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ATOMICS INTERNATIONAL
A Division of North American Aviation Inc.

NAA-SR-MEMO COVER SHEET

REPORT TITLE

TEMPR 8: STEADY STATE THERMAL SIMULATION OF A SNAP REACTOR

AUTHOR

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NAA-SR-MEMO 12218

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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR- TDR NO. 12218	APPROVALS
TECHNICAL DATA RECORD		PAGE 1 OF 26	
AUTHOR P. M. Magee <i>P.M. Magee</i>	DEPT. & GROUP NO. 731 14	DATE 10/28/66	
TITLE TEMPR 8: Steady State Thermal Simulation of a SNAP Reactor		GO NO 7695	
		S/A NO 13330	TWR
		SECURITY CLASSIFICATION	
		(CHECK ONE BOX ONLY)	(CHECK ONE BOX ONLY)
		AEC DOD UNCL. ☒ ☒ CONF. ☐ ☐ SECRET ☐ ☐	RESTRICTED DATA ☐ DEFENSE INFO. ☐
PROGRAM S8DS	SUBACCOUNT TITLE Thermal Analysis	AUTHORIZED CLASSIFIER SIGNATURE DATE 11/15/66	
DISTRIBUTION D/715-51 Cano 2 R. A. Johnson L. M. Maki D. G. Mason W. J. Roberts R. F. Wilson D/731-10 Cano 2 D. J. Cockeram D/731-12 Cano 2 E. B. Ash E. J. Donovan E. B. Harty D/731-14 Cano 2 R. F. Audette K. R. Birney S. R. Fields R. J. Gimera J. P. Hawley R. I. Jetter D. K. Nelson H. Rood J. Susnir L. D. Swenson C. A. Willis Heat & Mass Transfer Unit (15) D/742-22 Cano 4 H. R. Brager		STATEMENT OF PROBLEM Develop a thermal model to determine nominal and hot-channel steady-state temperature distributions within SNAP reactors.	
		ABSTRACT: The digital program, TEMPR 8, simulates a SNAP reactor by dividing it into concentric rings of elements and performing detailed thermal calculations for a typical element in each ring. At present, the code is being used to estimate beginning-of-life and end-of-life temperature profiles for S8ER and S8DS. Other SNAP reactors, with up to 20 rings of elements, can be simulated. The utility of the program lies in the various options provided:	
		1. Any flow profile can be duplicated. For reactors with up to nine rings of elements, both radial and axial dependence can be simulated. For reactors with greater than nine rings, only radial dependence can be simulated. 2. Bypass flow around the core can be simulated. 3. Radial and axial power profiles can be duplicated. 4. Gas gap conductivity can be calculated as a function of the equilibrium hydrogen pressure within the fuel, the moles of residual weld gas trapped in the element, and the integrated burnup (fission gas production). 5. Optional hot-channel factors on power, flow and overall thermal conductance (UA) are provided.	
		TEMPR 8 is written in FORTRAN 4. Typical running times are 11 seconds for loading and 3 seconds per case execution. The option of CRT output for each ring is provided.	

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INTRODUCTION

The computer program TEMPR 8 divides the reactor core radially into concentric rings of elements, and analyzes a representative element from each ring. Thus, TEMPR 8 is a thermal model of a fuel element and its associated coolant. If the effects of interactions between adjacent elements are desired, the digital code SNAP 8 GEOM must be used (see NAA-SR-TDR-11822).

The code calculates, for each element at 20 uniform axial positions, the centerline and average fuel temperatures, the temperature at the inside surface of the ceramic barrier, the temperature at the outside surface of the cladding and the bulk coolant temperature. In addition, fuel and ceramic inside surface temperatures are averaged for each element.

The basic thermal calculations and the available options are described in the following sections. Required inputs for the code are listed in Appendix A; typical pages of output are illustrated in Appendix B; and a complete program listing is presented in Appendix C.

BASIC THERMAL CALCULATIONS

A SNAP reactor fuel element consists of a circular uranium-zirconium hydride fuel rod encased in a thin-walled cladding cylinder. A ceramic barrier material is applied to the inside of the cladding to reduce the hydrogen leak rate from the element. A radial gap of approximately 3 mils is left between the fuel and the barrier. This gap is filled with evolved hydrogen gas in equilibrium with the hydrogen within the fuel, any other gases which are present at the time of final element closure, and fission gases generated as a function of fuel burnup.

The radial heat transfer between the fuel and its associated coolant is determined by the sum of the thermal resistances of (1) fuel, (2) gas gap, (3) barrier, (4) cladding, and (5) convective film. In terms of the average fuel temperature, this can be expressed as:

$$R_{\text{Total}} (\bar{T}_f - \bar{T}_{\text{NaK}}) = R_F + R_G + R_B + R_C + R_{\text{FILM}} \quad (\text{hr-OF/Btu})$$

$$= \frac{1}{\pi L} \left[\frac{1}{8k_f} + \frac{\Delta r_g}{k_g (d_f + \Delta r_g)} + \frac{\Delta r_b}{k_b (d_f + 2\Delta r_g + \Delta r_b)} + \frac{\Delta r_c}{k_c (d_f + 2\Delta r_g + 2\Delta r_b + \Delta r_c)} + \frac{12}{h (d_f + 2\Delta r_g + 2\Delta r_b + 2\Delta r_c)} \right]$$

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Any required radial temperature difference can be calculated from the local power and the appropriate resistance. For example, the temperature drop across the gas gap is given by

$$\Delta T_g = g_{ave} \phi(r) \phi(z) F_Q F_{UA} R_G$$

where

q_{ave} = Average power per node (Btu/hr) = $q_{total} / (20 \times \text{no. of elements in core})$

