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SUBJECT:

Evaluation of NaK as the Primary Coolant for the SNAP II System

CONTENTS:

I STATEMENT OF PROBLEM

An evaluation of the use of NaK as the primary coolant for the SNAP II system is to be undertaken. Pumping power limitations based on the Mercury Rankine cycle are to be analyzed. Problems pertinent to any design specification modifications are to be reviewed.

II. SUMMARY

The use of eutectic NaK (22, 78) will considerably simplify the SNAP II vehicle installation and the test program. It is recommended that the reactor temperature differential be increased to 300°F. However, adoptation of NaK should be contingent on experimental verification of the axial gap pump concept and confirmation that a NaK pump will require only minor modifications to the CRU.

III. ANALYSIS

The possibility of utilizing a low freezing point NaK instead of pure Na as the SNAP II primary coolant, appears very attractive. Primarily, the use of NaK would eliminate the need of special drain and fill capability, particularly with respect to the vehicle launch installation. It is problematical as to whether frozen sodium within small diameter piping can be successfully preheated by line heaters. In addition, most certainly the developmental and environmental SNAP II test program can be considerably simplified.

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Originally, the decision to use Na was based on the estimate of a very low primary pump efficiency. However, it would now appear from the TRW analysis, that the new axial gap pump concept can produce better efficiencies when using eutectic NaK. Additionally, if necessary, the pumping specification can be improved by decreasing the system pressure drop and/or by decreasing the primary coolant flow rate.

Listed in Table I below, are the important properties of Na and Nak which must be evaluated.

TABLE I

			Na	NaK(56,14)	NaK(22,78)
Density	~ #/ft^3	(1100°F)	50.5	48.0	45.7
		(60°F)	60.6	56.8	54.0
Specific Heat	~ BTU/#	(1100°F)	.30	.25	.21
Viscosity	~ #/hr-ft	(1100°F)	.52	.44	.38
Electrical Resistivity	~ microhm-cm	(1000°F)	29	73	77
Thermal Conductivity	~ BTU/hr-ft^2-°F	(1100°F)	36	16	15
Melting Point	~ °F		208	68	10

The use of NaK (56, 44) appears to be only a poor compromise. Accordingly, only the use of NaK (22, 78) will be evaluated relative to Na.

For a thermal power transfer equivalent to 50 kw, the following primary coolant flow rates, pumping powers, estimated pump efficiencies and shaft power requirements have been established based on a system pressure drop of 3 psi.

TABLE II

Na	100°F	200°F	300°F
Flow rate - #/sec	1.58	.79	.53
Pumping power - watts	18.4	9.2	6.1
Pump efficiency - percent	4	*6	10
Shaft power - watts	460	153	61
NaK			
Flow rate	2.32	1.16	.77
Pumping power	29.7	14.9	9.9
Pump efficiency	---	*1	*2½
Shaft power	---	1490	396

Thompson Ramo Wooldridge has estimated a 6% and 2½% primary pump efficiencies when utilizing respectively Na and Nak at flow rates approximating ~.75 #/sec. As yet, there is no experimental verification of these numbers.

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* TRW letter dated 30 April 1959

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The effects of various primary coolant pumping power requirements have been graphed as a function of system boiling pressure on Figure 1.0. The following conditions were used.

Alternator output power	3.6 kw (electrical)
Alternator efficiency	80%
Bearings power	.600 kw
Turbine efficiency	50%
Mercury pump efficiency	25%
Condensing temperature	600°F
Superheat temperature	1150°F
Subcooling temperature	100°F
Mercury pressure drop	50 psi

Thermal power requirements have been equated on the right hand ordinate into the required radiator surface area based on an emissivity of 0.9, a fin effectiveness of .95 and a sink temperature of 25°F.

For the same system characteristics, cycle thermal power and required radiator surface area has been graphed as a function of condenser-radiator temperature on Figure 2.0.

For the cycle conditions already specified, it can be seen that a limitation of the primary pump power to less than 1 kw is necessary to meet the existing 110 square foot radiator area.

In the advent that the axial gap pump efficiency is lower than expected, it is possible that either the primary flow rate or the system pressure drop can be further reduced. The decrease in flow rate would be at the expense of lowering the available boiler driving temperature differential. The reduction in system pressure drop can be accomplished by an increase in the primary coolant flow annulus of the boiler.

A change to NaK must be conditional on investigating the possible required modifications to the CRU. It is expected that at the same flow conditions, only minor modifications would be necessary. However, confirmation of the exact CRU changes should be obtained prior to any final decision.

In summary, it appears that the advantages of using a eutectic NaK as the SNAP II primary coolant justify the developmental delay caused by changing the pump design. Thermodynamically, the cycle at the specified conditions can accomodate primary coolant pumping power requirements not exceeding 1 kw. Tt is recommended that a 300°F temperature differential, a 3 psi system pressure drop and use of NaK (22, 78) be specified. The final decision to change to NaK (22, 78) should be based on (1) The experimental verification of the existing axial gap design and (2) Confirmation that only minor modifications to the CRU are involved. If necessary, decreasing the system pressure drop to 2 psi can be easily accomplished with only a slight increase of weight.

