DISCLAIMER

EGG-WM-7845

CONCEPTUAL DESIGN REPORT DECONTAMINATION AND DECOMMISSIONING OF THE EBR-I MARK-II NAK

B. W. Brown
D. M. La Rue
F. E. Stoll
M. R. Dolenc
D. L. Crandall

September 1987

EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Idaho Operations Office
Under DOE Contract No. DE-AC07-76ID01570

ABSTRACT

A conceptual design of a processing system for approximately 180 gallons of contaminated NaK (sodium/potassium eutectic alloy) is presented. This NaK resulted from an incident at EBR-1 at the Idaho National Engineering Laboratory in 1955. The proposed method of decommissioning the Nak is to chemically deactivate it by combining it with gaseous chlorine. This process will produce a solid mass of potassium chloride and sodium chloride salts which will mitigate the consequences of further chemical reaction of the NaK should the storage containers be breached in any way. Following the processing of the NaK, the storage vessels will be transferred to an appropriate storage facility for radioactive wastes.

SUMMARY

This conceptual design report addresses the processing system for the chemical deactivation of the EBR-I Mark-II radioactively contaminated sodium/potassium (NaK) primary reactant coolant presently stored at the Army Reentry Vehicle Facility Site (ARVFS) bunker. The design presented in this report is still somewhat preliminary in that some necessary operating data will not be obtained until early FY 1988. These data, when available, will not grossly impact the conceptual design presented in this report, but may impact operating rates of the processing equipment.

Due to the concern for potential adverse reactions occurring during transport of the NaK containers, the processing of the NaK will take place at the ARVFS. This will necessitate that all required services, e.g., potable water, electrical power, etc., be supplied through portable equipment.

The processing system will include subsystems and equipment to: (1) provide secondary containment for the NaK containers with internal components to penetrate the NaK containers; (2) filters and metering equipment to introduce the NaK into the chemical reactor; (3) integrated chlorine system to meter and vaporize chlorine prior to injection into the chemical reactor; (4) chemical reactor with necessary thermometry and pressure sensing equipment; (5) vacuum system to evacuate secondary containers and chemical reactor prior to operation; (6) chemical reactor coolant system with necessary instrumentation; (7) inert gas system for blanketing the secondary containers and the chemical reactor; and (8) integrated process control system to monitor/control process and provide emergency shutdown of system if required.

The system will be designed to accommodate necessary residual NaK decontamination and subsequent breakdown of components for disposal. The system will be skid mounted and will have necessary electrical power supplied by portable generating equipment.

Construction cost of this project is estimated at $860,000.00 (1987 Dollars). EG&G Idaho, Inc. will design the structures, systems, and components. Due to the D&D and R&D nature of this project, the skid mounted units will be fabricated by EG&G maintenance personnel. This project is not covered by Davis-Bacon legislation.

Present schedule calls for the preliminary design to be initiated in mid-FY1987 and completed by the end of the first quarter FY 1988. System testing will be performed during the fourth quarter FY 1988 and actual processing of the ARVFS NaK will be performed during the third quarter of FY1989.

This Conceptual Design Report describes the complete processing system and necessary ancillary systems.

CONTENTS

FIGURES

TABLE

1. PROJECT DESCRIPTION

1.1 Introduction

Approximately 180 gal of sodium/potassium (NaK) eutectic liquid metal were severely contaminated during a meltdown of the Mark-II core of the Experimental Breeder Reactor - I (EBR-I) in November 1955. This contaminated NaK, which is contained in four vessels, is currently stored in an underground bunker located at the Army Reentry Vehicle Facility Site (ARVFS) located approximately at the center of the Idaho National Engineering Laboratory (INEL) (see Figure 1). Figure 2 shows the ARVFS bunker and site.

The 180 gal of NaK are contained in two 55-gal drums and two vessels fabricated from pipe sections (Figure 3). After the cleanup of the EBR-I Mark-II core, the NaK was stored in a pit at the EBR-I site until 1974. During decontamination and decommissioning (D&D) operations for EBR-I in 1974, this contaminated NaK was removed from the EBR-I pit, placed in a dumpster, and then moved to storage at the ARVFS bunker (Figure 4). An inspection of the ARVFS bunker and the NaK containers was performed in 1979. Since that time, the NaK containers have not been further disturbed.

During the Mark-II core meltdown, uranium-238 was being transmuted to plutonium-239. It is believed that the radioactive contamination was from the core meltdown and not from the surrounding blanket being transmuted. In addition, a 10.5 g sample of plutonium, contained in a foil inside the reactor, was not recovered during cleanup, and is likely to be present in the NaK. The present level of contamination of the NaK (Appendix A) is estimated to be less than 30 g of radioactive material; it may also contain some nonradioactive core debris.

This Conceptual Design Report describes the processing system for the NaK stored at the ARVFS bunker.

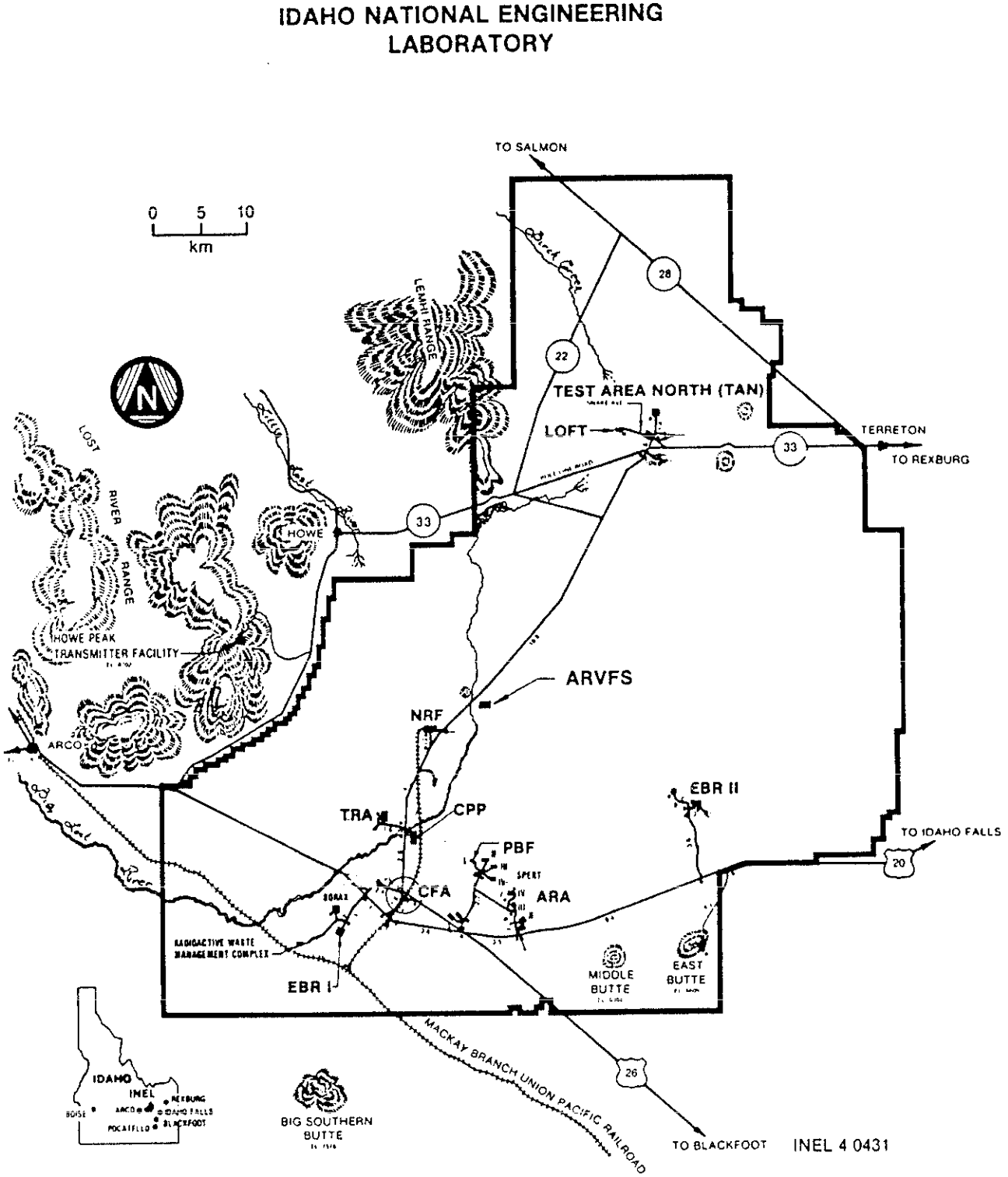
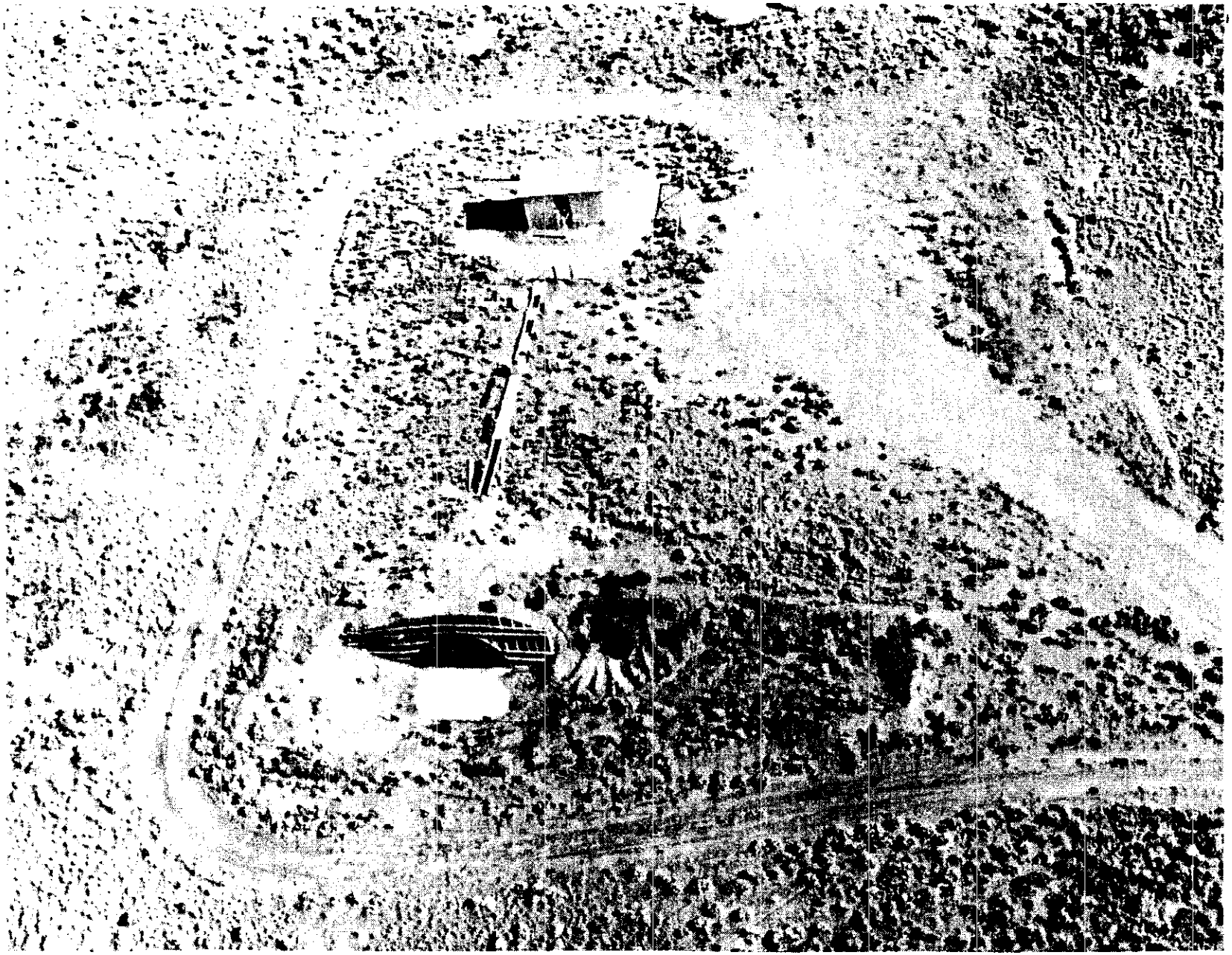
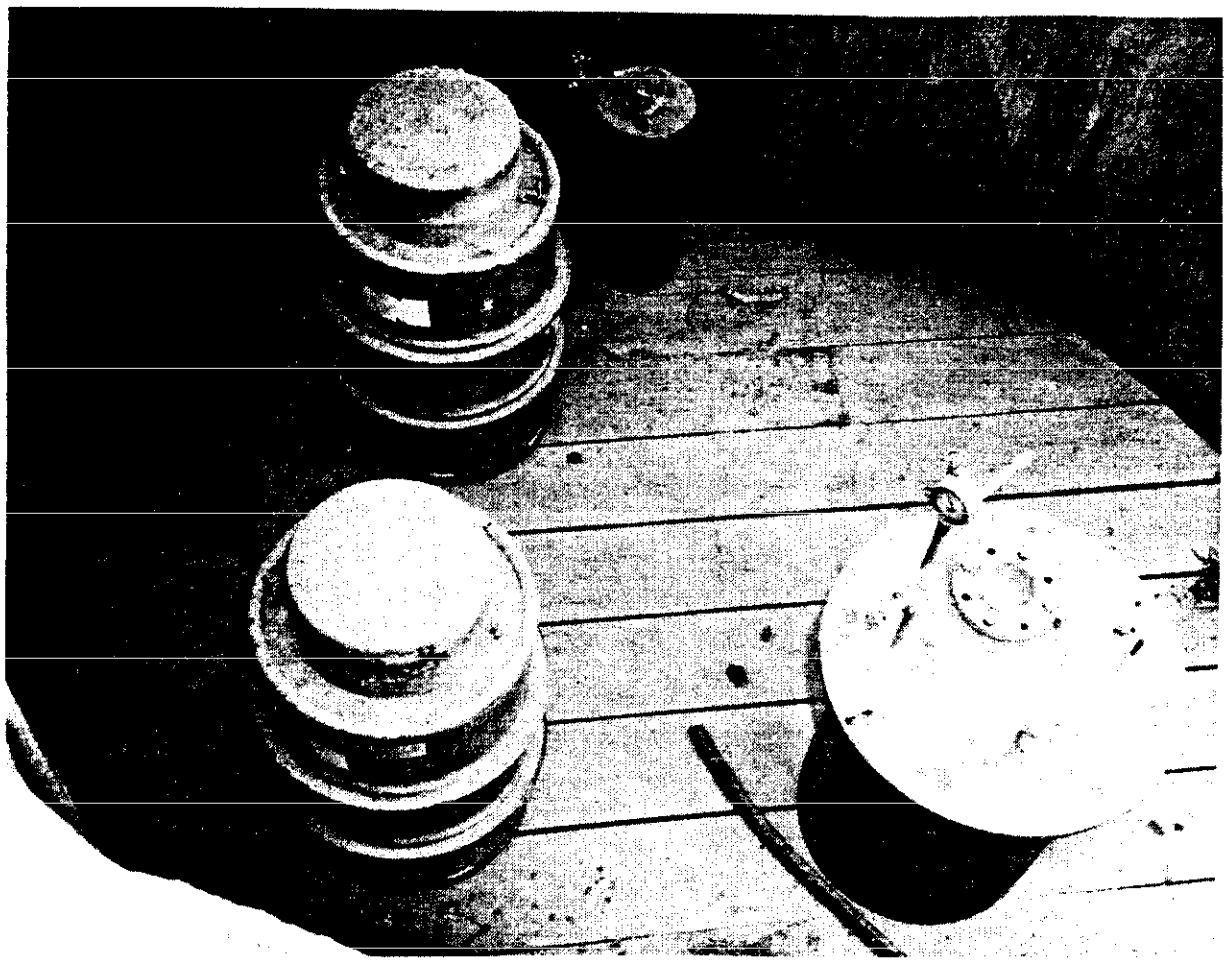


Figure 1. Map of INEL showing the location of ARVFS.



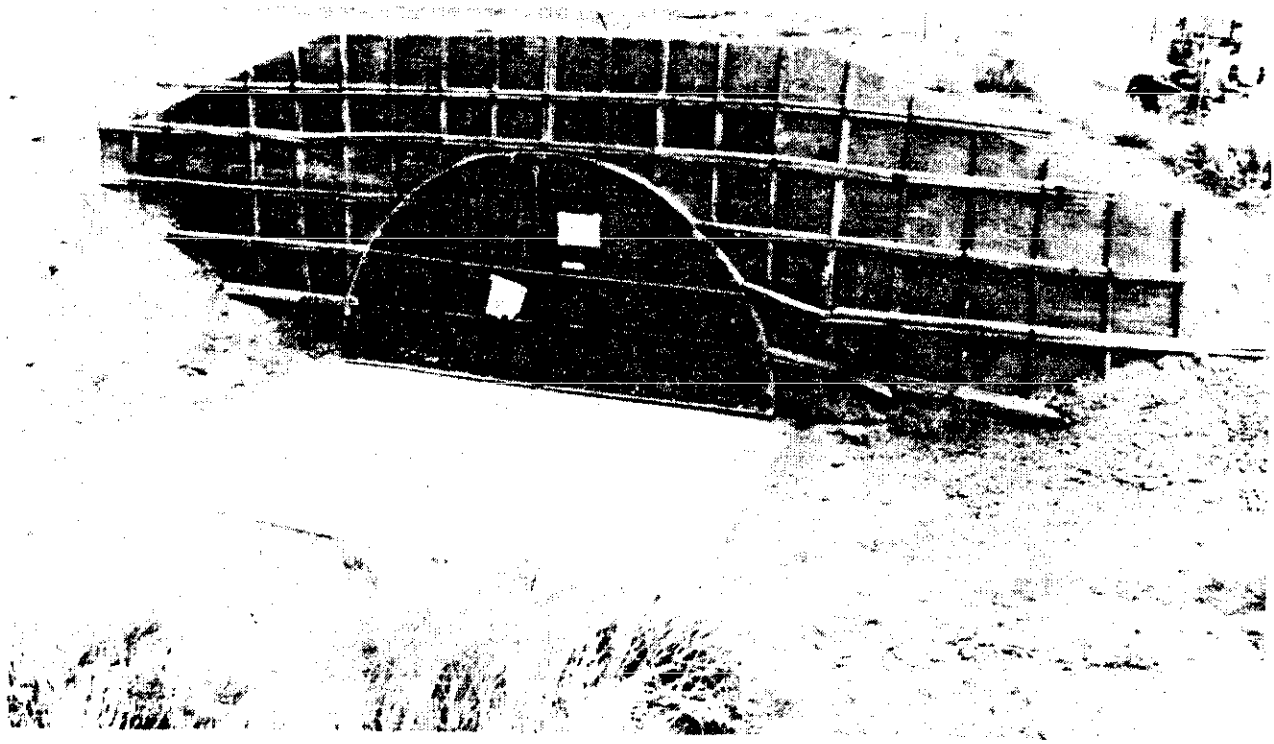
83-574-11-2

Figure 2. Aerial view of ARVFS looking to the east.



73-3533

Figure 3. Four containers of contaminated NaK in storage pit at the INEL EBR-1 site from 1955 to 1974.



79-7164

Figure 4. ARVFS bunker.

1.2 Project Objectives

The objectives of this project are as follows:

1. Chemically deactivate the NaK

2. Dispose of the contaminated product at a designated burial site

3. Chemically deactivate any residual NaK in the containers, and dispose of the containers at a designated burial site

4. D&D any contaminated process equipment used in these operations

5. D&D the ARVFS bunker site.

These objectives will be accomplished in a safe manner to minimize hazards to the workers, the public, and the environment. The work will be performed in compliance with appropriate standards, regulations, and guidelines.

Completion of the above technical objectives will allow for the effective disposition of the NaK, and will return the ARVFS bunker and immediate area to a reusable condition. Upon completion, the EBR-I NaK, which is now considered a significant potential hazard, will be removed from the Surplus Facilities Management Program priority listing of projects.

1.3 Facility Description

1.3.1 Physical

The physical description of the NaK containers and of ARVFS have been presented in detail in several reports (see References 1-5). The description provided in this document is a summary of the information contained in those reports.

NaK has been stored in two stainless steel 55 gal Mine Safety Appliance (MSA) drums and in two carbon steel containers fabricated from pipe sections. During the inspection in 1979 (Reference 5), the smaller of these fabricated vessels indicated some minimal external corrosion. No information exists concerning the internal condition of the NaK containers. Several attempts in locating engineering drawings for the two fabricated NaK containers since the 1955 incident have been unsuccessful. The four containers were originally blanketed with argon during their filling in 1955. These four containers have since been placed inside a sheet metal dumpster and covered with vermiculite to a depth of approximately 12 in. above the NaK containers. The dumpster and contents have been stored inside an underground bunker at the ARVFS site since 1974 (Figure 5).

