

POLITECNICO DI TORINO

ESAMI DI STATO PER L'ABILITAZIONE ALLA PROFESSIONE DI INGEGNERE II SESSIONE-ANNO 1996

Ramo: Ingegneria Nucleare

Tema n.ro 2

Nell'ambito della progettazione di un impianto nucleare innovativo a sicurezza intrinseca tipo ISIS, ovvero nell'ambito dei reattori refrigerati e moderati ad acqua leggera e in pressione, la scelta progettuale di riferimento è relativa alla realizzazione di un modulo in grado di generare la potenza elettrica di 200 Mwe secondo lo schema delle figure allegate.

I dati progettuali di riferimento sono:

| | |
|--|------------|
| potenza termica | 650 MW |
| temperatura dell'acqua in ingresso al nocciolo | 271 °C |
| temperatura dell'acqua in uscita dal nocciolo | 310 °C |
| pressione del circuito primario | 140 bar |
| temperatura dell'acqua di alimento | 120 °C |
| temperatura del vapore prodotto | 290 °C |
| pressione del vapore prodotto | 46 bar |
| portata vapore prodotto | 270.6 kg/s |

I dati di riferimento per gli aspetti termofluidodinamici del circuito primario e le caratteristiche del core sono riportati nelle tabelle allegate.

Il candidato sviluppi, con riferimento alle condizioni nominali, i seguenti aspetti del progetto:

1. Valuti la portata nel core, la generazione volumetrica di calore $q_v(z)$ nel combustibile con riferimento al sottocanale caldo e ne rappresenti graficamente l'andamento in funzione dell'altezza nel core.
2. Valuti il profilo assiale dell'entalpia $i(z)$ nel sottocanale caldo.
3. Effettui una stima delle cadute di pressione nel core.
4. Effettui un dimensionamento di massima del vessel del reattore con riferimento alle norme ASME
5. Effettui un dimensionamento di massima del generatore di vapore in termini di potenza, superficie di scambio termico.
6. Effettui un dimensionamento di massima del pressurizzatore in termini di volume, altezza, diametro, spessore del vessel spiegando e giustificando le ipotesi adottate per il dimensionamento.
7. Descrivi le modalità di funzionamento dell'impianto in condizioni normali e di emergenza e formuli una potenziale procedura di avviamento.

Tabella 1 Parametri termoidraulici di progetto per il circuito primario e core

| | |
|--|------|
| Potenza generata nel combustibile % | 97.4 |
| sezione di passaggio del fluido nel core m ² | 1.70 |
| superficie di scambio termico nel core m ² | 1594 |
| massima variazione di temperatura nel core °C | 61 |
| flusso termico medio kW/m ² | 408 |
| flusso termico massimo kW/m ² | 1020 |
| potenza termica media lineare kW/m | 11.9 |
| potenza termica lineare massima kW/m | 29.8 |
| caduta di pressione negli orifici della piastra di sostegno del core kPa | 13 |
| caduta di pressione associata alle griglie kPa | 6 |

Tab. 2 Parametri di progetto per il canale caldo

| | |
|---|------|
| fattore di picco di potenza radiale Fr | 1.55 |
| fattore assiale di canale caldo per il DNB (chopped cosine), Fz | 1.55 |
| fattore totale di canale caldo Fq | 2.50 |

Tab.3 Dati relativi al core

| | |
|---|------|
| Diametro equivalente m | 2.02 |
| altezza attiva m | 2.92 |
| rapporto altezza/diametro | 1.45 |
| rapporto moli H ₂ O/U (core freddo) | 2.42 |
| massa di uranio t | 25.4 |
| densità di potenza media nel fuel kW/kgU | 25.6 |
| densità di potenza media nel volume del core kW/dm ³ | 70 |

Tab.4 Dati caratteristici fasci di barre

| | |
|--|------------------------|
| numero | 69 |
| passo reticolo cm | 21.5 |
| numero di barre per fascio | 264 |
| tipologia del fascio | 17*17 |
| passo tra le barre cm | 1.26 |
| dimensioni trasversali fascio cm x cm | 21.4 x 21.4 |
| peso del combustibile come UO ₂ t | 28.8 |
| numero di griglie per fascio | 7 |
| tipo di griglie | R senza vani di mixing |

tab. 5 caratteristiche barre di combustibile

| | |
|-----------------------|-----------------|
| diametro esterno cm | 0.95 |
| numero barre | 18216 |
| spessore guaina cm | 0.057 |
| materiale guaina | zircaloy-4 |
| diametro pastiglie cm | 0.8191 |
| altezza pastiglie cm | 1.35 |
| densità %DT | 95 |
| materiale pastiglie | UO ₂ |

tab.6 dati di riferimento per il progetto del vessel

| | |
|--|-----|
| diametro interno m | 4.9 |
| pressione di progetto bar | 161 |
| temperatura di progetto °C | 330 |
| volume di riferimento per l'acqua fredda del vessel m ³ | 300 |
| tensione ammissibile MPa | 207 |

tab. 7 dati di riferimento per il generatore di vapore

| | |
|--|-------------|
| materiale | inconel 690 |
| tipo: attraversamento forzato, controcorrente, tubi elicoidali | |
| diametro tubi mm | 16 |
| altezza effettiva fascio tubiero m | 6.5 m |
| spessore tubi mm | 1.7 |
| diametro esterno virola interna m | 2.6 m |
| diametro interno virola esterna | 4.25 |
| coefficiente di scambio termico globale medio regione sottoraffreddata W/m ² °C | 3500 |
| coefficiente di scambio termico globale medio regione bollente W/m ² °C | 4500 |
| coefficiente di scambio termico globale medio regione surriscaldata W/m ² °C | 2100 |

