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CNLM-5734
DESIGN NO. 5 OF SNAP-50/SPUR
REACTOR TEST SYSTEMS

PRATT & WHITNEY AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION
CANEL
MIDDLETOWN • CONNECTICUT

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MIDDLETOWN, CONNECTICUT

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I. INTRODUCTION

Approved By:  
R. W. Kelly

July 7, 1964
I. INTRODUCTION

This document presents the initial definition of a 2 Mwt, SNAP-50 Flight Configuration Nuclear Powerplant Test and is intended to provide guidance to the Architect/Engineer in evaluating and costing various Nuclear Test Facility design concepts. The powerplant consists of a lithium-cooled reactor in combination with a potassium Rankine cycle power conversion system to provide a nominal 300 Kw of electrical power. The waste heat of the system is rejected by a radiator system which uses NaK as the working fluid. The information is based on preliminary studies; and, consequently, the configuration and component sizes have not been firmly established. Where the Nuclear Test Facility design concept will be affected, however, estimates of reactor test component sizes, envelopes, and requirements are presented where known so that facility design studies can proceed.

The objectives of the 2 Mwt SNAP-50 Flight Configuration Nuclear Powerplant Test are:

1. To demonstrate the operation of a 2 Mwt, 2000F, lithium-cooled reactor in conjunction with a power conversion system in flight configuration.

2. To ascertain operational and control characteristics of the reactor and power conversion system by such techniques as a Fuel Loading Experiment, and reactor transfer function determinations by means of a pile power oscillator.

3. Pre-flight qualification of reactor and power conversion system.

The following test guidelines have been formulated:

1. Reactor design power - 2.2 Mwt

2. Reactor coolant temperatures - 2000F/1900F

3. Design life - 10,000 hours reactor full power operation
   5,000 hours preheat, afterheat removal, and miscellaneous heating conditions

4. Environment - High vacuum \((3.75 \times 10^{-7} \text{ torr})\)

5. Power Conversion System - 345 Kwe generated for 10,000 hours
II. DESCRIPTION OF REACTOR POWERPLANT IN FLIGHT CONFIGURATION AND GROUND TEST SYSTEMS
A. REACTOR

The SNAP-50 reactor (Fig. 1) is lithium-cooled and is designed for a thermal power output of 2 Mw. Columbium base alloys will be utilized for the pressure vessel, core structure, and fuel pin cladding. The reactor will operate in the fast neutron energy range and will be controlled by six movable reflector segments which surround the pressure vessel in the region of the core. These segments will be operated by six drive motors which are located behind the shield. The motors are connected to their respective segments by means of shafts extending through penetrations in the shield. The reflector, shield, and control drive motors will be cooled by thermal radiation to space. Fig. 2 shows a cross section of the core and pressure vessel.

It is required in the test that the essential features of the reactor design be retained except that:

1. Scram devices will be included.
2. The reflectors will radiate to the walls of a vacuum chamber rather than space.
3. Control drive motors will require additional cooling.

Operation of the reactor in the flight configuration places the unit at the lowest elevation of the test system assembly as shown in Fig. 3, therefore, fuel loading and all other work on the reactor must be done in the access region below the powerplant. It is to be noted that Fig. 3 is a conceptual arrangement drawing.

The process conditions for the reactor test are given in the table below:

<table>
<thead>
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<th>Process Conditions</th>
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<tr>
<td><strong>a. Reactor</strong></td>
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<tr>
<td>Primary coolant</td>
</tr>
<tr>
<td>Max. reactor $\Delta P$, psi</td>
</tr>
<tr>
<td>Max. reactor $\Delta T$, F</td>
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<tr>
<td>Max. reactor flow rate, lb/sec</td>
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<td><strong>b. Afterheat Removal System</strong></td>
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<tr>
<td>Coolant</td>
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<tr>
<td>Flow rate, lb/hr</td>
</tr>
<tr>
<td>Helium $\Delta P$ in jacket, psi</td>
</tr>
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<td>Avg. helium exit temperature, F</td>
</tr>
<tr>
<td>Avg. helium entrance temperature, F</td>
</tr>
<tr>
<td>Helium purity requirements</td>
</tr>
</tbody>
</table>

Although not an integral part of the reactor, certain items associated with the test such as pile power oscillator, neutron startup source, and neutron foil insertion thimble will be included.

The pile power oscillator is a device for mechanically inducing reactor power oscillations. A BeO segment capable of both eccentric rotation and translation will provide this function. A thimble projecting through the vacuum chamber wall will be included to provide a leak-tight extension for its drive shaft and bearings.
REACTOR AND SHIELD FLIGHT DESIGN CONCEPT

- Reactor Pressure Vessel and Core
- Pressure Vessel Support Fingers
- Reactor Support Columns (6)
- Flexure Bearing
- Lower Reflector Support Ring
- Reflector Support Pylon
- 28" Reflectors Full Out
- Neutron Shield
- Coolant Exit Pipe
- Coolant Inlet Pipe
- Control Drive Mechanism
- Support Lugs
- Support Lug 67750 Dia
- Reactor Support Columns (6)
FIG 3
2 MWT SNAP-50 FLIGHT CONFIGURATION TEST
(ARRANGEMENT CONCEPT)

LEGEND
A ACCUMULATOR
B POWER CONVERSION SYSTEM ENVELOPE
C PRIMARY SYSTEM ENVELOPE
D REFLECTOR DRIVE
E SUPPORT REGION
F FLIGHT SHIELD
G LI PIPING
H REFLECTOR ASSEMBLY
I REACTOR

TO NaK HEAT REJECTION SYSTEM
ELEVATED FLOOR PLANE
NUCLEAR INSTRUMENTATION

VACUUM CHAMBER
DIFFUSION PUMP
220"
WORK PLATFORM REMOVABLE
ACCESS REGION
REMOVABLE SHIELD

50"
The neutron startup source will be either manually attached to the outer surface of the pressure vessel during final assembly of the reactor or remotely inserted through a leak-tight thimble which penetrates the vacuum chamber.

