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DECONTAMINATION AND DECOMMISSIONING OF THE EBR-I COMPLEX TOPICAL REPORT NO. 3 NAK DISPOSAL PILOT PLANT TEST

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DECONTAMINATION AND DECOMMISSIONING OF THE EBR-I COMPLEX, TOPICAL REPORT NO. 3 - NAK DISPOSAL PILOT PLANT TEST

by

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ABSTRACT

This report concerns planning, engineering, fabrication, and installation of the NaK Disposal Pilot Test Plant; and operation of the pilot test plant to obtain processing data to confirm the design criteria being used for design of the full-scale NaK processing system. The activity was performed as part of the decontamination and decommissioning of EBR-I and was funded by 189c I-215.

SUMMARY

Decontamination and decommissioning of the Experimental Breeder Reactor No. 1 (EBR-I)[1] requires processing of the primary coolant, an eutectic solution of sodium and potassium (NaK), remaining in the EBR-I primary and secondary coolant systems. While developing design criteria for the NaK processing system, reasonable justification was provided for the development of a pilot test plant for field testing some of the process concepts and proposed hardware. The objective of this activity was to prove the process concept on a low-cost, small-scale test bed.

Prior to the performance of the test program, it was necessary to develop the pilot test plant criteria, design the pilot test plant, develop a test operation procedure[2] and produce a Safety Analysis Report (SAR)[3].

The pilot test plant criteria provided a general description of the test including: the purpose, location, description of test equipment available, waste disposal requirements, and a flow diagram and conceptual equipment layout.

The pilot plant test operations procedure provided a detailed step-by-step procedure for operation of the pilot plant to obtain the desired test data and operational experience. It also spelled out the safety precautions to be used by operating personnel, including the requirement for alkali metals training certification, use of protective clothing, availability of fire protection equipment, and caustic handling procedures.

The Safety Analysis Report provided a general description of the test, the interaction of the pilot plant with existing plant facilities and operations, principal design criteria, control methods and procedures, safety of normal operations, discussion and evaluation of abnormal occurrences or conditions, and discussion of design basis accidents.

The pilot plant SAR and test operations procedure were submitted for review and approval of ANC Safety Division and ERDA-ID prior to fabrication and assembly of the pilot plant and conductance of the tests.

Fabrication of the pilot plant was initiated in March 1974 and completed on May 13, 1974. The plant was checked out and a dry run of the test operations was performed on May 15, 1974.

The pilot plant test was performed on May 16, 1974. During the test, 32.5 gallons or 240 lb of NaK was successfully converted to caustic by reaction with water in a caustic solution.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

The EBR-I primary and secondary coolant systems contain some 5,000 gallons of NaK which will be processed and converted to solid caustic (NaOH and KOH) by a process which involves injection of NaK and makeup water into a vessel of high-temperature, high-molarity caustic solution. Although technically sound and having been tested on a laboratory scale, the process had never been demonstrated at the expected process conditions of flow, temperature, and pressure. As a result, lack of operating data and experience with the process left numerous design questions unanswered. It was therefore felt that reasonable justification existed to provide a pilot test plant to confirm process concepts and equipment selection decisions.

II. OBJECTIVES

The NaK Disposal Pilot Plant Test was conducted for the purpose of studying some of the design variables for the NaK alloy disposal process. Test objectives were to:

(1) Examine the relative merits of two nozzles for NaK injection

(2) Examine the problems of injection of water into the high-temperature reaction medium

(3) Evaluate the use of the electromagnetic flowmeter

(4) Measure the pressures generated on the walls of the vessel caused by the reaction of the NaK with the caustic

(5) Evaluate and demonstrate startup, operation, and decommissioning techniques.

III. TECHNICAL APPROACH

Actions required to satisfy the test objectives included planning, engineering, fabrication and installation of the NaK Disposal Pilot Test Plant, and operation of the plant to obtain the desired data.

1. PLANNING

ANC Waste Management Projects Branch had overall responsibility for the NaK Disposal Pilot Plant Test, including the planning and coordination of all activities by supporting organizations. Planning for the test was initiated in December 1973, and testing was scheduled to begin in May 1974. Supporting organizations included ACC Process and Support Technology Branch, ANC Engineering Division, ANC Site Services Division, and ANC Safety Division.

2. ENGINEERING

Research and development of the NaK processing equipment and the design criteria was the assigned responsibility of ACC. Engineering and preparation of fabrication and installation drawings and detailed operating procedures were assigned to the ANC Engineering Division. The Waste Management Projects Branch prepared the Safety Analysis Report, Maintenance Job Requests (MJRs), and Safe Work Permits. ANC Safety Division prepared an alkali metals training course which was given to all project personnel and crafts people who would be directly involved in the engineering, fabrication, installation, and operation of the NaK Disposal Pilot Plant Test.

3. FABRICATION

Fabrication of the components and assemblies required by the pilot plant design was accomplished at the INEL central facilities machine and welding shops. Since the test equipment was considered to be a temporary outdoor installation, utilizing nonradioactive NaK, Quality Level III was assigned to all equipment and fabricated items. Fabrication was initiated in Fabruary 1974 and completed in April 1974.

4. INSTALLATION

ANC Site Services Maintenance Branch provided the crafts and equipment required to assemble the NaK Disposal Pilot Test Plant. The plant installation instructions were provided by a pilot plant flow diagram, a process system drawing, and MJR instructions. Installation of the plant was initiated in March 1974 and completed in May 1974. ANC Measurements Engineering Section provided an instrumentation trailer and completed the hookup of all test instrumentation by May 12, 1975.

5. OPERATION

Operation of the pilot plant was done by ANC operators, supervisd by ACC process engineering personnel. Prior to actual operation of the plant, it was purged with dry nitrogen gas, and all systems were checked out and operable. Since the plant would be processing NaK, operations were considered hazardous, and therefore were conducted by remote control from a safety shelter. All temperature and strain-gauge indicators were also located at the safety shelter. Personnel involved in the operation of the plant and observation of the tests were required to be dressed in alkali metal protective clothing. The plant was operated successfully on May 16, 1974 during an eight-hour period. The detailed description of the pilot plant and the tests will follow under Sections IV and V of this report.

IV. DISCUSSION

1. GENERAL

Early in the development of design criteria for the EBR-I NaK processing system, it became obvious that design decisions were not being made due to lack of actual process experience with caustic and NaK. Although the several nozzle designs proposed for the NaK processing had been flow tested in the laboratory using both oil and mercury as the test fluid injected into water, there was a lack of experience in using the nozzles to inject NaK into hot 14 M caustic solution. Additionally, the injection of cold water into 200°C caustic was expected to cause flashing of the water to steam, resulting in violent turbulence which needed investigation. It was decided that cost savings could be realized by conducting a pilot plant test in order to obtain the required equipment and operating experience early in the program.