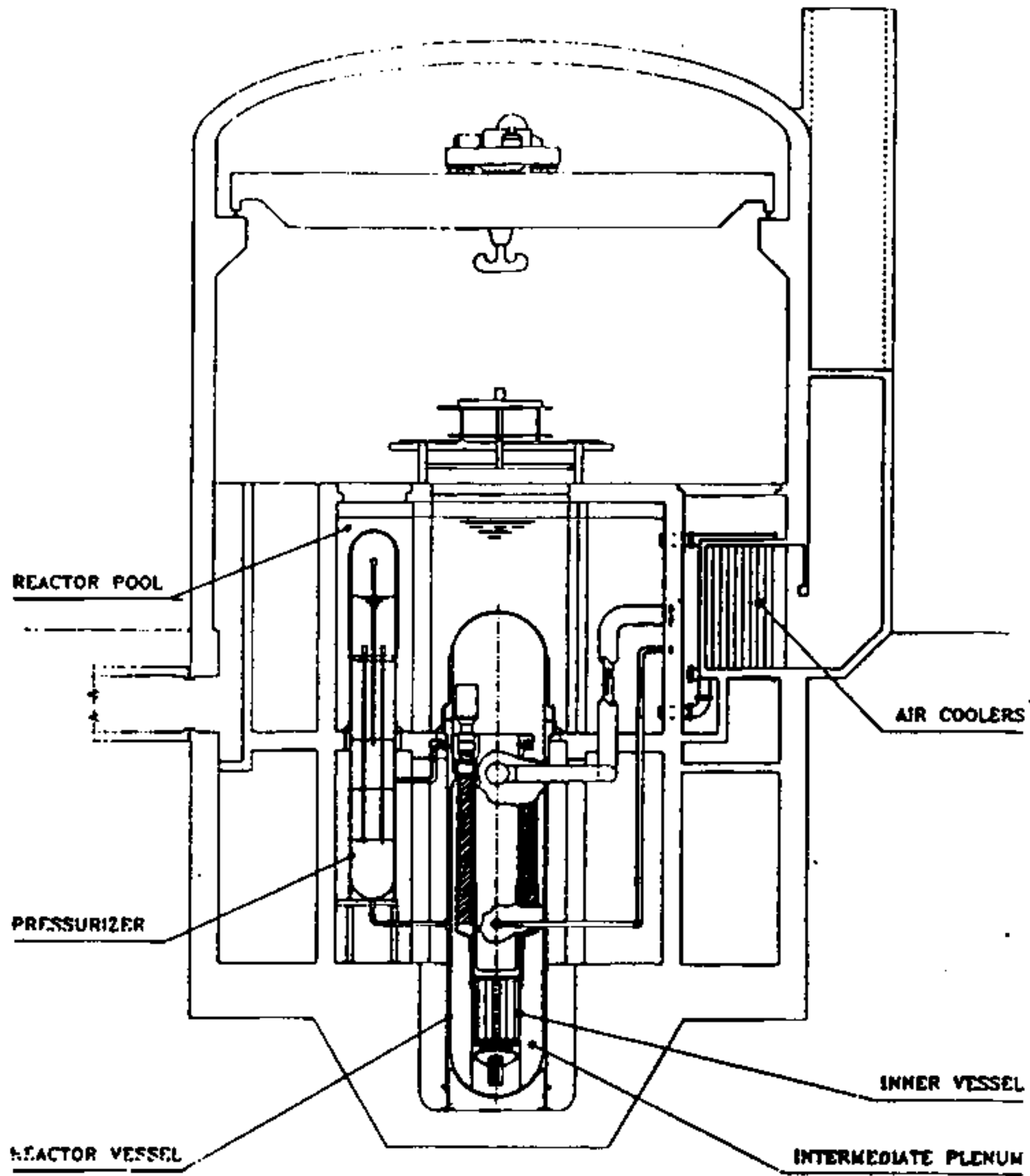


Fig. 1 - ISIS Reactor Building

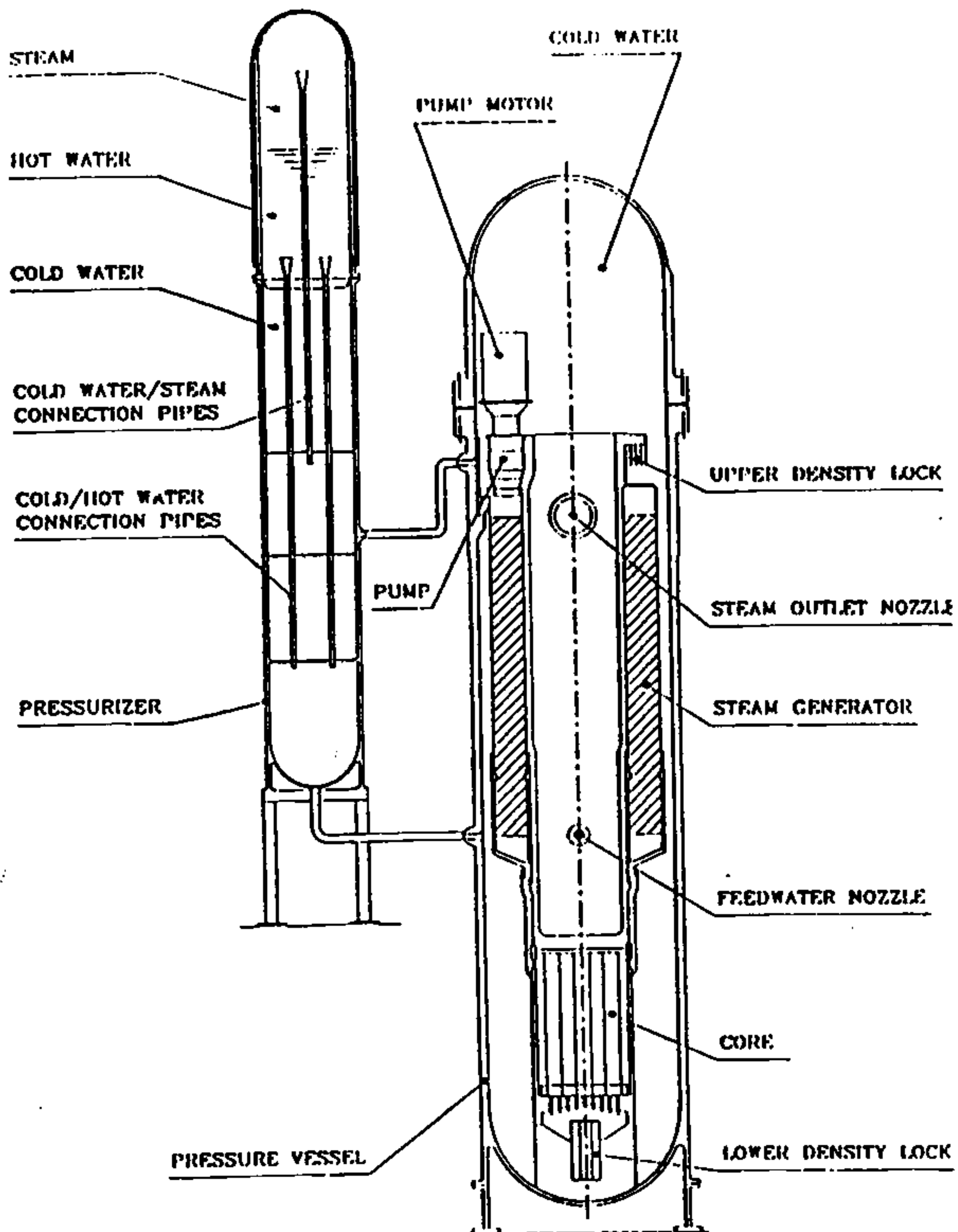


FIG. 2 : ISIS REACTOR MODULE

Table 3. Compressed Water and Superheated Steam (continued)