$\phi(r)$ = Radial power factor

$\phi(z)$ = Axial power factor

F_Q = Power hot channel factor

F_{UA} = UA hot channel factor

The bulk coolant temperature at any axial location along a fuel element is calculated by axially integrating the energy input into the coolant. Neglecting hot channel factors, this is

$$T_{NaK}(z) = T_{in} + \frac{\int_0^z g_{ave} \phi(r) \phi(z) dz}{WC_p}$$

where

W = Flow rate per element (lb/hr)

C_p = NaK specific heat (0.21 Btu/lb-°F)

FLOW OPTION

By means of a flow test input, different core flow distributions can be obtained. If the test is set to zero, a uniform flow profile throughout the core is assumed. If the test is set negative, a radial flow distribution (for up to 20 rings) is read in. The flow associated with an element in ring N is then given by

$$W(N) = \frac{W_{Total} (1 - W_{Bypass})}{\text{No. of elements in core}} (FF(N))$$

where

W_{Bypass} = fraction of total flow which bypasses the active core

and $FF(N)$ = flow factor associated with ring N

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Flow factors including radial and axial variations due to crossflow may be inserted into the code if the flow test is set positive. The factors are specified at 20 axial positions for a maximum of 9 rings. In this case, the flow associated with an element in ring N at an arbitrary axial location z is given by

$$W(N,z) = \frac{W_{\text{Total}} (1 - W_{\text{Bypass}})}{\text{No. of elements in core}} \quad (FF(N,z))$$

GAS GAP CONDUCTIVITY OPTION

Three gases may be present in the gap of a fuel element: (1) hydrogen released from the uranium-zirconium hydride fuel, (2) fission gas, largely xenon, produced within the fuel as a function of the kw hrs of operation and released to the gap, and (3) a residual gas associated with the closure weld on the element. For example, helium is present in S8ER elements because of the final TIG weld. S8DS elements have no residual gas as the closure is electron-beam welded in a vacuum. The gap conductivity is a function of the relative proportions of these gases and will change during the operational life of the reactor. Although the mixture conductivity could be calculated by hand and read as input to the code, an option is provided within the code whereby the conductivity is calculated internally. The option test and the required input constants are listed in Appendix A.

In the code calculations, the number of moles of each gas is determined, the associated conductivity is calculated based on a reference input temperature, and the mixture conductivity is determined from the mole fractions of each constituent. The hydrogen is assumed to be in equilibrium with the dissociation pressure of the fuel:

$$n_{H_2} = \frac{PV}{RT}$$

The amount of weld gas and its relative percentages of helium and argon are specified as input data. The amount of fission gas within the gap is given by:

$$n_{fg} = \frac{3.58 \times 10^{-13}}{N} \quad (\text{kw hr of operation})$$

where N = number of elements within the core. This formula assumes that $\frac{1}{4}$ of the fission products are gases and, of these, 0.0017 are released to the gap.

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The mixture conductivity is calculated from a simplified equation for non-polar gases, due to Brokaw, Ind. Eng. Chem. 47: 2398 (1955):

$$k_{mix} = \frac{1}{2} \left[\sum x_i k_i + \frac{1}{\sum x_i / k_i} \right]$$

where x_i = mole fraction of i-th component.

The average error in k_{mix} using this formula is reported to be 2.6% for some 113 nonpolar mixtures.

HOT-CHANNEL FACTORS

Three hot-channel factors are provided in the code: flow, power and overall thermal conductance (UA). The flow and power factors influence the bulk coolant temperature.

$$T_{NaK}(z) = T_{in} + \frac{F_Q}{F_W} \frac{\int_0^z q_{ave} \phi(r) \phi(z) dz}{WC_p}$$

The temperature differences of cladding, ceramic and fuel above the local bulk coolant are proportional to the power and UA factor.

$$T_1(z) = T_{NaK}(z) + F_{UA} F_Q q_{ave} \phi(r) \phi(z) R_1$$

Another factor, closely related to the hot-channel factors, is the ceramic peaking factor. This term approximates the maximum circumferential ceramic temperature at a given axial location in terms of the average ceramic temperature and the bulk coolant temperature.

$$\begin{aligned} T_{c, max} &= T_{NaK} + F_{Peak} (T_c - T_{NaK}) \\ &= T_{NaK} + F_{Peak} F_Q F_{UA} q_{ave} \phi(r) \phi(z) (RC + RB + R_{FILM}) \end{aligned}$$

The ceramic peaking factor must be determined from more detailed thermal models. In general, it is a function of the pitch-to-diameter ratio of the fuel elements and the eccentricity of the fuel rods within the elements.

CRT 3 PLOTTING OPTION

An option is provided within the program to plot axial temperature distributions for each ring. An example of this plotting is shown in Figure 1. The ring number is automatically specified on the abscissa. (No additional titling inputs are required for this option. The head title is that supplied

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FIGURE 1

EXAMPLE OF CRT OUTPUT

S8ER REFERENCE CASE, NOMINAL FLOW PROFILE, 0.05 B

7456-22
008 000

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for the run, and the abscissa and ordinate are generated internally.) The following symbols are used for plotting:

1. Bulk coolant temperature
2. Outside surface of cladding
3. Inside surface of barrier
4. Average fuel temperature
5. Fuel centerline temperature

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Appendix A. Input

Input to TEMPR 8 is made by means of a generalized data input subroutine simply named INPUT. The reading format for each data card is 2I1, I10, 5E12.8. The column 1 integer indicates how many consecutive pieces of data (1 to 5) are to be read on the card. The column 2 integer is used to flag the end of an input read: 0 if additional cards are to be read or 1 if this is the last input card for the run. Title and data for additional runs can, of course, follow a flag 1 card. Data for an additional run need only provide necessary changes in the data block; the other values will not be changed from the previous run. The I10 integer specifies the block location of the first data piece on the card.

