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**Potassium Vapor Topping Cycle Technical
Progress Report for January 1
to March 31, 1977**

R. S. Holcomb

OAK RIDGE NATIONAL LABORATORY
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Engineering Technology Division

POTASSIUM VAPOR TOPPING CYCLE¹¹¹ TECHNICAL PROGRESS
REPORT FOR JANUARY 1 TO MARCH 31, 1977

R. S. Holcomb

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CONTENTS

	<u>Page</u>
ABSTRACT.....	1
I. SCOPE.....	1
A. Introduction.....	1
B. Objective.....	7
1. Water tests.....	7
2. Potassium system.....	7
3. Potassium test.....	8
II. PROGRESS TO DATE.....	8
A. Work Prior to FY 1976.....	8
B. Accomplishments in FY 1976.....	9
C. Progress During the Past Quarter.....	9
1. Water tests.....	9
2. Potassium system.....	9
III. TECHNICAL PROGRESS.....	10
A. Summary of Progress This Quarter.....	10
1. Water tests.....	10
2. Potassium system.....	10
B. Progress by Task.....	12
1. Water tests.....	12
2. Potassium system design.....	17
3. Potassium system fabrication.....	19
4. Potassium system installation.....	20
REFERENCES.....	33
APPENDIX A. PRELIMINARY OPERATING PROCEDURE FOR THE POTASSIUM TOPPING CYCLE.....	35

POTASSIUM VAPOR TOPPING CYCLE TECHNICAL PROGRESS
REPORT FOR JANUARY 1 TO MARCH 31, 1977

R. S. Holcomb

ABSTRACT

The potassium vapor topping cycle is a concept for increasing the efficiency of the Rankine vapor cycle by raising the peak temperature by employing a potassium vapor cycle with a turbine inlet temperature of 1500 to 1600°F (815 to 870°C) in which the waste heat rejected from the condensing potassium vapor is transferred to boiling water and steam in a conventional steam cycle. An efficiency of about 50% is calculated for this cycle with a natural circulation potassium boiler fired by gas or oil.

An ERDA program is under way at ORNL to build a full-scale potassium boiler tube bundle and burner module and test it with water and then potassium. This is the second in a series of quarterly progress reports.

The water test program was completed during the quarter. The vapor separator performance was measured over a range of burner power output from 1.7 to 3×10^6 Btu/hr and the exit steam quality was found to be greater than 99.9%.

The mechanical design work for the potassium system has been completed. The electrical and instrument and controls design has progressed well. Fabrication of the condenser and its enclosure and the drain tank was completed. The condenser and its enclosure have been installed. A 3000-gal propane system has been installed to serve as an alternate fuel supply.

I. SCOPE

A. Introduction

One important step that can be taken to reduce the national fuel consumption is to increase the efficiency of thermodynamic cycles. Few realize that a major factor in keeping our consumption from increasing more rapidly than it has during the past century has been an increase in the thermal efficiency of steam plants by about a factor of 8. Unfortunately, there has been no further increase since about 1950 because at

that time we reached the practicable upper temperature limit for the steam cycle; namely, about 1000°F (538°C). To reach higher thermal efficiencies, it will be necessary to use higher temperatures, which in turn implies the use of other working fluids. A leading candidate for an advanced thermodynamic cycle is a potassium or a cesium vapor cycle.

The approach proposed by ORNL entails raising the peak temperature of the thermodynamic cycle by employing a potassium vapor Rankine topping cycle that operates with a turbine inlet temperature of 1500 to 1600°F (815 to 870°C) superimposed on a conventional steam cycle with a turbine inlet temperature of about 1000°F (538°C) by transferring the waste heat rejected from the condensing potassium vapor to the boiling water of the steam cycle.¹ Design studies have indicated that a cycle efficiency of about 50% can be achieved² with a natural-circulation boiler fired by gas or oil in a potassium topping cycle.

The basic layout of the power plant envisioned is shown in Fig. 1. Three basic systems are coupled to form the power plant: a gas turbine that supercharges the combustion chamber for the potassium boiler, the potassium vapor topping cycle, and an essentially standard steam cycle. The most important components involving new technology are the furnace-potassium boiler unit and the potassium condenser-steam generator unit, both of which employ tube bundle modules as their basic unit of construction.

The ORNL gas- or oil-fired potassium boiler concept employs a basic tube bundle module that consists of two annular rows of 1-in.-diam stainless steel tubes arranged around a 22-in.-diam, 16-ft-long, vertical, cylindrical chamber. A full-scale test unit is shown in Fig. 2. The flame from the burner directs hot gas upward through this combustion chamber. The tubes are bent at the top to provide flow passages between them so that the hot gas from the top of the combustion chamber can flow radially outward and then downward through an outer annulus over the outer row of tubes. To reduce the amount of heat transfer surface area required, the furnace and combustion chambers would be operated at a pressure of 6 to 10 atm, which is substantially above the 2 atm which would be the design operating pressure of the potassium vapor system. Potassium would circulate under natural thermal convection from a header

Fig. 2. Photograph of the ORNL potassium boiler under construction.

tank at the top of the tube bundle through two downcomers, one on either side, to two ring-shaped manifolds at the bottom and then vertically upward through the tubes back to a header drum and vapor separator at the top of the header tank.

