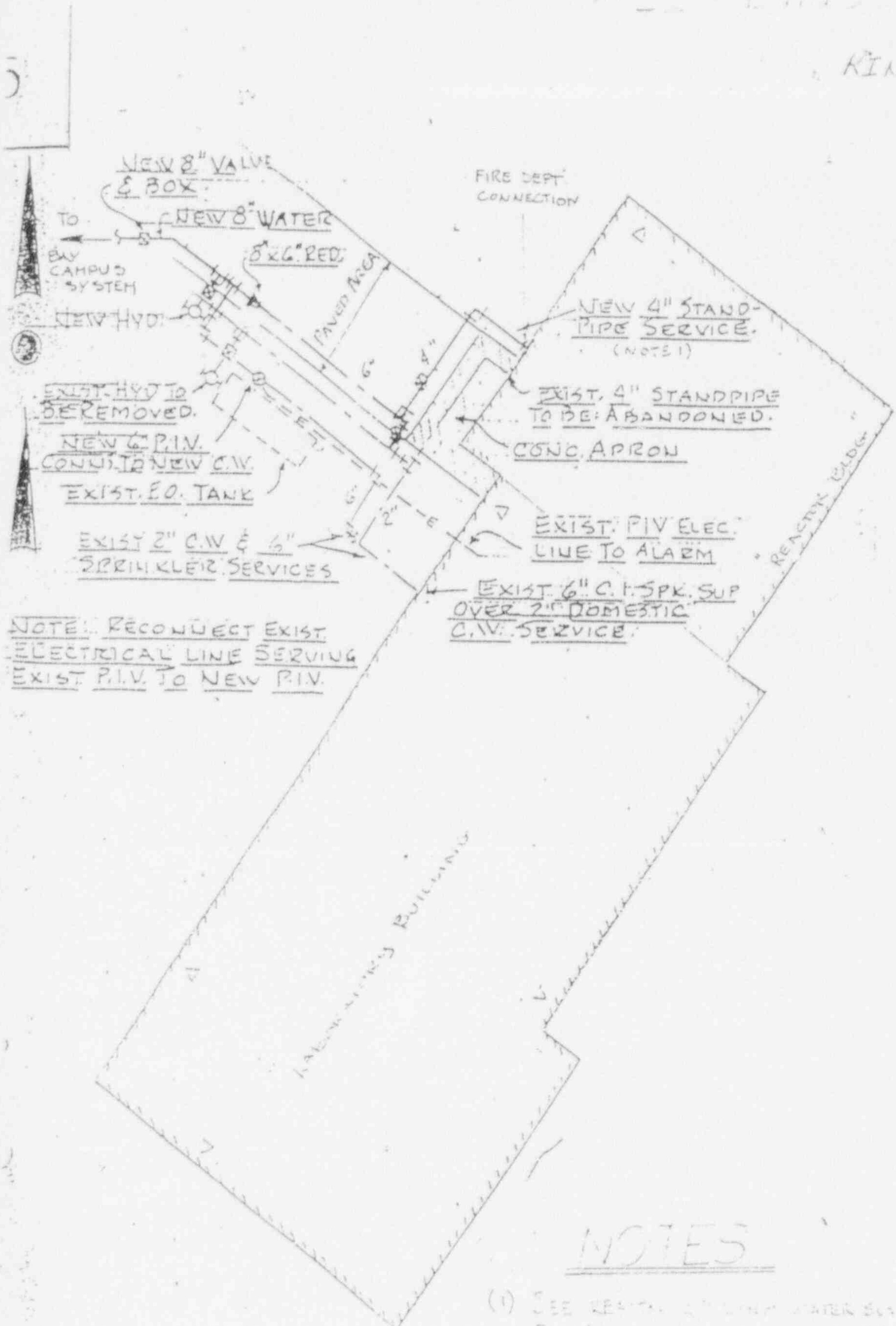
(1) URI Bay Campus Water System to Rhode Island Nuclear Science Center
RINSC Drawing #2130

(2) North Bunker Areas
RINSC Drawing #2005-C (Revised to show ECCS pipe routing)