TITLE: A 72 character title must be read in (on one card) at the beginning of each run. This title will be printed out at the top of each output page.

C BLOCK:

- C(1) - Inlet temperature, OF
- C(2) - Total core power, kwt
- C(3) - Total core flow, lb/hr
- C(4) - Fraction of flow which bypasses core elements (e.g., 0.05)
- C(5) - UA hot channel factor (1.0 for nominal case)
- C(6) - Flow hot channel factor
- C(7) - Power hot channel factor
- C(8) - Peaking factor for maximum ceramic temperature
 $T_{\text{cer, max}} - \bar{T}_{\text{NaK}} = F_{\text{Peak}} (T_{\text{cer, ave}} - \bar{T}_{\text{NaK}})$
- C(9) - Number of elements in core

Note: All of the following dimensions are to be taken at operating temperature. The code does not correct for thermal expansion.

- C(10) - Fuel rod length, in.
- C(11) - Fuel rod diameter, in.
- C(12) - Gas gap radial width, in.
- C(13) - Ceramic barrier thickness, in.
- C(14) - Cladding thickness, in.
- C(15) - Fuel thermal conductivity, Btu/hr-ft-OF
- C(16) - Gas gap conductivity, Btu/hr-ft-OF
- C(17) - Ceramic conductivity, Btu/hr-ft-OF
- C(18) - Cladding conductivity, Btu/hr-ft-OF
- C(19) - Effective film coefficient, Btu/hr-ft²-OF
Should include the effect of the tricuspid channel shape which raises the average clad surface temperature

$$h_{\text{eff}} = \frac{Q}{A} (T_{\text{cer, ave}} - T_b)$$

- C(20) - Test to specify flow profile

0: Uniform flow for up to 20 rings

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- +1: Use $F(r, Z)$ read in as C(21-200) for 9 rings.
Includes both radial and axial variations.
- 1: Use $F(r)$ read in as C(261-280) for 20 rings.
Includes radial flow variations only.
- C(21-200) - Flow factors $F(r, Z)$ 20 axial divisions, 9 rings
 - C(21-40) = $F(1, Z)$
 - C(41-60) = $F(2, Z)$, etc.
- C(201-220) - Twenty axial power factors normalized to core average (e.g., 0.94, 1.16). Corresponding axial locations are $Z/L = 0.025, 0.075, \dots, 0.925, 0.975$.
- C(221-240) - Radial power factors for up to 20 rings.
- C(241-260) - Normalized radial locations of rings
- C(261-280) - Radial flow factors $F(r)$ for up to 20 rings
- C(281) - Test for gap conductivity calculation
 - 0: Uses C(16) as gas gap conductivity
 - +1: Codes calculates conductivity with C(282) - C(287) inputs
- C(282) - Kw hrs of operation
- C(283) - Estimated gas gap temperature, OF
- C(284) - Equilibrium hydrogen pressure, psi
- C(285) - Axial clearance between fuel and cladding, in. (hot)
- C(286) - Quantity of residual weld gas at 700°F, moles
- C(287) - Fraction of weld gap which is argon; rest is assumed to be helium
- C(288-295) - Unassigned
- C(296) - CRT option, +1 if plots desired
- C(297-299) - Unassigned
- C(300) - Number of element rings in core

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APPENDIX B -

TYPICAL OUTPUT

S8DS REFERENCE CASE, NOMINAL FLOW PROFILE, 0.1 BYPASS (B-0-L)