| 44 bar ($t_s = 256.107^\circ\text{C}$) | | | | | t ($^\circ\text{C}$) | 46 bar ($t_s = 258.817^\circ\text{C}$) | | | | |
|--|---------|---------|---------|---------|-----------------------------|--|---------|---------|---------|---------|
| v ($\times 10^3$) | ρ | h | u | s | | v ($\times 10^3$) | ρ | h | u | s |
| 1.26605 | 789.86 | 1115.16 | 1109.59 | 2.84832 | t_1 | 1.27279 | 785.67 | 1128.52 | 1122.67 | 2.87303 |
| 45.096 | 22.175 | 2798.3 | 2599.9 | 6.0285 | t_2 | 43.053 | 23.227 | 2796.9 | 2598.8 | 6.0093 |
| 0.99800 | 1002.01 | 4.44 | 0.05 | 0.00016 | 0 | 0.99790 | 1002.11 | 4.64 | 0.05 | 0.00017 |
| 0.99791 | 1002.10 | 25.39 | 21.00 | 0.07618 | 5 | 0.99781 | 1002.19 | 25.59 | 21.00 | 0.07617 |
| 0.99822 | 1001.78 | 46.27 | 41.88 | 0.15056 | 10 | 0.99813 | 1001.88 | 46.46 | 41.87 | 0.15054 |
| 0.99887 | 1001.13 | 67.12 | 62.72 | 0.22355 | 15 | 0.99878 | 1001.22 | 67.31 | 62.71 | 0.22352 |
| 0.99981 | 1000.19 | 87.96 | 83.56 | 0.29527 | 20 | 0.99972 | 1000.28 | 88.15 | 83.55 | 0.29523 |
| 1.00101 | 998.99 | 108.81 | 104.41 | 0.36580 | 25 | 1.00092 | 999.08 | 109.00 | 104.39 | 0.36575 |
| 1.00245 | 997.56 | 129.67 | 125.26 | 0.43518 | 30 | 1.00236 | 997.65 | 129.85 | 125.24 | 0.43512 |
| 1.00410 | 995.92 | 150.53 | 146.11 | 0.50342 | 35 | 1.00401 | 996.01 | 150.71 | 146.09 | 0.50335 |
| 1.00595 | 994.09 | 171.39 | 166.96 | 0.57058 | 40 | 1.00586 | 994.18 | 171.57 | 166.94 | 0.57050 |
| 1.00799 | 992.08 | 192.25 | 187.81 | 0.63666 | 45 | 1.00790 | 992.16 | 192.42 | 187.79 | 0.63658 |
| 1.01020 | 989.90 | 213.11 | 208.66 | 0.70171 | 50 | 1.01012 | 989.99 | 213.28 | 208.63 | 0.70162 |
| 1.01260 | 987.56 | 233.97 | 229.51 | 0.76577 | 55 | 1.01251 | 987.65 | 234.14 | 229.48 | 0.76567 |
| 1.01515 | 985.07 | 254.83 | 250.37 | 0.82887 | 60 | 1.01506 | 985.16 | 255.00 | 250.33 | 0.82876 |
| 1.01787 | 982.44 | 275.70 | 271.22 | 0.89105 | 65 | 1.01778 | 982.53 | 275.87 | 271.19 | 0.89094 |
| 1.02075 | 979.67 | 296.58 | 292.09 | 0.95235 | 70 | 1.02066 | 979.76 | 296.75 | 292.05 | 0.95223 |
| 1.02378 | 976.77 | 317.48 | 312.97 | 1.01280 | 75 | 1.02369 | 976.86 | 317.64 | 312.93 | 1.01268 |
| 1.02697 | 973.74 | 338.39 | 333.87 | 1.07244 | 80 | 1.02688 | 973.83 | 338.55 | 333.83 | 1.07231 |
| 1.03031 | 970.58 | 359.33 | 354.79 | 1.13131 | 85 | 1.03021 | 970.67 | 359.48 | 354.75 | 1.13117 |
| 1.03380 | 967.31 | 380.29 | 375.74 | 1.18943 | 90 | 1.03370 | 967.40 | 380.44 | 375.69 | 1.18929 |
| 1.03744 | 963.91 | 401.28 | 396.71 | 1.24683 | 95 | 1.03734 | 964.00 | 401.43 | 396.66 | 1.24668 |
| 1.04123 | 960.40 | 422.30 | 417.71 | 1.30354 | 100 | 1.04113 | 960.49 | 422.45 | 417.66 | 1.30339 |
| 1.04517 | 956.78 | 443.35 | 438.75 | 1.35959 | 105 | 1.04507 | 956.87 | 443.50 | 438.69 | 1.35943 |
| 1.04927 | 953.04 | 464.44 | 459.82 | 1.41499 | 110 | 1.04916 | 953.14 | 464.59 | 459.76 | 1.41483 |
| 1.05352 | 949.20 | 485.57 | 480.93 | 1.46978 | 115 | 1.05341 | 949.30 | 485.71 | 480.87 | 1.46961 |
| 1.05792 | 945.25 | 506.74 | 502.08 | 1.52397 | 120 | 1.05781 | 945.35 | 506.88 | 502.01 | 1.52379 |
| 1.06249 | 941.19 | 527.95 | 523.27 | 1.57758 | 125 | 1.06237 | 941.29 | 528.09 | 523.20 | 1.57740 |
| 1.06721 | 937.02 | 549.21 | 544.51 | 1.63064 | 130 | 1.06710 | 937.12 | 549.34 | 544.43 | 1.63045 |
| 1.07210 | 932.74 | 570.51 | 565.80 | 1.68317 | 135 | 1.07198 | 932.85 | 570.65 | 565.71 | 1.68297 |
