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VOLUME ACCUMULATOR
DESIGN ANALYSIS
COMPUTER CODES

AEC

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VOLUME ACCUMULATOR DESIGN ANALYSIS COMPUTER CODES

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FOREWORD

The work described here was done at the Atomics International Division of Rockwell International Corporation, under the direction of the Space Nuclear Systems Division, a joint AEC-NASA office. Project management was provided by NASA-Lewis Research Center and the AEC-SNAP Project Office.

DISTRIBUTION

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ABSTRACT

The computer codes, VANEP and VANES, were written and used to aid in the design and performance calculation of the Volume Accumulator Units (VAU's) for the 5-kwe Reactor Thermoelectric System. VANEP computes the VAU design which meets the primary coolant loop VAU volume and pressure performance requirements. VANES computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop. The codes can also compute the performance characteristics of the VAU's under conditions of possible modes of failure which still permit continued system operation.

I. INTRODUCTION

A series of compact nuclear reactors and electrical power systems were designed, developed, and tested for the Systems for Nuclear Auxiliary Power (SNAP) Program. The zirconium hydride reactors for these systems were fueled by hydrided zirconium-uranium elements. Windows in the external beryllium neutron reflector were adjusted by rotating drums or sliding segments to regulate the neutron leakage from the core, and thus the power output of the reactor. A direct radiating thermoelectric module powered Power Conversion System (PCS) produced >500 w of electrical power on the flight-tested SNAP 10A System. Mercury Rankine cycle turbogenerator PCS of 3- and 30-kwe power range were demonstrated for the SNAP 2 and SNAP 8 Systems respectively. The latest 5-kwe Reactor Thermoelectric System, shown in Figure 1, was based on the use of a compact tubular thermoelectric PCS. The NaK, used to transfer the heat from the reactor to the PCS and from the PCS to the space radiator, was circulated by dc conduction electromagnetic pumps on the thermoelectric systems, and by mechanical centrifugal pumps on the mercury Rankine systems.

In the 5-kwe Reactor Thermoelectric System, volume accumulator units (VAU's)[1] are used in the NaK primary and secondary coolant loops to:

1) Accommodate NaK coolant thermal volumetric expansion and contraction during the 5-kwe Reactor Thermoelectric System startup, operation, shutdown, and storage
2) Provide void-free NaK coolant systems
3) Provide pressure regulation of the NaK coolant systems

As indicated in Figure 1, there are two VAU's for the primary coolant loop, and one VAU for the secondary coolant loop. All three VAU's are identical.

This report describes the computer codes that were written and used to aid in the design and performance calculations of the VAU's for the 5-kwe Reactor Thermoelectric System.

