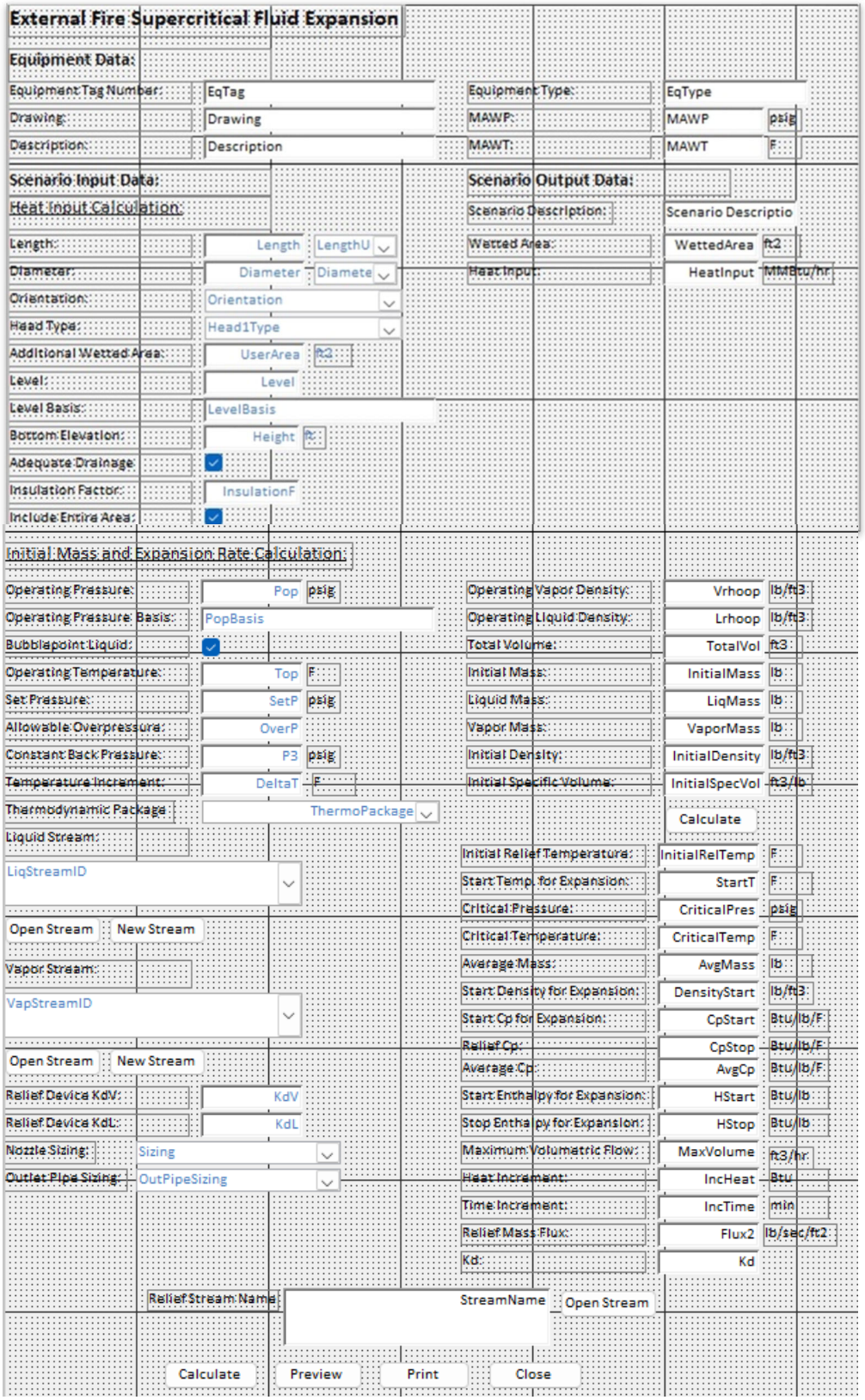
External Fire Supercritical Expansion



Equipment Data:

The six fields under Equipment Data are specified on the Overpressure Scenario Form.

