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ZIRCONIUM HYDRIDE REACTOR
TECHNOLOGY PROGRAM
PROGRESS REPORT
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I. PROGRAM OBJECTIVES

The overall objective of this program is to continue system and component engineering and test activities relating to the zirconium hydride (ZrH) reactor. The specific objectives for GFY 1976 are (1) to study standardized ZrH reactor space power systems and components, (2) to perform preconceptual analysis and design of ZrH reactor-organic Rankine power systems for subsea applications, (3) to conduct fuel and hydrogen barrier investigations, (4) to perform system studies in support of the Department of Defense and their contractors as directed by ERDA, (5) to test components, and (6) to provide for material disposal and facility surveillance.

II. SYSTEMS AND APPLICATIONS ENGINEERING

A report on the performance of various zirconium hydride reactor space nuclear power systems was published in this quarter (Reference 1). Four power conversion systems were investigated in this study - Brayton, organic Rankine, Stirling, and thermoelectric. Each power conversion type was incorporated in a power system conceptual design at power levels of 10, 25, 50, and 75 kWe except the thermoelectric type which was limited to 10 and 25 kWe. All of these power systems have telescoping, deployable radiators with Dowtherm A as the radiator coolant. The power systems are launched by the Space Shuttle and reach a geosynchronous orbit by means of an upper stage. The report includes power system schematics, performance data, and a breakdown of the mass. A discussion of the four power conversion types and of the major power system components is also presented.

Reference 1, N652TI140012, "10 to 75 kWe Space Nuclear Power System Study," W. B. Thomson, et al, May 1976

A. BRAYTON SYSTEMS

Upon completion of the 10 to 75 kWe power system study (Reference 1), more detailed analysis showed that fuel centerline temperatures and the resulting hydrogen leak rates were higher than desired. Therefore, the 10 and 50 kWe Brayton power systems were analyzed at the same and lower reactor outlet temperatures in an effort to mitigate these problems. The results of the revised analysis of the 10 kWe systems are shown in Table 1. The 10 kWe reactor can deliver 1300°F NaK and still have a centerline temperature just below the limit of 1400°F. The resulting power system mass increases from 1389 lb in the reference report to 1450 lb - an increase of 4.4%. At lower reactor outlet temperatures, the fuel centerline temperatures dropped significantly while power system mass increased moderately. It can be concluded that 10 kWe Brayton systems are satisfactory at reactor outlet temperatures in the range of 1250 to 1300°F.

TABLE 1

10 kWe BRAYTON SYSTEMS AT VARIOUS REACTOR OUTLET TEMPERATURES

	Ref. 1	Revised		
Reactor Outlet Temperature (°F)	1300	1200	1250	1300
Reactor Thermal Power (kWt)	57.2	65.9	61.3	57.2
Fuel Centerline Temperature (°F)	1350	1307	1352	1399
Total System Mass (lb)	1389	1505	1469	1450
Mass Increase (%)	--	8.4	5.8	4.4

The results of a similar study for 50 kWe Brayton systems are shown in Table 2. In this case, the more detailed analysis showed that a $1300^{o}F$ outlet temperature led to fuel centerline temperatures in excess of $1400^{o}F$. In addition, the reactor shutdown margin was insufficient. At $1275^{o}F$, the reactor design was feasible but led to a power system mass of 4175 lb - about 10.8% higher than the reference value of 3767 lb. At $1250^{o}F$, a minimum system mass of 4058 lb was reached - still 7.7% above the reference case.

In an effort to reduce this mass penalty for 50 kWe systems, other compressor inlet temperatures in combination with lower reactor outlet temperatures were examined. The results of this study are shown in Table 3. At a compressor inlet temperature of $160^{o}F$, the fuel centerline temperatures are satisfactory up to $1275^{o}F$ while the minimum system mass of 3830 lb at $1275^{o}F$ is only 1.7% above the reference value.

In summary, small reductions in both reactor outlet temperature and compressor inlet temperature in 50 kWe Brayton systems lead to more satisfactory fuel centerline temperatures and to lower hydrogen leakage rates with only a minor mass penalty. Consequently, the reference reactor outlet temperatures for the Brayton systems have been lowered to $1250^{o}F$.

As part of the effort to refine and reduce mass in the 50 kWe Brayton system, a study was made to optimize the design of the radiator manifolds. Each of the six radiator sections has a toroidal manifold at both ends to accommodate the inlet and outlet flow of the radiator coolant. Typically, these manifolds are of thin-walled aluminum alloy tubing about one inch in diameter. The optimum tubing diameter is the one which results in the lowest overall weight. This weight consists of the tubing, coolant, pump, and that part of the overall power system that is needed to supply power to the pump.