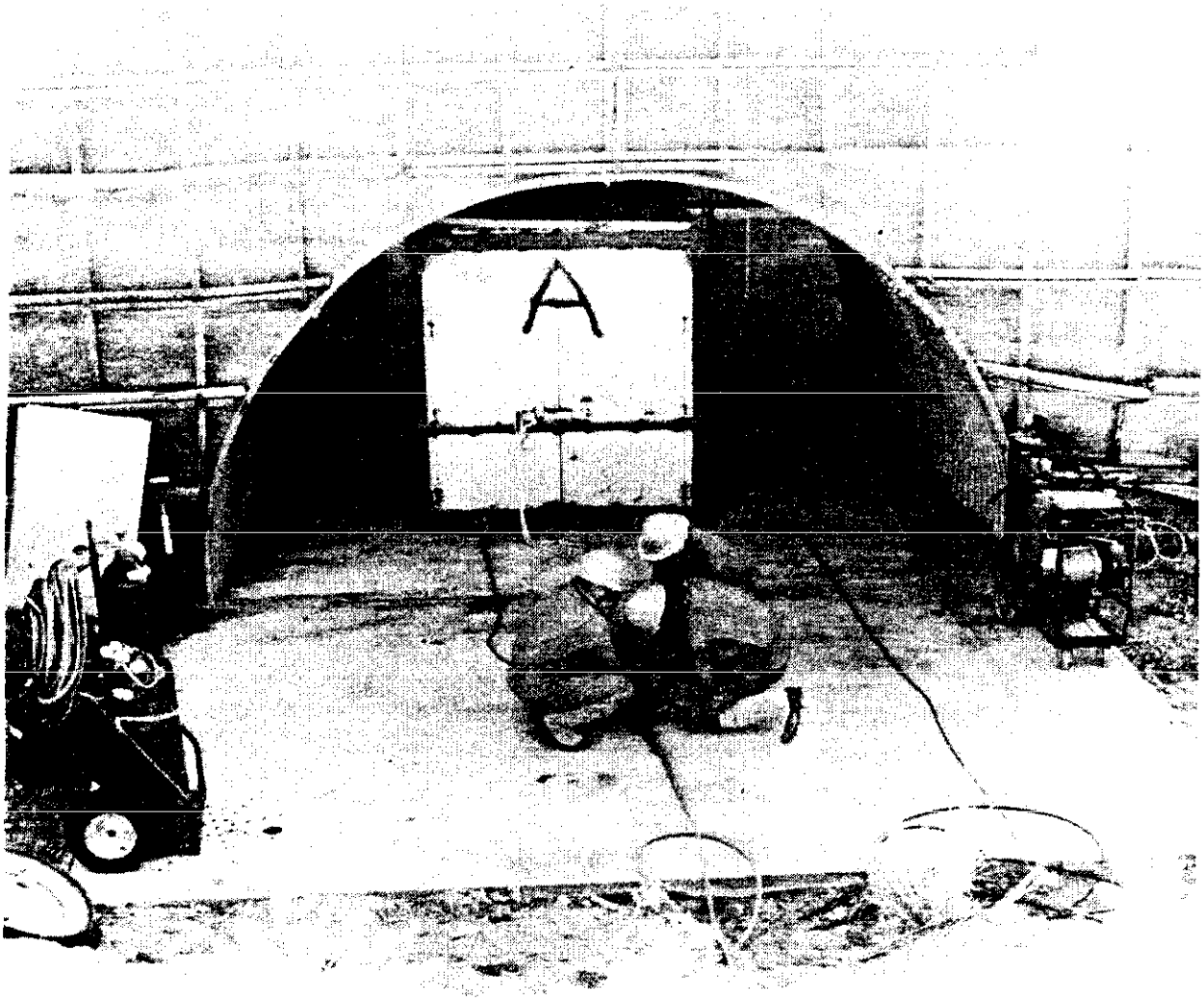
ARVFS is located approximately 1 mile due east of Lincoln Blvd., about 2-1/2 miles northeast of the Naval Reactor Facility (Figure 1). This remote location has neither electrical nor water service. However, a 230 kVA line runs past the site, 1/4 mile to the east; and 1/2 mile to the west is a water well, USGS 17. The Big Lost River is approximately 1 mile to the west.

ARVFS consists of an earth-covered bunker (Figure 2), a cylindrical test pit, and a metal shed covering the test pit (Figure 6). A cable trench (Figure 6) runs from the test pit to the bunker.

The bunker is an ARMCO multiplate arch building, 9 ft 3 in. high at the center, 16 ft wide and 18 ft long. It has a concrete floor about 9 ft below grade. Soil is mounded over the top of the building about 3 ft higher than the surrounding terrain.

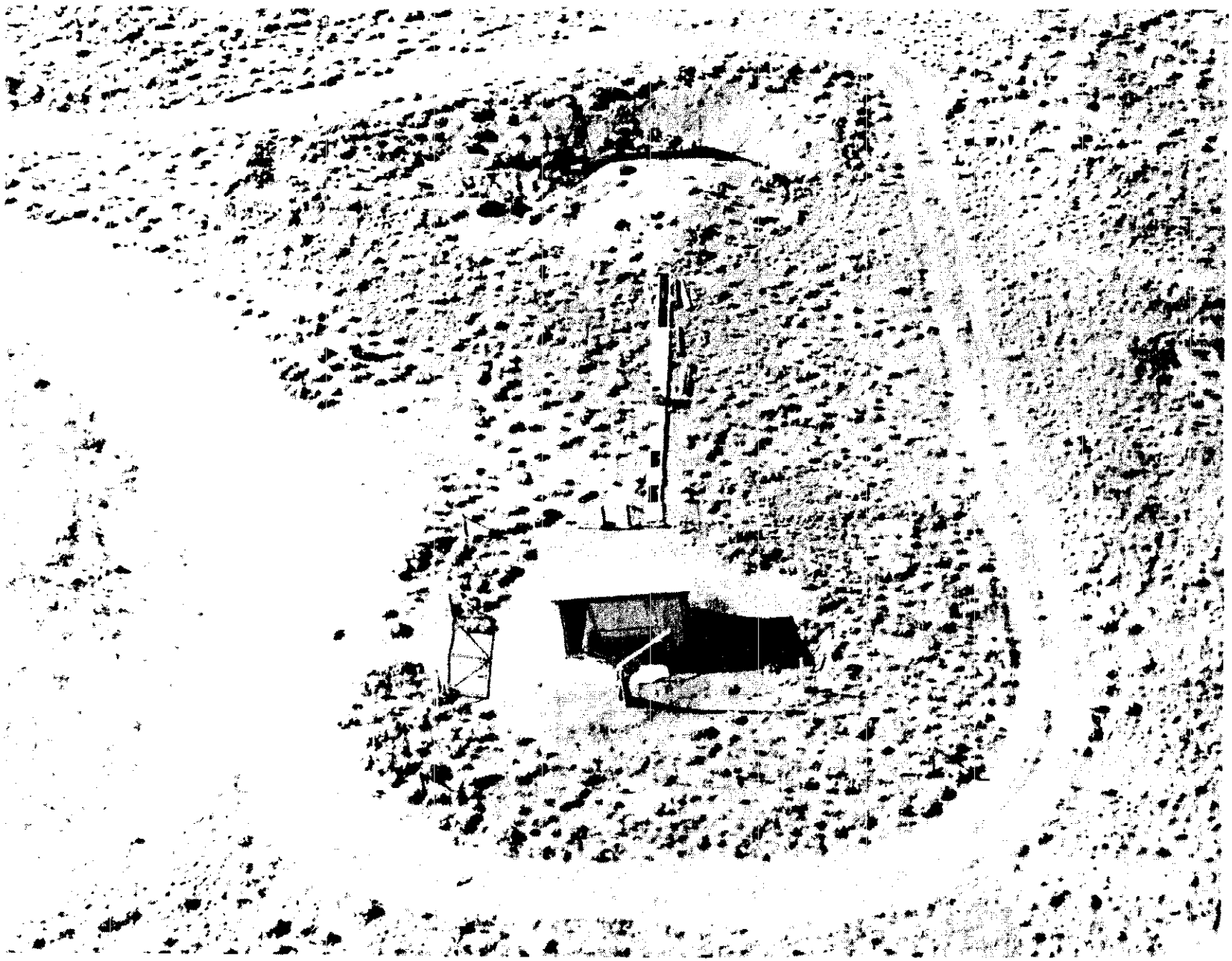
The cylindrical test pit is an open-top vessel made of 1/4 in A-36 structural steel. It has an inside diameter of 12 ft and is 16 ft deep.

The metal shed covering the test pit is a wood-frame structure, with corrugated sheet metal nailed to three sides and to the floor (Figure 7).



79-7187

Figure 5. Dumpster containing NaK drums and containers in ARVFS bunker.



83-574-11-3

Figure 6. Aerial view of ARVFS looking to the west.

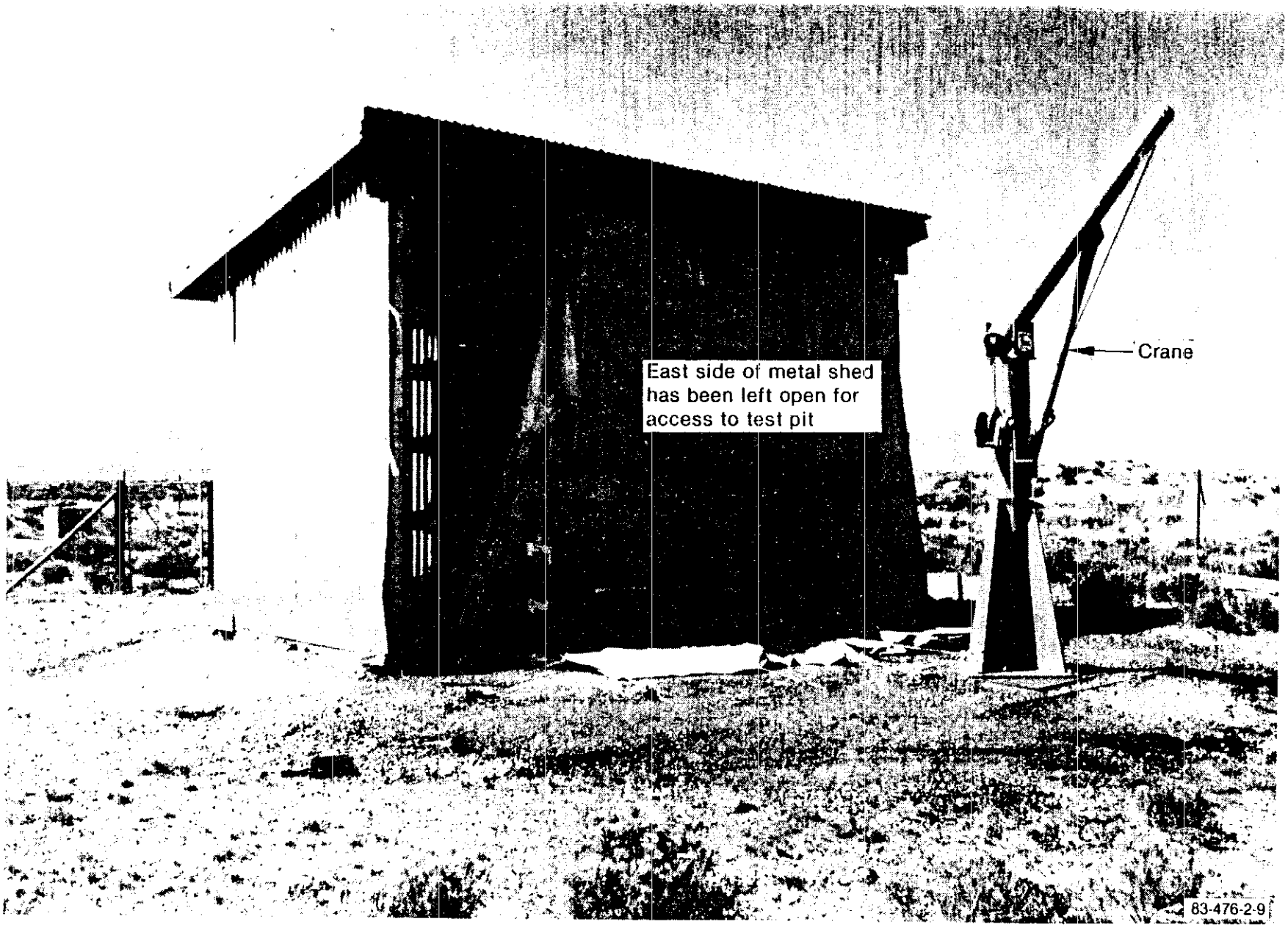


Figure 7. Metal shed covering test pit.

The hand-operated crane, seen in Figure 7 in front of the shed, has since been removed and excessed. The metal shed is 9 x 17 ft and about 8 ft high. The open side has been covered with a wood frame and plastic cover.

The cable trench, approximately 100 ft long, runs from the west side of the test pit to the bunker (Figure 8). The trench is 1.5 ft high and 1 ft wide, and is made of concrete.

1.3.2 Chemical Hazards

The chemical hazards associated with NaK have been described in detail in an Engineering Design File (EDF) document, Appendix B. The EDF addresses toxicity, fire, and explosion hazards. It also addresses potential contaminants in NaK, which may not actually be present, but which possibly exist in the NaK, particularly potassium superoxide (KO_2).

Probably the most significant chemical hazard is the explosive capability of NaK if exposed to air and allowed to form KO_2. The superoxide is extremely oxidizing and can cause thermal explosions, deflagrations, or detonations, depending upon reactant materials. Reaction of KO_2 with NaK is a thermite-type reaction, producing no gaseous products. However, the reaction is extremely exothermic and could possibly vaporize excess NaK which could lead to an increase in pressure.

NaK is a toxic substance and, as explained in Appendix B, will readily attack living tissue because of the moisture and oxidizing potential of living tissue.

It is possible that air has infiltrated one or more of the containers since their original containment. Oxygen may react with the potassium present to form potassium superoxide, potassium peroxide, and potassium oxide. The sodium may react to form sodium oxide. The sodium and potassium oxides, which are essentially inert, could potentially crystallize in such a manner that KO_2 and KO are isolated from the bulk of the NaK. This isolation could be broken with movement or vibration of

Figure 8. Metal shed and cable trench at ARVFS looking east.

the containers. If the contaminants are present, they could react as described above if brought into sudden and immediate contact. Experiments are being conducted in conjunction with this program which expose NaK samples to air in order to determine if oxides could form through small leaks in the NaK containers.

1.3.3 Radiological Hazards

The radiological hazards associated with NaK have been addressed in detail in an EDF (Appendix A). This EDF utilizes the available radiological information from earlier surveys to assess the hazards that will likely be encountered at the time of processing. This EDF on radiological hazards is further supported by an EDF on exposure estimates (Appendix C). A summary of the findings of these two EDFs is provided in the following discussion.

The EDF on radiological hazards reevaluated the 1955 EBR-I meltdown and concluded that the dominant radiological hazard associated with the NaK processing was fission product contamination. Based upon core operating history and makeup, a calculated (maximum credible value) fission product inventory for the NaK was developed. The inventory is presented in Appendix A.

The EDF on radiation exposure uses the fission product inventory and data gathered from radiation exposure estimates made in 1974 and 1979 to project exposure estimates. These exposure rates are presented in Appendix C, which also estimates thicknesses of lead or soil required to establish the amount of time workers could spend in the high gamma field while remaining in compliance with EG&G Idaho Administrative Dose Guidelines.

2. DESIGN REQUIREMENTS

2.1 Functional Requirements

This project consists of building skid-mounted processing units to chemically deactivate the EBR-I Mark-II NaK with chlorine gas to produce sodium chloride (NaCl) and potassium chloride (KCl) salts. These skid-mounted units will also have the necessary equipment to enclose the NaK containers and remotely penetrate the NaK containers to allow for the processing of NaK.

The system will be designed so that, at the completion of processing NaK, the system can be easily dismantled and chemically deactivated of any residual NaK before its disposal as contaminated equipment. The system will be designed so that all wastes, including the NaCl and KCl radioactively contaminated product, can be disposed of under existing INEL and Department of Energy (DOE) waste acceptance criteria (Reference 6, 8).

Because of the radiological hazard associated with this project, the unit will be remotely/automatically controlled and operated to the greatest degree reasonably possible.

ALARA (as low as reasonably achievable) principles of radiation exposure to personnel will be of prime importance in design and operation of the processing.

2.2 Operational Requirements

The actual process flow rates, operating parameters, and control parameters cannot be specified at this time. Further experimental work is planned during FY 1988. However, it is believed that the NaK will be reacted in a batchwise manner with a depth of 1-2 cm being reacted at once.

The following discussion addresses the general operational requirements that can be identified at this point in the project cycle.

2.2.1 NaK Handling, Containment, and Moving Equipment

The NaK containers will be removed from the ARVFS bunker and placed into secondary containment. This operation will be accomplished through the use of INEL Maintenance's hoisting and rigging equipment. To reduce the possibility of a superoxide/NaK reaction, vibration and shock to the NaK containers will be minimized before placement into the secondary containment. The secondary containers will be evacuated and then blanketed with an inert gas (argon) prior to remote penetration of the NaK containers.

2.2.2 Reaction Systems

NaK will be introduced in a batchwise manner into the reaction vessel by means of a metering system. The reaction vessel will have necessary penetrations to allow for process flow lines and necessary instrumentation for temperature and pressure measurement.

The chlorine injection system will have necessary vaporization equipment and metering/control equipment capable of controlling chlorine flow. The chlorine injection system will be designed to feed the required amount of gas to the reactor within a time span of one minute.

Once initiated, the NaK processing will be continuous (24 hr/day) until the operation is complete. The system will therefore be designed for continuous operation. Should system shutdown be necessary, design provisions will be incorporated to allow safe shutdown and restart.

2.2.3 Ancillary System Requirements

The ARVFS bunker area has no services available onsite. Therefore, electrical power must be provided by portable electrical generators. Power should be available for process operations, control trailer requirements, and area lighting. Power generation will have immediate backup capability for safe shutdown of the processing equipment should failure of the power generation system occur.

Water, both potable and service, will be brought in and stored onsite.

Since operations are to be performed during summer months, it is not envisioned that process steam or fuel will be required.

Office, control room, lunchroom, and restroom space will be provided by the short-term rental of a trailer. Human wastes will be stored temporarily onsite during operations and then transported to Central Facilities Area (CFA) for waste treatment.

During all operations, the ARVFS bunker area will be closed to all but required personnel. The road to the bunker will be posted with INEL Security personnel to ensure that unauthorized personnel are not permitted into the area.

2.2.4 Process Control Requirements

Processing will be controlled (manually/automatically) from a remote microprocessor system located in the trailer.

The control trailer will be located behind an earthen berm and sufficiently removed from the processing area to ensure minimal radiological exposure to operating personnel.

2.2.5 Safety Equipment Requirements

Necessary continuous air monitoring (CAM) and remote area monitoring (RAM) equipment will be located in close proximity to the processing area to forewarn operating personnel of radiological leaks, should they occur. The quantity, type, and location of these components will be specified during Title II design.

In addition, chlorine and caustic metals detection equipment will be located in such a manner as to notify operating personnel should a system leak occur.

Necessary fire fighting equipment for NaK or chlorine fires will be provided during operations. Fire fighting equipment will be specified during Title II design by EG&G Idaho Safety and the INEL Fire Department. Necessary personnel training will be provided by these two organizations.

Two-way radio communications will be constantly available in the control trailer during operations to notify INEL organizations, should an emergency occur that requires assistance, e.g., ambulance service.

2.3 Related Work

No related work that will be impacted by, or cause impact to this project's performance is anticipated to be ongoing at the INEL.

2.4 Interfaces

Organizational interfaces for this project are defined in the project's D&D Plan. These interfaces include D&D Programs, Engineering and Project Management Directorate personnel, Quality, Safety, Procurement, Planning and Budgets, Security, and Radioactive Waste Management Complex (RWMC).

2.5 Situations Requiring Special Considerations or Attention

2.5.1 Access and Security Access

The ARVFS bunker is located in a noncontrolled access portion of the INEL. During operations, INEL security will control road access to the bunker area to restrict entrance except to authorized personnel.

2.5.2 Design Packages

This project is not covered under Davis-Bacon legislation. All construction and operations will be performed by EG&G Idaho personnel. Construction will be performed by EG&G Idaho maintenance personnel. For this reason, the Construction Design Package (CDP) will not need to be as formal as typically required for construction by outside contractors. The CDP will contain necessary engineering drawings and special conditions for the construction, Quality Control inspection, and system operability (SO) testing of the project.

2.5.3 Quality Level

All components for this project are Quality Level B. Special Quality inspection instructions may be required for certain components, and these requirements will be specified during title design.

2.5.4 Long-Lead Items

No items require over six-months lead time.

2.5.5 Safety Items

Special consideration should be given to location of all safety-related equipment. In particular, since the processing will take place outdoors, all radiological and hazardous materials detection equipment should be located to accommodate the prevailing wind patterns.

Since the process will be operated for 24 hr/day, the processing of all four NaK containers will be continuous/sequentially. Special attention must be given to area lighting to cover the process area, operator routes, and potential emergency routes, should an emergency arise.

The operation will be performed during a period when dry/fair weather is anticipated. This will be done to minimize the consequences should the

unlikely incident of a NaK leak occur. However, poor weather will not affect normal operations.

2.6 Applicable Design Codes and Standards

All work on this project will be governed by the latest edition of the following codes and standards.

2.6.1 Department of Energy Codes (Manuals)

1. DOE Order 5480.1A, Chapter XI, "Requirements for Radiation Protection"

2. DOE-ID Appendix 0550, "Standard Operational Safety Requirements"

3. DOE-ID Publication 12044, "Operational Safety Design Criteria Manual"

4. DOE-Order-ID-5700.6, "Quality Assurance"

5. IDO-10074, "INEL Transuranic Waste Acceptance Criteria"

6. DOE/ID-10112, "INEL Low-Level Radioactive Waste Acceptance Criteria"

7. DOE/ID-10112, "Report on Criteria for Packaging Low-Level Radioactive Waste for Receipt at the Idaho National Engineering Laboratory Radioactive Waste Management Complex"

8. INEL Architectural Engineering Standards

9. INEL Quality Manual for Construction

10. DOE Order 5820.2, "Radioactive Waste Management"

2.6.2 Code of Federal Regulations (CFR)

1. Title 29 CFR, 1910, "Occupational Safety and Health Standards"

2. Title 29 CFR, 1926, "Safety and Health Regulations for Construction"

3. Title 40 CFR 61, Subpart H

2.6.3 General Reference Codes

1. ASME Boiler and Pressure Vessel Code, Section III, Subsection NC

2. ANSI B31.1

3. DOE Hoisting and Rigging Manual

4. American Welding Society (AWS), D1.1, "Structural Welding Code"

5. National Institute for Occupational Safety and Health (NIOSH)

6. National Electrical Manufacturers Association (NEMA)

7. American Institute of Steel Construction (AISC)

8. Underwriters Laboratories, Inc., standards and directories of listed products

9. American National Standards Institute, ANSI-C2, "National Electrical Code (NEC)"

10. American National Standards Institute, ANSI-C2, "National Electrical Safety Code"

11. Uniform Building Code (UBC)

12. American Iron and Steel Institute, Cold Formed Steel Design Manual

13. American Society of Testing and Materials (ASTM)

    a. A53, "Pipe, Steel, Black and Hot Dipped Zinc-Coated Welded and Seamless"

    b. A120, "Pipe, Steel, Black and Hot Dipped Zinc-Coated (galvanized) Welded and Seamless, For Ordinary Uses"

    c. A185, "Welded Steel Wire Fabric for Concrete Reinforcement"

    d. A615, "Deformed and Plain Billet--Steel Bars for Concrete Reinforcement"

    e. A36, "Structural Steel"

    f. A276, "Stainless and Heat Resisting Steel Bars and Shapes"

    g. A479, "Stainless and Heat Resisting Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels"

h. A266, "Forgings, Carbon Steel, for Pressure Vessel Components"

i. A312, "Seamless and Welded Austenitic Stainless Steel Pipe"

j. A193, "Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service"

k. A194, "Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High Temperature Service"

l. A269, "Seamless and Welded Austenitic Stainless Steel Tubing for General Service"

m. A182, "Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service"

14. Uniform Plumbing Code

2.6.4 Other

1. EG&G Idaho, Inc., Quality Manual

2. EG&G Idaho, Inc., Safety Manual

3. OSHA 29 CFR 1926.901

3. NaK DECOMMISSIONING PROCESS DESCRIPTION

This section addresses the conceptualized processing scheme for the ARVFS stored NaK from entry into the ARVFS bunker through the processing of the NaK, and the subsequent decommissioning of contaminated processing equipment. The decommissioning of the ARVFS area will not be addressed in detail in this document, but has been covered in the D&D Plan (Reference 9).