(3) Reactor Room ECCS Piping Plan
RINSC Drawing #2152

(4) Piping Plan - Reactor Building Supply
RINSC Drawing #2150

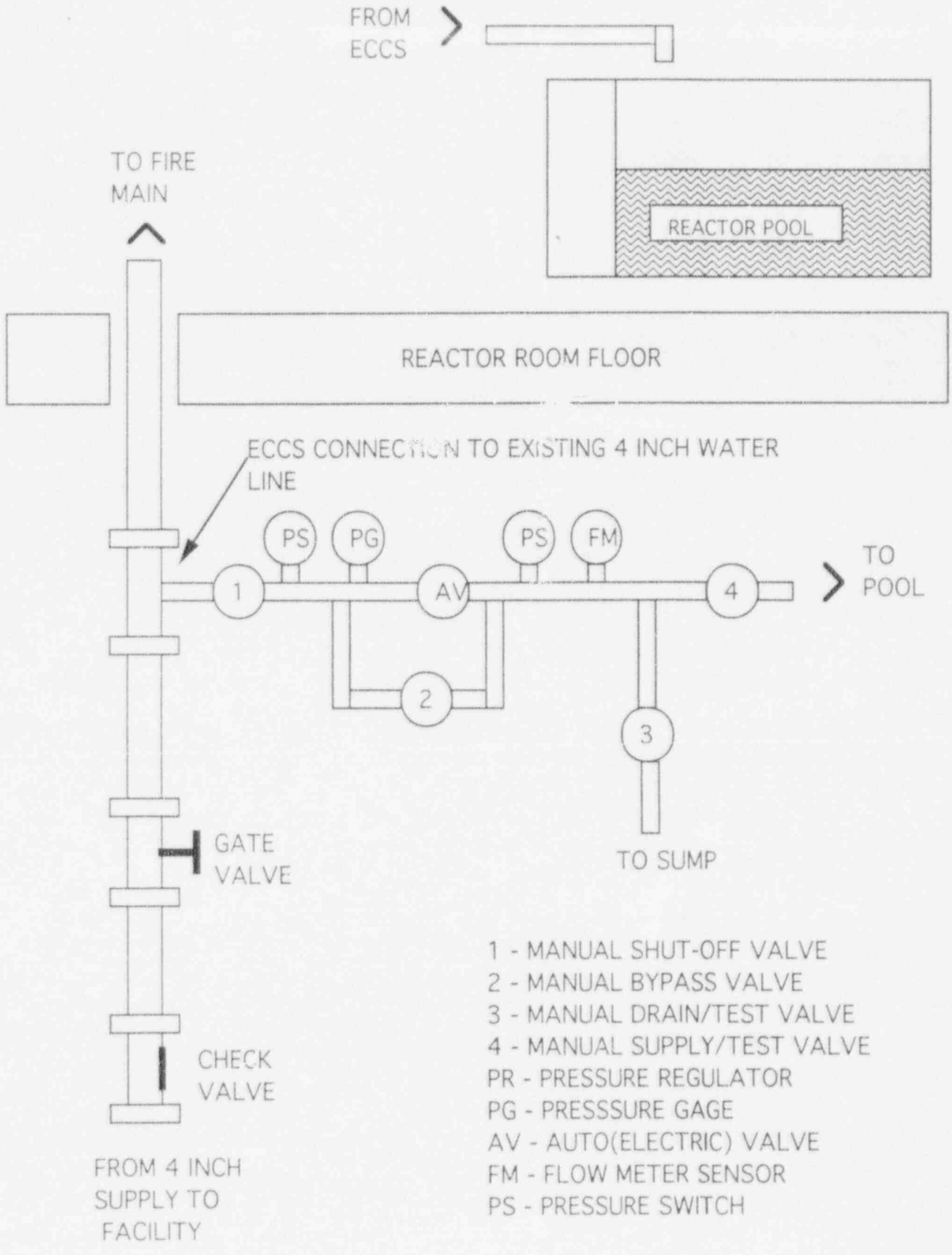
RINSC DWG # 2150



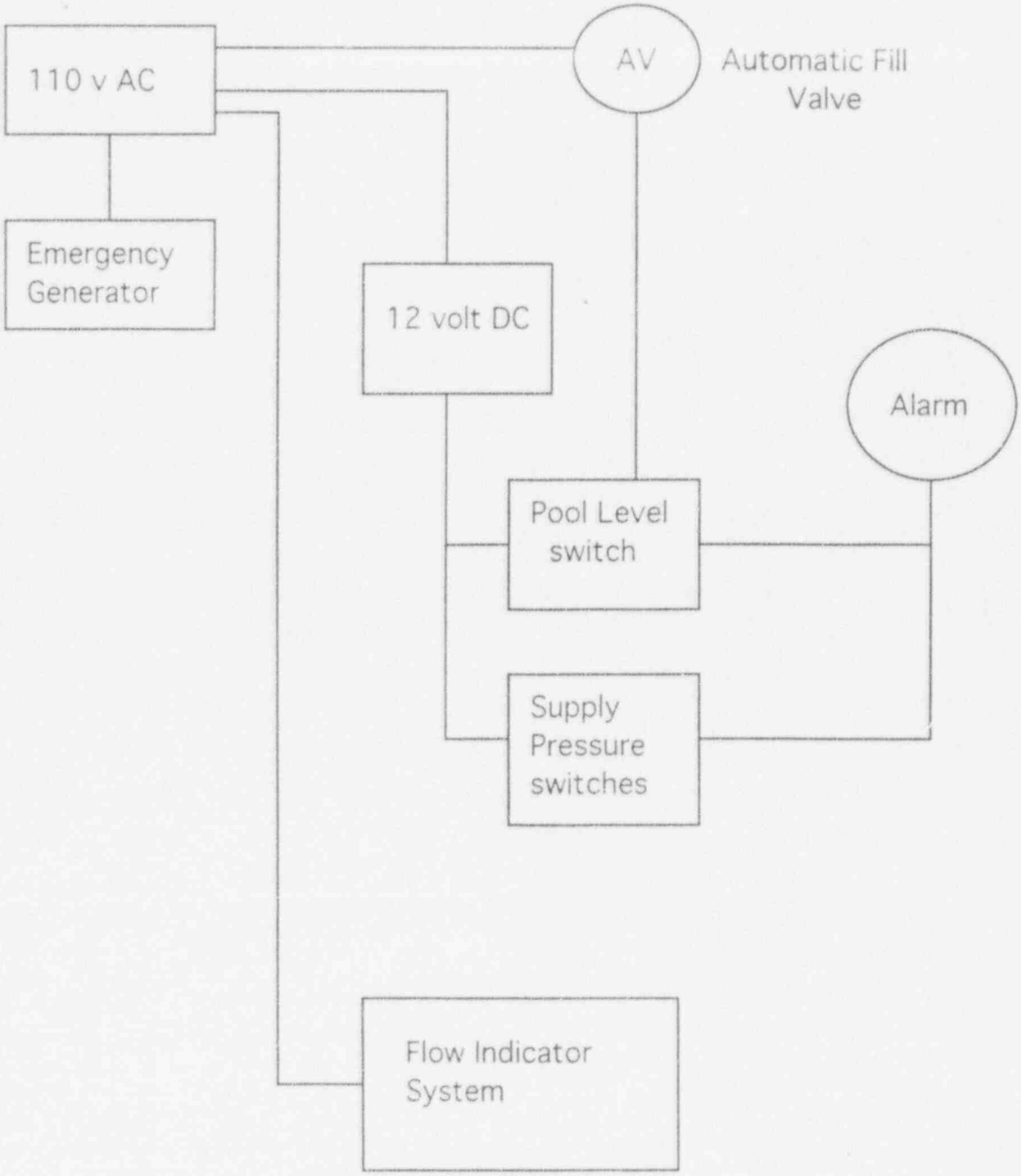
NOTES

(1) SEE [illegible] WATER [illegible] DETAILS [illegible] RINSC [illegible]

EMERGENCY CORE COOLING SYSTEM DIAGRAM



INSTRUMENTATION BLOCK DIAGRAM



CALCULATIONS

LEAK RATE (MAX)

Datum is el. 114.13 (invert of bottom of 8" beam tube)
el. 139.417 (water level of pool)

head = 139.417ft - 114.013ft = 25.287ft

area of leak = two 1/2 inch diameter holes

$a = 2\pi r2 = 2\pi\left(\underline{0.5/24}\right)^2$

$a = 2.727 \times 10^{-3}$ feet^2

0.61 - void coefficient/see attached
(Mechanical Engineering Handbook)