TABLE 2

50 kWe BRAYTON SYSTEMS AT VARIOUS REACTOR OUTLET TEMPERATURES

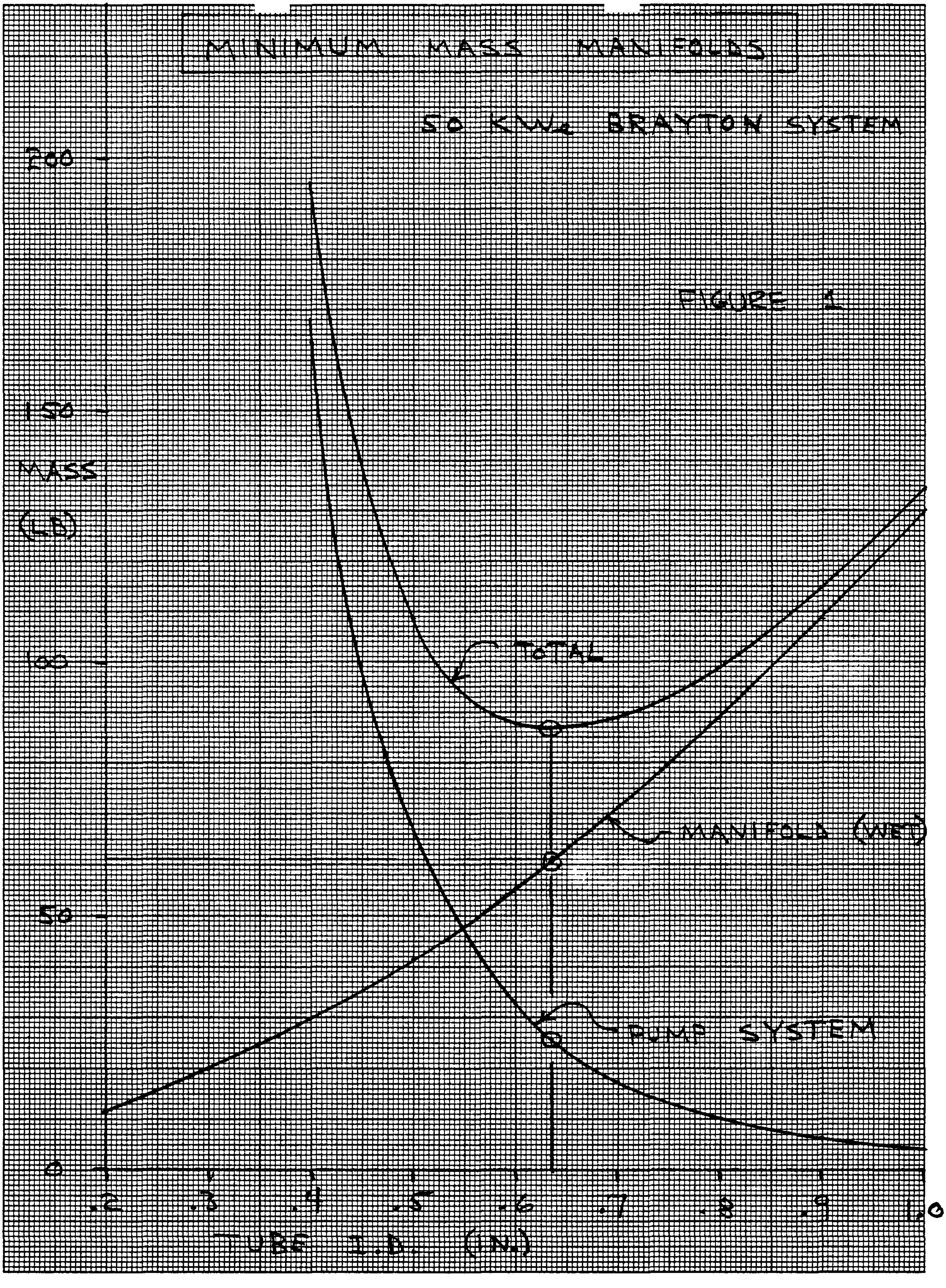
	Ref.	Revised			
Reactor Outlet Temperature (^{o}F)	1300	1200	1250	1275	1300
Reactor Thermal Power (kWt)	255	296	275	265	255
Fuel Centerline Temperature (^{o}F)	≥1400	1351	1358	1354	>1400
Total System Mass (lb)	3767	4173	4058	4175	--
Mass Increase (%)	--	10.8	7.7	10.8	--

TABLE 3

50 kWe BRAYTON SYSTEMS AT VARIOUS REACTOR OUTLET TEMPERATURES AND A COMPRESSOR INLET TEMPERATURE OF 160°F

	Revised			
Reactor Outlet Temperature (°F)	1200	1225	1250	1275
Reactor Thermal Power (kWt)	226	220	215	209
Fuel Centerline Temperature (°F)	1345	1355	1350	1374
Total System Weight (lb)	4079	3984	3935	3830
Mass Increase (%)	8.3	5.8	4.5	1.7

Analysis indicates that each of the 12 manifolds will lose about 1.5 velocity heads based on the maximum flow velocity in the manifold. Thus, a pumping power can be associated with any manifold tube diameter. Considerations of the mass of pump plus power system to drive the pump indicate that this penalty is about 80 lb/kWe. The manifold mass and the pump system mass were calculated for several manifold tube diameters. These results are shown in Figure 1. The minimum overall system mass occurs at a tube ID of 0.635 in. and is 87 lb of which the manifold weight is 61 lb and the pump system is 26 lb. The electrical power required at this point is 0.33 kWe. An earlier study done without optimization concluded that the tube ID should be 0.85 in. Thus, the optimization procedure reduced the manifold system weight by about 20%.



MINIMUM MASS MANIFOLDS

50 KWe BRAYTON SYSTEM

FIGURE 1

B. ORGANIC RANKINE SYSTEMS

A study was completed, during the quarter, to determine if significant organic Rankine system weight savings could be obtained by utilizing parallel hydraulic combinations of radiator segments in place of having all radiator segments in series hydraulically as is now employed in the reference design. Under this new concept, one or more radiator cylinder segments would comprise a loop. Any number of parallel loops can be configured by this method up to the number of cylinder segments plus the cone. However, for purposes of this study, the maximum number of loops was limited to three in order to maintain comparable heat rejection loop pressure drops and pumping powers. Parallel loops were considered only at 25, 50, and 75 kWe ORC system power levels, since they had the highest weights at these levels when compared to Stirling and Brayton Systems. However, the option of parallel loop radiators is certainly applicable to any other similar system.

The relation which describes a space radiator heated by the flow of a fluid through an integral tube is simply a steady-state heat balance between the heat lost by the fluid and the heat lost by the radiator. For equivalent absolute temperature drops of the fluid, the heat rejected, radiator area, and fluid flowrates are all directly proportional to one another. Consequently, fluid flow through each parallel loop was adjusted until its ratio to the total flow was the same as the ratio of the loop radiator area to total radiator area. In order to maintain comparable heat rejection loops, the fluid flow area of each loop was also adjusted such that equivalent velocities were achieved.

Cases of one, two, and three loops were then analyzed for each power level by the computer code RADAN 2 and the peripheral equipment configuration and weights were calculated by hand. In order to fairly evaluate the results, pumping power weight penalties were assigned to each case relative to the one loop (series) case.

The results of this study are shown in Tables 4, 5, and 6 for power levels of 25, 50, and 75 kWe, respectively. Significant savings (up to 15.7%) in system weight were achieved in the heat rejection loop and radiator components.