2. LOCATION

An existing NaK disposal pad located approximately 100 feet west of EBR-I had already been selected for the site of the NaK processing system, and since many of the support systems required were identical, it was decided to also use the pad for assembly of the pilot plant. Figure 1 shows the location of the NaK disposal pad in relation to the EBR-I complex. The pad is equipped with a large 12 by 20 foot carbon steel catch pan with carbon steel safety shelter and a concrete block safety shelter with a heavy glass-shielded observation window and water lance ports. The pad was designed and, in the past, used for disposal of small quantities of NaK.

3. PILOT PLANT DESCRIPTION

The pilot plant equipment consisted of:

(1) One semiscale process vessel fabricated from a 55-gallon drum, equipped with ports for nozzle entry and temperature probes, and having an open top

(2) One 55-gallon Mine Safety Appliance (MSA) NaK drum containing approximately 35 gallons of clean (nonradioactively contaminated) NaK (15 psig ultimate design pressure)

(3) One 78-gallon run vessel (WC-103, design pressure 60 psig at 1,500°F)

(4) One small vacuum pump, laboratory size

(5) One propane torch

(6) Three argon bottles (221 SCF each)

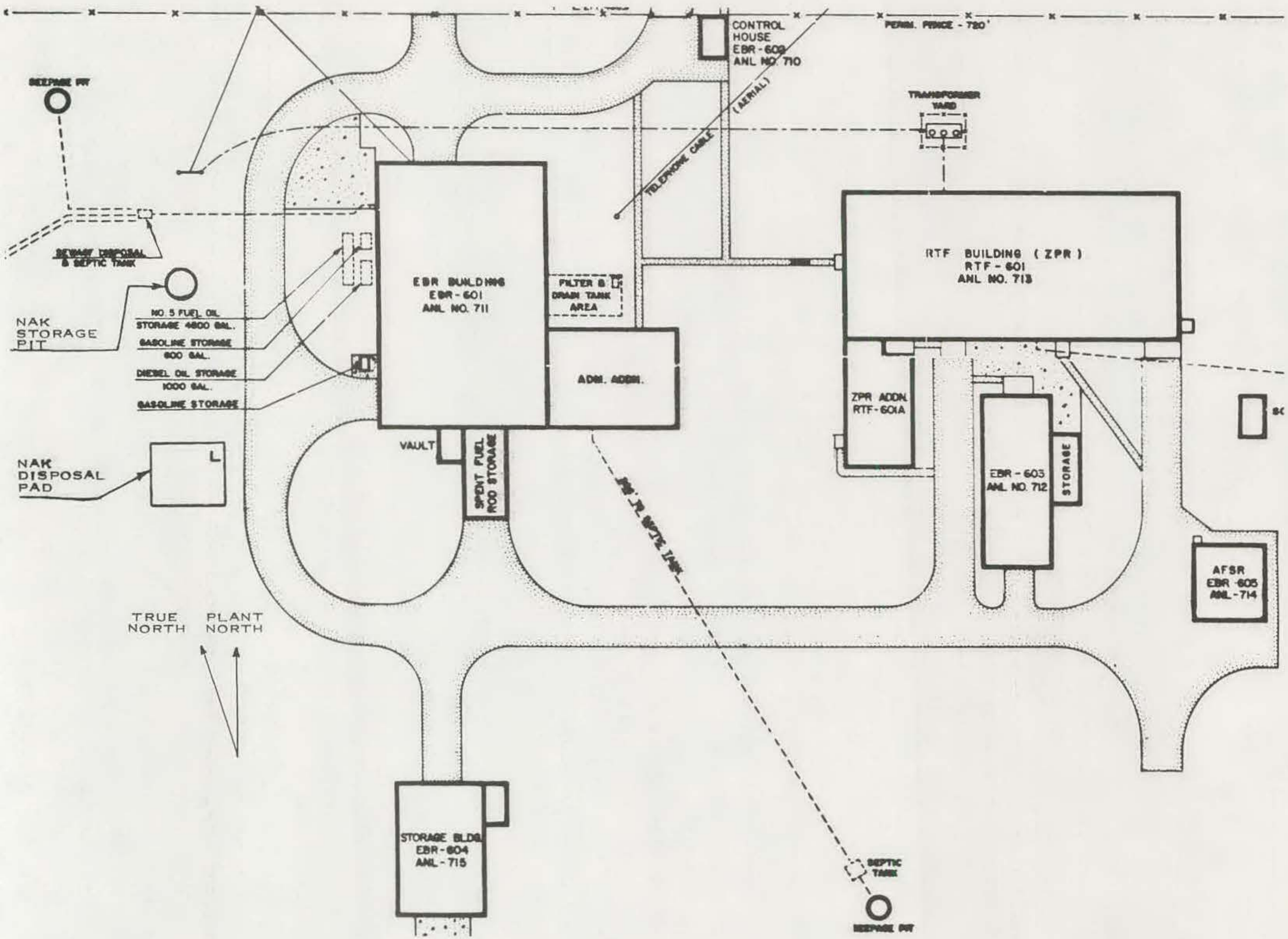

FIG. 1 EBR-I AREA PLOT PLAN.

(7) One propane bottle (250 gallon)

(8) Interconnecting piping valves and fittings

(9) Mirror for observing process surface

(10) Instrumentation including thermoscouples and strain gauges

(11) TV Camera.

The equipment was assembled on the EBR-I NaK disposal pad in accordance with Figure 2, pilot plant flow diagram; Figure 3, pilot plan processing system; Figure 4, vertical orientation of instrumentation and nozzles on process vessel; and Figure 5, horizontal orientation of instrumentation and nozzles on process vessel. The installed equipment just prior to beginning of the pilot plant tests is illustrated by Figures 6 and 7, EBR-I NaK Pilot Plant photographs of prerun checkout. Several items of equipment shown in the photographs, such as the weigh scale, safety shower, and water system were not shown as part of the pilot plant operation since they had already been installed to support the full-scale NaK processing system.

4. PREOPERATIONAL CHECKOUT

Prior to operation of the pilot plant, a detailed component and system checkout was performed to ensure that the plant was operational. Then the operational sequence was performed through all of the steps of a detailed operating procedure. The system checkout was done under the direction of the ANC project engineer, was conducted by the ACC process engineer, and was observed and commented on by an MSAR consultant, Dr. J. W. Mausteller, and by ANC Safety Division. Permission to initiate the pilot plant test operations required unanimous agreement by the checkout team that all systems were "go".