Preliminary studies have also indicated that a particularly attractive system could be obtained by coupling a potassium or cesium vapor cycle to a fluidized-bed coal-combustion system. One very promising concept is a fluidized bed that would operate at a temperature of about 1700°F (927°C) and a pressure of about 5 atm. This pressure yields an acceptable pressure drop with a bed of sufficient depth to employ a vertical-tube natural-circulation boiler. To minimize the problems of turbine bucket erosion, corrosion, and deposits, the hot gases leaving the bed would be cooled to about 1000°F (538°C) before being admitted to a gas turbine to give a power output just sufficient to drive the compressor. The studies indicate that a cycle efficiency of about 48% can be achieved with this type of system.

The key factor in achieving the lower capital cost and higher thermal efficiency projected by the ORNL design lies in employing a vertical-tube, natural-circulation boiler rather than a horizontal-tube forced-circulation one. Therefore, since this is a new design, it is very important that successful operation of the natural-circulation boiler be demonstrated. A program for testing a full-scale tube bundle and burner module on water and then on potassium was initiated to investigate the uncertainties that have become evident in the course of the design. These uncertainties fall into four major problem areas: burner performance; combustion gas heat transfer; flow distribution of the two-phase potassium liquid-vapor mixture and the tube bundle temperature distribution; and the vapor separator effectiveness. In many cases the cumulative uncertainties in the analysis are substantial and can be resolved only by obtaining test data. A section through the test module is shown in Fig. 3.

The water tests, which are being run with boiling at atmospheric pressure, are designed to provide as much insight into these problems as possible. In the first phase of the tests, the boiler drum top is open so that visual observation of the flow from the boiler tubes is possible. The open boiler drum will also make it much easier to install

Fig. 3. Section through the gas-fired potassium boiler tube bundle module, burner, and furnace assembly.

instrumentation that will provide a detailed picture of the flow distribution; this will not be the case in later tests with potassium.

The potassium test will provide a check of the boiler bundle and furnace at the design conditions of full pressure and temperature for operation. Although visual observation and measurement of flows from each boiler tube cannot be done while operating with potassium, the tube bundle temperature distribution will provide an indication of the potassium two-phase flow distribution.

The results obtained from the test program will provide boiler design data that will be beneficial to both gas-fired and coal-fired fluidized-bed systems.

B. Objective

The overall objectives of the program are to complete the water tests; design, fabricate, and install the potassium system; and run the potassium test. These objectives are to be achieved in the following manner:

1. Water tests

- a. Check out the boiler and furnace.
- b. Check out combustion air seals.
- c. Measure tube bundle and flue gas temperature distribution.
- d. Observe argon distribution.
- e. Operate at a power level of 2×10^6 Btu/hr.
- f. Observe boiling stability.
- g. Establish minimum power level for stable boiling in outer tube bank.
- h. Measure heat load on individual boiler tubes.
- i. Observe vapor separator performance.

2. Potassium system

- a. Complete the design of components and modifications.
- b. Perform system modifications and fabrication of components, including tower extension, condenser, drain tank, piping, sample box, electrical system, instruments and controls.
- c. Install the components.

3. Potassium test

- a. Check out system.
- b. Measure tube bundle and flue gas temperature distribution.
- c. Monitor boiling nucleation problem.
- d. Operate at power levels up to 4×10^6 Btu/hr.
- e. Observe liquid level control.
- f. Observe vapor separator performance.
- g. Run 2000-hr endurance test.
- h. Determine minimum argon flow required for nucleation.

II. PROGRESS TO DATE

A. Work Prior to FY 1976

Work on alkali metal vapor cycles at ORNL began with some design studies under the Aircraft Nuclear Propulsion Program in 1954 and was resumed in 1958 with studies of nuclear electric space power plants. This led to an extensive series of component and system tests resulting in ~200,000 hr of boiling potassium system operation in the early and middle sixties. When the pressing need for reductions in both fuel consumption and heat rejection to the environment became evident in 1970, a design study of a potassium vapor cycle plant sponsored by the National Science Foundation (NSF) was carried out.¹⁻³ This plant was designed to operate on clean gaseous fuel derived from coal, which was the preferred fuel of the future for central stations at that time. The study showed that the greatest uncertainties from both the design and cost standpoints were associated with the potassium boiler and that these could be resolved best by designing, building, and testing a full-scale tube bundle and burner module with water and then with potassium. Funds to begin this work were made available by NSF in July 1972 and NSF funding was continued in 1973. When ERDA was proposed in June 1973, the responsibility for the potassium vapor cycle work became uncertain, with NSF, AEC, OCR, and NASA all having claims in this area. As a consequence of these uncertainties, the program remained unfunded through 1974, when ERDA was formed; at this time some interim funds were made available from NSF and funds from ERDA-FE finally became available at ORNL for the program in December 1975.