TABLE 4

SYSTEM MASS
25 kWe ORC SPACE SYSTEM RADIATOR PARALLEL LOOPS

	1 Loop (Series)		2 Loops		3 Loops	
Reactor	565		565		565	
Shield	154		154		154	
Liquid Metal Components	317		317		317	
Pumps		74		74		74
Piping		66		66		66
Volume Accumulator		59		59		59
Boiler		118		118		118
Power Conversion Unit	375		375		375	
Heat Rejection Loop	223		163		144	
Hoses		187		122		103
Volume Accumulator		36		20		15
Pumping Penalty		0		20		26
Radiator/Structure	1269		1015		951	
Fins		334		334		334
Tubes		69		37		30
Armor		285		159		120
Manifolds		120		52		39
Structure		203		203		203
Alignment		74		74		74
Deployment		46		46		46
Coolant		52		25		19
AI-93 Coating		86		86		86
Electrical	60		60		60	
Transmission Line		35		35		35
Instrumentation		25		25		25
TOTAL	2963		2649		2565	

TABLE 5

SYSTEM MASS
50 kWe ORC SPACE SYSTEM RADIATOR PARALLEL LOOPS

	1 Loop (Series)		2 Loops		3 Loops	
Reactor	680		680		680	
Shield	163		163		163	
Liquid Metal Components	615		615		615	
Pumps		156		156		156
Piping		165		165		165
Volume Accumulator		80		80		80
Boiler		214		214		214
Power Conversion Unit	470		470		470	
Heat Rejection Loop	398		245		256	
Hoses		338		210		200
Volume Accumulator		60		32		28
Pumping Penalty		0		3		28
Radiator/Structure	2164		1885		1693	
Fins		564		564		564
Tubes		134		81		54
Armor		442		378		274
Manifolds		251		139		94
Structure		304		304		304
Alignment		163		163		163
Deployment		55		55		55
Coolant		100		50		54
AI-93 Coating		151		151		151
Electrical	98		98		98	
Transmission Line		73		73		73
Instrumentation		25		25		25
TOTAL	4588		4156		3975	

TABLE 6

SYSTEM MASS
75 kWe ORC SPACE SYSTEM RADIATOR PARALLEL LOOPS

	1 Loop (Series)		2 Loops		3 Loops	
Reactor	793		793		793	
Shield	164		164		164	
Liquid Metal Components	1200		1200		1200	
Pumps		306		306		306
Piping		356		356		356
Volume Accumulator		228		228		228
Boiler		310		310		310
Power Conversion Unit	597		597		597	
Heat Rejection Loop	888		676		621	
Hoses		701		558		527
Volume Accumulator		188		100		70
Pumping Penalty		0		18		24
Radiator/Structure	3853		3270		2911	
Fins		967		967		967
Tubes		170		130		89
Armor		946		649		464
Manifolds		459		320		222
Structure		556		556		556
Alignment		213		213		213
Deployment		80		80		80
Coolant		214		107		72
AI-93 Coating		248		248		248
Electrical	207		207		207	
Transmission Line		182		182		182
Instrumentation		25		25		25
TOTAL	7702		6906		6493	

C. STIRLING SYSTEMS

A study was initiated to determine the Stirling system sensitivity to reduced reactor outlet temperature. The 10 and 50 kWe systems were selected as representative of the range of 10 to 75 kWe. The subject temperatures were reduced to 1250 and 1200°F and design configuration and mass breakdown data generated for the 10 and 50 kWe systems.

The system performance characteristics for the 10 and 50 kWe Stirling space systems are tabulated for the three reactor outlet temperatures in Tables 7 and 8, respectively. The detailed mass breakdown of each of the systems studied is shown in Tables 9 and 10. System mass increases slightly with increasing changes in reactor outlet temperature over the range of temperatures studied. This seeming contradiction of the expected trend is due to the high percentage of the 10 kWe system mass attributable to the reactor and shield.

As a consequence of this study, the reference design reactor outlet temperature for the Stirling system at all power levels has been lowered to 1250°F. The configurations and component weights have been adjusted accordingly, and the new reference design performance and weight breakdowns are shown in Tables 11 and 12.

TABLE 7

SYSTEM PERFORMANCE CHARACTERISTICS
10 kWe STIRLING SPACE SYSTEM

NaK Reactor Outlet Temperature	(°F)	1200	1250	1300
ELECTRICAL POWER LEVELS	(kWe)			
Gross		10.5	10.5	10.5
Pumping		.3	.3	.3
Transmission Line Losses		.2	.2	.2
Net to Payload		10.0	10.0	10.0
THERMAL POWER	(kWt)			
Reactor		45.0	43.9	43.0
T.E. Pump		9.8	9.7	9.7
Heat Losses		4.1	4.0	4.0
Power Conversion Unit		31.1	30.2	29.3
Radiator		32.5	31.4	30.5
EFFICIENCIES	(%)			
System		23.3	23.9	24.4
Power Conversion Unit		33.7	34.8	35.8
TEMPERATURES	(°F)			
Reactor Outlet		1200	1250	1300
Reactor Δt		100	100	100
NaK Heater Inlet		1200	1250	1300
Dowtherm A Cooler Inlet		350	350	350
Dowtherm A Cooler Outlet		450	450	450
Radiator Outlet		350	350	350
Average Radiator		395	395	395
FLOWRATES	(lb/sec)			
Primary Loop		2.0	2.0	1.9
Heat Rejection Loop		0.6	0.6	0.6
PRESSURE DROPS	(psid)			
Primary Loop		1.0	1.0	1.0
Heat Rejection Loop		10.0	10.0	10.0
RADIATOR AREA	(ft^2)			
Gross Area		185	179	174
Net Area		185	179	174
Fin Effectiveness	(%)	82	82	82
REACTOR DATA				
Fuel Element Length (in.)		14.0	14.0	14.0
Fuel Element Diameter (in.)		1.200	0.854	0.877
No. Fuel Elements		31	55	55
Peak Fuel Temperature	(°F)	1314	1327	1382