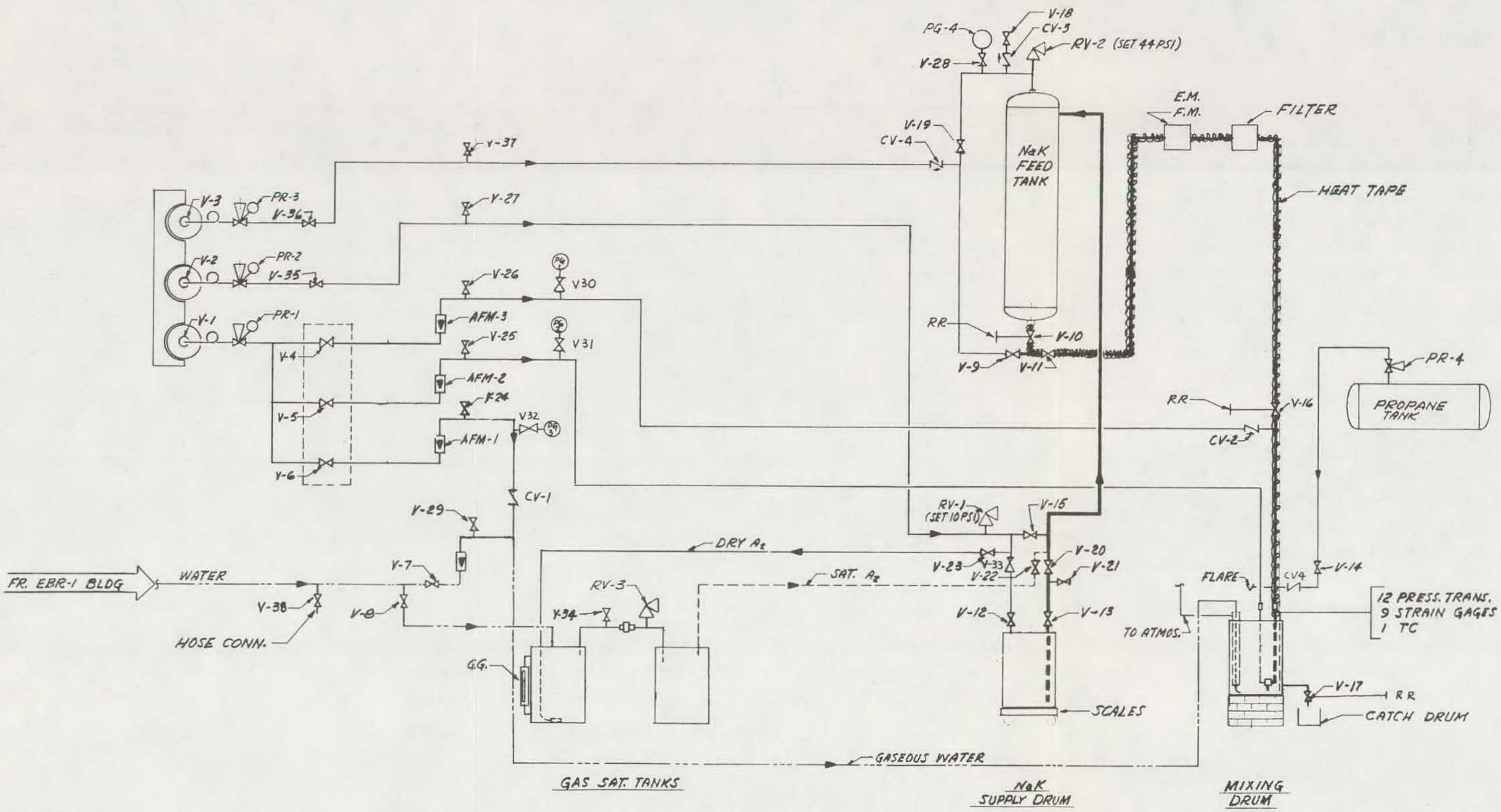

FIG. 2 EBR-I NAK D&D PILOT PLANT FLOOR DIAGRAM.