B. Accomplishments in FY 1976

The shakedown and performance tests of the burner operating outside the boiler in the open air were completed in May 1976. The water system installation was completed and the test begun in July 1976. Detailed design of the potassium system was resumed in April 1976 and much of the work was completed by the end of September. Fabrication of components for the potassium system, such as the condenser and drain tank, was initiated in August.

C. Progress During the Past Quarter

1. Water tests

All the tasks planned for the water tests were completed except for the vapor separator test.⁴ Those completed include measurement of the argon distribution, heat load of individual boiler tubes, boiler temperature distribution, combustion gas temperature distribution, and combustion air pressure drop.

2. Potassium system

Nearly all the mechanical design work for the potassium system components was completed this quarter. The tower extension drawings were almost finished, and all the condenser modification drawings were completed. All the drawings for the condenser enclosure were completed, and most of the design work on the potassium vapor and liquid return piping was done. The sample box assembly and sample box potassium piping drawings were finished and released.

Fabrication for modifications and new components for the potassium system proceeded well during the quarter. Work on piping and welding fabrication on the condenser was nearly completed. Fabrication of parts for the condenser enclosure was more than half completed. Fabrication of the cylindrical portion of the drain tank was completed, and welding of the dished heads to the cylinder was begun. Work was begun on the potassium sampler and enclosure and the modification of several existing instrument panels from another project.

III. TECHNICAL PROGRESS

A. Summary of Progress This Quarter1. Water tests

The vapor separator test was completed during the quarter. An exit steam quality of greater than 99.9% was obtained, which was better than the design goal of 99%. The vapor separator performance data were taken over a range of burner power output from 1.7 to 3×10^6 Btu/hr. This test completes the water test program.

Additional tests using argon as a tracer gas were run to determine the relative magnitude of the air leakage rate across the seal around the burner. The results indicated no significant change in the seal leakage.

A test was run to determine if the empty boiler tube bundle could be heated with the burner prior to filling it with potassium and if the temperature distribution could be held uniform enough to avoid excessive thermal stresses. Runs with the main burner at its minimum stable power level resulted in excessive temperature differences across the tube bundle. The pilot flame operating at its maximum power was not satisfactory for preheating. It was concluded that an external air preheater will be required for preheating the boiler before filling with potassium.

2. Potassium system

The last group of drawings for the mechanical design of the potassium system components was completed this quarter. An elevation drawing of the potassium test system is shown in Fig. 4. The tower extension drawings were completed and released in January, the drawings for the potassium vapor and liquid return piping were completed, and the last of the drawings for the sample box were completed. Design drawings for a propane supply system were prepared.

The design work on the electrical supply and heaters and instruments and controls has progressed well during the quarter. The drawings for installation of the heater control cabinets, the drawings for the tower light fixtures, and the heater and wiring drawings for the sample box were completed. Instrument and control drawings completed include the

instrument application drawing, condenser thermocouple details, and instrument cabinet panel and wiring drawings.

Fabrication was completed for all the potassium system components except for the sample box and final modifications of the vapor separator for potassium operation. The condenser and its enclosure were completed. The fill and drain tank was fabricated, and electric heaters and insulation were installed on it. The fabrication of the structural steel for the tower extension was finished.

Installation of the potassium components on the equipment tower, begun the last week of February, was nearly completed. The condenser and its enclosure along with the inlet and outlet air plenums have been installed. Erection of the structural steel for the tower extension is well under way.

The interruption of the supply of natural gas because of the fuel shortage brought about by the unusually cold weather in January led to the decision to install a 3000-gal propane supply system. The installation of this system was completed in March.

B. Progress by Task

1. Water tests

a. Vapor separator performance. The vapor separator assembly for the water tests (see Fig. 5) was installed in preparation for the final phase of the water system test program. Figure 6 shows the top of the boiler after the vapor separator was installed.

On January 20, the supply of natural gas to the KVTC experiment was terminated in response to a reduction in the regional gas supply. It was estimated that a fuel supply equivalent to 120,000,000 Btu would be adequate to complete the vapor separator tests.

A propane system was designed that consists of three 1000-gal propane storage tanks and a supply line which will connect the tanks to the fuel system at the point where it presently ties into the natural gas line. The installation of the propane system was completed in March. A photograph of the propane tanks is shown in Fig. 7.

PHOTO 6249-77

Fig. 5. Vapor separator.

PHOTO 6122-77

Fig. 6. Water boiler test with vapor separator installed.

PHOTO 6248-77

Fig. 7. Propane tanks.