TABLE 8

SYSTEM PERFORMANCE CHARACTERISTICS
50 kWe STIRLING SPACE SYSTEM

NaK Reactor Outlet Temperature	(°F)	1200	1250	1300
ELECTRICAL POWER LEVELS	(kWe)			
Gross		52.0	52.0	52.0
Pumping		1.0	1.0	1.0
Transmission Line Losses		.5	.5	.5
Net to Payload		50.5	50.5	50.5
THERMAL POWER	(kWt)			
Reactor		187.7	181.6	176.8
T.E. Pump		19.0	18.0	17.8
Heat Losses		7.7	7.4	7.2
Power Conversion Unit		161.0	156.4	151.8
Radiator		131.9	125.9	121.2
EFFICIENCIES	(%)			
System		27.7	28.6	29.4
Power Conversion Unit		32.3	33.3	34.3
TEMPERATURES	(°F)			
Reactor Outlet		1200	1250	1300
Reactor Δt		100	100	100
NaK Heater Inlet		1200	1250	1300
Dowtherm A Cooler Inlet		350	350	350
Dowtherm A Cooler Outlet		450	450	450
Radiator Outlet		350	350	350
Average Radiator		395	395	395
FLOWRATES	(lb/sec)			
Primary Loop		8.5	8.2	8.0
Heat Rejection Loop		2.5	2.4	2.3
PRESSURE DROPS	(psid)			
Primary Loop		1.2	1.2	1.2
Heat Rejection Loop		75	75	75
RADIATOR AREA	(ft^2)			
Gross Area		759	726	701
Net Area		723	690	665
Fin Effectiveness	(%)	77	77	77
REACTOR DATA				
Fuel Element Length (in.)		16.0	18.0	18.0
Fuel Element Diameter (in.)		0.466	0.369	0.380
No. Fuel Elements		151	187	199
Peak Fuel Temperature	(°F)	1333	1353	1400

TABLE 9

10 kWe STIRLING SYSTEM REDUCED PEAK TEMPERATURE STUDY
MASS BREAKDOWN (LB)

	Reactor Outlet NaK Temp (°F)		1200		1250		1300
	Reactor		396		412		423
	Shield		165		170		175
	Liquid Metal Components		103		100		96
Pump		26		26		26	
Piping (wet)		46		45		42	
Volume Accumulator		11		11		10	
NaK-Gas Hx		20		19		18	
	Power Conversion		292		288		286
	Heat Rejection Loop		28		27		27
Gas-Dta Hx		10		9		9	
Hoses		3		2		2	
Volume Accumulator		6		5		5	
Pump		10		10		10	
	Radiator/Structure		102		98		95
Fins		36		35		34	
Tubes		3		3		3	
Armor		14		14		13	
Manifolds		2		2		2	
Structure		34		32		31	
Alignment		0		0		0	
Deployment		0		0		0	
Coolant		3		3		3	
AI-93 Coating		10		9		9	
	Electrical		27		27		27
Transmission Line		2		2		2	
Instrumentation & Control		25		25		25	
	Total		1113		1122		1129

TABLE 10

50 kWe STIRLING SYSTEM REDUCED PEAK TEMPERATURE STUDY MASS BREAKDOWN (LB)

	Reactor Outlet NaK Temp (°F)		1200		1250		1300
	Reactor		559		615		654
	Shield		168		169		175
	Liquid Metal Components		294		280		271
Pump		78		77		76	
Piping (wet)		118		113		110	
Volume Accumulator		50		44		40	
NaK-Gas Hx		48		46		45	
	Power Conversion		916		896		880
	Heat Rejection Loop		153		147		142
Gas-Dta Hx		55		53		51	
Hoses		49		47		46	
Volume Accumulator		28		27		26	
Pump		20		20		20	
	Radiator/Structure		509		486		469
Fins		162		155		149	
Tubes		21		20		20	
Armor		75		72		69	
Manifolds		35		33		32	
Structure		110		105		101	
Alignment		21		20		20	
Deployment		30		29		28	
Coolant		11		11		10	
AI-93 Coating		44		42		40	
	Electrical		51		50		50
Transmission Line		26		25		25	
Instrumentation & Control		25		25		25	
	Total		2650		2643		2641

TABLE 11

STIRLING CYCLE
SYSTEM PERFORMANCE CHARACTERISTICS

Net Electrical Power (kWe)	10	25	50	75
Electrical Power Levels (kWe)				
Gross	10.5	26	52.0	77
Pumping	0.3	0.75	1.0	1.5
Transmission Line Losses	0.2	0.25	0.5	0.5
Net to Payload	10.0	25	50.5	75
Thermal Power (kWt)				
Reactor	43.9	96.4	181.6	264.4
TE Pump	9.7	13.1	18.0	24.2
Heat Losses	4.0	5.3	7.4	9.0
Power Conversion Unit	30.2	78.1	156.4	231.3
Radiator	31.4	67.8	125.9	182.9
Efficiencies (%)				
System	23.92	27.0	28.63	29.1
Power Conversion Unit	34.80	33.3	33.3	33.3
Temperatures (^{o}F)				
Reactor Outlet	1250	1250	1250	1250
Reactor ΔT	100	100	100	100
Heater Inlet (NaK)	1250	1250	1250	1250
Cooler Inlet (Dowtherm A)	350	350	350	350
Cooler Outlet (Dowtherm A)	450	450	450	450
Radiator Inlet	450	450	450	450
Radiator Outlet	350	350	350	350
Average Radiator	395	395	395	395
Flowrates (lb/sec)				
Primary Loop	1.99	4.35	8.18	11.90
Heat Rejection Loop	0.60	1.29	2.39	3.47
Pressure Drops (psid)				
Primary Loop	1.0	1.1	1.2	1.3
Heat Rejection Loop	10.0	50	75	90.0
Radiator (ft^2)				
Gross Area	179	465	726	1213
Effective Area	179	411	690	1087
Fin Effectiveness	0.82	0.71	0.77	0.71