Flow through the standard orifice:

$$V = 0.61a\sqrt{2\,gh}$$

$$V = 0.61 \times 2.727 \times 10^{-3}\sqrt{2 \times 32.2 \times 25.287}$$

$$V = 0.067\ \text{ft}^3/\text{sec}$$

$$V = 0.067\ \text{ft}^3/\text{sec} \times \frac{60\ \text{sec}}{\text{min}} \times \frac{7.48\ \text{gal}}{\text{ft}^3}$$

$$V = 30.127\ \frac{\text{gal}}{\text{min}}$$

Drain time for two 1/2 inch diameter holes:
Discharge under falling head

$$t = \frac{2A(\sqrt{h_1} - \sqrt{h_2})}{Ca\sqrt{2g}}$$

Datum is el. water level of pool 139.417ft

invert of bottom of beam tube 114.13ft

h_1 = 139.417 - 114.13ft = 25.287ft

h_2 = 0

A is the area of surface of pool = 150ft^2

C is the orifice coeficient = 0.61

a is cross sesction area of two 1/2 inch diameter holes = 2.727×10^{-3}ft^2

$$t = \frac{2 \times 150 \times \sqrt{25.287}}{0.61 \times 2.727 \times 10^{-3} \times \sqrt{2 \times 32.2}}$$

$$t = \frac{1508.6}{0.01335} = 113{,}010 \text{ seconds}$$

t = 31.39 hours

1. Bay Campus 300,000 gallon Tank Water Level:

The Bay Campus 300,000 gallon tank has an altitude valve that automatically maintains the water level at 128.1 feet using Wakefield Water Company's water supply at 40 psi. The automatic valve is monitored by a remote recorder at URI's maintenance office with malfunction alarms at the water station, maintenance and security offices.

If the Bay Campus tank fails, the pipe line supplying the Bay Campus can be cross connected to the Wakefield Water Company's 300,000 gallon tank that is about 1 mile away. This cross connection can provide 200 gpm at 40 psi.

The Bay Campus and the Wakefield Water Company tanks do not provide for gravity feed.

2. Use and testing of the ECCS:

The normal position of the valves are:

Valve #1 - Locked open
Valve #2 - Normally closed
Valve #3 - Locked open
Valve #4 - Locked open
Gate Valve (4 inch) - Locked open

Mannual Operation:

a. Check valve #1 open
b. Check valve #3 closed
c. Check valve #4 open
d. Open valve #2, check for proper flow indication
e. Check all valves in their normal positions and locked.

Automatic Operation:

Automatic operation is initiated by a low water level sensed by a magnetic float switch.

Testing:

To test system for proper operation, push float down approximately 1 inch. Water flow can be seen at the deluge outlet pipe located under the reactor bridge. Check proper flow rate on indication in Demineralizer Room. Release float, water flow should stop.

Appendix G

Mechanical Engineers' Ref. Material

MECHANICAL ENGINEERS' HANDBOOK

REVISED BY A STAFF OF SPECIALISTS

THEODORE BAUMEISTER, Editor

Consulting Engineer,
Stevens Professor of Mechanical Engineering,
Columbia University in the City of New York

LIONEL S. MARKS, Editor, 1916 to 1951

Late Gordon McKay Professor of Mechanical Engineering,
Harvard University

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1958

$$(h_1 + Z_1) - (h_2 + Z_2) = (V_2^2/2g) - (V_1^2/2g)$$

that is,

$$h_1 + Z_1 + (V_1^2/2g) = h_2 + Z_2 + (V_2^2/2g)$$

This formula is the mathematical expression of **Bernoulli's theorem.**

To summarize:

1. The **total head** present in a mass of flowing liquid is made up of potential hea[d], pressure head, and velocity head, mutually convertible, each into the other's for[m].

2. **Bernoulli's Theorem.** The total head in a particle of a continuous mass [of] flowing liquid at any one point in its stream line (*i.e.*, the path along which the liqu[id] flows) is equal to the total head at any other position of its strea[m] line, *provided* there is no loss between the two positions due t[o] energy dissipation, the giving up of work, etc., and no gain due to the application of outside work.

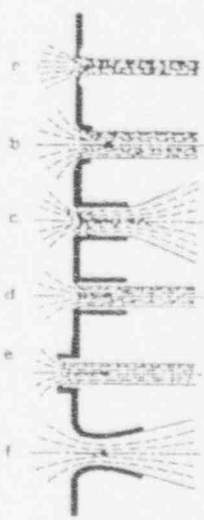

Fig. 9. Types of orifice.

Flow through Orifices and Nozzles

Flow of Liquids through Orifices. The general law of flow $V = \sqrt{2gh}$, in which V is the velocity of the jet at its smalle[st] section near or in the plane of the opening, h is the head referr[ed] to the level of the center of the stream cross section.