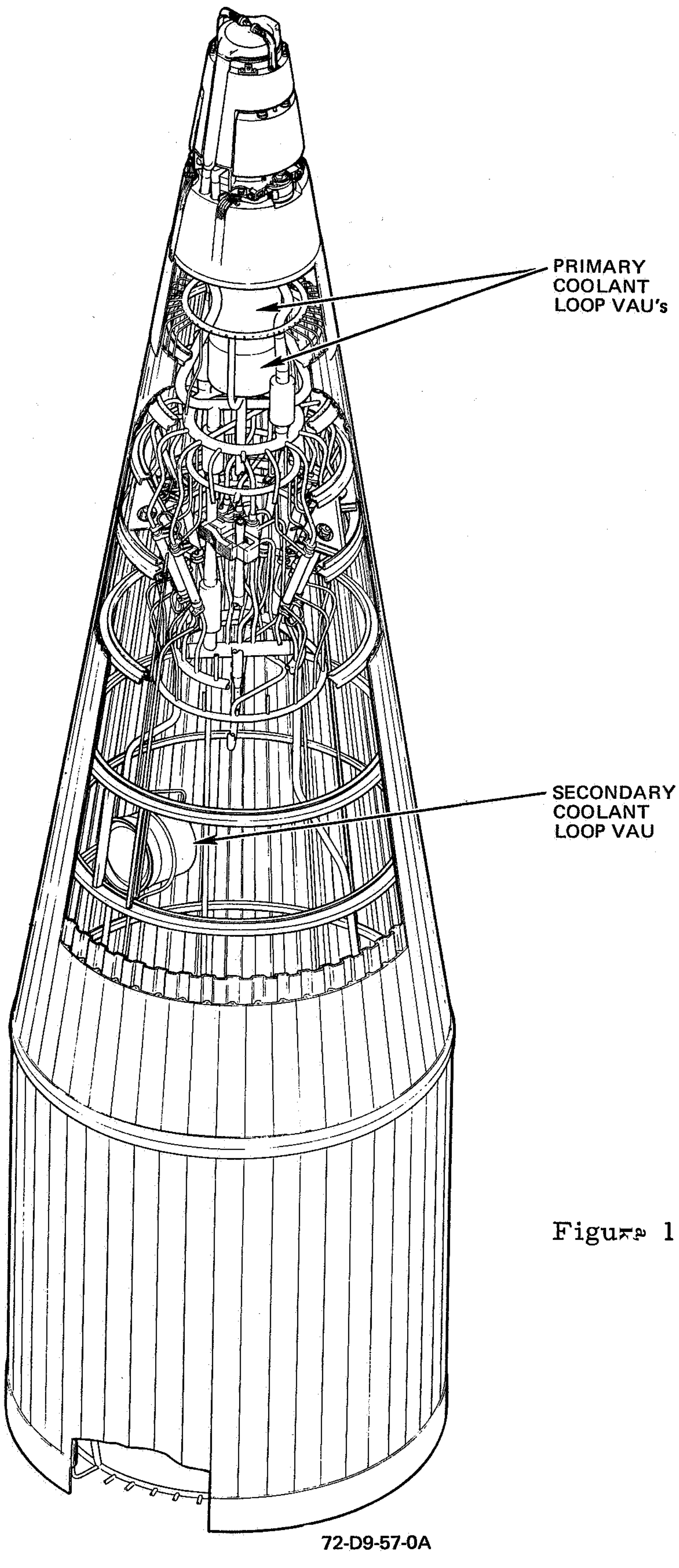

Figure 1 5-kwe Reactor Thermoelectric System

II. DESCRIPTION OF VOLUME ACCUMULATOR UNIT

Figure 2 shows a design layout of the prototype VAU. All VAU parts, except the NaK inlet tube, are fabricated from Inconel 718. The NaK inlet tube material is Type 316 stainless steel. As can be seen in Figure 2, there are three cavities in the VAU (viz, the primary containment cavity, the secondary containment cavity, and the secondary bellows cavity).

The primary containment cavity, which is formed by the NaK dome, primary containment bellows, and the movable head, accommodates the NaK fluid expansion volume from the coolant loop.

The secondary containment cavity, which is formed by the primary and secondary containment bellows and the shell, is evacuated, and provides secondary containment of the NaK, in the event of leakage through, or failure of, the primary containment bellows.

The secondary bellows cavity, which is formed by the movable head, secondary containment bellows, and gas dome, is charged with inert gas, and provides the gas pressure force needed to augment the bellows spring force to obtain the desired pressure regulation of the coolant loop.

The primary and secondary containment bellows are identical, and are the nested-formed type.

The performance requirements for the prototype VAU are:

1) NaK Volume Capacity — The VAU at 750°F shall be capable of accommodating a NaK volume increase of 337 in.^{3} above the residual volume.*

2) NaK Pressure — The combined action of the gas charge and the bellows force shall impose the following pressures on the NaK:

   a) Initial Pressure — The initial pressure at 100°F VAU temperature on the residual volume* of NaK in the VAU shall be 4 psia minimum.

   b) Operating Pressure — The operating pressure shall be 28.0 psia maximum at 750°F VAU temperature.

*The NaK volume at 100°F which is required to fill the primary containment cavity with the movable head positioned 0.12 in. from the NaK dome.