TABLE 12

STIRLING MASS BREAKDOWN

Power (kWe)	10	25	50	75
Reactor	412	493	615	703
Shield	170	156	169	196
Liquid Metal Components	100	158	280	415
Pump	26	44	77	102
Piping	45	69	113	174
Volume Accumulator	11	23	44	70
NaK - Gas NaK HX	19	23	46	69
Power Conversion Unit	288	448	896	1344
Heat Rejection Loop	27	75	147	340
Gas - DTA HX DTA	9	23	53	74
Hoses	2	23	47	180
Volume Accumulator	5	14	27	56
Pump	10	15	20	30
Radiator/Structure	98	306	486	952
Fins	35	98	155	256
Tubes	3	10	20	39
Armor	14	29	72	156
Manifolds	2	20	33	150
Structure	32	75	105	172
Alignment	0	21	20	52
Deployment	0	25	29	33
Coolant	3	5	11	31
AI 93 Coating	9	24	42	63
Electrical	27	35	50	76
Transmission Line	2	10	25	51
Instrumentation & Control	25	25	25	25
Total	1122	1671	2643	4026

D. Reactor Studies

A trade study was performed on the 10, 25, 50, and 75 kWe Brayton systems to determine the maximum permissible reactor outlet temperature as a function of linear power density, over a range of densities from 0.45 kW/ft to 1.15 kW/ft. Two constraints restricted the outlet temperature by requiring: 1) that maximum peak-average fuel temperature be less than 1350°F, and 2) that no Beta-phase fuel occur during the reactor life. The calculations were made using the ZIP timeshare code, which calculates the reactor parameters quickly and at low cost. As shown in Figure 2, the maximum reactor outlet temperature is a negatively sloped linear function of the linear power density. In general, since the Power Conversion System (PCS) efficiency increases with higher reactor outlet temperatures, a high outlet temperature, low power density reactor would be desirable. However, as indicated in Figure 3, reactor mass increases with lower power densities. The effect is that an optimal reactor exists which represents the best choice between lower reactor mass penalties at higher linear power densities and higher PCS efficiency at higher outlet temperatures.

During this quarter, parametric studies were performed on the 10 and 50 kWe Brayton and Stirling reactor systems to determine the minimum mass reactor for each system at outlet temperatures of 1200, 1250, and 1300°F. Again, constraints were placed on the design: 1) that maximum peak-average fuel temperature be less than 1350°F., except for the 1300°F outlet design which could be no higher than 1400°F, and 2) that no Beta-phase fuel occur during the seven year design life. These restrictions were included to ensure against excessive hydrogen leakage and fuel swelling. Two important design changes were included in this study that differ from earlier studies of similar systems. Both changes occurred in the hydrogen leakage calculation and are the following:

1. The value of the hydrogen permeation coefficient through the glass barrier was increased to be more in accord with the present state-of-the-art.