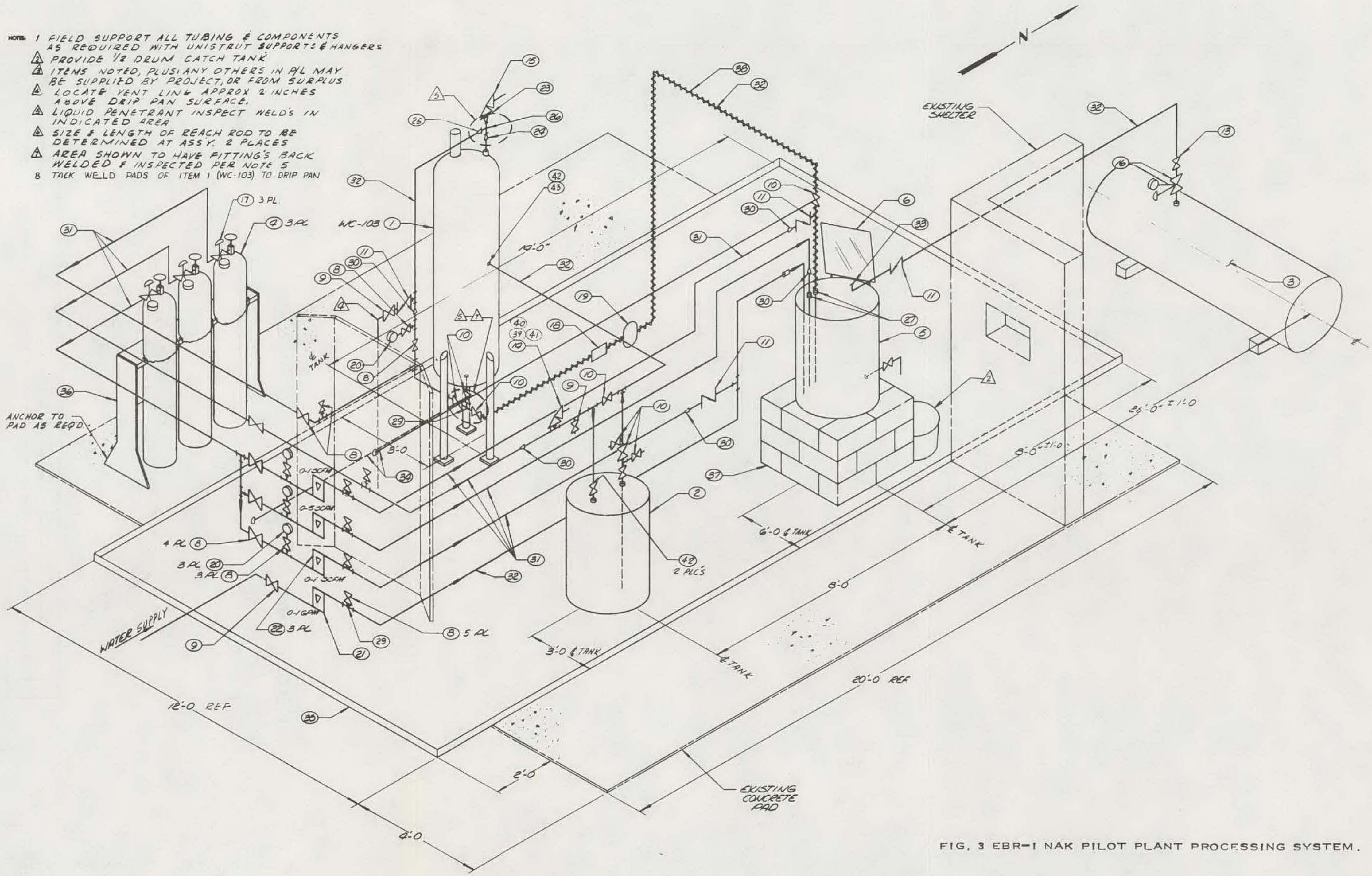

FIG. 3 EBR-I NAK PILOT PLANT PROCESSING SYSTEM.

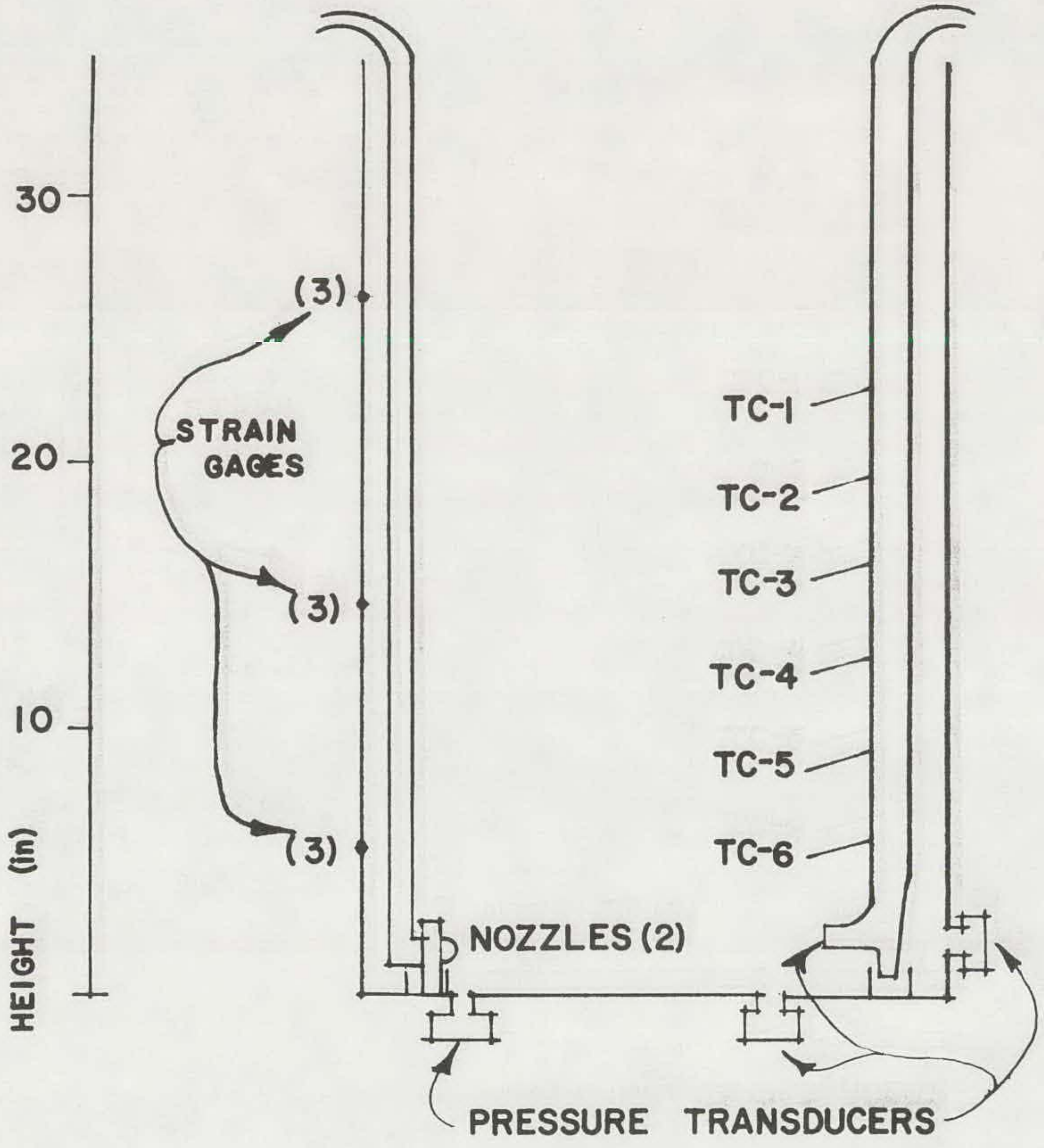

FIG. 4 VERTICAL ORIENTATION OF INSTRUMENTATION AND NOZZLES ON PROCESS VESSEL.