3.1 NaK Handling Prior to Chemical Deactivation

Detailed discussion of this procedure can be found in EDF NAK006, Appendix D.

Prior to actual entry into the ARVFS bunker, a preliminary radiation survey will be made around the bunker entrance and steel closure plate to determine if any unanticipated contamination is present as compared to the readings from the 1979 EBR-I Mark-II NaK Bunker Inspection, Reference 5. After this preliminary inspection, the welded retainers on the steel closure plate to the bunker will be removed, and the closure plate will be lifted from the bunker entrance. The inside of the bunker will then be surveyed for radiation and leak tested for possible liquid metal contamination. If the radiation levels are as expected and the leak test indicates no leakage from the NaK containers, the dumpster will then be pulled out of the bunker. The lid will be removed from the dumpster, and the vermiculite and any residual sand will be vacuumed from the dumpster to expose the NaK containers. The vermiculite will be inspected to make sure it is not radioactively contaminated before it is disposed of in landfill.

The existing lifting frameworks and valve covers for the two MSA drums will be removed. New lifting frameworks will be attached and the drums will be lifted from the dumpster and then placed into their individual secondary containers. Prior to actual placement into the secondary containers, the drums will be cleaned, either mechanically or with compressed air, to remove any residual sand vermiculite or dirt. Figure 9 represents a conceptualized secondary container for the NaK containers as well as a conceptualized reactor vessel.

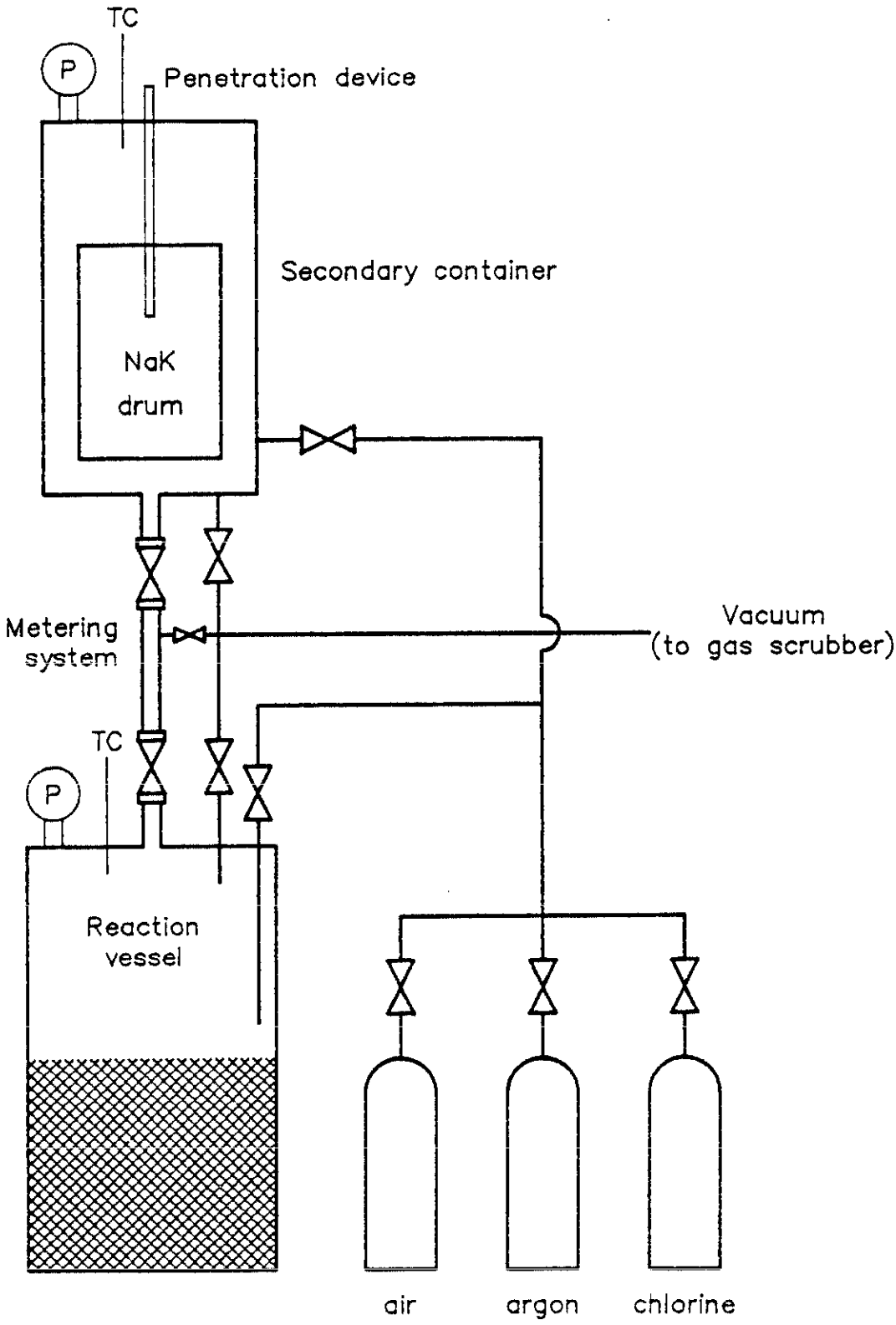


Figure 9. Conceptualized secondary container, metering system, and reactor vessel.

Once the secondary container is sealed, the secondary container will be evacuated and blanketed with argon gas. The NaK containers will be penetrated, both top and bottom with a remote penetration system to allow the NaK to drain. Figure 10 presents a diagram of the conceptualized penetration system. The remote penetration system consists of a rotating shaft and cutting bit which bores through the container from top to bottom. These two penetrations in the container should allow the NaK to drain from the container. Seals on the penetrator shaft have been shown to be satisfactory in preventing gas from escaping from the vessel. This remote penetrator was tested and proven during FY 1987. This procedure will be performed for all four of the NaK containers.

After a container has been penetrated, the motor drive will be removed from the secondary container for use on the other containers. A gasketed flange will be installed over the penetration access in order to provide an absolute seal should the secondary vessel experience any overpressure.

3.2 NaK Chemical Processing

A study was initiated to evaluate possible methods to accomplish the chemical deactivation of the contaminated NaK. The conclusions reached in this study were that the processing of the NaK with chlorine gas was the safest, would produce the smallest waste volume, and be the most cost-effective of the alternatives investigated. This evaluation is contained in EDF NAK001, Appendix E.

Chemical deactivation of NaK was demonstrated during experiments performed in FY 1987. These experiments were intended to determine the feasibility of converting the liquid metal to stable salts of sodium and potassium. Conclusions resulting from these experiments were that gaseous chlorine could be introduced to pooled NaK and produce a stable product consisting of sodium chloride and potassium chloride. These experiments showed that depths of up to 2 cm of NaK could be processed at a time, that total conversion to product is possible if the reaction is complete prior

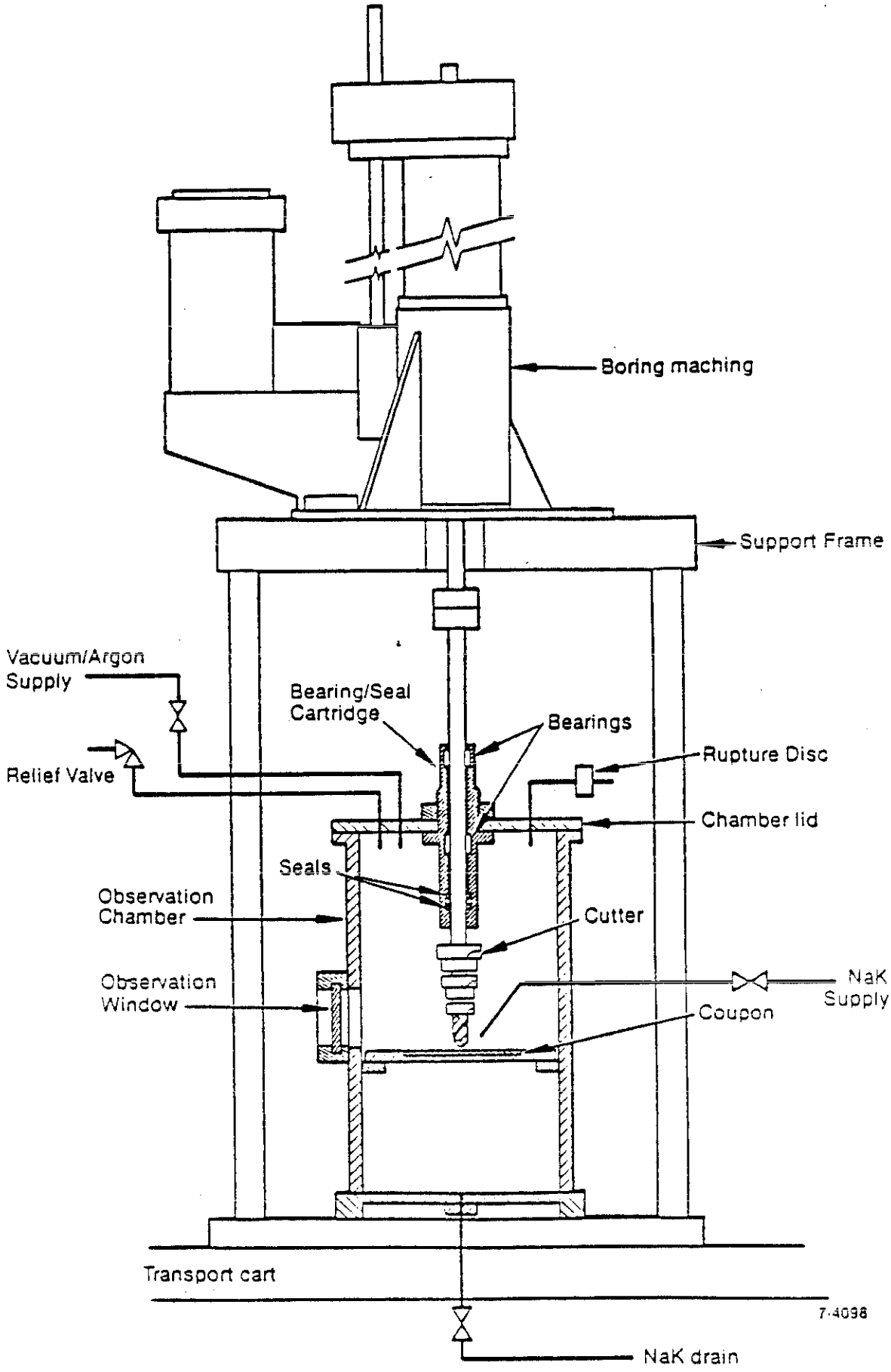


Figure 10. Penetration system proof-of-principle test set-up.

to solidification of the salt, and that small quantities of air (partial pressure of about 0.06 atm) lead to faster and more complete reactions.

Once the NaK containers have been penetrated and the liquid metal has been allowed to flow into the secondary container, the NaK is ready to be processed. The secondary containers will be pressurized with argon gas and the NaK will be pressure-fed as well as gravity-fed to the NaK metering system, in preparation for batch processing of the NaK.

The metering system, as seen in Figure 9, is comprised of two ball valves separated by a length of pipe. In order to meter NaK into the reaction vessel, the bottom ball valve will be closed and the upper ball valve will be opened, allowing the length of pipe to fill with liquid metal. Introduction of NaK to the reaction vessel will be accomplished by closing the upper ball valve and opening the bottom valve. A small amount of argon gas will be introduced to the metering system in order to facilitate the flow of NaK through the bottom valve. The bottom valve will be closed and the metering system will be evacuated in preparation for subsequent metering of NaK. This manner of injecting NaK into the reactor is a simple technique with a minimal possibility of plugging.

The reactor vessel, situated directly beneath the secondary container and metering system assembly, will be initially evacuated prior to the introduction of NaK. This will assist the flow of NaK from the metering system, and will prevent chlorine from the previous reaction sequence from entering the metering system. The NaK will be introduced as a thin layer covering the product of the previous reaction. Once the desired quantity of NaK has been introduced to the reactor vessel (to a depth of 1-2 cm), the bottom metering valve will be closed and the argon gas which entered the reactor vessel during the metering process will be evacuated.

Once the reactor vessel has been evacuated, chemical processing can begin. Approximately 1.0 psi oxygen or air (about 10 volume percent) will be introduced to the reactor vessel, after which chlorine will be

introduced to the reactor. Chlorine added will only be slightly in excess of stoichiometric; too much chlorine could lead to corrosion of the reactor vessel.

When it has been determined that the chlorine has reacted with the NaK, through temperature and pressure measurements, the excess chlorine will be evacuated from the reaction vessel. The integrity of the vessel will be verified by this procedure. The reactor will be allowed to cool sufficiently prior to introduction and processing of additional NaK.

Gases which are vented from the reaction vessel will be passed through a HEPA filter prior to venting to the atmosphere. Chlorine gas will be neutralized with a sodium hydroxide solution (to form a salt solution) prior to filtration. Since the gaseous chlorine will be completely neutralized, vented gases will be comprised of argon and air (or oxygen).

Chemical processing of the NaK will proceed continuously until each of the NaK containers has been successfully processed.

3.3 System Decommissioning

After completion of processing the NaK, any residual NaK contained in the secondary containment vessels, piping, filtration system, and NaK pump will be reacted with chlorine prior to disposal at appropriate radioactive waste sites. As of this writing a decision has not been made as to whether the wastes will be classified as Transuranic or Low-Level radioactive wastes. It is anticipated that this decision will be made prior to final design to permit design of vessels and components compatible with the applicable waste acceptance criteria.

The chlorine gas will pass through the various radioactively contaminated components, reacting with the residual NaK. After the completion of the chemical decommissioning of the radioactively contaminated components and piping, the residual chlorine gas in the system will be chemically reacted with sodium hydroxide (NaOH) prior to removal of

the reactor to its final disposition. The reaction system will be filled with a grout mixture to totally immobilize the solid product formed during the reaction process.

3.4 Preliminary Equipment Specifications

As of this writing the maximum credible pressure which the processing equipment must withstand has not been determined. It has been suggested that a reaction of NaK with KO_2 may occur, liberating heat which could vaporize some of the liquid NaK. It has been estimated that no vaporization will occur unless the sample is more than 13 percent KO_2. Since it is highly unlikely that KO_2 exists in this quantity within the storage containers, the process equipment will be designed to withstand a pressure of 200 psi, the vapor pressure of chlorine at 120°F.

3.4.1 Vessels

V-1A & 1B Secondary Containment for MSA drums

Design Pressure 200 psig @ 200°F
Carbon Steel
Wall Thickness 0.5 in.
26 in. OD X 61 in. Long

V-2 Secondary Containment for small fabricated container

Design Pressure 200 psig @ 200°F
Carbon Steel
Wall Thickness 0.5 in.
15 in. OD X 43 in. Long

V-3 Secondary Containment for large fabricated container

Design Pressure 200 psig @ 200°F
Carbon Steel

Wall Thickness 0.6 in.
35 in. OD X 61 in. Long

V-4A, 4B & 4C NaK Reactor for MSA drums and large fabricated container

Design Pressure 200 psig @ 1000°F
Carbon Steel, Ceramic lined (1 in. thickness)
Wall Thickness 0.5 in.
24 in. OD X 48 in. Long

V-4D NaK Reactor for small fabricated container

Design Pressure 200 psig @ 1000°F
Carbon Steel, Ceramic lined (1 in. thickness)
Wall Thickness 0.5 in
24 in. OD X 16 in. Long

V-5 Chlorine Surge Tank

Carbon Steel - Phenolic Resin Lined
Design Pressure 200 psig @ 100°F
Jacketed (Carbon Steel)
36 in. ID X 46 in. Long

V-6 Chlorine Storage

Leased

3.4.2 Pump

C-1 Vacuum Pump

Air 10 SCFM (max.)
1 Hp 220v/60Hz

Suction Pressure (min.) 5 in. water
Discharge Pressure 14 psia

3.4.3 Heat Exchangers

E-1 Chlorine Vaporizer

Hot Water on Steel (Carbon Steel)
Stainless Steel Helical Coil (1/2 in.)
Heat Duty 81,000 Btu/hr

3.4.4 Filters

F-1 HEPA Filter

Air/chlorine
10 micron

F-2 Vacuum Pump Filter

Air (10 SCFM)
10 micron (Fiber)

3.4.5 Ancillary Equipment

Electrical Generators (2) (Leased or Borrowed)

20 kW 200v/60Hz
500 gallon Fuel Tank

Trailer (Control Room) (Leased)

60 ft X 12 ft

Portable Restrooms (2) (Leased)

Portable Area Lighting

5 poles @ 1500 watts/ea.

Portable Potable Water

500 gallon Tank with 1/2 Hp Pump

Process Control System (2)

IBM System II or equivalent with Printer and Color Monitor

3.5 Service Requirements

3.5.1 Water Requirements

Water, both potable and service, will be provided by trucking in water and pumping into the Chlorine Vaporizer and the Potable Water Storage Tank. Anticipated water needs are 600 gallons (service water) and 1,000 gallons (potable water).

3.5.2 Electrical Requirements

Electrical power will be supplied by two portable diesel generators (40 kVA Caterpillar MG-480 v/3-phase with automatic frequency control) available from the INEL equipment pool.

Anticipated electrical power requirements are as follows:

Item	Quantity	Pwr/ea	Total
Electrically operated valves	25	0.1 kVA	2.5 kVA
Flow control valves	4	0.1 kVA	0.4 kVA
Heating tapes	10	0.5 kVA	5.0 kVA
Pump - vacuum	1	1.0 kVA	1.0 kVA
Trailer lights & power	1	10.0 kVA	10.0 kVA
Potable water system	1	0.5 kVA	0.5 kVA
Process control system	2	0.1 kVA	0.2 kVA
Area lighting	5	1.5 kVA	7.5 kVA
Portable detectors	10	0.5 kVA	5.0 kVA
Communication & alarms	--	0.5 kVA	0.5 kVA
		Estimated Total	32.6 kVA

3.6 Manpower Requirements

The operations at the ARVFS bunker are anticipated to take from 6 to 12 days. The site will be manned continuously during the chemical processing. Three shifts will provide the needed manpower and they will be comprised of at least the following types of personnel:

Technical Supervisor	1/shift
Operators	2/shift
Health Physicist	1/shift
Gate Security Person	1/shift
Total/shift	5

Additional manpower during daylight operations or as required are the project manager, the lead engineer, and the safety engineer.

Personnel requirements during the rigging operations and the D&D operations to the process system and the ARVFS bunker will be determined by planning after receiving necessary Site Work Release (SWR) information.

4. ALTERNATIVES

Alternatives to processing the NaK stored at the ARVFS bunker were investigated in 1982 and resulted in an internal report, "Decision Analysis for NaK Stored in the ARVFS Bunker", Reference 1. The summary from this report is presented below.

The decision analysis (D.A.) for the radioactive NaK stored in the ARVFS bunker at the INEL describes the factors considered for recommending a preferred mode for the continued storage or processing of the stored NaK. The D.A. includes evaluations for complete processing of the stored NaK, processing to reduce the radiation contained in the NaK, and various activities related to continued storage of the NaK.

The contaminated NaK, containing spent fuel fragments and fission products, resulted from the meltdown of the EBR-I Mark-II core in November 1955. The highly radioactive NaK was transferred from the core region into four storage containers: two MSA 55 gal drums and two containers fabricated from pipe sections. Details of this transfer activity are unavailable. The total volume is approximately 180 gallons and may contain 10.5 grams of plutonium. The four NaK containers were stored in an EBR-I storage pit until 1974. At that time, they were removed from the storage pit and placed in a steel dumpster; the dumpster was filled with sand and transported to the ARVFS bunker for interim storage (Reference 4).

An inspection of the bunker, the dumpster, and the exterior condition of the NaK storage containers was completed in August 1979. Characterization data obtained are summarized in this report (Reference 10).

The methodology used to develop a proposed recommendation involved a review of the advantages and disadvantages for each of seven alternatives considered; these alternatives are:

Alternative 1--Process the stored NaK

Alternative 2--Transfer the NaK into new storage containers for long term storage

Alternative 3--Relocate the NaK to above-ground storage

Alternative 4--Transfer the NaK from fabricated containers to MSA drums

Alternative 5--Process the NaK with a cesium gettering system

Alternative 6--Encase the existing NaK containers

Alternative 7--Do nothing.

Within the above alternatives, the D.A. identifies the significant radiation exposure potential, alkali metal handling hazards (including the assumption that potassium superoxide exists within the storage containers), processing system equipment and methods, and possible modes for continued storage. Considerations which must be evaluated for a processing site or for the design of complex processing systems are beyond the scope of this report.

Of the seven alternatives considered, Alternative 1 (process the stored NaK) is recommended. This alternative would involve the selection of a processing site, the design, construction, and testing of a processing system, processing the contaminated NaK, and the shipment of all wastes to approved INEL disposal locations. The required documentation, design and safety studies would be completed prior to the construction and operation of the processing system. This alternative would completely process the stored NaK and best meet the objectives considered in the decision analysis because all hazards would be removed and no future remedial action would be required. The program required for the performance of this alternative can be scheduled over a two-to-three year period to minimize funding and EG&G organizational impacts without significant increase in risk.

5. OUTLINE SPECIFICATIONS

The following specifications, derived for cost-estimating purposes, do not serve as a commitment for design. They are subject to change.

5.1 Architectural/Structural

5.1.1 Excavation

Excavation will consist of common excavation. Excavation material not required for backfilling will remain at the site for use during the D&D operations to be performed on the ARVFS bunker at the completion of the NaK processing.

5.1.2 Backfill

All backfill material shall be free from trash, organic material, and frozen particles. All backfill shall be compacted to 75% of maximum density at optimal moisture content, as determined by the American Association of State Highway and Transportation Officials (AASHTO), Method of Test T-99.

5.1.3 Concrete

None.

5.1.4 Structural Steel

Structural steel and miscellaneous metals shall conform to ASTM A36 and AISC. It shall have one shop coat of rust-inhibiting metal primer.

5.1.5 Painting

One primer coat and two finish coats shall be applied to all painted surfaces.

Exposed piping and conduit shall be defined and identified in accordance with the American Standards Scheme for the Identification of Piping Systems A13.1, and IDO-12028.

5.1.6 Protective Coatings

The coating shall be epoxy-type, contamination-resistant coating. It shall be Amercoat or an approved equal. Surfaces shall receive at least one coat of primer and two top coats.