Figure 2. Maximum Reactor Outlet Temperatures

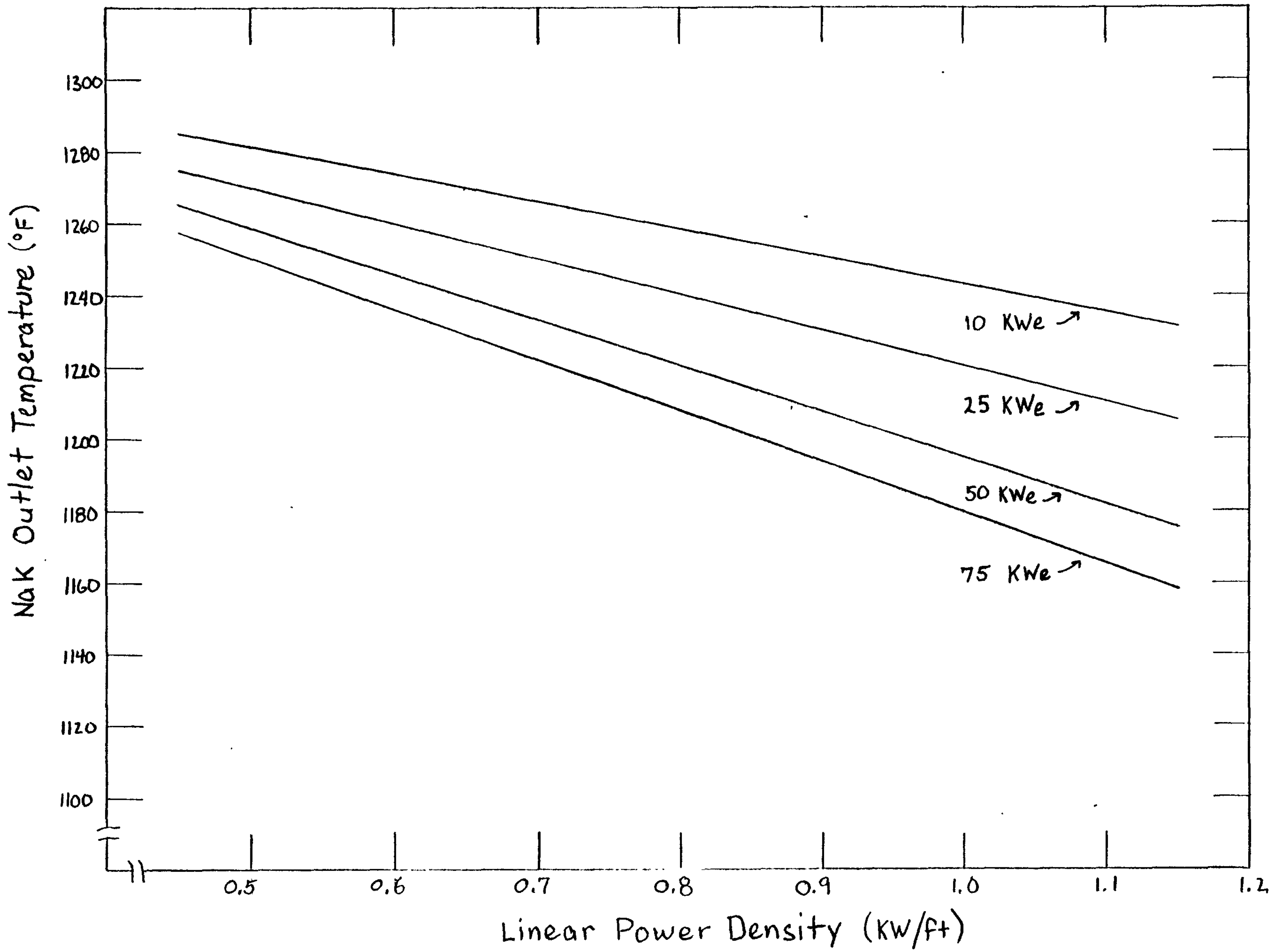
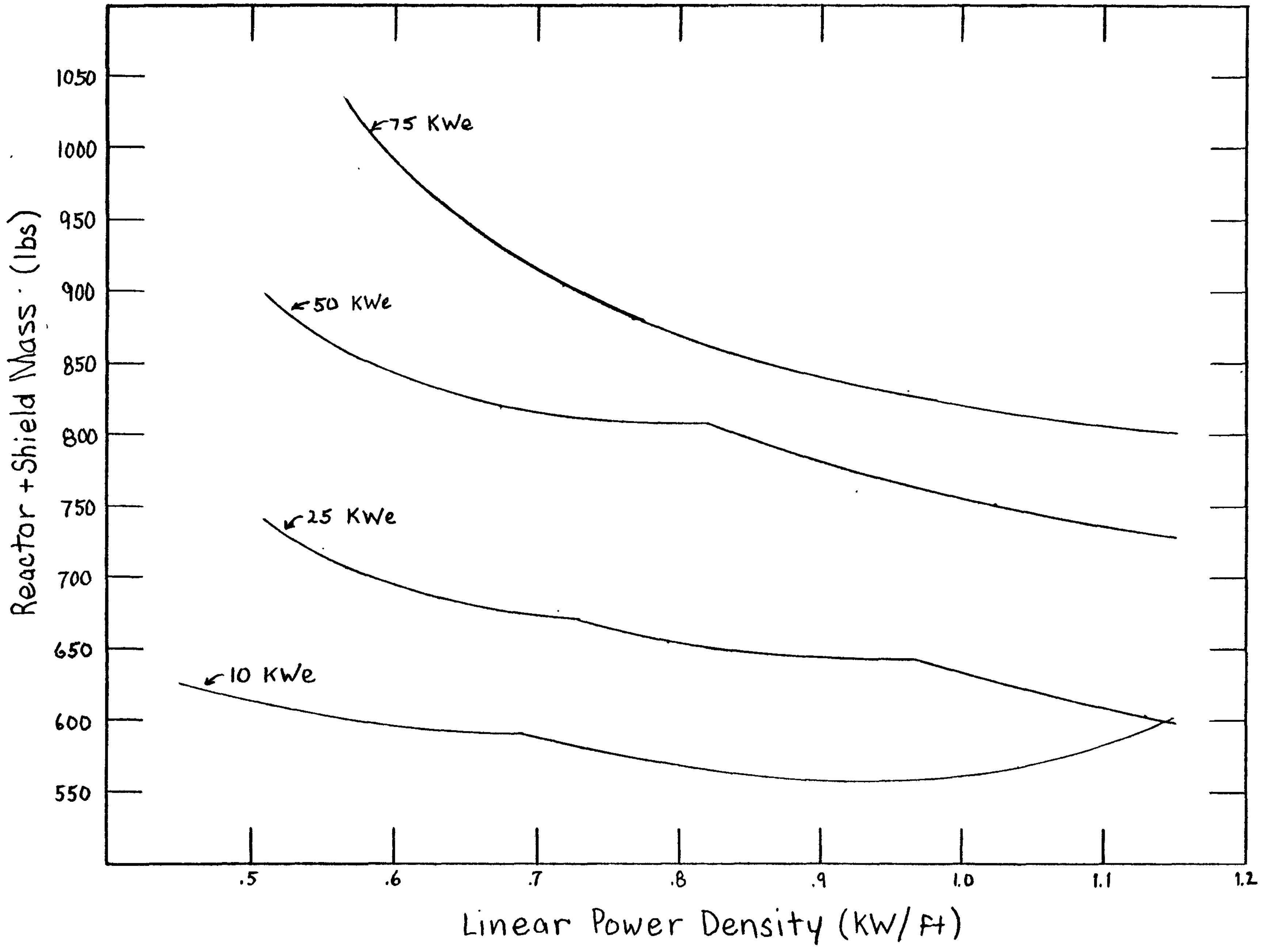


Figure 3. Reactor Mass vs. Reactor Outlet Temperature



2. The glass defect constant was changed from 0.0015 to a more conservative value of 0.002, where experimental values ranged from 0.001 to 0.002.

These design changes resulted in heavier reactor masses due to the increased initial reactivity requirements. The characteristics of each reactor design are summarized in Tables 13 and 14.

TEMPRO, a SNAP reactor heat transfer-lifetime code, has been checked out and is currently being employed for a more detailed reactor parameter study of the 50 kWe Brayton and organic Rankine designs. The code has provided a detailed core temperature distribution for the Brayton design which has been compared to the current design temperatures. TEMPRO also accurately describes hydrogen leakage rates as a function of axial and radial positions. These results were compared to the ZIP code which calculates leakage from a core averaging method. Results from TEMPRO show that temperature differs from the current Brayton design value by only -16^{o}F for the beginning-of-life peak-average fuel temperature. The hydrogen leakage calculations agree to within 0.2% based upon the H/Zr ratio. Results for the organic Rankine system are presently being investigated.

TABLE 13

10 and 50 kWe Brayton Reactor

10 kWe

Reactor Outlet Temp (^{O}F)	1200	1250	1300
Thermal Power (kW)	65.9	61.3	57.2
Peak-Average Temperature (^{O}F)	1307	1352	1399
Number of Fuel Elements	55	55	55
Active Fuel Length (in.)	14	15	16
Lattice Pitch (in.)	1.2746	1.236	1.22
Fuel Diameter (in.)	1.185	1.1448	1.1265
Linear Power Density (kW/ft)	1.027	0.892	0.780
Reactor Mass (lb)	422	430	447
Separation Distance (ft)	31	29	28
Reactor & Shield Mass (lb)	556	563	581

50 kWe

Reactor Outlet Temp (^{O}F)	1200	1250	1275*
Thermal Power (kW)	226	215	209
Peak-Average Temperature (^{O}F)	1345	1350	1353
Number of Elements	187	253	349
Active Fuel Length (in.)	15	17	17
Lattice Pitch (in.)	0.8356	0.7165	0.6430
Fuel Diameter (in.)	0.7455	0.6275	0.5598
Linear Power Density (kW/ft)	0.967	0.600	0.423
Reactor Mass (lb)	586	653	725
Separation Distance (ft)	94	88	85
Reactor & Shield Mass (lb)	707	779	866

*Reactor designs at 1300^{O}F were not considered due to large weight penalties.