C BLOCK

1	1.1000E 03	2	6.0000E 02	3	4.8800E 04	4	1.0000E-01	5	1.0000E 00
6	1.0000E 00	7	1.0000E 00	8	2.3300E 00	9	2.1100E 02	10	1.6825E 01
11	5.3000E-01	12	3.2000E-03	13	3.0000E-03	14	1.0000E-02	15	1.3000E 01
16	2.5000E-01	17	1.0000E 00	18	1.0000E 01	19	1.8500E 03	20	1.0000E 00
21	2.7300E 00	22	2.5800E 00	23	2.4500E 00	24	2.3000E 00	25	2.2000E 00
26	2.1000E 00	27	2.0000E 00	28	1.9200E 00	29	1.8400E 00	30	1.7700E 00
31	1.7200E 00	32	1.6300E 00	33	1.6100E 00	34	1.6100E 00	35	1.6000E 00
36	1.6000E 00	37	1.6300E 00	38	1.6700E 00	39	1.7200E 00	40	1.7900E 00
41	2.8000E 00	42	2.6500E 00	43	2.5000E 00	44	2.3300E 00	45	2.3000E 00
46	2.0500E 00	47	1.9500E 00	48	1.8500E 00	49	1.7500E 00	50	1.6800E 00
51	1.6300E 00	52	1.6000E 00	53	1.5800E 00	54	1.5800E 00	55	1.5500E 00
56	1.5500E 00	57	1.6000E 00	58	1.6500E 00	59	1.7200E 00	60	1.8000E 00
61	2.4200E 00	62	2.2800E 00	63	2.1700E 00	64	2.0500E 00	65	1.9500E 00
66	1.8500E 00	67	1.7700E 00	68	1.7000E 00	69	1.6300E 00	70	1.5800E 00
71	1.5400E 00	72	1.4800E 00	73	1.4700E 00	74	1.4800E 00	75	1.5000E 00
76	1.5400E 00	77	1.5700E 00	78	1.6300E 00	79	1.7000E 00	80	1.8000E 00
81	2.0700E 00	82	2.0200E 00	83	1.8600E 00	84	1.7700E 00	85	1.7000E 00
86	1.6200E 00	87	1.5500E 00	88	1.5000E 00	89	1.4600E 00	90	1.4300E 00
91	1.4000E 00	92	1.3100E 00	93	1.3200E 00	94	1.3300E 00	95	1.4000E 00
96	1.4200E 00	97	1.4700E 00	98	1.5200E 00	99	1.6000E 00	100	1.6700E 00
101	1.6800E 00	102	1.6000E 00	103	1.5200E 00	104	1.4500E 00	105	1.4000E 00
106	1.3500E 00	107	1.3000E 00	108	1.2600E 00	109	1.2400E 00	110	1.2200E 00
111	1.2000E 00	112	1.1300E 00	113	1.1500E 00	114	1.1700E 00	115	1.2500E 00
116	1.2800E 00	117	1.3500E 00	118	1.4000E 00	119	1.4800E 00	120	1.5700E 00
121	1.3800E 00	122	1.2700E 00	123	1.2200E 00	124	1.1500E 00	125	1.1000E 00
126	1.0600E 00	127	1.0200E 00	128	1.0000E 00	129	9.7000E-01	130	9.6000E-01
131	9.6000E-01	132	9.6000E-01	133	9.9000E-01	134	1.0200E 00	135	1.0600E 00
136	1.1100E 00	137	1.1600E 00	138	1.2300E 00	139	1.3000E 00	140	1.3900E 00
141	9.0000E-01	142	8.9000E-01	143	8.8000E-01	144	8.7000E-01	145	8.7000E-01
146	8.7000E-01	147	8.7000E-01	148	8.7000E-01	149	8.8000E-01	150	9.0000E-01
151	9.0000E-01	152	8.6000E-01	153	8.8000E-01	154	9.1000E-01	155	9.7000E-01
156	1.0000E 00	157	1.0300E 00	158	1.0600E 00	159	1.1000E 00	160	1.1500E 00
161	5.7000E-01	162	6.0000E-01	163	6.3000E-01	164	6.7000E-01	165	7.0000E-01
166	7.3000E-01	167	7.6000E-01	168	7.8000E-01	169	8.0000E-01	170	7.7000E-01
171	8.5000E-01	172	8.3000E-01	173	8.4000E-01	174	8.6000E-01	175	9.0000E-01
176	9.0000E-01	177	9.0000E-01	178	9.0000E-01	179	8.7000E-01	180	8.6000E-01
181	4.0000E-01	182	5.3000E-01	183	6.3000E-01	184	7.4000E-01	185	8.3000E-01
186	9.2000E-01	187	9.9000E-01	188	1.0300E 00	189	1.1000E 00	190	1.1200E 00
191	1.1500E 00	192	1.1600E 00	193	1.1600E 00	194	1.1500E 00	195	1.1400E 00
196	1.1000E 00	197	1.0300E 00	198	9.6000E-01	199	8.6000E-01	200	7.3000E-01
201	3.9000E-01	202	5.8500E-01	203	7.4500E-01	204	8.8000E-01	205	1.0050E 00

206	1.1100E 00	207	1.2000E 00	208	1.2700E 00	209	1.3250E 00	210	1.3600E 00
211	1.3700E 00	212	1.3500E 00	213	1.3000E 00	214	1.2300E 00	215	1.1400E 00
216	1.0250E 00	217	8.9500E-01	218	7.4500E-01	219	5.7000E-01	220	3.6500E-01
221	1.1480E 00	222	1.1360E 00	223	1.1200E 00	224	1.0940E 00	225	1.0550E 00
226	1.0050E 00	227	9.5800E-01	228	9.3300E-01	229	9.8500E-01	230	0.0000E-39
231	0.0000E-39	232	0.0000E-39	233	0.0000E-39	234	0.0000E-39	235	0.0000E-39
236	0.0000E-39	237	0.0000E-39	238	0.0000E-39	239	0.0000E-39	240	0.0000E-39
241	3.2000E-02	242	1.2900E-01	243	2.4300E-01	244	3.6100E-01	245	4.7900E-01
246	6.0400E-01	247	7.1700E-01	248	8.3600E-01	249	9.5100E-01	250	0.0000E-39
251	0.0000E-39	252	0.0000E-39	253	0.0000E-39	254	0.0000E-39	255	0.0000E-39
256	0.0000E-39	257	0.0000E-39	258	0.0000E-39	259	0.0000E-39	260	0.0000E-39
261	1.8000E 00	262	1.7100E 00	263	1.6100E 00	264	1.4600E 00	265	1.2400E 00
266	9.8000E-01	267	9.2000E-01	268	7.8000E-01	269	1.1400E 00	270	0.0000E-39
271	0.0000E-39	272	0.0000E-39	273	0.0000E-39	274	0.0000E-39	275	0.0000E-39
276	0.0000E-39	277	0.0000E-39	278	0.0000E-39	279	0.0000E-39	280	0.0000E-39
281	0.0000E-39	282	0.0000E-39	283	0.0000E-39	284	0.0000E-39	285	0.0000E-39
286	0.0000E-39	287	0.0000E-39	288	0.0000E-39	289	0.0000E-39	290	0.0000E-39
291	0.0000E-39	292	0.0000E-39	293	0.0000E-39	294	0.0000E-39	295	0.0000E-39
296	0.0000E-39	297	0.0000E-39	298	0.0000E-39	299	0.0000E-39	300	9.0000E 00

