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Screening Methods for Developing Internal Pressure Capacities for Components in Systems Interfacing With Nuclear Power Plant Reactor Coolant Systems

Prepared by
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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Recommendations are presented for establishing screening estimates of pressure capacities for fluid system components subjected to Interfacing System LOCA (ISLOCA) conditions for nuclear power plants. Included in this evaluation are tanks, heat exchangers, filters, pumps, valves, flanged connections and pipe. Tabular values are presented for stainless and carbon steel pipe as well as flanged connections with various bolt materials and preloads. Simple analysis methods together with expected variabilities are discussed for plant specific components which must be evaluated independently. In addition to failure or leak pressures, tabulated leak rates or leak areas are included where applicable.

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SCREENING METHODS FOR DEVELOPING INTERNAL PRESSURE CAPACITIES FOR NUCLEAR POWER PLANT COMPONENTS SUBJECTED TO INTERSYSTEM LOSS OF COOLANT ACCIDENTS (ISLOCA)

1. INTRODUCTION

A probabilistic risk assessment of a nuclear power plant requires the determination of the pressure capacities of one or more fluid systems designed for low pressure and temperature to withstand pressures and temperatures above the design levels due to intersystem LOCA. The probability of failure as a function of internal pressure has previously been developed (References 1, 2, and 3) for several representative PWRs as part of the USNRC Task Action Plan for Generic Issue 105, Intersystem LOCA in LWRs, dated February 13, 1990. The purpose of this report is to present guidelines for estimating pressure capacities of similar components in other plants using the insights gained in the above three investigations. Emphasis is placed on providing estimates of both median pressure capacities and the variability associated with the median over the expected temperature range of interest using simplified analytical methods or tabular values for common component configurations or generic components such as pipes and bolted flanges.

Included are guidelines for evaluation of tanks, heat exchangers, vessels, pumps, valves, and bolted flange connections. Where possible, an attempt has been made to provide guidelines which are expected to lead to realistic estimates of median capacities for the component, but include conservatively large estimates of the variability, using a minimum of analysis. For controlling components, however, a more detailed evaluation may be warranted, and care should be used to identify any plant specific detail which could invalidate capacities developed using the guidelines presented here. Several examples of such details are discussed in the following sections.

It is assumed that the pressure capacities have a lognormal distribution. This assumption is made because a lognormal distribution has been shown to be a valid description of the variability in material strengths. In addition, for a random variable that can be expressed as the product and quotient of several random variables, the distribution tends to be approximately lognormal, irrespective of the distributions of the independent base variables. Thus, when some variability is introduced to account for analytical modeling assumptions or use of generic capacities instead of site specific capacities, this variability can easily be combined with that associated with material strength with some assurance that the overall variability will be at least approximately lognormal, even if the distribution for modeling is not known.

With the pressure capacity assumed to be a lognormal random variable and denoting it as P, the probability of failure occurring at a pressure less than or equal to a specific value p is expressed as:

$$P_f = \text{Prob}(P \leq p) = \Phi\left[\frac{\ln(p / \hat{P})}{\beta_C}\right] \qquad (1\text{-}1)$$

where: P_f = probability that failure occurs at a pressure $P \leq p$

P = random pressure capacity

β_C = logarithmic standard deviation of P

$\hat{P}$ = median pressure capacity

$\Phi(.)$ = cumulative distribution function for a standard normal random variable

In equation (1-1), the pressure capacity for a given failure mode is probabilistically described by the following expression,

$$P = \hat{P} \cdot M \cdot S \qquad (1\text{-}2)$$

in which $\hat{P}$ is the median pressure capacity, M is a lognormally distributed random variable having a unit median and a logarithmic standard deviation β_M representing the uncertainty in modeling, and S is also a lognormally distributed random variable with a unit median value and a logarithmic standard deviation β_S representing the uncertainty in the material properties. The overall uncertainty in the median capacity, β_C, is obtained by taking the square root of the sum of the squares of β_M and β_S.

The median pressure capacity represents the internal pressure level for which there is a 50% probability of failure (leakage or burst) for a given failure mode. The median values are evaluated from limit state analyses for different failure modes. The uncertainties, β_M and β_S, are associated with variability due to a lack of knowledge related to differences between the analytical model and the real component. Modeling uncertainties are associated with the assumptions used to develop analytical models and their ability to properly represent the failure condition. The strength uncertainties are associated with variabilities related to the material resistance. Examples of the sources of strength uncertainties include: variability in steel yield and ultimate strengths, stress-strain relationships, and the influence of elevated temperatures on material strength.

Uncertainties will exist in the estimated pressure capacities due to differences between the analytical idealization of the structure and the real conditions. There are numerous possible sources of modeling uncertainties. Examples of the sources of modeling uncertainties include: assumptions used to develop the internal force distributions, failure criteria, and the use of empirical formulae. Moreover, since the uncertainties are dependent on the particular failure mode under consideration, they must be evaluated on a case-by-case basis. However, in many instances, the evaluation of these uncertainties would require very detailed analysis and/or extensive data which may not be available. As a result, it was necessary to use subjective evaluation and engineering judgement to estimate these uncertainties. The estimates of variability presented here are expected to be conservative and while considered appropriate for screening, additional analysis could be expected to result in reduced variabilities in some cases.

2. TANKS AND HEAT EXCHANGERS

Tanks and heat exchangers have been shown to often have capacities lower than pipe and other components in the system. They are designed to ASME criteria and hence are expected to have a significant factor of safety based on design conditions. However, since they are very likely plant specific, the factor of safety is often significantly less than many generic components such as valves which may be designed for use with higher pressures.

Design stresses in pressure vessels include provisions for stresses resulting from deadweight, earthquake and nozzle loads as well as internal pressure. Stresses from other than internal pressure may constitute a major or even controlling portion of the allowable design stress. The failure criteria developed for cylindrical vessel failure are based on internal pressure. However, potentially high thermal expansion loads on nozzles, etc. must be considered since ISLOCA temperatures may be substantially higher than design temperatures. The screening criteria presented here were developed to reasonably include such effects without requiring a detailed evaluation including thermal analysis at every location and temperature.

Two approaches are presented here for the investigation of cylindrical pressure vessels. The first involves a factor of safety times the design pressure together with an associated variability. This approach reflects the range of results obtained from References 1, 2, and 3. The second approach involves simple strength of materials analysis of the cylinder and heads. Both methods may be used for either stainless or carbon steel and include the temperature range from room temperature to 800°F. The factors of safety recommended here are based on design pressures for tanks and heat exchangers, either vertical or saddle mounted, fabricated from 304 and 316 stainless steel, and carbon steel with properties up to SA 516 Grade 70 material. Separate material properties for stainless and carbon steels are provided for the strength of materials approach. Separate factors of safety and analytical methods are presented for cylindrical (hoop) failure as well as failure of the dished heads. Failure of the cylinder is more likely to govern at the lower range of temperatures while buckling of semi-ellipsoidal or torispherical heads may control at higher temperatures. All temperatures indicated here are assumed to be metal temperatures.

This section is not applicable to atmospheric pressure design flat bottomed tanks which could conceivably become pressurized from ISLOCA in the event of a closed vent valve, etc. It is recommended that any such tanks identified as susceptible to ISLOCA be evaluated separately. Potential failure modes for such tanks should include hoop failure in the cylinder, membrane hinging in the cylinder at the base or dome ring girder, dome membrane failure, failure of the anchor system, and pressure unseating of manways.

Tubesheets in heat exchangers may sometimes be evaluated using capacities indicated in the following section for bolted flanges with Flexitallic or equivalent gaskets. However, such tube sheets often involve non-standard flange designs with dimensions and number, sizes, and bolt installation torques outside the range of applicability of the tables in the following section. Such cases must be evaluated on a component specific basis using techniques presented in Section 5 for bolted valve bonnets.

Bolted flange connections such as manways or other access hatches involving elastomeric seals must also be evaluated using separate techniques. Silicone rubber or EP O-rings can usually be relied upon to provide a seal at temperatures up to about 700°F in a steam environment provided flange lift off does not occur, even though the elastomer may be severely degraded. If flange separation occurs due to relatively low bolt preload, however, extrusion of the elastomer followed by leakage may occur, even at low bolt stresses. Also, if the elastomer is exposed to accident temperatures for a significant time period, compression set may occur such that much of the rebound of the seal is lost. Very small increases in pressure may then cause leakage in cases where relatively long temperature exposure times occur, even if the seal is not extruded. Evaluation of elastomeric seals involves consideration of the bolt clamping force, bolt length, type of elastomer, and time and temperature of normal operating condition as well as accident condition. Such evaluation should be based on the specific configuration under consideration.

2.1 Factor of Safety on Design Pressure

Controlling modes of failure for circular tanks with dished heads designed to ASME Code criteria include both hoop failure in the cylinder and plastic collapse of the head due to internal pressure. In general, hoop failure is expected to control at low temperatures. However, at increased temperatures in the range of 400°F or higher, plastic collapse of the head may control for typical tank designs. However, buckling of the head does not necessarily lead to formation of a crack. Median factors of safety for hoop failure at room temperature can be expected to range from about 4 to over 15 based on the design pressure. A median factor of safety of about 6.5 together with a lognormal standard deviation, β, of 0.45 is recommended for screening for cylinder hoop failure at room temperature. At increased temperatures, a decrease in the median factor of safety of about 20% for stainless steel tanks together with an increase in β to about 0.66 at 600°F is expected. The increase in β reflects the additional uncertainty in material properties as well as uncertainty regarding increased thermal nozzle loads resulting from piping systems designed for cold service. No reduction in the median factor of safety for carbon steel tanks is required for temperatures up to 600°F and the same β is recommended for carbon steel.

Both asymmetric and plastic collapse failure modes exist for dished heads subjected to internal pressure. For steel heads, the plastic collapse will govern. Buckling of the head does not automatically lead to crack formation. It is recommended that a probability of crack formation of 0.2 be used, given buckling of the head. It is recommended that a median factor of safety of 1.6 with a β of 0.5 be used for dished head buckling at 600°F compared to design pressure at room temperature.

A summary of expected factors of safety above design pressure for steel tanks (including heat exchanger shells, filters, etc.) is shown in Table 2-1.

Although the above variabilities are large, they are intended to provide a reasonable, yet conservative estimate for tank or vessel pressure capacity without conducting any analysis other than knowing the design pressure (and assuming a design temperature of 300°F or less). Assuming a room temperature hydrotest pressure equal to 150% of the design pressure was conducted, a probability of failure of less than 0.001 is indicated at the hydrotest pressure. While this may be

too conservative, it provides for corrosion or mechanical or thermal fatigue cracks introduced since the original hydrotest.

2.2 Tank Analysis

If a more accurate estimate of pressure vessel median capacity and variability is required, simple analytical methods are available. This subsection presents the recommended analytical expressions together with recommended material properties and associated variabilities. All material properties are considered to be median centered unless otherwise noted. All variabilities should be assumed to be associated with failure pressure and include provision for material strength and strain variations, tank modeling uncertainty, possibility of partial through-wall cracks, and nozzle loads from thermal strains in the attached piping.

2.2.1 Cylinder Hoop Failure

Failure in a cylindrical vessel due to hoop failure can be calculated from the simple relationships:

$$\hat{P}_f = \frac{\hat{\sigma}_f \, t}{r(1 + \hat{\epsilon}_f)}$$

where, $\hat{P}_f$ is the median failure pressure
$\hat{\sigma}_f$ is the median failure stress
t is the wall thickness (nominal)
r is the initial inside radius
and $\hat{\epsilon}_f$ is the median hoop strain at failure

The thickness, t, may include provision for corrosion allowance if applicable. Values of σ_f and ϵ_f for two representative tanks materials at discrete temperatures from room temperature to 800°F can be found in Tables 2-2 and 2-3.

Buckling of dished heads due to internal pressure can be calculated from analysis conducted by Galletly and his co workers (References 4 through 7) using the BOSOR-5 (Reference 8) computer program. The methods recommended here use the results of Galletly modified to provide appropriate median pressure capacities together with estimates of variability based on very limited test results. The median plastic collapse capacity, P_0, for dished heads may be calculated from:

$$P_0 = 1.78 \, \frac{\sigma_y t(1 + 50\epsilon_y)}{r} \qquad (2\text{-}1)$$

for 2:1 semi-ellipsoidal steel heads, and

$$P_0 = \frac{22.4 \, \sigma_y(1 + 240\epsilon_y)(r_t/2r)^{1.04}}{(2r/t)^{1.09} \, (R_s/2r)^{0.79}} \qquad (2\text{-}2)$$

for torispherical heads, where P_0 is the median plastic collapse pressure, and

where σ_y is the yield stress
t is the head thickness
r is the radius of the attached cylinder
ϵ_Y is the yield point strain
r_t is the toroidal (knuckle) radius
and R_s is the radius of the spherical portion

These expressions are valid for most tanks and vessels with dished heads used in typical nuclear power plant applications. Specifically, the ranges of parameters studied (Reference 4 through 7) were

$$200 < r/t < 750$$
$$30 \text{ ksi} < \sigma_y < 60\text{ksi}$$

and the strain hardening slope, S, = 0,5, and 10 percent for semiellipsoidal heads, and

$$250 < r/t < 750$$
$$1.5 < R_s/r < 3$$
$$0.12 < r_t/r < 0.36$$
$$20 \text{ ksi} < \sigma_y < 75 \text{ ksi}$$

and the strain hardening parameter, S, = 0 and 5 percent for torispherical heads. Again, it is estimated that a probability of crack formation of about 0.2 exists, given head collapse. Median material properties for typical nuclear power plant applications are shown in Tables 2-2 and 2-3. Plastic collapse, P_o, has been shown to control for steel heads. Should another material be encountered, asymmetrical buckling, P_{cr}, should be evaluated using methods outlined in Reference 1.

Variabilities associated with both cylinder hoop failure and dished head buckling are shown in Table 2-4. Separate variabilities for stainless and carbon steels are given. These values are considered representative for most tanks, vessels and heat exchangers. However, for unusual configurations such as thin-wall vessels with large thickness tolerances, etc., increased variabilities may be required. Except for extremely short cylinders or other unique configurations, leak areas associated with either cylinder hoop failure or dished head failure should be considered as large, uncontrolled leaks in the context of ISLOCA.

Table 2-1. Factors of Safety For Steel Tanks

Temperature (°F)	Median Factor of Safety (Design Press)		Lognormal Standard Deviation, ß
R.T.	Cylinder Hoop	6.5	0.45
600	Cylinder Hoop	6.5 Carbon Steel 5.2 Stainless Steel	0.66
	Dished Head Collapse	1.6	0.5

Table 2-2. 304 Stainless Steel Material Properties (Use for Tanks)

Temperature (°F)	Median Yield Strength, $\hat{\sigma}_y$ (ksi)	Median Failure Strength, $\hat{\sigma}_f$ (ksi)	Median Elongation, $\hat{\epsilon}_f$ (%)	Youngs Modulus, E (psi x 10^{-6})
R.T.	37	67	20	28.3
400	23	57.9	13	26.5
600	19.5	54.6	12	25.3
800	16.5	51.2	11.5	24.1

Table 2-3. SA 516 Grade 70 Steel Material Properties (Use For Tanks)

Temperature (°F)	Median Yield Strength, $\hat{\sigma}_y$ (ksi)	Median Failure Strength, $\hat{\sigma}_f$ (ksi)	Median Elongation, $\tilde{\epsilon}_f$ (1%)	Youngs Modulus, E (psi x 10^{-6})
R.T.	46	75.6	6.2	29.5
400	40	78.3	3.7	27.7
600	37	76.5	5.8	26.7
800	34	63.9	7.9	24.2

Table 2-4. Lognormal Standard Deviations (Use For Tanks)

Temperature (°F)	Lognormal Standard Deviation, ß			
	Cylinder		Dished Head	
	Stainless Steel	Carbon Steel	Stainless Steel	Carbon Steel
R.T.	0.19	0.16	0.19	0.22
400	0.30	0.22	0.23	0.25
600	0.33	0.24	0.23	0.27
800	0.37	0.20	0.24	0.30

3. PIPE

Both stainless steel and carbon steel pipe is used in nuclear power plant applications which may be susceptible to ISLOCA conditions. Type 304 stainless is the most common material used for stainless steel pipe although type 316 and occasionally other types may also be used. SA 106 Grade B is representative of carbon steel material in the more commonly found applications. Pipe may be considered a generic component as opposed to vessels which are often designed specifically for a given plant. Consequently, tabulated failure pressures have been developed for both 304 stainless and SA 106 Grade B pipe for use in ISLOCA pressure capacity evaluations.

Tables 3-1 through 3-3 show the median failure pressures for 304 stainless pipe for different pipe sizes and pipe schedules for a range of temperatures from 70 to 800 °F. Three discrete values for different assumed corrosion allowances are included. Most systems of importance for ISLOCA are not subject to continuous flow and erosion effects can normally be neglected. Linear interpolation may be used with the above tables to establish an intermediate corrosion pressure capacity if desired. Similarly, Tables 3-4 through 3-6 show similar information for SA 106 Grade B pipe.

Type 316 stainless steel exhibits somewhat higher strengths than 304 at increased temperatures. For 316 stainless pipe, the values in Table 3-1 through 3-3 may be increased by 10% for temperatures of 400°F and greater. Since failure pressures are dependent on both failure strains as well as stresses, care must be taken in ratioing Tables 3-1 through 3-6 to include other materials.

Variabilities included in pipe failure pressures include consideration of scatter in the strength and uniaxial elongation material properties, variation in properties with temperature, biaxial strain and gage length effects on failure strain, thermal bending strain, branch connections, flanges, and the possible existence of partial through wall cracks. Variabilities as expressed in terms of a lognormal standard deviation for both stainless and carbon steel pipe are shown in Table 3-7 together with the median failure stresses used to establish the failure pressures presented in Tables 3-1 through 3-6.