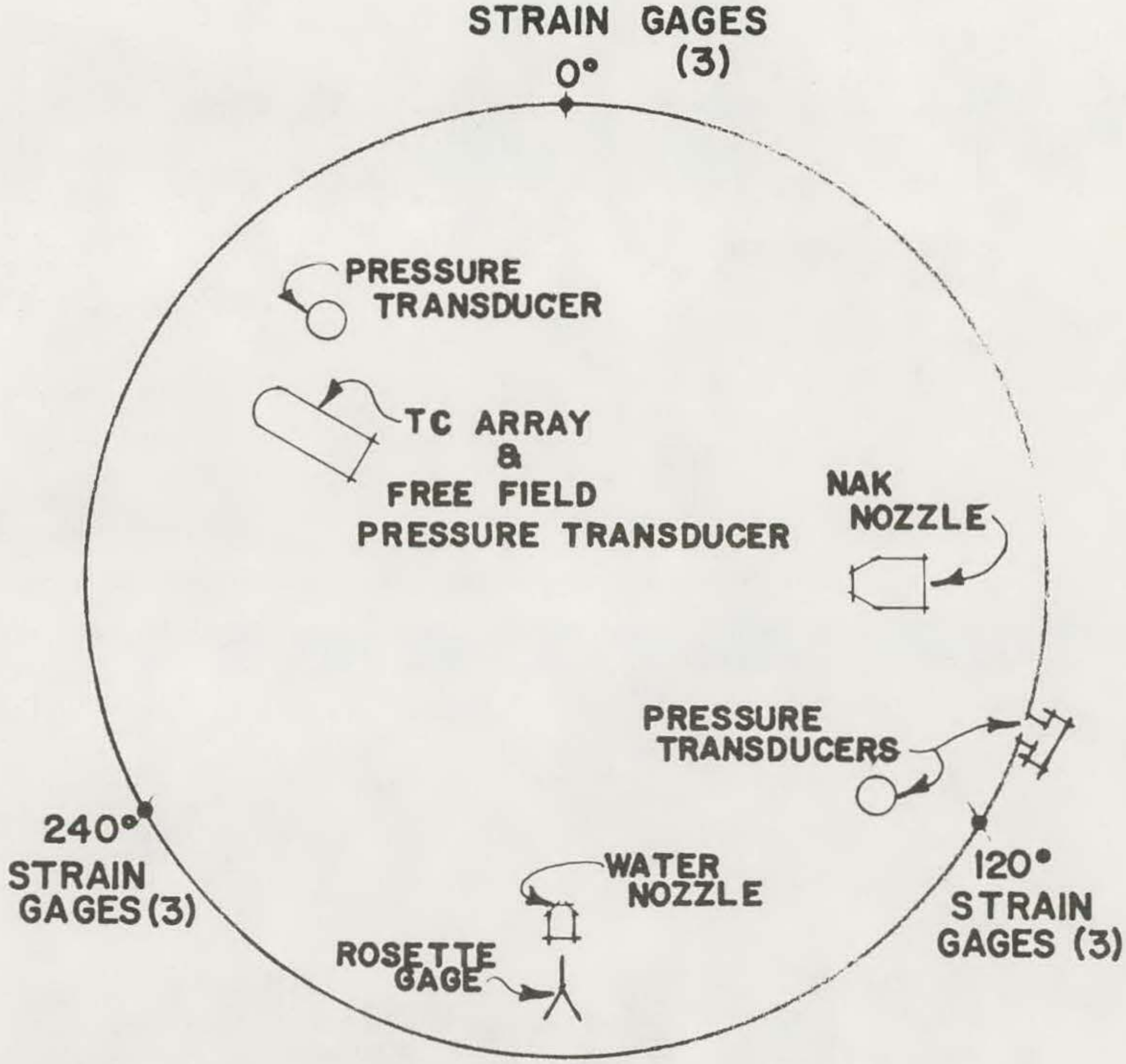

FIG. 5 HORIZONTAL ORIENTATION OF INSTRUMENTATION AND NOZZLES ON PROCESS VESSEL.

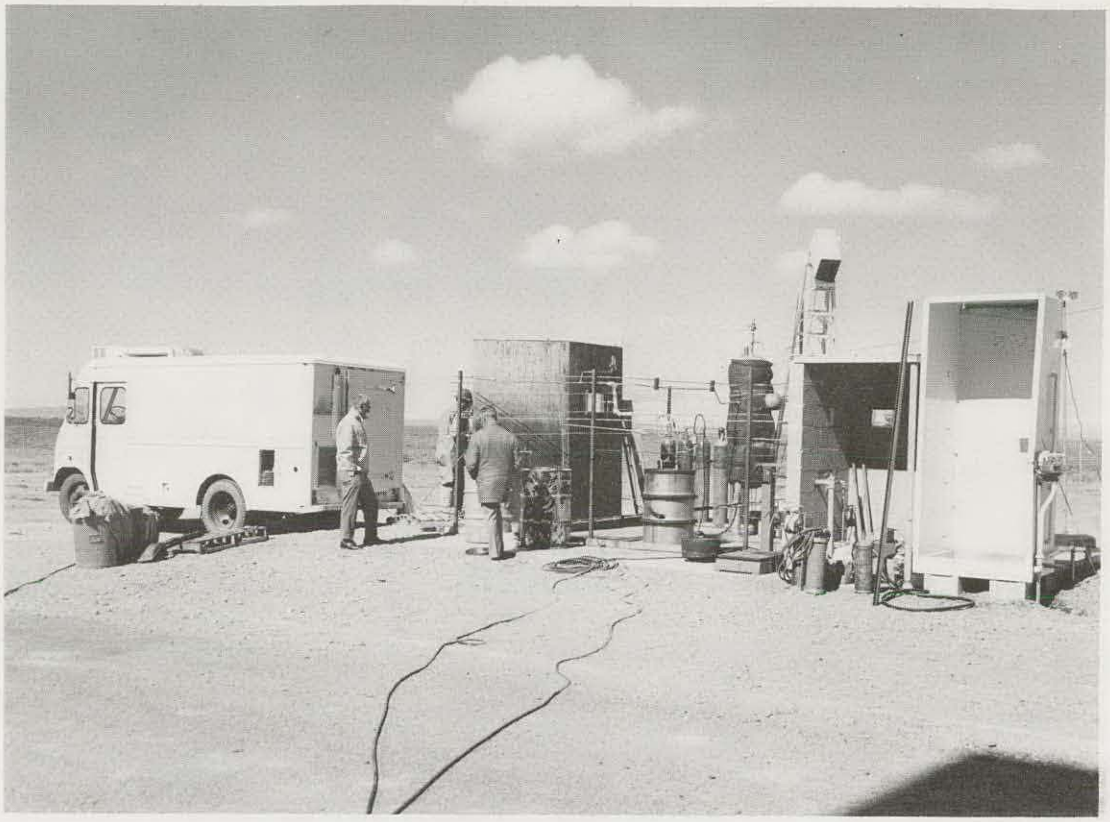

FIG. 6 EBR-I NAK PILOT PLANT PHOTOGRAPH OF PRERUN CHECKOUT.