S8DS REFERENCE CASE, NOMINAL FLOW PROFILE, 0.1 BYPASS (B-0-L)

NORMALIZED RADIUS R/R = 0.032 RING 1
 NORMALIZED RADIAL POWER = 1.148
 INLET TEMP = 1100.00 POWER, KWT = 600.0

Z/L	AXIAL POWER RATIO	FLOW FACTOR AT Z/L	BULK COOLANT TEMP	OUTSIDE CLAD TEMP	INSIDE CERAMIC TEMP	AVERAGE FUEL TEMP	MAXIMUM FUEL TEMP	MAX INSIDE CERAMIC TEMP
0.050	0.488	2.7300	1101.82	1116.04	1125.13	1166.59	1178.45	1156.14
0.100	0.665	2.5800	1104.71	1124.11	1136.51	1193.06	1209.24	1178.81
0.150	0.813	2.4500	1108.59	1132.29	1147.44	1216.54	1236.30	1199.12
0.200	0.942	2.3000	1113.46	1140.96	1158.53	1238.69	1261.61	1218.48
0.250	1.057	2.2000	1119.28	1150.13	1169.85	1259.79	1285.51	1237.11
0.300	1.155	2.1000	1126.02	1159.72	1181.25	1279.48	1307.57	1254.71
0.350	1.235	2.0000	1133.67	1169.70	1192.72	1297.75	1327.79	1271.27
0.400	1.297	1.9200	1142.10	1179.95	1204.14	1314.49	1346.04	1286.67
0.450	1.343	1.8400	1151.27	1190.44	1215.47	1329.64	1362.29	1300.86
0.500	1.365	1.7700	1161.07	1200.89	1226.34	1342.42	1375.62	1313.16
0.550	1.360	1.7200	1171.22	1210.89	1236.25	1351.91	1384.99	1322.75
0.600	1.325	1.6300	1181.77	1220.43	1245.13	1357.82	1390.04	1329.41
0.650	1.265	1.6100	1192.06	1228.97	1252.56	1360.13	1390.90	1333.01
0.700	1.185	1.6100	1201.80	1236.37	1258.47	1359.24	1388.06	1333.83
0.750	1.082	1.6000	1210.88	1242.46	1262.64	1354.70	1381.03	1331.49
0.800	0.960	1.6000	1219.04	1247.05	1264.95	1346.59	1369.94	1326.01
0.850	0.820	1.6300	1226.04	1249.96	1265.25	1334.99	1354.93	1317.41
0.900	0.657	1.6700	1231.73	1250.91	1263.17	1319.08	1335.08	1304.99
0.950	0.467	1.7200	1235.95	1249.59	1258.31	1298.06	1309.43	1288.04
1.000	0.262	1.7900	1238.55	1246.21	1251.10	1273.43	1279.81	1267.80

AVG AXIAL FUEL TEMP = 1299.72

AVG AXIAL CERAMIC TEMP = 1215.76

ATOMICS INTERNATIONAL

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APPENDIX C -

PROGRAM LISTING

TEMPR8

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TMAIN - FEN SOURCE STATEMENT - FEN(S) -

C	TEMPR8 (FORTRAN4) REVISED 3/66 BY R. TROMEL AND P. MAGEF	00000010	
	COMMON F(20,20),PR(20),PA(21),R(20),TR(20),TC(20),TCS(20),TF(20),	00000020	
	ITFM(20),TCM(20),TFAVG,TCAVG,TITLE(12),TIN,POWER	00000030	
	2 ,CGAP,TSTCRT,AVGAP	00000031	
	DIMENSION C(300)	00000035	
	PI=3.1416	00000036	
	DO 3 I=1,300	00000040	
	3 C(I)=0.0	00000050	
	100 READ (5,1) TITLE	00000060	9
	1 FORMAT (12A6)	00000070	
	CALL INPUT(C)	00000080	11
	WRITE (5,4) TITLE	00000085	12
	4 FORMAT (1H1,24X,12A6)	00000086	
	WRITE (6,2) (I,C(I),I=1,300)	00000090	14
	2 FORMAT (13H0 C BLOCK// (I5,1PE13.4,I5,E13.4,I5,E13.4,I5,E13.4,	00000100	
	1I5,E13.4))	00000110	
C		00000120	
C	C(1) - TIN, DEG F	00000130	
C	C(2) - TOTAL CORE POWER, KWT	00000140	
C	C(3) - TOTAL CORE FLOW, LB/HR	00000150	
C	C(4) - BYPASS FLOW (FRACTION, E.G., 0.05)	00000160	
C	C(5) - UA HOT CHANNEL FACTOR (1.00 FOR NOMINAL)	00000170	
C	C(6) - FLOW HOT CHANNEL FACTOR	00000180	
C	C(7) - POWER HOT CHANNEL FACTOR	00000190	
C	C(8) - PEAKING FACTOR FOR MAX. CERAMIC TEMP.	00000210	
C	C(9) - NUMBER OF ELEMENTS IN CORE	00000220	
C	ALL DIMENSIONS ARE AT TEMPERATURE	00000225	
C	C(10)- ELEMENT LENGTH, IN.	00000230	
C	C(11)- FUEL ROD DIAMETER, IN.	00000240	
C	C(12)- GAS GAP RADIAL WIDTH, IN.	00000250	
C	C(13)- CERAMIC THICKNESS, IN.	00000260	
C	C(14)- CLAD THICKNESS, IN.	00000270	
C	C(15)- COND. FUEL, BTU/HR-FT-F	00000280	
C	C(16)- COND. GAS GAP, BTU/HR-FT-F	00000290	
C	C(17)- COND. CERAMIC, BTU/HR-FT-F	00000300	
C	C(18)- COND. CLADDING, BTU/HR-FT-F	00000310	