TABLE 14

10 and 50 kWe Stirling Reactor

10 kWe

	1200	1250	1300
Thermal Power (kW)	45	43.9	43
Peak-Average Temeperature (^{O}F)	1314	1327	1382
Number of Fuel Elements	31	55	55
Active Fuel Length (in.)	14	14	14
Lattice Pitch (in.)	1.600	1.501	1.277
Fuel Diameter (in.)	1.509	1.408	1.185
Linear Power Density (kW/ft)	1.244	1.062	0.670
Reactor Weight (lb)	396	412	423
Separation Distance (ft)	16.5	16.1	15.7
Reactor & Shield Weight (lb)	561	583	598

50 kWe

	1200	1250	1300
Thermal Power (kW)	188	182	177
Peak-Average Temperature (^{O}F)	1333	1353	1400
Number of Fuel Elements	151	187	199
Active Fuel Length (in.)	16	18	18
Lattice Pitch (in.)	0.865	0.769	0.780
Fuel Diameter (in.)	0.775	0.680	0.689
Linear Power Density (kW/ft)	0.932	0.647	0.592
Reactor Weight (lb)	559	615	654
Separation Distance (ft)	43	43	43
Reactor & Shield Weight (lb)	727	784	830

E. RADIATOR DESIGN

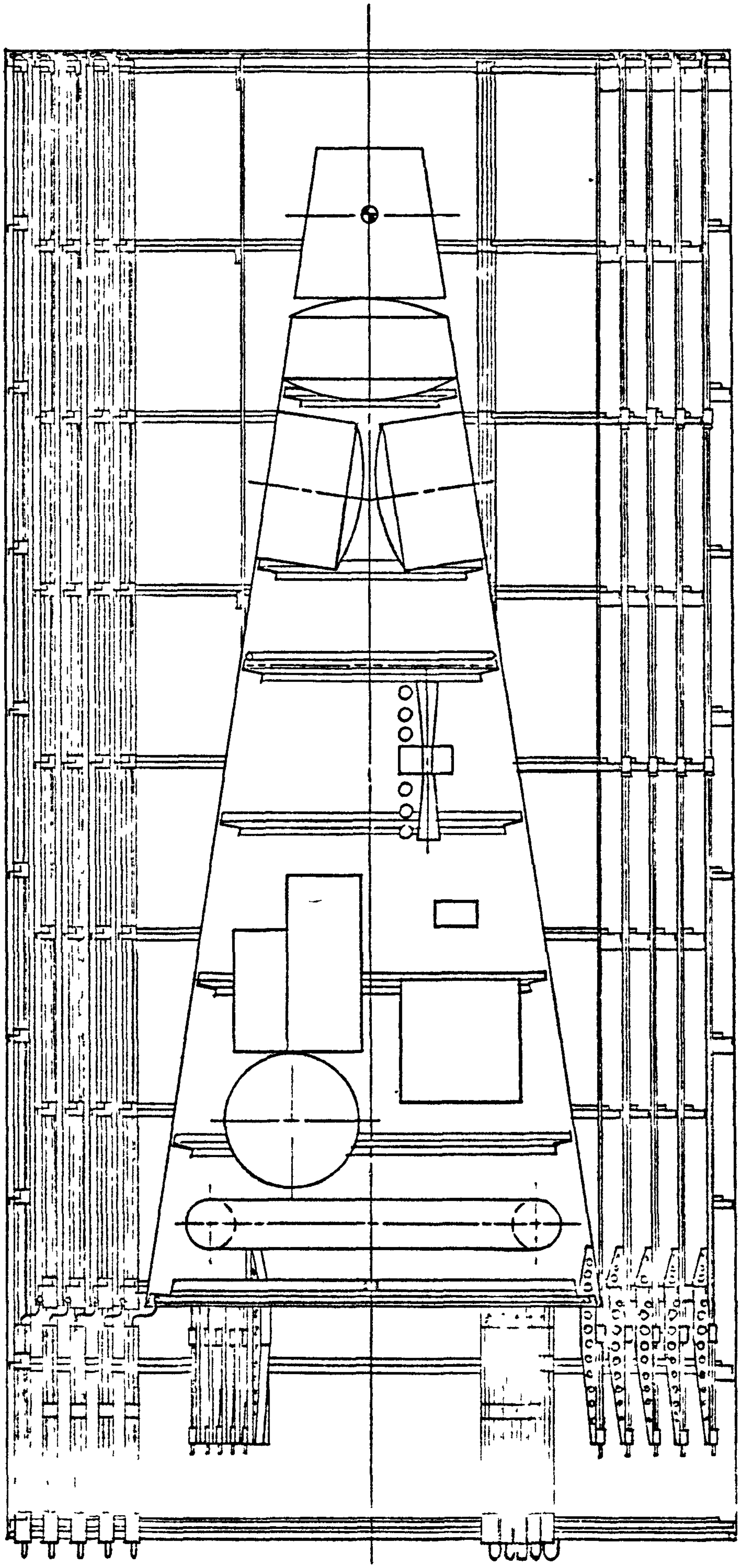
A number of mechanical features of the telescoping, deployable, and organic-cooled heat rejection radiators were studied during the quarter. The 50 kWe Brayton power system which has one conical section and five cylindrical sections was used as the basis of the design study. Figure 4 shows this power system with the radiator in the launch configuration.

The reference radiator is made of 0.015-in. aluminum alloy fins with 0.125-in. I.D. tubes spaced about 4.0 in. apart. The radiator sections are supported by Z-shaped stiffener rings spaced axially about every 24 in. A toroidal manifold is at each end of each radiator section. Three alignment shafts and ball bushing assemblies are spaced 120° apart around each cylindrical section. These mechanisms guide the motion of the sections as the radiator is deployed.