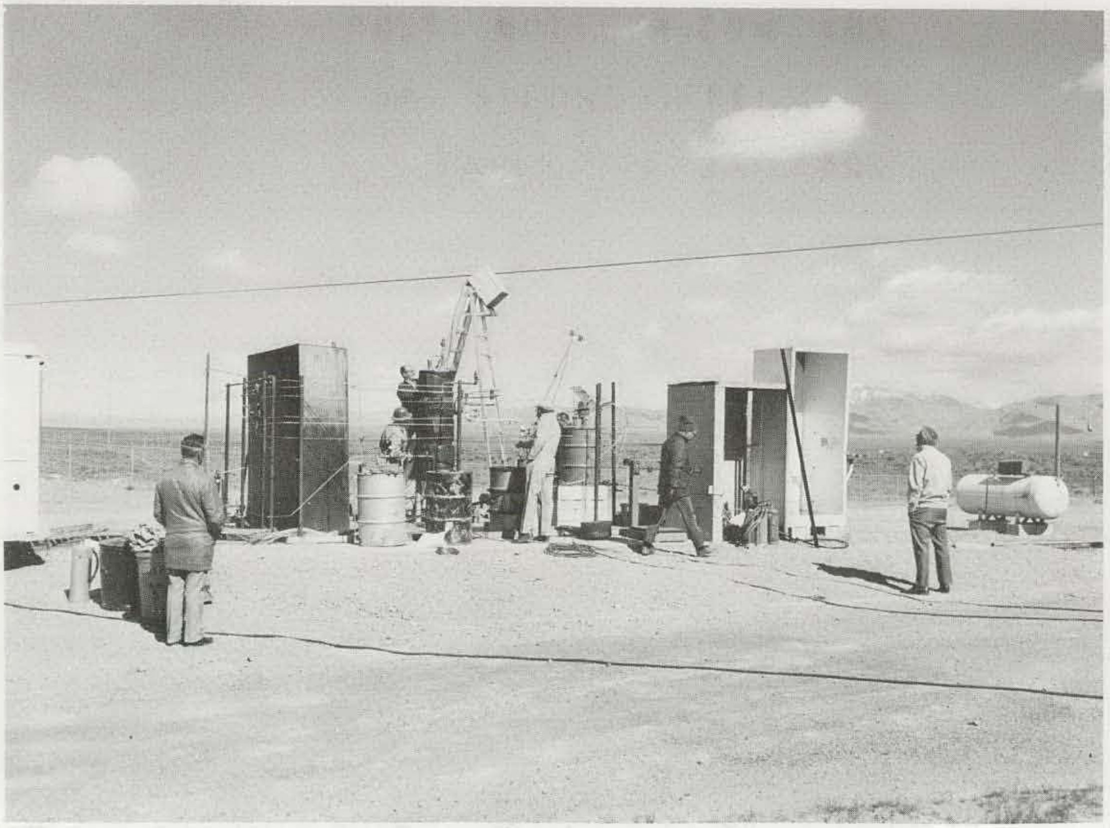

FIG. 7 EBR-I NAK PILOT PLANT PHOTOGRAPH OF PRERUN CHECKOUT.

V. OPERATIONS

1. PRETEST OPERATIONS

In the pretest preparation, dry argon gas was purged through the NaK feed tank and NaK feed and transfer lines to remove oxygen and moisture. At the end of the purging period, the argon was analyzed for moisture content. To check for leaks, the NaK feed tank was pressurized and allowed to stand overnight. By pressurization of the NaK supply drum, NaK was transferred to the NaK feed tank. The flow was restricted during the transfer operations at valve V-13. The restriction was removed by heating the valve with a propane torch. Approximately 240 lb (32.5 gallons) of NaK was transferred to the NaK feed tank, as obtained from the weight of the partially full drum of NaK and its estimated tare weight. To make up about 30 gallons of 14 M caustic in the mixing drum (a 55-gallon carbon steel drum with the top removed), an argon purge was started through the NaK feed nozzle by opening value V-4 followed by addition of 50 lb technical grade NaOH and water to the drum. A small flow of NaK was started and quickly stopped by pressurizing the NaK feed tank to 40 psig, opening V-11, opening and then closing V-10. The section of line through the electromagnetic flowmeter (EM-FM) was then heated so that the NaK would wet the surface of the stainless steel tubing in the EM-FM and give an accurate measure of the flow rate of NaK. The propane flare was ignited to burn hydrogen produced by the NaK/water reaction.

2. TEST OPERATIONS

NaK was injected into the caustic with a Bete Straight Jet J-80 nozzle (see Figure 8). The flow was quickly increased to two liters per minute, the design basis flow rate. Data from strain gauges, pressure transducers, thermocouples, and EM-FM were recorded during this period of time. In addition, closed circuit television pictures were taken and recorded on videotape. Water was added to the mixing drum before the temperature reached 200°C because of caustic loss from splashing (see Figure 9). Splashing of the caustic extinguished the propane flare shortly after the start of the test. The flow of NaK to the nozzle was stopped and restarted. A leak in a fitting and failure of a hold down for the reaction barrel resulted in premature shutdown of the test with the Straight Jet nozzle.

The Bete Straight Jet nozzle was replaced with a Spray Systems Company air atomizing nozzle, spray setup No. 42 with fluid cap 100150 and air cap 1891125 (see Figure 10). An atomizing gas pressure of argon of 20 to 30 psig was used for injection of NaK. The injection of NaK was started and increased to one liter per minute. The flow of NaK was stopped and restarted. Due to a decrease in argon pressure on the argon bottle, the injection of NaK was stopped and the bottle changed. The NaK injection and atomizing argon were restarted. The flow was increased to one liter per minute and then to two liters per minute. The flow of NaK from the nozzle was decreased to 0.8 liter per minute and continued until the decrease in argon pressure on the cylinder required its replacement again. The argon cylinder was then changed, which resulted in a restriction in the argon side of the atomizing nozzle after restarting the nozzle. The flow of NaK was continued at 0.7 liter per minute until the NaK feed tank was empty.

FIG. 8 BETE STRAIGHT JET NOZZLE.

FIG. 9 NAK PROCESSING USING BETE STRAIGHT JET NOZZLE.

