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ORNL-TM-333

AN IBM 7090 FORTRAN PROGRAM FOR ASME UNFIRED PRESSURE VESSEL DESIGN AND PRELIMINARY COST ESTIMATION

C. E. Prince
R. P. Milford

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CHEMICAL TECHNOLOGY DIVISION

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ABSTRACT

An IBM 7090 Fortran program was written for the preliminary design and cost estimation of unfired pressure vessels with or without a jacket. Both vessel and jacket designs conform to the 1959 ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels. Vessels and jackets from 5 in. pipe through 84 in. o.d. and 1/4 in. through 1-1/2 in. in metal thickness may be designed by this program as written. Total vessel cost is the sum of metal and fabrication costs, each on a weight basis.

INTRODUCTION

The design of an unfired pressure vessel under external pressure using the ASME Code is a trial and error process involving several calculations and the use of charts. This process can become tedious and time consuming if several vessels are to be designed. The increasing availability and use of modern high speed computing machines have reduced the time and effort required for problems of a similar nature to a minimum. With this in mind, a Fortran program was written for use with the IBM 7090 computer which will make the necessary design and cost estimation calculations for these vessels.

DESIGN EQUATIONS AND CALCULATION TECHNIQUES

The calculations in this program are consistent with the rules set forth in the 1959 edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, for the calculation of wall and head thickness of thin shelled vessels subjected to internal or external pressure. Schematic diagrams in Fig. 1 and Fig. 2 show the type vessels this program will design.

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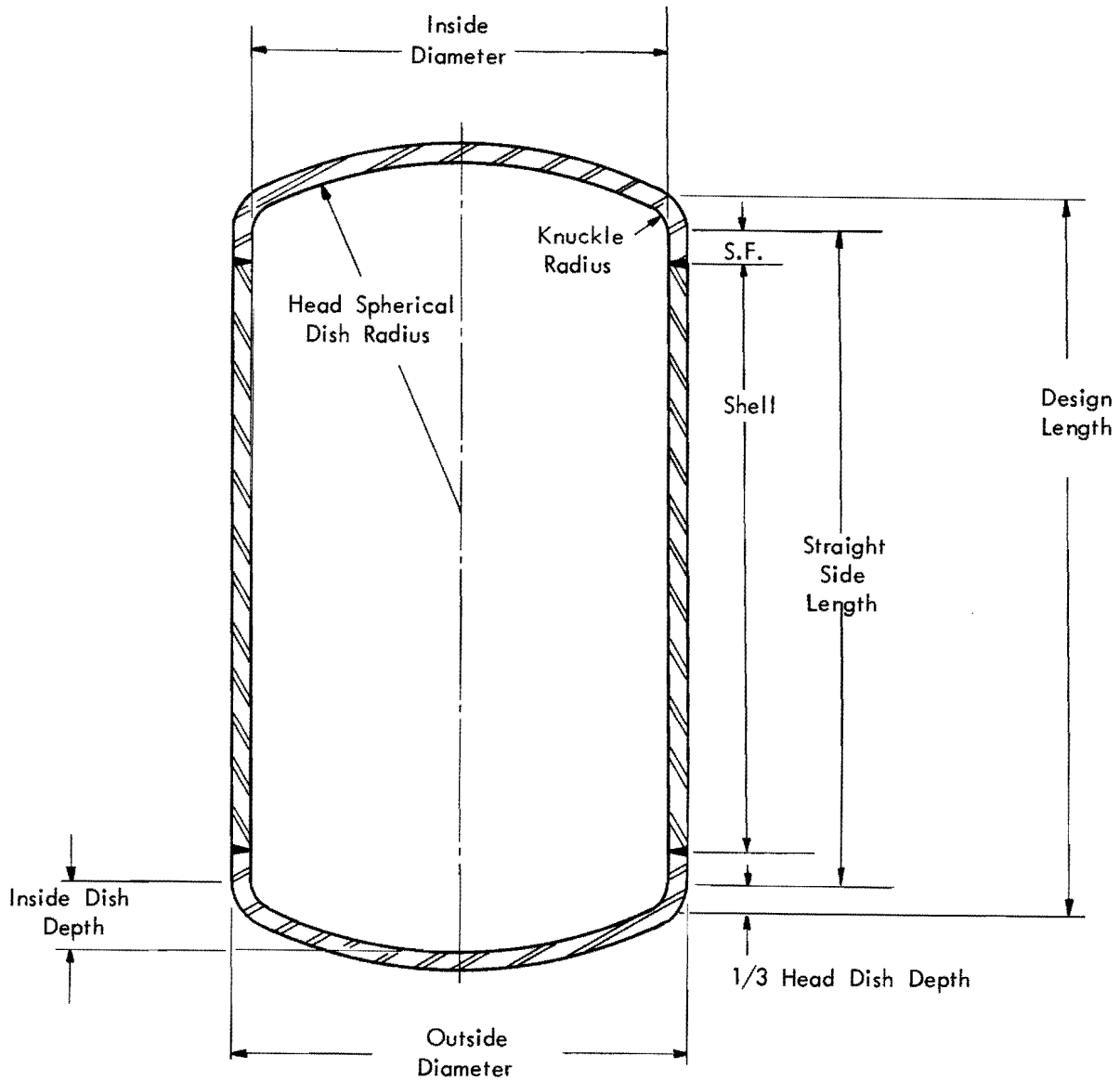

Fig. 1. Vessel with straight side/outside diameter ratio equal to or less than 4.0.

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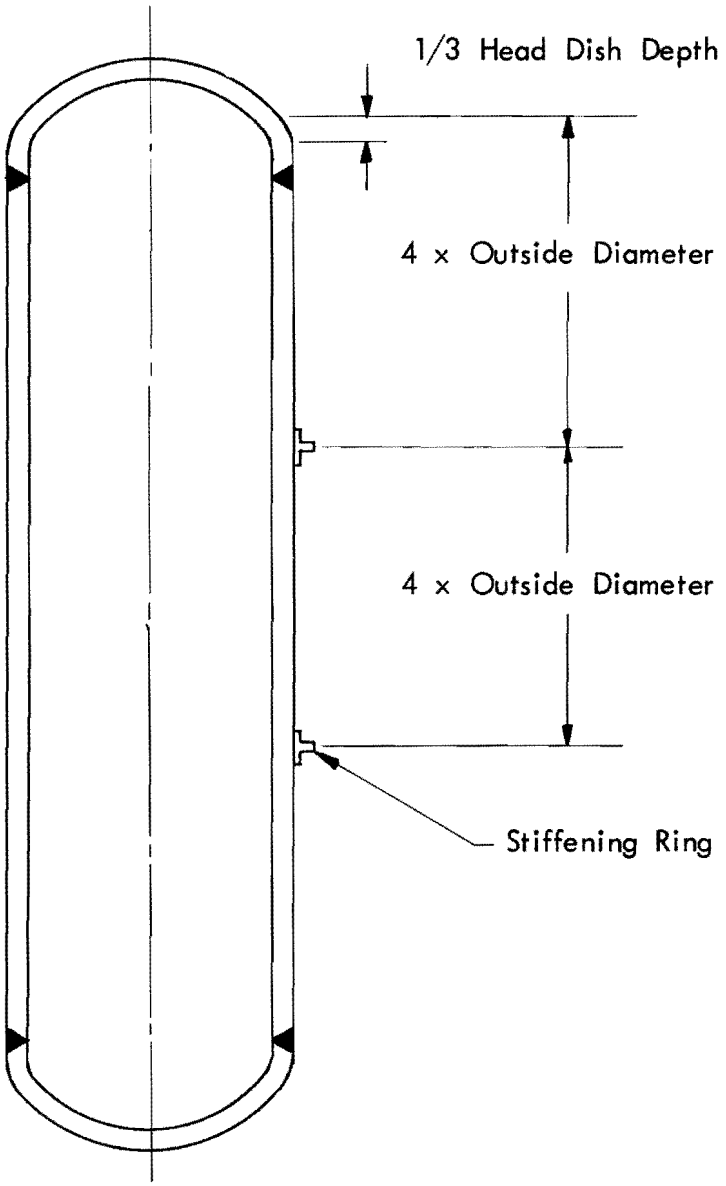

Note: For long vessels, stiffening rings are required every (4 x OD) in.

Fig. 2. Vessel with straight side/outside diameter ratio greater than 4.0.

Internal Pressure

From Ref. (1), par. UA-1 (1), the equation used for determining the shell thickness was:

$$t \doteq \frac{P\ R_o}{SE + 0.4\ P}, \qquad (1)$$

where

t = minimum required thickness of shell plates, exclusive of corrosion allowance,

P = design pressure, pounds per square inch,

R_o = outside radius of shell course,

S = maximum allowable stress value, pounds per square inch,

E = efficiency of longitudinal welded joints (Par. UW-12). (For seamless shells, use $E = 1.0$.)

From Par. US-4 (d), the equation for calculating the head thickness of an ASME type (torispherical) head was:

$$t = \frac{P\ L\ (0.25\ (3 + (\frac{L}{r})^{0.5}))}{2\ SE - 0.2\ P} \qquad (2)$$

where

t = minimum required thickness of head after forming, inches (exclusive of corrosion allowance),

P = design pressure, pounds per square inch,

L = inside spherical head radius, inches,

r = inside knuckle radius, inches,

S, E = same as in Equation (1).

External Pressure

The charts in Appendix V of Ref. (1) show the relationship of ratio of the compressive stress to tangent modulus of elasticity (S/E) to the dimensional ratios of length to outside diameter (L/D) and thickness to outside diameter (t/D). The latter two are properties which depend upon the geometry of the system and are the same for all materials. The

portion of the chart in the range of this study lies between the L/D ratios of 0.8 and 4.0. Vessels in this area are below the critical length and failure takes place at the yield stress which is assumed to be constant. These curves can be represented by the following equation, Ref. (2):

$$\frac{S}{E} = \frac{1.30\ (t/D)^{1.5}}{L/D - 0.45\ (t/D)^{0.5}} \qquad (3)$$

where

- t = minimum required shell thickness in inches, exclusive of corrosion allowance,
- S = compressive stress, psi,
- E = tangent modulus of elasticity and must be essentially constant throughout the range in question,
- D = outside diameter, inches,
- L = design length of a vessel section, taken as the largest of the following:
  - (1) the distance between head bend lines plus 1/3 of the depth of each head if there are no stiffening rings;
  - (2) if stiffening rings are required, the design length was taken as four times the outside diameter. Neither the center-to-center distance between any two adjacent stiffening rings nor the distance from the center of the first stiffening ring to the head-bend line plus 1/3 the depth of the head may exceed this distance. All measurements are taken parallel to the axis of the vessel, in inches.

Also shown on the chart are the properties that are dependent upon the material itself. These may be represented by the equation, Ref. (2):

$$S/E = \frac{2\ P\ D}{E\ t} \qquad (4)$$

where

S, E, D, and t are the same as in the above geometry dependent formula (Equation 3), and

P = maximum allowable working pressure (includes safety factor of 4), psi.

The thicknesses of ASME type heads are calculated from equations (5) and (6). Equation (5) was developed from the charts in Appendix V of Ref. (1) and equation (6) from the same reference and its similarity to equation (4), Ref. (1):

$$S/E = \frac{0.12\ t_h}{L_1} \tag{5}$$

and

$$S/E = \frac{2\ P\ L_1}{E\ t_h} \tag{6}$$

where

S, E, and P are the same as in equation (4),

L_1 = inside spherical radius of the head, inches,

t_h = minimum head thickness, exclusive of corrosion allowance, in inches.

To determine the required shell or head thickness for a given set of conditions, S/E values are calculated starting with a thickness of 1/64 in. and increasing the thickness by 1/64 in. until the S/E value, based on the geometry of the system, exceeds the S/E value based on the pressure of the system.