IV. APPENDIX I - CYCLE POWER REQUIREMENTS SAMPLE CALCULATIONS

Thermal Power $P = P_T/\eta$

$\eta = 10.8$ @ 100 psia

$= 13.4$ 200 psia

$= 15.9\%$ 400 psia

for

Turbine efficiency	= 50%
Superheat temperature	= 1150°F
Condensing Temperature	= 600°F
Subcooled	= 100°F
Enthalpy change	≅ 143.8 BTU/#

Turbine power output $P_T = P_A + P_B + P_H + P_P$

$P_A = 4.50$ kw (80% efficiency alternator)

$P_B = .60$ kw (bearings)

$P_H \cong 2P \times \frac{.948}{143.8} \times \frac{psi}{100} \times .1$ (25% efficiency pump)

$P_P = 0 - 5$ kw (1% efficiency primary pump)

Required thermal power - no losses returned to cycle

$$P = \frac{P_A + P_B + P_H + P_P}{\eta}$$

Required thermal power - losses returned to cycle

$$P^{1} + .2\,P_A + P_B + .75\,P_H + .99\,P_P = \frac{P_A + P_B + P_H + P_P}{\eta}$$

100 psia boiling condition - primpary pump = 2 kw

$$P = \frac{4.50 + 0.60 + .002P + 2}{.108}$$

$= 67.0$ kw

$$P^{1} = 67.0 - \left[0.90 + 0.60 + (.75 \times .002 \times .67) + 1.98\right]$$

$= 63.4$ kw

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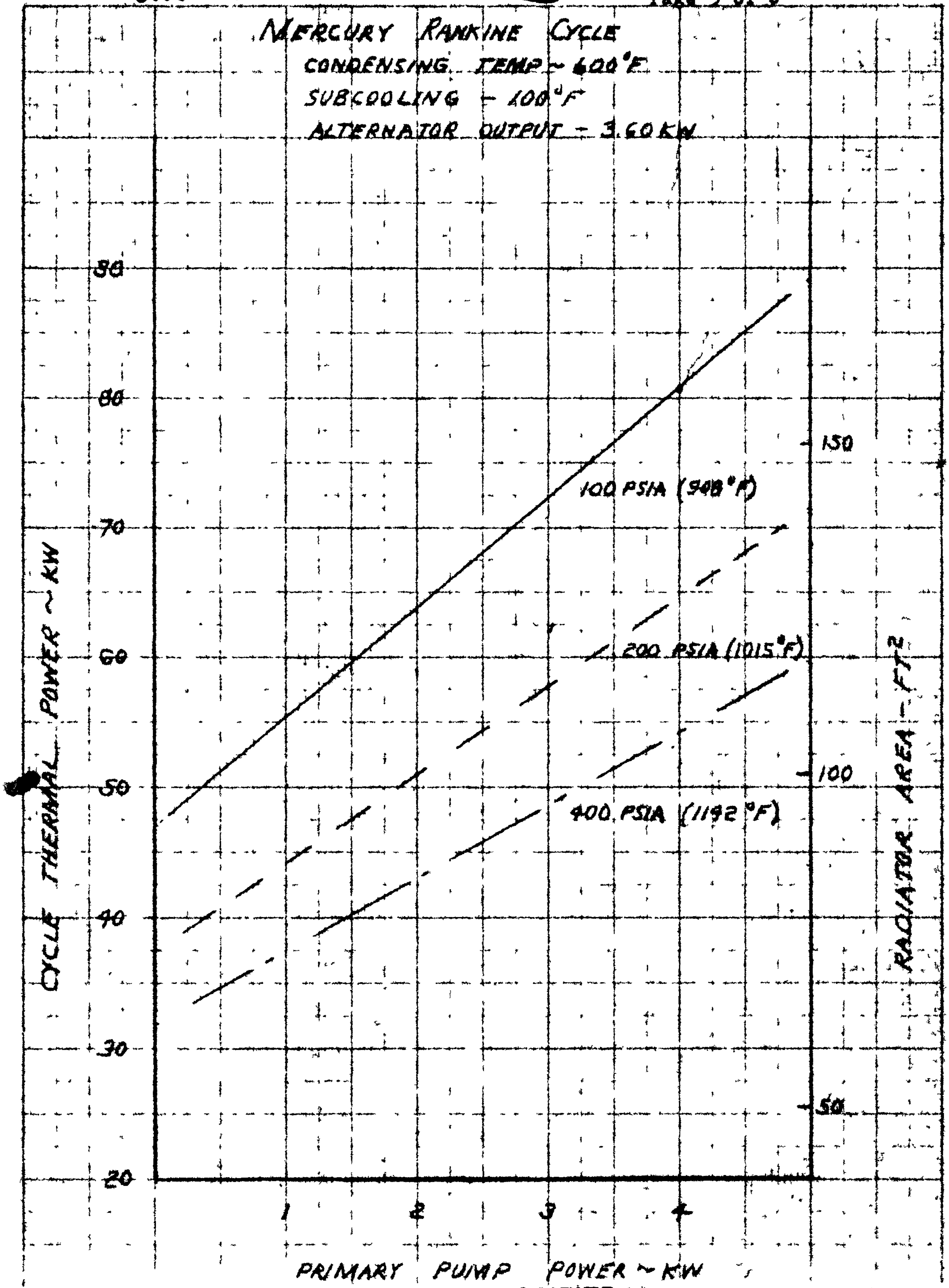