Input Data:

The form fields for inputs are blue and organized under the Scenario Input column. The are described below:

Length – Vessel seam-to-seam length for horizontal and vertical orientations. Not required for spheres.

LengthUnits – Units (ft, in or mm) associated with the Length.

Diameter – Vessel diameter generally taken as the outer diameter.

DiameterUnits – Units (ft, in or mm) associated with the Diameter.

Orientation – Vessel orientation (horizontal, vertical or spherical.

Head1Type – Both vessel heads assumed the same (2:1 ellipsoidal, hemispherical or flat).

UserArea – Any wetted area beyond normal geometry calculation to be added such as a boot or piping.

Level – Vessel liquid level for use in determining wetted area.

LevelBasis – Source for input liquid level such as LSHH, LSH, Upper LG Tap.

Height – Elevation above grade of vessel bottom for use only when considering maximum fire height

Adequate Drainage – If yes then 21,000 used in heat equation, if no 34,500 used in heat equation

InsulationF – Insulation factor used to reduce total heat input. 1.0 unless fireproof insulation is present then either 0.3 or calculated per API STD 521.

Include Entire Area – If yes then entire surface area is used for heat input calculation regardless of level (conservative).

Pop – Operating pressure used to quantify initial density and initial relief temperature. Higher value results in higher density and lower initial relief temperature.

Pop Basis – Source of operating pressure such as PSHH, PSH, Operating.

Bubblepoint Liquid – If yes, vapor composition and properties will be quantified based on liquid with PQFlash. If no, vapor stream with components in same order and Top are required to be entered.

Top – Only required if Bubblepoint is false, otherwise calculated. Higher value results in lower density and higher initial relief temperature.

SetP – Set pressure that will be used along with overpressure to determine relief pressure.

OverP – Allowable overpressure typically 21% used to determine relief pressure.

P3 – Constant back pressure when PSV is closed.

DeltaT – Temperature increment to be used for each expansion step used for required relief rate calculation.

ThermoPackage – Thermo package used for properties. VMG (Symmetry) packages or REFPROP 10.0 from NIST

LiquidStreamID – The liquid or supercritical stream initially contained in the vessel. A new stream can be added here. If initially supercritical, level should be 100% and VapStreamID = LiqStreamID. See Stream Definition Form.

VapStreamID – The vapor or supercritical stream initially contained in the vessel. A new stream can be added here. If initially supercritical, level should be 100% and VapStreamID = LiqStreamID. See Stream Definition Form.

Kdv – Manufacturer's certified vapor Kd or 0.975 for API STD 520 default.

Kdl – Manufacturer's certified liquid Kd or 0.65 for API STD 520 default.

Sizing – PSV sizing method: API 520 Vapor or Numerical Integration (recommended when Z <= 0.8).

OutPipeSizing – Outlet pressure drop method: Adiabatic, Omega Method or Numerical Integration.

Calculation Method:

The calculation method for external fire with supercritical expansion is performed in two steps. The first step involves determining the overall heat input and initial relief conditions. The heat input is based on the vaporizing liquid equation that is well established in API STD 521. As indicated above, the heat input may be evaluated based on the starting liquid level assuming the fluid is subcritical at the entered operating conditions or may be evaluated on the total surface area regardless of the liquid level. The wetted area is then calculated based on the input dimensions, level (if applicable) and orientation of the vessel using standard geometric equations. The heat input is subsequently calculated based on the wetted area using the following equations depending on the presence of adequate drainage and firefighting equipment:

Adequate drainage and firefighting equipment:

$$HeatInput = 21{,}000 \times InsulationF \times WettedArea^{0.82}$$

No adequate drainage and firefighting equipment:

$$HeatInput = 34{,}500 \times InsulationF \times WettedArea^{0.82}$$

The initial relief conditions are based on the input operating conditions and stream compositions. If the fluid is identified as a bubblepoint liquid at operating conditions, the liquid stream is set at the bubblepoint and the temperature and vapor stream composition are calculated using the selected thermodynamic package. If the fluid is not identified as a bubblepoint liquid, then it is required to enter the temperature and vapor stream composition. Note that in this case the components for the liquid and vapor stream need to be entered in identical order. The starting liquid and vapor densities are quantified using the selected thermodynamic package and the liquid and vapor volumes are quantified using the input liquid level and standard geometric equations which yields the overall starting vessel mass and density. The composition of the overall supercritical relief stream is then determined by mathematical addition of the liquid and vapor moles for each component divided by the total moles present.