5.2 Instrumentation and Controls

Instrumentation and control systems shall be grounded and located in the control room trailer.

All instrumentation, control, and communication equipment shall be sufficiently protected, shielded, and isolated from electrical noise. A single point grounding system shall be used to reduce noise interference. The wire runs, conduit, and wireways for the instrumentation and control wiring shall be separated from the power wiring systems.

5.2.1 Process Monitoring and Control

Control equipment and necessary signal conditioning equipment shall be installed in the control trailer. Control and signal-conditioning equipment shall be rack-mounted and laid out within human engineering guidelines.

Control equipment shall be digital, microprocessor-based where possible, with an emphasis on reliability and accuracy. An operator annunciator system shall be installed in the control trailer with additional annunciators located throughout the ARVFS area.

5.2.2 Communication Systems

Two way radio system will be installed in the control room to allow for constant contact with INEL security and the Fire Department.

5.3 Electrical Systems

The installation shall comply with the applicable parts of the latest National Electrical Code (NEC). All equipment and material shall be manufactured and tested in accordance with the latest applicable standards of the Institute of Electrical and Electronic Engineers (IEEE), the National Electrical Manufacturer's Association (NEMA), and the Underwriters' Laboratories, Inc. (UL).

Power will be supplied by one 40-kVA generator. Provision will be made for sufficient backup capability for safe shutdown of the processing equipment should the primary system fail.

5.3.1 Lighting

Sufficient area lighting will be installed to meet OSHA and INEL requirements.

5.3.2 Wiring and Devices

All wiring and devices shall be UL-listed and installed in accordance with NEC requirements.

Wiring systems shall be separated according to voltage and electrical noise requirements. Additional grounding capacity shall be added to all power services to electrically noisy equipment. Instrument and Control wiring shall not be combined with power wiring. A separate grounding system (single-point) shall be provided for each system.

5.4 Piping

5.4.1 Carbon Steel Piping Systems

The piping and fittings shall be carbon steel conforming to ASTM A53 Grade B.

5.4.2 Stainless Steel Piping Systems

The piping and fittings shall be welded/flanged construction of stainless steel type 304L.

6. SECURITY REQUIREMENTS

The ARVFS bunker area has no security other than the security perimeter surrounding the INEL. INEL security personnel will be stationed at the ARVFS bunker turnoff road from Lincoln Boulevard to prevent entrance to the area by unauthorized personnel during operations. The security personnel at the road will have two-way communications established between INEL security and the NaK processing control trailer.

7. PRELIMINARY SAFETY EVALUATION

This preliminary safety evaluation identifies and summarizes the hazards and risks associated with this project as identified at this phase of the design cycle. Each hazard is described, and the appropriate safety measure to minimize the hazard is developed. Recovery measures to be used, should an unpredicted incident occur, are also described. The administrative controls developed to ensure safe working conditions and practices are discussed.

A Preliminary Safety Analysis Report (PSAR) will be prepared as Title I design nears completion. A Final Safety Analysis Report (FSAR) will be published after prototype testing and prior to processing of the NaK. The PSAR will benefit not only from design work, but also from laboratory and development work completed during FY 1987, and testing work during FY 1988. The SAR will describe the hazards (including the possibility of thermal explosions, NaK or chlorine leaks, fires, and admixture reactions), the probability and consequences of such events, and the barriers and controls to be employed to reduce the probability or consequences of such events.

7.1 Industrial Health and Safety

All work will be conducted in accordance with established regulations in effect at the INEL, including, but not necessarily limited to, ID Appendix 0550, IDO-12044, DOE Order 5480.1A , the EG&G Safety Manual, the EG&G and DOE Hoisting and Rigging Manual, and the Occupational Safety and Health Act of 1970. Area health and safety personnel will be assigned to the project to evaluate the safety and health aspects of the operations for protection of property and personnel involved in the operations.

Cranes and hoisting operations will meet the EG&G and DOE Hoisting and Rigging Manual requirements.

Any hazardous material will be transported according to the EG&G Safety Manual, Section 19 and in compliance with DOT regulations. Radioactive material will be transported according to the EG&G Safety Manual, Section 13.

7.2 Hazards Associated with the NaK Processing

The hazards of processing the NaK have been addressed in EDFs and are available as appendices to this report. Work will be performed under the review and guidance of the Safety and Environmental Programs, and appropriate safety measures will be developed and implemented as they are identified.

All operators and supervisory personnel will be required to attend NaK training sessions that will be conducted by Safety and Environmental Programs prior to performing the processing. Only those personnel so trained will be allowed access to the area during ongoing operations.

7.2.1 Electrical

Electrical power for the operations will be provided from portable generators. Backup systems will be immediately ready should a problem arise with the primary power generator. To prevent system shutdown should a temporary power failure occur, critical process instrumentation and the process control system will have emergency battery backup.

7.2.2 Hoisting

The hoisting hazards associated with equipment failure, incorrect rigging procedures, and inadequate operating procedures may be encountered. Measures will be implemented to minimize risks from hoisting hazards. Lifting instructions and/or detailed procedures with rigging sketches will be included in engineering work packages that involve lifting large equipment or hazardous items. The job foreman for hoisting operations will be a rigging specialist who will ensure compliance with the EG&G and DOE Hoisting and Rigging Manual.

7.2.2.1 Equipment Adequacy. To ensure equipment adequacy, the crane, hooks, cables, and other lifting apparatus used will have current certification of load testing and periodic inspections per the EG&G and DOE Hoisting and Rigging Manual, Section VII. The person in charge of the lift will verify this certification prior to use of crane and associated lifting apparatus. The person in charge will ensure that the slings are sized adequately for the load.

7.2.2.2 Procedures. The EG&G and DOE Hoisting and Rigging Manual will be adhered to strictly in the procedures to be followed during hoisting and rigging operations. All equipment operators and riggers will be fully qualified for the particular equipment and load being rigged for hoisting.

7.2.3 Radiation Exposure

To prevent undue worker exposure, all D&D site operations personnel will be trained radiation workers and respirator-trained. This ensures familiarity with radiation hazards and procedures for work performance in radiation fields.

All D&D work performed will be under HP technician and Safety Engineering surveillance. Constant air monitors (CAMs) will be operating continuously, sampling air near the work location and downwind from the area in which work is being performed. Personnel working in the contamination area will wear anti-C clothing, protective respiratory equipment and appropriate radiation dosimetry. Components producing significant radiation fields in an area will be removed or shielded as soon as possible to reduce the working field during removal of remaining components.

Should any D&D operation expose NaK outside the reactor vessel or other containments, the operation will be stopped, until the source of the leak can be identified and corrected. Any leak will be surveyed for radiation hazards, and removed before continuing operations. If periodic

smearing reveals the presence of contamination levels that present a hazard, D&D work will stop, and the contamination will be cleaned up before work progresses.

All tasks in this project will be covered by approved engineering work packages. Every practical provision will be included in work instructions and procedures to incorporate the ALARA philosophy of personnel radiation exposure. Guidance on maintaining exposures to ALARA levels is given in the EG&G RAD CON Manual, Chapter 3. Provisions shall be included in the instructions and packages to ensure that the maximum allowable personnel radiation dose is not exceeded. If a CAM indicates the presence of airborne activity that exceeds allowable limits, the work area will be evacuated until the activity abates or workers equipped with appropriate respiratory protection can remove the source of air activity.

As a minimum, workers will survey themselves for contamination before their shift (as a baseline only), before taking breaks, before leaving the work area, and again at the end of their shift.

7.3 Hazards Associated with Natural Phenomena

7.3.1 Earthquake

Earthquake hazards are extremely remote. If an earthquake should occur during D&D operations, the work will stop and the hazardous work area will be evacuated immediately, after safe shutdown; work will later be resumed after assessment of the working conditions. The probability of an earthquake occurring during the D&D operations is extremely low, but it exists. Some of the probable consequences of an earthquake occurring are discussed here to identify the associated risks. The major risk is a hoisting incident. If an earthquake should occur during a hoisting operation, the load could possibly sway enough to lose its rigging and drop. Because of the swaying of the load, the falling material could possibly hit someone. Damage and/or shock to the containers could also

result in extreme conditions such as an explosion or fire. Probability of an earthquake occurring during the movement of the containers is extremely small.

The INEL is located between the Intermountain Seismic Belt to the south and east and the Central Idaho Seismic Belt to the north. There is evidence of seismic activity near the INEL within recent geological times. Prior to the 1983 Mackay earthquake, the most recent activity of large seismic-induced displacements near the INEL have been placed at 4,000 to 30,000 years ago . This conclusion was based on geological studies of the Arco and Howe scarps. In a review of this data during 1972, the largest earthquake that may be expected to occur near the ARVFS was determined not to exceed magnitude 7 (Richter scale). This was based on the nearest active fault, the Arco scarp, with an epicenter assumed to be approximately 16 miles from the ARVFS.

During the seismic analysis period of the 1970s, the INEL was within a Uniform Building Code (UBC) Seismic Probability Zone 3. The seismic zone is now 2. The change from a Seismic Zone 3 to 2 was approved at the International Conference of Building Officials meeting of October 8, 1981.

In a previous safety analysis of an operating TRA facility (the Sodium Loop Safety Facility Hazards Assessment), a major earthquake which would normally cause some structural damage was postulated to have an unlikely probability of occurrence. Experience observed during the 1983 Mackay earthquake showed only minor structural effects on INEL facilities.

7.3.2 Flood

7.3.2.1 Excessive Runoff. Runoff from snowmelt in the Lost River and Lemhi Ranges drains onto the INEL via three drainages: the Big Lost River, the Little Lost River, and Birch Creek. The Big Lost River channel runs between the TRA and the Idaho Chemical Processing Plant (ICPP) to the north towards TAN; the closest approach to ARVFS is one mile away. Often this channel is dry. Birch Creek feeds towards TAN and the large depression in

the northern part of the INEL. Thus, flooding from the Birch Creek drainage is not a problem to this project because the ARVFS is on much higher ground. The Little Lost River drains east to an area northeast of ARVFS and is located in a depression relative to ARVFS.

The primary concern is the possibility of flooding from the Big Lost River. ARVFS is located about one mile from the Big Lost River. Two dams are located on the river upstream of ARVFS: the Mackay Reservoir, about 50 miles upstream from the ARVFS, and the INEL flood diversion dam, about 10 miles upstream from the ARVFS. Several factors can influence and amplify the conditions for flooding: remaining reservoir capacity, snowpack, climatic change and ground conditions affecting seepage. Assuming the reservoir is full, a very large snowpack, a rapid warming trend, and the ground still frozen (eliminating seepage losses), the river channel could overflow. The INEL flood diversion facilities consisting of the dam, dikes, and spreading areas to the south have been designed to divert a Big Lost River flood away from the INEL facilities under normal flood conditions. Weather conditions will be of primary concern in scheduling the actual processing operations. Since the NaK will react violently with water, it is imperative that the processing takes place during dry weather should a leak in the system occur.

In the Preliminary Safety Analysis Report (PSAR) for the Sixth ICPP Calcined Solids Storage Facility (CSSF) (see Reference 10), the worst-case flooding conditions at the ICPP were shown as a probable maximum precipitation storm occurring between the Diversion Dam Facilities and the ICPP. This would be in the form of a large thunderstorm developing into two to three inches of rainfall for about a one-hour duration, which could lead to a flash flood in the Big Lost River channel. Maximum crest of the flooded river was shown to be after about two hours, with a flow rate of approximately 35,000 cfs. The flooded water elevation was found to just reach the building complex of CPP-601/602 which has an elevation of 4915.7 feet above sea level. Since the nominal elevation at ARVFS is approximately 4830 feet above sea level, it is likely that the probable maximum precipitation storm could cause flooding at the ARVFS, since no major topographic highs exist

in the immediate area to the south of ARVFS. Although an earth berm exists near the bunker, the maximum precipitation storm would likely inundate the bunker area if additional berms were not put in place. This again makes it imperative that the processing be scheduled during dry warm weather. July through October is the driest portion of the year and the likely window for processing to take place.

7.3.2.2 Dam Failure. Failure of the INEL Diversion Dam Facilities and the Mackay Reservoir dam are considered. The Diversion Dam Facilities include the dam, four flood water impounding areas (A, B, C and D) and connecting channels. Impounding areas A and B require dikes to retain the water. According to the Sixth CSSF PSAR, failure of dike 2 at impounding area B is more critical than dike 1 at impounding area A. Further, the resulting river flooding condition was found to be essentially the same as the postulated probable maximum precipitation flood; hence, this failure event could also cause flood waters at the ARVFS.

Failure of the Mackay Dam has been studied by the US Geological Survey. The Mackay Dam is an earthen dam, about 80 feet high and approximately 1968 feet long at dam crest on the Big Lost River 4.5 miles northwest of Mackay, Idaho. The reservoir behind the dam contains 1.93 million cubic feet of water at spillway crest. The dam was built in 1905. The study results are considered valid downstream only to above the diversion dam, due to inadequate knowlege of flood plain geometry below the diversion dam. At a distance of 2.6 miles above the diversion dam, the peak discharge for a full breach was calculated to be about 54,000 cfs. In the ICPP PSAR for the Sixth CSSF, it was shown that a flood of about 81,000 cfs would be necessary to flood CPP 601/602. Such an event would be a cause of concern for probable flooding at ARVFS.

7.3.3 Lightning

As previously noted, scheduling of the activities will be done taking into account applicable weather forecasts. The potential for accidents from a lightning strike should be minimized. However, an anomalous

thunderstorm could occur that may create a concern. Rigging and hoisting will not be initiated when a potential lightning hazard exits. If lightning should strike any part of the operation, an evaluation of the damage will be made prior to resumption of work.

7.3.4 Tornado and/or High Winds

Work will be terminated on the project any time tornado or high wind warnings are in effect at the INEL. Evaluation of any damage will be made prior to resumption of work. Hopefully by scheduling the processing of the NaK only during favorable weather conditions, the likelihood of such events will be minimized.

7.4 Administrative Controls

7.4.1 Training

Personnel working on the D&D project will receive standard EG&G safety training applicable to the tasks involved. This training includes:

1. Radiation worker training
2. Respirator training
3. Initial safety meeting to acquaint workers with hazards of work.
4. Work instructions and/or procedures reviewed and discussed with involved personnel prior to performance.
5. Daily meetings to identify job progress, future tasks, and potential hazards of upcoming work.
6. In addition to the standard safety training, all personnel will be required to be certified in NaK safety training. This course will be taught in advance of other operational training.

7.4.2 Site Work Release

All work performed by EG&G crafts will be covered by a Site Work Release (SWR). A SWR contains the written description of the work to be performed along with drawings, instructions, procedures, and other support material to allow a qualified craftsman to complete the job within normal supervision standards.

7.4.3 Safe Work Permits

A safe work permit (SWP) will be required for all jobs involving radiation safety. The criteria for use of a SWP are specified in the EG&G RAD CON Manual, Chapter 7. A required SWP will be processed at the beginning of each phase of the operations where appropriate.

8. ENVIRONMENTAL DOCUMENTATION

The processing of the NaK and return of the ARVFS bunker to a reusable condition will remove a significant radiological hazard from the INEL, and convert this hazard into a safe disposable form. This activity will, however, not be performed without some environmental concerns. At this time, due to the conceptual state of the project, these concerns cannot be addressed in detail. With the information from the developmental laboratory work, an environmental evaluation for the prototype test was prepared. A final evaluation will be prepared in the same time frame that the Safety Analysis Report will be updated to incorporate final design information.

In terms of summarizing potential environmental concerns at this time, it is recognized that the NaK processing will result in the transformation of TRU waste mixed with NaK to a stable salt form for disposal.

This project may require minor short-term adjustments to the environment (e.g., modifications to an existing berm at ARVFS). Any short-term alterations to the site will be returned to their "near-natural" state upon completion of the processing and the decommissioning of the ARVFS facility.

This project is not anticipated to result in any change in noise levels, air emissions, or liquid effluents. The NaK in its present form contains 2400 nCi/g of transuranic (special nuclear classified) material. The NaK is included under the Resource Conservation and Recovery Act (RCRA) as a hazardous mixed waste, according to the most recent guidance from DOE-HQ legal office.

Suggested alternatives that might be addressed in the environmental evaluation are:

1. Process the NaK as proposed

2. Process the NaK by some other technique (addressed in Reference 1)

3. Transfer the NaK into new storage containers (addressed in Reference 1)

4. Do nothing (addressed in Reference 1).

These alternatives have received a thorough analysis and option 1 is the only reasonable course to follow.

9. COST ESTIMATE SUMMARY

Cost estimates for the title design, procurement, and fabrication of the project are summarized in Table 1, EG&G Form-1589. Cost details are in Appendix G. However, the laboratory process development, conceptual design studies, environmental permit, and project administration costs are not included here.

TABLE 1

EG&G Idaho

FORM EG&G 1560
(Rev. 11/85)

COST ESTIMATE SUMMARY

Type of Estimate: Conceptual File No.: 8084 Date: 7-24-86

Project: ARVFS NaK D&D

Prepared By: A. R. Millward Checked/Approved By:

	Unescalated	Escalation		Totals:
Engineering, Design and Inspection Subtotal (19 % of construction costs)				104,000
Performance Specification				
Title I and II Design	90,000	3,500		
Title III Inspection	10,000	500		
Construction Costs Subtotal				189,000
Direct/Indirect Costs:			189,000	
4000 Improvement to Land	20,000	1,000		
5000 Buildings/Structures				
6000 Utilities				
7000 Equipment	160,000	8,000		
8000 Demolition and Removal				
Indirect Costs:				
Construction Management				
Field Engineer and Construction Management				
Construction Management Reserve				
Government Furnished Equipment/Materials Subtotal				369,000
Purchased By—(CM)				
Purchased By EG&G	310,000	15,000		
Procurement Fee	42,000	2,000		
Project Administration Costs Subtotal				
Project Management				
Project Support				
Subtotal:				662,000
Contingency (30 % of Subtotal)				198,000
Escalation: (included in above Totals)		30,400		
			Total Estimated Cost:	860,000

Comments: Project Administration will be funded by other funding means.
Construction labor will be done by EG&G site crafts.

10. METHOD OF ACCOMPLISHMENT

The method of accomplishment for this project is discussed in detail in "Decommissioning and Decontamination Plan for Processing the Contaminated NaK at the INEL," Reference 9. Figure 11 presents the management structure in place to accomplish this project, and Figure 12 presents the Work Breakdown Structure (WBS) for the project.

The design, procurement of equipment, inspection, and project administration will be performed by EG&G Idaho. Design, construction, and inspection will be performed in accordance with the guidelines of the EG&G Quality Manual and the EG&G Engineering Standard Practices Manual.

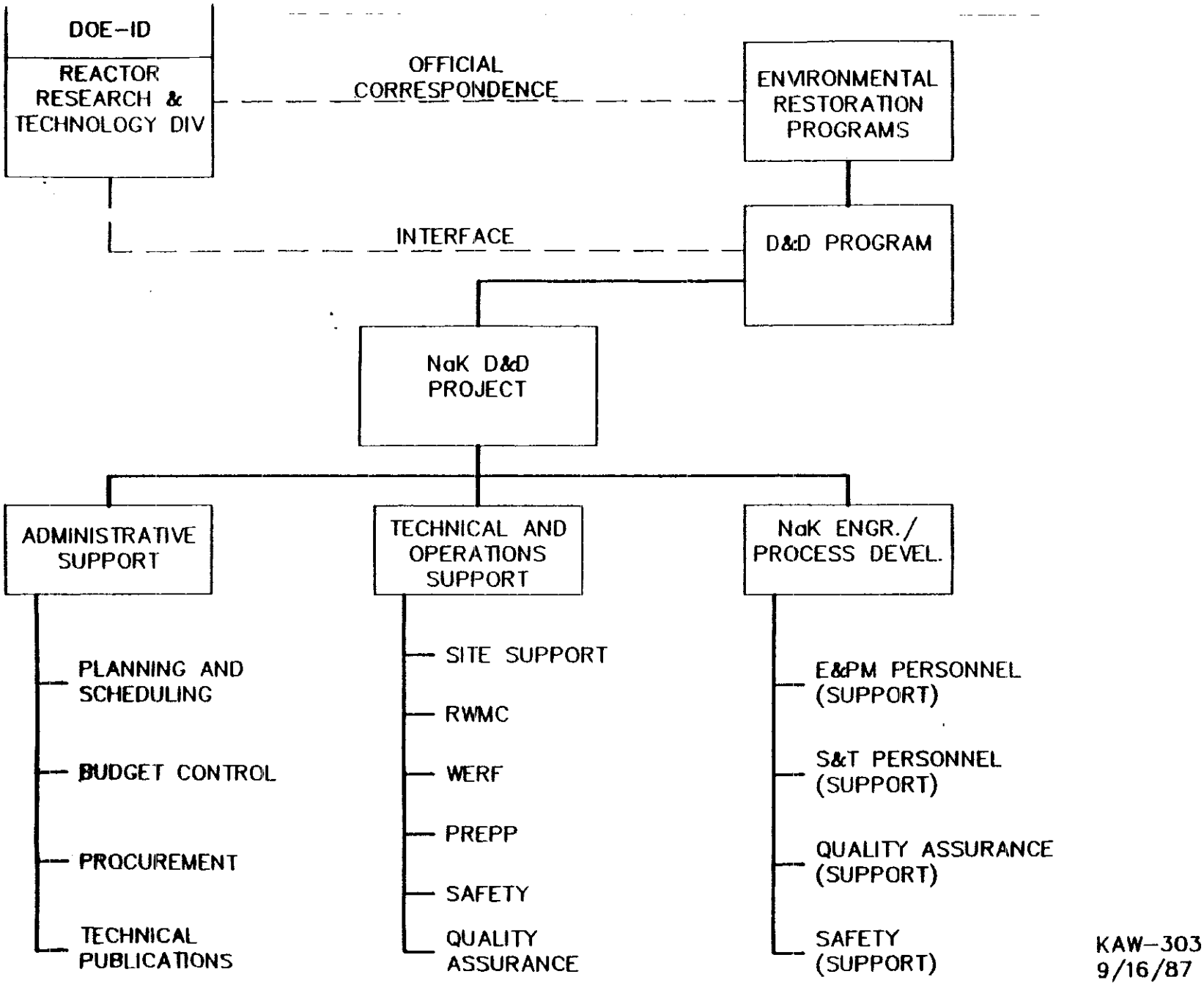


Figure 11. Management structure.