The local natural gas supply situation eased sufficiently in mid-February to allow us to resume system operation on a limited basis, and we were able to conduct the necessary tests with the vapor separator. The separator was found to operate as expected; a large amount of liquid is expelled from the system through the separator when the liquid in the system begins to boil. This continues until steady-state operation has been achieved, after which the discharge from the separator is essentially dry vapor. A 6-in.-diam glass pipe was connected to the discharge of the vapor separator, thus permitting us to observe and evaluate the relative quality of the discharge stream. Visual observation of the discharge by experienced personnel indicated that the amount of liquid carryover was less than 1% of the flow. A collection flask was positioned to catch the carryover that dripped from the end of the glass pipe. The results are shown in Table 1. At one point in the test, we increased the water feed rate to increase the liquid level in the expansion tank. When the water level became too high, the amount of carryover increased dramatically, thus emphasizing the importance of maintaining the liquid level within the prescribed limits.

Table 1. KVTC system parameters during separator vapor tests

Burner power, Btu/hr	1.65×10^6	2.4×10^6	2.95×10^6
Water flow rate, gpm	2.42	3.4	4.65
Furnace efficiency, %	71.2	68.8	76.5
Vapor separator carryover, milliliters/min	4.9	6.8	13.9
Vapor separator carryover, %	0.05	0.05	0.08 ^a

^aThis value was seen to increase to 14.2% with a high liquid level in the expansion tank.

b. Scal leakage test. The interruption of the water test program caused by the loss of natural gas supply provided an opportunity to reassess the furnace seal leakage problem. Additional tests of the system were made to determine the relative magnitude of the leak. In one of the tests a measured flow of argon was injected into the furnace through the orifice

through which the natural gas is normally fed. With varying amounts of air flowing through the furnace, samples are withdrawn from the interior of the furnace and from the exhaust duct. Analysis of the argon content of these samples allows us to calculate the bypass flow through the seals. The results of this test, shown graphically in Fig. 8, are in excellent agreement with burner air flow vs burner cup pressure drop data provided by the burner manufacturer. In the future, the pressure drop across the burner will be the primary method of determining combustion air flow. These tests showed no significant change in the seal leakage.

c. Boiler preheat test. Prior to each fill of the system with potassium, it will be necessary to preheat components above the melting point (147°F). Calculations indicate that during preheat of the boiler, the allowable thermal stresses are exceeded if the temperature differential between the inner row of tubes and the downcomer is 150°F and that between the outer row and the downcomer is 50°F. Tests were made to heat the empty boiler using the main burner. At 500,000 Btu/hr, the boiler temperatures increased rapidly and high ΔT 's developed. At powers below 500,000 Btu/hr, the main burner was unstable.

Several runs were made with the pilot burner at its maximum power (~90,000 Btu/hr) and with different amounts of auxiliary air through the main burner. With auxiliary air flows up to about 150 scfm, the temperature gradients were too high and the heatup rate was extremely slow. Therefore, we concluded that an air preheater would be required. Possible suppliers of air preheaters are being contacted.

2. Potassium system design

a. Tower extension. The structural drawings for the tower extension were completed and transmitted to the CPFF contractor in early January.

b. Condenser. The condenser design was completed last quarter.

c. Condenser enclosure. The drawings for the condenser enclosure were completed during the previous quarter.

d. Drain tank. The drain tank design was completed during the last quarter of FY 1976.

e. Potassium piping. The design of the potassium piping was completed this quarter, and five drawings of the condensate return piping were issued.

Fig. 8. Air flow vs burner ΔP .

f. Sample box. The final four drawings for the sample box and associated piping details were released during the quarter.

g. Air and argon piping. The design of the air and argon piping system was completed in March.

h. Boiler shroud analysis. The boiler shroud analysis for potassium operation was completed. The analysis indicated that the critical pressure difference at 1700°F is 8.3 psi, compared to a ΔP of 1.3 psi at a power of 3×10^6 Btu/hr and 3.1 psi at 4×10^6 Btu/hr. The safety factor at a ΔP of 3.1 psi is low enough that creep buckling may occur over a period of time. A test will be run at 4×10^6 Btu/hr; if the shroud temperature is as high as 1700°F, the power will be reduced to give a ΔP of 2 psi for the 2000-hr run.

i. Operating procedure. Preliminary procedures for operation with potassium were written for the facility to aid in control circuit design and identification of potential problem areas. These procedures are included in Appendix A.

j. Electrical. Ten drawings for the electrical system were completed during this period. These include drawings for the installation of light fixtures in the equipment tower, installation drawings for heater control cabinets in the control room, and the heater and wiring drawing for the sample box. Work is in progress on the design of the cable tray, junction box, and conduit layouts for heater and thermocouple circuits.

k. Instruments and controls. The design work completed for instruments and controls includes issuance of the instrument application diagram, two drawings for condenser thermocouple details, two instrument panel cutout drawings, a front elevation drawing of the new instrument cabinets, and five drawings for the wiring and piping for main control boards 6 and 7. Work is in progress on the boiler control diagram.