The **standard** orifice for measuring or regulating purpos[es] is the **sharp-edged orifice.** The jet contracts in size (Fig. 9a) just after coming through the opening of such an orifice. Th[e] area of the cross section of the jet, at a distance out from th[e] opening about one-half its diameter, is about 0.62 of the area o[f] the opening. The average velocity past this contracted section [is] about 0.98 to 0.99 of $\sqrt{2gh}$. Hence, calling A the area of th[e] opening, the discharge of a standard sharp-edged orifice is $Q =$ $0.61 A \sqrt{2gh}$, Q being in cu ft per sec when A is in sq ft, h in f[t], and g in ft per sec per sec. The value of 0.62 is called th[e] **contraction coefficient;** 0.98 to 0.99 is the **velocity coefficien[t]** and their product, or 0.61, is the **discharge coefficient.**

EXAMPLE. For a circular sharp-edged orifice, 1 in. in diam, unde[r] 50 ft head, $Q = 0.189$ cu ft per sec = 85 gpm.

Large Orifices with Low Heads, *e.g.*, sluice gates (see also Submergence, p. 3-64). Unless the orifice is in a horizontal plane, *e.g.*, in the bottom of a tank, the top may be s[o] much nearer the surface of the liquid than the bottom that the head at the level of cente[r]

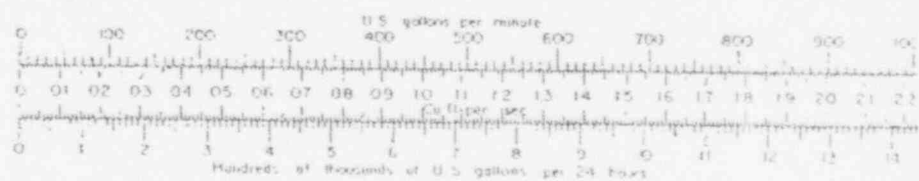

Fig. 10. Conversion scale, cu ft per sec to gal per min and gal per day.

of orifice does not correspond to the real average velocity of all the water flowing out but to more than the average; *i.e.*, the actual discharge is less than that shown by th[e] formula. (For theoretical principle, see Weirs, p. 3-67.) When the head above th[e] center is equal to the vertical dimension of the orifice, the discharge is only about [1] percent less, and when the head is twice the vertical dimension the diminution is neg[-]ligible, except for the most precise sort of investigations, for which a special calibration should be made to determine the exact coefficient. For lower heads, if h_c represent the head above the center and O the height of opening, Table 3 gives the percentag[e]