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T8MAIN - EFN SOURCE STATEMENT - IFN(S) -

C	C(19)- FFF. FILM COEFFICIENT, BTU/HR-FT**2-F	00000320
C	C(20)- FLOW TEST, 0-UNIFORM, +1-USE FACTORS READ IN	00000330
C	-1 --READ ONLY RADIAL PROFILE C(261-280) 20 RINGS	00000332
C	C(261) FOR RING 1, ETC.	00000334
C	C(21-200) - FLOW FACTORS ((F(R,Z)Z)R)	00000340
C	C(201-220) - AXIAL POWER FACTORS NORMALIZED TO CORE AVERAGE	00000350
C	C(221-240) - RADIAL POWER FACTORS	00000360
C	C(241-260) - NORMALIZED RADIUS (R/RCORE) OF RING	00000370
C	C(261-280) - RADIAL FLOW FACTORS, F(R) ONLY	00000372
C	C(281) - GAS MIXTURE TEST, +1-USE, 0-BYPASS	00000374
C	FISSION PRODUCT GAS ASSUMED TO BE XENON	00000375
C	C(282) - KW-HRS OF OPERATION (TO CALCULATE FISSION PRODUCT GAS)	00000376
C	C(283) - ESTIMATED GAS GAP TEMP., F	00000378
C	C(284) - EQUILIBRIUM HYDROGEN PRESSURE, PSI	00000380
C	C(285) - AXIAL FUEL-CLAD CLEARANCE, IN. (HOT)	00000382
C	C(286) - MOLES OF RESIDUAL WELD GAS PRESENT	00000384
C	C(287) - FRACTION OF WELD GAS ARGON, REST IS ASSUMED TO BE HELIUM	00000386
C	C(288-299) - UNASSIGNED	00000388
C	C(296) - CRT TEST, +1 IF PLOT DESIRED	00000389
C	C(300)- NO. OF ELEMENT RINGS IN CORE	00000390
	CGAP=C(16)	00000392
	TSTCRT=C(296)	00000394
	AVGAP=C(12)	00000396
	IF (C(281)) 104,104,101	00000400
101	TR= C(283)+460.	00000405
	D= C(11)+C(12)	00000410
	VOL= PI*D*(C(10)*C(12)+0.25*D*C(285))/1728.	00000415
	H2M=C(284)*VOL/(10.73*TR)	00000420
	ARGM=C(286)*C(287)	00000425
	HEM=C(286)-ARGM	00000430
	FGM=3.58E-13*C(282)/C(9)	00000435
	X=H2M+HEM+ARGM+FGM	00000440
	XH2=H2M/X	00000445
	XHE=HEM/X	00000450
	XA=ARGM/X	00000455
	XFG=FGM/X	00000460
	CH2=0.00322*TR**0.582	00000465

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T8MAIN - EFN SOURCE STATEMENT - IFN(S) -

CHE=0.00176*TR**0.618

00000470

24

CA=0.000196*TR**0.643

00000475

25

CFG=0.0000299*TR**0.746

00000480

26

CGAP=0.5*(XH2*CH2+XHF*CHE+XA*CA+XFG*CFG+1./((XH2/CH2+XHF/CHE+XA/CA+

00000485

1 XFG/CFG))

00000490

104 NRING=C(300)

00000500

TIN=C(1)

00000510

ELEND=C(9)

00000520

FLOW=(1.0-C(4))*C(3)*C(6)/ELEND

00000530

Q=3413.*C(2)*C(7)/(20.*ELEND)

00000540

POWER = C(2)

00000545

BLEN=C(10)/240.0

00000550

RF=1./(8.*PI*BLEN*C(15))

00000560

RG=C(12)/(CGAP*(C(11)+C(12))*PI*PLEN)

00000570

RB= C(13)/(C(17)*(C(11)+C(12)+C(12)+C(13))*PI*PLEN)

00000580

RC= C(14)/(C(18)*(C(11)+C(12)+C(12)+C(13)+C(13)+C(14))*PI*PLEN)

00000590

DELEM=C(11)+2.*(C(12)+C(13)+C(14))

00000600

RFILM=12./(C(19)*PI*PLEN*DELEM)

00000610

IF (C(20))120,140,105

00000615

105 K=0

00000620

DO 110 I=1,9

00000630

DO 110 J=1,20

00000640

K=K+1

00000650

110 F(I,J)=C(K+20)

00000655

GO TO 150

00000660

120 DO 125 NR=1,20

00000670

DO 125 NA=1,20

00000680

125 F(NR,NA)=C(NR+260)

00000690

GO TO 150

00000700

140 DO 145 I=1,20

00000706

DO 145 J=1,20

00000710

145 F(I,J)=1.0

00000720

150 DO 160 I=1,20

00000722

PA(I)=C(I+200)

00000723

PR(I)=C(I+220)

00000724

160 R(I)=C(I+240)

00000725

PA(21)=2.*PA(20)-PA(19)

00000728

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T8MAIN - FEN SOURCE STATEMENT - TFN(S) -