Jacket Design

This program will design two types of vessel jackets. They are shown in Fig. 3. The first type covers all or part of the straight side portion of the vessel but not the head. The second type covers all or part of the straight side portion of the vessel and the head of the vessel with an ASME type head. Jacket design calculations are the same as for the vessel. Connection of the jacket to the vessel on the end opposite the ASME head and on both ends of a straight side jacket

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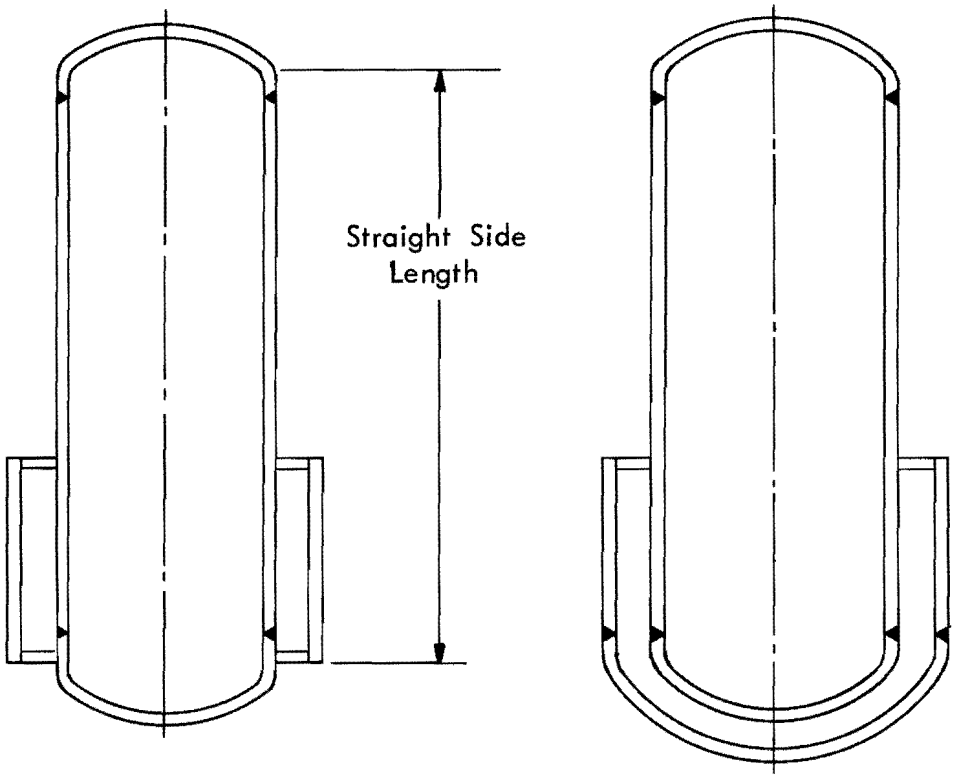

Notes: (1) Jacket may extend any length along vessel straight side length.
(2) Stiffening rings on jacket are located 4 x jacket OD apart.

Fig. 3. Jacket types.

is accomplished by welding to a washer type ring. The thickness of this ring is taken as twice the jacket shell thickness. However, a lower limit of 0.25 in. and an upper limit of 1.0 in. were assigned to this thickness.

A program flow diagram is given in Appendix C and a program card listing in Appendix D. Sample data sheets and deck setup are given in Appendices E and F, respectively. A sample problem showing input and output is given in Appendix G.

LIMITATIONS AND ASSUMPTIONS

Outside Diameter Range

The range of vessel outside diameters is from 5.563 inches (5 in. NPS Sch. 40 pipe) through 84 inches. These diameters are supplied as a list in the second data card. Jacket outside diameters for the type with one head are also taken from this list. A jacket on the straight side of the vessel only does not have to match a head and therefore is not restricted.

Metal Thicknesses

After the addition of corrosion allowance, the final thickness is chosen as the next greater size from an internal list of standard thicknesses supplied in the third data card. However, provision is included for accepting the first standard thickness under the required size if the excess is not greater than a certain fraction of that standard thickness. This allowable excess may be included in the input data as a decimal fraction of the standard thickness. The above feature is not included for the four pipe sizes. Their thickness is based on Sch. 40 pipe size and the ability of that thickness to withstand the design pressures. Corrosion allowance is not considered for the four pipe sizes.

Freeboard Ratio Variation

The initial volume estimated is based on a list of internal diameters (input data card No. 1); each i.d. is slightly less than the corresponding o.d. in the o.d. list. After an i.d. is selected which meets the volume requirement, the next larger o.d. is selected for the vessel. This will increase the freeboard ratio slightly above its input value.

Straight Side Length/o.d. Range

This length/outside diameter ratio was taken as 0.8 to 4.0 because one equation could be used to represent the line obtained by plotting length/outside diameter versus stress/modulus of elasticity for a given diameter/thickness ratio. For length/diameter ratios larger than 4.0, stiffening rings must be used every four diameters distance along the side of the vessel or jacket.

Modulus of Elasticity

This program is limited to the range in which the modulus of elasticity can be considered constant.

Head Dimension Approximations

Several approximations were used to obtain values of various head dimensions. Three of these values--the head dish volume, the head dish radius and the head knuckle radius--are printed as output and can be easily compared to manufacturer's literature. The inside depth of dish of the head--not printed as output--was estimated from the equation,

$$Y = 0.1545\ X + 1.4158, \tag{7}$$

which was obtained by plotting the inside dish depths versus outside diameter and drawing a straight line through the field obtained. This development is shown in Fig. 4, Appendix A. Data were taken from the 1955 Lukens Spun Heads Data book. Calculated head dimensions should be compared with manufacturer's literature and the jacket head depth of dish should be compared to the vessel head to ensure a correct fit. Head dish volume and weight will also vary due to the equations used for estimating these values. The head dish volume was estimated from the following equation:

$$V = (0.64)\ \text{i.d.}^3 \tag{8}$$

V = volume in U.S. gallons,

i.d. = inside diameter in inches,

0.64 = constant obtained by averaging eight selected heads using data from Buffalo Tank Corporation, Ref. (5).

The head weights were estimated from equations obtained on p. 32 of Ref. (4).

All pipe cap dimensions used were taken from Ref. (3) and represent standard ellipsoidal type caps rather than ASME torispherical caps. This will result in a conservative estimate of required thickness of about 13% (based on calculations using a 12-in. pipe cap and a 12-in. dished head).

External Pressure-Thickness Check

It is possible to check the thickness required by the external pressure on the vessel, or jacket, shell and head by a rapid hand calculation using the charts in Appendix V of Ref. (1). The safe working pressure may be calculated using the thickness determined by the program and compared to the design pressure. This is recommended for any design as a final step since the metal property-dependent lines in the external pressure charts of Ref. (1) deviate rapidly from straight lines for high L/o.d. ratios and o.d./thickness ratios below 100.

REFERENCES

1. "Unfired Pressure Vessels, Section VII," ASME Boiler and Pressure Vessel Code, 1959 Edition, Am. Soc. Mech. Engr., New York (1959).

2. E. O. Bergman, "The New-Type Code Chart for the Design of Vessels Under External Pressure," Pressure Vessel and Piping Design, collected papers 1927-1959, p. 649, Am. Soc. Mech. Engr., New York.

3. Tube-Turn Catalog and Engineering Data Book, Number 211, Tube Turns, Inc., Louisville 1, Kentucky (1949).

4. Lukens Steel Company Spun Heads Catalog, 1955, Lukens Steel Company, Coatesville, Pennsylvania (1955).

5. Buffalo Tank Handbook, 5th Printing, Buffalo Tank Company, New York (1945).

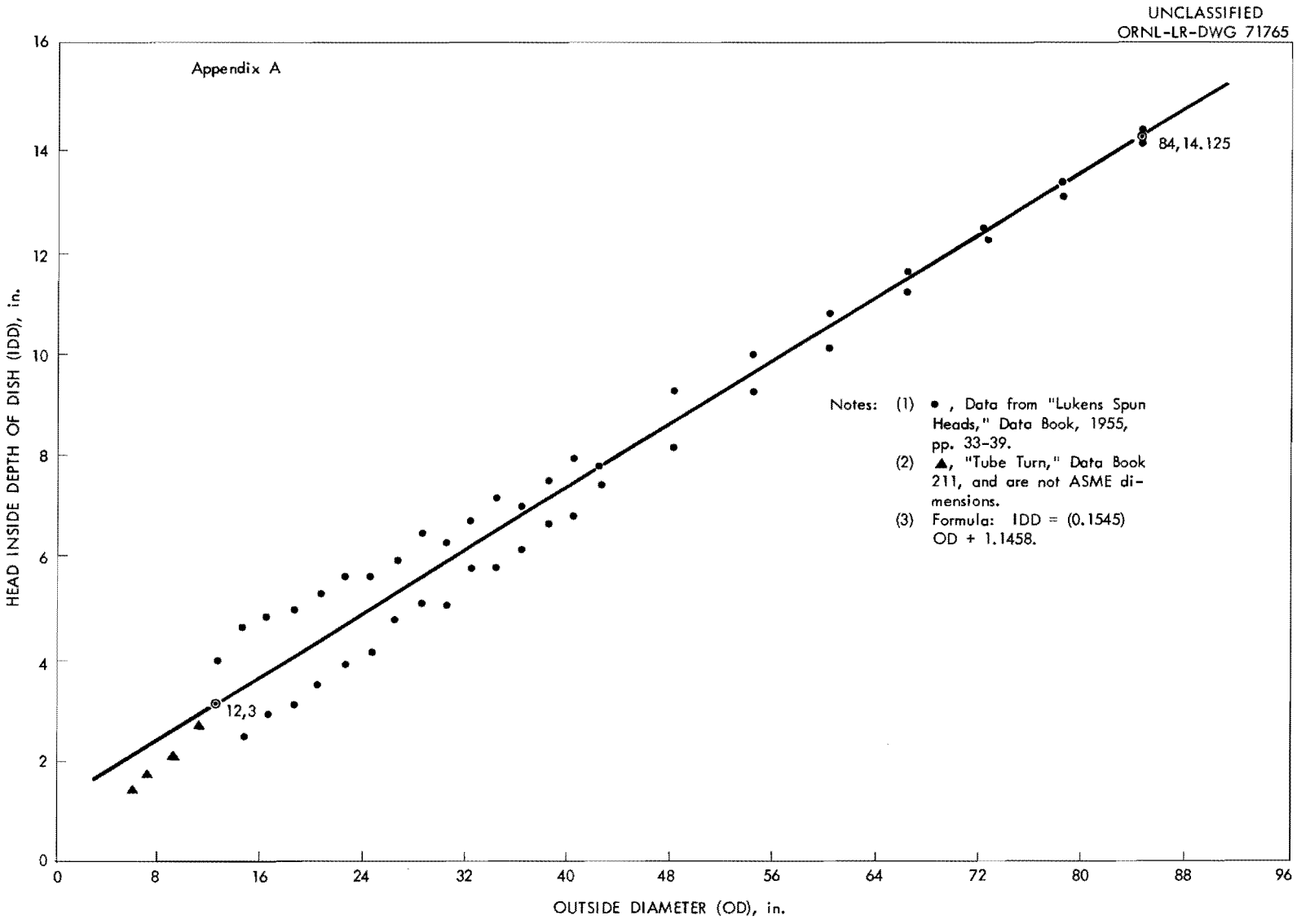

Fig. 4. Data for head inside depth of dish equation development.

APPENDIX B

List of Variables Used in Calculations

Variable Name	Variable
A	Used to float index integer
A1, A2	Working value of thickness, in.
A5, A6, A7	Used to input material of construction of vessel
A8, A9	Vessel identification
A5J, A6J, A7J	Used to input jacket material of construction
B1	Working value of head thickness, in.
B6	Working value of shell thickness, in.
CAPY	Design capacity, cu ft
CFPP	Cost of fabrication, $/lb
CMPP	Cost of vessel metal, $/lb
CMPPJ	Cost of jacket metal, $/lb
COR	Corrosion allowance, in.
COSTB	Cost to fabricate vessel, $
COSTM	Cost of vessel metal, $
COSTMJ	Cost of jacket metal, $
DENS	Vessel metal density, lb/cu ft
DENSJ	Jacket metal density, lb/cu ft
DENSQ	Vessel metal density, lb/cu in.
DENSQJ	Jacket metal density, lb/cu in.
DI	Working value of vessel shell inside diameter, in.
DIH	Inside diameter of head, in.
DIJ	Inside diameter of jacket shell, in.
DIS	Final vessel shell inside diameter, in.
DO	Working and final vessel outside diameter, in.
DOJ	Jacket outside diameter (working value under internal pressure and final value), in.
DOJEP	Jacket outside diameter (working value under external pressure), in.
E	Vessel metal modulus of elasticity, psi
EJ	Jacket metal modulus of elasticity, psi
FBR	Freeboard ratio, (vessel volume/design volume)
H	Vessel shell length, in.
HSEPC	Unsupported vessel shell length used in required thickness calculation, in.
HSEPCJ	Unsupported jacket shell length used in required thickness calculation, in.