The neutron foil insertion thimble will be used to irradiate various foil materials for absolute power measurements and calibration of instrumentation during reactor startup procedure.
B. PRIMARY SYSTEM

1. General

The basic function of the primary system is to remove heat generated by nuclear fission in the reactor core. This will be done by circulating lithium through a circuit consisting of a reactor, boiler, and pumps. Columbium alloy will be used in all primary system components and piping. A schematic of this flow circuit is shown in Fig. 4 and a heat balance schematic is shown in Fig. 5. In addition, auxiliary items such as vapor traps, accumulator, and fill and drain system are also included. Two basic requirements for the environment of the reactor and primary test system are: a) protection of columbium alloy structures from contamination, and b) simulation of space conditions for radiant heat transfer. Currently, one vacuum tank is proposed to contain the reactor and pressure vessel assembly, flight shield, reflector drive motors, and the components of the power conversion system in the flight configuration of this test. This concept is shown in Fig. 3.

The major components of the primary system are discussed in the following sections. Estimated component envelope sizes and liquid metal inventory are presented in Table I.

2. Boiler (Lithium to Potassium)

The boiler transfers heat from the primary circuit (lithium) to the power conversion system (potassium), the lithium entering the boiler at 2000°F and leaving at 1900°F. The estimated size of a 2 Mw boiler based on preliminary studies is shown in Fig. 6. The boiler is contained in the power conversion envelope of Fig. 3.

3. Lithium Pumps

A flight prototype, hermetically sealed, columbium alloy, centrifugal pump serves to circulate the 1900°F lithium coolant of the primary system. The main stage of the centrifugal pump is directly connected to a canned electric motor, this entire assembly being supported on lithium lubricated bearings. A secondary impeller on this shaft will supply nominal 600°F lithium flow for bearing lubrication, and drive motor and bearing coolant. This waste heat is transferred to the NaK auxiliary heat dump system. An envelope drawing of the pump is included in Fig. 7.

a. Operating Environment

The pump will be operated within the vacuum chamber in a vacuum of $3.75 \times 10^{-7}$ torr during reactor full power operation.

b. Service Requirements

The electric power necessary to operate the pump will be derived from either of two sources:

1) External MG-A power supplies.

2) Power supplied by the frequency conversion unit of the power conversion system discussed in the Power Conversion section of this document.

The electric power for operating the pump as supplied by either source will be 120 volts line to neutral, 3-phase at 400 cps. Controls must be provided in order that the pump may be operated from either of the above mentioned power sources.

4. Lithium Fill and Drain System

The lithium, as supplied by the manufacturer, is hot trapped or gettered by titanium at 1400°F in a transport tank, and then transferred through a filter to the fill and drain tank. The primary system is then vacuum filled through a micro-metallic filter in the fill line. Liquid level measurement will be accomplished by "J" probe transducers with the appropriate readout.
300 kW SNAP 50 FLOW SCHEMATIC

- REACTOR
- PRIMARY SYSTEM
- BOILER
- POWER CONVERSION SYSTEM
- TURBINE
- ALTERNATORS
- 4 CONDENSERS
- 4 SEGMENTED RADIATOR CIRCUITS
- 4 RADIATORS
- 4 AUX. RADS.

- BEARING
- TV - TANK VALVE
- CV - CONTROL VALVE
- IV - ISOLATION VALVE
- BV - BYPASS VALVE
- ACC - ACCUMULATOR
- PUMP

- MOTOR PUMP
- COOLER
- JET PUMP
- TANK
LITHIUM TO POTASSIUM BOILER

LITHIUM INLET

POTASSIUM OUTLET

LITHIUM OUTLET

POTASSIUM INLET

6.500 DIA

16.700

7.000

6.800

4.820R

3.580
LITHIUM PUMP ENVELOPE

TO: Li-NaK AUXILIARY HEAT EXCHANGER

RETURN FLOW FROM HEAT EXCHANGER

CANNED MOTOR REGION

SECONDARY IMPELLER REGION

MAIN IMPELLER REGION

LITHIUM DISCHARGE TO REACTOR

PUMP INLET FROM BOILER

EM SPEED PICKUP

TO: Li-NaK AUXILIARY HEAT EXCHANGER

RETURN FLOW FROM HEAT EXCHANGER

37"

15"
instruments (Re: "J" Probe Development, PWAC-423). The primary system is isolated from the fill and drain system by both a pneumatically controlled valve and an air-cooled freeze plug. The lithium is dumped from the system into the tank through an unfiltered line, in order that particulate matter may be returned to the fill and drain tank. The fluid is then refiltered upon refilling the system. The services required for this system include the following:

a. Power and controls for heating the fill and drain tank.
b. Temperature transducers (thermocouples) and temperature readout instruments.
c. "J" probe devices and readout instruments.
d. Vacuum pumps and associated controls are needed for liquid metal fill.
e. Purified helium (per CS-300A and 1983 specifications) at 100 psig is needed for the liquid metal cover gas system.
f. Compressed air as needed for the freeze plug and the valve operators.
g. Pressure indication for the cover gas and the air is needed to indicate system pressure level and valve position.