The metrascope, the instrument which provides individual graphic display of 50 thermocouples, has been received and checked out.

3. Potassium system fabrication

a. Tower extension. The structural steel members for the tower extension were fabricated by an outside vendor and received in March.

b. Condenser. The fabrication of the argon separator and the modification of the condensate lines were finished in January, and electric heaters were installed on the condenser vapor lines and ring headers. The condenser modifications were completed in February. The argon separator and the lower portion of the condenser are shown in Fig. 9. An overall view of the completed condenser is shown in Fig. 10.

c. Condenser enclosure. Fabrication of all the components of the condenser enclosure was completed. The outlet air plenum and support columns were assembled with the condenser before the condenser was installed on the equipment tower. Figure 11 is a photograph taken during the installation of the outlet air plenum.

d. Drain tank. Fabrication of the potassium fill-and-drain tank was completed; electric heaters and thermocouples were installed on the tank, and the tank was covered with insulation. Figure 12 is a photograph of the tank before it was insulated.

e. Sample box. The sample box and associated piping fabrication work is nearly complete. The sample box and manifold is shown in Fig. 13.

f. Electrical. The power supply cabinets for the electric heaters were modified for installation.

g. Instruments and controls. Work has begun on fabrication of the main control cabinets.

4. Potassium system installation

a. Condenser and enclosure. The CPFF contractor came on site the last week in February to begin work on installation of the potassium system components and extension of the equipment tower. The condenser and outlet plenum assembly was installed first. A view of the condenser during installation is shown in Fig. 14. The condenser was followed by the air inlet duct, shown being installed in Fig. 15. The cylindrical containment was installed next, as shown in Fig. 16. Finally, the outlet dampers and air exhaust stack were set (Fig. 17). An overall view of the completed condenser installation is shown in Fig. 18.

b. Tower extension. The erection of the structural steel for the tower extension has begun and is expected to be completed about the end of April.

Fig. 9. Potassium condenser and argon separator.

Fig. 10. Potassium condenser.

Fig. 11. Assembly of outlet air plenum with the condenser.

PHOTO 6278-77

Fig. 12. Drain tank.

Fig. 13. Sample box.

Fig. 14. Setting the condenser on the tower.

PHOTO 6288-77

Fig. 15. Inlet air plenum being installed.

PHOTO 6328-77

Fig. 16. Cylindrical containment installed on the condenser.

Fig. 17. Condenser containment showing air outlet dampers.

Fig. 18. Completed condenser containment.

c. Electrical. The power supply cabinets for the electric heaters (shown in Fig. 19) were installed in the control room and the main power supply connected.

Fig. 19. Electric power supply cabinets.

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APPENDIX A

PRELIMINARY OPERATING PROCEDURES FOR THE
POTASSIUM TOPPING CYCLE

A. INTRODUCTION

This appendix briefly describes the operation of the Potassium Vapor Cycle Facility (KVTC) as it is presently designed. The operating detail given is intended to allow review of the concept and to aid in the design of the control circuits. The Potassium System Instrument Application Diagram (I-10617-QG-035-D-D — preliminary print 12/20/76) and the Water Test System Instrument Application Diagram (I-10617-QG-014-D-0, which shows the present combustion system) are used as references.

B. ASSUMPTIONS

For the purpose of this document, it is assumed that construction is complete, shakedown has been done, and the system has been operated for some period. The potassium is in the drain tank, the drain valve (HCV-109A) is closed, and the entire system is cold with a slight argon overpressure supplied from the argon cylinder bank.

C. PREHEAT

The potassium portions of the system must first be heated to 400 to 600°F (204 to 316°C), which is well above the melting point of the potassium (147°F, 64°C). The electrically heated items will respond slower and are easier to control than the boiler and will therefore be heated first. As heatup proceeds, the pressure may increase and will be vented off periodically.

C-1

The drain tank will be heated by adjusting the Variacs to the heaters and observing the thermocouples.

C-2

Close the inlet damper and three outlet dampers on the condenser enclosure and heat it as a furnace using heaters attached to the center stand pipe and the lower drain header. Heater Variacs should be adjusted until all potassium parts are above 150°F (65.6°C). Additional heating of this area will occur as potassium starts refluxing in the stand pipe.

C-3

The bottom half of the sampler enclosure should be heated to 400°F (204°C).

C-4

All lines which will contain potassium should be heated to about 400°F (204°C). Calrod trace heaters are installed and there is at least one thermocouple for each Variac. This includes lines 100 through 107. Valves containing potassium should not be operated at temperatures less than 200°F (93°C).

C-5

All lines which could possibly get potassium in them (such as the nucleators) are trace heated back to the vapor traps or block valves and slope toward the potassium source. The Variacs should be adjusted to assure that they are above 200°F (93°C). The cold end of the vapor traps should be below the freezing point of potassium (say <150°F, 65.6°C). This includes lines 200, 203, 222, 223, 224, 225, 230, and 231.