The second calculation step involves successive expansions of the fluid based on the input DeltaT. The StartT, which is the intial temperature at the relief pressure prior to any fluid leaving the equipment, is first calculated by performing a PD Flash using the InitialDensity and P2 (relief pressure). A PT Flash is then performed to StartT + DeltaT to determine a new density and fluid properties. The rate of fluid loss during this expansion is quantified as follows:

AvgMass = (DensityStart + Density Stop)/2 * TotalVol

AvgCp = (Cp Start + CpStop)/2

IncHeat = AvgMass * AvgCp * DeltaT

TimeInc = HeatInc / HeatInput

RequiredRate = (DensityStart - Density End) * TotalVol / TimeInc

VolRate = RequiredRate / ((DensityStart + Density Stop)/2)

The process is repeated for successive increases in temperature by DeltaT to determine the maximum VolRate which represents the maximum required area for the scenario. Note that this is not necessarily the maximum mass flow rate.

Scenario Output Data:

The form fields for scenario-specific outputs are organized under the Scenario Output column. These are described below:

WettedArea – Surface area calculated using level plus UserArea or total surface area plus UserArea.

HeatInput – Calculated total heat input based on WettedArea, F and Adequate Drainage selection.

Vrhoop – Vapor density at input operating conditions

Lrhoop – Liquid density at input operating conditions

TotalVol – Total volume based on input dimensions

InitialMass – Total of vapor and liquid mass quantified based on relative volumes and densities

LiqMass – Total liquid mass based on level and liquid density

VaporMass – Total vapor mass based on level and vapor density

InitialDensity – Overall bulk density prior to any relief/loss of fluid

InitialSpecVol – 1 / InitialDensity

InitialRelTemp – Predicted temperature at which the relief pressure will be achieved and relief initiated

StartT – Starting temperature for maximum volumetric expansion rate which is basis for required rate

CriticalPres – Overall fluid critical pressure

CriticalTemp – Overall fluid critical temperature

AvgMass – Average mass over maximum volumetric expansion temperature increment

DensityStart – Density at Start T of maximum volumetric expansion temperature increment

CpStart – Mass heat capacity at Start T of maximum volumetric expansion temperature increment

CpStop - Mass heat capacity at StopT (T2) of maximum volumetric expansion temperature increment

AvgCp – Average Cp over maximum volumetric expansion temperature increment

HStart – Mass enthalpy at Start T of maximum volumetric expansion temperature increment

HStop - Mass enthalpy at StopT (T2) of maximum volumetric expansion temperature increment

MaxVolume – Maximum volumetric flowrate found from all expansions

IncHeat – Total heat added during StartT to StopT (T2)

IncTime – Time to heat from StartT to StopT (T2)

Flux2 – RequiredRateMass · RequiredArea * 144 / 3600

Kd – Discharge coefficient used to evaluate required area

Scenario Calculation Results:

The form fields for overall scenario results are organized in the Scenario Calculation Results Section. These outputs are typical of most of the scenario calculations and are detailed under Typical Scenario Calculation Results.