5. Primary System Preheat

Heat must be supplied to the primary system for bake out, preheat to liquid metal fill temperatures, and permit isothermal operation at 1000F during zero power operation.

Bakeout and preheat will be accomplished by heating the vacuum chamber system and relying on thermal radiation from the vacuum chamber walls. It appears that electrical heaters on the vacuum chamber walls are the most effective means for achieving the preheat temperature, however, alternate schemes should be considered.

This operation will be started only when a hard vacuum is achieved in the chamber. Some of the heating requirements during isothermal operation will be supplied by heat from the heat rejection and power conversion system.

6. Gas Separator

A gas separator is needed to remove gaseous helium generated from the decay of activated helium.

7. Lithium Accumulator

Upon filling the primary system with lithium, the fill and drain tank will be valved off. An accumulator in the piping system will then be used to allow for volume change and system pressure control as reactor operations are begun and temperatures are raised.

The accumulator is defined as a tank 42 inches long by 12 inches OD. Internal to the accumulator is a bellows which acts as the interface between the lithium and the inert gas back-up (helium per CS-300A and 1983).
C. POWER CONVERSION SYSTEM

1. General

The 2 Mwt power generated by the reactor is transferred by the lithium coolant of the primary system to the potassium coolant of the power conversion or secondary system through a lithium to potassium boiler. The potassium vapor formed in the boiler is then expanded through a vapor turbine coupled to an electrical alternator to generate the system electric power requirements. For the flight configuration reactor test system, a load device now under study will be used for the dissipation of the major portion of this electrical power. The remainder of this electrical power may then be used to operate the liquid metal pump motors and associated controls. The potassium vapor is then subcooled and condensed in a potassium-to-NaK heat exchanger and then repumped to the boiler. The power conversion system is to be contained in the vacuum tank with the primary heat rejection system, and the reactor, but isolated from the reactor by the flight shield. The envelope dimensions for this portion of the system is shown in Fig. 3.

The power conversion system will be constructed primarily from columbium alloy and will have a design life of 15,000 hours, 10,000 of which will be at full reactor power output, and 5000 hours will be during startup and shutdown.

Auxiliary items such as a preheat system, vapor traps, fill and drain system will also be included in this portion of the system. The major components are discussed in the following sections.

Estimated component envelope sizes and liquid metal inventory are presented in Table I.

2. Boiler

The boiler, as described in Section II-B of this document, is designed for a 2 Mwt heat load. Liquid potassium enters the boiler at about 1124°F and is completely vaporized at 1850°F at the boiler exit. The boiler is of shell and tube construction with lithium on the shell side and potassium in the tubes.

3. Turboalternator

The potassium vapor, upon exit from the boiler, enters a seven stage turbine operating at 24,000 rpm. The potassium expands to 1274°F at exit and delivers 413.9 Kw of shaft power. An electric alternator coupled to the turbine produces 345 Kw of electric power at 3200 cps. Approximately 40 Kw of this 3200 cps power is passed to a solid state frequency converter where frequency is converted to 400 cps and used to operate the system liquid-metal pump motors and controls. A second potassium system provides bearing lubrication and alternator cooling by transferring heat to the auxiliary cooling system.

4. Condensers

The potassium flow from the turbine enters four prototype condensers in a parallel array at 1274°F at 85 percent quality, where vapor is completely condensed and subcooled to 1120°F by rejection of heat to the NaK circuit. The condenser is a shell and tube design with potassium flowing in the tubes and NaK on the shell side. A drawing of one condenser is shown in Fig. 8.

5. Potassium Pump

A flight prototype, hermetically sealed, columbium alloy, centrifugal pump circulates the condensed potassium in the return line to the lithium-to-potassium boiler. The potassium centrifugal pump envelope is shown in Fig. 9.

The main stage of the centrifugal pump is directly connected to a canned electric motor, this entire assembly being supported on potassium lubricated bearings. A secondary impeller on
POTASSIUM PUMP ENVELOPE

TO:
- ALTERNATOR
- K-NaK HEAT EXCHANGER

RETURN FLOW FROM HEAT EXCHANGER

PUMP INLET FROM CONDENSER

EM SPEED PICKUP

CANNED MOTOR REGION

SECONDARY IMPELLER REGION

MAIN IMPELLER REGION

K DISCHARGE TO BOILER

37"

14"
this shaft will supply both lubricant and coolant flow requirements for both the pump and motor assembly, and the turboalternator at a nominal 600°F. This waste heat is then rejected to the auxiliary heat dump system.

A jet pump from the discharge to the inlet of the potassium pump to prevent damage caused by cavitation will be used and is subject of analysis.

a. Operating Environment

The pump will be operated within the system vacuum chamber in a vacuum of $3.75 \times 10^{-7}$ torr during full reactor power operation.

b. Service Requirements

The electric power necessary to operate the pump will be derived from either of two sources:

1) External MG-A power supplies.

2) Power supplied by a frequency conversion unit as discussed under the preceding section on the turboalternator.

The electric power to operate the pump as supplied by either source will be 120 volts line-to-neutral, 3-phase at 400 cps. Controls must be provided in order that the pump may be operated from either of the mentioned power sources.

6. Potassium Fill and Drain System

The potassium, as supplied by the manufacturer is hot trapped at 1400°F in a transport tank and then transferred through a filter to the fill and drain tank. The secondary loop is then vacuum filled through micro-metallic filters. Liquid level measurement is accomplished by "J" probe transducers with appropriate readout instruments. The secondary system is isolated from the fill and drain tank by a pneumatically controlled valve.

The potassium is dumped from the system into the tank through an unfiltered line in order that particulate matter may be returned to the fill and drain tank. The fluid is then refiltered upon filling the system.