APPENDIX B (continued)

Variable Name	Variable
I	Index or integer value
J	Input - if vessel is to have a jacket, this variable is "one"
JHED	Input - if jacket has a head, this variable is "one"
JLOD	Internal equivalent of a sense switch, set if jacket L/o.d. is greater than 4
K, L, L1, L2	Index value
PEX	Design external pressure for vessel, psi
PEXJ	Design external pressure for jacket, psi
PIN	Design internal pressure for vessel, psi
PINJ	Design internal pressure for jacket, psi
Q1, Q2, Q3, Q4	Working values used in average calculations (see 41, 486)
RADH	Vessel head spherical dish radius, in.
RADHJ	Jacket head spherical dish radius, in.
RADK	Vessel head knuckle radius, in.
RADKJ	Jacket head knuckle radius, in.
RK2, RK3	Working values vessel knuckle radius, in.
RK2J, RK3J	Working values jacket knuckle radius, in.
RLOD	Vessel straight side length/outside diameter
S	Maximum allowable stress in vessel metal, psi
SJ	Maximum allowable stress in jacket metal, psi
SEGH	S/E due to geometry of head, vessel
SEGHJ	S/E due to geometry of head, jacket
SEGS	S/E due to geometry of shell, vessel
SEGSJ	S/E due to geometry of shell, jacket
SEPH	S/E due to pressure on head, vessel
SEPHJ	S/E due to pressure on head, jacket
SEPS	S/E due to pressure on shell, vessel
SEPSJ	S/E due to pressure on shell, jacket
SF	Length of head straight flange, in.
SPACE	Min. space between jacket i.d. and vessel o.d., in.
SSL	Vessel straight side length, in.
SSLJ	Jacket straight side length, in.
SSLRJ	SSLJ/SSL
TCOST	Cost of vessel only (metal + fabrication), $
TCOSTB	Total fabrication cost, $
TCOSTM	Total metal cost, $
TCOSTI	Total unit cost, $
TEIEPJ	Thickness of end plate, in.
TEMP	Design temperature for vessel, ^{o}F

APPENDIX B (continued)

Variable Name	Variable
TEMPJ	Design temperature for jacket, ^{o}F
TH	Vessel head thickness (no corrosion allowance), in.
THC	Vessel head thickness plus corrosion allowance, in.
THCAST	Vessel head thickness plus corrosion allowance as standard thickness, in.
THEP	Vessel head thickness due to external pressure, in.
THEPJ	Jacket head thickness due to external pressure, in.
THIP	Vessel head thickness due to internal pressure, in.
THIPJ	Jacket head thickness due to internal pressure, in.
THJ	Final jacket head thickness, in.
TS, TSC, TSCAST, TSEP, TSEPJ, TSIP, TSIPJ, TSJ	The following eight variable are shell counterparts of above head values
TSEPJI	Jacket - Sch. 40 NPS pipe thickness, in.
TWJ	Weight of jacket, lbs
TWJV	Total weight of unit (vessel plus jacket), lbs
TWV	Weight of vessel, lbs
VOHD	Volume of one head dish, gal
VOLH	Volume of two pipe caps (not including straight flange), cu ft
VT	Total volume of vessel, cu ft
VT1	First estimate of total volume of vessel, cu ft
VT2	Ratio of VT1/VT
WELD	Weld efficiency, vessel, decimal fraction
WELDJ	Weld efficiency, jacket, decimal fraction
WJE	Weight of one jacket end, lbs
WJH	Weight of one jacket head, lbs
WJS	Weight of jacket shell, lbs
WTH	Weight of one vessel head, lbs
WTS	Weight of vessel shell, lbs
WTSR	Distance from head weld to first stiffening ring, vessel, in.
WTSRJ	Distance from head weld to first stiffening ring, jacket, in.
XSTA	Excess thickness allowable above a standard plate size before requiring the next larger standard thickness, expressed as a decimal fraction of the standard size

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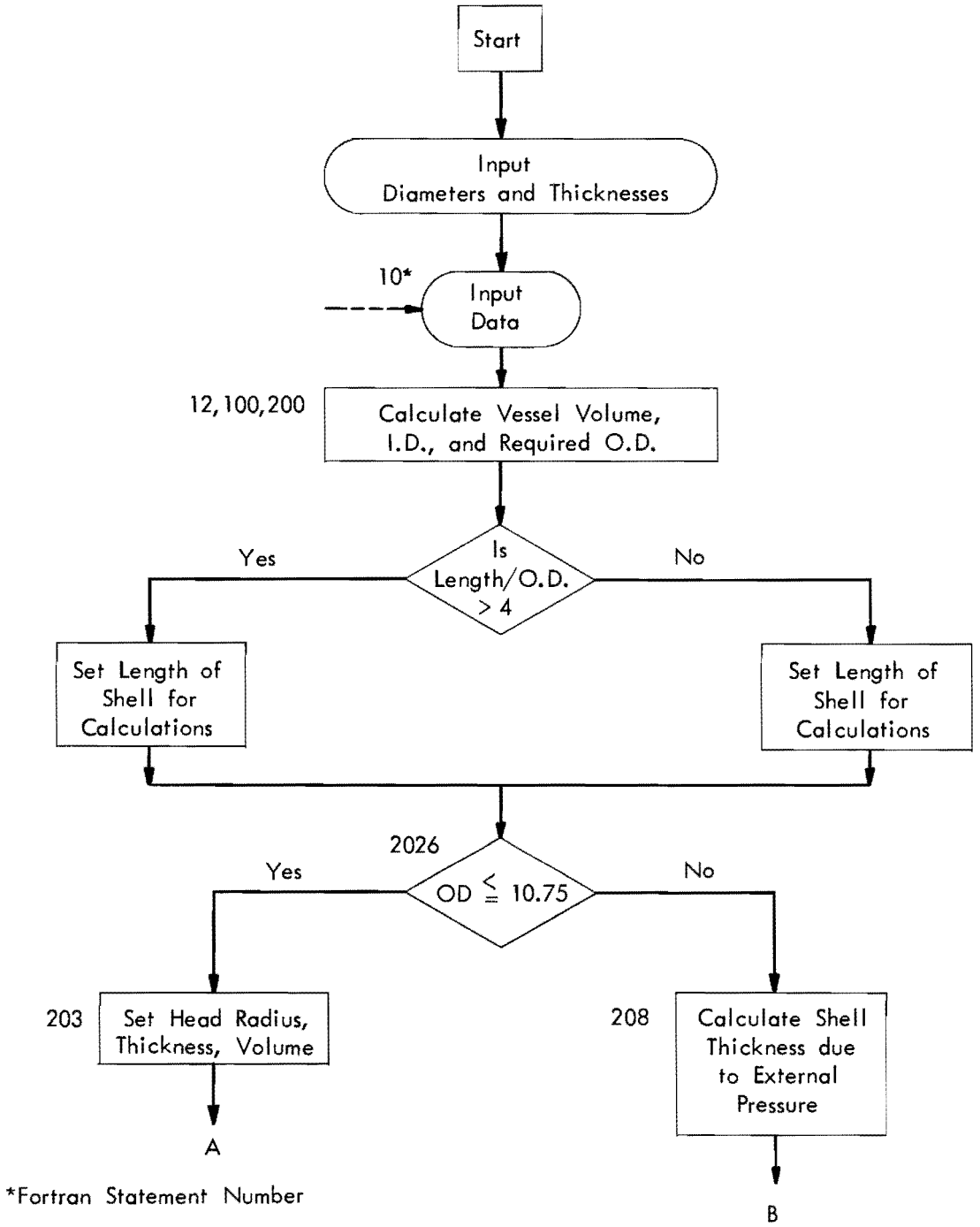

SHEET 1 OF 7

APPENDIX C

PROGRAM FLOW DIAGRAM

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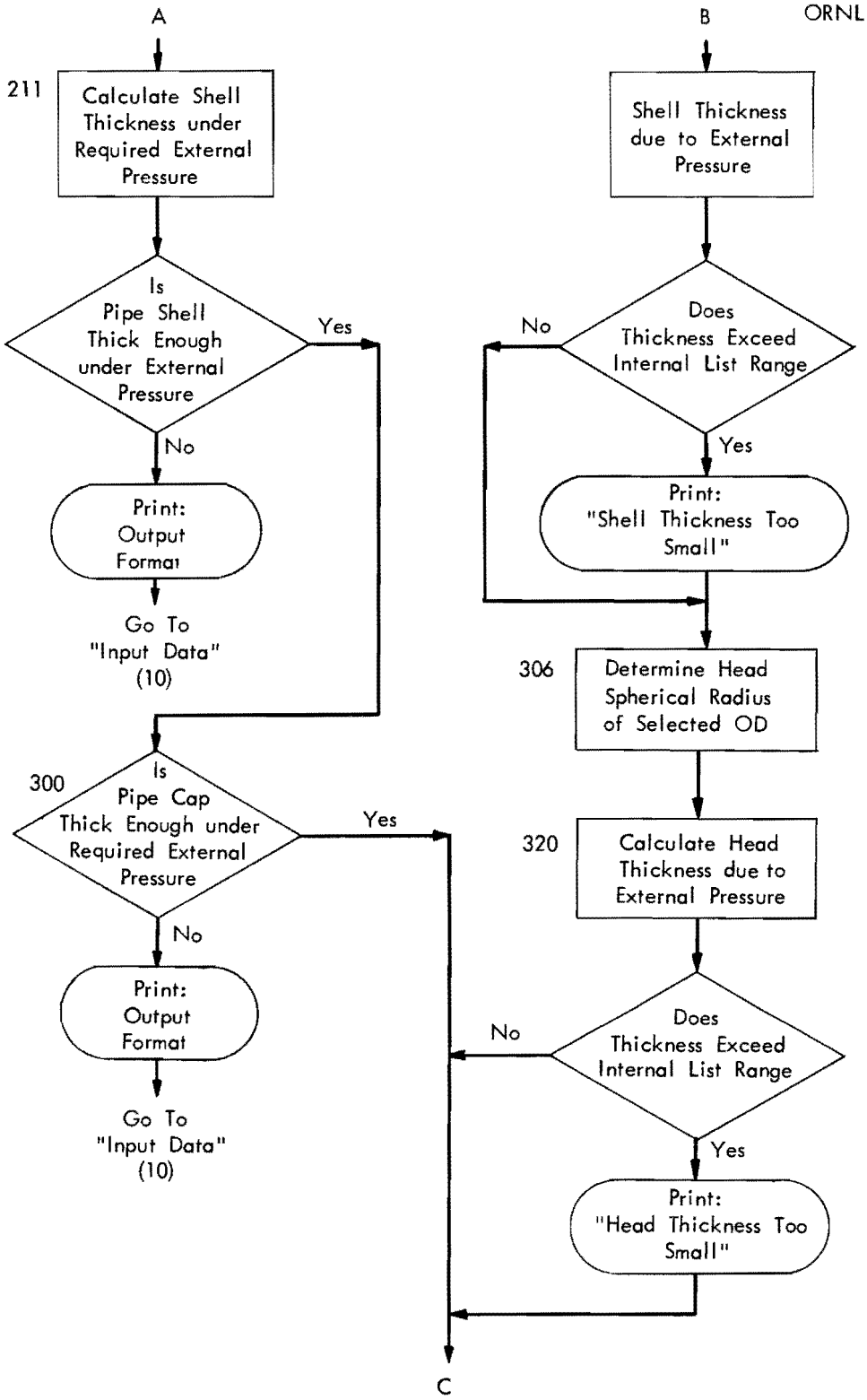

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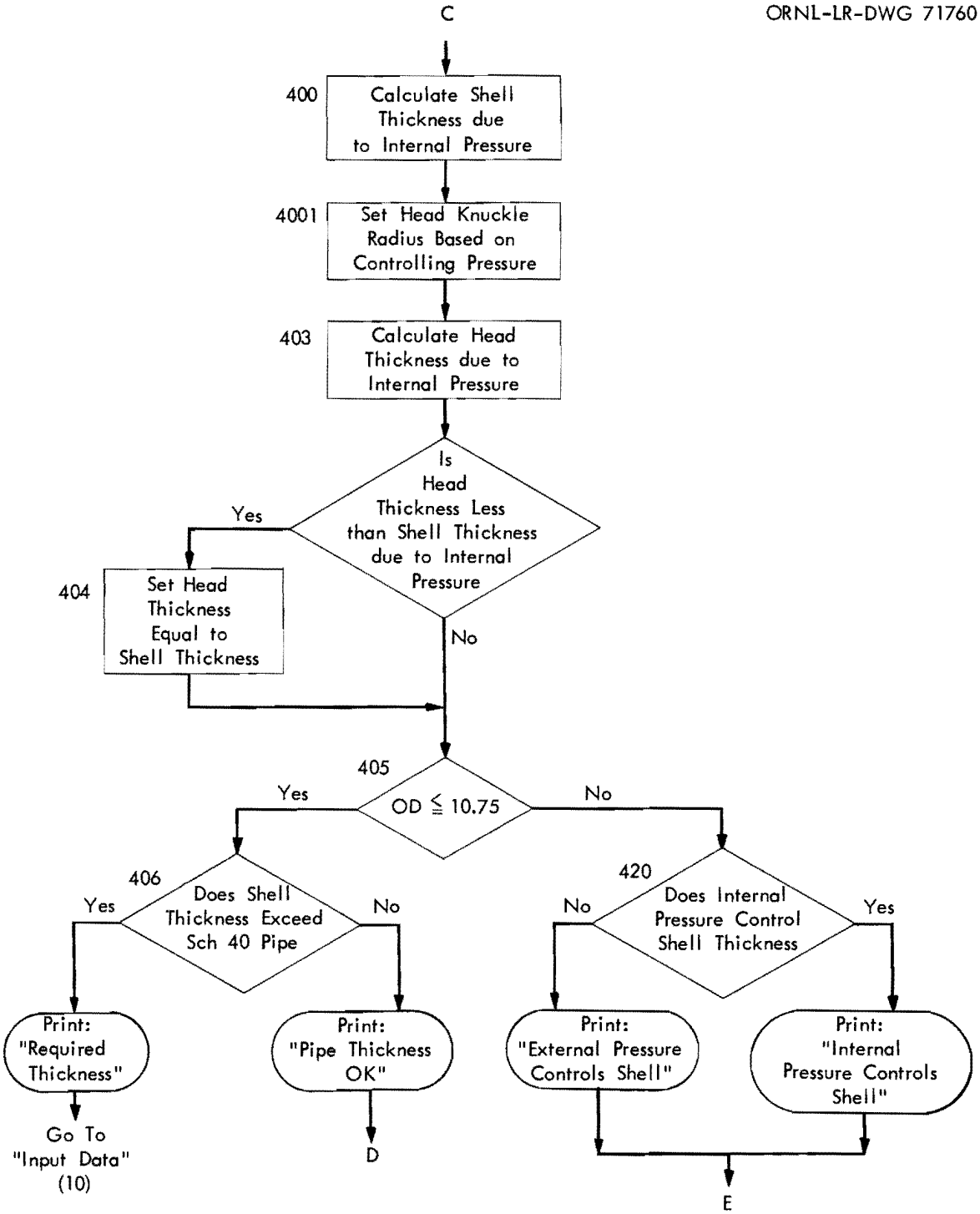