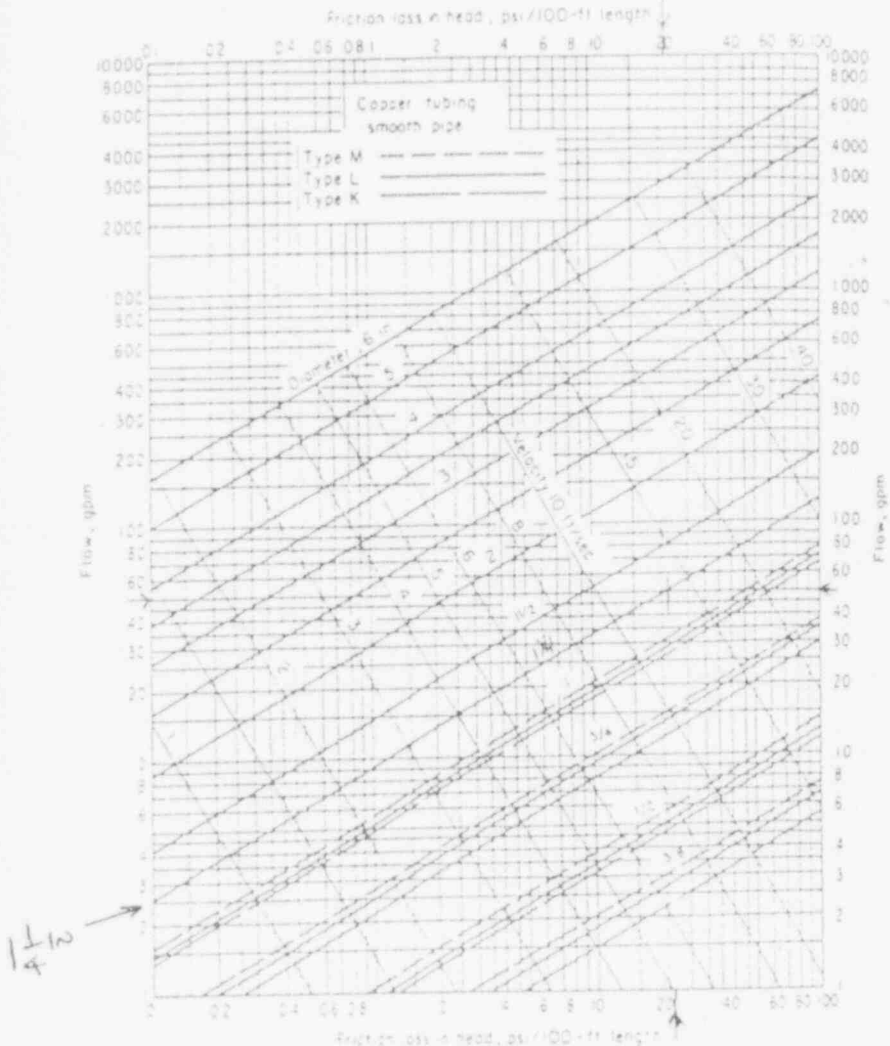

FIGURE C13.29 Friction loss for smooth pipe.

instantaneous-type heaters, an accurate approximation for steam can be calculated by multiplying the gpm requirements by 50 lb/h. This type of heater is almost always indirectly fired using either steam or hot water supplied from a central heating plant, steam utility system, or a boiler.

Semi-instantaneous-type heaters are similar to the instantaneous type except for having a limited water storage capacity, which permits easier control of outlet water temperature. This type of heater can be either directly or indirectly fired and is preferred over the instantaneous type. The far greater majority of installations are of the indirect fired type.

Storage-type heaters have a large storage capacity and lower recovery rate. This system consists of either a combination storage tank and a direct- or

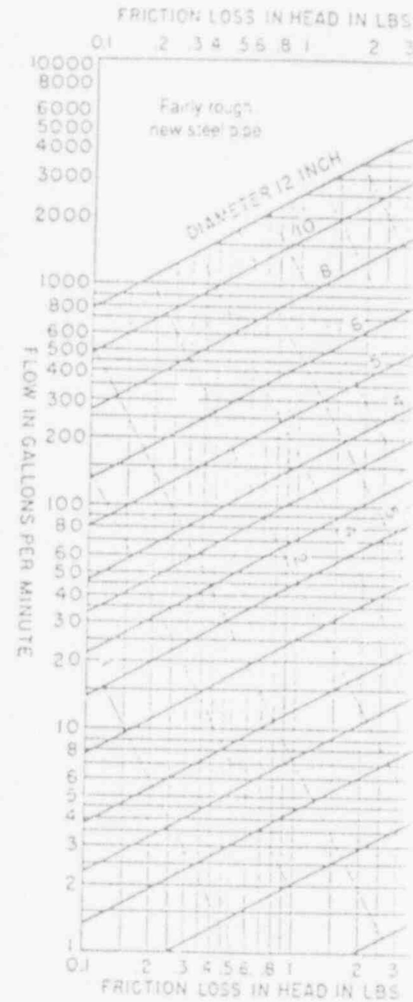

FIGURE C13.30 Friction loss for fairly rou

indirect-type immersion heater inside the age tank. This system should be conside countered for short periods of time and w ists. Disadvantages include large amou Advantages include a low instantaneous

Point-of-use heaters are used for isola economical to run piping from the prima

The choice of a primary fuel for he considerations:

1. Availability of fuel
2. Cost

:dule

Drainage		Water			
Size trap	Size vent	WFU	Size cold	Size hot	Flow, gpm
2	1½	2	½	½	5
		8			
		6			
1½	1½	2	½	½	5
1¼	1¼	1	½		2
3	1½	2	½	½	3
1½	1½	1	½	½	3
1½	1½	1	½	½	1
1¼	1¼	½	½		½
3	1½				
2	1½	2	½	½	3
1½	1½	2	½	½	3
1½	1½	2	½	½	3
1¼	1¼	1	⅜	⅜	2
1¼	1¼	2	⅜	⅜	2
1½	1½	2	½	½	5
2	1½	2	½	½	3
3	1½	3	¾	¾	4
1½	1½	2	½	½	4
1½	2	2	½	½	4.5
1½	1½	1	½	½	2
3	1½	5	1		15–30
2	1½	2	½	½	2.5
1½	1½	2	½	½	2.5
3	1½	10	1		15–40
2	1½	5	¾		10–20
3	1½	10	1		15–40
3	1½	5	½		3–5
3	1½	4	½		3–5
3	1½	10	1		15–40
3	1½	5	½		3–5
3	1½	4	½		3–5
1¼	1¼				
1½	1½				
2	1½				
3	1½				
4	2				
		5	¾		5
		3	½		3
		1	⅜		
		2	½		
		3	¾		
		10	1		