| 1.07717 | 928.36 | 591.87 | 587.13 | 1.73517 | 140 | 1.07704 | 928.47 | 592.00 | 587.05 | 1.73497 |
| 1.08240 | 923.87 | 613.28 | 608.52 | 1.78668 | 145 | 1.08227 | 923.98 | 613.41 | 608.43 | 1.78647 |
| 1.08781 | 919.28 | 634.75 | 629.96 | 1.83772 | 150 | 1.08768 | 919.39 | 634.87 | 629.87 | 1.83750 |
| 1.09341 | 914.57 | 656.27 | 651.46 | 1.88830 | 155 | 1.09328 | 914.68 | 656.40 | 651.37 | 1.88807 |
| 1.09920 | 909.75 | 677.87 | 673.03 | 1.93844 | 160 | 1.09906 | 909.87 | 677.99 | 672.93 | 1.93820 |
| 1.10519 | 904.82 | 699.53 | 694.67 | 1.98816 | 165 | 1.10505 | 904.94 | 699.64 | 694.56 | 1.98791 |
| 1.11139 | 899.77 | 721.26 | 716.37 | 2.03748 | 170 | 1.11124 | 899.90 | 721.37 | 716.26 | 2.03723 |
| 1.11781 | 894.61 | 743.08 | 738.16 | 2.08643 | 175 | 1.11765 | 894.74 | 743.18 | 738.04 | 2.08617 |
| 1.12445 | 889.32 | 764.97 | 760.03 | 2.13502 | 180 | 1.12428 | 889.45 | 765.08 | 759.90 | 2.13475 |
| 1.13133 | 883.91 | 786.96 | 781.98 | 2.18328 | 185 | 1.13116 | 884.05 | 787.06 | 781.86 | 2.18300 |
| 1.13846 | 878.38 | 809.05 | 804.04 | 2.23122 | 190 | 1.13828 | 878.52 | 809.14 | 803.91 | 2.23093 |
| 1.14586 | 872.71 | 831.24 | 826.20 | 2.27888 | 195 | 1.14567 | 872.85 | 831.33 | 826.06 | 2.27858 |
| 1.15353 | 866.90 | 853.54 | 848.47 | 2.32627 | 200 | 1.15333 | 867.05 | 853.63 | 848.32 | 2.32596 |
| 1.16150 | 860.95 | 875.97 | 870.86 | 2.37342 | 205 | 1.16129 | 861.11 | 876.05 | 870.70 | 2.37309 |
| 1.16979 | 854.85 | 898.53 | 893.38 | 2.42035 | 210 | 1.16957 | 855.01 | 898.60 | 893.22 | 2.42001 |
| 1.17842 | 848.60 | 921.23 | 916.04 | 2.46709 | 215 | 1.17818 | 848.76 | 921.29 | 915.87 | 2.46674 |
| 1.18740 | 842.18 | 944.08 | 938.86 | 2.51368 | 220 | 1.18715 | 842.35 | 944.14 | 938.68 | 2.51331 |
| 1.19677 | 835.58 | 967.11 | 961.84 | 2.56013 | 225 | 1.19651 | 835.76 | 967.16 | 961.65 | 2.55974 |
| 1.20656 | 828.80 | 990.31 | 985.00 | 2.60648 | 230 | 1.20629 | 828.99 | 990.35 | 984.80 | 2.60608 |
| 1.21681 | 821.82 | 1013.72 | 1008.36 | 2.65276 | 235 | 1.21651 | 822.02 | 1013.75 | 1008.15 | 2.65234 |
| 1.22754 | 814.64 | 1037.34 | 1031.93 | 2.69902 | 240 | 1.22722 | 814.85 | 1037.36 | 1031.71 | 2.69858 |
| 1.23881 | 807.23 | 1061.19 | 1055.74 | 2.74528 | 245 | 1.23847 | 807.45 | 1061.20 | 1055.50 | 2.74482 |
| 1.25067 | 799.57 | 1085.31 | 1079.81 | 2.79160 | 250 | 1.25031 | 799.80 | 1085.30 | 1079.55 | 2.79111 |
| 1.26318 | 791.65 | 1109.71 | 1104.15 | 2.83802 | 255 | 1.26279 | 791.90 | 1109.69 | 1103.88 | 2.83751 |
| 45.863 | 21.804 | 2813.4 | 2611.6 | 6.0569 | 260 | 43.283 | 23.104 | 2801.6 | 2602.5 | 6.0182 |
| 46.812 | 21.362 | 2831.9 | 2626.0 | 6.0916 | 265 | 44.228 | 22.610 | 2821.1 | 2617.6 | 6.0544 |
| 47.728 | 20.952 | 2849.8 | 2639.8 | 6.1246 | 270 | 45.137 | 22.155 | 2839.6 | 2632.0 | 6.0888 |
| 48.612 | 20.571 | 2867.0 | 2653.1 | 6.1560 | 275 | 46.013 | 21.733 | 2857.4 | 2645.8 | 6.1214 |
| 49.471 | 20.214 | 2883.6 | 2665.9 | 6.1862 | 280 | 46.860 | 21.340 | 2874.6 | 2659.1 | 6.1526 |
| 50.307 | 19.878 | 2899.7 | 2678.4 | 6.2152 | 285 | 47.680 | 20.973 | 2891.2 | 2671.9 | 6.1826 |
| 51.122 | 19.561 | 2915.4 | 2690.5 | 6.2432 | 290 | 48.482 | 20.626 | 2907.4 | 2684.4 | 6.2113 |
| 51.918 | 19.261 | 2930.7 | 2702.2 | 6.2703 | 295 | 49.261 | 20.300 | 2923.1 | 2696.5 | 6.2391 |