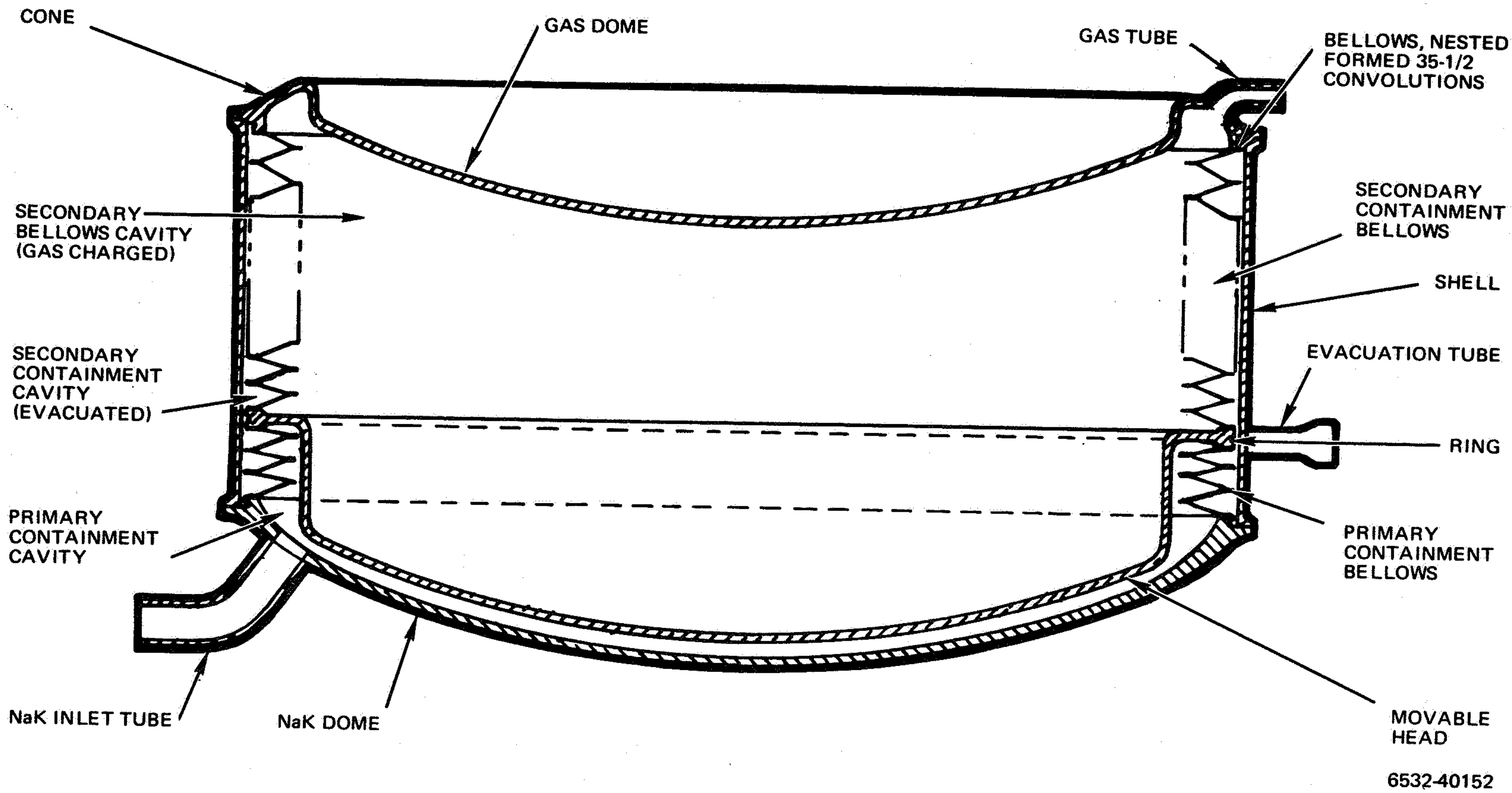

Figure 2. Prototype Volume Accumulator Unit Schematic

c) Failed Primary Bellows — In the event of primary bellows failure, the VAU shall maintain 6 psia minimum pressure on 236 $in.^3$ plus the residual volume of NaK in the primary and secondary containment cavities. This pressure shall be maintained at 600° F VAU temperature.

3) Useful Life — The VAU shall have an operational life of 5 years after being exposed to storage environment for up to 2 years, and then to preflight through launch environment, with no maintenance.

4) Reliability — The reliability of the VAU for 5 years of operation, without causing failure of the 5-kwe System, shall be not less than 0.997.

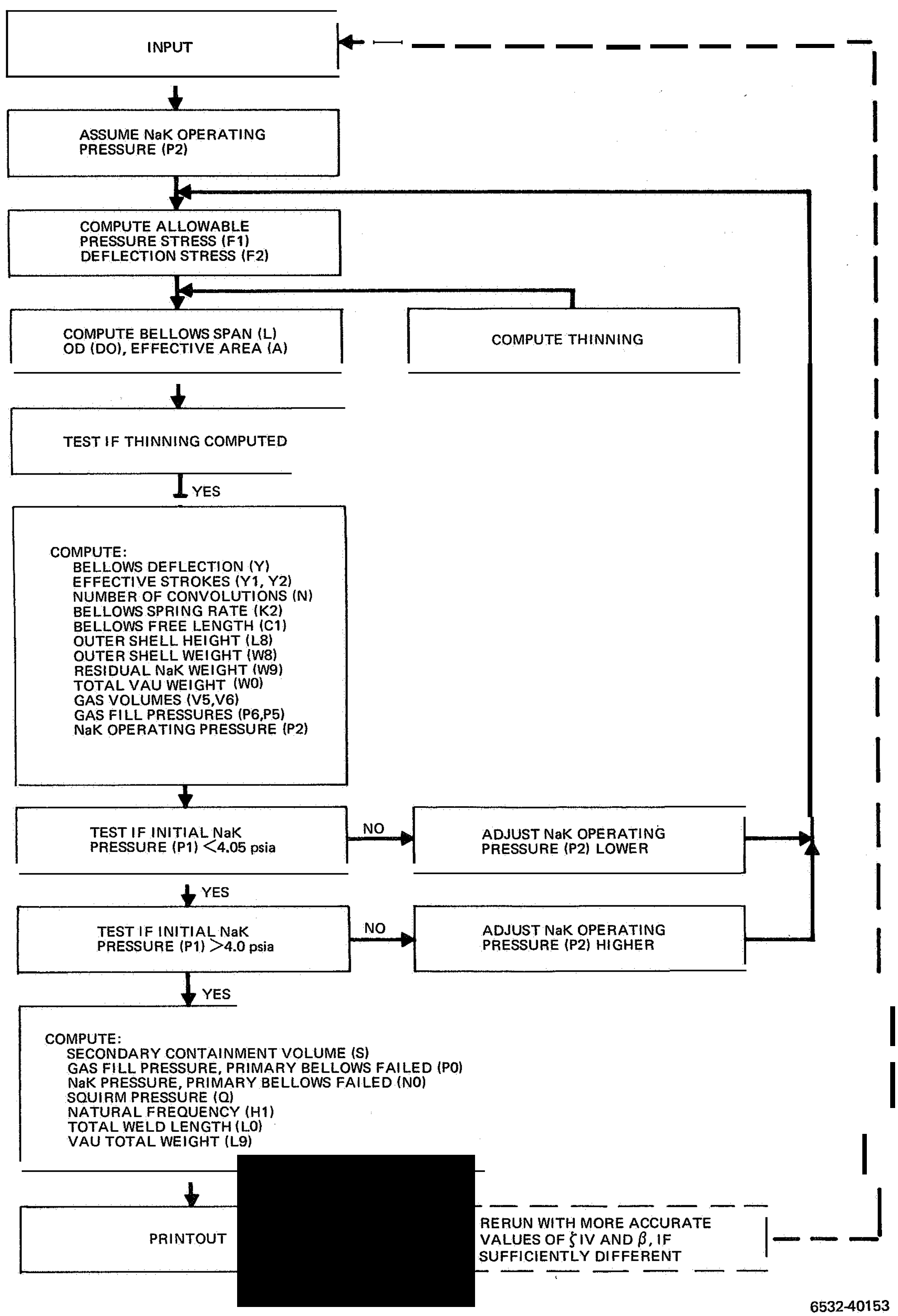

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Figure 3. Flow Chart for VANEP

III. DESCRIPTION OF COMPUTER CODES

A. GENERAL

Two computer codes, VANEP and VANES, were written to aid in the design and performance calculation of the VAU's for the 5-kwe Reactor Thermoelectric System. Both codes are written in BASIC Language for the Honeywell Time-Sharing Computer.