C-6

The boiler will be heated using the pilot and main gas burner. The sequence consists of purging all combustible gas from the furnace, igniting the pilot and then the main burner. After the main burner is burning, the pilot gas and air will be turned off to prevent the pilot flame from burning in the pilot tube. The main air-gas ratio will first be set based on an assumed seal leakage but will then be adjusted (manually or automatically) based on the CO content of the exhaust gas. [Note: Since the boiler heats

fairly rapidly with the main burner on and cools very slowly ($\sim 1^\circ\text{F}/\text{min}$ with the air off), it may be desirable to heat to 500 to 600°F (260 to 316°C) and then turn the main burner off while filling.]

D. PREPARATION FOR FILLING

D-1

The system can be filled at several pressures; however, to facilitate future level adjustments, it will be pressurized to 15 psig before the filling. Normal operating temperature is 1540°F (838°C). The vapor pressure at this temperature is 28.8 psia. Since the average barometric pressure in this area is 14.3 psia, the operating pressure will really be 14.5 psig. However, for the purpose of this appendix the atmospheric pressure will be assumed to be 14.8 psia, which gives a normal operating pressure of 15 psig.

Set PRC-70 to 15 psig, and check to ensure that the proper vent line valves are open.

D-2

To prevent backup in the lines, there should be some flow in the nucleators and downcomer ΔP lines. Adjust supply pressures PI-53 and PI-63 to 35 psig. Set FI-55, -57, -60, and -62 to 5 standard liters/min (SLM) and FIC-65 and -66 to 0.5 SLM.

D-3

When the system pressure reaches 15 psig, set PV-72 at 20 psig and PV-69 at 14 psig. This is the argon supply to the condenser for keeping the pressure from decreasing if the burner is cut off, thus allowing a drain and reducing the thermal transient on the boiler. [Note: PCV-72 and PCV-69 will probably be left at their proper setting and HV-227 (on main board) will be closed. If so, reopening V-227 will set up this backup supply.]

D-4

Set up potassium valving to take a sample during the early part of the fill. Close the condensate drain valve (V-102) and fill valves (104 and 105). Attach a sample bomb and open the sampler valves (106 and 107). Open valve 103 at the drain tank. [Note: If no sample is to be taken, the sampler valves (106 and 107) will be closed and the 104 valve will be opened to fill. (The other drain valve, 105, will remain closed since the downcomer ΔP instrument argon purge will break the siphon in this line.)]

D-5

Close the drain tank vent valve (PCV-68) by setting PRC-68 at 30 psig so that the drain tank can be pressurized through line 200 (PV-67 should not be set above approximately 10 psig until the fill is to be started).

E. FILL

After the entire potassium system is above 200°F (93°C) and the boiler and drain tank are at 400 to 600°F (204 to 316°C), the filling may be started. Filling consists of pressurizing the drain tank to force the potassium through the fill line to the boiler. With the systems at 15 psig, a pressure of about 25 psig will be required in the drain tank to completely fill the system.

E-1

The drain tank should be pressurized to slightly above the system pressure before opening the drain valve. Set PV-67 at 2 psi above PRC-70 and open V-200 until PRC-68 is at 2 psi above PRC-70.

E-2

Open drain valve HCV-109A.

E-3

Increase DT pressure using PV-67 and observe DT level LR-110 as the fill progresses. Approximately 18 ft³ is required to fill above the top

tube. After there has been sufficient flow to get a representative sample ($>1 \text{ ft}^3$), close the sampler valves (106 and 107) and open V-104. [Note: analysis of the sample should show less than 50 ppm oxygen.]

E-4

As the fill proceeds, boiler level instruments LR-105 and LR-106 will come on scale. Continue fill until the top tube is covered and then close the drain valve (HCV-109A). [Note: It may be necessary to restart the main burner to maintain the boiler at 400 to 600°F (204 to 316°C).]

E-5

Adjust the argon flow to the nucleators to 5 SLM and close the valves in the downcomer ΔP lines 230 and 231. (To prevent back diffusion beyond the heated shutoff valves, these will remain closed except when checking the downcomer ΔP .)