QA/QC Benchmarks:

As the calculation of the wetted area relies on simple geometric calculations and the heat input calculation is very straightforward as detailed in the calculation section, the primary benchmark for the external fire with supercritical expansion is the quantification of the initial relief composition and associated overall density followed by calculation of the expansion rate over each temperature increment. These two calculations were benchmarked against a commercial simulation (Symmetry) for a typical Cold Separator NGL liquid in a separator. The initial relief composition, density (18.1 lb/ft^3) and temperature (~ 35° F) were found to be nearly identical between Pressio and the simulator. The maximum expansion rate from Pressio was then recreated in the simulator from 215.5° F to 225.5° F to determine the required relief rate of 17,472 lb/hr versus 17,484 lb/hr from Pressio. Finally, the entire calculation was benchmarked against an internal RKR spreadsheet which determined an overall required relief rate of 17,415 lb/hr with similar intermediate results.

External Fire Supercritical Fluid Expansion

V-2000 External Fire

Equipment Data:

Equipment Tag:	**V-2000**	Type:	Pressure Vessel
Drawing:	PID-2000	MAWP:	1000 psig
Description:	Low Temperature Separator	MAWT:	-100 F

Scenario Description:

The Low Temperature Separator contains liquid hydrocarbon that could vaporize in the event of an external fire potentially resulting in overpressure. However, the fluid will be supercritical at the relief pressure of 1,210 psig, therefore the required relief rate was based on the expansion rate of the fluid with the normal liquid composition and associated dewpoint vapor at normal operating conditions of 700 psig and -20 F.

Scenario Calculation Results:

Required Rate:	17,483.8	lb/hr	Device Choke Pressure:	605.0	psig
Actual Capacity:	29,250.8	lb/hr	Outlet Temperature:	125.6	F
Required Area:	0.183	in2	Outlet Mass Quality:	1.000	
Actual Area:	0.307	in2	Outlet Density:	0.074	lb/ft3
Relief Pressure:	1210.0	psig	Outlet Ideal Cp/Cv:	1.156	
Relief Temperature:	225.5	F	Outlet Viscosity:	0.010	cP
Relief MW:	31.35		Inlet Non-Recoverble dP:	5.8	psi
Relief Mass Quality:	1.000		Inlet dP % Set:	0.6	% Set
Relief Density:	7.355	lb/ft3	Built-Up Back Pressure:	109.0	psig
Relief SG:	1.081		Built-Up Back P % Set:	10.9	% Set
Relief Z:	0.710		Total Back Pressure:	109.0	psig
Relief Ideal Cp/Cv:	1.139		Total Back P % Set:	10.9	% Set
Relief Viscosity:	0.012				

External Fire Supercritical Fluid Expansion

V-2000 External Fire

Equipment Data:

Equipment Tag:	**V-2000**	Type:	Pressure Vessel
Drawing:	PID-2000	MAWP:	1000 psig
Description:	Low Temperature Separator	MAWT:	-100 F

Scenario Input Data:

Heat Input Calculation:

Length:	12	ft	Bottom Elevation:	2	ft
Diameter:	5	ft	Adequate Drainage	☐	
Orientation:	Vertical		Insulation Factor:	1	
Head Type:	2:1 Ellipsoidal		Include Entire Area:	☑	
Additional Wetted Area:	0	ft2			
Level:	50%				
Level Basis:	LSHH-2000				

Scenario Output Data:

Wetted Area:	242.7	ft2
Heat Input:	3.1158	MMBtu/hr

Initial Mass and Expansion Rate Calculation:

Operating Pressure:	700	psig	Vapor Mass:	554	lb
Operating Pressure Basis:	PSHH-2000		Initial Density:	18.1	lb/ft3
Bubblepoint Liquid:	☑		Initial Specific Volume:	0.0552	ft3/lb
Operating Temperature:	-52.5	F	Initial Relief Temperature:	35.5	F
Set Pressure:	1000	psig	Start Temp. for Expansion:	215.5	F
Allowable Overpressure:	21.0%		Average Mass:	2014.3	lb
Constant Back Pressure:	0	psig	Start Density for Expansion:	7.66	lb/ft3
Temperature Increment:	10	F	Start Cp for Expansion:	0.731	Btu/lb/F
Use Thermodynamics:	☑		Relief Cp:	0.717	Btu/lb/F
Relief Device KdV:	0.975		Average Cp:	0.724	Btu/lb/F
Relief Device KdL:	0.650		Start Enthalpy for Expansion:	5941.8	Btu/lb
Nozzle Sizing:	API Numerical Integration Vapor		Stop Enthalpy for Expansion:	6168.9	Btu/lb/F
Outlet Pipe Sizing:	Numerical Integration		Maximum Volumetric Flow:	2328.8	ft3/hr
Operating Vapor Density:	4.129	lb/ft3	Heat Increment:	14583.3	Btu
Operating Liquid Density:	32.078	lb/ft3	Time Increment:	0.28	min
Total Volume:	268.3	ft3	Relief Mass Flux:	3821.6	lb/sec/ft2
Initial Mass:	4858	lb	Kd:	0.975	
Liquid Mass:	4304	lb			