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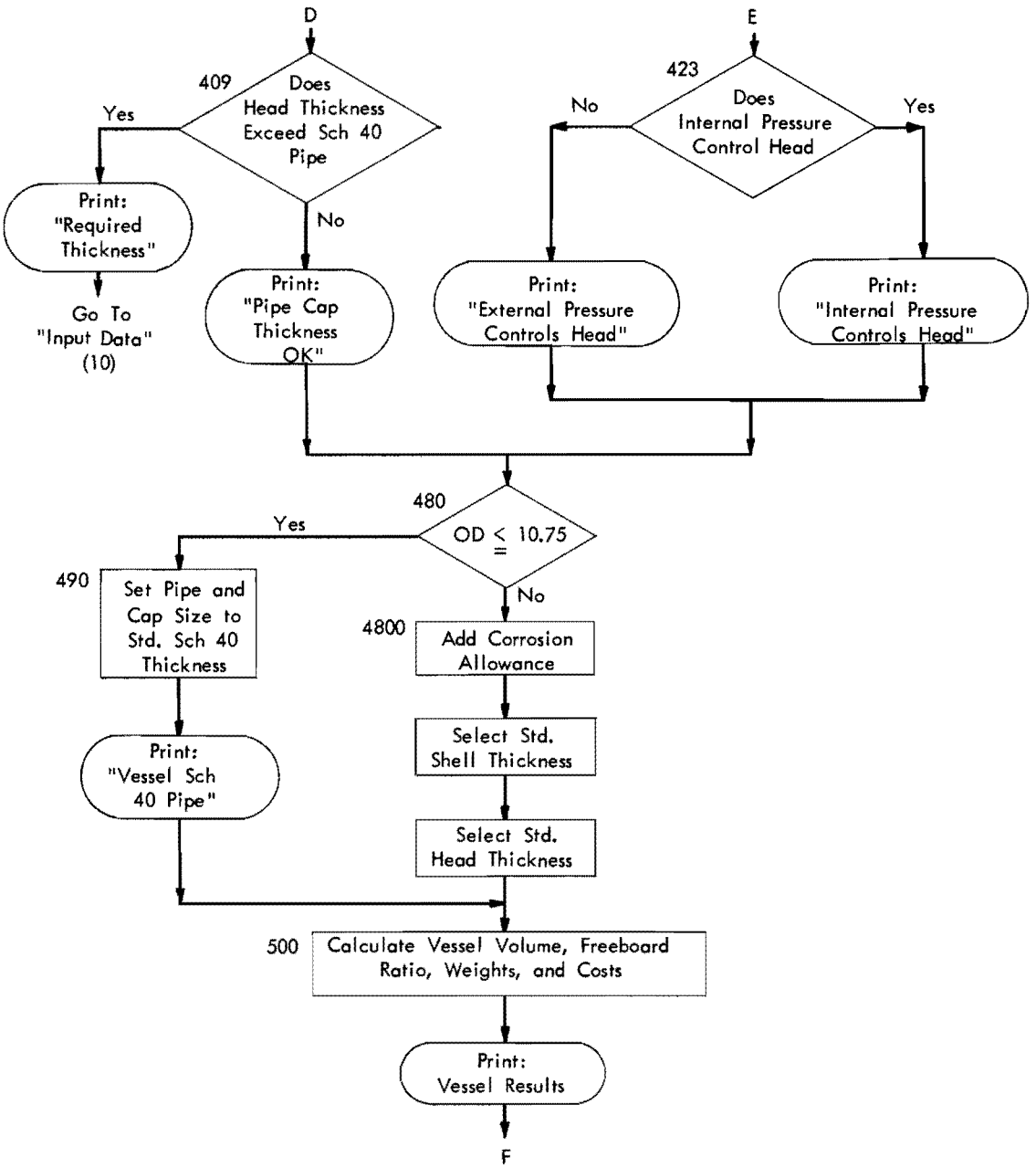

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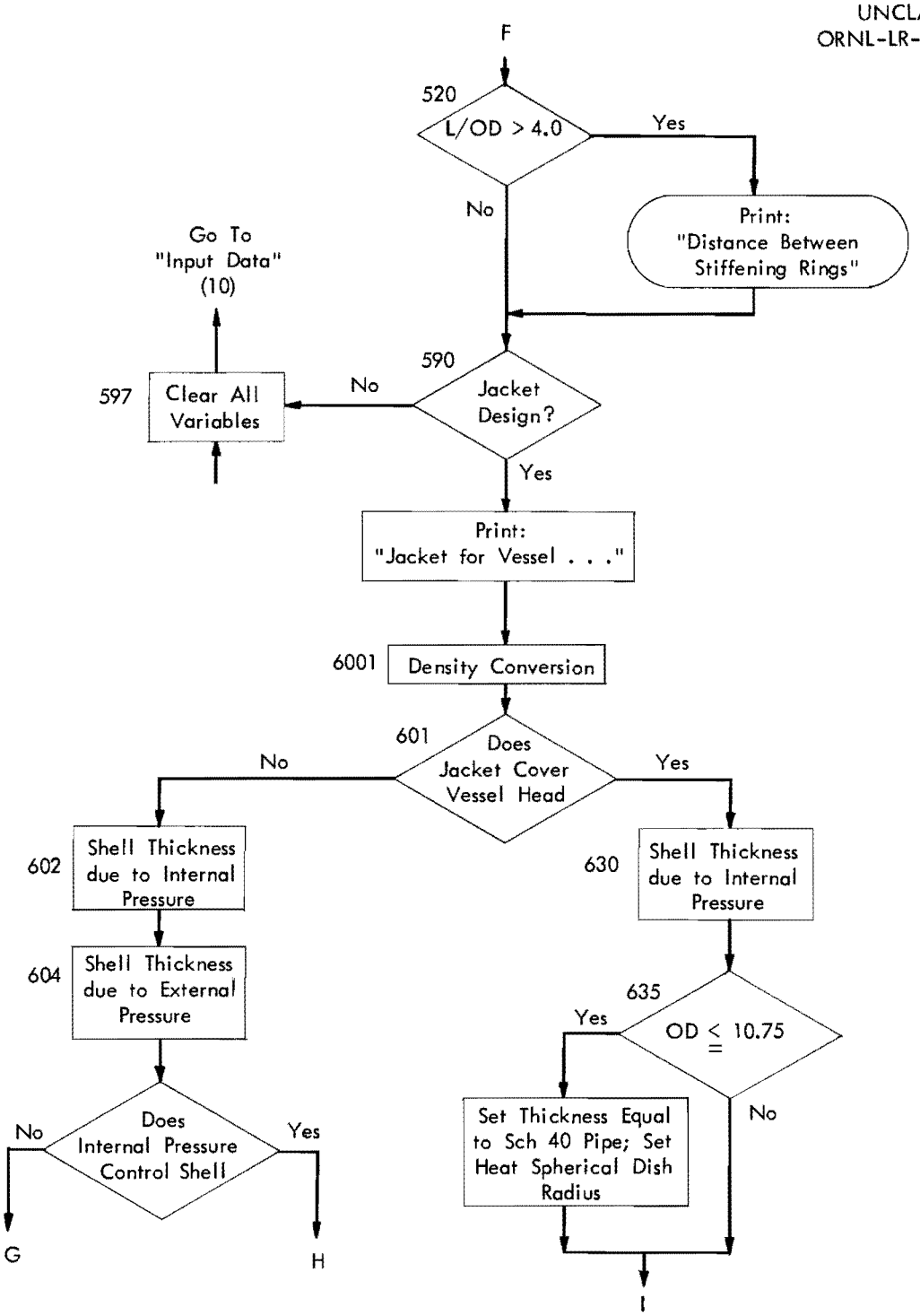

SHEET 5 OF 7

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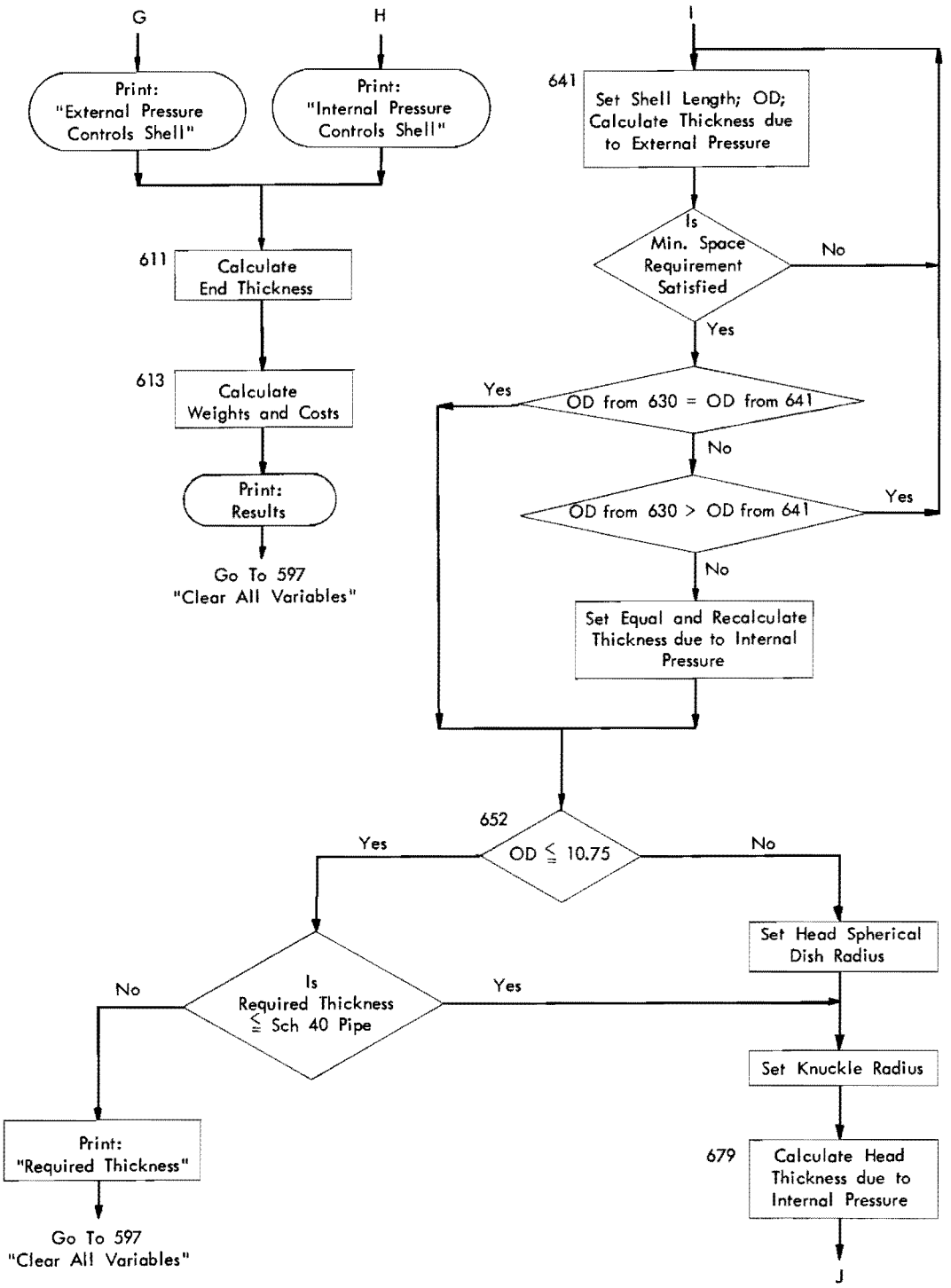