Table 3-1. 304 Stainless Steel Pipe Failure Pressure

CORROSION ALLOWANCE = 0.000

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	[illegible]°F	600°F	800°F
1-1/2	40S	1.900	1.610	9968	8556	7963	7525
	80	1.900	1.500	14757	12666	11788	11140
	160	1.900	1.337	23303	20001	18615	17591
2	40S	2.375	2.067	8246	7078	6587	6225
	80	2.375	1.939	12443	10680	9940	9393
	160	2.375	1.669	22476	19292	17955	16967
3	10S	3.500	3.260	4074	3497	3254	3075
	40S	3.500	3.068	7792	6688	6225	5882
	80	3.500	2.900	11449	9827	9146	8643
	160	3.500	2.624	18474	15857	14758	13946
4	10S	4.500	4.260	3118	2676	2490	2353
	40S	4.500	4.026	6515	5592	520[illegible]	4918
	80	4.500	3.826	9749	8367	7787	7359
	160	4.500	3.438	17094	14672	13655	12904
6	10S	6.625	6.357	2333	2002	1864	1761
	40S	6.625	6.065	5110	4386	4082	3857
	80	6.625	5.761	8299	7123	6630	6265
	120	6.625	5.501	11307	9705	903[illegible]	8536
	160	6.625	5.189	15314	13145	12234	11561
8	10S	8.625	8.329	1967	1688	1571	1485
	20	8.625	8.125	3405	2923	2720	2571
	40S	8.625	7.981	4465	3833	3567	3371
	80	8.625	7.625	7258	6229	5798	5479
	120	8.625	7.189	11054	9488	8830	8344
	140	8.625	7.001	12837	11018	10254	9690
	160	8.625	6.813	14718	12633	11757	11110
10	10S	10.750	10.420	[illegible]39	1504	1400	1323
	20	10.750	10.250	2699	2317	2156	2038
	40S	10.750	[illegible]020	4032	3460	3221	30[illegible]3
	80	10.750	9.564	6862	5890	5482	5180
	120	10.750	9.064	10254	6835	8223	7770
	140	10.750	8.750	12649	10857	10104	[illegible]548
	160	10.750	8.500	14649	12573	11702	[illegible]058
12	10S	12.750	12.390	1608	1380	1284	[illegible]4
	20	12.750	12.250	2259	1939	1804	1705
	Std	12.750	12.000	3459	2969	2763	2611
	40	12.750	11.938	3764	3231	3007	2841
	80	12.750	11.376	6684	5737	5339	5046
	120	12.750	10.750	10296	8837	8224	7772
	140	12.750	10.500	11858	10178	94[illegible]	8952
	160	12.750	10.126	14340	12308	11[illegible]5	10825
14	10S	14.000	13.624	1527	1311	1220	1153
	20	14.000	13.375	2586	2220	2066	1952
	Std	14.000	13.250	3132	2689	2502	2365
	40	14.000	13.125	3689	3167	2947	2785
	80	14.000	12.500	6641	5700	5305	5013
	120	14.000	11.814	10240	8789	8180	7730
	140	14.000	11.500	12030	10326	9610	9081
	160	14.000	11.188	13909	11938	11111	10500

Table 3-1 (Continued). 304 Stainless Steel Pipe Failure Pressures

CORROSION ALLOWANCE = 0.000

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	500°F	800°F
16	10S	16.000	15.624	1332	1143	1064	1005
	20	16.000	15.375	2250	1931	1797	1698
	Std	16.000	15.250	2722	2336	2174	2054
	40	16.000	15.000	3689	3167	2947	2785
	60	16.000	14.314	6518	5595	5207	4920
	120	16.000	13.564	9939	8530	7939	7502
	140	16.000	13.124	12127	10409	9687	9154
	160	16.000	12.814	13759	11810	10991	10387
18	10S	18.000	17.624	1181	1013	943	891
	20	18.000	17.375	1991	1709	1590	1503
	Std	18.000	17.250	2406	2065	1922	1816
	40	18.000	16.876	3686	3164	2944	2782
	80	18.000	16.126	6431	5520	5137	4855
	120	18.000	15.250	9979	8565	7972	7533
	140	18.000	14.876	11621	9975	9283	8772
	160	18.000	14.433	13677	11739	10925	10324
20	10S	20.000	19.564	1233	1059	985	931
	20	20.000	19.250	2156	1851	1722	1628
	Std	20.000	18.814	3488	2994	2787	2633
	80	20.000	17.938	6361	5460	5082	4802
	120	20.000	17.000	9766	8382	7801	7372
	140	20.000	16.500	11739	10075	9377	8861
	160	20.000	16.064	13559	11638	10831	10236
24	10S	24.000	23.500	1177	1011	941	889
	20S	24.000	23.250	1785	1532	1426	1348
	40	24.000	22.626	3361	2884	2684	2537
	80	24.000	21.564	6251	5366	4994	4719
	120	24.000	20.376	9842	8448	7862	7430
	140	24.000	19.876	11482	9855	9172	8666
	160	24.000	19.314	13426	11524	10725	10135

Table 3-2. 304 Stainless Steel Pipe Failure Pressures

CORROSION ALLOWANCE = 0.020

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
1-1/2	40S	1.900	1.610	8593	7375	6864	6487
	80	1.900	1.500	13281	11399	10609	10026
	160	1.900	1.337	21647	18580	17292	16341
2	40S	2.375	2.067	7175	6156	5732	5416
	80	2.375	1.939	11302	9700	9028	8532
	160	2.375	1.689	21166	18167	16906	15978
3	10S	3.500	3.260	4395	2914	2712	2563
	40S	3.500	3.068	7071	6069	5648	5338
	80	3.500	2.900	10686	9172	8536	8067
	160	3.500	2.624	17631	15133	14084	13309
4	10S	4.500	4.260	2598	2230	2075	1961
	40S	4.500	4.026	5966	5120	4765	4503
	80	4.500	3.826	9170	7871	7325	6922
	160	4.500	3.438	16450	14119	13141	12418
6	10S	6.625	6.357	1985	1704	1585	1498
	40S	6.625	6.065	4745	4072	3790	3582
	80	6.625	5.761	7915	6794	6323	5975
	120	6.625	5.501	10905	9360	8711	8232
	160	6.625	5.189	14888	12778	11893	11239
8	10S	8.625	8.329	1701	1460	1359	1284
	20	8.625	8.125	3133	2689	2503	2365
	40S	8.625	7.981	4188	3595	3345	3161
	80	8.625	7.625	6067	5980	5566	5259
	120	8.625	7.189	10745	9223	8584	8112
	140	8.625	7.001	12521	10747	10002	9452
	160	8.625	6.813	14393	12354	11498	10865
10	10S	10.750	10.420	1540	1322	1230	1163
	20	10.750	10.250	2484	2132	1984	1875
	40S	10.750	10.020	3811	3271	3044	2877
	80	10.750	9.564	6631	5691	5297	5006
	120	10.750	9.064	10049	8625	8028	7586
	140	10.750	8.750	12396	10640	9902	9357
	160	10.750	8.500	14388	12349	11494	10861
12	10S	12.750	12.390	1429	1227	1142	1079
	20	12.750	12.250	2078	1784	1660	1569
	Std	12.750	12.000	3274	2810	2616	2472
	40	12.750	11.938	3579	3072	2859	2701
	80	12.750	11.376	6469	5570	5184	4899
	120	12.750	10.750	10090	8660	8060	7617
	140	12.750	10.500	11648	9997	9304	8793
	160	12.750	10.126	14122	12121	11281	10660
14	10S	14.000	13.624	1365	1171	1090	1030
	20	14.000	13.375	2420	2077	1933	1827
	Std	14.000	13.250	2565	2545	2369	2238
	40	14.000	13.126	3521	3022	2812	2658
	80	14.000	12.500	6464	5548	5163	4879
	120	14.000	11.814	10052	8628	8030	7588
	140	14.000	11.500	11838	10160	9456	8936
	160	14.000	11.188	13711	11768	10953	10350

Table 3-2 (Continued). 304 Stainless Steel Pipe Failure Pressures

CORROSION ALLOWANCE = 0.020

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
16	10S	16.000	15.624	1190	1021	951	898
	20	16.000	15.375	2108	1807	1682	1589
	Std	16.000	15.250	2576	2211	2058	1945
	40	16.000	15.000	3542	3040	2829	2674
	80	16.000	14.314	6364	5462	5083	4804
	120	16.000	13.564	9775	8390	7809	7379
	140	16.000	13.124	11958	10264	9553	9027
	160	16.000	12.814	13586	11661	10853	10256
18	10S	18.000	17.624	1055	906	843	796
	20	18.000	17.375	1863	1599	1488	1407
	Std	18.000	17.250	2278	1955	1819	1719
	40	18.000	16.876	3555	3051	2839	2683
	80	18.000	16.126	6294	5402	5028	4751
	120	18.000	15.250	9834	8441	7856	7424
	140	18.000	14.876	11473	9847	9165	8660
	160	18.000	14.433	13523	11607	10803	10208
20	10S	20.000	19.564	1120	961	895	846
	20S	20.000	19.250	2041	1752	1630	1541
	40	20.000	18.814	3371	2893	2693	2545
	80	20.000	17.938	6238	5354	4983	4709
	120	20.000	17.000	9634	8270	7697	7274
	140	20.000	16.500	11604	9960	9270	8760
	160	20.000	16.064	13421	11520	10721	10132
24	10S	[illegible]	23.500	1083	930	865	818
	20S	[illegible]	23.250	1690	1450	1350	1276
	40	24.000	22.626	3263	2800	2606	2463
	80	24.000	21.564	6149	5278	4912	4642
	120	24.000	20.376	9734	8355	7776	7348
	140	24.000	19.876	11371	9760	9083	8584
	160	24.000	19.314	13312	11426	10634	10049

Table 3-3. 304 Stainless Steel Pipe Failure Pressures

CORROSION ALLOWANCE = 0.040

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
1-1/2	40S	1.900	1.610	7218	6195	5766	5449
	80	1.900	1.500	11806	10133	9431	8912
	160	1.900	1.337	19992	17159	15970	15091
2	40S	2.375	2.067	6104	5239	4876	4608
	80	2.375	1.939	10160	8721	8116	7670
	160	2.375	1.689	19855	17042	15861	14988
3	10S	3.500	3.260	2716	2331	2170	2050
	40S	3.500	3.068	6349	5450	5072	4793
	80	3.500	2.900	9923	8517	7927	7491
	160	3.500	2.624	16787	14409	13410	12672
4	10S	4.500	4.260	2078	1784	1660	1569
	40S	4.500	4.026	5416	4648	4326	4088
	80	4.500	3.826	8592	7374	6863	6486
	160	4.500	3.438	15807	13567	12627	11932
6	10S	6.625	6.357	1637	1405	1307	1235
	40S	6.625	6.065	4380	3759	3499	3306
	80	6.625	5.761	7531	6464	6016	5685
	120	6.625	5.501	10502	9014	8390	7928
	160	6.625	5.189	14461	12412	11552	10917
8	10S	8.625	8.329	1435	1232	1146	1083
	20	8.625	8.125	2861	2455	2285	2159
	40S	8.625	7.981	3911	3357	3124	2952
	80	8.625	7.625	6677	5731	5334	5040
	120	8.625	7.189	10438	8959	8338	7880
	140	8.625	7.001	12204	10475	9749	9213
	160	8.625	6.813	14068	12075	11238	10620
10	10S	10.750	10.420	1328	1140	1061	1002
	20	10.750	10.250	2268	1946	1811	1712
	40S	10.750	10.020	3590	3081	2868	2710
	80	10.750	9.564	6400	5493	5112	4831
	120	10.750	9.064	9805	8416	7833	7402
	140	10.750	8.750	12143	10422	9700	9166
	160	10.750	8.500	14128	12126	11286	10665
12	10S	12.750	12.390	1251	1073	999	944
	20	12.750	12.250	1897	1628	1516	1432
	Std	12.750	12.000	3090	2652	2468	2332
	40	12.750	11.938	3393	2912	2711	2561
	80	12.750	11.376	6295	5403	5028	4752
	120	12.750	10.750	9884	8483	7895	7461
	140	12.750	10.500	11437	9816	9136	8633
	160	12.750	10.126	13903	11933	11106	10495
14	10S	14.000	13.624	1202	1032	960	908
	20	14.000	13.375	2255	1935	1801	1702
	Std	14.000	13.250	2798	2402	2235	2112
	40	14.000	13.125	3352	2877	2678	2530
	80	14.000	12.500	6287	5396	5022	4746
	120	14.000	11.814	9865	8467	7880	7447
	140	14.000	11.500	11645	9995	9302	8791
	160	14.000	11.188	13513	11599	10795	10201

Table 3-3 (Continued). 304 Stainless Steel Pipe Failure Pressures

CORROSION ALLOWANCE = 0.040

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
16	10S	16.000	15.624	1048	900	837	791
	20	16.000	15.375	1962	1684	1567	1481
	Std	16.000	15.250	2431	2087	1942	1835
	40	16.000	15.000	3394	2913	2711	2562
	80	16.000	14.314	6209	5329	4960	4687
	120	16.000	13.564	9612	8250	7678	7256
	140	16.000	13.124	11790	10119	9418	8900
	160	16.000	12.814	13414	11513	10715	10126
18	10S	18.000	17.624	929	798	742	702
	20	18.000	17.375	1736	1490	1387	1310
	Std	18.000	17.250	2149	1845	1717	1623
	40	18.000	16.876	493	2938	2735	2584
	80	18.000	16.126		4284	4918	4647
	120	18.000	15.250	[illegible]	[illegible]	7740	7314
	140	18.000	14.876	[illegible]	[illegible]	9046	8548
	160	18.000	14.433	[illegible]	4.5	10680	10093
20	10S	20.000	19.564	765	864	804	760
	20S	20.000	19.250	1921	1653	1539	1454
	40	20.000	18.814	3253	2792	2599	2456
	80	20.000	17.938	6113	5248	4884	4616
	120	20.000	17.000	9563	8156	7593	7175
	140	20.000	16.500	11470	9845	9163	8659
	160	20.000	16.064	13284	11401	10611	10028
24	10S	24.000	23.500	989	849	790	747
	20S	24.000	23.250	1595	1369	1274	1204
	40	24.000	22.626	3165	2716	2528	2389
	80	24.000	21.564	6046	5189	4830	4564
	120	24.000	20.376	9625	8261	7689	7266
	140	24.000	19.876	11259	9664	8994	8499
	160	24.000	19.314	13197	11327	10542	9962

Table 3-4. SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.000

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
1-1/2	40S	1.900	1.610	9851	10781	10086	7666
	80	1.900	1.500	14584	15962	14932	11349
	160	1.900	1.337	23030	25205	23580	17920
2	40S	2.375	2.067	8150	8919	8344	6341
	80	2.375	1.939	12298	13459	12591	9569
	160	2.375	1.689	22213	24311	22743	17285
3	10S	3.500	3.260	4026	4407	4122	3133
	40S	3.500	3.068	7701	8428	7885	5992
	80	3.500	2.900	11316	12384	11585	8805
	160	3.500	2.624	18258	19982	18694	14207
4	10S	4.500	4.260	3081	3372	3155	2398
	40S	4.500	4.026	6439	7047	6593	5010
	80	4.500	3.826	9635	10544	9864	7497
	160	4.500	3.438	16894	18490	17297	13146
6	10S	6.625	6.357	2306	2523	2361	1794
	40S	6.625	6.065	5060	5527	5170	3929
	80	6.625	5.761	8202	8977	8398	6382
	120	6.625	5.501	11175	12230	11442	8696
	160	6.625	5.189	15135	16564	15496	11777
8	10S	8.625	8.329	1944	2127	1990	1512
	20	8.625	8.125	3366	3683	3446	2619
	40S	8.625	7.981	4413	4830	4518	3434
	80	8.625	7.625	7173	7850	7344	5581
	120	8.625	7.189	10925	11956	11185	8501
	140	8.625	7.001	12687	13885	12989	9872
	160	8.625	6.813	14546	15919	14893	11319
10	10S	10.750	10.420	1732	1896	1773	1348
	20	10.750	10.250	2668	2920	2732	2076
	40S	10.750	10.020	3985	4361	4080	3100
	80	10.750	9.564	6782	7423	6944	5277
	120	10.750	9.064	10173	11134	10416	7916
	140	10.750	8.750	12501	13681	12799	9727
	160	10.750	8.500	14477	15844	14823	11265
12	10S	12.750	12.390	1589	1739	1627	1237
	20	12.750	12.250	2232	2443	2286	1737
	Std	12.750	12.000	3418	3741	3500	2660
	40	12.750	11.938	3720	4071	3809	2895
	80	12.750	11.376	6606	7229	6763	5140
	120	12.750	10.750	10175	11136	10418	7918
	140	12.750	10.500	11720	12826	11999	9119
	160	12.750	10.126	14173	15511	14511	11028
14	10S	14.000	13.624	1509	1652	1545	1175
	20	14.000	13.375	2556	2797	2617	1989
	Std	14.000	13.250	3096	3388	3170	2409
	40	14.000	13.125	3646	3990	3733	2837
	80	14.000	12.500	6563	7183	6720	5107
	120	14.000	11.814	10120	11075	10361	7875
	140	14.000	11.500	11889	13012	12173	9252
	160	14.000	11.188	13746	15044	14074	10696

Table 3-4 (Continued). SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.000

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
16	10S	16.000	15.624	1316	1440	1348	1024
	20	16.000	15.375	2223	2433	2276	1730
	Std	16.000	15.250	2690	2944	2754	2093
	40	16.000	15.000	3646	3990	3733	2837
	80	16.000	14.314	6442	7050	6596	5013
	120	16.000	13.564	9822	10750	10057	7643
	140	16.000	13.124	11985	13117	12271	9326
	160	16.000	12.814	13598	14882	13923	10581
18	10S	18.000	17.624	1167	1277	1195	908
	20	18.000	17.375	1967	2153	2014	1531
	Std	18.000	17.250	2378	2602	2435	1850
	40	18.000	16.876	3643	3987	3730	2834
	80	18.000	16.126	6356	6956	6507	4946
	120	18.000	15.250	9862	10794	10098	7674
	140	18.000	14.876	11485	12570	11759	8937
	160	18.000	14.433	13517	14793	13839	10518
20	10S	20.000	19.564	1219	1334	1248	948
	20S	20.000	19.250	2131	2332	2182	1658
	40	20.000	18.814	3448	3773	3530	2683
	80	20.000	17.938	6287	6881	6437	4892
	120	20.000	17.000	9651	10563	9882	7510
	140	20.000	16.500	11601	12697	11878	9027
	160	20.000	16.064	13401	14666	13720	10427
24	10S	24.000	23.500	1164	1274	1191	905
	20S	24.000	23.250	1764	1931	1806	1373
	40	24.000	22.626	3321	3635	3400	2584
	80	24.000	21.564	6178	6762	6326	4807
	120	24.000	20.376	9727	10646	9959	7569
	140	24.000	19.876	11348	12419	11618	8830
	160	24.000	19.314	13269	14522	13586	10325