Notes:

External Fire Supercritical Fluid Expansion

V-2000 External Fire

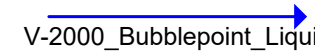
Equipment Data:

Equipment Tag:	**V-2000**	Type:	Pressure Vessel
Drawing:	PID-2000	MAWP:	1000 psig
Description:	Low Temperature Separator	MAWT:	-100 F

Relief Stream Composition:

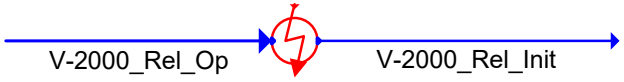
	Low Temp Separator Relief	Low Temp Separator Liquid	Low Temp Separator Gas
Component	**Mole Fraction**	**Mole Fraction**	**Mole Fraction**
methane	0.5684	0.4723	0.9363
ethane	0.1153	0.1352	0.0390
propane	0.1137	0.1405	0.0109
isobutane	0.0372	0.0465	0.0014
butane	0.0548	0.0687	0.0014
isopentane	0.0284	0.0357	0.0003
pentane	0.0215	0.0271	0.0002
hexane	0.0512	0.0645	0.0001
heptane	0.0000	0.0000	0.0000
octane	0.0000	0.0000	0.0000
nonane	0.0000	0.0000	0.0000
decane	0.0000	0.0000	0.0000
carbon dioxide	0.0082	0.0088	0.0057
nitrogen	0.0015	0.0007	0.0047

Initial V-2000 Bubblepoint Liquid



V-2000_Bubblepoint_Liquid	
T	-52.5 [F]
P	*700.00 [psig]
Mass Flow	*1000.00 [lb/h]
Vapor Mass Density	4.1310 [lb/ft3]
Liquid Mass Density	32.0790 [lb/ft3]

Relief Stream from Pop to Prelief (Constant Density)

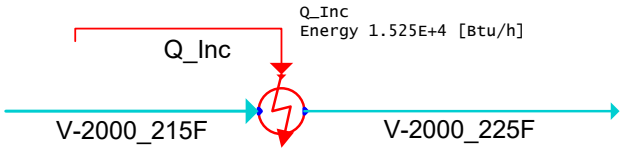


V-2000_Rel_Op	
T	*-52.5 [F]
P	*700.00 [psig]
Mass Density	18.1354 [lb/ft3]

V-2000_Rel_Init	
T	*35.0 [F]
P	*1210.00 [psig]
Mass Density	18.1298 [lb/ft3]

TotalVol = 268.3 ft3
DensityAvg = (7.6630 + 7.3579)/2 = 7.51 lb/ft3
DeltaMass = (7.6630 – 7.3579) lb/ft3 x 268.3 ft3 = 81.86 lb
CpAvg = (0.7315 + 0.7175) = 0.7245 Btu/lb/F
AvgVesselMass = 7.51 lb/ft3 x 268.3 ft3 = 2,104.9 lb
IncHeat = 2,104.9 lb x 0.7245 Btu/lb/F x 10 F = 14,598 Btu
FireHeat = 3,115,800 Btu/hr
IncTime = 14,598 Btu / 3,115,800 Btu/hr x 60 min/hr = 0.28 min
ExpansionRate = 81.86 lb / (0.28 min / 60 min / hr) = 17,472 lb/hr