F. HEATUP AND POWER INCREASES

The condenser, sampler, and piping heaters will not be adjusted during heatup. The main burner will be restarted and the temperature of potassium in the boiler increased until boiling is stable in all tubes (this is estimated to be at a burner input of $2 \times 10^6 \text{ Btu/hr}$). Until this power level is reached, the potassium level must be kept above the top tubes. This is accomplished by periodically opening the drain valve (HCV-109A) and adjusting the drain tank pressure as required. Approximately 4 ft^3 of potassium will need to be drained during heatup from 400 to 1500°F (204 to 816°C). As boiling starts, there will be some holdup in the condenser and piping ($\sim 1 \text{ ft}^3$); however, the boiler tubes will contain some potassium vapor (estimated at $\sim 2\%$ quality). When the power reaches $2 \times 10^6 \text{ Btu/hr}$, the boiler level should be decreased to near the bottom of the vapor separator assembly. This will mean draining approximately 9 ft^3 to the drain tank. After the boiler level has been adjusted, the drain tank pressure will be reduced so that an automatic drain can occur. This is done by reducing PV-67 to 5 psig and setting PCV-68 to 6 psig. [Note: Heaters on the drain tank are set to hold 400 to 600°F (204 to

316°C); however, the potassium drained will be at considerably higher temperature. The drain tank pressure should be reduced slowly enough that the potassium will not approach boiling. The temperatures on the vapor trap should be observed to assure that there is no potassium vapor in the argon being vented.]

As the system is heated to boiling the metrascope which monitors the tube temperatures should be observed to assure that no superheating is occurring. The boiler microphone should be on so that any explosive boiling noises will be heard.

If the burner is stopped, the control circuits require purging the system with air to assure that there is no explosive mixture present before starting the pilot. (Cooling rate with air on is about 10°/min and purge time is about 3 min.) This may cool the system sufficiently that it will be necessary to refill the boiler before restarting. Another possibility is to lower the system pressure to initiate boiling and then start the burner and repressurize.

After boiling starts, it will be necessary to match the power input of the burner to the heat removal rate of the condenser. This can be done in a number of ways, and the optimum method will have to be determined experimentally. A proposed scheme is given below.

The approach to full power will be done manually (the air-to-gas ratio may be automatically controlled). The condenser dampers will be closed initially. As boiling starts, the potassium vapor will condense in the standpipe. Thermocouples on this will be observed to see where condensation is occurring. As the vapor rises, the inlet damper should be opened to allow air to enter the bottom of the gas separator cooler, which has no damper at the top. When the inlet damper is wide open, start opening the three outlet dampers. The remaining thermocouples on the condenser should be watched closely to assure that the cooler parts are not below 200 to 300°F (93 to 149°C). The temperatures on the upper half of the gas separator should be observed to assure that no potassium vapor is vented out the top. These two conditions will govern whether we continue to open the outlet dampers to keep the condenser in the load following mode (i.e., all condensation in the riser) or leave the outlet dampers nearly closed as the burner power is increased and then open them when the temperature

starts to rise in the gas separator. In either case, when some vapor is going to the gas separator (uncondensed), the automatic controller can be actuated. This controls a temperature in the upper half of the gas separator by adjusting the power to the burner. This control scheme will be sluggish. If early tests indicate that there is too much variation in temperatures or power, the control circuit may be changed to control the gas separator temperatures by adjusting the condenser dampers.

G. NORMAL OPERATION

Normal operation will be to run at about the full heat-removal capacity of the condenser, which is calculated to be about 3×10^6 Btu/hr. The potassium overpressure will be maintained at 15 psig. The condensate flow rate and temperature can be measured and compared with the gas input rate to determine the boiler efficiency. The ΔP between the top and the bottom of the downcomer can be measured (by opening valves in lines 230 and 231) to get an indication of the downcomer flow rate. (This information will be based on air flow, ΔP tests, and water test information.) During operation, the only potassium samples that can be taken are of the condensate. Throttling the condensate chain valve (102) and/or sample valves (106 and 107) will allow condensate to flow by gravity from the condenser to the boiler fill and drain line (104).

H. POWER REDUCTION AND DRAIN

Power reductions can be made manually or may be actuated by various controls. Reduction in power is essentially the reverse of increasing power as described earlier. If a power scram occurs, the burner would be stopped and the condenser dampers would close. During operation, there is about 34 ft^3 of potassium vapor in the system. Since the nucleators (total of 20 SLM) cannot maintain the system pressure constant, the boiling point would decrease and the burner would cool rapidly due to the heat removed by the condenser (initially at about $30^\circ/\text{min}$). Therefore, a large argon supply line (203) was installed which will maintain the system at the set point (14 psig). Thus, boiling should stop immediately and the

cooldown rate will be dependent upon heat losses from the boiler. Since the combustion air flow will be stopped, this will be about $1^{\circ}/\text{min.}$

Since drain valve 104 is normally open and drain tank vent valve (PCV-68) is set at 6 psig, all that is necessary to drain is to open the drain valve (HCV-109A). Draining the low point in line 101 requires opening V-102, closing V-104 and -105, and pressurizing it to the drain tank. Since there is about 14 ft^3 of potassium in the drain tank at 400 to 600°F (204 to 316°C) and only about 4 ft^3 in the system at 1540°F (838°C), no boiling should occur in the drain tank. A sample can be isolated during a drain by closing the drain valves (V-104 and -105) and opening the sampler valves (V-106 and -107). During an attended drain, the DT level and pressure should be observed and the drain valve closed when the drain is complete.