The computer code VANEP (Volume Accumulator with NEsted-formed bellows, Primary coolant loop) performs the design computations for the VAU which meets the primary coolant loop VAU volume and pressure performance requirements listed previously.

The computer code VANES (Volume Accumulator with NEsted-formed bellows, Secondary coolant loop) computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop.

Both codes can be used to analyze any set of conditions (e.g., NaK pressure as a function of temperature, volume, and/or gas fill pressure, bellows stress as a function of pressure or volume, etc.).

The codes can also compute the performance characteristics of the VAU's under modes of failure which still permit continued system operation (e.g., in the primary coolant loop VAU's, the failure of one or both primary containment bellows and/or the failure of one or both gas domes).

B. VANEP

The flow chart for VANEP is shown in Figure 3, and the listing for VANEP is given in the Appendix.

The equations used in the VANEP code for computing the number of bellows convolutions, bellows spring rate, bellows squirm pressure, and bellows natural frequency are taken from Reference 2.

The input data required for VANEP are listed in Table 1. The bellows shape correction factors, ζ IV and β, are initially estimated from Figures 2a and 2b, respectively, of Reference 2. From the run results, more accurate values of

ζIV and β can be read from the figures; if there is sufficient difference, a rerun is made, using the more accurate values of ζIV and β, as indicated in Figure 3

Data written into the VANEP code include the initial NaK pressure (4 psia) at 100°F, and the wall thicknesses of the NaK dome, movable head, gas dome, and shell.

From a trade study, the optimum value of the ratio of pressure stress to total stress for the bellows, from the standpoints of VAU weight, weld length, and fabrication cost, was found to be 0.445. This value is used in the VANEP code.

TABLE 1

REQUIRED INPUT DATA FOR VANEP

Input Data Description	Units	Code Nomenclature
Primary Coolant Loop VAU Volumes, Pressures and Temperature		
Maximum capable volume	$in.^3$	B1
Design volume	$in.^3$	B
Assumed NaK operating pressure	psia	P2
Initial temperature	°R	T5
Design temperature	°R	T6
Material		
Material density	lb/in.*	R
Modulus of elasticity at initial temperature	psi	E1
Modulus of elasticity at design temperature	psi	E2
Bellows		
Design total stress	psi	F
Bellows ID	in.	D3
Number of plies	-	M
Bellows ply thickness	in.	T
Bellows convolution bend radius	in.	C0
ζIV (from Figure 2a of Reference 2)	-	C4
β (from Figure 2b of Reference 2)	-	B0

A description of the VANEP printout is given in Table 2. The items are listed in the order they appear in the printout.

C. VANES

The listing for VANES is given in the appendix.

The input data required for the VANES code are listed in Table 3. Note that some of the input data are results obtained from the VANEP code.

A description of the VANES printout is given in Table 2. The items are listed in the order they appear in the printout.

TABLE 2

DESCRIPTION OF VANEP AND VANES PRINTOUTS

Code Nomenclature	Description	Units	Input (I)/Output (O)	
			VANEP	VANES
T	Bellows Ply Thickness	in.	I	I
L	Calculated Bellows Span	in.	O	I
Y	Calculated Bellows Deflection	in.	O	O
P2	NaK Operating Pressure	psia	O	O
N	Number of Convolutions per Bellows	-	O	I
V5	Total Gas Volume at Initial Temperature	$in.^3$	O	I
V6	Total Gas Volume at Design Temperature	$in.^3$	O	O
W8	Outer Shell Weight	lb	O	O
W9	Weight of Residual NaK at Initial Temperature	lb	O	O
Y1	Effective Stroke, Prior to System Startup	in.	O	I
L8	Height of Outer Shell	in.	O	O
H1	Natural Frequency of Bellows at Initial Temperature, With no Damping	Hz	O	O
Y2	Effective Stroke During Operation	in.	O	O

(Continued)

TABLE 2 (Continuation)

Code Nomenclature	Description	Units	Input (I)/Output (O)	
			VANEP	VANES
W0	Total VAU Weight	lb	O	O
P5	Gas Fill Pressure at Initial Temperature	psia	O	I
P6	Gas Fill Pressure at Operating Temperature	psia	O	O
S	Secondary Containment Volume	$in.^3$	O	O
P0	Gas Fill Pressure, Primary Bellows Failed, Design Volume	psia	O	O
N0	NaK Pressure, Primary Bellows Failed, Design Volume	psia	O	O
D3	Bellows ID	in.	I	I
D0	Calculated Bellows OD	in.	O	O
F1	Pressure Stress	psi	O	O
F2	Deflection Stress	psi	O	O
F	Design Total Stress	psi	I	O
C1	Bellows Free Length	in.	O	O
Q	Squirm Pressure at Maximum Capable Volume	psi	O	O
P1	Initial NaK Pressure at Initial Temperature	psia	written in*	O
C0	Bellows Convolution Bend Radius	in.	I	I
K2	Bellows Spring Rate Per Bellows at Design Temperature	lb/in.	O	O
L0	Total Weld Length (bellows and primary containment structure)	ft	O	O
L9	VAU total height	in.	O	O