Maximum Expansion Rate Increment



V-2000_215F	
T	*215.5 [F]
P	*1210.00 [psig]
Mass Flow	*2105.00 [lb/h]
Mass Density	7.6630 [lb/ft3]
Cp Mass	0.7315 [Btu/lb-F]

V-2000_225F	
T	*225.5 [F]
P	1210.00 [psig]
Mass Flow	2105.00 [lb/h]
Mass Density	7.3579 [lb/ft3]
Cp Mass	0.7175 [Btu/lb-F]

External Fire Supercritical Expansion
API STD 521 4.4.13.2.4.4

User-Entered Inputs		
P_{relief}	1,210.0	psig
P_{atm}	14.7	psia
K_d	0.975	
Q_{fire}	3,116,000	Btu/hr
P_{op}	700.0	psig
T_{op}	-52.5	F
Vol_v	121.4	ft^3
Vol_l	121.4	ft^3
T_{inc}	10.0	F
Thermo Inputs		
T_{init}	36.0	F
Results		
Vol_t	242.7	ft^3
M_v	484.3	lb
M_l	3892.8	lb
M_t	4377.1	lb
ρ_{init}	18.04	lb/ft^3
W_{req}	17415.2	lb/hr
A_{req}	0.192	in^2
W_{act}	27893.4	lb/hr