Table 3-5. SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.020

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
1-1/2	40S	1.900	1.610	8492	9294	8695	6608
	80	1.900	1.500	13126	14365	13439	10214
	160	1.900	1.337	21394	23414	21904	16647
2	40S	2.375	2.067	7091	7761	7260	5518
	80	2.375	1.939	11170	12224	11436	8691
	160	2.375	1.689	20918	22893	21417	16277
3	10S	3.500	3.260	3355	3672	3435	2611
	40S	3.500	3.068	6988	7648	7155	5438
	80	3.500	2.900	10561	11558	10813	8218
	160	3.500	2.624	17425	19070	17840	13559
4	10S	4.500	4.260	2568	2810	2629	1998
	40S	4.500	4.026	5896	6452	6036	4588
	80	4.500	3.826	9063	9919	9279	7052
	160	4.500	3.438	16258	17793	16646	12651
6	10S	6.625	6.357	1962	2147	2008	1526
	40S	6.625	6.065	4689	5132	4801	3649
	80	6.625	5.761	7823	8561	8009	6087
	120	6.625	5.501	10777	11795	11034	8386
	160	6.625	5.189	14714	16103	15065	11449
8	10S	8.625	8.329	1681	1840	1721	1308
	20	8.625	8.125	3096	3389	3170	2409
	40S	8.625	7.981	4139	4530	4238	3221
	80	8.625	7.625	6886	7536	7050	5358
	120	8.625	7.189	10620	11623	10874	8264
	140	8.625	7.001	12374	13543	12669	9629
	160	8.625	6.813	14225	15568	14564	11069
10	10S	10.750	10.420	1522	1666	1558	1184
	20	10.750	10.250	2454	2686	2513	1910
	40S	10.750	10.020	3766	4122	3856	2931
	80	10.750	9.564	6553	7172	6710	5099
	120	10.750	9.064	9932	10870	10169	7728
	140	10.750	8.750	12251	13408	12543	9533
	160	10.750	8.500	14220	15563	14559	11065
12	10S	12.750	12.390	1413	1546	1446	1099
	20	12.750	12.250	2054	2248	2103	1598
	Std	12.750	12.000	3236	3541	3313	2518
	40	12.750	11.938	3537	3871	3621	2752
	80	12.750	11.376	6413	7019	6566	4990
	120	12.750	10.750	9972	10913	10210	7759
	140	12.750	10.500	11511	12598	11786	8957
	160	12.750	10.126	13956	15274	14289	10860
14	10S	14.000	13.624	1349	1476	1381	1050
	20	14.000	13.375	2392	2618	2449	1861
	Std	14.000	13.250	2931	3207	3001	2280
	40	14.000	13.125	3479	3808	3562	2707
	80	14.000	12.500	6388	6991	6540	4971
	120	14.000	11.814	9935	10873	10172	7730
	140	14.000	11.500	11699	12804	11978	9103
	160	14.000	11.188	13551	14830	13874	10544

Table 3-5 (Continued). SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.020

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
16	10S	16.000	15.624	1176	1287	1204	915
	20	16.000	15.375	2081	2277	2131	1619
	Std	16.000	15.250	2546	2787	2607	1981
	40	16.000	15.000	3500	3831	3584	2724
	80	16.000	14.314	6289	6883	6439	4894
	120	16.000	13.564	9661	10573	9891	7517
	140	16.000	13.124	11818	12934	12100	9196
	160	16.000	12.814	13428	14695	13748	10448
18	10S	18.000	17.624	1043	1141	1068	811
	20	18.000	17.375	1841	2015	1885	1433
	Std	18.000	17.250	2251	2464	2305	1752
	40	18.000	16.876	3513	3845	3597	2734
	80	18.000	16.126	6220	6807	6368	4840
	120	18.000	15.250	9719	10637	9951	7563
	140	18.000	14.876	11338	12409	11609	8823
	160	18.000	14.433	13365	14627	13684	10400
20	10S	20.000	19.564	1107	1212	1133	861
	20S	20.000	19.250	2017	2208	2065	1570
	40	20.000	18.814	3331	3646	3411	2592
	80	20.000	17.938	6165	6747	6312	4797
	120	20.000	17.000	9523	10422	9750	7410
	140	20.000	16.500	11469	12552	11742	8924
	160	20.000	16.064	13264	14517	13581	10321
24	10S	24.000	23.500	1071	1172	1096	833
	20S	24.000	23.250	1670	1828	1710	1300
	40	24.000	22.626	3225	3529	3301	2509
	80	24.000	21.564	6077	6651	6222	4729
	120	24.000	20.376	9620	10528	9849	7485
	140	24.000	19.876	11238	12299	11506	8744
	160	24.000	19.314	13156	14398	13470	10237

Table 3-6. SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.040

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
1-1/2	40S	1.900	1.610	7134	7807	7304	5551
	80	1.900	1.500	11668	12769	11946	9079
	160	1.900	1.337	19758	21623	20229	15374
2	40S	2.375	2.067	6033	6602	6177	4694
	80	2.375	1.939	10041	10990	10281	7813
	160	2.375	1.689	19523	21476	20091	15269
3	10S	3.500	3.260	2684	2938	2748	2089
	40S	3.500	3.068	6275	6867	6425	4883
	80	3.500	2.900	9807	10733	10041	7631
	160	3.500	2.624	16591	18158	16987	12910
4	10S	4.500	4.260	2054	2248	2103	1598
	40S	4.500	4.026	5352	5858	5480	4165
	80	4.500	3.826	8491	9293	8694	6607
	160	4.500	3.438	15622	17097	15994	12156
6	10S	6.625	6.357	1617	1770	1656	1259
	40S	6.625	6.065	4328	4737	4432	3368
	80	6.625	5.761	7443	8146	7620	5791
	120	6.625	5.501	10380	11360	10627	8077
	160	6.625	5.189	14292	15642	14633	11121
8	10S	8.625	8.329	1418	1552	1452	1104
	20	8.625	8.125	2827	3094	2895	2200
	40S	8.625	7.981	3865	4230	3957	3007
	80	8.625	7.625	6599	7222	6756	5135
	120	8.625	7.189	10316	11290	10562	8027
	140	8.625	7.001	12062	13201	12349	9385
	160	8.625	6.813	13904	15217	14235	10819
10	10S	10.750	10.420	1312	1436	1343	1021
	20	10.750	10.250	2241	2453	2294	1744
	40S	10.750	10.020	3548	3883	3633	2761
	80	10.750	9.564	6325	6922	6476	4921
	120	10.750	9.064	9691	10606	9922	7540
	140	10.750	8.750	12001	13134	12287	9338
	160	10.750	8.500	13962	15281	14296	10865
12	10S	12.750	12.390	1236	1353	1265	962
	20	12.750	12.250	1875	2052	1920	1459
	Std	12.750	12.000	3054	3342	3126	2376
	40	12.750	11.938	3354	3670	3434	2609
	80	12.750	11.376	6221	6809	6369	4841
	120	12.750	10.750	9768	10691	10001	7601
	140	12.750	10.500	11303	12370	11573	8795
	160	12.750	10.126	13740	15038	14068	10692
14	10S	14.000	13.624	1188	1300	1217	925
	20	14.000	13.375	2229	2439	2282	1734
	Std	14.000	13.250	2766	3027	2832	2152
	40	14.000	13.125	3313	3626	3392	2578
	80	14.000	12.500	6213	6800	6361	4834
	120	14.000	11.814	9750	10670	9982	7586
	140	14.000	11.500	11509	12596	11784	8955
	160	14.000	11.188	13355	14616	13674	10392

Table 3-6 (Continued). SA 106 Grade B Pipe Failure Pressures

CORROSION ALLOWANCE = 0.040

Pipe Size (in)	Schedule	OD (in)	ID (in)	FAILURE PRESSURES 70°F	400°F	600°F	800°F
16	10S	16.000	15.624	1036	1134	1061	806
	20	16.000	15.375	1939	2122	1985	1509
	Std	16.000	15.250	2403	2630	2460	1870
	40	16.000	15.000	3354	3671	3434	2610
	80	16.000	14.314	6136	6716	6283	4775
	120	16.000	13.564	9500	10397	9726	7392
	140	16.000	13.124	11652	12752	11930	9067
	160	16.000	12.814	13257	14509	13573	10315
18	10S	18.000	17.624	919	1005	940	715
	20	18.000	17.375	1716	1877	1756	1335
	Std	18.000	17.250	2124	2325	2175	1653
	40	18.000	16.876	3383	3703	3464	2633
	80	18.000	16.126	6084	6659	6230	4734
	120	18.000	15.250	9576	10480	9804	7451
	140	18.000	14.876	11191	12248	11458	8708
	160	18.000	14.433	13213	14461	13529	10282
20	10S	20.000	19.564	995	1089	1019	774
	20S	20.000	19.250	1904	2083	1949	1481
	40	20.000	18.814	3215	3519	3292	2502
	80	20.000	17.938	6043	6614	6187	4702
	120	20.000	17.000	9394	10281	9618	7310
	140	20.000	16.500	11336	12406	11607	8821
	160	20.000	16.064	13128	14368	13441	10215
24	10S	24.000	23.500	977	1070	1001	761
	20S	24.000	23.250	1576	1725	1614	1226
	40	24.000	22.626	3128	3423	3202	2434
	80	24.000	21.564	5975	6540	6118	4650
	120	24.000	20.376	9513	10411	9739	7402
	140	24.000	19.876	11128	12178	11393	8659
	160	24.000	19.314	13043	14274	13354	10149

Table 3-7. Failure Stresses and Variabilities For Pipe

Temperature (°F)	304 Stainless Steel $\hat{\sigma}_f$ (ksi)	ß	SA 106 B Carbon Steel $\hat{\sigma}_f$ (ksi)	ß
RT.	74	0.22	61.2	0.17
400	62.9	0.33	64.8	0.24
600	59.5	0.36	62.1	0.27
800	55.7	0.39	49.5	0.23

where $\hat{\sigma}_f$ denotes the median hoop failure stress and ß is the lognormal standard deviation

4. GASKETED FLANGE CONNECTIONS

Although most of the piping joints in lines normally of importance for ISLOCA are full penetration butt welds, a number of gasket flange connections are required for the installation of flow restricting orifices, flow elements, and major equipment components. The elements of the flanged joints include standard ANSI B16.5 flanges with asbestos-filled, spiral-wound gaskets. The normal lines of interest for ISLOCA may be designed for 150, 300, 400, or 600 lb rated service and typically employ raised-face flanges fabricated from either stainless or carbon steel depending on the pipe material. As in the case of pipe, flanges may be considered generic.

The flanges may be secured with bolts or studs of different materials with different bolt preloads from plant to plant. Bolts or studs may be classified into two fairly broad categories: low strength ("soft") and high strength. An example of a soft bolt is SA-193 B8 which has minimum specified room temperature yield and ultimate strengths of 30,000 and 75,000 psi respectively. Examples of high strength bolts include SA-193 B7 with minimum room temperature yield and ultimate strengths of 105,000 and 125,000 psi respectively, and SA 564 Grade 630-HT 1100 with 115,000 psi yield and 140,000 psi ultimate. Since soft bolts are much more likely to be preloaded to lower values, and are much more likely to yield at relatively lower internal pressures, flanged connections should be evaluated on a plant specific basis, at least to the extent of determining the bolt material and installation torque range.

The behavior of gasketed-flanges under pressure and temperature conditions is quite complex. The probability of leakage, under a given pressure loading, is as much or more dependent upon the previous history of the joint than it is on its state at the time the pressure is applied. As a result, numerous variables are introduced. These include:

- Bolt/Stud Preload
- Bolt/Stud Temperature
- Bolt/Stud Yield Strength
- Bolt/Stud Stress-Strain Relationship
- Bolt Relaxation
- Flange Flexibility
- Initial Gasket Stress
- Gasket Loading Stiffness
- Gasket Unloading/Reloading Stiffness
- Gasket Creep and Relaxation
- Pipe Bending Moments

Discussions of the effects of these parameters on the leak pressures and leak rates or leak areas of flanged connections may be found in References 1 through 3.

Although the flange leak characteristics are plant specific to the extent that different bolt materials and bolt preloads are used, tabular values of Gross Leak Pressure (GLP) and leak rates and leak areas for various flange ratings and pipe sizes have been developed. Two sets of tables corresponding to "soft" and "high strength" bolts are presented here. For a given pipe diameter and flange rating, the recommended procedure requires the determination of the plant specific bolt material, and a determination of the expected initial bolt prestress and joint relaxation. To account for relaxation and cyclic creep for those cases where lock-up between the flange and compression gauge ring does not occur (normally all 150 lb flanges and 300 and 600 lb flanges with low bolt stress and high gasket loading stiffness) a median joint relaxation of 25% is recommended with the range from 0 to 25% taken as a 3ß variation. Once the required parameters have been determined, the GLP as well as the leak rate or leak area at discrete values over the range of 0.25 to 2.0 times GLP can be calculated. Results for low strength bolts are given in Tables 4-5 through 4-29 and for high strength bolts in Tables 4-30 through 4-54. Variabilities expected for bolted flange leak rates are shown in Table 4-55. A variability in leak area of 0.12 is recommended for all pipe diameters and flange ratings.

Table 4-1. 150# ANSI Flange and Gasket Data

Flange Diameter (in)	GASKET				Pressure Area	BOLTS			
	OD (in)	ID (in)	Width (in)	Area (sq in)	(sq in)	Number	Diameter (in)	Area (sq in)	Length (in)
Flanges									
1-1/2	2.750	2.125	0.2500	1.865	3.547	4	1/2	0.1416	1.625
2	3.375	2.750	0.2500	2.356	5.940	4	5/8	0.2256	1.750
2-1/2	3.875	3.250	0.2500	2.749	8.296	4	5/8	0.2256	2.000
3	4.750	4.000	0.3125	4.234	12.566	4	5/8	0.2256	2.125
4	5.875	5.000	0.3750	6.332	19.635	8	5/8	0.2256	2.125
6	8.250	7.188	0.4688	11.275	40.574	8	3/4	0.3340	2.250
8	10.375	9.188	0.5313	16.220	66.296	8	3/4	0.3340	2.500
10	12.500	11.313	0.5313	19.767	100.509	12	7/8	0.4612	2.625
12	14.750	13.375	0.6250	27.489	140.500	12	7/8	0.4612	2.750
14	16.000	14.625	0.6250	29.943	167.989	12	1	0.6051	3.000
16	18.250	16.625	0.7500	40.939	217.077	16	1	0.6051	3.125
18	20.750	18.688	0.9688	59.822	274.279	16	1-1/8	0.7627	3.375
20	22.750	20.688	0.9688	65.909	336.129	20	1-1/8	0.7627	3.625
24	27.000	24.750	1.0625	86.161	481.105	20	1-1/4	0.9684	4.000

Bolt areas correspond to tensile stress area

Table 4-2. 300# ANSI Flange and Gasket Data

Flange Diameter (in)	GASKET				Pressure	BOLTS			
	OD (in)	ID (in)	Width (in)	Area (sq in)	Area (sq in)	Number	Diameter (in)	Area (sq in)	Length (in)
Flanges									
1-1/2	2.750	2.125	0.2500	1.865	3.547	4	3/4	0.3340	1.875
2	3.375	2.750	0.2500	2.356	5.940	8	5/8	0.2256	2.000
2-1/2	3.875	3.250	0.2500	2.749	8.296	8	3/4	0.3340	2.250
3	4.750	4.000	0.3125	4.234	12.566	8	3/4	0.3340	2.500
4	5.875	5.000	0.3750	6.332	19.635	8	3/4	0.3340	2.750
6	8.250	7.188	0.4688	11.275	40.574	12	3/4	0.3340	3.125
8	10.375	9.188	0.5313	16.220	66.296	12	7/8	0.4612	3.500
10	12.500	11.313	0.5313	19.767	100.509	16	1	0.6051	4.000
12	14.750	13.375	0.6250	27.489	140.500	16	1-1/8	0.7896	4.250
14	16.000	14.625	0.6250	29.943	167.989	20	1-1/8	0.7896	4.500
16	18.250	16.625	0.7500	40.939	217.077	20	1-1/4	0.9985	4.750
18	20.750	18.688	0.9688	59.822	274.279	24	1-1/4	0.9985	5.000
20	22.750	20.688	0.9688	65.909	336.129	24	1-1/4	0.9985	5.250
24	27.000	24.750	1.0625	86.161	481.105	24	1-1/2	1.4899	5.750

Bolt areas correspond to tensile stress area

Table 4-3. 400# ANSI Flange and Gasket Data

Flange Diameter (in)	GASKET OD (in)	GASKET ID (in)	GASKET Width (in)	GASKET Area (sq in)	Pressure Area (sq in)	BOLTS Number	BOLTS Diameter (in)	BOLTS Area (sq in)	BOLTS Length (in)
Flanges									
1-1/2	2.750	2.125	0.2500	1.865	3.547	4	3/4	0.3340	2.125
2	3.375	2.750	0.2500	2.356	5.940	8	5/8	0.2256	2.375
2-1/2	3.875	3.250	0.2500	2.749	8.296	8	3/4	0.3340	2.625
3	4.750	4.000	0.3125	4.234	12.566	8	3/4	0.3340	2.875
4	5.875	5.000	0.3750	6.332	19.635	8	7/8	0.4612	3.125
6	8.250	7.188	0.4688	11.275	40.574	12	7/8	0.4612	3.625
8	10.375	9.188	0.5313	16.220	66.296	12	1	0.6051	4.125
10	12.500	11.313	0.5313	19.767	100.509	16	1-1/8	0.7896	4.625
12	14.750	13.375	0.6250	27.489	140.500	16	1-1/4	0.9985	4.875
14	16.000	14.625	0.6250	29.943	167.990	20	1-1/4	0.9985	5.125
16	18.250	16.625	0.7500	40.939	217.077	20	1-3/8	1.2319	5.375
18	20.750	18.688	0.9688	59.822	274.279	24	1-3/8	1.2319	5.625
20	22.750	20.688	0.9688	65.909	336.129	24	1-1/2	1.4899	5.875
24	27.000	24.750	1.0625	86.161	481.105	24	1-3/4	1.8983	6.375