Table 3. Compressed Water and Superheated Steam (continued)

| 44 bar | | | | | t (°C) | 46 bar | | | | |
|------------------------|--------|--------|--------|--------|-----------|------------------------|--------|--------|--------|--------|
| v (× 10 ³) | ρ | h | u | s | | v (× 10 ³) | ρ | h | u | s |
| 52.70 | 18.976 | 2945.6 | 2713.8 | 6.2965 | 300 | 50.03 | 19.990 | 2938.4 | 2708.3 | 6.2660 |
| 53.46 | 18.705 | 2960.3 | 2725.1 | 6.3219 | 305 | 50.77 | 19.696 | 2953.4 | 2719.8 | 6.2920 |
| 54.21 | 18.446 | 2974.7 | 2736.1 | 6.3467 | 310 | 51.51 | 19.415 | 2968.1 | 2731.1 | 6.3173 |
| 54.95 | 18.198 | 2988.8 | 2747.0 | 6.3708 | 315 | 52.23 | 19.148 | 2982.5 | 2742.2 | 6.3418 |
| 55.68 | 17.960 | 3002.7 | 2757.7 | 6.3943 | 320 | 52.93 | 18.891 | 2996.6 | 2753.1 | 6.3658 |
| 56.40 | 17.732 | 3016.4 | 2768.2 | 6.4173 | 325 | 53.63 | 18.646 | 3010.6 | 2763.9 | 6.3892 |
| 57.10 | 17.512 | 3029.9 | 2778.6 | 6.4398 | 330 | 54.32 | 18.410 | 3024.3 | 2774.4 | 6.4121 |
| 57.80 | 17.300 | 3043.2 | 2788.9 | 6.4618 | 335 | 55.00 | 18.182 | 3037.8 | 2784.8 | 6.4344 |
| 58.49 | 17.096 | 3056.4 | 2799.0 | 6.4834 | 340 | 55.67 | 17.964 | 3051.2 | 2795.1 | 6.4563 |
| 59.18 | 16.899 | 3069.4 | 2809.0 | 6.5046 | 345 | 56.33 | 17.752 | 3064.4 | 2805.3 | 6.4778 |
| 59.85 | 16.708 | 3082.3 | 2819.0 | 6.5254 | 350 | 56.99 | 17.548 | 3077.5 | 2815.4 | 6.4989 |
| 60.52 | 16.523 | 3095.1 | 2828.8 | 6.5458 | 355 | 57.63 | 17.351 | 3090.5 | 2825.3 | 6.5196 |
| 61.19 | 16.344 | 3107.8 | 2838.6 | 6.5659 | 360 | 58.28 | 17.159 | 3103.3 | 2835.2 | 6.5399 |
| 61.84 | 16.170 | 3120.4 | 2848.3 | 6.5857 | 365 | 58.91 | 16.974 | 3116.0 | 2845.0 | 6.5600 |
| 62.50 | 16.001 | 3132.9 | 2857.9 | 6.6052 | 370 | 59.55 | 16.794 | 3128.7 | 2854.7 | 6.5797 |
| 63.14 | 15.837 | 3145.3 | 2867.5 | 6.6245 | 375 | 60.17 | 16.619 | 3141.2 | 2864.4 | 6.5991 |
| 63.79 | 15.677 | 3157.6 | 2877.0 | 6.6434 | 380 | 60.79 | 16.449 | 3153.6 | 2874.0 | 6.6182 |
| 64.43 | 15.522 | 3169.9 | 2886.4 | 6.6621 | 385 | 61.41 | 16.284 | 3166.0 | 2883.5 | 6.6371 |
| 65.06 | 15.370 | 3182.1 | 2895.8 | 6.6806 | 390 | 62.02 | 16.123 | 3178.3 | 2893.0 | 6.6557 |
| 65.69 | 15.223 | 3194.2 | 2905.2 | 6.6988 | 395 | 62.63 | 15.967 | 3190.6 | 2902.5 | 6.6741 |
| 66.32 | 15.079 | 3206.3 | 2914.5 | 6.7168 | 400 | 63.24 | 15.814 | 3202.7 | 2911.8 | 6.6923 |
| 67.56 | 14.801 | 3230.3 | 2933.0 | 6.7522 | 410 | 64.44 | 15.519 | 3226.9 | 2930.5 | 6.7279 |
| 68.79 | 14.537 | 3254.1 | 2951.4 | 6.7868 | 420 | 65.62 | 15.239 | 3250.9 | 2949.0 | 6.7628 |
| 70.01 | 14.283 | 3277.8 | 2969.8 | 6.8207 | 430 | 66.80 | 14.971 | 3274.7 | 2967.5 | 6.7969 |
| 71.22 | 14.041 | 3301.3 | 2988.0 | 6.8540 | 440 | 67.96 | 14.714 | 3298.4 | 2985.8 | 6.8303 |
| 72.42 | 13.808 | 3324.8 | 3006.1 | 6.8866 | 450 | 69.12 | 14.468 | 3322.0 | 3004.0 | 6.8631 |
| 73.61 | 13.585 | 3348.1 | 3024.2 | 6.9186 | 460 | 70.26 | 14.232 | 3345.4 | 3022.2 | 6.8954 |
| 74.79 | 13.370 | 3371.4 | 3042.3 | 6.9502 | 470 | 71.40 | 14.006 | 3368.8 | 3040.3 | 6.9270 |
| 75.97 | 13.163 | 3394.6 | 3060.3 | 6.9812 | 480 | 72.53 | 13.787 | 3392.1 | 3058.4 | 6.9582 |
| 77.14 | 12.963 | 3417.7 | 3078.3 | 7.0117 | 490 | 73.66 | 13.577 | 3415.3 | 3076.5 | 6.9888 |
| 78.30 | 12.771 | 3440.8 | 3096.3 | 7.0418 | 500 | 74.77 | 13.374 | 3438.5 | 3094.6 | 7.0190 |
| 80.61 | 12.405 | 3486.9 | 3132.2 | 7.1006 | 520 | 76.99 | 12.988 | 3484.8 | 3130.6 | 7.0781 |
| 82.90 | 12.062 | 3532.9 | 3168.2 | 7.1579 | 540 | 79.19 | 12.627 | 3531.0 | 3166.7 | 7.1356 |
| 85.18 | 11.740 | 3579.0 | 3204.2 | 7.2138 | 560 | 81.38 | 12.289 | 3577.1 | 3202.8 | 7.1917 |
| 87.44 | 11.437 | 3625.0 | 3240.3 | 7.2684 | 580 | 83.54 | 11.970 | 3623.3 | 3239.0 | 7.2464 |
| 89.68 | 11.151 | 3671.1 | 3276.5 | 7.3219 | 600 | 85.70 | 11.669 | 3669.5 | 3275.3 | 7.2999 |
| 91.91 | 10.880 | 3717.3 | 3312.8 | 7.3741 | 620 | 87.84 | 11.384 | 3715.7 | 3311.7 | 7.3523 |
| 94.14 | 10.623 | 3763.6 | 3349.4 | 7.4254 | 640 | 89.97 | 11.115 | 3762.1 | 3348.3 | 7.4037 |
| 96.35 | 10.379 | 3810.0 | 3386.0 | 7.4757 | 660 | 92.09 | 10.858 | 3808.6 | 3385.0 | 7.4541 |
| 98.56 | 10.147 | 3856.5 | 3422.9 | 7.5251 | 680 | 94.21 | 10.615 | 3855.3 | 3421.9 | 7.5035 |
| 100.75 | 9.925 | 3903.3 | 3460.0 | 7.5736 | 700 | 96.32 | 10.383 | 3902.1 | 3459.0 | 7.5521 |
| 102.95 | 9.714 | 3950.2 | 3497.2 | 7.6213 | 720 | 98.42 | 10.161 | 3949.1 | 3496.3 | 7.5999 |
| 105.13 | 9.512 | 3997.3 | 3534.7 | 7.6683 | 740 | 100.51 | 9.949 | 3996.2 | 3533.9 | 7.6469 |
| 107.31 | 9.319 | 4044.6 | 3572.4 | 7.7145 | 760 | 102.60 | 9.747 | 4043.6 | 3571.6 | 7.6932 |
| 109.48 | 9.134 | 4092.1 | 3610.4 | 7.7600 | 780 | 104.68 | 9.553 | 4091.1 | 3609.6 | 7.7388 |
| 111.65 | 8.956 | 4139.8 | 3648.5 | 7.8049 | 800 | 106.76 | 9.367 | 4138.9 | 3647.8 | 7.7837 |
| 117.06 | 8.543 | 4260.0 | 3745.0 | 7.9144 | 850 | 111.94 | 8.933 | 4259.2 | 3744.3 | 7.8933 |
| 122.45 | 8.167 | 4381.7 | 3842.9 | 8.0203 | 900 | 117.10 | 8.540 | 4380.9 | 3842.3 | 7.9993 |
| 127.81 | 7.824 | 4504.7 | 3942.3 | 8.1231 | 950 | 122.24 | 8.181 | 4504.1 | 3941.8 | 8.1021 |
| 133.17 | 7.509 | 4629.2 | 4043.3 | 8.2228 | 1000 | 127.36 | 7.852 | 4628.6 | 4042.8 | 8.2019 |
| 141.84 | 6.952 | 4882.5 | 4249.6 | 8.4143 | 1100 | 137.58 | 7.269 | 4882.0 | 4249.2 | 8.3935 |
| 144.48 | 6.473 | 5141.4 | 4461.7 | 8.5963 | 1200 | 147.76 | 6.768 | 5141.0 | 4461.3 | 8.5755 |
| 145.09 | 6.057 | 5405.5 | 4679.2 | 8.7697 | 1300 | 157.91 | 6.333 | 5405.2 | 4678.8 | 8.7490 |
| 145.68 | 5.692 | 5674.7 | 4901.7 | 8.9356 | 1400 | 168.05 | 5.951 | 5674.4 | 4901.4 | 8.9149 |
| 146.25 | 5.369 | 5948.4 | 5128.9 | 9.0945 | 1500 | 178.16 | 5.613 | 5948.2 | 5128.6 | 9.0738 |
| 146.81 | 5.0810 | 6226.4 | 5360.4 | 9.2470 | 1600 | 188.27 | 5.3115 | 6226.2 | 5360.2 | 9.2263 |
| 147.36 | 4.8224 | 6508.4 | 5596.0 | 9.3936 | 1700 | 198.37 | 5.0412 | 6508.2 | 5595.7 | 9.3730 |
| 147.91 | 4.5891 | 6793.9 | 5835.1 | 9.5348 | 1800 | 208.45 | 4.7972 | 6793.8 | 5834.9 | 9.5142 |
| 148.45 | 4.3774 | 7082.9 | 6077.8 | 9.6709 | 1900 | 218.54 | 4.5759 | 7082.8 | 6077.6 | 9.6503 |
| 148.98 | 4.1845 | 7375.0 | 6323.5 | 9.8024 | 2000 | 228.61 | 4.3742 | 7375.0 | 6323.4 | 9.7818 |