Temp (F)	Density (lb/ft3)	Enthalpy (Btu/lb)	Cp (Btu/lb/F)	Mass (lb)	Avg Mass (lb)	Avg Cp (Btu/lb/F)	Heat Input (Btu)	Time (Hours)	Delta Mass (lb)	Mass Rate (lb/hr)	Vol Rate (ft3/hr)
36.0	17.926	26.2	0.7181	4,351							
46.0	16.714	34.7	0.7187	4,056	4,204	0.718	30,198	0.0097	294	30,363	1,816.6
56.0	15.668	43.3	0.7194	3,803	3,929	0.719	28,255	0.0091	254	28,002	1,787.3
66.0	14.752	51.8	0.7204	3,580	3,691	0.720	26,574	0.0085	222	26,070	1,767.3
76.0	13.940	60.4	0.7215	3,383	3,482	0.721	25,101	0.0081	197	24,463	1,755.0
86.0	13.212	69.0	0.7229	3,207	3,295	0.722	23,797	0.0076	176	23,110	1,749.1
96.0	12.555	77.6	0.7244	3,047	3,127	0.724	22,629	0.0073	159	21,956	1,748.7
106.0	11.957	86.4	0.7260	2,902	2,975	0.725	21,573	0.0069	145	20,961	1,753.0
116.0	11.410	95.2	0.7277	2,769	2,836	0.727	20,610	0.0066	133	20,096	1,761.3
126.0	**10.905**	**104.1**	**0.7293**	2,647	2,708	0.728	19,726	0.0063	122	19,337	1,773.2
136.0	10.439	113.1	0.7308	2,533	2,590	0.730	18,908	0.0061	113	18,666	1,788.2
146.0	10.005	122.3	0.7321	2,428	2,481	0.731	18,146	0.0058	105	18,069	1,806.0
156.0	9.601	131.5	0.7333	2,330	2,379	0.733	17,433	0.0056	98	17,534	1,826.3
166.0	9.223	140.9	0.7341	2,238	2,284	0.734	16,760	0.0054	92	17,054	1,849.1
176.0	8.869	150.4	0.7346	2,152	2,195	0.734	16,123	0.0052	86	16,623	1,874.4
186.0	8.535	160.1	0.7347	2,072	2,112	0.735	15,516	0.0050	81	16,238	1,902.4
196.0	8.221	169.9	0.7342	1,995	2,033	0.734	14,935	0.0048	76	15,895	1,933.4
206.0	7.925	179.9	0.7331	1,923	1,959	0.734	14,376	0.0046	72	15,596	1,968.0
216.0	7.642	189.9	0.7306	1,855	1,889	0.732	13,825	0.0044	69	15,489	2,026.8
226.0	**7.339**	**197.2**	**0.7167**	**1,781**	**1,818**	**0.724**	**13,156**	**0.0042**	**74**	**17,415**	**2,373.0**
236.0	7.067	204.3	0.7056	1,715	1,748	0.711	12,433	0.0040	66	16,510	2,336.1
246.0	6.822	211.3	0.6966	1,656	1,686	0.701	11,818	0.0038	59	15,682	2,298.6
256.0	6.600	218.2	0.6895	1,602	1,629	0.693	11,288	0.0036	54	14,923	2,261.1
266.0	6.396	225.1	0.6838	1,552	1,577	0.687	10,828	0.0035	49	14,225	2,224.1
276.0	6.209	231.9	0.6793	1,507	1,530	0.682	10,425	0.0033	45	13,584	2,187.8
286.0	6.036	238.7	0.6759	1,465	1,486	0.678	10,068	0.0032	42	12,991	2,152.4
296.0	5.875	245.4	0.6733	1,426	1,445	0.675	9,750	0.0031	39	12,443	2,117.9
306.0	5.726	252.1	0.6714	1,390	1,408	0.672	9,466	0.0030	36	11,935	2,084.4
316.0	5.586	258.9	0.6702	1,356	1,373	0.671	9,209	0.0030	34	11,463	2,052.0
326.0	5.456	265.5	0.6696	1,324	1,340	0.670	8,976	0.0029	32	11,023	2,020.5
336.0	5.333	272.2	0.6694	1,294	1,309	0.669	8,765	0.0028	30	10,612	1,990.1
346.0	5.217	278.9	0.6697	1,266	1,280	0.670	8,571	0.0028	28	10,228	1,960.7
356.0	5.107	285.6	0.6703	1,239	1,253	0.670	8,393	0.0027	27	9,868	1,932.3
366.0	5.003	292.3	0.6712	1,214	1,227	0.671	8,229	0.0026	25	9,530	1,904.7
376.0	4.905	299.1	0.6724	1,190	1,202	0.672	8,078	0.0026	24	9,212	1,878.1
386.0	4.811	305.8	0.6739	1,168	1,179	0.673	7,937	0.0025	23	8,912	1,852.3
396.0	4.722	312.5	0.6756	1,146	1,157	0.675	7,807	0.0025	22	8,629	1,827.3
406.0	4.637	319.3	0.6775	1,126	1,136	0.677	7,685	0.0025	21	8,362	1,803.1
416.0	4.556	326.1	0.6796	1,106	1,116	0.679	7,571	0.0024	20	8,109	1,779.7
426.0	4.479	332.9	0.6819	1,087	1,096	0.681	7,464	0.0024	19	7,869	1,757.0
436.0	4.404	339.7	0.6843	1,069	1,078	0.683	7,363	0.0024	18	7,641	1,735.0
446.0	4.333	346.6	0.6868	1,052	1,060	0.686	7,269	0.0023	17	7,425	1,713.7
456.0	4.264	353.5	0.6895	1,035	1,043	0.688	7,179	0.0023	17	7,219	1,692.9
466.0	4.198	360.4	0.6923	1,019	1,027	0.691	7,095	0.0023	16	7,023	1,672.8
476.0	4.135	367.3	0.6951	1,004	1,011	0.694	7,015	0.0023	15	6,836	1,653.3
486.0	4.074	374.3	0.6981	989	996	0.697	6,939	0.0022	15	6,658	1,634.3
496.0	4.015	381.3	0.7012	974	982	0.700	6,868	0.0022	14	6,488	1,615.9
506.0	3.958	388.3	0.7043	961	968	0.703	6,799	0.0022	14	6,325	1,597.9
516.0	3.903	395.4	0.7075	947	954	0.706	6,734	0.0022	13	6,169	1,580.5
526.0	3.850	402.5	0.7107	934	941	0.709	6,672	0.0021	13	6,020	1,563.5