DO 300 J=1,NRING	00000740	
QR=Q*PR(J)	00000745	
TEX=TIN	00000746	
DO 200 I=1,20	00000750	
DELTB=QR*PA(I)/(0.21*FLOW*F(J,I))	00000760	
TB(I)= TEX+ DELTB	00000770	
200 TEX= TB(I)	00000780	
DO 210 I=1,20	00000790	
QRA=C(5)*QR*(PA(I)+PA(I+1))/2.	00000800	
TC(I)= TB(I)+QRA*(RFILM+RC+RB)	00000810	
TCS(I)=TB(I)+QRA*RFILM	00000815	
TCM(I)=TB(I)+QRA*C(8)*(RFILM+RC+RB)	00000820	
TF(I)=TC(I)+QRA*(RG+RF)	00000830	
210 TFM(I)= TF(I)+QRA*RF	00000840	
SUMF=0.0	00000850	
SUMC=0.0	00000860	
DO 220 I=1,20	00000870	
SUMF=SUMF+TF(I)	00000880	
220 SUMC=SUMC+TC(I)	00000890	
TEAVG=SUMF/20.0	00000900	
TCAVG=SUMC/20.0	00000910	
CALL OUTPUT (J)	00000920	115
300 CONTINUE	00000930	
GO TO 100	00000940	
END	00000950	

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TEIN

- EFN SOURCE STATEMENT - IFN(S) -

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```
SUBROUTINE INPLT(C)
  DIMENSION C(300),B(5)
  2 READ (5,40) N,L,K,(B(I),I=1,5)
40 FORMAT (2I1,I10,5E12.6)
  N=N+K-1
  DO 20 I=K,N
  M=I-K+1
20 C(I)=B(M)
  IF (L) 2,2,22
22 RETURN
  END
```

```
00400010
00400020
00400030      1
00400040
00400050
00400060
00400070
00400080
00400090
00400100
00400110
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TROUT

- FEN SOURCE STATEMENT - IFN(S) -

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SUBROUTINE OUTPUT (NRING)                                00401010
COMMON F(20,20),PR(20),PA(21),R(20),TR(20),TC(20),TCS(20),TF(20) 00401020
1,TEM(20),TCM(20),TEAVG,TCAVG,TITLE(12),TIN,POWER          00401030
2 ,CGAP,TSTORT,AVGAP                                       00401031
  DIMENSION A(20),Z(21),TX(9),TY(9),SX(9)                 00401032
  DATA TX(1),TY(1)/54H                                     00401033
1      ,54H                                               00401034
2//,SX(1)/54H 1      2      3      4      5      6      7      8      9 /00401035
  DO 1 I=1,20                                             00401036
1  A(I)=1000.*AVGAP                                       00401037
  WRITE (6,2) TITLE                                       00401040      8
2  FORMAT (1H),///24X,12A6)                               00401050
  WRITE (6,4) R(NRING),NRING,PR(NRING),TIN,POWER         00401060      10
4  FORMAT (/,10X,23HNORMALIZED RADIUS R/R =F8.3,10X,5HPING ,12/10X,2500401070
1HNORMALIZED RADIAL POWER =F8.3/10X,12HINLET TEMP =F8.2,10X,11HPOWE0401080
2R,KWT =F8.1)                                           00401085
  WRITE (6,6)                                             00401090      13
6  FORMAT(1H0,12X,5HAXIAL,5X,4HFLOW,7X,4HBULK,7X,7HOUTSIDE,4X,6HINSID00401100
1E,5X,7HAVERAGE,4X,7HMAXIMUM,4X,10HMAX INSIDE,2X,6HRADIAL/13X,5HPOW00401110
2ER,5X,6HFACTOR,5X,7HCOOLANT,4X,4HCLAD,7X,7HCERAMIC,4X,4HFUEL,7X,4H00401120
3FUEL,7X,7HCERAMIC,5X,2HGAP/5X,3H7/L,5X,5HRATIO,5X,6HAT 7/L,5X,4HTE00401130
4MP,7X,4HTEMP,7X,4HTEMP,7X,4HTEMP,7X,4HTEMP,7X,4HTEMP,8X,6H(MILS)) 00401140
  Z(1)=0.0                                               00401150
  DO 10 I=1,20                                           00401160
  Z(I+1)=Z(I)+0.05                                       00401170
  R=0.5*(PA(I)+PA(I+1))                                   00401175
10 WRITE (6,12) Z(I+1),R,F(NRING,I),TR(I),TCS(I),TC(I),TF(I),TEM(I) 00401180
  1 ,TCM(I),A(I)                                         00401190      21
12 FORMAT (2X,F6.3,3X,F6.3,4X,F7.4,4X,F8.2,5F11.2,F8.2) 00401200
  WRITE (6,14) TEAVG,TCAVG,CGAP                          00401210      32
14 FORMAT (//,2X,22HAVG AXIAL FUEL TEMP = F8.2//,2X,25HAVG AXIAL CERA00401220
  UNIC TEMP = F8.2//,2X,33HEFF GAS GAP COND (BTU/HR-FT-F) = F8.5) 00401230
  IF (TSTORT) 25,25,20                                   00401240
20 TX(7)=SX(NRING)                                       00401250
  TMIN=TR(1)                                              00401252
  TMAX=C.0                                                00401254

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- EFN SOURCE STATEMENT - IFN(S) -