SHEET 6 OF 7

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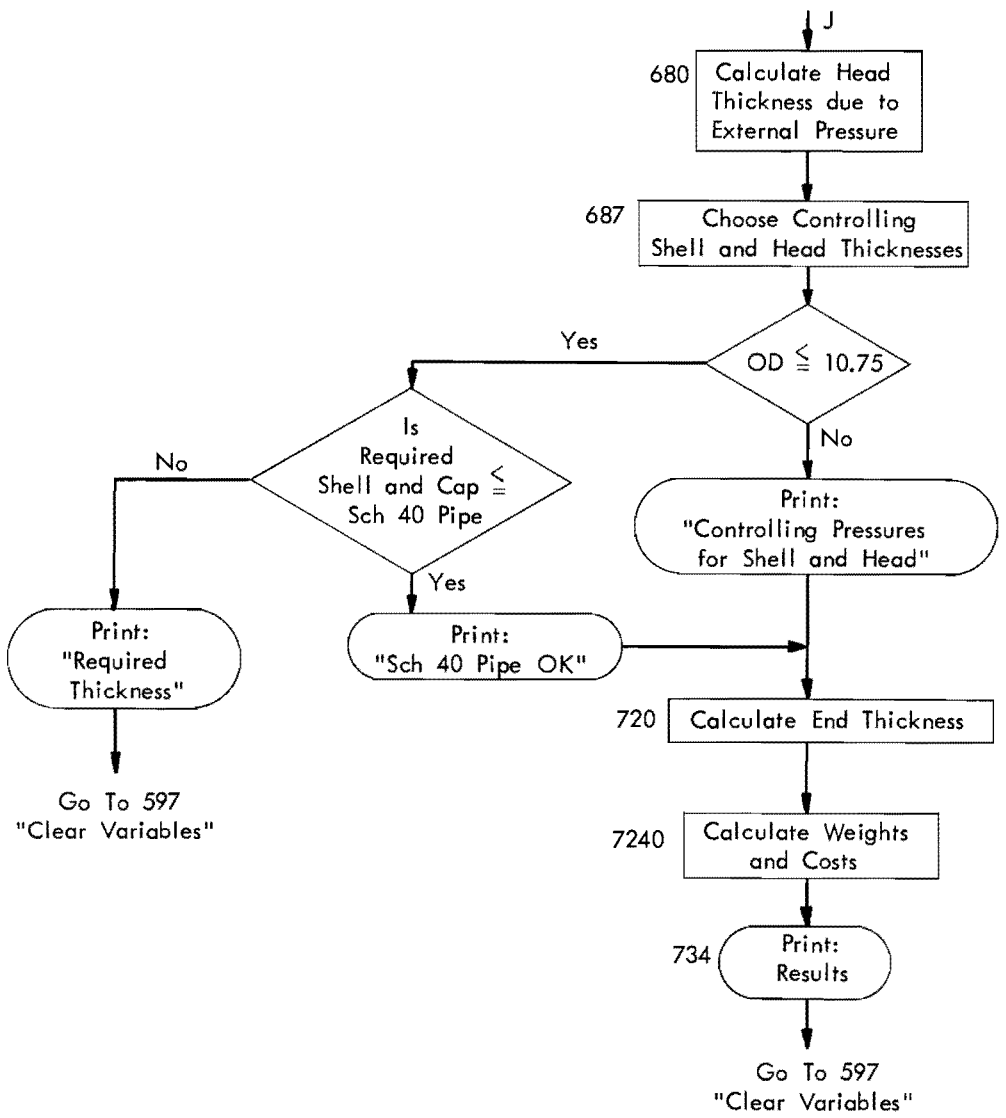

Note: Program Ends After All Data Has Been Read.

SHEET 7 OF 7

APPENDIX E

UNFIRED PRESSURE VESSEL DESIGN DATA SHEET

WRITTEN BY: _____ REQUEST NUMBER _____ DATE _____ (SHEET 1 OF 2)

Control Cards:

```
1    5
*ID
1
*CHARGE(    )
1
*TAPE(9,ØUTPUT)(10,INPUT)
1
*DUMP*(1000,77460,D)
1
*EXECUTE
1
*TYPE(BINARY)
```

NOTES:

1. ID: SHOULD HAVE JOB DESCRIPTION OR TITLE, NAME, AND ADDRESS.
2. CHARGE: 4-DIGIT NUMBER SUPPLIED BY COMPUTER OPERATIONS.
3. DUMP: ADDITIONAL TYPES OF DUMP MAY BE SPECIFIED.
4. TYPE: IF FORTRAN DECK IS TO BE RUN, CHANGE BINARY TO FORTRAN.
5. SETUP: PLACE THESE CARDS IN FRONT OF BINARY DECK (OR FORTRAN) IN THE ABOVE ORDER, FOLLOW WITH DATA CONTROL CARD, THE THREE DATA CARDS WHICH CONTAIN THE DIAMETER AND THICKNESS LISTS, AND THE VESSEL DESIGN DATA CARDS.

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APPENDIX E (CONT'D)

UNFIRED PRESSURE VESSEL DESIGN DATA SHEET

WRITTEN BY: REQUEST NUMBER: DATE: (SHEET 2 of 2)

Vessel Design Data:

Capacity, cu ft (1)	Free Board Ratio (11)	Straight Side/ OD Ratio (16)	Head-Straight Flange, in. (24)	Modulus of Elasticity, psi (29)	Maximum Allowable Tensile, Stress psi (39)	Design Temp., °F (49)	Design External Pressure, psi (55)	Design Internal Pressure, psi (63)	
			1.5	E					1

Metal Cost, $/lb (1)	Fabrication Cost, $/lb (9)	Weld Eff., Dec. Fract. (17)	Corrosion Allowance, in. (21)	Allowance over Std. Thickness, Dec. Fract. (26)	Material of Construction (2) (31)	Vessel Identity (2) (49)	Metal Density, lbs/cu ft (3) (57)	Metal Density, lbs/cu in. (3) (65)	
									2

Jacket Design Data:

Jacket Straight Side/Vessel Straight Side (1)	Min. Space Between Vessel OD and Jacket ID, in. (9)	H (7) (17)	Design External Pressure, psi (18)	Design Internal Pressure, psi (25)	Design Temp., °F (32)	Modulus of Elasticity, psi (38)	Maximum Allowable Tensile, Stress psi (48)	Metal Cost, $/lb (57)	Weld Eff., Dec. Fract. (65)	J (6) (69)	
						E					3

Material of Construction (2) (1)	Metal Density, lbs/cu ft (3) (19)	Metal Density, lbs/cu in. (3) (27)	
			4

NOTES:

1. All decimal points are coded to the extreme right of the field and do not take up a space. However, a decimal point may be located in any other space and will override the printed point. (See: Head-straight flange in card No. 1).
2. Use any Fortran characters.
3. Only one density value required.
4. The final shell and head thicknesses of the vessel are selected from an internal list by selecting the next larger size. To allow a small overage above one std. thickness before choosing the next larger size, insert allowable excess as decimal fraction of std. thickness.
5. All four data cards must be included for each vessel.
6. J: If a jacket is to be designed, insert "1".
7. H: If a jacket is to have a head, insert "1". Jacket may have no more than one head.

APPENDIX D

Listing of Fortran Deck

```
C       UNFIRED PRESSURE VESSEL DESIGN PROGRAM,  R.P. MILFORD, C.E. PRINCE
        DIMENSION DIAI(27),DIAO(27),THIK(14)
      10READINPUTTAPE10,2,(DIAI(I),I#1,27),(DIAO(I),I#1,27),
       1(THIK(I),I#1,14)
      2 FORMAT(27F2.0/4F5.3,23F2.0/14F4.4)
C     9 READ IN DATA
     100READ INPUT TAPE 10,11,(CAPY,FBR,RLOD,SF,E,S,TEMP,PEX,PIN,CMPP,CFPP
       1,WELD,CCR,XSTA,A5,A6,A7,A8,A9,DENS,DENSG,SSLRJ,SPACE,JHED,PEXJ,PIN
       2J,TEMPJ,EJ,SJ,CMPPJ,WELDJ,J,A5J,A6J,A7J,DENSJ,DENSGJ)
     11FORMAT(F10.0,F5.0,F8.0,F5.0,E10.0,F10.0,F6.0,F8.0,F8.0/
       1F8.0,F8.0,F4.0,F5.0,F5.0,3A6,2A4,F8.0,F8.0/F8.0,F8.0,I1,F7.0,F7.0,
       2F6.0,E10.0,F9.0,F8.0,F4.0,I1/3A6,F8.0,F8.0)
C    12 CALCULATE VESSEL VOLUME
        VT#CAPY*FBR
C    99 SELECT INSIDE DIAMETER FOR REQUIRED VOLUME
   100 DO199I#1,27
        DI#DIAI(I)
        SSL#DI*RLOD
        VTI#3.14159*DI**2*SSL/(1728.*4.)+1.28*DI**3/(1728.*7.481)
        IF(VT-VTI)101,102,103
   101 DI#DIAI(I-1)
   102 GOTO200
   103 VT2#VTI/VT
        IF(VT2-0.97)199,200,200
   199 CONTINUE
C1990 SELECT NEXT GREATER STANDARD OUTSIDE DIAMETER
   200 DO201I#1,27
        DO#DIAO(I)
        IF(DO-DI)201,202,202
   201 CONTINUE
C2010 SET LENGTH OF SIDE FOR USE IN CALCULATIONS
   202 SSL#DO*RLOD
  2020 H#SSL-3.
  2021 IF(RLOD-4.)2022,2022,2024
  2022 HSEPC#SSL+2.*(.1545*DO+1.1458)/3.
  2023 GO TO 2026
  2024 HSEPC#4.*DO
  2025 WTSR#HSEPC-1.5-(.1545*DO+1.1458)/3.
  2026 IF(DO-10.75)203,207,208
C2027 IF VESSEL IS PIPE, SET SHELL THICKNESS EQUAL TO SCHEDULE 40 PIPE,
C2028 ALSO SET HEAD DISH RADIUS AND VOLUME.
   203 IF(DO-6.625)204,205,206
   204 TSEP#THIK(1)
        RADH#4.42
        VOLH#32.8/1728.
        RADK#.84
        GOTO211
   205 TSEP#THIK(2)
        RADH#5.31
        VOLH#67.8/1728.
        RADK#1.01
        GOTO211
   206 TSEP#THIK(3)
        RADH#6.98
        VOLH#147./1728.
        RADK#1.33
        GOTO211
   207 TSEP#THIK(4)
        RADH#8.77
        VOLH#354.8/1728.
```