Bolt areas correspond to tensile stress area

Table 4-4. 600# ANSI Flange and Gasket Data

Flange Diameter (in)	*----------GASKET----------* OD (in)	ID (in)	Width (in)	Area (sq in)	Pressure Area (sq in)	*----------BOLTS----------* Number	Diameter (in)	Area (sq in)	Length (in)
Flanges									
1-1/2	2.750	2.125	0.3125	2.393	3.547	4	3/4	0.3340	2.375
2	3.375	2.750	0.3125	3.007	5.940	8	5/8	0.2256	2.625
2-1/2	3.875	3.250	0.3125	3.497	8.296	8	3/4	0.3340	2.875
3	4.750	4.000	0.3750	5.154	12.566	8	3/4	0.3340	3.125
4	5.875	4.750	0.5625	9.388	17.721	8	7/8	0.4612	3.625
6	8.250	6.875	0.6875	16.334	37.122	12	1	0.6051	4.375
8	10.375	8.875	0.7500	22.678	61.862	12	1-1/8	0.7896	5.000
10	12.500	10.813	0.8438	30.897	91.821	16	1-1/4	0.9985	5.625
12	14.750	12.875	0.9375	40.681	130.192	20	1-1/4	0.9985	5.875
14	16.000	14.250	0.8750	41.577	159.485	20	1-3/8	1.2319	6.125
16	18.250	16.250	1.0000	54.192	207.394	20	1-1/2	1.4899	6.625
18	20.750	18.500	1.1250	69.360	268.803	20	1-5/8	1.7723	7.125
20	22.750	20.500	1.1250	76.429	330.064	24	1-5/8	1.7723	7.625
24	27.000	24.750	1.1250	91.450	481.105	24	1-7/8	2.4107	8.625

Bolt areas correspond to tensile stress area

Tables 4-5 through 4-29

LOW STRENGTH BOLTS

Tables 4-30 through 4-54

HIGH STRENGTH BOLTS

Table 4-5. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	6073	6073	0.034	3273	14	2	5	9	0.21	0.52	0.83	1.14	51764
2	7660	7660	0.034	3427	5	1	2	3	0.34	0.80	1.27	1.96	54059
2-1/2	6566	6566	0.033	2617	13	2	4	7	0.55	1.21	1.86	3.11	56065
3	4263	4263	0.034	1657	118	16	37	68	0.52	1.34	2.16	3.36	53913
4	5700	5700	0.034	2015	26	3	8	15	0.26	1.24	2.21	3.18	50904
6	4740	4740	0.033	1347	74	8	20	38	0.01	0.91	2.27	3.63	46588
8	3295	3295	0.033	757	535	49	123	248	0.01	0.03	1.70	3.46	42167
10	5600	5600	0.033	1004	38	3	7	16	0.02	0.03	1.24	3.42	40061
12	4027	4027	0.033	659	213	15	39	83	0.02	0.04	0.06	2.27	36727
14	4850	4850	0.033	734	86	6	15	32	0.02	0.04	0.07	2.87	36974
16	4730	4730	0.033	750	94	7	17	36	0.03	0.05	0.08	3.28	36827
18	4080	4080	0.033	731	183	14	36	75	0.03	0.06	0.09	3.59	36419
20	4629	4629	0.033	759	102	7	19	40	0.04	0.07	0.11	4.61	36721
24	4496	4496	0.033	683	127	9	22	48	0.05	0.10	0.15	6.44	36962

Bolt Yield Stress = 33,000 psi (SA193 B8)

DGmax = 0.050 in

Table 4-6. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	7591	7591	0.042	2323	4	0	1	1	0.22	0.44	0.66	0.88	47545
2	9575	9575	0.042	2383	1	0	0	0	0.32	0.64	0.97	1.29	48686
2-1/2	8207	8207	0.042	1740	3	0	1	1	0.44	0.87	1.31	1.75	49000
3	5329	5329	0.042	1222	33	3	6	10	0.61	1.21	1.82	2.43	50021
4	7125	7125	0.042	1794	8	1	2	3	0.86	1.73	2.59	3.61	52512
6	5925	5925	0.041	1684	23	2	6	12	1.61	3.31	5.03	8.87	58235
8	4118	4118	0.041	946	166	15	38	77	0.80	3.00	5.20	7.82	52708
10	7000	7000	0.041	1255	12	1	2	5	0.02	2.74	5.47	8.20	50076
12	5033	5033	0.041	824	66	5	12	26	0.02	1.49	4.59	7.69	45909
14	6062	6062	0.041	917	27	2	5	10	0.03	1.88	5.61	9.35	46218
16	5912	5912	0.041	938	29	2	5	11	0.03	2.15	6.54	10.93	46033
18	5100	5100	0.041	913	57	4	11	23	0.04	2.37	7.60	12.83	45524
20	5786	5786	0.041	949	32	2	6	12	0.05	3.03	9.33	15.64	45902
24	5620	5620	0.041	854	40	3	7	15	0.06	4.22	12.63	21.04	46203

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-7. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 30000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket D.tllect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	9109	9066	0.050	4877	2	0	1	1	0.65	1.77	3.89	6.81	77133
2	11490	11430	0.050	5120	1	0	0	0	1.07	2.94	6.69	11.06	89766
2-1/2	9848	9800	0.050	3916	2	0	0	1	1.69	4.58	10.58	*	83922
3	6394	6350	0.050	2477	15	2	5	8	1.76	4.96	11.42	19.17	80607
4	8550	8500	0.050	3015	3	0	1	2	1.45	4.58	10.20	19.36	76171
6	7110	7110	0.050	2020	9	1	2	5	2.04	5.00	10.05	19.65	69882
8	4942	4942	0.050	1136	64	6	15	30	2.64	5.28	10.00	17.05	63250
10	8400	8400	0.049	1506	5	0	1	2	3.15	6.43	10.58	17.98	60091
12	6040	6040	0.050	988	25	2	5	10	1.95	5.67	9.39	15.56	55091
14	7275	7275	0.049	1101	10	1	2	4	2.38	6.87	11.35	19.07	55462
16	7095	7095	0.050	1126	11	1	2	4	2.78	8.05	13.32	22.21	55240
18	6120	6120	0.049	1096	22	2	4	9	3.24	9.52	15.80	25.71	54628
20	6943	6943	0.050	1138	12	1	2	5	3.97	11.54	19.10	31.65	55082
24	6744	6744	0.049	1024	15	1	3	6	5.37	15.46	25.54	42.91	55443

* Bolt Ultimate Strength Exceeded

Bolt Ultimate Strength = 82,500 psi (SA193 B8)

Bolt Yield Stress = 33,000 psi (SA193 B8)

DGmax = 0.050 in

Table 4-8. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 15%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	6453	6453	0.041	3412	4	1	2	3	0.32	0.65	0.97	1.49	54364
2	8139	8139	0.041	3508	1	0	0	1	0.47	0.95	1.42	2.33	56039
2-1/2	6976	6976	0.041	2556	4	0	1	2	0.64	1.28	1.92	3.21	56500
3	4529	4529	0.041	1760	35	5	11	20	0.84	1.71	2.62	4.44	57283
4	6057	6057	0.041	2141	8	1	2	4	0.64	1.67	3.09	4.25	54086
6	5036	5036	0.041	1431	22	2	6	11	0.06	1.51	0.36	4.40	49500
8	3501	3501	0.041	804	161	15	37	74	0.01	0.71	2.58	4.45	41802
10	5950	5950	0.040	1067	12	1	2	5	0.02	0.03	2.30	4.62	42565
12	4278	4278	0.041	700	64	5	12	25	0.02	0.04	0.99	3.62	39023
14	5153	5153	0.040	780	26	2	4	10	0.02	0.05	1.31	4.49	39285
16	5025	5025	0.040	697	28	2	5	11	0.03	0.06	1.46	5.19	39128
18	4335	4335	0.040	776	55	4	11	23	0.03	0.07	1.45	5.90	38695
20	4918	4918	0.040	806	31	2	6	12	0.04	0.08	2.01	7.36	39016
24	4777	4777	0.040	726	38	3	7	14	0.05	0.11	2.94	10.09	39272

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-9. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	5693	5693	0.040	3068	4	1	2	3	0.07	0.36	0.65	0.94	48529
2	7181	7181	0.040	3213	1	0	0	1	0.15	0.59	1.02	1.45	50680
2-1/2	6155	6155	0.040	2453	4	1	1	2	0.29	0.91	1.52	2.25	52580
3	3996	3996	0.041	1553	34	5	11	20	0.19	0.96	1.73	2.50	50544
4	5344	5344	0.040	1869	8	1	2	4	0.01	0.80	1.71	2.61	47723
6	4444	4444	0.040	1263	22	2	6	11	0.01	0.31	1.58	2.86	43676
8	3089	3089	0.040	710	157	14	36	73	0.01	0.02	0.83	2.48	39531
10	5250	5250	0.039	941	11	1	2	5	0.02	0.03	0.18	2.23	37557
12	3775	3775	0.040	618	62	4	11	24	0.02	0.03	0.05	1.91	34432
14	4547	4547	0.040	688	25	2	4	9	0.02	0.04	0.06	1.25	34663
16	4434	4434	0.040	704	28	2	5	11	0.02	0.05	0.07	1.36	34525
18	3825	3825	0.040	585	54	4	10	22	0.03	0.06	0.09	1.27	34143
20	4340	4340	0.040	711	30	2	5	12	0.04	0.07	0.11	1.85	34426
24	4215	4215	0.039	640	37	3	6	14	0.05	0.09	0.14	2.79	34652

Bolt Yield Stress = 33,000 psi (SA193 B7)

ΔG_{max} = 0.050 in

Table 4-10. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi
JOINT RELAXATION = 33%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (p⁻¹)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	5086	5086	0.040	2741	4	1	1	3	0.00	0.11	0.37	0.63	43352
2	6415	6415	0.039	2870	1	0	0	1	0.00	0.24	0.62	1.01	45274
2-1/2	5499	5499	0.039	2192	4	0	1	2	0.00	0.43	0.98	1.53	46972
3	3570	3570	0.040	1387	34	5	11	19	0.01	0.36	1.05	1.74	45152
4	4774	4774	0.040	1687	7	1	2	4	0.01	0.09	0.90	1.72	42632
6	3970	3970	0.039	1128	21	2	6	11	0.01	0.02	0.48	1.62	39017
8	2759	2759	0.040	634	153	14	35	71	0.01	0.02	0.03	0.90	35314
10	4690	4690	0.039	841	11	1	2	5	0.01	0.03	0.04	0.32	33551
12	3372	3372	0.040	552	61	4	11	24	0.02	0.03	0.05	0.06	30759
14	4062	4062	0.039	614	25	2	4	9	0.02	0.04	0.06	0.07	30966
16	3961	3961	0.039	529	27	2	5	10	0.02	0.04	0.07	0.09	30842
18	3417	3417	0.039	612	52	4	10	21	0.03	0.05	0.08	0.10	30501
20	3877	3877	0.039	636	29	2	5	11	0.03	0.06	0.09	0.13	30754
24	3765	3765	0.039	572	36	2	6	14	0.04	0.08	0.13	0.17	30956

Bolt Yield Stress = 33,000 psi (SA193-B8)
DGmax = 0.050 in

Table 4-11. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 50%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	3796	3796	0.038	2045	4	1	1	2	0.00	0.00	0.00	0.01	32352
2	4787	4787	0.037	2142	1	0	0	1	0.00	0.00	0.01	0.07	33787
2-1/2	4103	4103	0.038	1636	3	0	1	2	0.00	0.01	0.01	0.23	35053
3	2664	2664	0.039	1035	32	4	10	18	0.00	0.01	0.01	0.11	33696
4	3563	3563	0.038	1259	7	1	2	4	0.00	0.01	0.01	0.02	31815
6	2962	2962	0.038	842	20	2	5	10	0.01	0.01	0.02	0.03	29118
8	2059	2059	0.039	473	144	13	33	67	0.01	0.02	0.02	0.03	26354
10	3500	3500	0.038	628	10	1	2	4	0.01	0.02	0.03	0.04	25038
12	2517	2517	0.039	412	57	4	10	22	0.01	0.02	0.03	0.05	22955
14	3031	3031	0.038	459	23	2	4	9	0.01	0.03	0.04	0.06	23109
16	2956	2956	0.038	469	25	2	5	10	0.02	0.03	0.05	0.07	23017
18	2550	2550	0.039	457	49	4	10	20	0.02	0.04	0.06	0.08	22762
20	2893	2893	0.038	474	28	2	5	11	0.02	0.05	0.07	0.09	22951
24	2810	2810	0.038	427	34	2	6	13	0.03	0.06	0.09	0.12	23101

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-12. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	759	7591	0.042	726	3	0	0	0	0.07	0.14	0.21	0.28	32045
2	957	9575	0.042	745	1	0	0	0	0.10	0.20	0.30	0.40	32402
2-1/2	8207	8207	0.042	544	3	0	0	0	0.14	0.27	0.41	0.55	32500
3	8329	8329	0.042	382	26	1	2	3	0.19	0.38	0.57	0.76	32819
4	7125	7125	0.042	560	6	0	0	1	0.27	0.54	0.81	1.08	33598
6	5925	5925	0.041	549	18	1	2	2	0.55	1.11	1.66	2.22	35633
8	4118	4118	0.041	560	149	8	19	32	1.30	2.60	3.90	5.20	41389
10	7000	7000	0.041	1255	12	1	2	5	2.62	5.35	8.79	14.96	50076
12	5033	5033	0.041	824	66	5	12	26	1.63	4.73	7.32	12.94	45909
14	6062	6062	0.041	917	27	2	5	10	1.99	5.72	9.46	15.87	46218
16	5912	5912	0.041	938	29	2	5	11	2.32	6.71	11.10	18.47	46033
18	5100	5100	0.041	913	57	4	11	23	2.70	7.94	13.17	21.38	45524
20	5786	5786	0.041	949	32	2	6	12	3.31	9.62	15.92	27.33	45902
24	5620	5620	0.041	854	40	3	7	15	4.47	12.88	21.29	35.69	46203

Bolt Yield Stress = 27,500 psi (SA193-B8)

DGmax = 0.050 in

Table 4-13. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress ...i)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	14325	14325	0.033	6897	0	0	0	0	0.32	0.64	0.96	3.59	51310
2	15320	15320	0.034	5809	0	0	0	0	0.45	0.90	1.35	1.83	52118
2-1/2	19441	19441	0.033	5344	0	0	0	0	0.60	1.21	1.81	2.56	52697
3	12622	12622	0.033	4388	0	0	0	0	0.86	1.73	2.59	3.85	53635
4	8439	8439	0.033	3104	3	0	1	2	1.31	2.61	3.92	6.38	55807
6	7110	7110	0.036	2386	9	1	3	5	1.45	3.68	5.92	9.65	55029
8	6824	6824	0.033	1825	12	1	3	6	0.02	2.72	5.59	8.46	49082
10	9796	9796	0.033	2014	2	0	0	1	0.03	1.85	5.66	9.48	45923
12	9192	9192	0.033	1688	3	0	1	1	0.03	0.06	3.29	7.59	41208
14	10548	10548	0.033	1596	1	0	0	1	0.03	0.07	0.10	4.30	36974
16	9756	9756	0.032	1548	2	0	0	1	0.04	0.08	0.12	4.98	36827
18	8012	8012	0.034	1435	5	0	1	2	0.05	0.09	0.14	5.31	36419
20	7272	7272	0.034	1192	10	1	2	4	0.05	0.11	0.16	6.07	36721
24	8300	8300	0.035	1261	5	0	1	2	0.07	0.14	0.22	9.25	36962

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-14. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17906	17906	0.042	4245	0	0	0	0	0.20	0.39	0.59	0.79	44268
2	19150	19150	0.042	3575	0	0	0	0	0.28	0.55	0.83	1.10	44765
2-1/2	24301	24301	0.041	3904	0	0	0	0	0.37	0.74	1.12	1.49	45121
3	15778	15778	0.041	2700	0	0	0	0	0.53	1.06	1.60	2.13	45698
4	10549	10549	0.042	1910	1	0	0	0	0.80	1.61	2.41	3.22	47035
6	8887	8887	0.045	1756	3	0	0	1	1.64	3.29	4.93	6.57	50778
8	8530	8530	0.041	2024	4	0	1	2	3.18	6.36	9.54	16.31	57242
10	12245	12245	0.041	2517	1	0	0	0	3.51	8.28	13.05	22.97	57404
12	11490	11490	0.041	2109	1	0	0	0	0.85	6.24	11.61	16.99	51510
14	13185	13185	0.041	1995	0	0	0	0	0.04	2.82	8.42	14.02	46218
16	12195	12195	0.040	1935	1	0	0	0	0.05	3.27	9.94	16.62	46033
18	10015	10015	0.042	1793	2	0	0	1	0.06	3.51	11.26	19.01	45524
20	9090	9090	0.042	1490	3	0	1	1	0.07	4.39	13.52	22.65	45902
24	10375	10375	0.043	1576	2	0	0	1	0.09	6.07	18.15	30.24	46203

Bolt Yield Stress = 33,000 psi (SA193-B6)

DGmax = 0.050 in

Table 4-15. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 30000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	21487	21487	0.050	13850	0	0	0	0	1.83	5.64	*	*	92871
2	22979	22800	0.050	12652	0	0	0	0	3.62	9.78	*	*	99790
2-1/2	29161	29161	0.050	14393	0	0	0	0	5.99	14.65	*	*	104178
3	18933	18933	0.050	9024	0	0	0	0	5.71	16.93	*	*	99174
4	12659	12659	0.050	5425	0	0	0	0	5.67	17.56	*	*	92591
6	10665	9900	0.050	3464	2	0	0	1	4.07	12.06	28.09	48.53	79881
8	10236	10236	0.049	2738	1	0	0	1	4.30	12.19	24.80	50.26	73622
10	14694	14694	0.049	3021	0	0	0	0	5.72	12.74	25.83	50.51	68885
12	13788	13788	0.049	2531	0	0	0	0	6.45	12.89	22.77	38.39	61812
14	15822	15822	0.049	2394	0	0	0	0	3.58	10.30	17.02	28.61	55462
16	14634	14634	0.048	2322	0	0	0	0	4.23	12.24	20.25	33.76	55240
18	12018	11900	0.050	2152	1	0	0	0	4.80	14.11	23.41	38.09	54628
20	10908	10800	0.050	1788	1	0	0	0	5.75	16.71	27.67	45.84	55082
24	12450	12000	0.050	1891	1	0	0	0	7.71	22.22	36.72	61.68	55443

* Bolt Ultimate Strength Exceeded

Bolt Ultimate Strength = 82,500 psi (SA193-B8)