Table 3. Compressed Water and Superheated Steam (continued)

| 140 bar ($t_s = 336.701\text{ }^\circ\text{C}$) | | | | | t ($^\circ\text{C}$) | 142 bar ($t_s = 337.824\text{ }^\circ\text{C}$) | | | | |
|---|---------|--------|--------|---------|-----------------------------|---|---------|--------|--------|---------|
| v ($\times 10^3$) | ρ | h | u | s | | v ($\times 10^3$) | ρ | h | u | s |
| 1.6096 | 621.3 | 1570.4 | 1547.9 | 3.6220 | t_1 | 1.6188 | 617.8 | 1578.3 | 1555.3 | 3.6344 |
| 11.485 | 87.07 | 2637.1 | 2476.3 | 5.3711 | t_2 | 11.245 | 88.93 | 2631.9 | 2472.2 | 5.3589 |
| 0.99325 | 1006.79 | 14.11 | 0.21 | 0.00058 | 0 | 0.99316 | 1006.89 | 14.31 | 0.21 | 0.00058 |
| 0.99333 | 1006.71 | 34.85 | 20.94 | 0.07580 | 5 | 0.99324 | 1006.81 | 35.04 | 20.94 | 0.07579 |
| 0.99377 | 1006.27 | 55.53 | 41.62 | 0.14952 | 10 | 0.99368 | 1006.36 | 55.73 | 41.62 | 0.14949 |
| 0.99451 | 1005.52 | 76.22 | 62.30 | 0.22193 | 15 | 0.99442 | 1005.61 | 76.41 | 62.29 | 0.22189 |
| 0.99553 | 1004.49 | 96.92 | 82.98 | 0.29315 | 20 | 0.99544 | 1004.58 | 97.10 | 82.97 | 0.29310 |
| 0.99678 | 1003.23 | 117.63 | 103.68 | 0.36322 | 25 | 0.99669 | 1003.32 | 117.82 | 103.66 | 0.36317 |
| 0.99825 | 1001.75 | 138.37 | 124.39 | 0.43218 | 30 | 0.99816 | 1001.84 | 138.55 | 124.37 | 0.43212 |
| 0.99992 | 1000.08 | 159.11 | 145.11 | 0.50004 | 35 | 0.99984 | 1000.16 | 159.29 | 145.09 | 0.49997 |
| 1.00178 | 998.22 | 179.86 | 165.83 | 0.56683 | 40 | 1.00170 | 998.30 | 180.03 | 165.81 | 0.56676 |
| 1.00382 | 996.19 | 200.61 | 186.55 | 0.63258 | 45 | 1.00374 | 996.28 | 200.78 | 186.53 | 0.63249 |
| 1.00603 | 994.01 | 221.36 | 207.28 | 0.69730 | 50 | 1.00595 | 994.09 | 221.53 | 207.25 | 0.69721 |
| 1.00840 | 991.67 | 242.12 | 228.00 | 0.76104 | 55 | 1.00832 | 991.75 | 242.29 | 227.97 | 0.76094 |
| 1.01093 | 989.19 | 262.88 | 248.73 | 0.82383 | 60 | 1.01084 | 989.27 | 263.05 | 248.69 | 0.82373 |
| 1.01361 | 986.57 | 283.65 | 269.46 | 0.88572 | 65 | 1.01353 | 986.65 | 283.81 | 269.42 | 0.88560 |
| 1.01645 | 983.82 | 304.43 | 290.20 | 0.94672 | 70 | 1.01636 | 983.91 | 304.59 | 290.16 | 0.94660 |
| 1.01943 | 980.94 | 325.23 | 310.95 | 1.00689 | 75 | 1.01934 | 981.03 | 325.39 | 310.91 | 1.00676 |
| 1.02255 | 977.95 | 346.04 | 331.72 | 1.06624 | 80 | 1.02246 | 978.03 | 346.20 | 331.68 | 1.06611 |
| 1.02582 | 974.83 | 366.87 | 352.51 | 1.12483 | 85 | 1.02573 | 974.92 | 367.03 | 352.47 | 1.12469 |
| 1.02924 | 971.60 | 387.73 | 373.32 | 1.18266 | 90 | 1.02914 | 971.68 | 387.89 | 373.27 | 1.18252 |
| 1.03279 | 968.25 | 408.62 | 394.16 | 1.23978 | 95 | 1.03270 | 968.34 | 408.77 | 394.11 | 1.23964 |
| 1.03649 | 964.80 | 429.53 | 415.02 | 1.29621 | 100 | 1.03639 | 964.89 | 429.69 | 414.97 | 1.29606 |
| 1.04033 | 961.23 | 450.48 | 435.92 | 1.35198 | 105 | 1.04023 | 961.32 | 450.63 | 435.86 | 1.35182 |
| 1.04432 | 957.56 | 471.46 | 456.84 | 1.40709 | 110 | 1.04421 | 957.66 | 471.61 | 456.78 | 1.40693 |
| 1.04845 | 953.79 | 492.48 | 477.80 | 1.46159 | 115 | 1.04834 | 953.89 | 492.62 | 477.74 | 1.46142 |
| 1.05272 | 949.92 | 513.53 | 498.80 | 1.51549 | 120 | 1.05262 | 950.01 | 513.68 | 498.73 | 1.51532 |
| 1.05715 | 945.94 | 534.63 | 519.83 | 1.56881 | 125 | 1.05704 | 946.04 | 534.77 | 519.76 | 1.56863 |