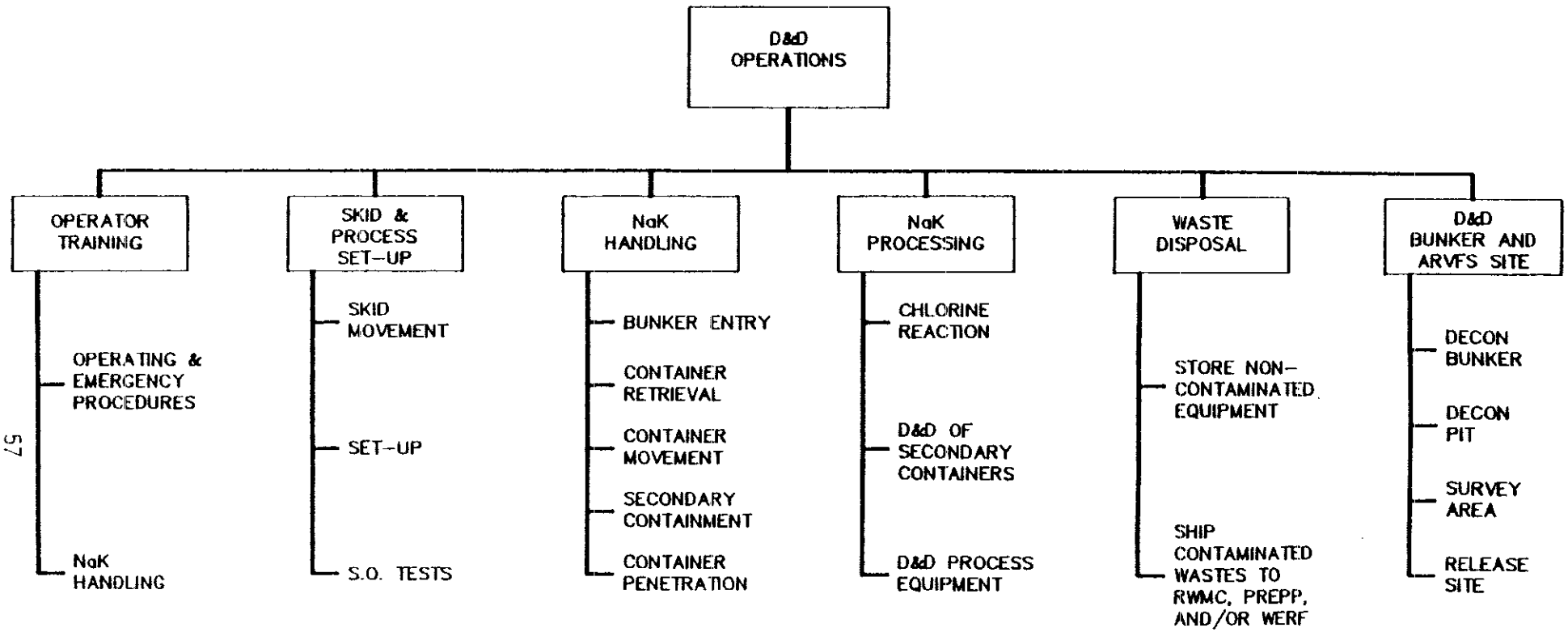


Figure 12. Work breakdown structure.

KAW-304
9/16/87

11. SCHEDULE

A new project baseline schedule is presently undergoing preparation on a computerized project management information system (PROMIS) to be finalized during the first quarter of FY 1988. A tentative schedule is as follows:

	Start	Complete
Preliminary Design	4th Q FY87	2nd Q FY88
Prototype Test	4th Q FY88	4th Q FY88
Final Design	3rd Q FY88	2nd Q FY89
Process EBR-I NaK	3rd Q FY89	4th Q FY89

12. QUALITY ASSURANCE

This project will be accomplished within the guidelines of the Quality Program Plan, Waste Management Programs, 053-3/1/86, and the EG&G Quality Manual.

13. REFERENCES

1. D. H. Schoonen, Decision Analysis for NaK Stored in the ARVFS Bunker, EG&G Idaho Internal Technical Report PG-WM-84-009, July 1984.

2. D. L. Smith, Radiological Characterization and Decision Analysis for the Decommissioning of ARVFS, EG&G Idaho Internal Technical Report PG-WM-84-013, August 1984.

3. R. D. Turner, Preconceptual Studies for Processing of the EBR-I Mark-II Contaminated NaK, EG&G Idaho Internal Report RE-D-79-221, September 1979.

4. E. W. Kendall and D. K. Wang, Decontamination and Decommissioning of the EBR-I Complex Final Report, ANCR-1242, July 1975.

5. R. D. Turner, EBR-I Mark-II Bunker Inspection, Engineering Design File No. 2701, Project File No. 2701, September 11, 1979.

6. Nuclear Fuel Cycle Division, Idaho Operations Office, INEL Low-Level Radioactive Waste Acceptance Criteria (WAC), DOE/ID-10112, March 1985.

7. G. R. Darnell, Process Experimental Pilot Plant (PREPP) Waste Acceptance Criteria (WAC), EG&G Idaho Internal Technical Report PG-WM-85 (Draft), 1985.

8. TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant, September 1985, WIPP-DOE-069, Revision 2, UC-70.

9. D. M. La Rue and M. R. Dolenc, Decontamination and Decommissioning Plan for Processing the Contaminated NaK at the INEL (Draft, WM-PD-86-007, March 1986.

10. Exxon Nuclear Idaho Co. Report ENI-142, Preliminary Safety Analysis Report for the ICPP Sixth Calcined Solids Storage Facility, June 1981.

APPENDIX A

LEVEL OF RADIOACTIVITY

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev. 4-78)

ENGINEERING DESIGN FILE

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK003

FUNCTIONAL FILE NO. 3KNOPNAKE

PROJECT/TASK NaK Disposal/EBR-I

DATE March 25, 1986

SUBTASK Engineering

EDF PAGE NO. 1 OF 9

SUBJECT: FISSION PRODUCT INVENTORY ESTIMATES

ABSTRACT

Fission product inventory and activity estimates are developed for contaminated NaK from the 1955 EBR-I meltdown. Maximum credible values are calculated using conservative models for the core irradiation history and fission product release to the NaK.

DISTRIBUTION (COMPLETE PACKAGE):
M. R. Dolenc, R. H. Meservey, S. R. Adams, D. L. Crandall, D. M. La Rue, B. G. Schnitzler

DISTRIBUTION (COVER SHEET ONLY): PROJECT EDF FILE LOG, EDF SERIAL NO. LOG

J. A. Lake

AUTHOR	DEPT.	REVIEWED	DATE	APPROVED	DATE
B. G. Schnitzler		J. A. Lake	3/25/86		

Summary

Fission product inventory estimates are required to support planned disposal of contaminated NaK from the 1955 EBR-I meltdown. Maximum credible fission product inventory and activity estimates are developed using conservative models for the core irradiation history and fission product release to the NaK.

Background

The EBR-I Mark II core had been fabricated using a uranium - 2 wt% zirconium alloy for both fuel and blanket regions. The fuel region (93.2 wt% ^{235}U) contained approximately 52 kilograms ^{235}U. The second core was installed in the early part of 1954 and operated intermittently until late 1955. A partial meltdown occurred on November 29, 1955, and involved 40 - 50% of the fueled (core) region.[1] There was no significant involvement of the axial blanket regions in the meltdown. Plutonium samples totaling 10.5 grams were not recovered from the core and assumed dispersed to the molten fuel alloy.[1]

The damaged core was removed early in 1956. The NaK coolant was transferred to containers and stored at the EBR-I site until 1974 when it was moved to a bunker at the Army Reentry Vehicle Facility Site (ARVFS).[2] Past radiological hazard characterization work includes radiation surveys of the NaK containers prior to the 1974 relocation[2] and during a bunker inspection[3] conducted in August, 1979. Radiological consequences of fires involving the NaK were addressed in References 4 and 5.

Fission product contamination provides the dominant radiological hazard associated with the NaK processing. The NaK drum contents are not yet well characterized but could potentially include solid fuel particle debris, remains of the plutonium samples, structural material activation products, and potassium-40.

Activated structural material and ^{40}K activity levels should be very low compared with the fission product activity levels. Some accident scenarios (e.g., NaK fire and atmospheric dispersal) may require consideration of ^{40}K and the plutonium samples; these contaminants will not impact shielding requirements. Materials of radiological significance in the fuel debris would be limited to uranium and the retained fission products. Negligible quantities of ^{239}Pu would have been produced in the high enrichment core region involved in the meltdown. No criticality hazard exists as long as the ^{235}U inventory is less than about 760 grams.[6] Estimates of TRU content may be required prior to final disposal.

Calculational Model

The core fission product inventory available for release to the NaK coolant is a function of the core operating history. Operating history data is difficult (perhaps impossible) to recover after more than 30 years. The only definitive items identified to date are measured radial and axial fission rate distributions[7] for the earlier (Mark I) core loading and a reported maximum core burnup of approximately 0.1 atom percent[8] at the time of the meltdown.

Fission product inventories have been calculated using the isotopic generation and depletion code ORIGEN2[9] and a modified cross section library. The ^{235}U radiative capture cross section was adjusted to reflect measured[10] capture-to-fission ratios reported for the EBR-I Mark I core loading. The measured ratios varied from about 0.11 at the core center to about 0.17 at the core peripnery. The ^{235}U radiative capture cross section was adjusted based on the lowest reported value (0.11 ± 0.01). This procedure is conservative since it will result in the highest calculated fission product inventory for a specified atom percent burnup.

The burnup for the entire fuel region was conservatively assumed to be the 0.1 atom percent reported as the core maximum. The entire exposure was assumed to be accumulated at constant power during the 45 days of operation immediately preceding the meltdown. The resulting burnup is about 45 MWd compared to the more conservative assumption of 75 MWd utilized in the analyses reported in References 4 and 5.

The calculated inventory was decayed to August, 1988. The entire fission product inventory from 50% of the core region was assumed to be released to the NaK. All the released fission products, including noble gases and other volatiles, were assumed to remain in the NaK.

The isotopic inventory associated with the unrecovered plutonium samples was approximated using ORIGEN2 and assuming simple decay of the initial 10.5 gram sample inventory to August, 1988. This conservative treatment yields the maximum heavy metal inventory; the fission product inventory resulting from fission events in the plutonium sample is negligible compared to that from the fueled core.

Results

Calculated fission product inventories are shown in Table 1. All fission products with an activity of greater than one microcurie are listed. The corresponding mass for each isotope is included. The calculated fission product elemental composition is listed in Table 2. All fission product elements with mass inventories of greater than one milligram are shown. The total activity for all isotopes of that element is also tabulated.

The total fission product mass inventory is approximately 23.3 grams and the total fission product activity is about 133 curies. The calculated fission product decay heat is only 380 milliwatts.

The initial and August, 1988, plutonium sample inventories are listed in Table 3. Table 4 documents the ORIGEN2 input model employed for the fission product inventory calculations.

Conclusions

The calculated fission product inventories hinge on two critical assumptions made for this analysis. The entire exposure history has been constructed around a single reported burnup value. Although there is no reason to suspect the reported burnup, it is disconcerting to not have some confirmation of so important a parameter.

The assumption of total fission product release to the NaK is also important. This assumption is clearly conservative for the primary application of estimating maximum fission product contamination levels in the NaK. Actual release fractions could be expected to vary from almost complete for many volatiles (e.g., halogens) to very small for many isotopes preferentially retained in the fuel (e.g., ^{144}Ce). All reported values should be viewed as the maximum credible fission product inventories in the NaK.

References

1. J. H. Kittel, M. Novick, and R. F. Buchanan, The EBR-I Meltdown - Physical and Metallurgical Changes in the Core, ANL-5731, November 1957.

2. D. M. LaRue, "EBR-I NaK/Disposal Process Selection," EDF-NAK001, January 1986.

3. R. D. Turner, "EBR-I Mark II NaK/Bunker Inspection," EFD-2701, September 1979.

4. J. F. Sommers ltr to J. W. McCaslin, "EBR-I NaK Fire Analysis," Som-23-73, March 15, 1973.

5. H. K. Peterson ltr to S. L. Bhatia, "Radiological Consequences of EBR-I NaK Fire," HKP-44-79, June 3, 1979.

6. J. T. Thomas, ed., Nuclear Safety Guide, TID-7016 Revision 2, June 1978.

7. C. D. Curtis et al., A Physical Determination of the Conversion Ratio of the Experimental Breeder Reactor, ANL-5222, August 1954.

8. J. H. Kittel et al., "Disassembly and Metallurgical Evaluation of the Melted-Down EBR-I Core," Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958, P/2437, Vol. 7, p.472, United Nations, New York, 1958.

9. A. G. Croff, ORIGEN2--A Revised and Updated Version of the Oak Ridge Isotope and Depletion Code, ORNL-5621, July 1980.

10. H. V. Lichtenberger et al., "Operating Experience and Experimental Results Obtained from an NaK-Cooled Fast Reactor," Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva 1955, P/813, Vol. 3, p. 345, United Nations, New York, 1956.

TABLE 1. CALCULATED ISOTOPIC INVENTORY FOR EBR-I NaK (ALL FISSION PRODUCTS FROM 50% OF CORE, DECAYED TO AUGUST 1988).

Isotope	Inventory (Grams)	Activity (Curies)
^{3}H	5.24×10^{-6}	5.05×10^{-2}
^{79}Se	4.17×10^{-3}	2.91×10^{-4}
^{85}Kr	2.76×10^{-3}	1.08×10^{0}
^{90}Sr	2.36×10^{-1}	3.22×10^{1}
^{90}Y	5.91×10^{-5}	3.22×10^{1}
^{93}Zr	5.99×10^{-1}	1.51×10^{-3}
^{93m}Nb	4.11×10^{-6}	1.16×10^{-3}
^{99}Tc	6.09×10^{-1}	1.03×10^{-2}
^{107}Pd	2.06×10^{-2}	1.06×10^{-5}
^{113m}Cd	8.64×10^{-6}	1.87×10^{-3}
^{121m}Sn	6.72×10^{-7}	3.98×10^{-5}
^{125}Sb	1.38×10^{-6}	1.42×10^{-3}
^{125m}Te	1.92×10^{-8}	3.47×10^{-4}
^{126}Sn	9.07×10^{-3}	2.58×10^{-4}
^{126}Sb	4.31×10^{-10}	3.60×10^{-5}
^{126m}Sb	3.28×10^{-12}	2.58×10^{-4}
^{129}I	9.20×10^{-2}	1.62×10^{-5}
^{134}Cs	1.25×10^{-9}	1.62×10^{-6}
^{135}Cs	8.34×10^{-1}	9.61×10^{-4}
^{137}Cs	3.92×10^{-1}	3.41×10^{1}
^{137m}Ba	6.00×10^{-8}	3.23×10^{1}
^{147}Pm	5.93×10^{-5}	5.50×10^{-2}
^{151}Sm	4.90×10^{-2}	1.29×10^{0}
^{152}Eu	3.43×10^{-8}	5.94×10^{-6}
^{154}Eu	1.14×10^{-6}	3.07×10^{-4}
^{155}Eu	5.74×10^{-5}	2.67×10^{-2}

TABLE 2. CALCULATED ELEMENT INVENTORY FOR EBR-I NaK (ALL FISSION PRODUCTS FROM 50% OF CORE, DECAYED TO AUGUST 1988).

Element	Inventory (Grams)	Activity (Curies)
Se	4.38×10^{-2}	2.91×10^{-4}
Br	1.72×10^{-2}	0.0
Kr	3.06×10^{-1}	1.08×10^{0}
Rb	3.29×10^{-1}	1.96×10^{-8}
Sr	5.57×10^{-1}	3.22×10^{1}
Y	4.25×10^{-1}	3.22×10^{1}
Zr	3.15×10^{0}	1.51×10^{-3}
Mo	2.38×10^{0}	0.0
Tc	6.09×10^{-1}	1.03×10^{-2}
Ru	1.14×10^{0}	2.48×10^{-8}
Rh	3.24×10^{-1}	2.48×10^{-8}
Pd	1.88×10^{-1}	1.06×10^{-5}
Ag	4.84×10^{-3}	$<10^{-9}$
Cd	1.11×10^{-2}	1.87×10^{-3}
In	1.85 x 10-3	$<10^{-9}$
Sn	2.35×10^{-2}	2.97×10^{-4}
Sb	5.14×10^{-3}	1.71×10^{-3}
Te	2.51×10^{-1}	3.47×10^{-4}
I	1.13×10^{-1}	1.62×10^{-5}
Xe	2.89×10^{0}	0.0
Cs	2.12×10^{0}	3.41×10^{1}
Ba	1.38×10^{0}	3.23×10^{1}
La	8.94×10^{-1}	$<10^{-9}$
Ce	1.67×10^{0}	2.05×10^{-8}
Pr	8.29×10^{-1}	$<10^{-9}$
Nd	2.96×10^{0}	$<10^{-9}$
Sm	5.98×10^{-1}	1.29×10^{0}
Eu	3.95×10^{-2}	2.70×10^{-2}
Gd	9.83×10^{-3}	$<10^{-9}$

TABLE 3. EBR-I PLUTONIUM SAMPLE PROPERTIES.

Isotope	November 1955 Inventory (Grams)	November 1955 Activity (Curies)	August 1988 Inventory (Grams)	August 1988 Activity (Curies)
^{235}U	---	---	9.22×10^{-3}	1.99×10^{-8}
^{236}U	---	---	1.69×10^{-3}	1.09×10^{-7}
^{239}Pu	9.97×10^{0}	6.20×10^{-1}	9.96×10^{0}	6.20×10^{-1}
^{240}Pu	4.97×10^{-1}	1.13×10^{-1}	4.95×10^{-1}	1.13×10^{-1}
^{241}Pu	3.15×10^{-2}	3.25×10^{0}	6.54×10^{-3}	6.74×10^{-1}
^{242}Pu	1.26×10^{-3}	4.81×10^{-6}	1.26×10^{-3}	4.81×10^{-6}
^{241}Am	---	---	2.42×10^{-2}	8.30×10^{-2}
TOTAL	10.500	3.983	10.498	1.490

TABLE 4. ORIGEN2 INPUT MODEL.

```
    205   922350   5.138   0.0   0.0  46.71   0.0   0.0   -1
    205   922380   2.929   0.0   0.0   0.0    0.0   0.0   -1
*EOR
    -1
    -1
    -1
    BAS    EBR-I MARK II FUEL (52 KG U-235)
    TIT    CONSTANT FLUX IRRADIATION TO 0.1 ATOM PERCENT BURNUP
    CUT    3 1.0E-25   5 1.0E-12   7 1.0E-24   27 0.1   28 1.0E-75   -1
    LIP    0 0 0
    LPU    922350   922380   -1
    LIB    0  0  2  3  0  -205  206  9  3  0  4  0
    PHO    0  102  103  10
    OPTL   8 8 8 8 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
    OPTA   8 8 7 8 7   8 7 8 6 8   8 8 6 8 6   8 6 8 5 5   5 5 8 8
    OPTF   8 8 7 8 7   8 7 8 6 8   8 8 6 8 6   8 6 8 8 8   8 8 8 8
    INP    1   2   -1   -1   1   1
    IRF     5.0   4.96E+12    1    2    4    2
    IRF    10.0   4.96E+12    2    3    4    0
    IRF    15.0   4.96E+12    3    4    4    0
    IRF    20.0   4.96E+12    4    5    4    0
    IRF    25.0   4.96E+12    5    6    4    0
    IRF    30.0   4.96E+12    6    7    4    0
    IRF    35.0   4.96E+12    7    8    4    0
    IRF    40.0   4.96E+12    8    9    4    0
    IRF    45.0   4.96E+12    9   10    4    0
    OUT    10   0   0   0
    DEC         32.67        10    1    5    0
    MOV    1    2    0    0.5
    HED    1  * AUG 1988
    HED    2  *HALF CORE
    OUT     2   0   0   0
    STP    4
    2        922350   221.2766       923800    15.9412        0   0.0
    0
```

APPENDIX B

CHEMICAL HAZARDS

APPENDIX B

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev. 4-78)

PROJECT FILE NO 3KNOPNAKO

EDF SERIAL NO NAK002

FUNCTIONAL FILE NO 3KNOPNAKE

ENGINEERING DESIGN FILE

PROJECT/TASK NaK Disposal - EBR-II

DATE 1/21/86

SUBTASK Engineering

EDF PAGE NO ___ OF ___

SUBJECT

Chemical Hazards Analysis

ABSTRACT

This EDF addresses the chemical hazards associated with the EBR-I Mark-II NaK. It addresses the toxicity, fire, and explosion hazards associated with the NaK, NaK contaminants, and processing scheme. This EDF does not discuss the safety methodology to be employed in handling of these materials.

DISTRIBUTION (COMPLETE PACKAGE)

M. Dolenc, R. Meservey, R. Green, D. Crandall

DISTRIBUTION (COVER SHEET ONLY) PROJECT EDF FILE LOG, EDF SERIAL NO LOG

AUTHOR	DEPT	REVIEWED	DATE	APPROVED	DATE
D. M. LaRue	F&PM	John L. Rebenstorf	23 Jan 85	Mark R. Dolenc	1-23-85

Introduction

This EDF addresses the chemical hazards associated with the decommissioning of the EBR-I Mark-II NaK stored at the ARVFS Bunker. The radiological concerns associated with this material will be discussed in a subsequent EDF. The purpose of this EDF is to specify the hazards, not to formally address the methodology of how these materials will be safely handled. That discussion will take place in subsequent EDF's, design package documents, and safety documents. Due to the uncertainties associated with the contaminants of this material, this EDF will also address the chemical hazards associated with contaminants which may not actually be present, but which have some probability of existing in the NaK. In addition, the chemical hazards associated with the planned chemical deactivation of the NaK will also be addressed. The chemical hazards of the materials will be discussed under the following classifications (where data is available):

1) Toxicological Characteristics

2) Fire Hazards

3) Explosion Hazards

1. NaK Eutectic Metal

1.1 Physical Properties

Sodium-potassium alloy is generally referred to as NaK. Eutectic NaK is an alloy containing approximately 78% potassium (K) and 22% sodium (Na). The melting point is -12.6 C (9.3 F). Liquid NaK is similar to mercury in appearance. The density and viscosity of eutectic NaK at 20 C (68 F) are 0.87 g/cc and 0.9 centipoise, respectively, compared to 1.0 g/cc and 1.0 centipoise, respectively, for water at 20 C. The boiling point of eutectic NaK is 785 C (1445 F). The surface tension, at room temperature, is approximately 105 dynes/cm, compared to water which has a surface tension of 72.8 dynes/cm at room temperature.

1.2 Toxicological Characteristics

NaK in elemental form is highly reactive, particularly with moisture, with which it reacts violently, and therefore, attacks living tissue. NaK reacts exothermally with the moisture of body or tissue surfaces, causing thermal and chemical burns due to the reaction with NaK and the hydroxides formed. NaK is not a systemic poison.