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-16. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 15%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	15220	15220	0.042	6234	0	0	0	0	0.29	0.58	0.87	1.16	49549
2	16277	16277	0.042	5251	0	0	0	0	0.41	0.81	1.22	1.62	50279
2-1/2	20656	20656	0.041	5734	0	0	0	0	0.55	1.09	1.64	2.19	50803
3	13411	13411	0.041	3966	0	0	0	0	0.78	1.56	2.34	3.13	51651
4	8967	8967	0.042	2805	1	0	0	0	1.18	2.36	3.54	5.25	53614
6	7554	7554	0.045	2536	3	0	1	2	2.30	4.67	7.16	1[illegible].32	58468
8	7251	7251	0.041	1939	4	0	1	2	0.92	3.97	7.02	10.29	52149
10	1040[a]	10408	0.041	2140	1	0	0	0	0.03	3.46	7.51	11.56	48794
12	9766	9766	0.041	1793	1	0	0	0	0.03	0.81	5.37	9.94	43783
14	11207	11207	0.041	1695	0	0	0	0	0.04	0.07	1.97	6.73	39285
16	10366	10366	0.040	1645	1	0	0	0	0.04	0.08	2.22	7.89	39128
18	8512	8512	0.042	1524	2	0	0	1	0.05	0.10	2.15	8.74	38695
20	7726	7726	0.042	1267	3	0	1	1	0.06	0.12	2.90	10.67	39016
24	8819	8819	0.043	1339	2	0	0	1	0.08	0.15	4.23	14.50	39272

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-17. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	13429	13429	0.042	7561	0	0	0	0	0.35	0.70	1.05	1.52	53070
2	14362	14362	0.042	6368	0	0	0	0	0.49	0.98	1.48	2.22	53956
2-1/2	18226	18226	0.041	6954	0	0	0	0	0.65	1.33	1.99	3.08	54591
3	11833	11833	0.041	4810	0	0	0	0	0.95	1.90	2.84	4.60	55619
4	7912	7912	0.042	3391	1	0	0	1	1.42	2.84	4.27	7.45	57870
6	6665	6665	0.045	2237	3	0	1	1	0.60	2.70	4.79	6.88	51590
8	6398	6398	0.041	1711	4	0	1	2	0.02	1.48	4.17	6.86	46014
10	9184	9184	0.041	1888	1	0	0	0	0.03	0.24	3.81	7.39	43053
12	8617	8617	0.041	1582	1	0	0	0	0.03	0.06	1.21	5.24	38632
14	9889	9889	0.041	1496	0	0	0	0	0.03	0.06	0.09	1.87	34663
16	9146	9146	0.040	1451	1	0	0	0	0.04	0.07	0.11	2.07	34525
18	7511	7511	0.042	1345	2	0	0	1	0.04	0.09	0.13	1.89	34143
20	6817	6817	0.042	1118	3	0	1	1	0.05	0.10	0.15	2.68	34426
24	7781	7781	0.043	1182	2	0	0	1	0.07	0.13	0.20	4.01	34652

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-18. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 33%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	11997	11997	0.042	7733	0	0	0	0	0.24	0.63	0.96	1.33	51853
2	12830	12830	0.042	7102	0	0	0	0	0.52	1.06	1.61	2.66	56014
2-1/2	16281	16281	0.041	7930	0	0	0	0	0.76	1.51	2.27	3.92	57621
3	10571	10571	0.041	5038	0	0	0	0	0.77	1.77	2.76	4.(	55372
4	7068	7068	0.042	3029	1	0	0	1	0.46	1.74	3.02	4.29	51697
6	5954	5954	0.045	1999	3	0	1	1	0.01	1.12	2.99	4.86	46087
8	5715	5715	0.041	1529	3	0	1	2	0.02	0.04	1.89	4.29	41106
10	8204	8204	0.041	1687	1	0	0	0	0.02	0.05	0.86	4.05	38461
12	7698	7698	0.041	1413	1	0	0	0	0.03	0.05	0.08	1.48	34511
14	8834	8834	0.041	1336	0	0	0	0	0.03	0.06	0.08	0.11	30966
16	8171	8171	0.040	1296	1	0	0	0	0.03	0.07	0.10	0.13	30842
18	6710	6710	0.042	1201	2	0	0	1	0.04	0.08	0.12	0.15	30501
20	6090	6090	0.042	998	3	0	1	1	0.05	0.09	0.14	0.18	30754
24	6951	6951	0.043	1056	1	0	0	1	0.06	0.12	0.18	0.24	30956

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-19. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 50%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leax Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	8953	8953	0.042	5771	0	0	0	0	0.00	0.00	0.14	0.40	38696
2	9575	9575	0.042	5300	0	0	0	0	0.00	0.01	0.42	0.83	41801
2-1/2	12150	12150	0.041	5997	0	0	0	0	0.00	0.14	0.71	1.29	43407
3	7889	7889	0.041	3760	0	0	0	0	0.01	0.01	0.67	1.41	41322
4	5275	5275	0.042	2261	1	0	0	1	0.01	0.01	0.35	1.30	38580
6	4444	4444	0.045	1492	2	0	1	1	0.01	0.02	0.03	0.55	34393
8	4265	4265	0.041	1141	3	0	1	2	0.01	0.03	0.04	0.05	30676
10	6122	6122	0.041	1259	1	0	0	0	0.02	0.04	0.05	0.07	28702
12	5745	5745	0.041	1055	1	0	0	0	0.02	0.04	0.06	0.08	25755
14	6592	6592	0.041	997	0	0	0	0	0.02	0.04	0.06	0.08	23109
16	6098	6098	0.040	967	1	0	0	0	0.02	0.05	0.07	0.10	23017
18	5007	5007	0.042	897	1	0	0	1	0.03	0.06	0.09	0.12	22762
20	4545	4545	0.042	745	3	0	0	1	0.03	0.07	0.10	0.14	22951
24	5188	5188	0.043	788	1	0	0	1	0.04	0.09	0.13	0.18	23101

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-20. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17906	17906	0.042	1326	0	0	0	0	0.06	0.12	0.18	0.25	31021
2	19150	19150	0.042	1117	0	0	0	0	0.09	0.17	0.26	0.35	31176
2-1/2	24301	24301	0.041	1220	0	0	0	0	0.12	0.23	0.35	0.47	31288
3	15778	15778	0.041	844	0	0	0	0	0.17	0.33	0.50	0.67	31468
4	10549	10549	0.042	597	1	0	0	0	0.25	0.50	0.75	1.01	31886
6	8887	8887	0.045	549	2	0	0	0	0.51	1.03	1.54	2.05	33056
8	8530	8530	0.041	632	3	0	0	0	0.99	1.99	2.98	3.97	35076
10	12245	12245	0.041	1003	1	0	0	0	1.90	3.80	5.70	7.60	37917
12	11490	11490	0.041	1729	1	0	0	0	4.40	8.81	13.21	21.74	46731
14	13185	13185	0.041	1995	0	0	0	0	2.98	8.58	14.18	23.86	46218
16	12195	12195	0.040	1935	1	0	0	0	3.52	10.20	16.87	28.16	46033
18	10015	10015	0.042	1793	2	0	0	1	4.00	11.76	19.51	31.78	45524
20	9090	9090	0.042	1490	3	0	1	1	4.79	13.93	23.06	38.24	45902
24	10375	10375	0.043	1576	2	0	0	1	6.43	18.51	30.60	51.45	46203

Bolt Yield Stress = 27,500 psi (SA193-B8)

DGmax = 0.050 in

Table 4-21. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	14325	14325	0.033	6897	0	0	0	0	0.36	0.73	1.09	4.07	51310
2	15320	15320	0.034	5809	0	0	0	0	0.53	1.07	1.60	2.18	52118
2-1/2	19441	19441	0.033	6344	0	0	0	0	0.71	1.41	2.12	2.98	52697
3	12622	12622	0.033	4388	0	0	0	0	0.99	1.99	2.98	4.42	53635
4	11653	11653	0.046	4286	1	0	0	0	1.48	2.97	4.45	7.25	55807
6	9817	9817	0.050	3295	2	0	0	1	1.68	4.27	6.86	11.20	55029
8	8953	8953	0.043	2395	3	0	1	1	0.03	3.21	6.59	9.97	49082
10	12783	12783	0.043	2628	1	0	0	0	0.03	2.13	6.55	10.96	45923
12	11624	11624	0.041	2134	1	0	0	0	0.04	0.07	3.78	8.71	41208
14	13339	13339	0.041	2018	0	0	0	0	0.04	0.08	0.11	4.90	36974
16	12036	12036	0.040	1910	1	0	0	0	0.04	0.09	0.13	5.64	36827
18	9884	9884	0.042	1770	2	0	0	1	0.05	0.10	0.16	5.98	36419
20	10851	10800	0.050	1779	1	0	0	0	0.06	0.12	0.18	7.47	36721
24	10575	10575	0.044	1606	1	0	0	1	0.08	0.16	0.24	10.26	36962

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-22. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17906	17906	0.042	4245	0	0	0	0	0.22	0.45	0.67	0.89	44268
2	19150	19150	0.042	3575	0	0	0	0	0.33	0.66	0.98	1.31	44765
2-1/2	24301	24301	0.041	3904	0	0	0	0	0.43	0.87	1.30	1.74	45121
3	15778	15778	0.041	2700	0	0	0	0	0.61	1.22	1.84	2.45	45698
4	14567	12700	0.050	5787	0	0	0	0	2.00	5.43	10.89	21.52	71524
6	12272	9900	0.050	3761	2	0	0	1	2.96	5.91	11.09	18.78	62804
8	11192	10350	0.050	2919	1	0	0	1	4.12	8.24	13.42	22.73	59830
10	15978	14850	0.050	3229	0	0	0	0	3.52	8.95	14.37	24.71	56431
12	14529	14100	0.050	2657	0	0	0	0	0.83	7.00	13.14	19.28	51312
14	16673	16200	0.050	2522	0	0	0	0	0.05	3.21	9.59	15.97	46218
16	15046	15046	0.050	2387	0	0	0	0	0.06	3.70	11.25	18.81	46033
18	12356	11900	0.050	2212	1	0	0	0	0.06	3.95	12.67	21.39	45524
20	13563	10800	0.050	2224	1	0	0	0	0.08	4.91	15.13	25.34	45902
24	13219	12000	0.050	2008	1	0	0	0	0.10	6.73	20.13	33.53	46203

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-23. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 30000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	21487	21487	0.050	13850	0	0	0	0	2.07	6.39	*	*	92871
2	22979	22800	0.050	12652	0	0	0	0	4.30	11.62	*	*	99790
2-1/2	29161	29161	0.050	14393	0	0	0	0	6.99	17.09	*	*	104178
3	18933	18933	0.050	9024	0	0	0	0	6.57	19.47	*	*	99174
4	17480	12700	0.050	6324	0	0	0	0	1.27	7.66	17.62	31.44	78159
6	14726	9900	0.050	4214	2	0	0	1	3.31	8.31	16.72	32.86	70371
8	13430	10350	0.050	3321	1	0	0	1	4.69	10.22	20.81	39.41	68051
10	19174	14850	0.050	3728	0	0	0	0	6.26	12.52	25.09	43.61	65157
12	17435	14100	0.050	3121	0	0	0	0	7.03	14.24	23.58	39.86	60274
14	20008	16200	0.050	3027	0	0	0	0	4.07	11.73	19.38	32.58	55462
16	18055	15100	0.050	2865	0	0	0	0	4.79	13.85	22.91	38.20	55240
18	14827	11900	0.050	2655	1	0	0	0	5.40	15.87	26.34	42.85	54628
20	16276	10800	0.050	2668	1	0	0	1	6.44	18.70	30.96	51.30	55082
24	15863	12000	0.050	2409	1	0	0	0	8.55	24.63	40.71	68.39	55443

* Bolt Ultimate Strength Exceeded

Bolt Ultimate Strength = 82,500 psi (SA193-B8)

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-24. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 15%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	15220	15220	0.042	6234	0	0	0	0	0.33	0.66	0.99	1.31	49546
2	16277	16277	0.042	5251	0	0	0	0	0.48	0.96	1.44	1.93	50279
2-1/2	20656	20656	0.041	5734	0	0	0	0	0.64	1.28	1.91	2.55	50803
3	13411	13411	0.041	3966	0	0	0	0	0.90	1.80	2.70	3.60	51651
4	14567	10795	0.050	5321	0	0	0	0	1.84	3.69	7.79	13.50	65772
6	12272	8415	0.050	3537	2	0	0	1	2.78	5.56	8.76	15.04	59058
8	11192	8798	0.050	2782	1	0	0	1	3.08	7.01	10.93	18.92	57021
10	15978	12623	0.050	3119	0	0	0	0	2.47	7.70	12.94	21.05	54511
12	14529	11985	0.050	2607	0	0	0	0	0.19	6.21	12.24	18.26	50337
14	16673	13770	0.050	2522	0	0	0	0	0.05	3.21	9.59	15.97	46218
16	15046	12789	0.050	2387	0	0	0	0	0.06	3.70	11.25	18.81	46033
18	12356	10115	0.050	2212	1	0	0	0	0.06	3.95	12.67	21.39	45524
20	13563	9180	0.050	2224	1	0	0	0	0.08	4.91	15.13	25.34	45902
24	13219	10200	0.050	2008	1	0	0	0	0.10	6.73	20.13	33.53	46203

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-25. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	13429	13429	0.042	7561	0	0	0	0	0.40	0.80	1.19	1.72	53070
2	14362	14362	0.042	6368	0	0	0	0	0.58	1.17	1.75	2.64	53956
2-1/2	18226	18226	0.041	6954	0	0	0	0	0.77	1.55	2.32	3.60	54591
3	11833	11833	0.041	4810	0	0	0	0	1.09	2.18	3.27	5.29	55619
4	14567	9525	0.050	5011	0	0	0	0	1.74	3.47	6.35	10.61	61937
6	12272	7425	0.050	3387	2	0	0	1	2.12	4.78	7.45	12.68	56561
8	11192	7763	0.050	2691	1	0	0	1	2.31	6.11	9.91	16.31	55149
10	15978	11138	0.050	3046	0	0	0	0	1.76	6.87	11.98	18.62	53230
12	14529	10575	0.050	2573	0	0	0	0	0.04	5.69	11.63	17.58	49687
14	16673	12150	0.050	2522	0	0	0	0	0.05	3.21	9.59	15.97	46218
16	15046	11284	0.050	2387	0	0	0	0	0.06	3.70	11.25	18.81	46033
18	12356	8925	0.050	2212	1	0	0	0	0.06	3.95	12.67	21.39	45524
20	13563	8100	0.050	2224	1	0	0	0	0.08	4.91	15.13	25.34	45902
24	13219	9000	0.050	2008	1	0	0	0	0.10	6.73	20.13	33.53	46203

Bolt Yield Stress = 33,000 psi (SA193-B8)

DGmax = 0.050 in

Table 4-26. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 33%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	11997	11997	0.042	7733	0	0	0	0	0.28	0.68	1.09	1.50	51853
2	12830	12830	0.042	7102	0	0	0	0	0.61	1.26	1.91	3.16	56014
2-1/2	16281	16281	0.041	7930	0	0	0	0	0.88	1.76	2.65	4.58	57621
3	10571	10571	0.041	5038	0	0	0	0	0.89	2.03	3.17	5.18	55372
4	14567	8509	0.050	4763	0	0	0	0	1.65	3.30	5.19	8.92	58870
6	12272	6633	0.050	3267	2	0	0	1	1.55	4.12	6.69	10.75	54564
8	11192	6935	0.050	2618	1	0	0	1	1.70	5.39	9.09	14.22	53651
10	15978	9950	0.050	2987	0	0	0	0	1.19	6.21	11.22	16.67	52206
12	14529	9447	0.050	2546	0	0	0	0	0.04	5.27	11.15	17.03	49167
14	16673	10854	0.050	2522	0	0	0	0	0.05	3.21	9.59	15.97	46218
16	15046	10081	0.050	2387	0	0	0	0	0.06	3.70	11.25	18.81	46033
18	12356	7973	0.050	2212	1	0	0	0	0.06	3.95	12.67	21.39	45524
20	13563	7236	0.050	2224	1	0	0	0	0.08	4.91	15.13	25.34	45902
24	13219	8040	0.050	2008	1	0	0	0	0.10	6.73	20.13	33.53	46203

Bolt Yield Stress = 33,000 psi (SA193 B8)

DGmax = 0.050 in

Table 4-27. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 50%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	8953	8953	0.042	5771	0	0	0	0	0.00	0.00	0.15	0.46	38696
2	9575	9575	0.042	5300	0	0	0	0	0.00	0.02	0.50	0.99	41801
2-1/2	12150	12150	0.041	5997	0	0	0	0	0.00	0.17	0.83	1.50	43407
3	7889	7889	0.041	3760	0	0	0	0	0.01	0.01	0.77	1.62	41322
4	14567	6350	0.050	4236	0	0	0	0	0.64	2.11	3.58	5.23	52351
6	12272	4950	0.050	3013	2	0	0	1	0.34	2.71	5.07	7.44	50318
8	11192	5175	0.050	2463	1	0	0	1	0.40	3.87	7.35	10.82	50468
10	15978	7425	0.050	2863	0	0	0	0	0.04	4.80	9.60	14.41	50029
12	14529	7050	0.050	2489	0	0	0	0	0.04	4.38	10.13	15.88	48063
14	16673	8100	0.050	2522	0	0	0	0	0.05	3.21	9.59	15.97	46218
16	15046	7523	0.050	2387	0	0	0	0	0.06	3.70	11.25	18.81	46033
18	12356	5950	0.050	2212	1	0	0	0	0.06	3.95	12.67	21.39	45524
20	13563	5400	0.050	2224	1	0	0	0	0.08	4.91	15.13	25.34	45902
24	13219	6000	0.050	2008	1	0	0	0	0.10	6.73	20.13	33.53	46203

Bolt Yield Stress = 33,000 psi (SA193-B8)

DCmax = 0.050 i.