The following services will be required for this system.

a. Power and controls for heating the fill and drain tank.

b. Temperature transducers (thermocouple) and temperature readout instruments.

c. "J" probe devices and readout instrument.

d. Vacuum pumps and associated controls are needed for liquid-metal fills.

e. Purified helium (per CS-300A and 1983 specifications) at 100 psig is needed for the liquid metal cover gas system.

f. Compressed air as needed for valve operation.

g. Pressure indication for cover gas and the air is needed to indicate system pressure level and valve position.

7. Accumulator

Upon filling of the power conversion system with the potassium, the fill and drain tank will be valved off. An accumulator in the piping system will be used to allow for the expansion and pressure control of the potassium as reactor operations are begun and temperatures are raised.
The accumulator is defined as a tank 13 inches in diameter and 13 inches long. A large bellows inside the tank, acts as the interface between the K and the inert gas backup. The required operating system conditions will be controlled by adjusting the gas pressure on this bellows.

8. Power Conversion Preheat and Bakeout

Heat must be supplied to the power conversion system for bake out, preheat the system to liquid metal fill temperatures and permit isothermal operation at 1000F during zero power operation.

Bakeout and preheat is accomplished in the same manner as for the primary system.

9. Valves

Three columbium alloy valves are required in the power conversion system. One of these, the potassium flow control valve, controls the potassium flow during powerplant operation. The remaining two valves are placed in the turbine inlet and turbine bypass lines and are used only during startup and shutdown. These valves are shown in Fig. 4.

These valves will be powered by electro-mechanical actuating mechanisms, radiatively cooled, and designed for zero leakage to the vacuum or space environment.
D. HEAT REJECTION SYSTEM

1. General

The 2 Mw of thermal power generated by the test reactor will be transferred by the lithium coolant of the primary system to the power conversion system, and the heat of condensation is then transferred to one or more NaK heat rejection loops, the number of loops being subject to analysis. Fig. 4 shows a four loop system, but this number of loops is not intended to be a fixed requirement and should be further studied. The NaK heat rejection loops provide the media whereby heat is transferred from the potassium condenser array within the vacuum chamber to the NaK-to-air heat exchangers which are external to the vacuum chamber. The design of the heat rejection system must consider the over-all operation and control characteristics of the reactor and powerplant test systems.

The heat rejection system will be constructed of type 316 stainless steel, and will have a design life of 15,000 hours, 10,000 hours of which will be at full reactor power output, and 5000 hours will be during reactor startup and shutdown. The system will be capable of operating at a heat rejection rate to 150 percent of the nominal reactor power output of 2 Mw. Redundancy in the design should be considered to protect the nuclear powerplant test in the event of a component failure.

P&WA drawing L-102464 is an initial design study of the power conversion system concept in flight configuration but does not show the heat rejection system, and will be modified as further requirements dictate. A NaK inventory for this heat rejection system is approximately 24.6 cubic feet or 1036 pounds at 1000F if one loop is used, and this figure will increase if study requires more than one loop. This does not include liquid metal contained in the fill and drain tank after charging the heat rejection system.

2. Columbium-Stainless Steel Interface

A co-extruded columbium-to-stainless steel joint is used to mate the columbium portions of this powerplant to the stainless steel heat rejection system. This joint is located at the tube-side inlet and exit of the potassium-to-NaK condenser within the power conversion system vacuum tank. This same joint is used on all piping attached to the respective fill and drain tanks, accumulators if outside the vacuum chamber, and connections to the auxiliary potassium-to-NaK heat exchanger.

3. NaK-to-Air Heat Exchanger

The NaK coolant leaves the condenser at 1246F and flows to one or more NaK-to-air heat exchangers within a blower-stack system for final disposal of the heat, where the NaK is cooled to 1096F. The NaK-to-air heat exchangers are constructed of type 316 stainless steel and capable of dissipating a maximum of 3 Mw. To provide for the possible failure of the air blower, two or more such blowers are recommended to provide sufficient redundancy for reliability considerations.

4. NaK Pumps

Four hermetically sealed, stainless steel alloy, centrifugal pumps to be provided by Pratt & Whitney Aircraft circulate the NaK of the heat rejection system. The pumps are parallel connected with suitable valving to provide sufficient pumping capacity for the heat rejection system. An envelope drawing of this pump is shown in Fig. 10.

The main stage of the centrifugal pump is directly connected to an electric motor, this entire assembly being supported on NaK lubricated bearings. A secondary impeller on this shaft will supply NaK for bearing lubrication, drive motor and bearing coolant, and sufficient NaK flow for the auxiliary heat dump system.
FIG 10

**NaK PUMP ENVELOPE**

- **EM SPEED PICKUP**
- **CANNED MOTOR REGION**
- **SECONDARY IMPELLER REGION**
- **RETURN FLOW FROM AUXILIARY RADIATOR**
- **MAIN IMPELLER REGION**
- **PUMP INLET FROM MAIN RADIATOR**
- **NaK DISCHARGE TO CONDENSER**

**AUX. COOLANT TO:**
- Condensate Pump Heat Exchanger
- Reactor Coolant Pump Heat Exchanger
- Auxiliary Radiator
a. Operating Environment

The pumps will be operated external to the vacuum chamber in ambient environment.

b. Service Requirements

The electric power necessary to operate the pumps will be derived from either of two sources:

1) External MG-A power supplies.

2) Power supplied by the frequency conversion unit of the power conversion system.

The electric power for operating these pumps, as supplied by either source will be 120 volts line-to-neutral, 3-phase at 400 cps. Controls must be provided in order that the pumps may be operated from either of the above mentioned power sources.