If exposed to air, the NaK will burn to produce oxides; these oxides will react with moisture to form their respective hydroxides which are extremely corrosive and

irritating to skin, eyes, and mucous membrane. Ingestion may cause violent pain in throat and epigastrium, hematemesis, and collapse. Inhalation of the dust can cause damage to the upper respiratory tract and lung tissue, depending upon the severity of the exposure. Thus, affects of inhalation may vary from mild irritation of the mucous membrane to a severe pneumonitis. It can cause an irritation to the skin.

1.3 Fire Hazard

Sodium-potassium alloy reacts violently with moisture to form hydroxides and hydrogen. The reaction evolves much heat, causing the metal to splatter. It also ignites the hydrogen, which burns, or, if there are sufficient concentrations, the hydrogen can explode. Burning NaK is a Class D fire and requires and requires a Class D extinguishing agent; dry powdered soda ash or NaCl are recommended.

1.4 Explosion Hazard

NaK reacts violently with the following materials under required conditions of temperature, state of division, and reactant concentrations: acetylene, air, chlorocuprate, water, $AlBr_3$, metal halides, ammonium chlorocuprate, ammonium bromide, ammonium iodide, ammonium sulfates and nitrates, antimony and arsenic halides, bismuth oxide, boric acid, carbon, carbon dioxide, carbon disulfide, carbon tetrachloride, charcoal, chlorinated hydrocarbons, and a number of other compounds. When reacting with water, sufficient concentrations of hydrogen can be generated to explode if oxygen is present. Potassium metal, if exposed to the air, will form the peroxide (K_2O_2), potassium oxide (K_2O), and the superoxide (KO_2). The the peroxide and the superoxide are strong oxidizing compounds, and if sufficient oxidizable material is present, can cause thermal explosions, deflagarations, or detonations depending upon the reactant.

2. Potassium Chloride (KCl)

2.1 Physical Properties

Colorless or white crystals or powder. KCl is soluble in water. Specific gravity is 1.987. Melting point is 773 C (1500 F) and it sublimes at 1500 C (2880 F).

2.2 Toxicological Characterstics

KCl is a nutrient and/or dietary supplement food additive. Large oral doses cause gastric irritations, purging, weakness, and circulatory problems.

2.3 Fire Hazard

None.

2.4 Explosion Hazard

None.

3. Sodium Chloride (NaCl)

3.1 Physical Properties

Colorless, transparent crystals or white crystalline powder. NaCl is soluble in water. Specific gravity is 2.165. Melting point is 801 C (1554 F), and NaCl boils at 1413 C (2717 F).

3.2 Toxicological Characteristics

NaCl is common table salt. A skin or eye irritant. Ingestion of large quantities can cause irritation of the stomach.

3.3 Fire Hazard

None.

3.4 Explosion Hazard

None.

4. Chlorine (Cl_2)

4.1 Physical Properties

Greenish-yellowish gas, liquid, or rhombic crystal. Specific gravity of vapor is 2.49 (heavier than air). Melting point is -101 C (-160 F). Boiling point is -34.5 C (-30 F). Vapor pressure at 20 C (68 F) is 4800 mm (92.8 psi).

4.2 Toxicological Characteristics

Chlorine is extremely irritating to the mucous membrane of the eyes at 3 ppm and the respiratory tract. It combines with moisture to form hydrochloric acid and liberate nascent oxygen. Both these substances, if present in quantity, cause inflammation of the tissue with which they come in contact. If the lung tissues are attacked, pulmonary edema may result. A concentration of 3.5 ppm produces a detectable odor; 15 ppm causes immediate irritation of the throat. Concentrations of 50 ppm are

dangerous for even short exposures, 1000 ppm may be fatal, even when the exposure is brief. Because of its intensely irritating properties, severe industrial exposure seldom occurs, as the workman is forced to leave the exposure area before he can be seriously affected. In cases where this is impossible, the initial irritation of the eyes and mucous membrane of the nose and throat is followed by a cough, a feeling of suffocation, and later, pain and a feeling of constriction of the chest. If the exposure has been severe, pulmonary edema may follow, with rales being heard over the chest. It is a common air contaminant. It is used in the chlorination of swimming pools and water supplies.

4.3 Fire Hazard

Since chlorine is a strong oxidizer, stronger than oxygen, it can react to cause fires upon contact with many substances which are combustible in air if the proper concentrations of reactants are present.

4.4 Explosion Hazard

There is a potential of explosion with many organic and metal materials if sufficient concentrations, division of reactants, and confinement are present. The danger of explosion is greatly reduced if the reactants are not confined.

5. Potassium Superoxide (KO_2 or K_2O_4) [1]

5.1 Physical Properties

Potassium superoxide is yellowish in color, resembling flowers of sulfur. KO_2 has a specific gravity of 2.14. It melts at 380 C (716 F) and disassociates at 600 C (1112 F).

5.2 Toxicological Characteristics

Potassium superoxide, although not a systemic poison, is a very strong oxidizer. It will attack living tissue in the same manner as potassium hydroxide, since it reacts with the moisture in the skin to form the hydroxide, see section 1.2.

[1] There is a strong possibility that air has leaked into one or more of the NaK containers since there original containment. If air has gotten into the containers, oxygen will react with the potassium present to form potassium superoxide, potassium peroxide, and potassium oxide. The potassium oxide, which is essentially inert, can bridge within the containers and isolate the potassium super and peroxides from the NaK. This bridge could be broken with movement or vibration of the containers.

5.3 Fire Hazard

Since potassium superoxide is such a strong oxidizing material, it can initiate fires with many materials which will combust in air. It will not itself burn in air.

5.4 Explosion Hazard

KO_2 is such a strong oxidizer, there is considerable concern about explosions. If the superoxide comes in contact with organic materials, it can detonate. It can also react so exothermally with other materials, that there is the potential of a thermal explosion under certain conditions of confinement and sufficient reactants. Of particular concern, is the thermal reaction between NaK and KO_2.

6. Potassium Peroxide (K_2O_2) [1]

Although not as strong an oxidizer as KO_2, it still presents the same toxicological, fire, and explosion hazards as the superoxide.

7. Potassium Peroxyferrate (K_2FeO_5) [2]

Can self explode or react violently with non-metals.

8. Potassium Chromates [2]

Potassium Bichromate ($K_2Cr_2O_7$) or Potassium Chromate (K_2CrO_4), these compounds are potentially carcinogenic.

9. Uranium (U238) [3]

9.1 Physical Properties

A heavy, silvery-white, malleable, ductile, softer-than-steel metal. Specific gravity is 18.95; it melts at 1132 C (2183 F); and boils at 3818 C (7286 F). Uranium (238) is non-radioactive.

2 If the superoxide has formed inside the containers, this is a potential corrosion product between the superoxide and the stainless steel containers.

3 The Mark II fuel elements which contaminated this NaK were U(238) being transmuted to Pu(239). It is highly probable that the NaK contains some U(238).

9.2 Toxicological Characteristics

Uranium is a highly toxic element on an acute basis. The permissible levels for soluble compounds are based on chemical toxicity. The high chemical toxicity of U and its salts is largely shown in kidney damage, and acute necrotic arterial lesions. The rapid passage of soluble uranium compounds through the body tends to allow relatively large amounts to be taken in.

9.3 Fire Hazard

Uranium is pyrophoric.

9.4 Explosion Hazard

Can react violently with certain oxidizers, including air.

REFERENCES:

1) Dangerous Properties of Industrial Materials, Sixth Edition, N. Irving Sax, Van Nostrand Reinhold Company, 1984, NY, NY.

2) Sodium-NaK Engineering Handbook, Volume I, Sodium Chemistry and Physical Properties, O.J. Foust (editor), Gordon and Breach Science Publishers, Inc., 1974, NY, NY.

3) Alkali Metals Safety for the Decontamination and Decommissioning of EBR-I, R.C. Green, INEL, 1974.

APPENDIX C

EXPOSURE ESTIMATES

APPENDIX C

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev 4-78)

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK004

FUNCTIONAL FILE NO. SRA-10-86

DATE March 31, 1986

EDF PAGE NO. 1 OF 9

ENGINEERING DESIGN FILE

PROJECT/TASK EBR-I Mark II NaK Disposal

SUBTASK Radiological Engineering

SUBJECT Radiation Exposure Rates in the Vicinity of the Containers of EBR-I Mark II NaK

ABSTRACT

Radiation exposure rates were calculated at several points around the four EBR-I Mark II core NaK containers. The calculations were designed to produce bounding values for the potential exposure rates that could be encountered during disposal of the EBR-I Mark II core NaK. The data included in this report is conservative and can be used for calculating shielding requirements or in planning radiation safety procedures. The highest radiation exposure rate calculated was 35.7 R/h at the side of the MSA container. Approximately 98% of all exposure rates calculated were due to Cs-137. Radiation rates as a function of shield thickness for lead and soil shielding were also calculated.

Introduction

In November 1955 the Mark II core of the EBR-I partially melted during the last of a series of experiments designed to study its behavior when put on positive periods with reduced or zero coolant flow. A certain fixed amount of reactivity was put into the reactor with the control rods, and the reactor was started up on a short enough period so that temperature differentials would be established in the fuel slugs. A prompt positive temperature coefficient appeared, and, as the power increased, the reactivity increased, thus further shortening the period. When the period reached one second, the operator mistakenly activated the slow-acting motor-driven control rods instead of the faster acting scram rods. By the time the scram was initiated the period had reached 0.3 seconds. The uranium became heated above 720°C and the uranium-iron eutectic formed. Melting occurred in 40-50% of the EBR-I core. The core assembly was removed from the reactor by use of a temporary hot cell and shipped to ANL-W for examination and disassembly (Reference 1).

The NaK coolant from the EBR-I Mark II core was contaminated with fission products, fuel, and plutonium samples totaling 10.5 grams. The NaK coolant is stored in four containers at the Army Reentry Vehicle Facility Site (ARVFS). Post radiological hazard characterization work was performed in 1974 and 1979 (Reference 2). The previous radiation exposure measurements were performed under conditions of poor geometry and with uncalibrated instruments; therefore, the radiation

DISTRIBUTION (COMPLETE PACKAGE): D.M. Larue, M. R. Dolenc, B. G. Schnitzler, E. L. Crandall, S. R. Adams (2), EDF File, R. H. Meservey

DISTRIBUTION (COVER SHEET ONLY): PROJECT EDF FILE LOG, EDF SERIAL NO. LOG T. K. Campbell, J. L. Clark, L. L. Reed, B. L. Rich, W. D. Schofield

AUTHOR	DEPT	REVIEWED	DATE	APPROVED	DATE
S. R. Adams	S&E Programs		4/1/86	M. R. Dolenc	4/1/86

fields reported are only considered rough estimates (Reference 2). This EDF presents the maximum credible radiation exposure rates using conservative models for the core irradiation history and fission product release to the NaK. Discussions of the effects of shielding on radiation exposure fields and man-rem dose estimates are also included.

Analysis

The fission product inventory assumed was that of Reference (3). As stated in the reference, "Operating history data is difficult (perhaps impossible) to recover after more than 30 years. The only definitive items identified to date are measured radial and axial fission rate distributions for the earlier (Mark I) core loading and a reported maximum core burnup of approximately 0.1 atom present at the time of the meltdown."

Table 1 lists the fission product radionuclides used in this analysis. The inventory of activation products was assumed to be negligible because of the short operating time of the Mark II core and the total lack of activation product signal in the gamma spectrum taken of the NaK containers (Reference 2, Figure 7).

The ISOSHLD II code was used to model the four NaK containers. The code input is included as an addendum to the EDF (Reference 4). The following assumptions were made in the code calculations:

- The fission product inventory is uniformly distributed throughout the NaK. The density of the NaK is 0.75 g/cm^3 (Reference 5).
- The MSA containers were modeled as a right circular cylinder with a radius of 30.16 cm, a height of 91.12 cm, and a steel wall thickness of 0.3175 cm (Reference 2, Figure 9).
- The fabricated container #2 was modeled as a right circular cylinder with a radius of 29.2 cm, a height of 91.12 cm, a steel wall thickness of 0.3175 cm, and a steel cap 3.175 cm thick (Reference 2, Figure 10).
- The fabricated container #1 was modeled as a right circular cylinder with a radius of 13.0 cm, a height of 66.0 cm and a wall thickness of 0.3175 cm (Reference 2, Figure 11).

The results of the calculations are shown in Table 2. The calculated radiation exposure rates at the surface of the containers varied from 20-36 R/h. The highest values were calculated at the side of MSA containers, about 36 R/h. These values were calculated conservatively and should bound the actual radiation exposure rates encountered in the vicinity of the NaK containers.

These calculated values would preclude any extended stay times in the vicinity of the NaK containers. The EG&G Administrative Dose Guides for the whole body and hands are 0.05 and 0.4 rem/day respectively. Without

additional shielding, and assuming the worker is one foot away from the container while their hands were in contact, would limit stay times to about 18 seconds. For this reason a series of calculations were made to determine the radiation exposure rate as a function of shielding thickness. The MSA container was used for these calculations since it presents the highest radiation exposure rate. The results are shown in Figure 1. This data can then be used to plan the amount of shielding required to perform the necessary hands-on operations during the NaK container D&D project. For example, assume that workers will be required to remain in close proximity to each container for approximately 15 minutes. That would result in a total stay time of one hour. Therefore, the radiation exposure to the whole body should not exceed 0.05 R/h. Figure 1 shows that this would require about 4.3 cm of lead shielding around the containers.

Per the verbal request of M. R. Dolenc of Waste Programs, the radiation field as a function of shielding thickness using soil was estimated. Examination of the ISOSHLD II output shows that about 98% of the exposure is due to the 0.66 MeV photons of the Cs-137/Ba-137m. The attenuation coefficient for Pb at this energy is approximately 1.28 cm^{-1}. For soil the attenuation coefficient was calculated assuming an atomic elemental distribution of: Oxygen - 0.452, Hydrogen - 0.156, Flurine - 0.189, Silicon - 0.136, Aluminum - 0.044, and Fe - 0.012; and a density of 1.5 g/cm^3 (Reference 6). The attenuation coefficient is then 0.115.

As a first approximation, the ratio of soil/lead to obtain equivalent radiation exposure rate attentuation is 1.28/0.115 or 11.2 (see Figure 2). Because of the wide variability in soil composition, water content, and density a more rigorous calculation was not made. Figure 2 gives the approximate radiation field as a function of soil shield thickness for the MSA NaK containers.

Conclusions

A series of calculations have been made to bound the potential radiation exposure rates around the four EBR-I Mark II NaK containers. These calculated values are conservative, the actual values should be less. More precise values could be obtained if the radiological source terms could be defined exactly. As the radiological terms will most likely remain speculative, the values calculated in this EDF are still useful for planning purposes. The following points should be considered when applying the calculated values:

- The radiation exposure rates were for single containers. Grouping the containers together will modify the expected results due to a combination of photon field additive interactions, self-shielding, and sky-shine.

- The radiation fields at the top of the MSA and fabricated container #2 could be considerably less than the values in Table 1 due to the shielding in their lids. Figure 9 of Reference 2

shows an 8 inch, 16 inch O.D. lid of unstated material on the MSA container. Figure 10 shows 1.25 inch, 30 inch O.D. flange on the fabricated container #2, though the text describes it as a 0.5 inch plate.

The data below should assist in the planning of the EBR-I Mark NaK container disposal. This data is very preliminary, more exact calculations can be made as the project tasks are defined.

Time spent in the vicinity of each NaK Container (minutes)	Shielding thickness required to remain in compliance with the EG&G Administrative Dose Guides	
	Lead (cm)	Soil (cm)
5.0	3.4	38
10.0	4.0	45
20.0	4.6	51
60.0	5.4	61

References

1. S. R. Adams, Theory Design and Operation of Liquid Metal Fast Breeder Reactors, Including Operational Health Physics, NUREG/CR-4375, October 1985.

2. R. D. Turner, Report of Bunker Inspection, August 1979, EDF 2701, September 11, 1979.

3. B. G. Schnitzler, Fission Product Inventory Estimates, EDF NAK003, March 25, 1986.

4. G. L. Simmons, et al., ISOSHLD-II: A Computer Code for General Purpose Isotope Shielding Analysis, BNWL-236 and Supplements, March 1967.

5. A. J. Friedland, Coolant Properties, Heat Transfer, and Fluid Flow of Liquid Metals, in Fast Reactor Technology Plant Design, J. G. Yevick, (Ed) MIT Press, Cambridge, Mass., 1966.

6. R. G. Jeager, (Ed) Engineering Compendium on Radiation Shielding, v II, p 31, Springer-Verlag, New York, 1975.

TABLE 1. CALCULATED ISOTOPIC INVENTORY FOR EBR-I NaK (ALL FISSION PRODUCTS FROM 50% OF CORE, DECAYED TO AUGUST 1988). (Reference 2)

Isotope	Inventory (Grams)	Activity (Curies)
^{3}H	5.24×10^{-6}	5.05×10^{-2}
^{79}Se	4.17×10^{-3}	2.91×10^{-4}
^{85}Kr	2.76×10^{-3}	1.08×10^{0}
^{90}Sr	2.36×10^{-1}	3.22×10^{1}
^{90}Y	5.91×10^{-5}	3.22×10^{1}
^{93}Zr	5.99×10^{-1}	1.51×10^{-3}
^{93m}Nb	4.11×10^{-6}	1.16×10^{-3}
^{99}Tc	6.09×10^{-1}	1.03×10^{-2}
^{107}Pd	2.06×10^{-2}	1.06×10^{-5}
^{113m}Cd	8.64×10^{-6}	1.87×10^{-3}
^{121m}Sn	6.72×10^{-7}	3.98×10^{-5}
^{125}Sb	1.38×10^{-6}	1.42×10^{-3}
^{125m}Te	1.92×10^{-8}	3.47×10^{-4}
^{126}Sn	9.07×10^{-3}	2.58×10^{-4}
^{126}Sb	4.31×10^{-10}	3.60×10^{-5}
^{126m}Sb	3.28×10^{-12}	2.58×10^{-4}
^{129}I	9.20×10^{-2}	1.62×10^{-5}
^{134}Cs	1.25×10^{-9}	1.62×10^{-6}
^{135}Cs	8.34×10^{-1}	9.61×10^{-4}
^{137}Cs	3.92×10^{-1}	3.41×10^{1}
^{137m}Ba	6.00×10^{-8}	3.23×10^{1}
^{147}Pm	5.93×10^{-5}	5.50×10^{-2}
^{151}Sm	4.90×10^{-2}	1.29×10^{0}
^{152}Eu	3.43×10^{-8}	5.94×10^{-6}
^{154}Eu	1.14×10^{-6}	3.07×10^{-4}
^{155}Eu	5.74×10^{-5}	2.67×10^{-2}

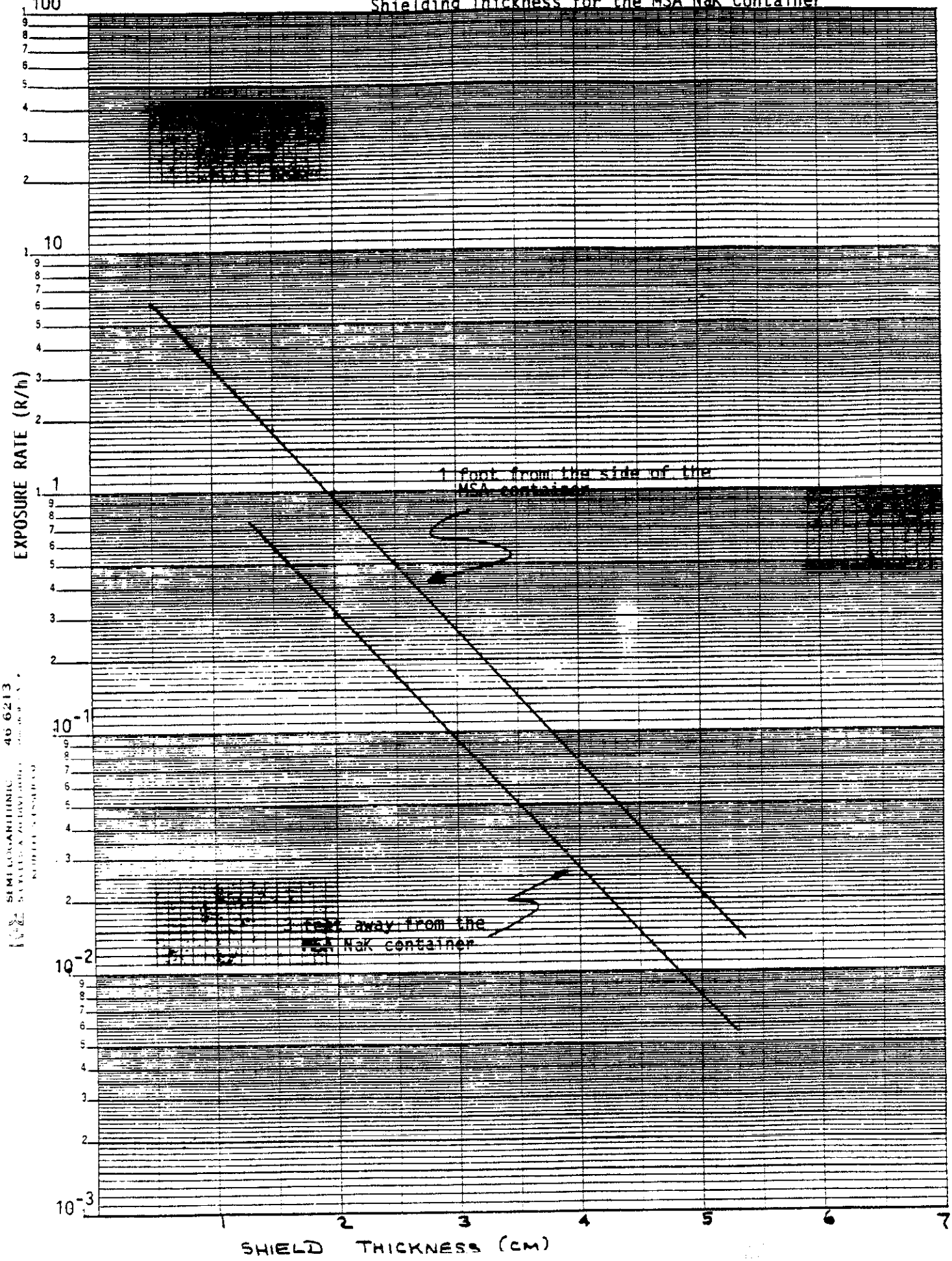
Table 2. Radiation Exposure Rates in the Vicinity of the NaK Containers (R/hour)

Container Type	Geometry	Exposure At The Surface	Exposure At 1 Ft.	Exposure At 3 Ft.
Fabricated #1	Side	23.1	3.38	0.66
	Top	20.3	1.95	0.71
Fabricated #2	Side	34.5	9.61	2.51
	Bottom[a]	33.9	7.78	1.72
MSA	Side	35.7	10.0	2.64
	Bottom[b]	30.2	7.12	1.57

a. The bottom of the container was calculated to have greater radiation fields. Exposure rate at the top, due to 0.25 inches of steel were approximately 17 R/h at the surface and 6 R/h at a foot.

b. Figure 9 in Reference 7 shows an 8 inch thick, 16 inch O.D. "Lid" on the MSA container. No information could be obtained on what material(s) this "Lid" was constructed. This thickness of steel, for instance, would reduce the exposure rate to about 10 mR/h at the surface.