*Already written in code

TABLE 3

REQUIRED INPUT DATA FOR VANES

Input Data Description	Units	Code Nomenclature
Secondary Coolant Loop VAU Volumes and Temperatures		
Maximum capable volume*	$in.^3$	B1
Design volume	$in.^3$	B
Initial temperature	°R	T5
Design temperature	°R	T6
Material		
Material density	$lb/in.^3$	R
Modulus of elasticity at initial temperature	psi	E1
Modulus of elasticity at design temperature	psi	E2
Bellows		
Bellows ID*	in.	D3
Bellows ply thickness*	in.	T
Bellows convolution bend radius*	in.	C0
ζIV (from Figure 2a of Reference 2)*	-	C4
β (from Figure 2b of Reference 2)*	-	D0
Effective stroke prior to system startup†	in.	Y1
Number of bellows convolutions†	-	N
Calculated bellows span†	in.	L
Total gas volume at initial temperature†	$in.^3$	V5
Gas pressure at initial temperature†	psia	P5

*Same as input data for VANEP

†From VANEP output

```
90    FØR M=1 TØ 3 STEP 2
270   FØR D3=10 TØ 12 STEP 2
281   FØR T=.008 TØ .010 STEP .002
279 PRINT "NØ. PLY="M
960 NEXT T
970 NEXT D3
980 NEXT M
RUN


VANEP       17:12  NR T/S MAY 16, 1973

T              L              Y              P2             N
V5             V6             W8             W9             Y1
L8             H1             Y2             W0

P5             P6             S              P0             N0
D3             D0             F1             F2             F
C1             Q              P1             C0             K2
L0             L9
NØ. PLY= 1
BELLØWS I.D = 10 , DELTA VØL= 337
 .008           .43219         3.9426         25.[illegible]5        50.051
 880.61         543.61         10.337         1.4[illegible]0[illegible]     1.9713
 10.129         39.395         1.9713         20.[illegible]9[illegible]

 6.[illegible]028        23[illegible]1         96.783         19.6[illegible]8        20.6[illegible]4
 10             10[illegible]4         44500.         5550[illegible].       [illegible]+5
 4.3738         49 [illegible]2        4.012          2              5[illegible].7[illegible]7
 18.042         12[illegible]                                        [illegible]

 .01            .50185         3.8905         28.6           45.089
 934.48         59[illegible].48        10.887         1.8472         1.9453
 10.682         40.479         1.9453         23.297

 7.5235         25.425         115.46         21.308         22.[illegible]07
 10             11.004         44500.         55500.         1E+[illegible]
 4.6506         66.52          4.0068         2              70[illegible]686
 18.409         12.783

NØ. PLY= 1
BELLØWS I.D.= 12 , DELTA VØL= 337
 .008           .46613         2.7611         22.3           30.421
 919.66         582.66         10.934         1.2414         1.3805
 7.0388         55.803         1.3805         19.361

 6.0117         20.502         86.787         17.844         18.7[illegible]6
 12             12.932         44500.         55500.         1E+5
 2.8407         116.69         4.0205         2              79[illegible]4[illegible]3
 1[illegible].447        9.4199

 .01            .54568         2.726[illegible]        24.7           2[illegible].0[illegible]4
 962.36         625.36         11.35[illegible]        1.5317         1[illegible]36[illegible]1
 7.3232         57.269         1.3631         21.813

 6.7009         22.281         102.97         19.131         20.072
 12             13.091         44500.         55500.         1E+5
 2.9833         156.52         4.0[illegible]16        2              109.68
 19.758         9.7274
```

a. Number of Plies = 1

Figure 4. Printout of Parametric Study

IV. SOME EXAMPLES OF USE OF CODES

A. PARAMETRIC STUDY OF PRIMARY COOLANT LOOP VAU

By making some minor changes in the VANEP code, a parametric study can be made of the effects of number of plies, ply thickness, bellows ID, etc, on the primary coolant loop VAU's. An example is shown in Figures 4a and 4b, in which the parameters investigated are number of plies (1 and 3), bellows ID (10 and 12 in.) and ply thickness (0.008 and 0.010 in.). The changes made to the VANEP code are shown at the top of Figure 4a, (viz, modification of Lines 90, 270, and 281, and addition of new lines 279, 960, 970, and 980). The printout for number of plies = 1 is shown in Figure 4a, and the printout for number of plies = 3 is shown in Figure 4b.