5. NaK Fill and Drain System

Sufficient heat must be supplied to heat the fill and drain tank to 500°F. A micro-metallic filter must be supplied in order to remove particulate matter during the charging cycle. A separate dump line must be supplied which bypasses the filter and, therefore, allows particulate matter from the system to settle in the tank. Liquid level measurement is required which will continuously indicate the liquid metal level in the tank. A gas supply (per CS-300A and 1983) is required to provide sufficient head to pressure fill the NaK system if necessary.

6. Oxide Control

a. NaK Hot Trap and Sampling System

NaK hot trap bypass system as shown on P&WA drawing 1039414, Sheets 1 and 2, to remove oxide impurities will be included in the systems to inhibit corrosion effects. In conjunction with this item a NaK sampling station will be provided so that representative NaK samples can be taken to determine fluid purity at any time. A five percent bypass flow is required through these hot traps at all times.

b. NaK Cold Trap and Plugging Indicator

NaK cold traps to remove oxide precipitates will be included in the system with necessary valving, in conjunction with a plugging indicator. A one percent bypass flow is required through the cold traps during the NaK system clean-up cycle.

7. Potassium-to-NaK Bypass

A line bypassing the NaK-to-potassium condenser will be included along with necessary valving in each loop so that the heat rejection loops may be operated for cleanup of the NaK system. The bypass line is to be manufactured from type 316 stainless steel and be sized to minimize diversion of NaK flow from the condenser in event of a failure of a bypass valve in the open position.

8. Heat Rejection System Preheat

Because the interior surfaces of the system must be free of moisture prior to NaK fill, it will be necessary to preheat the piping and components, and bakeout at 400°F. During isothermal operation and preheat of the lithium primary cooling system, it will be necessary to operate the heat rejection system at 1000°F, but capable of attaining 1300°F. Methods for achieving the required temperature for isothermal operation should be studied. A suggested method is flowing heated air through the radiators while circulating the NaK. A heating rate of 100°F per hour is considered acceptable.
9. NaK Accumulator

Upon filling the heat rejection system with NaK, the fill and drain tank will be valved off. An accumulator in each loop will be used to allow for volume changes and system pressure control as reactor operations are initiated to full power conditions.

The accumulator will contain an internal bellows which acts as the interface between the NaK and the inert gas back-up (CS-300A and 1983). The accumulators each have an envelope of approximately 13 inches long by 13 inches OD.

10. Valves

All liquid metal valves must be bellows sealed. Stellite 6 and 12 seat materials are recommended to prevent self-welding. Failure modes must be considered in establishing the fail safe position. Pneumatic operators are considered consistent with the operating requirements and mechanical over-rides should be included.

11. Auxiliary Heat Rejection System

The auxiliary heat rejection system, as shown in Fig. 4, consists of four parallel independent NaK loops which remove the Li, K, and NaK pump and motor coolant heat load, and the heat load of the turboalternator system as previously discussed. The NaK flow in passing through the Li-to-NaK and K-to-NaK auxiliary heat exchangers will be in the tube side of the heat exchanger, thus the flow in each loop is not intermixed with that of an adjacent auxiliary heat rejection loop. The NaK flow for each auxiliary loop is circulated by the secondary impeller of one of the four required NaK pumps utilized in the main heat rejection system.

This heat load is then rejected to four auxiliary NaK-to-air radiators similar to those of the main heat rejection system.

12. Low Temperature Cooling System

A low temperature cooling system is required to remove about 8 Kw of heat from the controls, electronics and power conversion frequency conversion unit. This system is under study to determine the means of providing this cooling and the required components.
TABLE I
ESTIMATED COMPONENT ENVELOPE SIZES AND LIQUID METAL INVENTORY

a. Envelope
1) Reactor
   36" Dia. x 126" long
2) Boiler
   21" x 39" x 5"
3) Shield
   68" Dia. x 36" long
4) Turboalternator
5) Condenser (4 units)
6) Valves
7) Accumulator Li
   Accumulator (K)
   42" x 13" OD
   13" x 13" OD
   Accumulator NaK (1 of 4)
   13" x 13" OD
8) Auxiliary Heat Exchanger (K-to-NaK)
   Auxiliary Heat Exchanger (Li-to-NaK)
9) Pumps
   Li
   37" x 15" OD
   K
   37" x 14" OD
   NaK (1 of 4)
   30" x 15" OD
10) Fill and Drain Tanks
    Li
    30" OD x 48"
    K
    24" OD x 48"
    NaK
    36" OD x 84"

b. Inventory*

<table>
<thead>
<tr>
<th>Volume (ft³)</th>
<th>Weight at 1000°F (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Lithium</td>
<td>7.7</td>
</tr>
<tr>
<td>2) Potassium</td>
<td>6.0</td>
</tr>
<tr>
<td>3) NaK</td>
<td>24.6</td>
</tr>
</tbody>
</table>

*This does not include liquid metal contained in the fill tank after charging
E. MAIN VACUUM SYSTEM

1. General

The purpose of the vacuum environment is to protect all of the components of the primary and power conversion systems manufactured from columbium due to oxygen contamination, and to simulate radiant heat transfer. The main vacuum system will consist of a chamber containing the reactor, the primary, and power conversion systems as shown in Fig. 3.

2. Requirements

a. Vacuum

A hard vacuum will be required for 15,000 hours.

1) A final vacuum of $3.75 \times 10^{-7}$ torr at full reactor power conditions.