Figure 1. Radiation Exposure Rate as a Function of Lead Shielding Thickness for the MSA NaK Container



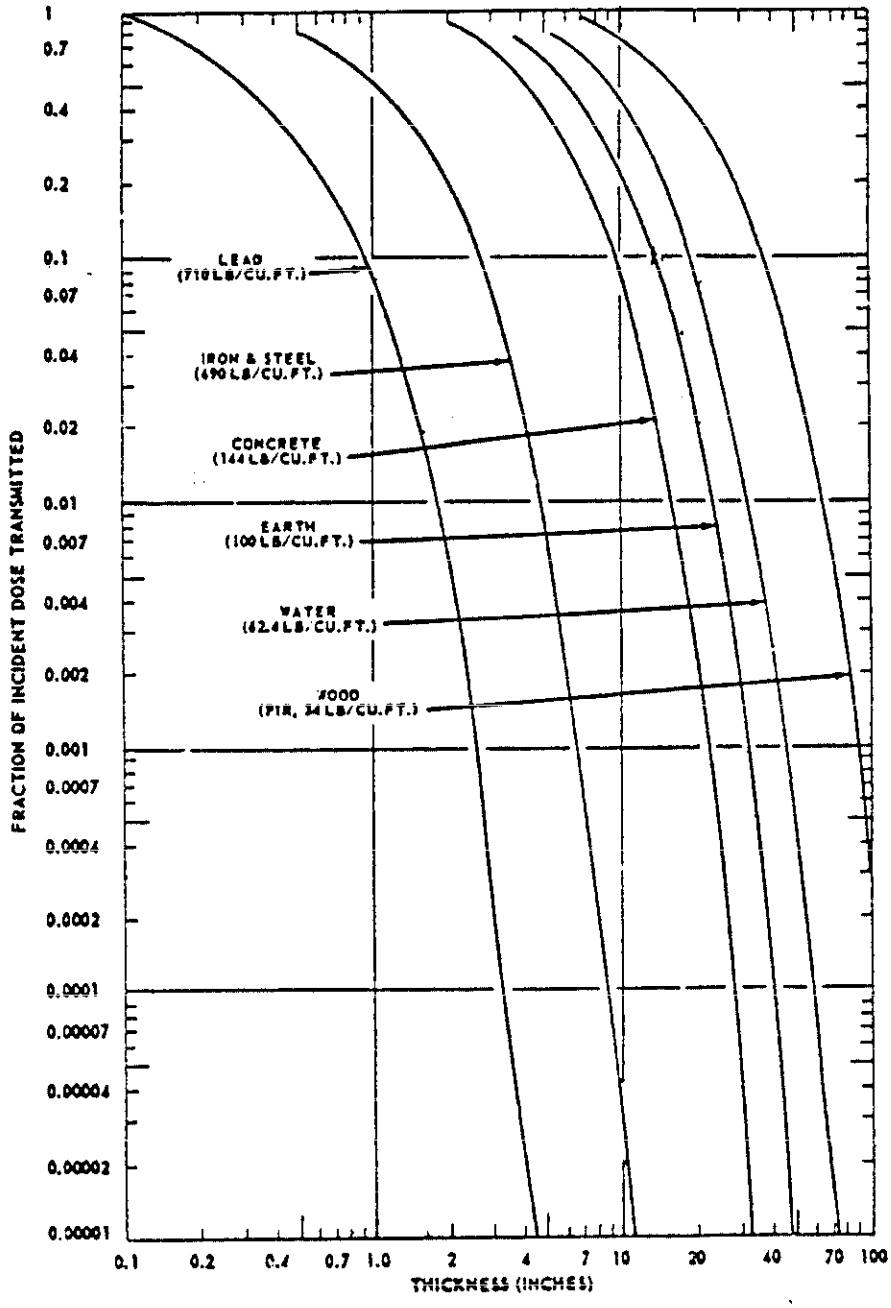
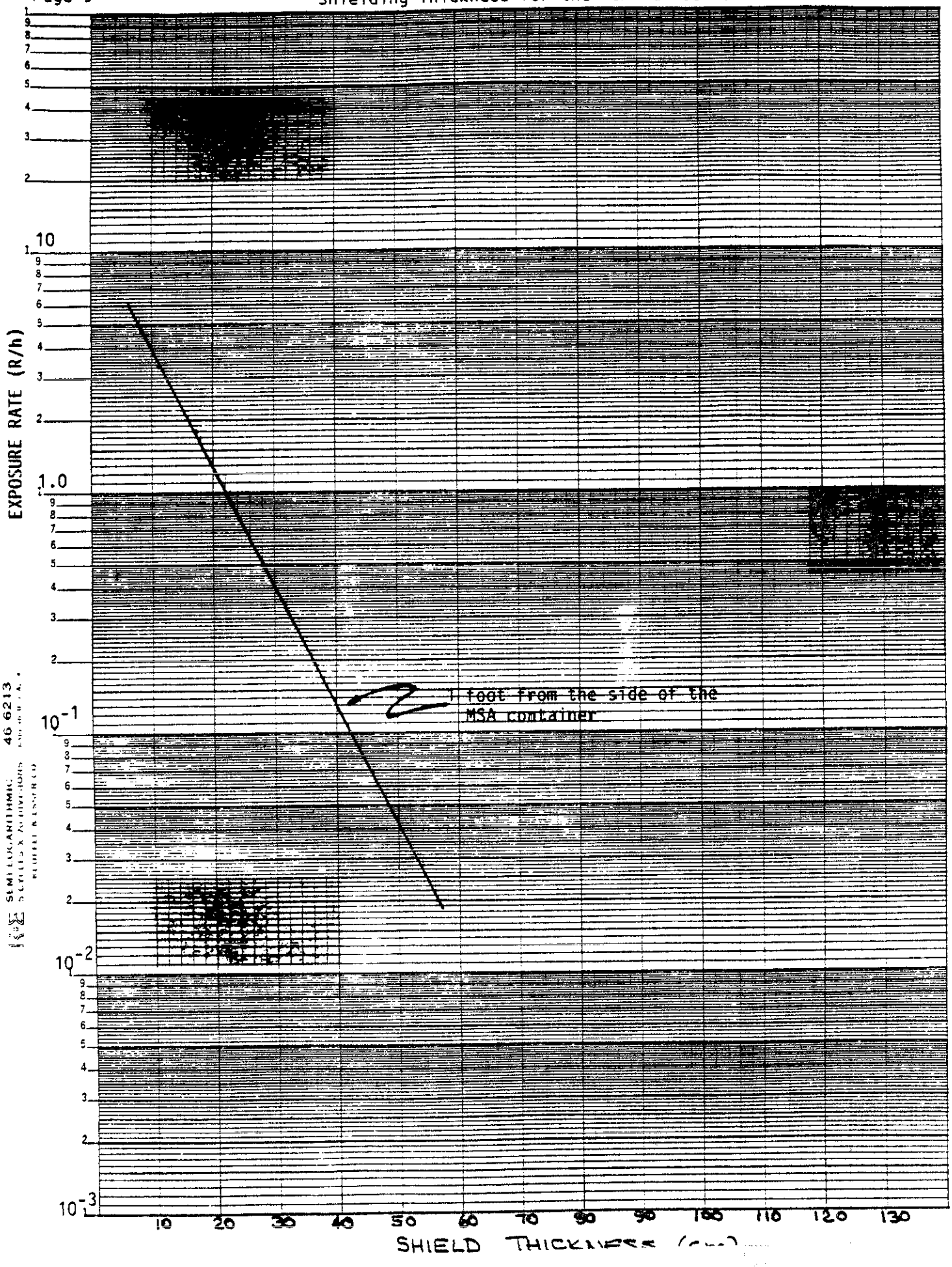


FIGURE 2

Transmission of fission product gamma radiation in several shield materials (From Brodsky, A., & G.V. Beard, Ed. A Compendium of Information for Use in TID-8206, Controlling Radiation Emergencies, 1960)

Figure 3. Radiation Exposure Rates as a Function of Soil Shielding Thickness for the MSA NaK Container



```
                2
R/H FROM THE  CONTAMINATED NAK IN FAT CONTAINER #2, TOP OF THE CONTAINER
 $INPUT NEXT=1,
 IGEOM=9,NSHLD=2,JOUT=1,
 WEIGHT(055)=.4822,
 WEIGHT(082)=14.38,
 WEIGHT(084)=14.38,
 WEIGHT(141)=4.6E-3,
 WEIGHT(206)=8.35E-4,
 WEIGHT(269)=5.34E-4,
 WEIGHT(335)=15.23,
 WEIGHT(380)=.02456,
 WEIGHT(403)=.576,
 WEIGHT(418)=1.16E-4,
 SLTH=29.2,
 T(1)=91.12,
 T(2)=.3175,
  NTHETA=19,
 DELR=1.,
 X=91.44,
 SSV1=0.0,
 ISPEC=3,
 $END
         7        .75
         9                7.3                                          1
R/H AT 1 FT FROM THE TOP OF THE CONTAINER
 $INPUT NEXT=4,X=121.9,$END
R/H AT 3 FT FROM THE TOP OF THE CONTAINER
 $INPUT NEXT=4,X=182.9,$END
```

```
                2
R/H FROM CONTAMINATED NAK IN EAR CONTAINER #1, SIDE OF CONTAINER
 $INPUT NEXT=1,WEIGHT(055)=.072E,,EIGHT(082)=2.163,WEIGHT(084)=2.163,
 WEIGHT(141)=6.92E-4,WEIGHT(206)=1.25E-4,WEIGHT(269)=9.54E-5,
 WEIGHT(335)=2.29,WEIGHT(366)=3.69E-3,WEIGHT(403)=.097,
 WEIGHT(419)=1.79E-3,
 IGEOM=7,NSHLD=2,JBUF=1,
 T(1)=13.,
 T(2)=.3175,
 SLTH=66.,
 X=13.4,
 Y=33.,
 NTHETA=29,
 NPSI=29,
 DELR=1.0,
 ISPEC=3,
 $END
          7       .75                                                  1
          9              7.3
R/H AT 1 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=43.88,$END
R/H AT 3 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=104.8,$END
```

```
                2
R/H FROM CONTAMINATED NAK IN FAR CONTAINER #2, SIDE OF CONTAINER
 $INPUT NEXT=1, IGEOM=7,NSHLD=2,JBUF=1,
 WEIGHT(055)=.4823,
 WEIGHT(082)=14.38,
 WEIGHT(084)=14.38,
 WEIGHT(141)=4.6E-3,
 WEIGHT(206)=9.35E-4,
 WEIGHT(269)=6.34E-4,
 WEIGHT(335)=15.23,
 WEIGHT(380)=.02456,
 WEIGHT(403)=.576,
 WEIGHT(418)=1.16E-4,
 T(1)=29.2,
 T(2)=.3175,
 SLTH=91.44,
 X=29.6,
 Y=45.72,
 NTHETA=29,
 NPSI=29,
 DELR=1.0,
 ISPEC=3,
  $END
          7        .75
          9                  7.3                                    1
R/H AT 1 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=60.,$END
R/H AT 3 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=121.,$END
```

```
                2
R/H AT THE TOP SURFACE OF THE FAB 1 CONTAINER
 $INPUT NEXT=1,
 WEIGHT(055)=.0725,WEIGHT(082)=2.163,WEIGHT(084)=2.163,
 WEIGHT(141)=3.92E-4,WEIGHT(206)=1.26E-4,WEIGHT(269)=9.54E-5,
 WEIGHT(335)=2.29,WEIGHT(386)=3.69E-3,WEIGHT(403)=.087,
 WEIGHT(418)=1.79E-2,
 IGEOM=9,
 NSHLD=2,JBUF=1,
 SLTH=13.4,
 T(1)=66.,
 T(2)=.3175,
 X=66.4,
 SSV1=0.0,
 NTHETA=29,
 NPSI=29,
 DELR=.1,
 ISPEC=3,
 $END
          7        .75
          9                7.3                                          1
R/H AT 1 FT FROM THE TOP OF FAB 1
 $INPUT NEXT=4,X=96.88,$END
R/H AT 3 FT FROM THE TOP OF FAB 1
 $INPUT NEXT=4,X=127.4,$END
```

```
                2
R/H FROM THE CONTAMINATED NAK IN MSA CONTAINER, TOP
 $INPUT NEXT=1,
 IGEOM=9,NSHLD=2,JBUF=2,
 WEIGHT(055)=.525,
 WEIGHT(082)=15.7,
 WEIGHT(084)=15.7,
 WEIGHT(141)=.005,
 WEIGHT(206)=.0009,
 WEIGHT(269)=.0007,
 WEIGHT(335)=16.6,
 WEIGHT(380)=.027,
 WEIGHT(403)=.63,
 WEIGHT(418)=.013,
 SLTH=30.16,
 T(1)=91.2,
 T(2)=.3175,
 NTHETA=19,
 DELR=1.,
 X=91.44,
 SSV1=0.0,
  ISPEC=3,
 $END
          7        .75
          9          7.3                              1
R/H AT 1 FT FROM THE TOP OF THE CONTAINER
 $INPUT NEXT=4,X=121.9,$END
R/H AT 3 FT FROM THE TOP OF THE CONTAINER
 $INPUT NEXT=4,X=182.9,$END
```

```
                                                    MSA CONTAINER, SIDE OF CONTAINER
    $INPUT NEXT=1,
    IGEOM=7,NSHL)=2,JPLF=1,
    WEIGHT(055)=.525,
    WEIGHT(082)=15.7,
    WEIGHT(084)=15.7,
    WEIGHT(141)=.005,
    WEIGHT(206)=.0009,
    WEIGHT(269)=.0007,
    WEIGHT(335)=16.6,
    WEIGHT(380)=.027,
    WEIGHT(403)=.63,
    WEIGHT(418)=.013,
    T(1)=30.16,
    T(2)=.3175,
    X=30.5,
    SLTH=91.44,
    Y=45.72,
    NTHETA=19,
    NPSI=19,
    DELR=1.,
    ISPEC=3,
    $END
            7          .75                                                    1
            9                    7.3
  R/H AT 1 FT FROM THE SIDE OF THE CONTAINER
    SINPUT NEXT=4,X=61.,$END
  R/H AT 3 FT FROM THE SIDE OF THE CONTAINER
    SINPUT NEXT=4,X=122.,$END
```

```
                2
R/H FROM CONTANINATED NAK IN MSA CONTAINER, SIDE OF CONTAINER
 $INPUT NEXT=1,
 WEIGHT(055)=.525,
 WEIGHT(082)=15.7,
 WEIGHT(084)=15.7,
 WEIGHT(141)=.005,
 WEIGHT(206)=.0009,
 WEIGHT(269)=.0007,
 WEIGHT(335)=16.6,
 WEIGHT(380)=.027,
 WEIGHT(403)=.63,
 WEIGHT(418)=.013,
 IGEOM=7,NSHLD=3,JBUF=1,
 T(1)=30.16,
 T(2)=.3175,
 T(3)=0.5,
 X=31.,
 SLTH=91.44,
 Y=45.72,
 NTHETA=19,
 NPSI=19,
 DELR=1.,
 ISPEC=3,
 $END
          7          .75
          9                    7.3
         14                              11.3                              1
 R/H AT 1 FT, 5 CM PB
  $INPUT NEXT=4,T(3)=5.,X=66.,$END
R/H AT 1 FT, 10 CM PB
 $INPUT NEXT=4,T(3)=10.,X=71.,$END
R/H AT 3 FT, 10 CM PB
 $INPUT NEXT=4,T(3)=10.,X=132.,$END
R/H AT 3 FT, 5 CM PB
 $INPUT NEXT=4,T(3)=5.,X=127.,$END
R/H AT 3 FT 2.5 CM PB
 $INPUT NEXT=4,T(3)=2.5,X=124.5,$END
R/H AT 3 FT, 2 CM PB
 $INPUT NEXT=4,T(3)=2.,X=124.,$END
R/H AT 3 FT, 1.5 CM PB
 $INPUT NEXT=4,T(3)=1.5,X=123.5,$END
R/H AT 3 FT, 1 CM PB
 $INPUT NEXT=4,T(3)=1.,X=123.,$END
```

```
                2
  R/H FROM CONTANINATED NAK IN MSA CONTAINER, SIDE OF CONTAINER
   $INPUT NEXT=1,
   WEIGHT(055)=.525,
   WEIGHT(082)=15.7,
   WEIGHT(084)=15.7,
   WEIGHT(141)=.005,
   WEIGHT(206)=.0009,
   WEIGHT(269)=.0007,
   WEIGHT(335)=16.6,
   WEIGHT(380)=.027,
   WEIGHT(403)=.63,
   WEIGHT(418)=.013,
   IGEOM=7,NSHLD=3,JBUF=1,
   T(1)=30.16,
   T(2)=.3175,
   T(3)=0.5,
   X=31.,
   SLTH=91.44,
   Y=45.72,
   NTHETA=19,
   NPSI=19,
   DELR=1.,
   ISPEC=3,
   $END
            7        .75
            9                  7.3
          14                              11.3                              1
  R/H AT 1 FT FROM THE SIDE OF THE CONTAINER,0.5 CM PB SHIELD
   $INPUT NEXT=4,X=61.5,$END
  R/H AT 1 FT,  1 CM PB SHIELD
   $INPUT NEXT=4,T(3)=1.,X=62.,$END
  R/H AT 1 FT 1.5 CM OF PB
   $INPUT NEXT=4,T(3)=1.5,X=62.5,$END
  R/H AT 1 FT FROM THE SIDE OF THE CONTAINER, 2 CM OF PB
   $INPUT NEXT=4,T(3)=2.,X=63.,$END
  R/H WITH 2.5 CM OF PB
   $INPUT NEXT=4,T(3)=2.5,X=63.5,$END
```

APPENDIX D

NAK HANDLING

APPENDIX D

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev. 4-78)

ENGINEERING DESIGN FILE

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK006

FUNCTIONAL FILE NO. 3KNOPNAKE

PROJECT/TASK NaK Disposal/EBR-1

DATE 6/11/86

SUBTASK Engineering

EDF PAGE NO. 1 OF 24

SUBJECT

Conceptual NaK Handling Design Report

ABSTRACT

This EDF provides a requirements summary, a handling process description, and equipment descriptions for a conceptual design to handle the EBR 1 Mark II Core NaK and deliver it to a processing system.

Conventional lifting techniques are used to move the NaK filled drums from the ARVFS bunker into shielded secondary containers where the drums are penetrated by shaped explosive charge. The NaK then drains into the bottom of the secondary containers and is pumped to a processing system.

DISTRIBUTION (COMPLETE PACKAGE): M. R. Dolenc, R. H. Meservey, D. L. Crandall, D. M. LaRue, B. G. Schnitzler, B. W. Brown, R. C. Green, D. P. Halls

DISTRIBUTION (COVER SHEET ONLY): PROJECT EDF FILE LOG, EDF SERIAL NO. LOG

D. A. Lopez

AUTHOR	DEPT.	REVIEWED	DATE	APPROVED	DATE
D. L. Crandall	E&PM				

CONCEPTUAL NaK HANDLING DESIGN REPORT

TABLE OF CONTENTS

6.0 FIGURES

1.0 REQUIREMENTS SUMMARY

The baseline requirements for this conceptual design are provided by Reference 1, Conceptual NaK Handling Design Data Sheet. These requirements are summarized as follows:

1) Vibration and shock to the drums containing NaK shall be minimized prior to containment, to reduce the possibility of potassium superoxide deflagration.

2) Means shall be provided to transport the NaK drums from the ARVFS bunker to the disposal facility.

3) The NaK filled drums shall be completely contained during drum penetration and draining to prevent release of NaK to the atmosphere. The containment shall withstand possible superoxide deflagration.

4) Penetration and draining systems shall be provided capable of removing the maximum quantity of NaK from the drums.

5) This design shall include equipment necessary to deliver the NaK to a separate chlorine reaction system.

6) The containment, penetration and draining system size and weight shall be minimized to reduce disposal cost.

7) Features shall be provided to remove or react to a stable form, all NaK left in the drums following draining.

2.0 HANDLING PROCESS DESCRIPTION

The following sequence provides safe extraction of NaK from the subject drums for processing.

2.1 Prerequisites

1) Closeout of processing equipment fabrication documentation.

2) Component Checkout and System Operational Testing completion.

3) Release of approved procedures for NaK handling and removal from the storage drums.

4) Acceptable weather conditions.

5) Completion of operational and safety training for participating personnel.

2.2 Bunker Entry and Inspection

1) Ensure that necessary equipment is present.

2) Complete a radiation survey of the grounds and ARVFS bunker steel closure plate.

3) Determine the bunker oxygen and radioactive contamination levels.

4) Remove welded retainers on the steel closure plate and lift the closure plate from the bunker entrance.

5) Survey the bunker interior for radioactive contamination. Determine the radiation field by survey with multiple calibrated detectors and compare to prior data listed in Reference 2, EBR-1 Mark II NaK Bunker Inspection.

2.3 Dumpster Extraction

1) Using holes located in the 4-inch channels welded to the dumpster, attach shackles and cables as necessary for dumpster extraction. Use pipe segments as rollers to support the dumpster during extraction. See Figure 6.1.

2) Using a tractor or winch slowly withdraw the dumpster from the ARVFS bunker. Wait 20 minutes minimum before proceeding, to mitigate the consequences of possible KO_2 reactions.

2.4 Drum Removal Preparations

1) Provide local shielding to control and minimize exposure.

2) Remove any cover present on the dumpster.

3) Visually examine samples of the vermiculite for evidence of alkali metal. Survey vermiculite samples for radioactive contamination.

4) Remove the vermiculite by vacuum to storage boxes taking additional contamination samples at several levels.

5) Remove any residual sand by vacuum to storage boxes taking samples for alkali metal and/or radioactive contamination.

6) Complete a detailed radiation survey of the drums using calibrated detectors.

7) Using reach rods as necessary remove the existing lifting frameworks and valve covers from the two MSA drums. Refer to Figure 6.2.