A weight study was made to determine the effect of varying the radial clearance between radiator sections. In one example, reducing the radial clearance from 6.0 to 4.25 in. reduced radiator weight from 1,612 to 1,421 lb - a saving of 11.8%. Studies are also in progress to (1) reduce the radiator coolant inventory, (2) compare various deployment mechanisms, and (3) to select preferred radiator hoses.

1

FIG. 4



F. METEOROID PROTECTION

During this reporting period studies were directed toward reducing the weight of a meteoroid shield which provides 360^0 protection for the liquid coolant space radiator tubes. This is accomplished by utilizing the bumper concept for the portion of the tube facing inward to the cylinder wall and by varying tube cross section to minimize the tube vulnerable area. A Rockwell Space Division computer program which analyzes the fracture mechanics of a space projectile striking a bumper has been selected to predict penetration depth and necessary tube armor thickness associated with a given meteoroid size and velocity. This computer program is presently being used in the design of the Space Shuttle.

Further studies are also being directed toward determining the optimum geometry of the tube/armor system for minimum mass subject to the combined constraints of fluid pressure drop, heat transfer, structural stiffness, and system reliability.

G. RELIABILITY ANALYSIS

Studies have been initiated to define the total power system reliability based on reasonable achievable component performance. The system selected for analysis was the 50 kWe Brayton whose main subsystems are the ZrH reactor, the Brayton Power Conversion System, and the space radiator system. Component failure rate estimates are being obtained from various sources including AI reports, AI nuclear reactor component test data, vendor data, and past space station studies which incorporated nuclear Brayton power systems.

III. COMPONENT TECHNOLOGY

A. JPL SYSTEM COST REVIEW

JPL subcontracted to General Electric for a study, conducted during 1971 and 1972, which produced a Document GESP-7074, Nuclear Electric Propulsion, Mission Engineering Study, Development Program and Cost Estimates. A brief review of this report was conducted during this quarter to modify the cost associated with the heat rejection system to reflect current changes in the system and power level, as well as the impact of inflation. An attempt is being made to proportion this modified cost and equivalent man-hours to the labor classifications within the various program phases. Because this allocation is being made without the benefit of design drawings or program definition, the cost estimates are extremely preliminary.

B. ACTUATOR AND DRIVE TRAIN (REFLECTOR DRIVE)

This task consists of the endurance testing of the actuator and drive train which was designed during FY 1974 and fabricated and performance mapped during FY 1975. The actuator and drive train was performance tested through 428% of its total design life travel, and then disassembled for inspection, due to increased torque. (See Progress Report October-December 1975). The actuator was then reassembled with another ball-nut and screw and placed back on test. (See Progress Report January-March 1976.)

During this quarter, additional endurance testing continued with satisfactory operation. The test has now been terminated as was planned. The reflector drive test history during this final series of tests is shown in Table 15.

The design travel requirement for the reflector drive is a total of 400 inches. During this test phase the actuator and new ball screw accumulated 1040 inches of travel (260% of design travel) of which 850 inches were at 300°F or above. This test was at 300°F and above for 3871 hours. The actuator has accumulated 8900 hours at 300°F or above during the two endurance tests.

TABLE 15

REFLECTOR DRIVE TEST HISTORY

Screw Temperature (°F)	Actuator Temperature (°F)	Dwell Time (hours)	Stepping Travel (inches)	Scram Travel (inches)
100	100	-	31	159
300	300	64	31	150
500	500	54	31	150
700	600	199	31	150
900	700	146	21	100
1000	800	3015	31	155

IV. FUEL ELEMENT TECHNOLOGY

The fuel element technology effort is composed of four subtasks during GFY 1976: 1) facility modifications, 2) fuel casting, 3) hydrogen barrier evaluation, and 4) NaK bonding studies.

The GFY 1976 workscope requires the activation of an induction melting furnace and the reestablishment of capabilities for radioactive machining, frit smelting, NaK loading and bonding, hydriding and permeation testing.

The objective of the fuel casting task is to demonstrate the technical feasibility of producing fuel rods by induction melting and direct casting of 4- to 6-in. long segments. This approach is a significant departure from the previous practice of arc melting and extrusion for fuel rod fabrication.

The hydrogen barrier evaluations are a continuation of the work performed during GFY 1975. Based on coupon tests, three candidate coating compositions were selected for additional testing. During GFY 1976, hydrogen permeation data will be obtained on the new coatings in addition to further characterization of the material properties.

The NaK bonding studies will include development of bonding procedures, techniques for determination of bonding quality, evaluation of total system compatibility, and determination of hydrogen leakage over a range of temperatures.

A. CERAMIC HYDROGEN BARRIER

The new apparatus for "flow coating" closed-end tubing was checked out and operates acceptably. Twelve (12) Hastelloy X closed-end tubes were preoxidized, coated, and fired using coatings SCB, A, E, and J. Preoxidation parameters for all compositions were 15 minutes at 1950°F in a mixture of 55%Ar-45%O_2 flowing at a rate of 575 cc/min.

The coated tubes were examined using a borescope and coating quality was generally good. Representative tubes from each coating composition were processed through closure welding. Pressure probes were also welded on to permit hydrogen pressurization. These membranes will now be leak tested under two atmospheres of hydrogen pressure at 1400°F. The performance of the candidate coatings, A, E, and J, will be compared against the reference coating, SCB.

B. FACILITY MODIFICATIONS

With the completion of radioactive exhaust ducting in the hot machine shop, all facility modifications were completed.

C. FUEL CASTING

Three unsuccessful attempts were made at processing an induction melting and casting heat. During the first attempt, a water leak in the coil aborted the cycle. On the next two melt cycles, the melt charge could not be raised above 1600°C. The temperature required to melt the zirconium is about 1800°C. A review of the induction melting system revealed that substantial modification to the coil design and insulation might be required to achieve satisfactory results. As an alternate, a laboratory scale induction power supply is being set up for melting. It appears that this system can be brought on line fairly rapidly.

D. NaK BONDING

Tubing, end caps, and mock-up beryllium reflectors were received and stored for this task. A fixture for the glovebox closure welding operation was designed and is being fabricated.