Note: For sudden enlargements or sudden contractions, use the smaller diameter on the nominal pipe size scale.

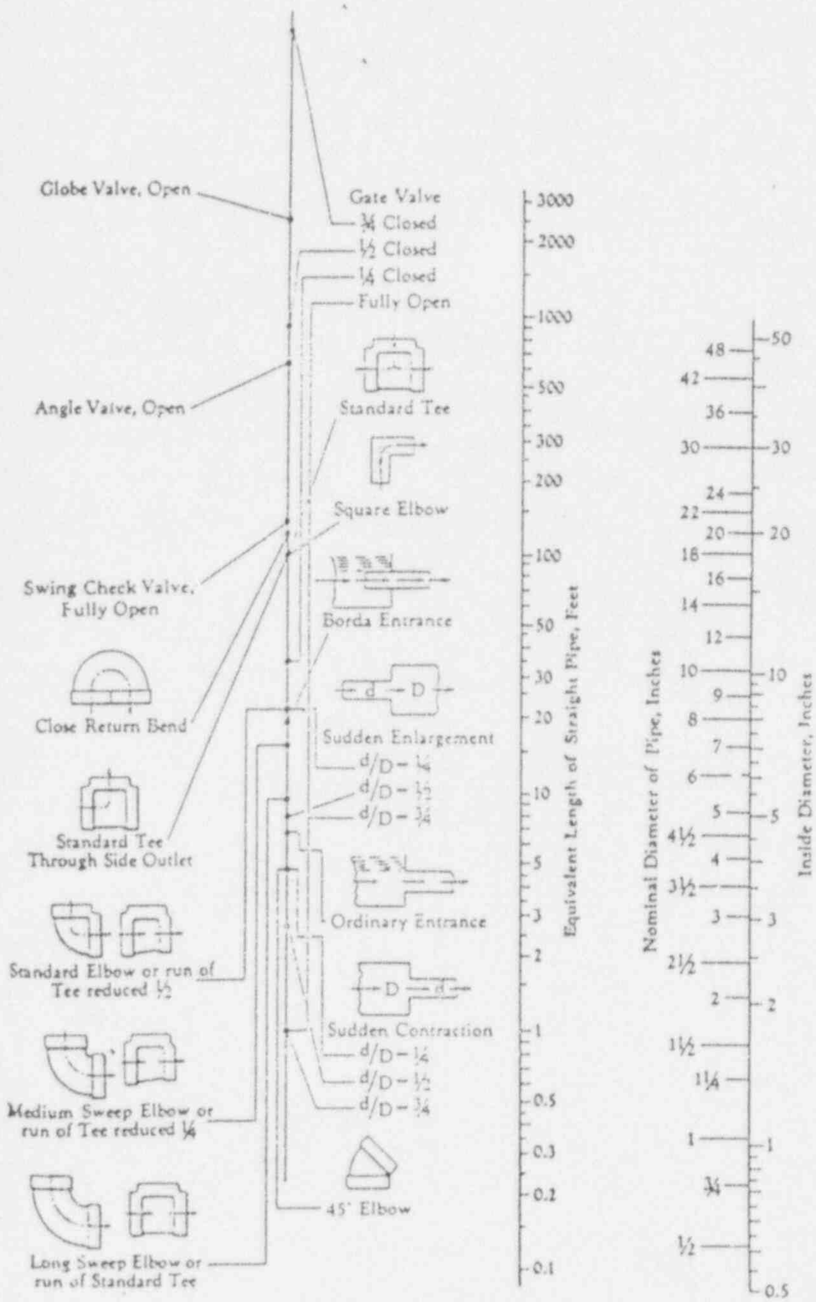

FIGURE C13.1 Resistance of valves and fittings to flow of fluids.