APPENDIX D (continued)

```
      RACK#1.67
C 210 CALCULATE S/E VALUES BASED ON GEOMETRY OF SYSTEM AND PRESSURE TO
C210C SEE IF SCH 40 PIPE IS THICK ENOUGH UNDER EXTERNAL PRESSURE
  211 DO 2115 I#1,96
      A1#I
      A1#A1*.015625
      SEGS#1.3*(A1/DO)**1.5/(HSEPC/DO-.45*SQRTF(A1/DO))
      SEPS#2.*PEX*DO/(E*A1)
      IF(SEGS-SEPS)2115,2116,2116
 2115 CONTINUE
 2116 IF(TSEP-A1)212,300,300
  212 WRITE OUTPUT TAPE 9,213,A1
  2130FORMAT(1H1,5X89HSCHEDULE 40 PIPE TOO THIN FOR VESSEL SHELL UNDER E
     1XTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES.///)
  214CWRITECUTPUTTAPE9,215,A8,A9,A5,A6,A7,TEMP,CAPY,FBR,RLOD,DC,SF,
     1DENS,DENSC,E,S,CCR,XSTA,WELC,CMPP,CFPP,PEX,PIN
  215CFORMAT(1H ,4X13HVESSEL NUMBER 28X2A4/5X24HMATERIAL OF CONSTRUCTION
     17X3A6/5X7HTEMP. F F43.0/5X21HDESIGN CAPACITY CU FT F31.2/5X15HFREE
     28CARC RATIO F37.2/5X31HSTRAIGHT LENGTH TO OUTSIDE DIAM F22.3/5X16H
     3OUTSIDE DIAM IN. F37.3/5X8HS.F. IN. F43.1/5X26HMETAL DENSITY LB PE
     4R CU FT F27.3/5X27HMETAL DENSITY LB PER CU IN. F28.5/5X21HMODULUS
     5OF ELAST. PSI 27XE11.5/5X32HMAX ALLOWABLE TENSILE STRESS PSI F18.0
     6/5X23HCORROSION ALLOWANCE IN. F31.4/5X35HALLOWANCE OVER STD THIK.
     7DEC.FRACT. F19.4/5X24HWELD EFFICIENCY FRACTION F29.3/5X22HCOST OF
     8METAL $ PER LB F32.4/5X22HCOST TO BUILD $ PER LB F32.4/5X18HDESIGN
     9 EXT PR. PSI F34.2/5X18HDESIGN INT PR. PSI F34.2)
      GOTO10
C208A CALCULATE WALL THICKNESS FOR A DIAMETER LARGER THAN 10 IN. PIPE
C208B UNDER EXTERNAL PRESSURE
  208 DO 209 I#1,96
      A#I
      TSEP#A*0.015625
 2082 SEGS#1.3*(TSEP/DO)**1.5/(HSEPC/DO-.45*SQRTF(TSEP/DO))
      SEPS#2.*PEX*DO/(E*TSEP)
      IF(SEGS-SEPS)2085,306,306
 2085 IF(I-96)209,2086,2086
 2086 WRITE OUTPUT TAPE 9,2087,A8,A9
 2087 FORMAT(1H1,5X41HSHELL THICKNESS TOO SMALL FOR VESSEL NO.   2A4)
  209 CONTINUE
      GOTO306
C 298 TEST SCH 40 PIPE CAP UNDER EXTERNAL PRESSURE FOR UP THROUGH
C 299 10 IN. PIPE
  300 DO 3005 I#1,96
      A2#I
      A2#A2*.015625
      SEGH#.12*A2/RACH
      SEPH#2.*PEX*RACH/(E*A2)
      IF(SEGH-SEPH)3005,3006,3006
 3005 CONTINUE
 3006 IF(TSEP-A2)301,3007,3007
 3007 THEP#TSEP
      GO TO 400
  301 WRITE OUTPUT TAPE 9,302,A2
  3020FORMAT(1H1,5X92HSCHEDULE 40 PIPE CAP TOO THIN FOR VESSEL HEAD UNDE
     1R EXTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES.///)
  303 GOTO214
C 304 SORT DIAMETERS AND SET HEAD DISH RADIUS FOR DIAMETERS LARGER THAN
C 305 10 IN. PIPE
  306 IF(DO-48.)307,315,316
  307 IF(DO-12.)300,311,308
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APPENDIX D (continued)

```
  308 IF(DO-24.)312,311,309
  309 IF(DO-30.)313,311,310
  310 IF(DO-36.)313,311,313
  311 RADH#DO
      GOTO320
  312 IF(DO-16.)313,314,313
  313 RADH#DO-2.0
      GOTO320
  314 RADH#DO-1.0
      GOTO320
  315 RADH#DO-6.0
      GOTO320
  316 IF(DO-84.)317,311,311
  317 IF(TSEP-0.5)311,311,318
  318 RADH#DO-6.0
C 319 CALCULATE HEAD THICKNESS FOR VESSEL DIAMETERS LARGER THAN
C319O 10 IN. PIPE UNDER EXTERNAL PRESSURE
  320 DO 323 I#1,96
      THEP#I
      THEP#THEP*.015625
      SEGH#0.12*THEP/RADH
 3221 SEPH#2.*PEX*RADH/(E*THEP)
 3222 IF(SEGH-SEPH)3223,324,324
 3223 IF(I-96)323,3224,3224
 3224 WRITE OUTPUT TAPE 9,3225,A8,A9
 3225 FORMAT(1H1,5X40HHEAD THICKNESS TOO SMALL FOR VESSEL NO.   2A4)
  323 CONTINUE
  324 IF(THEP-TSEP)325,400,400
  325 THEP#TSEP
C 399 CALCULATE THICKNESS OF SHELL UNDER INTERNAL PRESSURE ALL DIAMETERS
  400 TSIP#(PIN*DO/2.)/(S*WELD+.4*PIN)
C400+ ESTIMATE HEAD KNUCKLE RADIUS BASED ON CONTROLLING THICKNESS
      IF(DO-11.)403,403,4000
 4000 RK2#.06*DO
 4001 IF(TSEP-TSIP)4004,4002,4002
 4002 B6#TSEP
 4003 GO TO 4005
 4004 B6#TSIP
 4005 RK3#3.*B6
      IF(RK2-RK3)402,401,401
  401 RADK#RK2
      GOTO403
  402 RADK#RK3
C4029 CALCULATE HEAD THICKNESS DUE TO INTERNAL PRESSURE
  403 THIP#PIN*RADH*(.25*(3.+SQRTF(RADH/RADK)))/(2.*S*WELD-.2*PIN)
      IF(THIP-TSIP)404,405,405
  404 THIP#TSIP
  405 IF(DO-10.75)406,406,420
C4058 COMPARE REQUIRED SHELL AND HEAD THICKNESS TO SCH 40 PIPE FOR
C4059 DIAMETERS EQUAL TO OR LESS THAN 10 IN. PIPE
  406 IF(TSIP-TSEP)407,407,408
  407 TS#TSEP
 4070 WRITEOUTPUTTAPE9,4071
 4071OFORMAT(1H1,5X70HSCHEDULE 40 PIPE SHELL THICK ENOUGH FOR INTERNAL A
     IND EXTERNAL PRESSURE /)
      GOTO409
  408 WRITEOUTPUTTAPE9,4080
 4080OFORMAT(1H1,5X56HSCHEDULE 40 PIPE TOO THIN FOR REQUIRED INTERNAL PR
     IESSURE///)
 4081 WRITE OUTPUT TAPE 9,4082,TSIP
```

APPENDIX D (continued)

```
 4082OFORMAT(1H ,4X24HREQUIRED SHELL THICKNESS F3O.4//)
      GOTO214
  4O9 IF(THIP-THEP)41O,41O,411
  41O TH#THEP
 41OO WRITEOUTPUTTAPE9,41O1
 41O1OFORMAT(1H ,5X68HSCHEDULE 4O PIPE CAP THICK ENOUGH FOR INTERNAL AND
     1 EXTERNAL PRESSURE //)
      GOTO48O
  411 WRITEOUTPUTTAPE9,412
  412OFORMAT(1H1,5X6OHSCHEDULE 4O PIPE CAP TOO THIN FOR REQUIRED INTERNA
     1L PRESSURE///)
 412O WRITEOUTPUTTAPE9,4121,THIP
 4121 FORMAT(1H ,5X23HREQUIRED HEAD THICKNESS24XF7.4)
      GOTO214
C4198 CHOOSE CONTROLLING THICKNESS OF SHELL AND HEAD FOR DIAMETERS
C4199 GREATER THAN 1O IN PIPE
  42O IF(TSIP-TSEP)421,421,422
  421 TS#TSEP
 421O WRITEOUTPUTTAPE9,4211
 4211 FORMAT(1H1,5X47HSHELL THICKNESS CONTROLLED BY EXTERNAL PRESSURE/)
      GOTO423
  422 TS#TSIP
 4221O WRITEOUTPUTTAPE9,4221
 4221 FORMAT(1H1,5X47HSHELL THICKNESS CONTROLLED BY INTERNAL PRESSURE/)
  423 IF(THIP-THEP)424,424,425
  424 TH#THEP
 424O WRITEOUTPUTTAPE9,4241
 4241 FORMAT(1H ,5X46HHEAD THICKNESS CONTROLLED BY EXTERNAL PRESSURE//)
      GOTO48O
  425 TH#THIP
 425O WRITEOUTPUTTAPE9,4251
 4251 FORMAT(1H ,5X46HHEAD THICKNESS CONTROLLED BY INTERNAL PRESSURE//)
  48O IF(DO-1O.75)49O,49O,48OO
C48O+ ADD CORROSION ALLOWANCE TO VESSELS OF GREATER THAN 1O IN. PIPE
 48OO TSC#TS+COR
      THC#TH+COR
C48O2 SELECT NEXT LARGER STANDARD THICKNESS OVER REQUIRED THICKNESS FOR
C4O83 BOTH SHELL AND HEAD
      DO483I#5,14
      IF(TSC-THIK(I))482,482,481
  481 Q1#(TSC-THIK(I))/THIK(I)
      Q2#XSTA*THIK(I)
 4811 IF(Q2-Q1)4821,482,482
  482 TSCAST#THIK(I)
      GOTO485
 4821 IF(I-14)483,4822,4822
 4822 TSCAST#TSC
  483 CONTINUE
  485 DO488I#5,14
      IF(THC-THIK(I))487,487,486
  486 Q3#(THC-THIK(I))/THIK(I)
      Q4#XSTA*THIK(I)
 4861 IF(Q4-Q3)4871,487,487
  487 THCAST#THIK(I)
      GOTO5OO
 4871 IF(I-14)488,4872,4872
 4872 THCAST#THC
  488 CONTINUE
      GOTO5OO
  49O TSCAST#TS
```

APPENDIX D (continued)