Table 4-28. 400# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17906	17906	0.042	1326	0	0	0	0	0.07	0.14	0.21	0.28	31021
2	19150	19150	0.042	1117	0	0	0	0	0.10	0.20	0.31	0.41	31176
2-1/2	24301	24301	0.041	1220	0	0	0	0	0.14	0.27	0.41	0.54	31288
3	15778	15778	0.041	844	0	0	0	0	0.19	0.38	0.57	0.76	31468
4	14567	12700	0.050	5787	0	0	0	0	3.73	10.47	23.12	35.76	71524
6	12272	9900	0.050	3761	2	0	0	1	2.96	9.08	19.02	37.66	62804
8	11192	10350	0.050	2919	1	0	0	1	4.12	10.85	22.00	43.98	59830
10	15978	14850	0.050	3229	0	0	0	0	5.42	11.30	23.55	43.99	56431
12	14529	14100	0.050	2657	0	0	0	0	6.14	12.28	21.48	36.12	51312
14	16673	16200	0.050	2522	0	0	0	0	3.40	9.77	16.15	27.18	46218
16	15046	15046	0.050	2387	0	0	0	0	3.99	11.54	19.09	31.8[illegible]	46033
18	12356	11900	0.050	2212	1	0	0	0	4.50	13.23	21.95	35.75	45524
20	13563	10800	0.050	2224	1	0	0	0	5.37	15.58	25.80	42.79	45902
24	13219	12000	0.050	2008	1	0	0	0	7.13	20.53	33.93	57.04	46203

Bolt Yield Stress = 27,500 psi (SA193-B8)

DGmax = 0.050 in

Table 4-29. 600# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

BOLT RELAXATION = 10%

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq-in)	Leak Area at 1.50GLP (sq-in)	Leak Area at 1.75GLP (sq-in)	Leak Area at 2.0GLP (sq-in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17586	8625	0.050	7085	0	0	0	0	0.42	0.83	1.25	1.89	53809
2	18909	8625	0.050	6355	0	0	0	0	0.64	1.29	1.93	3.21	55914
2-1/2	24065	8625	0.050	7137	1	0	0	0	0.87	1.74	2.61	4.54	57158
3	16330	8625	0.050	4750	1	0	0	0	1.17	2.34	3.51	6.14	57338
4	12380	8625	0.050	4287	0	0	0	0	1.52	3.04	4.56	7.49	55591
6	14003	8625	0.050	4279	1	0	0	0	2.77	5.55	8.32	14.33	56875
8	13161	8625	0.050	3530	1	0	0	0	4.25	8.50	13.20	22.80	58050
10	16288	8625	0.050	4101	1	0	0	0	5.92	11.84	18.87	32.24	58569
12	15463	8625	0.050	3681	1	0	0	0	7.46	14.92	24.26	41.12	59001
14	18666	8625	0.050	3860	1	0	0	0	8.87	17.74	30.07	50.10	59986
16	17320	8625	0.050	3588	1	0	0	0	10.93	21.87	37.06	61.76	59974
18	16098	8625	0.050	3302	1	0	0	0	13.41	26.83	45.58	75.88	60039
20	17531	8625	0.050	3296	1	0	0	0	16.16	32.32	56.05	92.56	60577
24	19929	8625	0.050	3183	1	0	0	0	22.63	45.26	81.03	132.16	61469

Bolt Yield Stress = 33000 psi (SA193-B8 Class 1)

Kgasket = 230,000 psi/in

DGmax = 0.050 in

Table 4-30. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 15000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	4555	4555	0.025	2455	62	10	23	40	0.00	0.00	0.00	0.01	38823
2	5745	5745	0.025	2570	22	3	8	13	0.00	0.00	0.01	0.01	40544
2-1/2	4924	4924	0.025	1963	57	8	18	33	0.00	0.01	0.01	0.01	42064
3	3197	3197	0.025	1243	531	72	168	306	0.00	0.01	0.01	0.02	40435
4	4275	4275	0.025	1511	118	15	35	66	0.01	0.01	0.02	0.02	38178
6	3555	3555	0.025	1010	336	36	88	171	0.01	0.01	0.02	0.03	34941
8	2471	2471	0.025	568	2412	223	553	1118	0.01	0.02	0.03	0.04	31625
10	4200	4200	0.025	753	173	13	34	71	0.01	0.02	0.03	0.05	30046
12	3020	3020	0.025	494	960	69	176	375	0.01	0.03	0.04	0.05	27545
14	3637	3637	0.025	550	388	26	67	146	0.02	0.03	0.05	0.06	27731
16	3547	3547	0.025	563	424	30	76	163	0.02	0.04	0.06	0.07	27620
18	3060	3060	0.025	548	826	64	161	339	0.02	0.04	0.07	0.09	27314
20	3472	3472	0.025	569	461	33	85	181	0.03	0.05	0.08	0.11	27541
24	3372	3372	0.024	512	575	39	100	216	0.04	0.07	0.11	0.14	27722

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-31. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (In)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	6073	6073	0.034	3273	14	2	5	9	0.00	0.00	0.01	0.01	51764
2	7660	7660	0.034	3427	5	1	2	3	0.00	0.01	0.01	0.01	54059
2-1/2	6566	6566	0.033	2617	13	2	4	7	0.00	0.01	0.01	0.02	56085
3	4263	4263	0.034	1657	118	16	37	68	0.01	0.01	0.02	0.02	53913
4	5700	5700	0.034	2015	26	3	8	15	0.01	0.01	0.02	0.03	50904
6	4740	4740	0.033	1347	74	8	20	38	0.01	0.02	0.03	0.04	46588
8	3295	3295	0.033	757	535	49	123	248	0.01	0.02	0.04	0.05	42167
10	5600	5600	0.033	1004	38	3	7	16	0.02	0.03	0.05	0.06	40061
12	4027	4027	0.033	659	213	15	39	83	0.02	0.04	0.05	0.07	36727
14	4850	4850	0.033	734	86	6	15	32	0.02	0.04	0.06	0.08	36974
16	4730	4730	0.033	750	94	7	17	36	0.02	0.05	0.07	0.10	36827
18	4080	4080	0.033	731	183	14	36	75	0.03	0.06	0.09	0.12	36419
20	4629	4629	0.033	759	102	7	19	40	0.04	0.07	0.11	0.14	36721
24	4496	4496	0.033	683	127	9	22	48	0.05	0.10	0.14	0.19	36962

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-32. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	7591	7591	0.042	4091	4	1	2	3	0.00	0.01	0.01	0.01	64705
2	9575	9575	0.042	4284	2	0	1	1	0.00	0.01	0.01	0.02	67574
2-1/2	8207	8207	0.042	3271	4	1	1	2	0.01	0.01	0.02	0.02	70107
3	5329	5329	0.042	2071	37	5	12	21	0.01	0.01	0.02	0.03	67392
4	7125	7125	0.042	2518	8	1	2	5	0.01	0.02	0.03	0.03	63630
6	5925	5925	0.041	1684	23	2	6	12	0.01	0.02	0.04	0.05	58235
8	4118	4118	0.041	946	166	15	38	77	0.02	0.03	0.05	0.06	52708
10	7000	7000	0.041	1255	12	1	2	5	0.02	0.04	0.06	0.08	50076
12	5033	5033	0.041	824	66	5	12	26	0.02	0.04	0.07	0.09	45909
14	6062	6062	0.041	917	27	2	5	10	0.03	0.05	0.08	0.11	46218
16	5912	5912	0.041	938	29	2	5	11	0.03	0.06	0.09	0.12	46033
18	5100	5100	0.041	913	57	4	11	23	0.04	0.07	0.11	0.15	45524
20	5786	5786	0.041	949	32	2	6	12	0.04	0.09	0.13	0.18	45902
24	5620	5620	0.041	854	40	3	7	15	0.06	0.12	0.18	0.24	46203

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-33. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 30000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	9109	9000	0.050	4877	2	0	1	1	0.00	0.01	0.01	0.01	77133
2	11490	11400	0.050	5120	1	0	0	0	0.00	0.01	0.01	0.02	80766
2-1/2	9848	9800	0.050	3916	2	0	0	1	0.01	0.01	0.02	0.03	83922
3	6394	6350	0.050	2477	15	2	5	8	0.01	0.02	0.03	0.03	80607
4	8550	8500	0.050	3015	3	0	1	2	0.01	0.02	0.03	0.04	76171
6	7110	7100	0.050	2020	9	1	2	5	0.01	0.03	0.04	0.06	69882
8	4942	4942	0.050	1136	64	6	15	30	0.02	0.04	0.06	0.07	63250
10	8400	8400	0.049	1506	5	0	1	2	0.02	0.05	0.07	0.09	60091
12	6040	6040	0.050	988	25	2	5	10	0.03	0.05	0.08	0.11	55091
14	7275	7275	0.049	1101	10	1	2	4	0.03	0.06	0.10	0.13	55462
16	7095	7095	0.050	1126	11	1	2	4	0.04	0.07	0.11	0.15	55240
18	6120	6120	0.049	1096	22	2	4	9	0.04	0.09	0.13	0.18	54628
20	6943	6943	0.050	1138	12	1	2	5	0.05	0.11	0.16	0.21	55082
24	6744	6744	0.049	1024	15	1	3	6	0.07	0.14	0.21	0.29	55443

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-34. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	10628	9000	0.050	5245	2	0	1	1	0.00	0.01	0.01	0.01	82956
2	13405	11400	0.050	5540	1	0	0	0	0.01	0.01	0.02	0.02	97388
2-1/2	11490	9800	0.050	4243	2	0	1	1	0.01	0.02	0.02	0.03	90932
3	7460	6350	0.050	2696	15	2	5	[illegible]	0.01	0.02	0.03	0.04	87750
4	9976	8500	0.050	3312	3	0	1	2	0.01	0.02	0.03	0.05	83680
6	8295	7150	0.050	2259	9	1	2	5	0.02	0.03	0.05	0.06	78154
8	5766	4965	0.050	1292	64	6	16	31	0.02	0.04	0.06	0.08	71947
10	9799	8500	0.050	1734	4	0	1	2	0.03	0.05	0.08	0.11	69177
12	7047	6100	0.050	1153	25	2	5	11	0.03	0.06	0.09	0.12	64273
14	8487	7350	0.050	1284	10	1	2	4	0.04	0.07	0.11	0.15	64705
16	8277	7150	0.050	1313	11	1	2	5	0.04	0.09	0.13	0.17	64447
18	7140	6200	0.050	1278	21	2	[illegible]	9	0.05	0.10	0.16	0.21	63733
20	8100	7000	0.050	1328	12	1	2	5	0.06	0.12	0.19	0.25	64262
24	7868	6900	0.050	1195	14	1	3	6	0.08	0.17	0.25	0.33	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-35. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 40000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	12146	9000	0.050	5613	2	0	1	1	0.00	0.01	0.01	0.02	88780
2	15320	11400	0.050	5959	1	0	0	0	0.01	0.01	0.02	0.02	94010
2-1/2	13131	9800	0.050	4570	2	0	1	1	0.01	0.02	0.02	0.03	97943
3	8526	6350	0.050	2916	15	2	5	9	0.01	0.02	0.03	0.04	94894
4	11401	8500	0.050	3509	3	0	1	2	0.01	0.02	0.04	0.05	91188
6	9480	7150	0.050	2495	9	1	3	5	0.02	0.04	0.05	0.07	86307
8	6589	4965	0.050	1447	66	7	17	34	0.02	0.05	0.07	0.10	80591
10	11199	8500	0.050	1960	5	0	1	2	0.03	0.06	0.09	0.12	78190
12	8053	6100	0.050	1318	26	2	6	12	0.04	0.07	0.11	0.14	73455
14	9700	7350	0.050	1467	10	1	2	4	0.04	0.08	0.13	0.17	73940
16	9460	7150	0.050	1501	11	1	2	5	0.05	0.10	0.15	0.20	73653
18	8160	6200	0.050	1461	22	2	5	10	0.06	0.12	0.18	0.24	72838
20	9258	7000	0.050	1518	12	1	3	6	0.07	0.14	0.21	0.29	73443
24	8992	6900	0.050	1366	14	1	3	6	0.10	0.19	0.29	0.38	73924

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-36. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 50000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	15182	9000	0.050	6349	2	0	1	1	0.00	0.01	0.01	0.02	100427
2	19150	11400	0.050	6799	1	0	0	0	0.01	0.01	0.02	0.03	107255
2-1/2	16414	9800	0.050	5224	2	0	1	1	0.01	0.02	0.03	0.04	111964
3	10657	6350	0.050	3355	16	3	6	10	0.01	0.02	0.04	0.05	109181
4	14251	8500	0.050	4203	3	1	1	2	0.01	0.03	0.04	0.06	106205
6	11849	7150	0.050	2967	9	1	3	6	0.02	0.04	0.06	0.08	102613
8	8237	4965	0.050	175-	68	9	20	38	0.03	0.06	0.00	0.12	97880
10	13999	8500	0.050	2412	5	1	1	2	0.04	0.07	0.11	0.15	96218
12	10067	6100	0.050	1647	27	3	7	13	0.04	0.09	0.13	0.18	91818
14	12125	7350	0.050	1834	11	1	3	5	0.05	0.11	0.16	0.21	92436
16	11824	7150	0.050	1876	12	1	3	6	0.06	0.12	0.19	0.25	92067
18	10200	6200	0.050	1826	23	3	6	12	0.07	0.15	0.22	0.30	91047
20	11572	7000	0.050	1897	13	1	3	7	0.09	0.18	0.27	0.36	91803
24	11239	6900	0.050	1707	15	1	4	7	0.12	0.24	0.36	0.48	92406

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-37. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 15%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	6453	6453	0.041	3477	4	1	2	3	0.00	0.00	0.01	0.01	54999
2	8139	8139	0.041	3641	1	0	1	1	0.00	0.01	0.01	.01	57438
2-1/2	6976	6976	0.041	2780	4	1	1	2	0.00	0.01	0.01	0.02	59591
3	4529	4529	0.041	1760	35	5	11	20	0.01	0.01	0.02	0.02	57283
4	6057	6057	0.041	2141	8	1	2	4	0.01	0.01	0.02	0.03	54086
6	5036	5036	0.041	1431	22	2	6	11	0.01	0.02	0.03	0.04	49500
8	3501	3501	0.041	804	161	15	37	74	0.01	0.03	0.04	0.05	44802
10	5950	5950	0.040	1067	12	1	2	5	0.02	0.03	0.05	0.07	42565
12	4278	4278	0.041	700	64	5	12	25	0.02	0.04	0.06	0.07	39023
14	5153	5153	0.040	780	26	2	4	10	0.02	0.04	0.07	0.09	39285
16	5025	5025	0.040	797	28	2	5	11	0.03	0.05	0.08	0.11	39128
18	4335	4335	0.040	776	55	4	11	23	0.03	0.06	0.09	0.13	38695
20	4918	4918	0.040	806	31	2	6	12	0.04	0.08	0.11	0.15	39016
24	4777	4777	0.040	726	38	3	7	14	0.05	0.10	0.15	0.20	39272

Bolt Yield Stress = 111,700 psi (SA193-87)

DGmax = 0.050 in

Table 4-38. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	5693	5693	0.040	3068	4	1	2	3	0.00	0.00	0.01	0.01	48529
2	7181	7181	0.040	3213	1	0	0	1	0.00	0.01	0.01	0.01	50680
2-1/2	6155	6155	0.040	2453	4	1	1	2	0.00	0.01	0.01	0.02	52580
3	3996	3996	0.041	1553	34	5	11	20	0.01	0.01	0.02	0.02	50544
4	5344	5344	0.040	1889	8	1	2	4	0.01	0.01	0.02	0.03	47723
6	4444	4444	0.040	1263	22	2	5	11	0.01	0.02	0.03	0.04	43676
8	3089	3089	0.040	710	157	14	36	73	0.01	0.02	0.03	0.05	39531
10	5250	5250	0.039	941	11	1	2	5	0.01	0.03	0.04	0.06	37557
12	3775	3775	0.040	618	62	4	11	24	0.02	0.03	0.05	0.07	34432
14	4547	4547	0.040	688	25	2	4	9	0.02	0.04	0.06	0.08	34663
16	4434	4434	0.040	704	28	2	5	11	0.02	0.05	0.07	0.09	34525
18	3825	3825	0.040	685	54	4	10	22	0.03	0.06	0.08	0.11	34143
20	4340	4340	0.040	711	30	2	5	12	0.03	0.07	0.10	0.13	34426
24	4215	4215	0.039	640	37	3	6	14	0.04	0.09	0.13	0.18	34652

Bolt Yield Stress = 111,700 psi (SA193 '37)

DGmax = 0.050 in

Table 4-39. 150# Flange Gasket Stress, Gross Leak Pressure and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 33%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	5086	5086	0.040	2741	4	1	1	3	0.00	0.00	0.01	0.01	43352
2	6415	6415	0.039	2870	1	0	0	1	0.00	0.01	0.01	0.01	45274
2-1/2	5499	5499	0.039	2192	4	0	1	2	0.00	0.01	0.01	0.02	46972
3	3570	3570	0.040	1387	34	5	11	19	0.00	0.01	0.01	0.02	45152
4	4774	4774	0.040	1687	7	1	2	4	0.01	0.01	0.02	0.02	42632
6	3970	3970	0.039	1128	21	2	6	11	0.01	0.02	0.02	0.03	39017
8	2759	2759	0.040	634	153	14	35	71	0.01	0.02	0.03	0.04	35314
10	4690	4690	0.039	841	11	1	2	5	0.01	0.03	0.04	0.05	33551
12	3372	3372	0.040	552	61	4	11	24	0.01	0.03	0.04	0.06	30759
14	4062	4062	0.039	614	25	2	4	9	0.02	0.04	0.05	0.07	30966
16	3961	3961	0.039	629	27	2	5	10	0.02	0.04	0.06	0.08	30842
18	3417	3417	0.039	612	52	4	10	21	0.02	0.05	0.07	0.10	30501
20	3877	3877	0.039	636	29	2	5	11	0.03	0.06	0.09	0.12	30754
24	3765	3765	0.039	572	36	2	6	14	0.04	0.08	0.12	0.16	30956

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-40. 150# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 50%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	3796	3796	0.038	2045	4	1	1	2	0.00	0.00	0.00	0.01	32352
2	4787	4787	0.037	2142	1	0	0	1	0.00	0.00	0.01	0.01	33787
2-1/2	4103	4103	0.038	1636	3	0	1	2	0.00	0.01	0.01	0.01	35053
3	2664	2664	0.039	1035	32	4	10	18	0.00	0.01	0.01	0.01	33696
4	3563	3563	0.038	1259	7	1	2	4	0.00	0.01	0.01	0.02	31815
6	2962	2962	0.038	842	20	2	5	10	0.01	0.01	0.02	0.02	29118
8	2059	2059	0.039	473	144	13	33	67	0.01	0.02	0.02	0.03	26354
10	3500	3500	0.038	628	10	1	2	4	0.01	0.02	0.03	0.04	25038
12	2517	2517	0.039	412	57	4	10	22	0.01	0.02	0.03	0.04	22955
14	3031	3031	0.038	459	23	2	4	9	0.01	0.03	0.04	0.05	23109
16	2956	2956	0.038	469	25	2	5	10	0.02	0.03	0.05	0.06	23017
18	2550	2550	0.039	457	49	4	10	20	0.02	0.04	0.06	0.07	22762
20	2893	2893	0.038	474	28	2	5	11	0.02	0.04	0.07	0.09	22951
24	2810	2810	0.038	427	34	2	6	13	0.03	0.06	0.09	0.12	23101