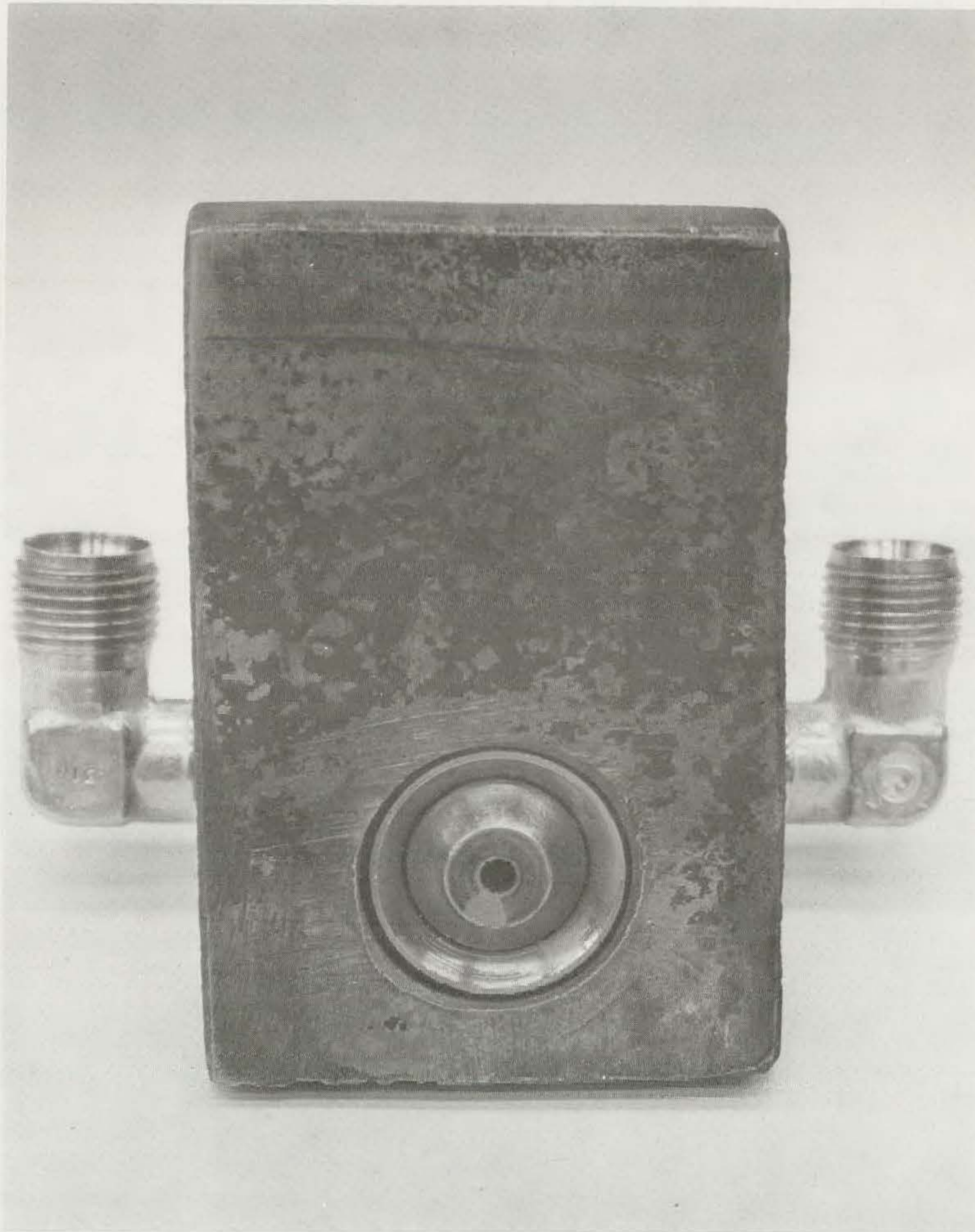

FIG. 10 SPRAY SYSTEMS COMPANY AIR ATOMIZING NOZZLE.

3. CLEANUP

The caustic solution in the reaction barrel was transferred to the catch drum by opening valve V-17. The caustic from the large catch pan below the mixing drum was removed and placed in two other drums. The trace of caustic remaining in the catch pan was diluted and neutralized with nitric acid before being drained to the soil. Argon gas was saturated with water vapor in the gas saturation tanks and passed through all lines and vessels containing residues of NaK. The lines and feed tanks were finally rinsed with water and the rinsings drained to the catch drum. All lines and nozzles were disassembled and examined.

VI. OBSERVATION AND CONCLUSIONS

1. PRETEST OPERATION

The pretest purging of NaK lines and vessels prior to the introduction of NaK into the system was found to be satisfactory. There were no occurrences of system pressure spikes or flow restrictions such as might have happened if water or moisture had remained in the system. Restrictions did occur at a valve which had not been in the system purge and due to caustic back flow into a test nozzle. The valve restriction was eliminated by the application of heat to the valve.

2. TEST OPERATIONS

2.1 NaK Injection Using the Bete Straight Jet Nozzle

In the preliminary testing of the Bete Straight Jet nozzle, oil and mercury were individually sprayed into a water column. The nozzle dispersed both of the liquids into fine droplets as observed through the glass column. However, when used to inject NaK into the caustic solution, the resulting reaction was not smooth. Apparently, the NaK was not dispersed adequately into fine droplets since particles of the NaK appeared on the caustic surface where it continued to react quite violently. A dense white smoke was observed coming from the mixing drum during the test. Due to the smoke, the TV pictures did not provide useful information. At full flow, the burning hydrogen and/or the NaK/water reaction resulted in violent rocking of the mixing drum, even to the point of straightening one of the hooks which was holding the drum on the cinder-block stand. Early in the test and during maximum flow of NaK through the nozzle, the violent rocking motion of the drum resulted in the severance of many of the instrument lead wires. Accordingly, strain gauge and pressure transducer readings were obtained only during the early minutes of the operation.

The experimental data[4] for NaK injection into caustic with the Bete Straight Jet nozzle are given in Table I. During the test, the temperatures in the solution were reasonably uniform with the top thermocouple showing the effects of the burning hydrogen gas and splashing caustic.

During the flow of NaK through the Bete Straight Jet nozzle, the maximum pressure pulses seen were 20 psi on the bottom and 10 psi on the sides of the mixing drum. These pressure pulses appeared four to five times per second.

The strain gauges showed maximum wall strains to be on the order of 160 μ in./in. The strain on the wall next to the NaK nozzle was found to reach a maximum of 145 μ in./in. One burst of strain on the rosette strain gauge with an angle of 120° between the three legs of the strain gauge was seen in which one leg was stretching and the other two were under compression. The stretched leg was under 675 μ in./in., and the other two under

TABLE I

EXPERIMENTAL DATA FOR NAK INJECTION AT TWO

LITERS PER MINUTE WITH THE BETE STRAIGHT JET NOZZLE

The maximum temperature recorded on each temperature sensor during NaK injection with the Bete Straight Jet nozzle (Part 1) of the test series was as follows:

Sensor		Temperature
TC#1	Top	150°C
TC#2		90°C
TC#3		80°C
TC#4		90°C
TC#5		90°C
TC#6	Bottom	80°C

The maximum pressure recorded on each pressure sensor during Part 1 of the test series was as follows:

Free field pressure		10 psi
Bottom pressure transducer	S/N 2237	5 psi
Bottom pressure transducer	S/N 2135	20 psi
Wall pressure transducer		10 psi

The maximum strain recorded on each strain sensor during Part 1 was as follows:

0° Rosette	675 μ in./in.	
120° Rosette	300 μ in./in.	Compression
240° Rosette	270 μ in./in.	Compression
0° Top	40 μ in./in.	
0° Middle	60 μ in./in.	
0° Bottom	95 μ in./in.	
120° Top	50 μ in./in.	
120° Middle	90 μ in./in.	
120° Bottom	145 μ in./in.	
240° Top	90 μ in./in.	
240° Middle	90 μ in./in.	
240° Bottom	160 μ in./in.	Elongation 190 μ in./in. Compression

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compression at 300 and 270 μ in./in. In general, at the time the strain gauge readings were high, the pressure spikes were at a minimum.