2) The main pump load in the operating range will be helium and hydrogen.

b. Preheat

The vacuum chamber walls may be used to radiate heat to the chamber contents in order to raise their temperature to 1000°F for the liquid metal fill operation.

c. Heat Load

The vacuum chamber must accept a 190 Kw load generated by the reactor and reflector system and the power conversion system. The chamber walls must have an absorptivity that will simulate space radiant heat transfer while operating at a maximum of 150°F.

3. Considerations

The radiation environment must be considered when placing vacuum pumps and instrumentations.
F. CONTROL AND INSTRUMENTATION

Preliminary studies of the reactor power conversion system have, to date, resulted in the instrumentation and control flow diagrams for the primary and heat rejection system given in the Reference Section.

Table II presents an estimate of the number of instrument bays (22" W x 24" D x 84" H) required for the SNAP-50 Reactor Test and is based either on existing instrumentation flow diagrams or a consideration, where possible, of similarities between this test and the LCRE.

Because of the preliminary nature of the instrumentation studies that have been conducted to date, a margin of safety of 50 percent should be applied in sizing the facility accommodations related to space requirements for instrumentation.

In addition, an operating console will be required for the Control Area which has the approximate floor dimensions of 11 feet by 11 feet.
TABLE II
ESTIMATE OF INSTRUMENT BAY REQUIREMENTS

<table>
<thead>
<tr>
<th>System</th>
<th>Main Control</th>
<th>Auxiliary Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Coolant System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Pump Control</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Process Conditions (T, P, F, L) Readout, Record Control</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Accumulator Controls including Vapor Trap</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Preheat Readout and Control</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>Power Conversion System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Pump Controls</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Turboalternator Machinery</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Accumulator Controls including Vapor Trap</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Boiler Process</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Condenser Process</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Preheat Readout and Control</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>Heat Rejection System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Pump Controls</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Process Conditions (T, P, F, L) Readout, Record Control</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Accumulator Controls including Vapor Trap</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Preheat Readout and Control</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>Primary Fill and Drain System</strong></td>
<td>1 1/2</td>
<td></td>
</tr>
<tr>
<td>Tank and Line Preheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Control and Readout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor Trap Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Conversion Fill and Drain System</strong></td>
<td>1 1/2</td>
<td></td>
</tr>
<tr>
<td>Tank and Line Preheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Control and Readout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor Trap Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heat Rejection Fill &amp; Drain System</strong></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Tank and Line Preheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM Control and Readout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor Trap Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heat Rejection Oxide Control System</strong></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>Heat Sink System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Main Control</td>
<td>Auxiliary Control</td>
</tr>
<tr>
<td>---</td>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>i.</td>
<td>Control System</td>
<td>*</td>
</tr>
<tr>
<td>j.</td>
<td>Flux Monitoring System</td>
<td>8</td>
</tr>
</tbody>
</table>
k. | Pile Oscillator System | 2 | 1 |
l. | Core Installation Monitoring System | 1 |   |
m. | Fuel Loading Experiment | 1 |   |
n. | Test Cell Gamma Monitoring System | * | * |
o. | Safety System |
|   | Signal Conditioners and Logic Circuits | 9 |   |
p. | Shield Cooling System | * | * |
q. | Test Cell Cooling System | * | * |
r. | Area Radiation Monitoring System | * | * |
s. | Helium Purification System | * | * |
t. | Argon Purification System | * | * |
u. | Afterheat Removal System | * | * |
v. | Fission Gas Release System | * | * |
w. | Main Vacuum System | * | * |

*These items to be determined by Architect/Engineer*
III. REACTOR FLIGHT CONFIGURATION POWER CONVERSION TEST PROGRAM
A. OBJECTIVE

The experimental data to be obtained from a 10,000 hour test of the SNAP-50 reactor power conversion system falls into three categories:

1. Demonstration of integrated operation of the reactor and power conversion system in flight configuration.

2. Operational and control characteristics.

3. Pre-flight qualification.

Specific information to be obtained from this test is presented in the following.

1. Develop and evaluate subsystem and power plant assembly procedures. Attention must be given to nuclear safety procedures, liquid metal handling, etc.

2. Develop and evaluate check-out procedures applicable to the power plant flight test.

3. Evaluate preheat and filling methods applicable to flight.

4. Evaluate startup procedures.

5. Evaluate power plant performance. Determine maximum power output and power output over a range from idle to maximum power and determine power plant stability over this range. Determine component interactions. Evaluate control system capability over the above mentioned range.

6. Evaluate control system and power plant response to step changes in load, simulating some potential load changes.

7. Determine component performance in order to better evaluate malfunctions and mismatches within the power plant.

8. Evaluate result of component failures where redundancy exists. By valving off one or more condenser segments it will be possible to evaluate performance in the transient and at final steady state condition.

9. Evaluate shield performance in so far as possible: Temperature distribution, heating rates, and gamma attenuation.

10. Determine radiation doses throughout the power plant in so far as possible.


12. Evaluate instrumentation system.

13. Evaluate piping systems using similar piping runs and support schemes as are to be used in flight.

14. At the conclusion of the test perform a complete posttest examination on all components to evaluate structural integrity, corrosion, erosion and material properties.

15. Evaluate launch type ground support equipment in so far as possible.
B. TEST SEQUENCE

A complete description of functions pertinent to the assembly, operation, and disassembly of the reactor test experiment are contained in CNLM-5729 and are reviewed here.

It is proposed that the reactor test proceed as follows:

1. Fuel Loading Experiment

The fuel loading experiment is defined as being performed in the Nuclear Test Facility.