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-41. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	14325	9000	0.050	6797	2	0	1	1	0.00	0.00	0.01	0.01	45574
2	15320	11400	0.050	7004	1	0	0	0	0.00	0.01	0.01	0.02	55246
2-1/2	19441	9800	0.050	5455	2	0	-	1	0.00	0.01	0.01	0.02	46721
3	12622	6350	0.050	4132	16	3	6	9	0.01	0.01	0.02	0.02	45418
4	8439	8439	0.050	3617	3	0	1	1	0.01	0.02	0.03	0.04	61728
6	7110	7110	0.050	2386	9	1	2	3	0.02	0.03	0.05	0.06	55029
8	6824	4965	0.050	1661	68	7	14	21	0.02	0.04	0.06	0.07	44669
10	9796	8500	0.050	1950	5	0	1	1	0.03	0.05	0.08	0.10	44465
12	9192	6100	0.050	1614	27	2	5	7	0.03	0.06	0.09	0.12	39406
14	10548	7350	0.050	1596	11	1	2	2	0.03	0.06	0.10	0.13	36974
16	9756	7150	0.050	1548	12	1	2	3	0.04	0.08	0.1*	0.15	36827
18	8012	6200	0.050	1435	22	2	3	5	0.04	0.09	0.1_	0.18	36419
20	7272	7000	0.050	1192	12	1	1	2	0.05	0.10	0.15	0.21	36721
24	8300	6900	0.050	1261	14	1	2	3	0.07	0.14	0.21	0.27	36962

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-42. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 25000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	17906	9000	0.050	7466	2	0	1	1	0.00	0.00	0.01	0.01	50953
2	19150	11400	0.050	7683	1	0	0	0	0.00	0.01	0.01	0.02	60596
2-1/2	24301	9800	0.050	7270	2	0	1	1	0.00	0.01	0.01	0.02	52624
3	15778	6350	0.050	4689	17	3	7	10	0.01	0.01	0.02	0.03	51533
4	10549	8500	0.050	4020	3	0	-	1	0.01	0.02	0.04	0.05	68616
6	8887	7150	0.050	2721	9	1	2	3	0.02	0.04	0.05	0.07	62736
8	8530	4965	0.050	1967	70	8	17	25	0.02	0.04	0.07	0.09	52890
10	12245	8500	0.050	2332	5	0	1	1	0.03	0.06	0.09	0.12	53191
12	11490	6100	0.050	1981	28	4	6	9	0.04	0.07	0.11	0.14	48368
14	13185	7350	0.050	1995	11	1	2	3	0.04	0.08	0.12	0.16	46218
16	12195	7150	0.050	1935	12	1	2	3	0.05	0.09	0.14	0.19	46033
18	10015	6200	0.050	1793	23	2	4	6	0.05	0.11	0.16	0.22	45524
20	9090	7000	0.050	1490	12	1	2	3	0.06	0.13	0.19	0.26	45902
24	10375	6900	0.050	1576	15	1	2	3	0.09	0.17	0.26	0.34	46203

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-43. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 30000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	21487	9000	0.050	8135	2	0	1	1	0.00	0.01	0.01	0.01	54552
2	22979	11400	0.050	8361	1	0	0	0	0.00	0.01	0.01	0.02	65947
2-1/2	29161	9800	0.050	8086	2	0	1	1	0.01	0.01	0.02	0.02	58527
3	18933	6350	0.050	5245	17	4	7	11	0.01	0.01	0.02	0.03	57649
4	12659	8500	0.050	4409	3	1	1	2	0.01	0.03	0.04	0.05	75252
6	10665	7150	0.050	3049	9	1	2	4	0.02	0.04	0.06	08	70303
8	10236	4965	0.050	2273	72	10	19	29	0.03	0.05	0.08	0.10	61112
10	14694	8500	0.050	2715	5	0	1	1	0.04	0.07	0.11	0.15	61916
12	13788	6100	0.05 /	2348	29	3	7	10	0.04	0.08	0.13	0.17	57331
14	15822	7350	0.050	2394	11	1	2	4	0.05	0.10	0.14	0.19	55462
16	14634	7150	0.050	2322	13	1	3	4	0.06	0.11	0.17	0.23	55240
18	12018	6200	0.050	2152	24	3	5	8	0.07	0.13	0.20	0.26	54628
20	10908	7000	0.050	1788	13	1	2	3	0.08	0.15	0.23	0.31	55082
24	12450	6900	0.050	1891	15	1	3	4	0.10	0.21	0.31	0.41	55443

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-44. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	9000	0.050	8805	2	0	1	1	0.00	0.01	[illegible]	0.01	59041
2	26809	11400	0.050	9039	1	0	0	0	0.00	0.01	[illegible]	0.02	71297
2-1/2	34021	9800	0.050	8902	2	0	1	1	0.01	0.01	0.02	0.02	64431
3	22085	6350	0.050	5802	17	4	8	12	0.01	0.02	0.02	0.03	63765
4	14769	8500	0.050	4798	4	1	1	2	0.01	0.03	0.04	0.06	81888
6	12442	7150	0.050	3377	10	1	3	4	0.02	0.04	0.07	0.09	77869
8	11942	4965	0.050	2579	74	11	22	33	0.03	0.06	0.09	0.11	69333
10	17143	8500	0.050	3098	5	1	1	2	0.04	0.08	0.12	0.17	70642
12	16086	6100	0.050	2715	30	4	8	12	0.05	0.10	0.15	0.20	66294
14	18459	7350	0.050	2792	12	1	3	4	0.06	0.11	0.17	0.22	64705
16	17073	7150	0.050	2709	13	2	3	5	0.07	0.13	0.20	0.26	64447
18	14021	6200	0.050	2510	24	3	6	9	0.08	0.15	0.23	0.31	63733
20	12726	7000	0.050	2086	13	1	3	4	0.09	0.18	0.27	0.36	64262
24	14525	6900	0.050	2206	16	2	3	5	0.12	0.24	0.36	0.48	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-45. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 40000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	28649	9000	0.050	9474	2	1	1	2	0.00	0.01	0.01	0.01	63529
2	30639	11400	0.050	9718	1	0	0	0	0.01	0.01	0.02	0.02	76648
2-1/2	38881	9800	0.050	9717	2	0	1	1	0.01	0.01	0.02	0.03	70334
3	25245	6350	0.050	6358	18	4	9	13	0.01	0.02	0.03	0.04	69881
4	16879	8500	0.050	5187	4	1	1	2	0.02	0.03	0.05	0.06	88523
6	14219	7150	0.050	3705	10	1	3	4	0.02	0.05	0.07	0.10	85436
8	13648	4965	0.050	2884	76	12	25	37	0.03	0.06	0.10	0.13	77554
10	19592	8500	0.050	3480	5	1	1	2	0.05	0.09	0.14	0.19	79367
12	18384	6100	0.050	3082	31	4	9	13	0.06	0.11	0.17	0.22	75257
14	21096	7350	0.050	3191	12	2	3	5	0.06	0.13	0.19	0.25	73949
16	19512	7150	0.050	3096	13	2	3	5	0.08	0.15	0.23	0.30	73653
18	16023	6200	0.050	2869	25	3	7	10	0.09	0.18	0.26	0.35	72838
20	14544	7000	0.050	2384	14	1	3	4	0.10	0.21	0.31	0.41	73443
24	16600	6900	0.050	2521	16	2	4	5	0.14	0.27	0.41	0.55	73924

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-46. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 50000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	35812	9000	0.050	10813	2	1	1	2	0.00	0.01	0.01	0.01	72507
2	38299	11400	0.050	11074	1	0	0	1	0.01	0.01	0.02	0.02	87349
2-1/2	48601	9800	0.050	11348	2	1	1	2	0.01	0.02	0.02	0.03	82141
3	31556	6350	0.050	7471	18	5	10	16	0.01	0.02	0.03	0.04	82112
4	21098	8500	0.050	5965	4	1	1	2	0.02	0.04	0.05	0.07	101795
6	17774	7150	0.050	4361	10	2	3	5	0.03	0.06	0.09	0.12	100569
8	17060	4965	0.050	3496	79	15	30	45	0.04	0.08	0.12	0.16	93996
10	24489	8500	0.050	4246	5	1	2	2	0.06	0.11	0.17	0.23	96818
12	22979	6100	0.050	3816	32	6	11	17	0.07	0.14	0.21	0.27	93182
14	26370	7350	0.050	3989	13	2	4	6	0.08	0.16	0.24	0.32	92436
16	24390	7150	0.050	3870	14	2	4	6	0.09	0.19	0.28	0.38	92067
18	20029	6200	0.050	3586	26	4	8	13	0.11	0.22	0.33	0.44	91047
20	18180	7000	0.050	2980	14	2	4	5	0.13	0.26	0.39	0.52	91803
24	20751	6900	0.050	3152	17	2	5	7	0.17	0.34	0.51	0.68	92406

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-47. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 60000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	42974	9000	0.050	12152	2	1	1	2	0.00	0.01	0.01	0.02	81484
2	45959	11400	0.050	12431	1	0	0	1	0.01	0.01	0.02	0.03	98050
2-1/2	58322	9800	0.050	12979	2	1	1	2	0.01	0.02	0.03	0.03	93918
3	37867	6350	0.050	8584	19	6	12	18	0.01	0.02	0.04	0.05	94343
4	25318	8500	0.050	6742	4	1	2	2	0.02	0.04	0.06	0.81	115066
6	21329	7150	0.050	5018	10	2	4	6	0.03	0.07	0.10	1.53	115702
8	20472	4965	0.050	4107	82	18	35	53	0.05	0.09	0.14	0.18	110439
10	29387	8500	0.050	5011	6	1	2	3	0.07	0.13	0.20	2.04	114269
12	27575	6100	0.050	4550	33	7	13	20	0.08	0.16	0.25	0.33	111107
14	31644	7350	0.050	4787	13	2	5	7	0.10	0.19	0.29	0.38	110923
16	29268	7150	0.050	4644	15	3	5	8	0.11	0.23	0.34	0.45	110480
18	24035	6200	0.050	4304	27	5	10	15	0.13	0.26	0.39	0.53	109257
20	21816	7000	0.050	3576	15	2	4	7	0.15	0.31	0.46	0.62	110164
24	24901	6900	0.050	3782	18	3	5	8	0.21	0.41	0.62	0.82	110887

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-48. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 15%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	7650	0.050	8187	2	1	1	2	0.00	0.01	0.01	0.01	56236
2	26809	9690	0.050	8396	1	0	0	0	0.00	0.01	0.04	0.02	67739
2-1/2	34021	8330	0.050	8423	2	0	1	1	0.01	0.01	0.03	0.02	61963
3	22089	5398	0.050	5516	17	4	9	13	0.01	0.02	0.03	0.03	61572
4	14769	7225	0.050	4487	4	1	1	2	0.01	0.03	0.09	0.05	78294
6	12442	6078	0.050	3215	10	1	3	4	0.02	0.04	0.14	0.09	75491
8	11942	4220	0.050	2513	74	12	24	37	0.03	0.06	0.14	0.11	68285
10	17143	7225	0.050	3035	5	1	1	2	0.04	0.08	0.28	0.16	69832
12	16086	5185	0.050	2693	30	4	9	13	0.05	0.10	0.26	0.19	66019
14	18459	6248	0.050	2792	12	2	3	5	0.06	0.11	0.33	0.22	64705
16	17073	6078	0.050	2709	13	2	3	5	0.07	0.13	0.38	0.26	64447
18	14021	5270	0.050	2510	24	3	7	10	0.08	0.15	0.40	0.31	63733
20	12726	5950	0.050	2086	13	1	3	4	0.09	0.18	0.52	0.36	64262
24	14525	5865	0.050	2206	16	2	4	5	0.12	0.24	0.64	0.48	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-49. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 25%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	6750	0.050	7775	2	1	1	2	0.00	0.01	0.01	0.01	54366
2	26809	8550	0.050	7957	1	0	0	0	0.00	0.01	0.01	0.02	65367
2-1/2	34021	7350	0.050	8103	2	0	1	1	0.01	0.01	0.02	0.02	60318
3	22089	4763	0.050	5325	17	5	9	11	0.01	0.01	0.02	0.03	60111
4	14769	6375	0.050	4279	3	1	1	2	0.01	0.03	0.04	0.05	75899
6	12442	5363	0.050	3107	9	2	3	5	0.02	0.04	0.06	0.08	73906
8	11942	3724	0.050	2469	73	13	19	36	0.03	0.05	0.08	0.11	67587
10	17143	6375	0.050	2993	5	1	1	2	0.04	0.08	0.12	0.16	69292
12	16086	4575	0.050	2679	30	5	10	12	0.05	0.10	0.14	0.19	65836
14	18459	5513	0.050	2792	12	2	3	4	0.06	0.11	0.17	0.22	64705
16	17073	5363	0.050	2709	13	2	4	5	0.07	0.13	0.20	0.26	64447
18	14021	4650	0.050	2510	24	4	7	10	0.08	0.15	0.23	0.31	63733
20	12726	5250	0.050	2086	13	2	2	5	0.09	0.18	0.27	0.36	64262
24	14525	5175	0.050	2206	16	2	3	6	0.12	0.24	0.36	0.48	64684

Bolt Yield Stress = 111,700 psi (SA193 B7)

DGmax = 0.050 in

Table 4-50. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 33%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	6030	0.050	7446	2	1	1	2	0.00	0.00	0.01	0.01	52870
2	26809	7638	0.050	7623	1	0	0	1	0.00	0.01	0.01	0.02	63469
2-1/2	34021	6566	0.050	7848	2	1	1	2	0.01	0.01	0.01	0.02	59001
3	22089	4255	0.050	5173	17	5	10	15	0.01	0.01	0.02	0.03	58942
4	14769	5695	0.050	4113	3	1	1	2	0.01	0.02	0.03	0.05	73982
6	12442	4791	0.050	3020	9	2	3	5	0.02	0.04	0.05	0.08	72638
8	11942	3327	0.050	2434	73	14	29	43	0.03	0.05	0.07	0.11	67028
10	17143	5695	0.050	2959	5	1	1	2	0.04	0.08	0.11	0.16	68860
12	16086	4087	0.050	2667	30	5	11	16	0.05	0.10	0.13	0.19	65690
14	18459	4925	0.050	2792	12	2	4	6	0.06	0.11	0.15	0.22	64705
16	17073	4791	0.050	2709	13	2	4	6	0.07	0.13	0.18	0.26	64447
18	14021	4154	0.050	2510	24	4	8	12	0.08	0.15	0.21	0.31	63733
20	12726	4690	0.050	2086	13	2	4	5	0.09	0.18	0.24	0.36	64262
24	14525	4623	0.050	2206	16	2	4	7	0.12	0.24	0.32	0.48	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-51. 300# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 50%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	6030	0.050	7446	2	1	1	2	0.00	0.00	0.01	0.01	52870
2	26809	7638	0.050	7623	1	0	0	1	0.00	0.01	0.01	0.02	63469
2-1/2	34021	6566	0.050	7848	2	1	1	2	0.01	0.01	0.01	0.02	59001
3	22089	4255	0.050	5173	17	5	10	15	0.01	0.01	0.02	0.03	58942
4	14769	5695	0.050	4113	3	1	1	2	0.01	0.02	0.03	0.05	73982
6	12442	4791	0.050	3020	9	2	3	5	0.02	0.04	0.05	0.08	72638
8	11942	3327	0.050	2434	73	14	29	43	0.03	0.05	0.07	0.11	67028
10	17143	5695	0.050	2959	5	1	1	2	0.04	0.08	0.11	0.16	68860
12	16086	4087	0.050	2667	30	5	11	16	0.05	0.10	0.13	0.19	65690
14	18459	4925	0.050	2792	12	2	4	6	0.06	0.11	0.15	0.22	64705
16	17073	4791	0.050	2709	13	2	4	6	0.07	0.13	0.18	0.26	64447
18	14021	4154	0.050	2510	24	4	8	12	0.08	0.15	0.21	0.31	63733
20	12726	4690	0.050	2086	13	2	4	5	0.09	0.18	0.24	0.36	64262
24	14525	4623	0.050	2206	16	2	4	7	0.12	0.24	0.32	0.48	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-52. 600# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 20000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	14325	9000	0.050	7554	2	0	1	1	0.00	0.01	0.01	0.01	50652
2	15320	11400	0.050	8327	1	0	0	0	0.01	0.01	0.02	0.02	65680
2-1/2	19441	9800	0.050	7314	2	0	1	1	0.01	0.01	0.02	0.03	52938
3	12622	6350	0.050	4631	17	3	7	11	0.01	0.02	0.02	0.03	50898
4	8948	8500	0.050	5317	3	0	1	2	0.01	0.03	0.04	0.05	62955
6	9862	7150	0.050	4100	7	1	3	5	0.02	0.04	0.06	0.08	50240
8	8863	4965	0.050	2768	57	9	18	33	0.02	0.05	0.07	0.10	43668
10	10890	8500	0.050	3327	3	0	1	2	0.04	0.07	0.11	0.14	45537
12	10248	6100	0.050	2640	21	3	6	11	0.04	0.08	0.12	0.16	40637
14	12004	7350	0.050	2511	9	1	2	4	0.04	0.09	0.13	0.17	38888
16	11095	7150	0.050	2228	10	1	2	4	0.05	0.10	0.15	0.20	36919
18	10857	6200	0.050	2122	21	2	5	9	0.06	0.12	0.18	0.24	36091
20	11820	7000	0.050	2116	12	1	2	5	0.07	0.15	0.22	0.29	36420
24	13430	6900	0.050	2040	16	1	3	6	0.10	0.21	0.31	0.41	36962