B. DESIGNING TO SPECIFIED OPERATING PRESSURE, RATHER THAN INITIAL PRESSURE

To design a primary coolant loop VAU in which the operating NaK pressure, rather than the initial NaK pressure, is specified, Lines 694 through 699 are deleted in the VANEP code, and input P2 is the specified operating pressure. The printout of the VANES listing shown in the appendix, in which Lines 694 through 699 were deleted and the operating pressure (P2) was specified as 25 psia, is shown in Figure 5.

```
T               L               Y               P2              N
V5              V6              W8              W9              Y1
L8              H1              Y2              W0

P5              P6              S               P0              N0
D3              D0              F1              F2              F0
C1              Q               P1              C0              KC
L0              L9
NØ. PLY= 3
BELLØWS I.D.= 10 , DELTA VØL= 337
 .008            .56922          3.8295          41.15           27.09
 855.16          518.16          10.286          1.6905          1.914
 9.5447          42.154          1.9147          28.394

 10.017          35.72           115.05          29.193          30.89
 10              11.17           44500.          55500.          1E+5
 4.0826          129.02          4.0018          2               124.79
 17.338          11.67

 .01             .63619          3.7786          49.85           26.33
 936.49          599.49          11.071          2.2171          1.8893
 10.423          43.331          1.8893          35.345

 12.499          42.187          139.21          34.237          35.569
 10              11.312          44500.          55500.          1E+5
 4.5225          175.09          4.0104          2               180.86
 17.763          12.569

NØ. PLY= 3
BELLØWS I.D.= 12 , DELTA VØL= 337
 .008            .63502          2.6809          33.7            15.389
 880.38          543.38          10.906          1.3879          1.3405
 6.4989          59.738          1.3405          25.473

 8.4741          29.666          105.32          24.85           26.362
 12              13.302          44500.          55500.          1E+5
 2.5716          299.53          4.0056          2               189.15
 19.15           8.9337

 .01             .71581          2.6454          40.15           14.704
 942.64          605.64          11.473          1.7774          1.3227
 6.9411          61.414          1.3227          30.564

 10.261          34.507          124.84          28.61           30.072
 12              13.472          44500.          55500.          1E+5
 2.7931          409.42          4.0095          2               271.77
 19.507          9.4006


RUNNING TIME= 23.1 SECS    I/Ø TIME = 2.0 SECS

ØK
```

b. Number of Plies = 3

Figure 4. Printout of Parametric Study

```
Ø L:ΩA ΩP

ØK

694
695
696
697
698
699
RUN


VANEP      17:07  NR T/S MAY 16, 1973

T              L              Y              P2             N
V5             V6             W8             W9             Y1
L8             H1             Y2             W0

P5             P6             S              P0             NO
D3             D0             F1             F2             F
C1             Q              P1             C0             K3
L0             L9
BELLØWS I D = 11 , DELTA VØL= 337
 .01           .53826          3.223          25             32.56
 922.69        585.69          10.86          1.620≤         1.6 15
 8.4972        48.799          1.6115         21.861

 6.555 I       22.313          107.85         18.843         19.31
 11            12.077          40500 *        55500.         1E 5
 3.5651        104.44          3.5791         2              87 162
 18.916        10.754


RUNNING TIME:    2 1 SECS    I/Ø TIME :      3 S≤<S

ØK
```

Figure 5. Printout for Case of Specified Operating Pressure

V. SUMMARY

Two computer codes, VANEP and VANES, written and used to aid in the design and performance calculation of the volume accumulator units for the 5-kwe Reactor Thermoelectric System, are described. VANEP computes the VAU design which meets the primary coolant loop VAU volume and pressure performance requirements. VANES computes the performance of the VAU design, determined from the VANEP code, at the conditions of the secondary coolant loop. The codes can also compute the performance characteristics of the VAU's under conditions of possible modes of failure which permit continued system operation (e.g., in the primary coolant loop VAU's, the failure of one or both primary containment bellows and/or the failure of one or both gas domes).

REFERENCES

1 W. D. Whitaker and T. T. Shimazaki, "Space Nuclear System Volume Accumulator Development Summary Report," AI-AEC-13090 (June 1973)

2 "Aerospace Recommended Practice," ARP 735 (8-15-66)

APPENDIX – LISTING OF VANEP AND VANES CODES

VANEP

```
2 REM PRIMARY LØØP UNITS
5 REM GAS BACK, NESTING-FØRM BELL; V=234 & 668, T=600&750F
6 REM 2 UNITS IN PRI LØØP, 1 UNIT IN SEC LØØP
7 REM B1=MAX CAPABLE VØL
8 LET B1=344
9 REM B=FAILURE MØDE V L
10 LET B=337
30 LET T6=1210
40 LET F=100000
50 LET R=.297
60 LET E1=28.8E6
62 LET E2=26E6
70 LET C4=.39
75 LET BO=1.19
80 LET T5=560
90 LET M=1
99 REM Q1=THICKNESS CØRRECTIØN FACTØR
240 PRINT "T","L","Y","P2","N"
250 PRINT "V5","V6","W8","W9","Y1"
253 PRINT "L8","H1","Y2","WO"
254 PRINT
255 PRINT "P5","P6","S","PO","NO"
257 PRINT "D3","DO","F1","F2","F"
258 PRINT "C1","Q","P1","CO","K2"
259 PRINT "LO","L9"
260 LET V=B
270 LET D3=11
280 PRINT "BELLØWS I.D.="D3;", DELTA VØL="V
281 LET T=.010
285 LET P2=25
287 LET CO=2
288 REM STRESS CØRRECTED FØR THINNING
290 LET F1=.445*F
295 LET F2=F-F1
299 LET Q1=1
300 LET L=SQR(F1*2*M*(T*Q1)↑2/P2)
301    IF L=>.15*D3 THEN 951
310 LET DO=D3+2*L+2*(M*T-T)
312 LET D2=D3+L+(M*T-T)
315 LET A=(3.1416*D2↑2)/4
316    IF Q1<1 THEN 320
317 LET Q1=D3/DO
318    GØ TØ 300
320 LET Y=V/A
321 LET Z=.50
322 LET Y1=Z*Y
325 LET Y2=Y-Y1
327 REM Y5=TØTAL DEFL. FØR "B1" VØL
328 LET Y5=B1/A
330 LET N=3*Y2*E2*(T*Q1)/(F2*2*.91 [illegible])
```