| 1.06173 | 941.86 | 555.76 | 540.90 | 1.62156 | 130 | 1.06161 | 941.96 | 555.90 | 540.83 | 1.62138 |
| 1.06646 | 937.68 | 576.94 | 562.01 | 1.67378 | 135 | 1.06634 | 937.79 | 577.08 | 561.94 | 1.67358 |
| 1.07135 | 933.41 | 598.17 | 583.17 | 1.72547 | 140 | 1.07123 | 933.51 | 598.30 | 583.09 | 1.72527 |
| 1.07640 | 929.03 | 619.45 | 604.38 | 1.77665 | 145 | 1.07627 | 929.13 | 619.58 | 604.29 | 1.77645 |
| 1.0816 | 924.5 | 640.8 | 625.6 | 1.8273 | 150 | 1.0815 | 924.7 | 640.9 | 625.5 | 1.8271 |
| 1.0870 | 920.0 | 662.2 | 646.9 | 1.8776 | 155 | 1.0869 | 920.1 | 662.3 | 646.8 | 1.8774 |
| 1.0926 | 915.3 | 683.6 | 668.3 | 1.9274 | 160 | 1.0924 | 915.4 | 683.7 | 668.2 | 1.9271 |
| 1.0983 | 910.5 | 705.1 | 689.7 | 1.9767 | 165 | 1.0982 | 910.6 | 705.2 | 689.6 | 1.9765 |
| 1.1042 | 905.6 | 726.7 | 711.2 | 2.0256 | 170 | 1.1041 | 905.7 | 726.8 | 711.1 | 2.0254 |
| 1.1104 | 900.6 | 748.3 | 732.7 | 2.0742 | 175 | 1.1102 | 900.7 | 748.4 | 732.6 | 2.0739 |
| 1.1167 | 895.5 | 770.0 | 754.4 | 2.1224 | 180 | 1.1166 | 895.6 | 770.1 | 754.2 | 2.1221 |
| 1.1233 | 890.3 | 791.8 | 776.1 | 2.1702 | 185 | 1.1231 | 890.4 | 791.9 | 775.9 | 2.1699 |
| 1.1300 | 884.9 | 813.6 | 797.8 | 2.2176 | 190 | 1.1299 | 885.1 | 813.7 | 797.7 | 2.2174 |
| 1.1370 | 879.5 | 835.6 | 819.7 | 2.2648 | 195 | 1.1369 | 879.6 | 835.7 | 819.6 | 2.2645 |
| 1.1443 | 873.9 | 857.7 | 841.7 | 2.3117 | 200 | 1.1441 | 874.0 | 857.8 | 841.5 | 2.3114 |
| 1.1518 | 868.2 | 879.8 | 863.7 | 2.3583 | 205 | 1.1516 | 868.3 | 879.9 | 863.6 | 2.3580 |
| 1.1596 | 862.4 | 902.1 | 885.9 | 2.4046 | 210 | 1.1594 | 862.5 | 902.2 | 885.7 | 2.4043 |
| 1.1677 | 856.4 | 924.5 | 908.2 | 2.4508 | 215 | 1.1675 | 856.5 | 924.6 | 908.0 | 2.4504 |
| 1.1761 | 850.3 | 947.0 | 930.6 | 2.4967 | 220 | 1.1759 | 850.4 | 947.1 | 930.4 | 2.4963 |
| 1.1848 | 844.0 | 969.7 | 953.1 | 2.5424 | 225 | 1.1846 | 844.2 | 969.8 | 953.0 | 2.5421 |
| 1.1939 | 837.6 | 992.5 | 975.8 | 2.5880 | 230 | 1.1937 | 837.8 | 992.6 | 975.6 | 2.5876 |
| 1.2034 | 831.0 | 1015.5 | 998.7 | 2.6335 | 235 | 1.2031 | 831.2 | 1015.6 | 998.5 | 2.6331 |
| 1.2132 | 824.3 | 1038.7 | 1021.7 | 2.6788 | 240 | 1.2129 | 824.4 | 1038.7 | 1021.5 | 2.6784 |
| 1.2235 | 817.3 | 1062.0 | 1044.9 | 2.7241 | 245 | 1.2232 | 817.5 | 1062.1 | 1044.7 | 2.7237 |
| 1.2343 | 810.2 | 1085.6 | 1068.3 | 2.7694 | 250 | 1.2340 | 810.4 | 1085.6 | 1068.1 | 2.7689 |
| 1.2456 | 802.8 | 1109.4 | 1092.0 | 2.8146 | 255 | 1.2452 | 803.1 | 1109.4 | 1091.7 | 2.8142 |
| 1.2574 | 795.3 | 1133.4 | 1115.8 | 2.8599 | 260 | 1.2571 | 795.5 | 1133.4 | 1115.6 | 2.8595 |
| 1.2699 | 787.5 | 1157.7 | 1140.0 | 2.9053 | 265 | 1.2695 | 787.7 | 1157.7 | 1139.7 | 2.9048 |
| 1.2830 | 779.4 | 1182.4 | 1164.4 | 2.9508 | 270 | 1.2826 | 779.7 | 1182.3 | 1164.1 | 2.9503 |
| 1.2969 | 771.1 | 1207.3 | 1189.1 | 2.9965 | 275 | 1.2965 | 771.3 | 1207.2 | 1188.8 | 2.9959 |
| 1.3117 | 762.4 | 1232.6 | 1214.2 | 3.0424 | 280 | 1.3112 | 762.7 | 1232.5 | 1213.9 | 3.0418 |
| 1.3273 | 753.4 | 1258.3 | 1239.7 | 3.0887 | 285 | 1.3268 | 753.7 | 1258.2 | 1239.3 | 3.0880 |
| 1.3441 | 744.0 | 1284.4 | 1265.6 | 3.1353 | 290 | 1.3435 | 744.3 | 1284.3 | 1265.2 | 3.1346 |
| 1.3620 | 734.2 | 1311.0 | 1292.0 | 3.1824 | 295 | 1.3613 | 734.6 | 1310.9 | 1291.6 | 3.1817 |