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-53. 600# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 35000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	25068	9000	0.050	8872	2	0	1	1	0.00	0.01	0.01	0.01	59490
2	26809	11400	0.050	9750	1	0	0	0	0.01	0.01	0.02	0.03	76901
2-1/2	34021	9800	0.050	9132	2	0	1	1	0.01	0.02	0.02	0.03	66101
3	23089	6350	0.050	5925	18	4	8	12	0.01	0.02	0.03	0.04	65120
4	15659	8500	0.050	6516	3	1	1	2	0.02	0.03	0.05	0.07	77152
6	17258	7150	0.050	5573	8	2	3	5	0.03	0.05	0.08	0.10	68290
8	15510	4965	0.050	4099	62	13	27	40	0.04	0.07	0.11	0.14	64658
10	19058	8500	0.050	5014	4	1	1	2	0.05	0.11	0.16	0.21	68638
12	17935	6100	0.050	4217	23	4	9	13	0.06	0.12	0.19	0.25	64921
14	21007	7350	0.050	4197	10	2	3	5	0.07	0.15	0.22	0.29	65008
16	19416	7150	0.050	3843	11	2	3	5	0.09	0.18	0.26	0.35	63699
18	18999	6200	0.050	3713	24	4	8	12	0.11	0.21	0.32	0.43	63159
20	20684	7000	0.050	3703	14	2	4	6	0.13	0.26	0.38	0.51	63734
24	23502	6900	0.050	3570	17	3	5	8	0.18	0.36	0.54	0.72	64684

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-54. 600# Flange Gasket Stress, Gross Leak Pressure, and Leak Rate

INITIAL BOLT STRESS = 60000 psi

JOINT RELAXATION = 0%

Flange Diameter (in)	Eff Gasket Stress (psi)	Act Gasket Stress (psi)	Gasket Deflect. (in)	Gross Leak Pressure (psi)	Leak Rate at GLP (mg/sec)	Leak Rate at .25GLP (mg/sec)	Leak Rate at .50GLP (mg/sec)	Leak Rate at .75GLP (mg/sec)	Leak Area at 1.25GLP (sq in)	Leak Area at 1.5GLP (sq in)	Leak Area at 1.75GLP (sq in)	Leak Area at 2.0GLP (sq in)	Bolt Stress at 2.0GLP (psi)
Flanges													
1-1/2	42974	9000	0.050	11069	2	1	1	2	0.00	0.01	0.01	0.02	74220
2	45959	11400	0.050	12121	1	0	0	1	0.01	0.02	0.03	0.03	95603
2-1/2	58322	9800	0.050	12163	2	1	1	2	0.01	0.02	0.03	0.04	88038
3	37867	6350	0.050	8082	19	6	11	17	0.01	0.03	0.04	0.06	88822
4	26844	4500	0.050	8514	3	1	1	2	0.02	0.04	0.06	0.09	100815
6	29585	7150	0.050	8029	8	2	5	7	0.04	0.07	0.11	0.15	98373
8	26588	4965	0.050	6317	68	21	41	62	0.06	0.11	0.17	0.22	99645
10	32671	8500	0.050	7827	4	1	2	3	0.08	0.16	0.25	0.33	107141
12	30745	6100	0.050	6846	25	7	14	21	0.10	0.20	0.30	0.40	105393
14	36012	7350	0.050	7008	11	3	5	8	0.12	0.24	0.36	0.49	108541
16	33285	7150	0.050	6537	12	3	6	9	0.15	0.30	0.45	0.60	108333
18	32570	6200	0.050	6366	27	7	14	20	0.18	0.37	0.55	0.73	108273
20	35459	7000	0.050	6348	15	4	7	11	0.22	0.44	0.66	0.88	109259
24	40290	6900	0.050	6120	20	4	9	13	0.31	0.62	0.92	1.23	110887

Bolt Yield Stress = 111,700 psi (SA193-B7)

DGmax = 0.050 in

Table 4-55. Flange Connection Leak Rate Variabilities

Flange Rating (lb)	Low Strength Bolts, ß	High Strength Bolts, ß
150	0.62	0.54
300	0.51	0.54
400	0.51	0.54

5. VALVES

Valves have generally not been shown to be a major contribution to risk in the three pilot studies conducted to date (References 1 through 3). For valves with common configurations such as globe, gate, diaphragm, swing check or butterfly, the three failure modes postulated include failure of the value body, failure of the stem packing, and failure of the bolted bonnet. Since the valve body thickness is typically greater than that of the adjacent piping (one supplier used 600lb bodies for all valves rated for 600lb service and less), it is judged that failure of the adjacent piping will occur prior to failure of the valve body. Also the types of valve stem packing currently used in most nuclear plants tend to compress under high pressure conditions providing a greater resistance to leakage. Although it is certainly possible that the stem packing for some valves could deteriorate in response to service conditions, it was judged that any resulting leak rate or leak area would be quite small and have a negligible effect on both the valve and system operation. Thus, it is felt that the only credible failure modes for the system valves pertains to failure of the bolted bonnet seal.

The bolted bonnet valves are typically sealed using Style R spiral wound gaskets compressed between the bonnet and the valve body which are machined in a tongue and groove configuration. Normally, the valves are fitted with high strength bolts with tensile yield strengths of 100,000 psi or greater, and the bonnet bolts are normally torqued to specified levels which prestress the bolt in the range of 35,000 to 45,000 psi. Preloading of the bolt to the specified levels results in a substantial lock-up force between the bonnet and valve body. Frequently a seal weld is applied to the lip at this junction. The bolted bonnet valves should be analyzed in a manner identical to that for the gasketed flange connections with no credit being taken for the seal weld.

In the plants investigated in References 1 through 3 no valves of 3 inch diameter or smaller were found to have GLP less than the peak pressures (2500 psig) of interest for ISLOCA, no matter what flange rating was used for valve design. Also, 1500 lb valves are normally hydrotested at 2500 psig or greater, thus providing a margin against ISLOCA conditions.

In estimating the gross leak pressure, leak rates, and leak areas for bolted bonnet valves greater than 3 inches, values of the parameters from flanged joint Tables 4-5 through 4-55 may be used provided the bonnet gasket dimensions correspond to those used for standard flanges. For other gasket dimensions, either the flanged joint table values may conservatively be used if the bonnet gasket dimensions indicate actual bonnet leak pressures will be higher or leak pressures, etc., may be calculated as discussed in the remaining part of this section.

The definition of the onset of gross leakage, or the Gross Leak Pressure, as the point at which the gasket stress is equal to the pressure being retained, is used quite generally throughout the gasket industry. Calculation of GLP requires knowledge of gasket stiffness and compressed gasket thickness. For pressures less than GLP, the mass leak rate is calculated from results of gasket leakage tests conducted with water (Reference 11). Leakage of this form is related to the presence of seams and crevasses in the flange/gasket joint rather than any apparent leak area. The tests involved 4"-600 lb rated flanges and gaskets subjected to both standard and cyclic load pressure sequences. Estimates of leak rates for other pipe

sizes and flange ratings may be determined by use of a Tightness Parameter, T_p, defined as:

$$T_p = \frac{p}{p^*} \left[\frac{L^*_{RM}}{L_{RM}} \right]^a \qquad (5\text{-}1)$$

where p = Internal Fluid Gauge Pressure (psig)

p^* = Reference Atmospheric Pressure (14.7 psia)

L^*_{RM} = Reference Mass Leak Rate (1 mg/sec)

L_{RM} = Total Mass Leak Rate through the Gasket (mg/sec)

and a = Tightness Parameter Exponent (1.0 for water)

Thus, the total mass leak rate for the water case is computed as:

$$L_{RM} = \frac{p}{(14.7 \cdot T_p)} \qquad (5\text{-}2)$$

Since the leak rate data correspond to the total mass leakage from a 4"—600# rated gasket and not, for example, the leakage per unit mean circumference, a correction must be made to the calculated mass leak rate to account for the various gasket sizes. Since the probability of leakage increases with gasket perimeter, it is reasonable to assume that leakage through a larger diameter gasket will increase in proportion to the gasket diameter. In addition, a correction factor must be introduced to account for variations in the gasket width. It should be noted that the calculation of gasket width and gasket area should not include the outer 1/8" which is ineffective in the sealing process. The leak rate at the Gross Leak Pressure is then determined as:

$$LR_{GLP} = \frac{(D_O + D_i)(p)}{384.6 W_G} \left[\frac{1}{e^{(6.1872 - 6.2361(9.2103 - \ln SG_0) - .791331(\ln SG_0 - \ln SG))}} \right] \qquad (5\text{-}3)$$

where D_O = Gasket Outside Diameter (in)

D_i = Gasket Inside Diameter (in)

W_g = Gasket Width (in)

SG_0 = Initial Gasket Stress (psi) = Actual Gasket Stress/(1-JR/100)

SG = Current Gasket Stress (psi)

and JR = Joint Relaxation expressed in percent of SG_0

Note that in Equation 5-3 the quantity, 348.6, is the product of 14.7 from Equation 5-2 and 23.714 which is the value of $(D_O + D_i)/W_G$ for a 4"-600# rated

gasket. The quantity in the denominator of the term within the brackets in Equation 5-3 represents the Tightness Parameter(T_p) which is obtained by curve fitting using the curves from Reference 11.

For pressures above the Gross Leak Pressure, it is judged that the leakage is no longer due to seams and crevasses in the flange/seal joint but due to actual separation of the flange and gasket. Thus, a leak area is calculated which is intended to be in addition to the leak rate calculated at Gross Leak Pressure. The leak area is calculated as the mean gasket perimeter times the separation distance at the gasket. The separation distance is affected by bolt extension, gasket recovery, and flange flexibility. Of these, the contribution of bolt extension is by far the most dominant one. Therefore, the separation distance calculated in this study includes the effect of bolt extension only. Note that excluding the effect of gasket recovery from the leak area calculation is conservative and leads to slightly higher leak area values. The leak area at pressures above the Gross Leak Pressure is equated as shown in Equations 5-4 and 5-5, respectively, for the case where the bolt stress is less than or equal to the bolt material yield stress and for the case where the bolt stress exceeds the material yield.

For bolt stress ≤ yield

$$A_L = \left[\frac{\pi(D_O + D_i)}{2} \; L_B \left\{ \frac{(p - p_{GL})(A_p)}{N_B(A_B)(E_B)} \right\} \right] \qquad (5\text{-}4)$$

For bolt stress > yield

$$A_L = \frac{\pi(D_O + D_i)}{2} \left[L_B \left\{ \frac{(S_{By} - S_{Ba})}{E_B} + \left[S_{Ba} + \frac{(p - p_{GL})(A_p)}{N_B(A_B)} - S_{By} \right] / E'_B \right\} \right] \qquad (5\text{-}5)$$

where L_B = Bolt/Stud Length (in)

p_{GL} = Gross Leak Pressure (psi)

A_p = Pressure Area (in^2) - based on gasket inside diameter

N_B = Number of Flange Bolts

A_B = Bolt Tensile Stress Area (in^2) - per bolt

E_B = Bolt Material Elastic Modulus (psi)

SG_{pGL} = Gasket Stress at Gross Leak Pressure (psi)

S_{By} = Bolt Material Yield Stress (psi)

S_{Ba} = Actual Bolt Stress (psi) = $(1\text{-}JR/100)S_{Bo}$ for no lockup case
= S_{Bo} for lockup case

S_{Bo} = Initial Bolt Stress (psi)

and E'_B = Bolt Modulus for appropriate inelastic portion of the stress-strain diagram (psi)

A lognormal standard deviation of 0.54 is recommended for bonnet leak rates and 0.12 for leak areas calculated using the above expressions.

Table 5-1. Stiffnesses For Asbestos-Filled Spiral Wound Gaskets

Flange Diameter (in)	Pressure Rating (#)	GASKET OD (in)	GASKET ID (in)	GASKET Width (in)	GASKET Area (sq in)	BOLTS Number	BOLTS Diameter (in)	BOLTS Area (sq in)	BOLTS Length (in)	Gasket Test Load (lbs)	Bolt Stress at GTL (psi)	GASKET STIFFNESS T_g=0.125 (psi/in)	GASKET STIFFNESS T_g=0.130 (psi/in)	GASKET STIFFNESS T_g=0.135 (psi/in)
1-1/2	150	2.750	2.125	0.2500	1.865	4	1/2	0.1416	1.625	15100	26660	161902	179892	202378
	300	2.750	2.125	0.2500	1.865	4	3/4	0.3340	1.875	36200	27096	388137	431263	485171
	600	2.750	2.125	0.2500	1.865	4	3/4	0.3340	2.375	36200	27096	388137	431263	485171
2	150	3.375	2.750	0.2500	2.356	4	5/8	0.2256	1.750	24200	26817	205416	228240	256770
	200	3.375	2.750	0.2500	2.356	8	5/8	0.2256	2.000	48400	26817	410832	456480	513540
	600	3.375	2.750	0.2500	2.356	8	5/8	0.2256	2.625	48400	26817	410832	456480	513540
2-1/2	150	3.875	3.250	0.2500	2.749	4	5/8	0.2256	2.000	24200	26817	176071	195634	220089
	300	3.875	3.250	0.2500	2.749	8	3/4	0.3340	2.250	72500	27133	527485	586094	659356
	600	3.875	3.250	0.2500	2.749	8	3/4	0.3340	2.875	72500	27133	527485	586094	659356
3	150	4.750	4.000	0.3125	4.234	4	5/8	0.2256	2.125	24200	26817	114318	127021	142898
	300	4.750	4.000	0.3125	4.234	8	3/4	0.3340	2.500	72500	27133	342483	380537	428104
	600	4.750	4.000	0.3125	4.234	8	3/4	0.3340	3.125	72500	27133	342483	380537	428104
4	150	5.875	5.000	0.3750	6.332	8	5/8	0.2256	2.125	48500	26873	153184	170204	191479
	300	5.875	5.000	0.3750	6.332	8	3/4	0.3340	2.750	72500	27133	228966	254429	286232
	600	5.875	4.750	0.5000	8.247	8	7/8	0.4612	3.625	101000	27374	244947	272163	306184
6	150	8.250	7.188	0.4688	11.275	8	3/4	0.3340	2.250	72500	27133	128606	142895	160757
	300	8.250	7.188	0.4688	11.275	12	3/4	0.3340	3.125	100700	25125	178629	198477	223286
	600	8.250	6.875	0.6250	14.726	12	1	0.6051	4.375	190000	26166	258043	286715	322554
8	150	10.375	9.188	0.5313	16.220	8	3/4	0.3340	2.500	72500	27133	89394	99327	111743
	300	10.375	9.188	0.5313	16.220	12	7/8	0.4612	3.500	150800	27248	185940	206600	232425
	600	10.375	9.875	0.6875	20.654	12	1-1/8	0.7627	5.000	262000	28626	253710	281900	317137
10	150	12.500	11.313	0.5313	19.767	12	7/8	0.4612	2.625	151000	27284	152781	169756	190976
	300	12.500	11.313	0.5313	19.767	16	1	0.6051	4.000	264400	27310	267518	297242	334398
	600	12.500	10.913	0.7813	28.455	16	1-1/4	0.9684	5.625	449000	28785	313474	348304	391842
12	150	14.750	13.375	0.6250	27.489	12	7/8	0.4612	2.750	151000	27284	109862	122065	137328
	300	14.750	13.375	0.6250	27.489	16	1-1/8	0.7627	4.250	349400	28632	254211	282457	317764
	600	14.750	12.875	0.8750	37.797	20	1-1/4	0.9684	5.875	557000	28759	294730	327478	368413
14	150	16.000	14.625	0.6250	29.943	12	1	0.6051	3.000	198000	27298	132250	146944	165312
	300	16.000	14.625	0.6250	29.943	20	1-1/8	0.7627	4.500	436000	28583	291217	323574	364021
	600	16.000	14.250	0.8125	38.448	20	1-3/8	1.1538	6.125	—	27408	328990	365553	411247
16	150	18.250	16.625	0.7500	40.939	16	1	0.6051	3.125	264000	27288	128973	143303	161216
	300	18.250	16.625	0.7500	40.939	20	1-1/4	0.9684	4.750	557000	28759	272113	302348	340141
	600	18.250	16.250	0.9375	50.621	20	1-1/2	1.4041	6.625	—	27643	306701	340778	383376
18	150	20.750	18.688	0.9688	59.822	16	1-1/8	0.7627	3.375	—	27262	111226	123584	139032
	300	20.750	18.688	0.9688	59.822	24	1-1/4	0.9684	5.000	—	27565	214187	237965	267733
	600	20.750	18.500	1.0625	65.298	20	1-5/8	1.7723	7.125	—	28439	308754	343060	385943
20	150	22.750	20.688	0.9688	65.909	20	1-1/8	0.7627	3.625	—	27262	126190	140213	157740
	300	22.750	20.688	0.9688	65.909	24	1-1/4	0.9684	5.250	—	27565	194406	216007	243008
	600	22.750	20.500	1.0625	71.974	24	1-5/8	1.7723	7.625	—	28439	336140	373488	420175
24	150	27.000	24.750	1.0625	86.161	20	1-1/4	0.9684	4.000	—	27565	123927	137696	154908
	300	27.000	24.750	1.0625	86.161	24	1-1/2	1.4041	5.750	—	27643	216232	240258	270290
	600	27.000	24.750	1.0625	86.161	24	1-7/8	2.4107	8.525	—	28667	385000	427778	481250
44	300	42.625	45.425	0.9375	137.138	40	1-3/8	1.1538	10.215	—	27408	307457	368948	461185

Reference: MIL-G-21032E, Amendment 2

GTL = Gasket Test Load

T_g = Compressed Gasket Thickness

6. PUMPS

A wide range of pump types and vendors may be of importance for ISLOCA investigations. An insufficient sampling of pump capacities exists in References 1 through 3 upon which to develop generic evaluation guidelines. Although in the three plants evaluated, pumps were not determined to be the dominant contributor to risk, it is currently recommended that a plant specific evaluation of pumps subjected to ISLOCA conditions be conducted.

Potential leak or failure locations include case rupture, bolted flange connections, mechanical shaft seals, and occasionally specific applications such as seal water cooling tubes, etc. Pump casing hydrotest pressures obtained from the vendor may be used to provide a lower bound estimate of the case capacity. However, often the hydro test does not include the seal and shaft assemblies, but often uses a dummy plate to replace the seal assembly. Separate vendor test information is sometimes available from the vendor, or the seal face loading springs and elements are often amenable to analysis using conventional strength of material methods. In such a case, leak areas based on calculated seal distortions may be determined.

7. REFERENCES

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11. ABSTRACT (200 words or less)

Recommendations are presented for establishing screening estimates of pressure capacities for fluid system components subjected to Interfacing System LOCA (ISLOCA) conditions for nuclear power plants. Included in this evaluation are tanks, heat exchangers, filters, pumps, valves, flanged connections, and pipe. Tabular values are presented for stainless and carbon steel pipe, as well as flanged connections with various bolt materials and preloads. Simple analysis methods, together with expected variabilities, are discussed for plant-specific components that must be evaluated independently. In addition to failure or leak pressures, tabulated leak rates or leak areas are included where applicable.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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