2.2 NaK Injection Using the Spray Systems Company Atomizing Nozzle

The Spray Systems Company air atomizing nozzle operated much more smoothly than the Bete Straight Jet nozzle. There was no evidence of surface burning of the NaK, no hydrogen explosions taking place, and little motion of the barrel when the nozzle was operating at full flow. Violent motions of the barrel were noted only when the atomizing gas pressure dropped or flow of atomizing gas was stopped. During this part of the test, dense white smoke was given off the surface of the caustic (see Figure 11).

FIG. 11 NAK PROCESSING USING AIR ATOMIZING NOZZLE.

During the operation, the NaK flow stopped and was then restarted without difficulty. Twice, the purge gas to the air side of the nozzle was shut off while gas bottles were being changed. The first time, restrictions in the nozzle did not occur. The second time, however, a partial restriction in the atomizing gas side of the nozzle occurred, which seriously affected the operation of the nozzle. Even with the restriction and consequent loss of atomization, operation was smoother than that with the Bete Straight Jet nozzle.

Due to the severing of many instrument leads during the test with the Bete Straight Jet nozzle, data were not obtained from the pressure transducers and many of the strain gauges for the test with the atomizing nozzle. Inadvertently, data were not obtained when the flow rate of NaK reached two liters per minute. The data for the atomizing nozzle at 0.8 liter per minute and one liter per minute are given in Table II.

TABLE II

EXPERIMENTAL DATA FOR NAK INJECTION WITH

SPRAY SYSTEMS COMPANY AIR ATOMIZING NOZZLE

The maximum temperature recorded on each temperature sensor during injection of NaK with the atomizing nozzle (Part 2) of the test series was as follows:

	Sensor		Temperature
Part 2 First Data Point:	TC#1	Top	80°C
	TC#2		80°C
	TC#3		80°C
	TC#4		80°C
	TC#5		80°C
	TC#6	Bottom	80°C
Part 2 Second Data Point:	TC#1	Top	120°C
	TC#2		120°C
	TC#3		120°C
	TC#4		120°C
	TC#5		120°C
	TC#6	Bottom	125°C

The NaK flow rate recorded during Part 2 was as follows:

Part 2 First Data Point	0.8 liter/min
Part 2 Second Data Point	1.0 liter/min

The noise level converted to strain on two sensors during Part 2 is given below; however, the actual strain level will be below these figures.

Part 2 First Data Point:	0° Middle	60 μ in./in.
	0° Bottom	10 μ in./in.
Part 2 Second Data Point:	0° Middle	115 μ in./in.
	0° Bottom	50 μ in./in.

The temperatures in the solution during the test with the atomizing nozzles were reasonably uniform.

Due to the high instrument noise level, the strains could not be obtained but were considerably less than the strain equivalent to the observed noise levels given in Table II. The smooth reaction, as visually observed, indicates much lower pressures and much lower strains than those in the test with the Bete Straight Jet nozzle. The data for the strain gauges and the pressure transducers given in Table I for the Bete Straight Jet nozzle are, therefore, taken as the upper limits for operation with the atomizing nozzle. The smoother reaction with the atomizing nozzle indicates that the NaK was dispersed into finer droplets than those with the Straight Jet nozzle.

3. CONCLUSIONS

In the test, 32.5 gallons or 250 lb of NaK was successfully converted to caustic by reaction with water in a caustic solution. During this reaction, an air atomizing nozzle was identified as the best nozzle for NaK injection into caustic for the disposal process. The nozzle gave a smooth reaction of NaK with caustic and could be turned off and restarted as long as a gas purge through the nozzle was maintained. Pressure pulses in the reaction vessel during the NaK injection were never more than 20 psi, considerably less than the allowable operating pressure of 180 psi for the reaction vessel for the NaK disposal process, VFE-1. The stresses on the 55-gallon barrel of 0.049-inch wall thickness reached a maximum of 675 μ in./in. The stress in VFE-1, therefore, will be considerably less due to the greater wall thickness, 0.313 inch., and adequately low.

Purging the lines with dry argon apparently was an adequate pretreatment for drying the steel surfaces before NaK service, since the two restrictions which occurred during the test were in a valve that was not purged and from backflow of caustic into a nozzle.

The electromagnetic flowmeter worked satisfactorily during the test. The NaK volume calculated from the estimated average flow rate and time of injection agreed with the volume of NaK disposed of during the test.

Cleaning procedures using water-saturated argon followed by a water rinse worked well. The water in the saturated argon apparently had reacted with nearly all the liquid metal residues in the vessel lines before the subsequent water rinses.

Due to losses of caustic by splashing from the top of the barrel, water had to be added before the caustic reached 200°C. The caustic temperature reached a maximum of 125°C during the test so that the injection of water at the expected steady state operating conditions of VFE-1 was not possible. However, at a temperature of 125°C, there were no difficulties encountered with water injection.

This test demonstrated that alkali metals could be completely and safely reacted with caustic even with a nozzle submergence of only 18 inches. However, a low nozzle submergence does not permit the scrubbing action of caustic to remove the aerosols produced such as Na_2O, K_2O, NaOH, and KOH. In the NaK disposal plant, an average seven-foot submergence of the nozzle should remove most of the aerosols produced. In a disposal of NaK at Fire Station 2, only a slight amount of smoke was observed for a submergence of nine feet and for a disposal rate of 5 to 10 gallons/minute[5].

4. RECOMMENDATIONS

Based on the pilot plant test, the following are recommendations for design of the NaK disposal plant:

(1) During the drying of lines and tanks that will contain NaK, the purge gas moisture content should be monitored.

(2) Spray Systems Company air atomizing nozzle spray setup No. 42 with fluid cap 100150 and air cap 1891125 should be used in the NaK disposal reaction vessel.

(3) The positioning of the thermocouples to be used in the feedback control system for temperature control in VFE-1 is not critical, since uniform temperatures were observed in the caustic solution; therefore, with the lower caustic level during process startup, switching from a lower to a higher thermocouple in VFE-1 for better temperature control will be unnecessary.

(4) Accurate determination of the quantity of NaK fed to the process is possible only if the measurement from the feed line flowmeter is continuously recorded.

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