VANEP CØNTINUED

```
350 LET W=2*3.1416*D2*N*R*M*T*((L-a GO*T)+3.1416 GO F]
360 LET K1=3.1416*E1*D2*M*T↑3/(6*.3 I*C *N L↑3)
365 LET K2=K1*E2/E1
400 REM S2=SØL. HT. FØRMED BELLaωS
440 LET S2=((2*CO*T)+2*M*T]*N
490 REM C1=FREE LENGTH
500 LET C1=S2+Y1
600 REM STRU: +.25! XT FØR aTTaCH. PRESS DØME: Z8=ωT. ØF GaS DØME
610 LET D8=D0+.25
620 LET L8=(2*S2)+Y5+.80+2*.25
624 REM ØUTER CAN WEIGHT
626 LET W8=3.1416*D8*.04*L8*R
628 REM NAK DØME, MØVE. HEAD, BELL. RINGS WEIGHT
630 LET W8=W8+3.1416*R*(D8↑2/4*.06+(D0-.6)*.12*.6)
632 LET W8=W8+3.1416*R*((D3-.26)↑2/4*.06+(D3-.26)*(S2+2 *60) *06)
634 LET W8=W8+3.1416*R*D2*(L+.25)*.032*2
636 REM W9=WT ØF RESID NAK AT ZERØ VØL DISPL AT 100F
638 LET W9=3.1416*(D2-.02)*L*(S2+.12)*54/1728
640 LET W9=W9+3.1416*(D2-L-.10)*.10*(S2+.12)*54/1728
642 LET W9=W9+D0↑2/4*.12*54/1728
648 REM Z8=GAS DØME WEIGHT
650 LET Z8=3.1416*R*(D0↑2/4*.032+(D8*.032*.4]]
652 LET Z8=Z8+3.1416*D8*.08*.3*R
660 LET W0=2*W+W8+W9+Z8
680 REM V1=GAS VØL. IN ECU CAVITY
685 LET V1=3.1416*(D2↑2/4*(S2+Y5)+(D2-L-.32 ↑2/4*(S3+.62])
686 LET V5=V1+3.1416*((1/11*D0)↑2*(15-(1/11 D0)/3)-c I↑2*[15-1/3]]]
687 LET V5=V5+3.1416*(D3-.06)↑2/4*.7
689 LET V5=V5+3.1416*D0↑2/4*.6
690 LET V6=V5-A*Y
691 LET P6=P2-(K2*Y2/A)*2
692 LET P5=P6*V6*T5/(T6*V5)
693 LET P1=P5-(K1*Y1/A)*2
694   IF P1=<4.05 THEN 697
695 LET P2=P2-.3
696   GØ TØ 290
697   IF P1=>4.0 THEN 700
698 LET P2=P2+.05
699   GØ TØ 290
700 REM FAILURE MØDE ANAL; S=SECD VØL EXT TØ BELLØWS
705 REM P0=GAS PRESS, PRI BELLØWS FAILED, VØL=B
708 REM N0=NAK PRESS, PRE BELLØWS FAILED, VØL=B
710 LET S=3.1416*(D2*L*.5*(Y5+2*S2)+((D0+.06)*.06*(Y5+2*S2+1.75)))
715 LET S=S+3.1416*D2*L*.88
760 LET P0=T6*V5*P5/(T5*(V6+S+(V-B)))
775 LET N0=P0+2*K2*((B-S)/A-Y1)/A
820 REM Q=SQUIRM PRESS AT FULL VØL
825 LET Q=2*3.1416*K2/(S2+Y5)
830 REM H1=NATURAL FREQUENCY AT 100F
835 LET H1=9.85*SQR(K1/W)
```

VONEP CONTINUED

```
840 R≤M LO=WELD LENGTH, FEET
845 L≤T LO=(2*3.1416*DO+.75+(L-2*CO*T+3.1416*CO*T)*2*N)/12
846 L≤T LO=LO+(3.1416*DO)/12*3
847 LET L9=L8+(1.6/11)*DO+.50
900 SET DIGITS 5
910 PRINT T,L,Y,P2,N
920 PRINT V5,V6,W8,W9,Y1
930 PRINT L8,H1,Y2,WO
931 PRINT
935 PRINT P5,P6,S,PO,NO
940 PRINT D3,DO,F1,F2,F
942 PRINT C1,Q,P1,CO,K2
950 PXINT LO,L9
951 PRINT
999 END
```