```
      THCAST#TH
 49C1 WRITE OUTPUT TAPE 9,49C2
 49C2CFORMAT(1H ,4X104HBASIS CF ANSWER IS SCH 40 PIPE WITH CORROSICN ALL
     1OWANCE OF DIFFERENCE BETWEEN REQUIREC AND STC THICKNESS//)
C 499 CALCULATE FINAL VESSEL VOLUME ANC FREEBCARD RATIO
  5CC DIS#CO-2.*TSCAST
      IF(CC-1C.75)5C1,5C1,5C2
  5C1 VT#3.14159*CIS**2*SSL/(4.*1728.)+VOLH
      GCTC5C3
  5C2 DIH#CO-2.*THCAST
 5C2C VT#3.14159*CIS**2*SSL/(4.*1728.)+1.28*DIH**3/(1728.*7.481)
  5C3 FBR#VT/CAPY
C5C3+ CALCULATE WEIGHTS ANC COSTS
 5C3C IF(DENS)5C31,5C31,5C39
 5C31 DENS#DENSQ*1728.
 5C39 WTS#3.14159*DENS*H*(CO*CO-DIS*DIS)/(4.*1728.)
      IF(THCAST-1.)5C4,5C5,5C5
  5C4 WTH#DENS*THCAST*(DO+DO/24.+3.+2.*RADK/3.)**2*3.14159/(1728.*4.)
      GCTC5C6
  5C5CWTH#DENS*THCAST*(DO+DO/24.+3.+2.*RADK/3.+THCAST)**2*3.14159/(1728.
     1*4.)
  5C6 TWV#WTS+2.*WTH
      CCSTM#CMPP*TWV
      COSTB#CFPP*TWV
      TCOST#CCSTM+COSTB
  5C0 IF(CC-10.75)511,511,512
  511 VOHD#VOLH*7.481/2.
      GCTC513
  512 VCHC#.64*(CIH/12.)**3
C5129 WRITE CUT RESULTS
  513CWRITEOUTPUTTAPE 9,514,A8,A9,A5,A6,A7,TEMP,CAPY,FBR,VT,VOHD,RLOD,DO
     1,TSCAST,H,THCAST,RADH,RADK,SF,WTS,WTH
  514CFCRMAT(1H ,4X13HVESSEL NUMBER28X2A4/5X24HMATERIAL OF CONSTRUCTICN7
     1X3A6/5X13HDESIGN TEMP FF37.C//5X21HDESIGN CAPACITY CU FTF32.3/5X15
     2HFREEBCARD RATIOF37.2/5X2CHVESSEL VCLUME  CU FTF33.3/5X24HONE HEAD
     3 DISH VCLUME GALF28.2/5X29HSTRAIGHT LENGTH /CUTSIDE DIAMF24.3/5X20
     4HOUTSIDE DIAMETER IN.F34.4/5X19HSHELL THICKNESS IN.F35.4/5X16HSHEL
     5L LENGTH IN.F37.3/5X18HHEAD THICKNESS IN.F36.4/5X2CHHEAC DISH RADI
     6US IN.F33.3/5X23HHEAC KNUCKLE RADIUS IN.F3C.3/5X24HHEAD STRAIGHT F
     7LANGE IN.F28.2/5X19HWEIGHT OF SHELL LBSF34.3/5X22HWEIGHT OF CNE HE
     8AC LBSF31.3)
  515CWRITEOUTPUTTAPE9,516,TWV,DENS,DENSQ,PEX,PIN,E,S,CCR,XSTA,WELD,CMPP
     1,CFPP,COSTM,COSTB,TCOST
  516CFCRMAT(1H ,4X26HTOTAL WEIGHT OF VESSEL LBS F27.3/ 5X26HMETAL DENSI
     1TY LB PER CU FT F27.3/ 5X27HMETAL DENSITY LB PER CU IN. F27.4/ 5X2
     28HDESIGN EXTERNAL PRESSURE PSI F23.1/ 5X28HDESIGN INTERNAL PRESSUR
     3E PSI F23.1/ 5X25HMCDULUS OF ELASTICITY PSI E34.5/ 5X32HMAX ALLOWA
     4BLE TENSILE STRESS PSI F18.C/ 5X23HCORRCSION ALLOWANCE IN. F31.4/
     55X35HALLOWANCE OVER STC THIK. DEC.FRACT. F19.4/ 5X26HWELD EFFICIEN
     6CY DEC.FRACT. F27.3// 5X19HMETAL COST $ PER LB F35.4/ 5X25HFABRICA
     7TICN COST $ PER LB F29.4/ 5X19HMETAL COST TOTAL  $ F34.3/ 5X25HFAB
     8RICATION COST TOTAL  $ F28.3// 5X18HTOTAL UNIT COST  $ F35.3///)
 516C WRITE OUTPUT TAPE 9,5161
 5161CFCRMAT(1H ,4X54H(THE ABCVE CALCULATICN IS FOR ASME TORISPHERICAL H
     1EAC))
  52C IF(RLOD-4.)59C,59C,521
  521 WRITE CUTPUT TAPE 9,521C,HSEPC,WTSR
 5210CFCRMAT(1H ,4X100HTHE ABCVE RESULTS ASSUME THAT STIFFENING RINGS AR
     1E PLACED NO GREATER THAN 4 OUTSIDE DIAMETERS APART( F7.3,1X 7HINCH
     2ES)/ 5X 98HAND ALSO NO FURTHER THAN 4 CUTSIDE DIAMETERS MINUS (1.5
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APPENDIX D (continued)

```
      3+1/3 HEAD IDD) FROM THE HEAD-TO-SHELL WELD( F7.3,1X 7HINCHES))
  590 IF(J)597,597,600
  597 DO 598 I#15,134
  598 THIK(I)#0.
  599 GO TO 10
C     JACKET DESIGN CALCULATIONS
  600 WRITE OUTPUT TAPE 9,6000,A8,A9
 6000 FORMAT(1H1,5X28HJACKET FOR VESSEL NUMBER    2A4///)
 6001 IF(DENSJ)6002,6002,601
 6002 DENSJ#DENSQJ*1728.
  601 IF(JHED)6011,6011,630
C     JACKET ON STRAIGHT SIDE OF VESSEL ONLY
C     JACKET SHELL THICKNESS, INTERNAL AND EXTERNAL PRESSURE
 6011 DIJ#DO+2.*SPACE
  602 TSIPJ#(PINJ*DIJ/2.)/(SJ*WELDJ-.6*PINJ)
  603 SSLJ#SSL*SSLRJ
  604 DO 605 I#1,96
 6040 TSEPJ#I
 6041 TSEPJ#TSEPJ*.015625
 6042 DOJ#DIJ+2.*TSEPJ
 6043 IF(SSLJ/DOJ-4.)6045,6045,6044
 6044 SSLJ#4.*DOJ
      HSEPCJ#SSLJ
      JLOD#1
      WTSRJ#0.
 6045 SEGSJ#1.3*(TSEPJ/DOJ)**1.5/(SSLJ/DOJ-.45*SQRTF(TSEPJ/DOJ))
 6046 SEPSJ#2.*PEXJ*DOJ/(EJ*TSEPJ)
 6047 IF(SEGSJ-SEPSJ)605,606,606
  605 CONTINUE
  606 IF(TSIPJ-TSEPJ)607,607,609
  607 TSJ#TSEPJ
 6070 WRITE OUTPUT TAPE 9,608
  608 FORMAT(1H ,5X42HEXTERNAL PRESSURE CONTROLLING JACKET SHELL/)
      GO TO 611
  609 TSJ#TSIPJ
 6090 WRITE OUTPUT TAPE 9,610
  610 FORMAT(1H ,5X42HINTERNAL PRESSURE CONTROLLING JACKET SHELL/)
C     END THICKNESS
  611 TEIEPJ#2.*TSJ
      IF(TEIEPJ-.25)6110,6110,6111
 6110 TEIEPJ#.25
      GO TO 613
 6111 IF(TEIEPJ-1.)613,613,6112
 6112 TEIEPJ#1.
C     WEIGHTS AND COSTS FOR JACKET, AND JACKET PLUS VESSEL
  613 WJS#DENSJ*SSLJ*3.14159*(DOJ*DOJ-DIJ*DIJ)/(4.*1728.)
  614 WJE#DENSJ*TEIEPJ*3.14159*(DIJ*DIJ-DO*DO)/(4.*1728.)
  615 TWJ#WJS+2.*WJE
  616 TWJV#TWV+TWJ
  617 COSTMJ#TWJ*CMPPJ
  618 TCOSTB#TWJV*CFPP
  619 TCOSTM#COSTM+COSTMJ
  620 TCOSTI#TCOSTB+TCOSTM
  621 GO TO 734
C     JACKET WITH ONE HEAD
C     JACKET SHELL THICKNESS DUE TO INTERNAL PRESSURE
  630 DOJ#DO
      L1#1
  631 DO 634 L#L1,27
      L2#L
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APPENDIX D (continued)

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  632 IF(DOJ-DIAO(L))633,634,634
  633 DOJ#DIAO(L)
      TSIPJ#(PINJ*DOJ/2.)/(SJ*WELDJ+.4*PINJ)
      IF((DOJ-2.*TSIPJ-DO)-(2.*SPACE))634,641,641
  634 CONTINUE
C     JACKET SHELL THICKNESS DUE TO EXTERNAL PRESSURE
  641 SSLJ#SSL*SSLRJ
 6410 DOJEP#DO
  642 DO 649 I#1,27
 6420 IF(DOJEP-DIAO(I))6421,649,649
 6421 DOJEP#DIAO(I)
 6422 HSEPCJ#SSLJ+(.1545*DOJEP+1.1458)/3.
 6423 IF(HSEPCJ/DOJEP-4.)643,643,6424
 6424 HSEPCJ#4.*DOJEP
      WTSRJ#HSEPCJ-1.5-(.1545*DOJEP+1.1458)/3.
      JLOD#1
  643 DO 644 K#1,96
      TSEPJ#K
      TSEPJ#TSEPJ*.015625
      SEGSJ#1.3*(TSEPJ/DOJEP)**1.5/(HSEPCJ/DOJEP-.45*SQRTF(TSEPJ/DOJEP))
      SEPSJ#2.*PEXJ*DOJEP/(EJ*TSEPJ)
      IF(SEGSJ-SEPSJ)644,645,645
  644 CONTINUE
  645 IF((DOJEP-2.*TSEPJ-DO)-(2.*SPACE))649,6450,6450
 6450 IF(ABSF(DOJEP-DOJ)-.5)652,6451,6451
 6451 IF(DOJEP-DOJ)649,6452,6452
 6452 DOJ#DOJEP
      TSIPJ#(PINJ*DOJ/2.)/(SJ*WELDJ+.4*PINJ)
      GO TO 652
  649 CONTINUE
C     SET SCH 40 PIPE THICKNESS, PIPE CAP DISH RADIUS AND KNUCKLE RADIUS
  652 IF(DOJ-10.75)6520,6524,657
 6520 IF(DOJ-6.625)6521,6522,6523
 6521 TSEPJ1#THIK(1)
      RADHJ#4.42
      RADKJ#.84
      GO TO 653
 6522 TSEPJ1#THIK(2)
      RADHJ#5.31
      RADKJ#1.01
      GO TO 653
 6523 TSEPJ1#THIK(3)
      RADHJ#6.98
      RADKJ#1.33
      GO TO 653
 6524 TSEPJ1#THIK(4)
      RADHJ#8.77
      RADKJ#1.67
  653 IF(TSEPJ-TSEPJ1)656,656,654
  654 WRITE OUTPUT TAPE 9,655,TSEPJ
  655FORMAT(1H ,5X89HSCHEDULE 40 PIPE TOO THIN FOR JACKET SHELL UNDER E
     1XTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES.)
 6550 GO TO 734
  656 TSEPJ#TSEPJ1
C     HEAD THICKNESS DUE TO INTERNAL PRESSURE
C     SET UP DISH RADIUS AND KNUCKLE RADIUS
  657 IF(DOJ-10.75)672,672,658
  658 IF(DOJ-48.)659,667,668
  659 IF(DOJ-12.)672,663,660
  660 IF(DOJ-24.)664,663,661
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APPENDIX D (continued)

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  661 IF(DOJ-30.)665,663,662
  662 IF(DOJ-36.)665,663,665
  663 RADHJ#DOJ
      GO TO 672
  664 IF(DOJ-16.)665,666,665
  665 RADHJ#DOJ-2.
      GO TO 672
  666 RADHJ#DOJ-1.
      GO TO 672
  667 RADHJ#DOJ-6.
      GO TO 672
  668 IF(DOJ-84.)669,663,663
  669 IF(TSEPJ-TSIPJ)670,671,671
  670 IF(TSIPJ-.5)663,663,667
  671 IF(TSEPJ-.5)663,663,667
  672 RK2J#.06*DOJ
 6720 IF(DOJ-11.)679,679,673
  673 IF(TSEPJ-TSIPJ)674,675,675
  674 RK3J#3.*TSIPJ
      GO TO 676
  675 RK3J#3.*TSEPJ
  676 IF(RK2J-RK3J)678,677,677
  677 RADKJ#RK2J
      GO TO 679
  678 RADKJ#RK3J
  679THIPJ#PINJ*RADHJ*(.25*(3.+SQRTF(RADHJ/RADKJ)))/(2.*SJ*WELDJ-.2*PIN
     1J)
C     THICKNESS OF HEAD DUE TO EXTERNAL PRESSURE
  681 DO 686 I#1,96
      B1#I
      B1#B1*.015625
  682 THEPJ#B1
  683 SEGHJ#.12*THEPJ/RADHJ
  684 SEPHJ#2.*PEXJ*RADHJ/(EJ*THEPJ)
  685 IF(SEGHJ-SEPHJ)686,687,687
  686 CONTINUE
C     CHOOSE CONTROLLING SHELL AND HEAD THICKNESS
  687 IF(DOJ-10.75)688,688,697
  688 IF(TSEPJ-TSIPJ)689,689,691
  689 WRITE OUTPUT TAPE 9,690,TSIPJ
  690FORMAT(1H ,5X89HSCHEDULE 40 PIPE TOO THIN FOR JACKET SHELL UNDER I
     1NTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES.)
      GO TO 734
  691 WRITE OUTPUT TAPE 9,692
  692FORMAT(1H ,5X80HSCHEDULE 40 PIPE THICK ENOUGH FOR INTERNAL AND EXT
     1ERNAL PRESSURE ON JACKET SHELL /)
  693 IF(TSEPJ-THEPJ)694,6930,6930
 6930 IF(TSEPJ-THIPJ)6931,696,696
 6931 WRITE OUTPUT TAPE 9,6932,THIPJ
 6932FORMAT(1H ,5X92HSCHEDULE 40 PIPE CAP TOO THIN FOR JACKET HEAD UNDE
     1R INTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES./)
      GO TO 734
  694 WRITE OUTPUT TAPE 9,695,THEPJ
  695FORMAT(1H ,5X92HSCHEDULE 40 PIPE CAP TOO THIN FOR JACKET HEAD UNDE
     1R EXTERNAL PRESSURE. REQUIRED THICKNESS IS F7.4, 1X 7HINCHES./)
 6950 GO TO 734
  696 WRITE OUTPUT TAPE 9,6960
 6960 FORMAT(1H ,5X79HSCHEDULE 40 PIPE THICK ENOUGH FOR INTERNAL AND EXT
     1ERNAL PRESSURE ON JACKET HEAD //)
 6961 THEPJ#TSEPJ
```