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FIG 10

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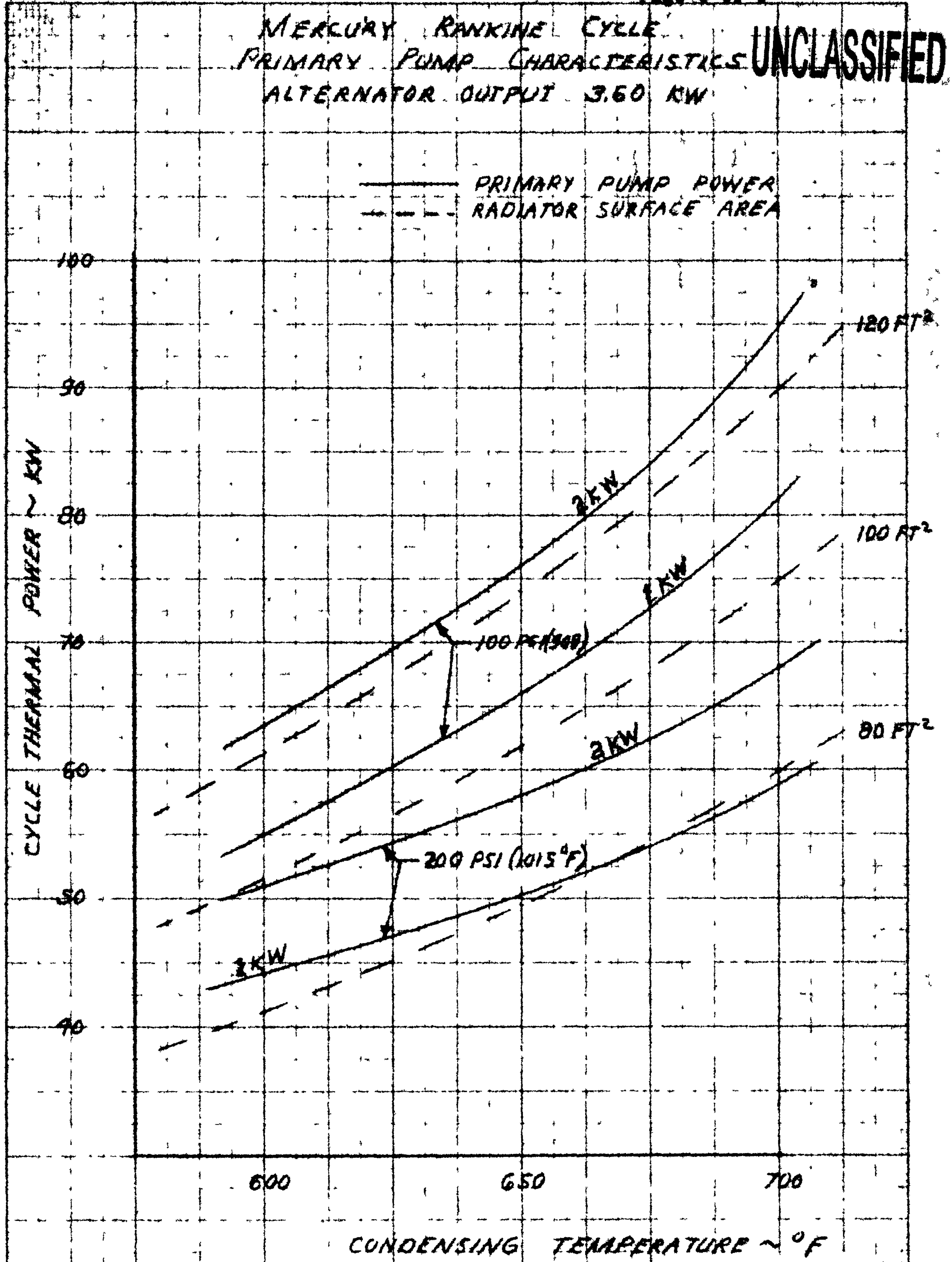

MERCURY RANKINE CYCLE
PRIMARY PUMP CHARACTERISTICS
ALTERNATOR OUTPUT 3.60 KW

FIG 20

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