VANES

```
2 REM SEC0NDARY L00P UNITS
5 REM GAS BACK, NESTING-F0RM BELL; V=234 & 668, T=000&750F
6 REM 3 IDENTICAL UNITS: 1 IN SEC, 2 IN PRI L00P
7 REM B1=MAX CAPABLE V0L
8 LET B1=344
9 REM 3=FAILURE M0DE V0L
10 LET B=236
30 LET T6=1060
50 LET R=.297
60 LET E1=28.8E6
62 LET E2=26.6E6
70 LET C4=.39
75 LET B0=1.19
80 LET T5=560
90 LET M=1
99 REM Q1=THICKNESS C0RRECTI0N FACT0R
240 PRINT "T","L","Y","P2","N"
250 PRINT "V5","V6","W8","W9","Y1"
253 PRINT "L8","H1","Y2","W0"
254 PRINT
255 PRINT "P5","P6","S","D0","N0"
257 PRINT "D3","D0","F1","F2","F"
258 PRINT "C1","Q","P1","C0","K2"
259 PRINT "L0","L9"
260 LET V=B
270 LET D3=11
275 LET T=.010
280 PRINT "BELL0WS I.D.= 3;", DELTA V0L="V
281 LET Y1=1.6153
282 LET N=34.436
283 LET L=.52473
285 LET V5=943.48
286 LET P5=7.0502
287 LET C0=2
288 REM STRESS C0RRECTED F0R THINNING
289 LET D0=D3+2 L+2*(M*T-T)
290 LET D2=D3+L+(M*T-T)
291 LET A=(3.1416*D2↑2)/4
292 LET Y=V/A
293 LET Y2=Y-Y1
299 LET Q1=D3/D0
301   IF L=>.15 D3 THEN 951
302 LET V0=V5-D *
304 LET P6=P5*T6*V5/(V6*T5)
327 REM Y5=T0TAL DEFL. F0R "B1" V0L
328 LET Y5=B1/A
350 LET W=2*3.1416*D2*N*R*M*T*((L-2*C0*T)+3.1416*C0 T)
360 LET K1=3.1416*E1*D2*M*T↑3/(6*.91*C4*N*L↑3)
365 LET K2=K1*E2/E1
370 LET P2=P6+(K2*Y2/A)*2
```

```
375 LET F1=P2 K↑2/(2*M *(T*Q1)↑2)
380 LET F2=3 *Z E2*(T*Q1)/(2*.91 BQ N K↑2)
385 LET F=F1+F2
400 REM S2=CØL. HT. FØRMED BELLØWS
440 LET S2=((2 *O*T +2 *M*T)*N
490 REM C1=FREE LEN TH
500 LET C1=S2+Y1
600 REM STRU: +.25" HT FØR ATTACH. PRESS DØME: Z8=WT. ØF GAS DØME
610 LET D8=DO+.25
620 LET L8=(2 *2)+Y3+.80+2*.25
624 REM ØUTER CAN WEIGHT
626 LET W8=3.1416*D8*.04*L8*R
628 REM NAK DØME, MØVE. HEAD, BELL. RINGS WEIGHT
630 LET W8=W8+3.1416 R*(D8↑2/4*.06+(DO-.6)*.12*.6)
632 LET W8=W8+3.1416*X *(D3-.26)↑2/4*.06+(D3-.26)*(S2+2*.60)*.06)
634 LET W8=W8+3.1416 R D2 *L+.25)*.032*2
636 REM D9=WT ØF RESID NAK AT ZERØ VØL DISPL AT 100F
638 LET W9=3.1416 *D2-.02)*L*(S2+.12)*54/1728
640 LET W9=W9+3.1416 *D2-L-.10)*.10*(S2+.12)*54/1728
642 LET W9=W9+D0↑2/4 *12 *4/1728
648 REM Z8=GAS DØME WEIGHT
650 LET Z8=3.1416 R*((D0↑2/4*.032+(D8*.032*.4))
652 LET Z8=Z8+3.1 16 D8 *D8*.3*R
660 LET W0=2 W+W8+W9+Z8
680 REM V1=GAS VØL. IN ECU CAVITY
687 REM GAS PRESS CALCS: P5/P6=INIT/FINAL (AT VØL=V) GAS PRESS
693 LET D1=P5-(K1*Y1/D)*2
700 REM FAILURE MØDE ANAL: S=SECD VØL EXT TØ BELLØWS
705 REM PO=GAS PRESS, PRI BELLØWS FAILED, VØL=B
708 REM NO=NAK PRESS, PRE BELLØWS FAILED, VØL=B
710 LET S=3.1416*(D2*L*.5*(Y5+2*S2)+((DO+.06)*.06 *Y5+2 *2+1.75)))
715 LET S=S+3.1416*D2*L*.88
760 LET PO=T6*V5*P5/(T5*(V6+S+(V-B)))
775 LET NO=PO+2*K2*((B-S)/A-Y1)/A
820 REM Q=SQUIRM PRESS AT FULL VØL
825 LET Q=2*3.1416*K2/(S2+Y5)
830 REM H1=NATURAL FREQUENCY AT 100F
835 LET H1=9.85*SQR(K1/W)
840 REM LO=WELD LENGTH, FEET
845 LET LO=(2*3.1416*DO+.75+(L-2*CO*T+3.1416 *D*H)*2 N)/12
846 LET LO=LO+(3.1416*DO)/12*3
847 LET L9=L8+(1.6/11)*DO+.50
900 SET DIGITS 5
910 PRINT T,L,Y,P2,N
920 PRINT V5,V6,W8,W9,Y1
930 PRINT L8,H1,Y2,WO
931 PRINT
935 PRINT P5,P6,S,PO,NO
940 PRINT D3,DO,F1,F2,F
942 PRINT C1,Q,P1,CO,K2
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VØNES CØNTINUED

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950 PRINT L0,L9
951 PRINT
999 END
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