Loading and unloading operations will be performed through the bottom of the vacuum chamber on a retractable platform. Generally, individual fuel cans (dummy or loaded) will be handled by tools attached to the bottom of the cans. For these procedures, the reflectors will always be locked in their least reactive position during the movement of fuel or when reactivity changes are made. Access through the vacuum chamber will be provided by ports at the top, bottom and side.

Individually, each dummy fuel element assembly will be replaced with loaded assemblies. Either between additions of assemblies or after the fueled core has been completed, criticality and reactivity measurements, core compaction reflector calibration, pile oscillator calibration and fuel loading adjustments will be conducted.

The objectives of this experiment are:

a. To assure a reactor fuel loading which is sufficient for safe operation and endurance at design power for the 10,000-hour lifetime.

b. To determine the reactivity effects of basic components and characteristics such as the pile oscillator and compaction of the core assembly.

c. To verify the operational capabilities of the control and reactor safety system.

d. To calibrate low level nuclear instrumentation in terms of power level and to obtain supplemental data for low power calibration tests subsequent to the fuel loading experiment.

2. Assembly

The assembly of the core will be conducted with poison shrouds circumferentially enclosing the core. These shrouds will provide subcritical conditions for the core assembly for reflection from various infinite media, including water, concrete, stainless steel and lead. Therefore, the shrouds will provide a nuclear safe condition for all less extreme reflecting environments that the core should encounter during final assembly such as heavy machinery, personnel, lead shields during X-ray inspection, and chambers for welding and annealing. Instrumentation to check criticality will be installed to provide continuous monitoring of criticality through all phases of the assembly.

A tentative list of the steps required for final assembly of the SNAP-50 core and pressure vessel starting with completion of the fuel loading experiment is presented in CNLM-5729.

3. Reactor Test Startup

The highest attainable vacuum should be achieved in the reactor and power conversion system vacuum chamber at ambient temperature. Final verification of the integrity of the primary and power conversion system, as well as for protection of the columbium primary piping during preheat, low pressure, high purity helium gas should be introduced into the primary and power conversion system piping. Leaks in the piping systems within the vacuum chambers will be indicated by the detection of this helium in the vacuum system. Presence of helium will be monitored throughout the cleanup and preheat phases so that if a leak is detected prior to liquid metal fill, operation can be halted and repairs made.
Preheat of the chamber walls will be initiated and continued, maintaining the best attainable vacuum, until the vacuum chambers and their contents reach 400°F. When a vacuum of approximately $10^{-8}$ torr is reached, the chamber wall temperature will be increased to 1000°F at a rate limited by the impurity levels within the chambers resulting from component off-gassing. It is desirable to maintain a vacuum of approximately $10^{-8}$ torr during this preheat phase.

Liquid metal filling will proceed after the columbium piping systems have attained the preheat temperature of 1000°F, first by filling the NaK heat rejection system followed by the potassium system, and then the lithium system. After filling, these systems will be kept at temperature.

The vacuum chamber cooling systems will be used to lower the walls of the chambers to approximately 150°F; this will be maintained for the duration of the test.

Before nuclear operation is finally achieved, a number of nuclear and systems tests and measurements will be performed. After criticality, reactor power levels and temperatures will be raised to steady state design conditions. During this phase the power conversion and heat rejection systems must be controlled so as not to permit conditions which exceed design requirements in the primary, power conversion or heat rejection system components. This transition from isothermal operation to design conditions might present critical control problem due to the interaction of the systems and thermal inertia.

4. Reactor Test Operation

Once the system is operating, it will be run continuously for the 10,000-hour test period unless there is an unscheduled interruption. Interrupted operation and possible repair should be considered in the design. During this phase of the program the pile power oscillator will be activated to induce reactor power oscillation by changing reactivity by approximately two to three cents. This will permit evaluation of the reactor transfer functions and the effects on the remainder of the system.

5. Shutdown

Afterheat Removal

Afterheat removal subsequent to normal shutdown of the reactor will be provided by circulating the primary coolant, lithium, through the core and the initiation of 360 lb/hr helium flow through the reactor shroud, until the power has decayed to a sufficiently low level for reactor removal to be started, probably in the range of 40 to 60 days after reactor shutdown (see Fig. 11). To compensate for heat losses during this period, auxiliary heat from the heat rejection system and the power conversion system may be used to maintain primary system temperatures above the freezing temperature of lithium.

6. Disassembly

Disassembly is concerned with the handling of systems components, the decontamination of these components, and post-test examination.

Following shutdown and the draining of all liquid metal from the primary, power conversion and heat rejection systems with the exceptions of undrainable pockets and the reactor core and pressure vessel, remote disassembly of the reactor and primary system will be initiated.

This disassembly will proceed as outlined in the following sequence which is presented only to convey the complex requirements involved in remote handling.

a. Flood test cell with pure argon to prevent oxidation of exposed columbium alloy surfaces when the vacuum chamber is opened, and to prevent exothermic reactions of lithium with the residual atmosphere when the reactor is severed from the primary system.
b. Open the vacuum chamber at bottom. Remove reactor afterheat by flowing test cell argon through the reactor afterheat shroud.

c. Insert poison segments and reflector blocks between the reflector assembly and the reactor to prevent accidental reflection from extraneous materials or inadvertent rotation of the reflectors.

d. Tap the inlet and exit pipes of the reactor in order to ascertain completeness of the lithium drain. Drain through these taps if necessary.

e. Sever the reactor from the primary system by cutting the inlet and exit lines below the tap holes.

f. Attach pipe extensions to the severed reactor pipes to prevent lithium spillage during handling or overflow from thermal expansion of liquid lithium when the afterheat removal system is stopped.