APPENDIX D (continued)

```
      TSJ#TSEPJ
      THJ#TSEPJ
 6964 IF((DCJ-2.*TSJ-DO)-(2.*SPACE))7C30,720,720
  697 IF(TSEPJ-TSIPJ)699,698,698
  698 TSJ#TSEPJ
      GO TO 7C0
  699 TSJ#TSIPJ
  700 DO 702 I#5,14
      IF(TSJ-THIK(I))701,701,702
  701 TSJ#THIK(I)
      GC TO 703
  702 CONTINUE
  703 IF((DOJ-2.*TSJ-DO)-(2.*SPACE))7C30,7C4,704
 7030 LI#L2+1
      GC TO 631
  704 IF(TSEPJ-TSIPJ)705,7C5,707
  705 WRITE OUTPUT TAPE 9,706
  706CFORMAT(1H ,5X54HJACKET SHELL THICKNESS CONTROLLED BY INTERNAL PRES
     1SURE )
      GO TO 7C9
  707 WRITE OUTPUT TAPE 9,708
  708CFORMAT(1H ,5X54HJACKET SHELL THICKNESS CONTROLLED BY EXTERNAL PRES
     1SURE )
  709 IF(THEPJ-THIPJ)711,710,710
  710 THJ#THEPJ
      GC TC 712
  711 THJ#THIPJ
  712 DO 714 I#5,14
      IF(THJ-THIK(I))713,713,714
  713 THJ#THIK(I)
      IF(THJ-TSJ)714,715,715
  714 CONTINUE
  715 IF(THEPJ-THIPJ)718,718,716
  716 WRITE OUTPUT TAPE 9,717
  717CFORMAT(1H ,5X53HJACKET HEAD THICKNESS CONTROLLED BY EXTERNAL PRESS
     1URE //)
      GC TO 720
  718 WRITE OUTPUT TAPE 9,719
  719CFORMAT(1H ,5X53HJACKET HEAD THICKNESS CONTROLLED BY INTERNAL PRESS
     1URE //)
C     END THICKNESS
  720 TEIEPJ#2.*TSJ
      IF(TEIEPJ-.25)721,721,722
  721 TEIEPJ#.25
      GO TO 724
  722 IF(TEIEPJ-1.)724,724,723
  723 TEIEPJ#1.
  724 DIJ#DOJ-2.*TSJ
C     WEIGHTS AND COSTS
 7240 WJS#DENSJ*(SSLJ-1.5)*3.14159*(DCJ*DCJ-DIJ*DIJ)/(4.*1728.)
  725 WJE#DENSJ*TEIEPJ*3.14159*(DIJ*DIJ-DO*DO)/(4.*1728.)
      IF(THJ-1.)726,727,727
  726 WJH#DENSJ*THJ*(DOJ+DCJ/24.+3.+2.*RADKJ/3.)**2*3.14159/(4.*1728.)
 7260 GC TC 728
  727CWJH#DENSJ*THJ*(DCJ+DCJ/24.+3.+2.*RADKJ/3.+THJ)**2*3.14159/(1728.*4
     1.)
  728 TWJ#WJS+WJE+WJH
  729 TWJV#TWV+TWJ
  730 COSTMJ#TWJ*CMPPJ
  731 TCOSTB#TWJV*CFPP
```

APPENDIX D (continued)

```
  732 TCCSTM#COSTM+CCSTMJ
  733 TCOSTI#TCOSTB+TCOSTM
  734CWRITE CUTPUT TAPE 9,735,A5J,A6J,A7J,TEMPJ,SSLRJ,DCJ,TSJ,CIJ,CO,
     ITEIEPJ,THJ,RADHJ,RADKJ,SF,DENSJ,DENSQJ,PINJ,PEXJ,EJ
  735CFORMAT(1H ,4X24HMATERIAL OF CONSTRUCTION 7X3A6/ 5X 13HDESIGN TEMP
     1F F37.0/ 5X 34HSTRAIGHT SIDE/VESSEL STRAIGHT SIDE F19.3/ 5X 20HOUT
     2SIDE DIAMETER IN. F34.4/ 5X 19HSHELL THICKNESS IN. F35.4/ 5X 20HEN
     3D OUTSIDE DIAM IN. F34.4/ 5X 19HEND INSIDE DIAM IN. F35.4/ 5X 17HE
     4ND THICKNESS IN. F37.4/ 5X 18HHEAD THICKNESS IN. F36.4/ 5X 20HHEAD
     5 DISH RADIUS IN. F33.3/ 5X 23HHEAD KNUCKLE RADIUS IN. F30.3/ 5X24H
     6HEAD STRAIGHT FLANGE IN. F28.2/ 5X 23HMETAL DENSITY LBS/CU FT F30.
     73/ 5X 24HMETAL DENSITY LBS/CU IN. F3C.4// 5X 28HDESIGN INTERNAL PR
     8ESSURE PSI F23.1/ 5X 28HDESIGN EXTERNAL PRESSURE PSI F23.1/ 5X 25H
     9MODULUS OF ELASTICITY PSI 23XE11.5)
  736CWRITE OUTPUT TAPE 9,737,SJ,WELDJ,WJS,WJE,WJH,TWJ,TWJV,CMPPJ,COSTMJ
     1,TCOSTM,TCCSTB,TCOSTI
  737CFORMAT(1H ,4X 32HMAX ALLOWABLE TENSILE STRESS PSI F18.0/ 5X 26HWEL
     1D EFFICIENCY DEC.FRACT. F27.3// 5X 19HWEIGHT OF SHELL LBS F34.3/ 5
     2X 21HWEIGHT OF ONE END LBS F32.3/ 5X 18HWEIGHT CF HEAD LBS F35.3/
     35X 26HTOTAL WEIGHT OF JACKET LBS F27.3/ 5X 33HTOTAL WEIGHT OF JACK
     4ET+VESSEL LBS F20.3// 5X 22HJACKET METAL COST $/LB F31.3/ 5X 20HJA
     5CKET METAL COST  $ F33.3/ 5X 27HJACKET+VESSEL METAL COST  $ F26.3/
     65X 25HTOTAL FABRICATION COST  $ F28.3/ 5X 33HTOTAL UNIT COST(JACKE
     7T+VESSEL)  $ F20.3 //)
  738 WRITE OUTPUT TAPE 9,739
  739CFORMAT(1H ,4X92H(JACKET END ASSUMED TO BE TWICE THE SHELL THICKNES
     IS BUT LIMITED TO BETWEEN 0.25 AND 1.C IN.))
 7390 IF(JHED)7391,7391,7393
 7391 WRITE OUTPUT TAPE 9,7392
 7392 FORMAT(1H ,4X 40H(JACKET ON STRAIGHT SIDE OF VESSEL ONLY))
      GO TO 740
 7393 WRITE OUTPUT TAPE 9,7394
 7394 FORMAT(1H ,4X 40H(JACKET HAS ONE ASME TORISPHERICAL HEAD))
  740 IF(JLOD)597,597,741
  741 WRITE OUTPUT TAPE 9,521C,HSEPCJ,WTSRJ
  750 GO TO 597
      END
```

APPENDIX F

Deck Setup for Central Data Processing Facility, ORGDP

```
*ID
*Charge
*TAPE (9, OUTPUT) (10, INPUT)
*DUMP *(1000, 77460, D)
*EXECUTE
*TYPE (BINARY)
 (Binary Deck of Cards)
*DATA
 List of inside diameters (first card)
 List of outside diameters (second card)
 List of thicknesses (third card)
 (Data cards for vessel design)
```

Note: Fortran deck may be used by changing TYPE card to FORTRAN and using Fortran deck.

APPENDIX G

UNFIRED PRESSURE VESSEL DESIGN DATA SHEET

UNCLASSIFIED
ORNL-LR-DWG 71757

WRITTEN BY: R. P. Milford REQUEST NUMBER: X X X X DATE: 9/6/62 (SHEET 2 of 2)

Vessel Design Data:

Capacity, cu ft (1)	Free Board Ratio (11)	Straight Side/ OD Ratio (16)	Head-Straight Flange, in. (24)	Modulus of Elasticity, psi (29)	Maximum Allowable Tensile, Stress psi (39)	Design Temp., °F (49)	Design External Pressure, psi (55)	Design Internal Pressure, psi (63)	
60	1.5	2.5	1.5	26.7E06	12848	312	95	20	1

Metal Cost, $/lb (1)	Fabrication Cost, $/lb (9)	Weld Eff., Dec. Fract. (17)	Corrosion Allowance, in. (21)	Allowance over Std. Thickness, Dec. Fract. (26)	Material of Construction (2) (31)	Vessel Identity (2) (49)	Metal Density, lbs/cu ft (3) (57)	Metal Density, lbs/cu in. (3) (65)	
0.65	2.50	0.8	0.125	0.04	SA-240, 304L SS	EXAMPLE	501		2

Jacket Design Data:

Jacket Straight Side/Vessel Straight Side (1)	Min. Space Between Vessel OD and Jacket ID, in. (9)	H (7) (17)	Design External Pressure, psi (18)	Design Internal Pressure, psi (25)	Design Temp., °F (32)	Modulus of Elasticity, psi (38)	Maximum Allowable Tensile, Stress psi (48)	Metal Cost, $/lb (57)	Weld Eff., Dec. Fract. (65)	J (6) (69)	
0.75	0.75	1	15	80	312	26.7E06	12848	0.65	0.8	1	3

Material of Construction (2) (1)	Metal Density, lbs/cu ft (3) (19)	Metal Density, lbs/cu in. (3) (27)	
SA-240, 304L SS	501		4

NOTES:

1. All decimal points are coded to the extreme right of the field and do not take up a space. However, a decimal point may be located in any other space and will override the printed point. (See: Head-straight flange in card No. 1).
2. Use any Fortran characters.
3. Only one density value required.
4. The final shell and head thicknesses of the vessel are selected from an internal list by selecting the next larger size. To allow a small overage above one std. thickness before choosing the next larger size, insert allowable excess as decimal fraction of std. thickness.
5. All four data cards must be included for each vessel.
6. J: If a jacket is to be designed, insert "1".
7. H: If a jacket is to have a head, insert "1". Jacket may have no more than one head.

APPENDIX G (continued)

SHELL THICKNESS CONTROLLED BY EXTERNAL PRESSURE
HEAD THICKNESS CONTROLLED BY EXTERNAL PRESSURE

VESSEL NUMBER	EXAMPLE
MATERIAL OF CONSTRUCTION	SA-240, 304L SS
DESIGN TEMP F	312.
DESIGN CAPACITY CU FT	60.000
FREEBOARD RATIO	1.43
VESSEL VOLUME CU FT	85.949
ONE HEAD DISH VOLUME GAL	25.06
STRAIGHT LENGTH /OUTSIDE DIAM	2.500
OUTSIDE DIAMETER IN.	42.0000
SHELL THICKNESS IN.	0.6250
SHELL LENGTH IN.	102.000
HEAD THICKNESS IN.	0.6250
HEAD DISH RADIUS IN.	40.000
HEAD KNUCKLE RADIUS IN.	2.520
HEAD STRAIGHT FLANGE IN.	1.50
WEIGHT OF SHELL LBS	2402.491
WEIGHT OF ONE HEAD LBS	333.805
TOTAL WEIGHT OF VESSEL LBS	3070.100
METAL DENSITY LB PER CU FT	501.000
METAL DENSITY LB PER CU IN.	*0.
DESIGN EXTERNAL PRESSURE PSI	95.0
DESIGN INTERNAL PRESSURE PSI	20.0
MODULUS OF ELASTICITY PSI	0.26700E 08
MAX ALLOWABLE TENSILE STRESS PSI	12848.
CORROSION ALLOWANCE IN.	0.1250
ALLOWANCE OVER STD THIK. DEC.FRACT.	0.0400
WELD EFFICIENCY DEC.FRACT.	0.800
METAL COST $ PER LB	0.6500
FABRICATION COST $ PER LB	2.5000
METAL COST TOTAL $	1995.565
FABRICATION COST TOTAL $	7675.250
TOTAL UNIT COST $	9670.815

(THE ABOVE CALCULATION IS FOR ASME TORISPHERICAL HEAD)

APPENDIX G (continued)

JACKET FOR VESSEL NUMBER EXAMPLE

JACKET SHELL THICKNESS CONTROLLED BY EXTERNAL PRESSURE
JACKET HEAD THICKNESS CONTROLLED BY INTERNAL PRESSURE

MATERIAL OF CONSTRUCTION	SA-240, 304L SS
DESIGN TEMP F	312.
STRAIGHT SIDE/VESSEL STRAIGHT SIDE	0.750
OUTSIDE DIAMETER IN.	48.0000
SHELL THICKNESS IN.	0.2500
END OUTSIDE DIAM IN.	47.5000
END INSIDE DIAM IN.	42.0000
END THICKNESS IN.	0.5000
HEAD THICKNESS IN.	0.3750
HEAD DISH RADIUS IN.	42.000
HEAD KNUCKLE RADIUS IN.	2.880
HEAD STRAIGHT FLANGE IN.	1.50
METAL DENSITY LBS/CU FT	501.000
METAL DENSITY LBS/CU IN.	-0.
DESIGN INTERNAL PRESSURE PSI	80.0
DESIGN EXTERNAL PRESSURE PSI	15.0
MODULUS OF ELASTICITY PSI	0.26700E 08
MAX ALLOWABLE TENSILE STRESS PSI	12848.
WELD EFFICIENCY DEC.FRACT.	0.800
WEIGHT OF SHELL LBS	839.954
WEIGHT OF ONE END LBS	56.045
WEIGHT OF HEAD LBS	257.558
TOTAL WEIGHT OF JACKET LBS	1153.557
TOTAL WEIGHT OF JACKET+VESSEL LBS	4223.657
JACKET METAL COST $/LB	0.650
JACKET METAL COST $	749.812
JACKET+VESSEL METAL COST $	2745.377
TOTAL FABRICATION COST $	10559.143
TOTAL UNIT COST(JACKET+VESSEL) $	13304.521

(JACKET END ASSUMED TO BE TWICE THE SHELL THICKNESS BUT LIMITED TO BETWEEN 0.25 AND 1.0 IN.) (JACKET HAS ONE ASME TORISPHERICAL HEAD)

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