I. POTASSIUM CLEANUP

Zirconium foil getter is installed in the drain tank. For best utilization of this, the potassium should be heated to 1300°F (704°C). Since the heaters are only installed on the sides of the drain tank, considerable natural convection should occur. Additional mixing could be accomplished by bubbling argon (from the boiler to the drain tank) through the drain tank dip tube. The time of treatment will depend upon the degree of contamination. Samples will be taken as required.

J. MAJOR CONTROLS AND INTERLOCKS

In normal operation the potassium system pressure is controlled at the set point on PRC-70 (normally 15 psig) and the four argon nucleator flows are vented to the atmosphere. If the pressure increases, an alarm will occur at 16 to 17 psig and the gas and air to the burner will be shut off at 17 to 18 psig. [An increase of 3 psi is equivalent to an increase of 20°F (11°C) boiling point.] If the pressure decreases for any reason (such as failure of the burner), PV-69 will supply extra argon to maintain the system at its set point (13 to 14 psig). Low pressure will also be annunciated at 13 to 14 psig.

In normal operations the condenser dampers will remain in the set position and therefore the heat removal rate should remain fairly constant. Changes will be automatically compensated for by adjusting the burner output. A thermocouple on the top half of the gas separator (GS-2 or -3), which is connected to a controller, will supply more gas if the temperature decreases and less gas if it increases. Which thermocouple to use and its set point will be determined experimentally. Another thermocouple near the top of the gas separator will close the vent valve (PCV-70A) if the temperature indicates that potassium vapor may enter the vent line (set point around 1000°F, 538°C).

The argon flow to each of the four nucleators is manually set using a throttling valve (normally 5 SLM in each). If the flow drops below the set point, an alarm will occur (4 SLM). If the flow continues to decrease, the burner will be turned off at about 2 SLM.

Two thermocouples in a thermocouple well located in the expansion chamber of the boiler are recorded on TR-103 and -104 (normally 1540°F, 838°C). Annunciation will occur at approximately 1550°F (843°C) and the burner will be stopped at approximately 1560°F (849°C). [Note: when boiling stops, the liquid level will drop well below these thermocouples and they will no longer provide information on the potassium temperature.]

Thermocouples are attached near the bottom and the top of six of the inner and six of the outer tubes. These temperatures are displayed on a scope in the control room. High temperatures are annunciated at 30°F (17°C) above normal temperatures indicated by each thermocouple. At 50°F (28°C) above normal, the burner will be shut off. A low alarm occurs at 1500°F (816°C).

Other temperatures of the boiler, condenser, gas separator, drain tank, lines, etc., are recorded on multipoint recorders. These have no alarm or control action.

The boiler level is indicated by two level elements. The upper level (LE-106) will be used in startup and will have a low and high alarm. The lower element (LE-105) will be used in operation and will also have a low and high alarm. In addition, a lower level will shut off the burner and initiate a drain.

One level element is installed in the drain tank. This has no alarm or control action.

The drain tank pressure is controlled by a supply pressure regulator (PV-67) and a pressure controller (PRC-68) which regulates a pressure control valve (PCV-68).

High (30-psig) and low (3-psig) alarms are provided. For a fill, PRC-68 will be set at ~30 psig and PV-67 will be set as required. To permit an automatic drain during operation and yet maintain an overpressure on the drain tank, PV-67 will be set at 5 psig and PRC-68 will be set at 6 psig.

A smoke detector will be installed in one of the condenser exhaust ducts (line 501). Administrative procedures will be used to assure that this damper is open whenever either of the other two is open. If smoke is detected (indicating a potassium leak), an alarm will occur, the 4 condenser dampers will close, the burner will be shut off, and a drain will be initiated (i.e., the drain valve, HCV-109A, will open).

Another smoke detector and a potassium detector will be installed in the exhaust gas from the boiler. Since the smoke detector may be influenced by incomplete combustion, it will alarm only. The potassium detector will alarm, the burner will be shut off, a drain will be initiated, and the burner will be flooded with argon (to prevent a fire).

No smoke detector will be installed in the drain tank enclosure.

The burner control circuit requires a purge of at least 4 volume changes (150 cfm for 3 min) before the pilot burner can be started. If the pilot burner does not start within 10 sec, the gas is turned off. The pilot burner flame detector ($A_{FL}E-26$) must indicate a flame before the main burner can be started. If the main burner flame detector ($A_{FL}E-27$) does not indicate a flame within 10 sec after energizing the main burner, the main burner gas valves will close.

After startup, whenever the main burner flame detector ($A_{FL}E-27$) indicates that the main burner is out, an alarm will occur, the main burner gas and air will be shut off, and the condenser inlet damper and the three outlet dampers will close. Cooldown of the boiler to freezing will take about a day if the burner air is off and if boiling is suppressed by maintaining the potassium pressure above 14 psig. Therefore, it will usually

be possible for someone to manually drain the boiler. However, after a time delay of ~ 8 hr, an automatic drain will occur.

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