DO 22 I=10,20	00401256	
22 TMAX= AMAX1(TMAX,TEM(I))	00401258	
CALL AICRT3(0,0,Z(2),TB(1),20,1,2,1,1,TITLE,IX,IY,1,1,32.0,16.0,1,00401260		
10.0,0.0,2,TMIN,TMAX)	00401270	43
CALL AICRT3(0,0,Z(2),TCS(1),20,1,2,1,2,TITLE,IX,IY,2,1,32.0,16.0,100401280		
1,0.0,0.0,2,TMIN,TMAX)	00401290	45
CALL AICRT3(0,0,Z(2),TC(1),20,1,2,1,3,TITLE,IX,IY,2,1,32.0,16.0,1,00401300		
10.0,0.0,2,TMIN,TMAX)	00401310	47
CALL AICRT3(0,0,Z(2),TE(1),20,1,2,1,4,TITLE,IX,IY,2,1,32.0,16.0,1,00401320		
10.0,0.0,2,TMIN,TMAX)	00401330	49
CALL AICRT3(0,0,Z(2),TEM(1),20,1,2,1,5,TITLE,IX,IY,2,1,32.0,16.0,100401340		
1,0.0,0.0,2,TMIN,TMAX)	00401350	51
25 RETURN	00401360	
END	00401370	

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MAIN PROGRAM

COMMON VARIABLES

COMMON BLOCK // ORIGIN 00001 LENGTH 01130

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
F	00000	R	PP	00620	R	PA	00644	R
R	00671	P	TR	00715	R	TC	00741	R
TCS	00765	R	TF	01011	R	TEM	01035	R
TCM	01061	R	TEAVG	01105	R	TCAVG	01106	R
TITLE	01107	R	TIN	01123	R	POWER	01124	R
CGAP	01125	R	TSTCPT	01126	R	AVGAP	01127	R

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
C	01131	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
PI	01605	R	I	01606	I	TR	01607	R
D	01610	R	VOL	01611	R	H2M	01612	R
ARGM	01613	R	HEM	01614	R	FGM	01615	R
X	01616	P	XH2	01617	R	XHE	01620	R
XA	01621	R	XFG	01622	R	CH2	01623	R
CHE	01624	R	CA	01625	R	CEG	01626	R
NRING	01627	I	ELFNO	01630	R	FLOW	01631	R
Q	01632	R	PLEN	01633	R	FF	01634	R
RG	01635	R	RB	01636	R	RC	01637	R
DELEM	01640	R	REFLM	01641	R	K	01642	I
J	01643	I	NR	01644	I	QR	01645	R
TEX	01646	R	DELTB	01647	R	ORA	01650	R

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SUMF 01651 R SUMC 01652 R

ENTRY POINTS

..... SECTION 4

SUBROUTINES CALLED

.FRDD.	SECTION	5	.FSLI.	SECTION	6	INPUT	SECTION	7
.FWRD.	SECTION	8	.FSLQ.	SECTION	9	.XP3.	SECTION	10
OUTPUT	SECTION	11	.UN05.	SECTION	12	.FRTN.	SECTION	13
.FCNV.	SECTION	14	.UN06.	SECTION	15	.FFIL.	SECTION	16
CC.1	SECTION	17	CC.2	SECTION	18	CC.3	SECTION	19
CC.4	SECTION	20	SYSLOC	SECTION	21			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
3	5A	01742	100	9A	01745	1	FORMAT	01717
4	FORMAT	01720	2	FORMAT	01723	104	27A	02222
101	22A	02027	120	44A	02416	140	57A	02441
105	30A	02367	110	37A	02403	150	68A	02460
125	50A	02431	145	63A	02451	160	76A	02465
300	116A	02635	200	90A	02531	210	105A	02602
220	112A	02616						

DECK LENGTH IN OCTAL IS 01533.

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SUBROUTINE INPUT

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
E	CCCC1	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
N	CCCC6	I	L	00007	I	K	CCC10	I
I	CCCC11	I	M	00012	I			

ENTRY POINTS

INPLT SECTION 3

SUBROUTINES CALLED

.FRDD.	SECTION	4	.UN05.	SECTION	5	.FRTN.	SECTION	6
.FCNV.	SECTION	7	SYSLEC	SECTION	8			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
2	1A	CCC24	40	FORMAT	00021	20	15A	CCC63
22	21A	CCC75						

DECK LENGTH IN OCTAL IS CC12C.

SUBROUTINE OUTPUT

COMMON VARIABLES

COMMON BLOCK			//	ORIGIN			00001	LENGTH	01130
SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	
F	00000	R	PR	00620	R	PA	00644	R	
R	00671	R	TR	00715	R	TC	00741	R	
TCS	00765	R	TF	01011	R	TEM	01035	R	
TCM	01061	R	TEAVG	01105	R	TCAVG	01106	R	
TITLE	01107	R	TIN	01123	R	POWER	01124	R	
CGAP	01125	R	TSTCPT	01126	R	AVGAP	01127	R	

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
A	01131	R	Z	01155	R	TX	01202	R
TY	01213	R	SX	01224	R			

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
B	01235	R	TMIN	01236	R	TMAX	01237	R

ENTRY POINTS

OUTPUT SECTION 4

SUBROUTINES CALLED

.FWRD. SECTION 5 .FSLO. SECTION 6 ATCPT3 SECTION 7

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.UNQ6.
SYSLOC

SECTION
SECTION R
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.FFIL.

SECTION 9

.FCNV.

SECTION 10

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
1	5A	01441	2	FORMAT	01263	4	FORMAT	01266
6	FORMAT	01315	10	21A	01526	12	FORMAT	01403
14	FORMAT	01413	25	52A	02017	20	34A	01602
22	39A	01611						

DECK LENGTH IN OCTAL IS 00715.