g. Stop argon flow and lower reactor from test assembly into a poison shroud which circumferentially encloses the pressure vessel (the reactor will be independently supported from the top and bottom during removal). The lowering mechanism and necessary manipulators are supported on a retractable platform beneath the reactor. This operation will be conducted at a time when reactor afterheat is sufficiently low to limit core temperatures to less than 1000F.

h. Place shrouded reactor on dolly and transfer to the disassembly shop. Maintain argon atmosphere.

i. Invert the shrouded reactor (pipe openings at bottom) over a floor pan which will confine any liquid lithium which drains from the reactor pipes during the inversion.

j. Immerse the shrouded reactor in a NaK filled container in the inverted position (pipe openings at bottom). This NaK container will have a constant temperature control in the range of 400F to 500F. The reactor will be independently supported from the top and bottom during this operation. The rate of immersion will be controlled to minimize thermal stresses and to allow melting of the lithium to progress from the open ends of the pressure vessel.

k. After the reactor and NaK bath are at an isothermal condition, a hole will be cut in the bottom of the pressure vessel (the closed end) while holding the bottom portion partially submerged in the NaK. This hole will let the more dense NaK displace the liquid lithium in the core when the core is submerged.

l. Drain the liquid lithium from the top of the NaK container.

m. Withdraw the shrouded reactor from the NaK container and make circumferential and longitudinal cuts in the pressure vessel to remove the core.

n. With the poison shroud in position, cut the compacting bands around the core assembly and repeat the NaK procedure of step j.

o. Remove the core assembly from the NaK bath after draining the surface lithium. Machine off the support nuts to free the fuel element assemblies from the core plate. This operation will be performed in a combination poison shroud and structural basket which will restrict movement of the loosened fuel element assemblies.
p. Individually remove each fuel element assembly from the core assembly, insert into poison shrouds (required for 7 can assembly of the 2 Mw reactor), immerse the individual assemblies into the NaK bath if necessary, and store for further disassembly and post-test inspection.

The primary, power conversion, and heat rejection systems will be dismantled, decontaminated, and selectively examined. Depending on the degree of activity and size, the decontamination and sectioning may be performed either in the disassembly cell or the Hot Laboratory. Decontamination of the primary system components will probably use the NaK flushing procedure previously described. The power conversion and heat rejection systems will use the steam procedure described in CS-5001.

Following decontamination and sectioning, specific areas of the reactor, primary system components, and the remaining system components will be subjected to metallographic and chemical analysis. This evaluation will be performed either in the Hot Laboratory (Building 450) or in the General Laboratory (Building 140), depending on the degree of activation.
IV. REFERENCES
A. DOCUMENTS

1. PWAC-337, "The Design, Fabrication and Test of a 1500F NaK-NaK Heat Exchanger" (classified).
5. PWAC-401, Part II, "LCRE Valve Development, Final Report".
7. PWAC-423, "Development of Liquid Metal Level Probes".
8. PWAC-422, "Thermocouple Development Lithium-Cooled Reactor Experiment".
10. TIM-814, "Proposed SNAP-50 Shield Development Program" (classified).
12. CNLM-5260, "Environmental Condition Required for Testing Cb-1 Zr at 2000F" (classified).
13. CNLM-5730, "Design No. 1 of SNAP-50/SPUR Reactor Test System" (classified).
14. CNLM-5731, "Design No. 2 of SNAP-50/SPUR Reactor Test System" (classified).
15. CNLM-5732, "Design No. 3 of SNAP-50/SPUR Reactor Test System" (classified).
16. CNLM-5733, "Design No. 4 of SNAP-50/SPUR Reactor Test System" (classified).
17. CNLM-5729, "SNAP-50/SPUR Nuclear Test Facility Initial Design Requirements".
18. NAA-SR-4383, "A Study of Sodium Fires".
B. LAYOUTS AND DRAWINGS

1. L-102464, "Flight Configuration Power Plant Test".

2. L-102224, "Reactor & Containment Study" (classified).

3. L-102232, "Process Diagram Reactor Test Li-NaK-Air" (classified).

4. L-102251, "Test Cell Powerplant Facility".

5. L-102258, "Reactor Test Arrangement Study Li-NaK-Air 2 Mw" (classified).

6. L-102260, "300 Kwe NNST in Minimum Vacuum Tanks".

7. L-102266, "Envelope, Test Powerplant, 4 Module".

8. L-102267, "Reactor with One Power Conversion Unit".

9. L-102269, "Power Conversion Unit Arrangement Test".

10. L-102307, "Shield Test-Study" (classified).

11. L-102311, "Reactor Scram Mechanism Design Study" (classified).

*12. L-102312, "Reactor Test Arrangement Study" (classified).

13. L-102313, "Pile Oscillator Study" (classified).

   
   a. 1039418, "Reactor Control System" (classified).
   b. 1039417, "Primary Circuit-Flux Monitoring".
   c. 1039412, "Primary System" (classified).
   e. 1039414, "Oxide Control Station".
   f. 1039415, "Heat Sink System".
   g. 1039420, "Fuel Loading Experiment".
   h. 1039419, "Core Installation Monitoring System".
   i. 1039416, "Pile Oscillator".

*The arrangement depicted on this drawing was developed in conjunction with a heat rejection system different from the one selected, however, those portions of the drawing showing reactor, vacuum chamber, shield test, vacuum pump arrangement and gamma and neutron leakage flux is appropriate to the test design and reflects more recent work than that incorporated on drawing L-102258.

**Each of these diagrams consists of two sheets. Sheet 1 is the flow diagram and Sheet 2 is the parts list.