Table 3. Compressed Water and Superheated Steam (continued)

| 140 bar | | | | | t (°C) | 142 bar | | | | |
|------------------------|-------|--------|--------|--------|-----------|------------------------|-------|--------|--------|--------|
| v (x 10 ³) | ρ | h | u | s | | v (x 10 ³) | ρ | h | u | s |
| 1.3814 | 723.9 | 1338.3 | 1318.9 | 3.2301 | 300 | 1.3806 | 724.3 | 1338.1 | 1318.5 | 3.2293 |
| 1.4024 | 713.1 | 1366.1 | 1346.5 | 3.2785 | 305 | 1.4015 | 713.5 | 1365.9 | 1346.0 | 3.2777 |
| 1.4254 | 701.6 | 1394.8 | 1374.8 | 3.3279 | 310 | 1.4244 | 702.1 | 1394.5 | 1374.3 | 3.3269 |
| 1.4507 | 689.3 | 1424.4 | 1404.1 | 3.3784 | 315 | 1.4496 | 689.8 | 1424.0 | 1403.5 | 3.3773 |
| 1.4790 | 676.1 | 1455.1 | 1434.4 | 3.4303 | 320 | 1.4777 | 676.7 | 1454.6 | 1433.7 | 3.4291 |
| 1.5111 | 661.8 | 1487.1 | 1466.0 | 3.4842 | 325 | 1.5095 | 662.5 | 1486.6 | 1465.2 | 3.4828 |
| 1.5482 | 645.9 | 1521.0 | 1499.3 | 3.5406 | 330 | 1.5462 | 646.7 | 1520.3 | 1498.4 | 3.5390 |
| 1.5924 | 628.0 | 1557.3 | 1535.0 | 3.6005 | 335 | 1.5898 | 629.0 | 1556.5 | 1533.9 | 3.5986 |
| 11.985 | 83.44 | 2670.6 | 2502.8 | 5.4258 | 340 | 11.585 | 86.32 | 2655.1 | 2490.6 | 5.3967 |
| 12.642 | 79.10 | 2713.9 | 2536.9 | 5.4962 | 345 | 12.269 | 81.51 | 2701.0 | 2526.8 | 5.4714 |
| 13.218 | 75.65 | 2751.3 | 2566.2 | 5.5565 | 350 | 12.860 | 77.76 | 2740.2 | 2557.6 | 5.5345 |
| 13.737 | 72.79 | 2784.7 | 2592.3 | 5.6098 | 355 | 13.389 | 74.69 | 2774.8 | 2584.7 | 5.5898 |
| 14.214 | 70.35 | 2815.0 | 2616.0 | 5.6580 | 360 | 13.873 | 72.08 | 2806.1 | 2609.1 | 5.6395 |
| 14.659 | 68.22 | 2843.0 | 2637.8 | 5.7020 | 365 | 14.322 | 69.82 | 2834.9 | 2631.5 | 5.6848 |
| 15.076 | 66.33 | 2869.2 | 2658.1 | 5.7429 | 370 | 14.743 | 67.83 | 2861.7 | 2652.3 | 5.7266 |
| 15.472 | 64.63 | 2893.8 | 2677.2 | 5.7810 | 375 | 15.141 | 66.05 | 2886.9 | 2671.9 | 5.7656 |
| 15.849 | 63.10 | 2917.2 | 2695.3 | 5.8170 | 380 | 15.519 | 64.44 | 2910.7 | 2690.3 | 5.8022 |
| 16.210 | 61.69 | 2939.5 | 2712.5 | 5.8509 | 385 | 15.881 | 62.97 | 2933.4 | 2707.8 | 5.8368 |
| 16.558 | 60.39 | 2960.8 | 2729.0 | 5.8833 | 390 | 16.229 | 61.62 | 2955.1 | 2724.6 | 5.8696 |
| 16.894 | 59.19 | 2981.4 | 2744.9 | 5.9142 | 395 | 16.565 | 60.37 | 2975.9 | 2740.7 | 5.9010 |
| 17.219 | 58.08 | 3001.3 | 2760.2 | 5.9438 | 400 | 16.889 | 59.21 | 2996.0 | 2756.2 | 5.9310 |
| 17.842 | 56.05 | 3039.2 | 2789.4 | 5.9997 | 410 | 17.511 | 57.11 | 3034.4 | 2785.8 | 5.9876 |
| 18.434 | 54.25 | 3075.1 | 2817.0 | 6.0519 | 420 | 18.101 | 55.25 | 3070.7 | 2813.7 | 6.0403 |
| 19.002 | 52.63 | 3109.4 | 2843.4 | 6.1011 | 430 | 18.665 | 53.58 | 3105.4 | 2840.4 | 6.0900 |
| 19.547 | 51.16 | 3142.5 | 2868.8 | 6.1477 | 440 | 19.208 | 52.06 | 3138.7 | 2865.9 | 6.1370 |
| 20.075 | 49.81 | 3174.4 | 2893.3 | 6.1922 | 450 | 19.732 | 50.68 | 3170.9 | 2890.7 | 6.1818 |
| 20.588 | 48.57 | 3205.4 | 2917.2 | 6.2348 | 460 | 20.241 | 49.40 | 3202.1 | 2914.7 | 6.2247 |
| 21.087 | 47.42 | 3235.6 | 2940.4 | 6.2757 | 470 | 20.736 | 48.23 | 3232.5 | 2938.0 | 6.2659 |
| 21.573 | 46.35 | 3265.2 | 2963.1 | 6.3152 | 480 | 21.219 | 47.13 | 3262.2 | 2960.9 | 6.3056 |
| 22.050 | 45.35 | 3294.1 | 2985.4 | 6.3534 | 490 | 21.691 | 46.10 | 3291.3 | 2983.3 | 6.3440 |
| 22.517 | 44.41 | 3322.6 | 3007.4 | 6.3905 | 500 | 22.154 | 45.14 | 3320.0 | 3005.4 | 6.3813 |
| 23.426 | 42.69 | 3378.3 | 3050.3 | 6.4616 | 520 | 23.055 | 43.37 | 3375.9 | 3048.5 | 6.4527 |
| 24.308 | 41.14 | 3432.6 | 3092.3 | 6.5293 | 540 | 23.928 | 41.79 | 3430.4 | 3090.7 | 6.5206 |
| 25.166 | 39.74 | 3485.9 | 3133.6 | 6.5940 | 560 | 24.778 | 40.36 | 3483.9 | 3132.1 | 6.5856 |
| 26.005 | 38.45 | 3538.4 | 3174.3 | 6.6563 | 580 | 25.608 | 39.05 | 3536.5 | 3172.9 | 6.6480 |
| 26.828 | 37.28 | 3590.3 | 3214.7 | 6.7163 | 600 | 26.421 | 37.85 | 3588.5 | 3213.3 | 6.7082 |
| 27.64 | 36.19 | 3641.6 | 3254.7 | 6.7745 | 620 | 27.22 | 36.74 | 3640.0 | 3253.4 | 6.7665 |
| 28.43 | 35.17 | 3692.5 | 3294.5 | 6.8309 | 640 | 28.01 | 35.71 | 3691.0 | 3293.3 | 6.8230 |
| 29.22 | 34.23 | 3743.2 | 3334.2 | 6.8858 | 660 | 28.78 | 34.74 | 3741.8 | 3333.1 | 6.8780 |
| 29.99 | 33.34 | 3793.6 | 3373.8 | 6.9392 | 680 | 29.55 | 33.84 | 3792.3 | 3372.7 | 6.9316 |
| 30.76 | 32.51 | 3843.9 | 3413.3 | 6.9914 | 700 | 30.30 | 33.00 | 3842.6 | 3412.3 | 6.9839 |
| 31.52 | 31.73 | 3894.1 | 3452.8 | 7.0425 | 720 | 31.05 | 32.20 | 3892.9 | 3451.9 | 7.0350 |
| 32.27 | 30.99 | 3944.1 | 3492.4 | 7.0924 | 740 | 31.80 | 31.45 | 3943.0 | 3491.5 | 7.0850 |
| 33.01 | 30.29 | 3994.2 | 3532.0 | 7.1413 | 760 | 32.53 | 30.74 | 3993.1 | 3531.2 | 7.1339 |
| 33.75 | 29.63 | 4044.3 | 3571.8 | 7.1893 | 780 | 33.26 | 30.06 | 4043.3 | 3570.9 | 7.1820 |
| 34.49 | 29.00 | 4094.4 | 3611.6 | 7.2364 | 800 | 33.99 | 29.42 | 4093.4 | 3610.8 | 7.2292 |
| 36.30 | 27.55 | 4219.9 | 3711.6 | 7.3507 | 850 | 35.78 | 27.95 | 4219.0 | 3710.9 | 7.3436 |
| 38.10 | 26.25 | 4346.0 | 3812.6 | 7.4606 | 900 | 37.55 | 26.63 | 4345.2 | 3812.0 | 7.4535 |
| 39.87 | 25.08 | 4472.8 | 3914.7 | 7.5665 | 950 | 39.30 | 25.44 | 4472.2 | 3914.1 | 7.5595 |
| 41.63 | 24.02 | 4600.7 | 4017.9 | 7.6689 | 1000 | 41.04 | 24.37 | 4600.1 | 4017.3 | 7.6619 |
| 45.11 | 22.17 | 4859. | 4228. | 7.864 | 1100 | 44.47 | 22.49 | 4859. | 4227. | 7.858 |
| 48.55 | 20.60 | 5122. | 4443. | 8.049 | 1200 | 47.87 | 20.89 | 5122. | 4442. | 8.043 |
| 51.97 | 19.24 | 5390. | 4662. | 8.225 | 1300 | 51.24 | 19.52 | 5390. | 4662. | 8.218 |
| 55.36 | 18.06 | 5662. | 4887. | 8.393 | 1400 | 54.59 | 18.32 | 5662. | 4886. | 8.386 |
| 58.74 | 17.02 | 5938. | 5116. | 8.553 | 1500 | 57.92 | 17.27 | 5938. | 5115. | 8.546 |
| 62.11 | 16.10 | 6218. | 5348. | 8.706 | 1600 | 61.24 | 16.33 | 6218. | 5348. | 8.700 |
| 65.47 | 15.28 | 6501. | 5585. | 8.854 | 1700 | 64.55 | 15.49 | 6501. | 5585. | 8.847 |
| 68.82 | 14.53 | 6788. | 5825. | 8.996 | 1800 | 67.85 | 14.74 | 6788. | 5825. | 8.989 |
| 72.16 | 13.86 | 7079. | 6068. | 9.132 | 1900 | 71.15 | 14.05 | 7079. | 6068. | 9.126 |
| 75.50 | 13.25 | 7372. | 6315. | 9.264 | 2000 | 74.44 | 13.43 | 7372. | 6315. | 9.258 |

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