8) Clean the accessible surfaces of the drums to remove sand, dust, rust and corrosion to the maximum extent possible by mechanical means and within reasonable exposure limits.

9) Install drum lifting collars (Figure 6.3) on the two MSA drums.

10) Attach lifting rigging to the lifting collars on the two MSA drums. Inspect and make necessary repairs to the existing rigging attached to the two fabricated drums.

Note: All work on the inside of the dumpster shall be done by remote means. Personnel shall not enter the dumpster while the NaK drums are within the dumpster.

2.5 Drum Removal and Insertion into Secondary Containers

1) Position the mobile crane to reach both the drums in the dumpster and the secondary containers. Attach the crane to one MSA drum and then transport the drum into its secondary container.

2) Install and seal the secondary container closure including the top penetrator device and shielding. Leak test the closure.

3) Repeat Steps 1 and 2 for the second MSA drum.

4) Attach the crane to one fabricated container, lift the container out of the dumpster and transport to the location where cleaning and nondestructive examination (NDE) can take place.

5) Using local shielding as necessary clean the bottom of the fabricated drum to the maximum extent possible by mechanical means.

6) Using TBD NDE technique determine and record the thickness of the top and bottom of this fabricated drum.

7) Install the bottom penetrator device, appropriate for the thickness, into the secondary container.

8) Transport the fabricated drum into the corresponding secondary container.

9) Install and seal the secondary container closure including the top penetrator device selected for the material thickness. Leak test the closure.

10) Repeat Steps 4 through 9 for the second fabricated drum.

11) Complete connections to purge, drain, vacuum, post drain cleaning, pressure measurement and penetrator control. See Figure 6.4.

12) Install remaining shielding over secondary containers.

2.6 Drum Penetration, Liquid Metal Filtration and Transfer

Refer to Figure 6.4 for the following operational sequence.

1) Purge the secondary containers and lines down to the connections at the reaction chamber with argon gas.

2) Demonstrate that a temporary pressure difference can be established from top to bottom in each secondary container by supplying a small argon pressure in the container top. Isolate the argon supply from the secondary containers.

3) Evacuate the secondary containers both above and below the control seal, and the drain lines down through the filter system.

4) Isolate the secondary containers at all other connections.

5) Evacuate personnel, arm the shaped charge penetrator on one fabrication drum and detonate that penetrator. Monitor the secondary container inner wall temperature for 20 minutes. If a rise above 50°C occurs wait until the temperature drops below 50°C before proceeding.

6) Survey the secondary container for radioactive or alkali metal contamination. Proceed only if no contamination is found.

7) Open the valves downstream of the secondary containment and initiate pump operation appropriate to support reaction chamber operation. Continuously record the NaK flow. If flow fails to start as indicated by the NaK flow meter, supply a small argon pressure to the top of the secondary container. Continue flowing NaK as appropriate to the reaction chamber until the flowmeter indicates that all the NaK has been drained from the secondary container. Stop pump operation and close valves downstream of the pump.

8) Confirm that the maximum quantity of NaK has been removed from the drum by demonstrating that no pressure difference can be established between the top and bottom of the secondary container. A small amount of argon may be introduced into the top of the secondary container for this purpose.

9) Bring the secondary container to atmospheric pressure using the argon supply and vent features as necessary. Isolate this secondary container at all valves.

10) Repeat Steps 5 through 9 for the second fabricated drum and for the two MSA drums.

Note: An alternative sequence calls for penetration of all four NaK drums prior to draining any drum to the processing system. Further evaluation of safety vs operational advantages will determine which method is used.

11) Complete connections to the post-drain cleaning system as necessary to complete removal of residual NaK using the TBD method.

12) Dismantle the secondary containers and piping system in preparation for final disposal.

2.7 Contingency Plans

The following actions are recommended in response to the listed unanticipated events.

1) Event: Radioactive or alkali metal contamination in the ARVFS bunker or storage dumpster.

Action: Return the dumpster to a position in the bunker and cover the bunker entry. Develop a new disposal plan based on the extent of the leak and contamination.

2) Event: Drum rupture due to KO_2 reaction or lifting/moving accident prior to enclosure of drums in the secondary containers.

Action: Extinguish any liquid metal fires using established procedures and trained personnel. Return the drums to the dumpster if necessary. Other action the same as Item 1.

3) Event: Failure to accurately determine the thickness of the fabricated drum tops and bottoms.

Action: Conservatively select the drum penetrating system to assure penetration.

4) Event: Alkali metal leak from the secondary containers or piping.

Action: Extinguish any liquid metal fires using established procedures and trained personnel. Repair the leak(s) as necessary and within exposure guidelines and proceed with disposal. If repair is not possible, develop a new disposal plan based on the extent of the incident and contamination.

5) Event: Failure to establish a purge through a drum following the draining sequence.

Action: Evaluate the total NaK removed by integrating the flowmeter recording for that drum, and compare that amount to what the drum might contain. If insufficient NaK has been removed activate backup penetration systems and repeat draining sequence.

6) Event: Filter plugging as indicated by excessive pressure drop.

Action: Switch flow to a backup filter in the parallel filter system.

7) Event: Line or component plugging as evidenced by loss of flow or high pressure drop.

Action: Identify plug location using pressure indication. Replace plugged pipe or component using liquid metal freezing, pipe cutting and rewelding techniques. Local shielding would be used as necessary.

3.0 EQUIPMENT DESCRIPTIONS

3.1 Dumpster Handling Equipment

This equipment is considered conventional off-the-shelf or on hand. Detailed descriptions will not be provided. A list of equipment follows:

1) Winch truck

2) Survey monitors

3) Welding and cutting equipment

4) Gas analyzers

5) Water supply tanks

6) Cable sheaves

7) Ropes and cables

8) Electric power and lights

3.2 Drum Handling Equipment

Lifting collars would be required for the two MSA drums. The existing lifting collars are too bulky to allow insertion of these drums into their secondary container. The new lifting collars will require a right angle drive to actuate the clamping mechanisms and are shown in Figure 6.3. The remainder of the drum handling equipment is assumed to be conventional off-the-shelf or on hand. Detailed descriptions will not be provided. A list of this drum handling equipment follows:

1) Mobile crane

2) Portable lead shielding

3) Vacuum for vermiculite and sand removal

4) Boxes for used vermiculite and sand

5) Inspection mirrors

6) Radiation spectral analysis equipment

7) Right angle drive wrench

3.3 Drum Secondary Containers

The general features of the secondary containers as shown in Figures 6.5, 6.7 and 6.9 include a flanged closure to allow insertion of the NaK drums. Each secondary container would be a minimum size to accept its drum. The wall thickness of the secondary containers would be selected to withstand possible KO_2 reaction. The material of construction is austinetic stainless steel with fabrication techniques and cleanliness requirements selected to preclude organics or other undesirable contaminants. The containers provide a support to position the NaK drums and a sealing system to isolate the top penetration zone from the bottom penetration zone in each drum prior to penetration. This seal is necessary to confirm complete draining of each drum.

Additional features of the secondary containers are shown in Figure 6.4. Instrumentation includes pressure indicators, temperature indicators and necessary penetrator control circuits.

Penetrations into the container include: argon supply, vacuum connections and a bottom drain connection including screen to prevent downstream valve plugging.

A lead shielded enclosure to limit personnel exposure would be built to surround the four secondary containers. This enclosure incorporates exit paths for the process lines with barriers to protect against direct radiation.

3.4 Drum Penetration System and Alternatives

A number of drum penetration systems were investigated. The three systems including shaped charge, driven penetrator and drilling, are considered most feasible and are described as follows:

Alternative 1

A secondary container with a linear shaped charge penetration system is shown in Figure 6.5. Figure 6.6 shows details of this penetration system.

Linear shaped charge systems function by the explosive phenomenon known as the Munroe Effect which is generally described as interaction of detonation products and cavity liner material emanating at high velocity from a shaped charge as the explosive detonates. The explosive decomposition releases large quantities of gas almost instantaneously under extreme pressure - as much as several million pounds per square inch. Shock waves produced by the expanding gases move outward radially as well as longitudinally, and conform generally in shape to the cord cross section. The shock waves emanating from the lower portion of a typical charge converge in a plane parallel to the charge axis and cause an extreme pressure concentration along the plane of convergence. These directed shock waves, together with the products of explosive decomposition and the metal fragments from the sheathing material, form the primary cutting action - the jet. If a shaped charge is detonated on a metal plate, the jet exerts a force of several million pounds per square inch along a very narrow line. This force causes the metal to be pushed out of the way of the advancing jet by plastic flow. If the shaped charge is properly sized the metal plate will be completely penetrated or "cut" along the path of the charge.

The linear shaped charge would be formed into a circle of approximately 6 in. in diameter. The charge circle for the drum top would be somewhat smaller than the one for the bottom to prevent occlusion of the bottom hole by the piece cut from the top. These shaped charges are placed on or in a standoff system and attached to the top and bottom of the NaK drums prior to secondary container closure. The standoff space is necessary to maximize the cutting effect of the jet. The linear shaped charges are initiated remotely by electric blasting caps located on the free ends of the charge. Backup charges may be installed for use in the event the first charge fails to penetrate the drum.

Advantages of this penetration method include simplicity, extreme reliability of penetration and low cost. The principle drawback is high pulse pressure inside the secondary container at detonation and possible need for greater secondary container wall thickness. Residual pressure after detonation is expected to be less than atmospheric pressure if detonation occurs in an evacuated secondary container. This linear shaped charge penetration is the recommended method.

A minor variation of the shaped charge penetration system involves the use of what is called a conical shaped charge. Several variations exist (hemispherical shaped charge and explosively formed penetrator or EFP), but basically these systems use a metal shape backed by a cylinder of explosives to produce a small round hole. More explosive charge is required to produce equivalent sized holes and therefore increase pulse pressure containment problems.

Alternative 2

A secondary container with a driven penetrator is shown in Figure 6.7. Figure 6.8 shows the details of this penetrator system.

The concept involves penetrators incorporating flow paths which are driven through the drum top and bottom. A seal required for post drain purge is incorporated into the penetrator housing. The force to propel the penetrator may be provided by a propellent charge (i.e., gun powder), by compressed gas or by a gas shock wave produced in a shock tube. The configuration would vary depending on the propelling method used. The sealing systems allow bleed off of the propellent pressure after penetration with no radioactive release.

Advantages of these systems include; no pulse pressure inside the secondary container, better confinement of the NaK (i.e., no NaK on the secondary container walls), and much less perturbation of the NaK and possible KO_2.

Principle drawbacks include the high pressures and/or long barrels required to achieve sufficient energy to penetrate the fabricated drums, smaller resulting hole size and the requirement for significant research and development to ensure reliable penetration. Unknowns concerning material type and thickness of the fabricated drum tops and bottoms decrease the probability of penetration.

Alternative 3

Figure 6.9 shows a secondary container system incorporating a drill type penetrator. Drill torque would be provided by an electric motor and drill feed would be pneumatic. Shaft seals would allow penetration of the drill bit shaft through the secondary container.

Advantages of this system include; no pulse pressure inside the secondary container, better NaK confinement, and minimum perturbation of the NaK and possible KO_2.

The disadvantages include a potential for seal failure and radioactive release to the environment. If the drilling equipment is moved inside the secondary container then the container must be very large. A further disadvantage would be the relatively small drain hole. There is also a concern of unreliable penetration due to unknowns of fabricated drum thickness and material type and because no cutting oil can be used due to explosive reaction with KO_2.

3.5 Draining System and Pump

Refer to Figure 6.4. The draining system consists of piping from the drain connections of the secondary containers and the pump, flow meter, filter system and valves.

A conventional ac conduction or linear induction pump with proper process system pressure output, and a straight throat mounted in a verticle orientation would be used. The flow meter would be an electromagnetic type. The filter system would consist of as many as eight separate filters mounted in parallel with isolation valves to facilitate switching in the event of plugging. Pressure indicators would serve to identify impending plugging. The filter pore size would be selected to preclude clogging of nozzles in the processing system. The valves would be all welded bellows seal type. All containment material is austinetic stainless steel. A flow control system would use input from the processing system (such as chlorine flow rate and/or temperature) to control NaK flow based on indication from the NaK flowmeter.

3.6 Auxiliary Systems

Refer to Figure 6.4. Auxiliary systems include argon gas supply, vacuum system and penetrator control system.

The argon gas supply system used for purging prior to penetration, and to confirm complete draining, consists of argon bottles, pressure regulator, valves, and flow indicator. A filter is included to prevent possible release of contamination.

The vacuum system evacuates the secondary containers and downstream lines prior to drum penetration and incorporates both a LN_2 NaK trap and an exhaust filter to prevent release of contamination.

The penetrator control system would consist of detonator controls and safety interlocks or in the event of one of the other penetrator systems, the necessary electrical controls for their operation.

3.7 Safety Equipment

The following equipment is expected to be in use or on hand for operations leading to, during, and after NaK draining:

1) Portable CAM (Constant Air Monitor)

2) Radiation monitors with alarms

3) Safety barriers

4) Alkali metal protective clothing

5) Scott Air Packs or other emergency breathing equipment

6) Alkali metal and electrical fire fighting equipment including remote controlled fire suppression compound delivery systems and/or portable alkali metal fire extinguishers with extension nozzles

7) Shallow alkali metal catch pans under secondary containers and along the lifting path from the dumpster to the secondary containers

8) Safety shower

9) Emergency lighting

10) Connections to the Warning Communications Center

11) Emergency transportation

12) Oxygen monitor

4.0 CODES AND STANDARDS

The codes and standards recommended to apply for the design of the NaK Handling System are as follows:

1) ASME Boiler and Pressure Vessel Code Section III Subsection NC for all NaK or NaK vapor containing piping and vessels.

2) ANSI B31.1 for all other pressure or vacuum piping.

3) ANSI/NFPA 70-1984 (National Electrical Code) for all electrical systems.

4) DOE Hoisting and Rigging Manual.

5) DOE-ID 5480.1, Chapter XI for Radiation Protection.

6) EG&G Standard 7022 for Cleanliness

7) EG&G Standard 7017 for Electrical Fabrication

8) EG&G Standard 7006B for Component Marking

9) ASTM Material Standards

NOTE: The version of the above Codes and Standards approved at the start of final design shall apply.

5.0 REFERENCES

5.1 Documents

1) Conceptual NaK Handling Design Data Sheet, Project No. 015094, March 18, 1986.

2) EBR-1 Mark II NaK Bunker Inspection, EDF 3KKBJ00E1, September 11, 1979.

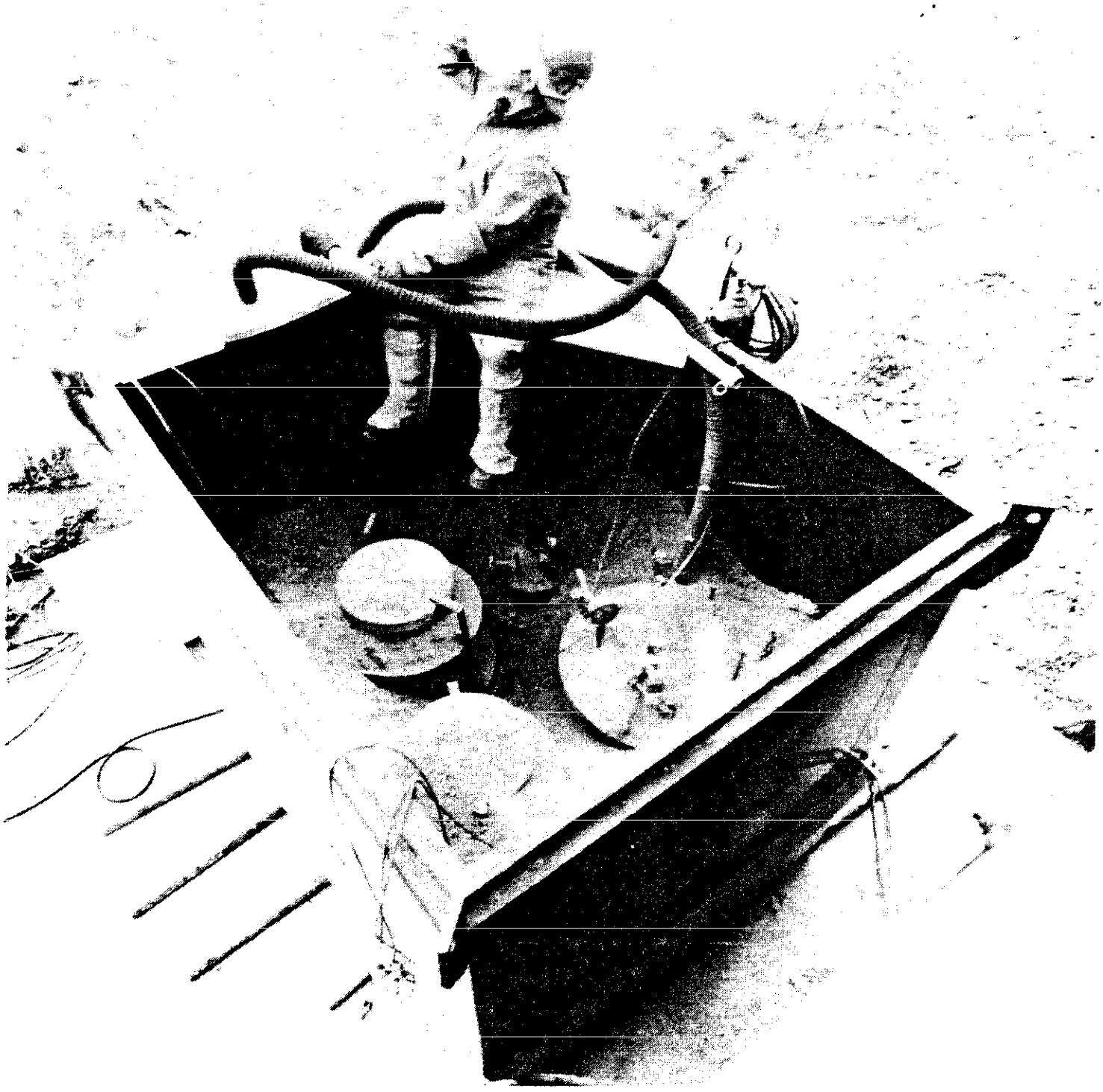
3) Decontamination and Decommissioning of the EBR-1 Complex Final Report, ANCR-1242, July 1975.

5.2 People

Stanley Golaski, conical and hemispherical shaped charge expert, Balistics Research Laboratory, Maryland, Phone 301-278-6074.

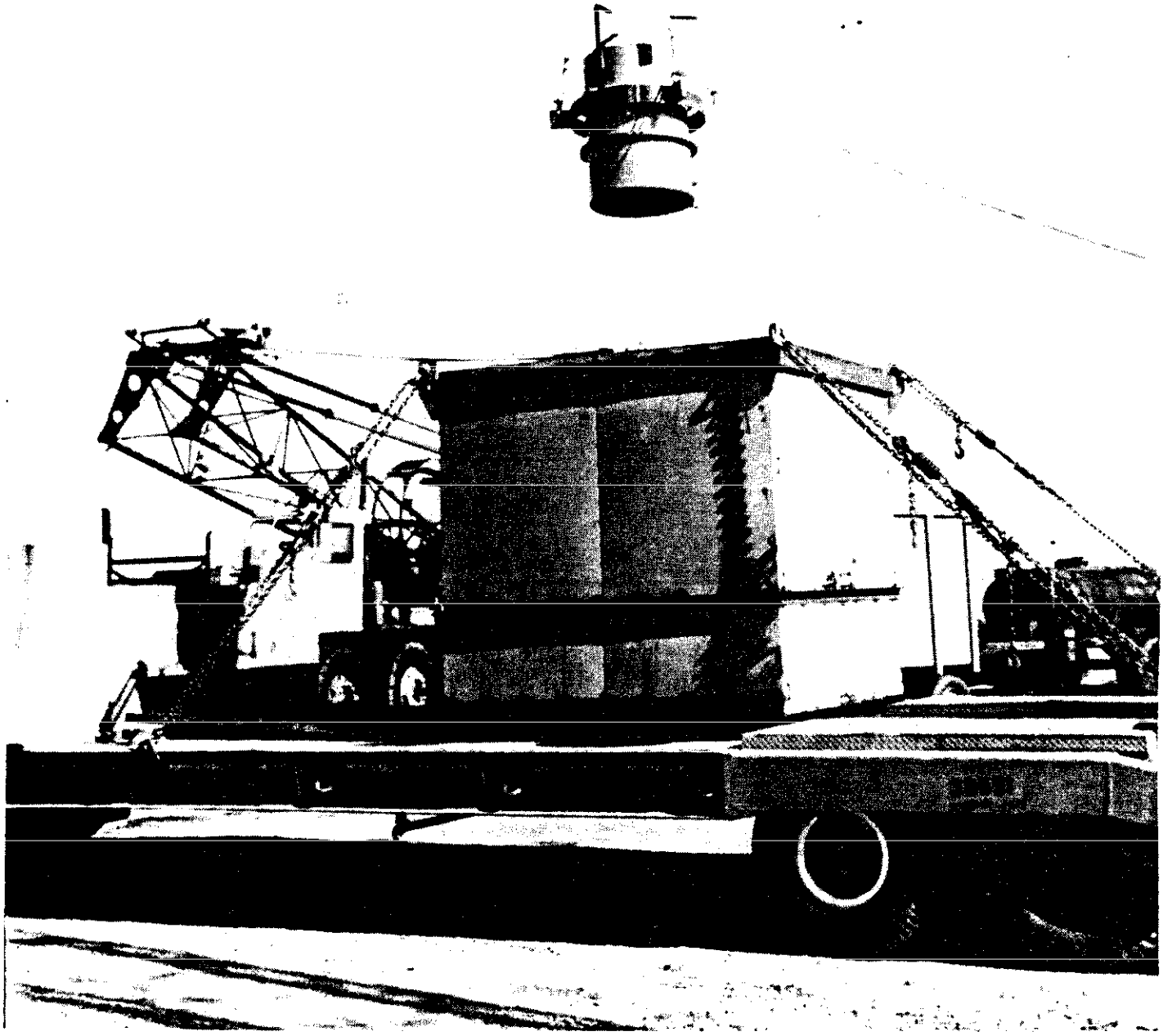
R. J. (Bob) Richards, Vendor for a linear shaped charge product, Explosive Technology, Inc., Fairfield, California, Phone 707-422-1880

Dr. Ernest Bloore, Materials Scientist and expert on military penetrators and materials to resist penetration, Pickatiny Armament Research Command, Dover, New Jersey, FTS Phone 8-654-2879.



79-7179

Figure 6.1 Dumpster



74-416

Figure 6.2 Drum Lifting

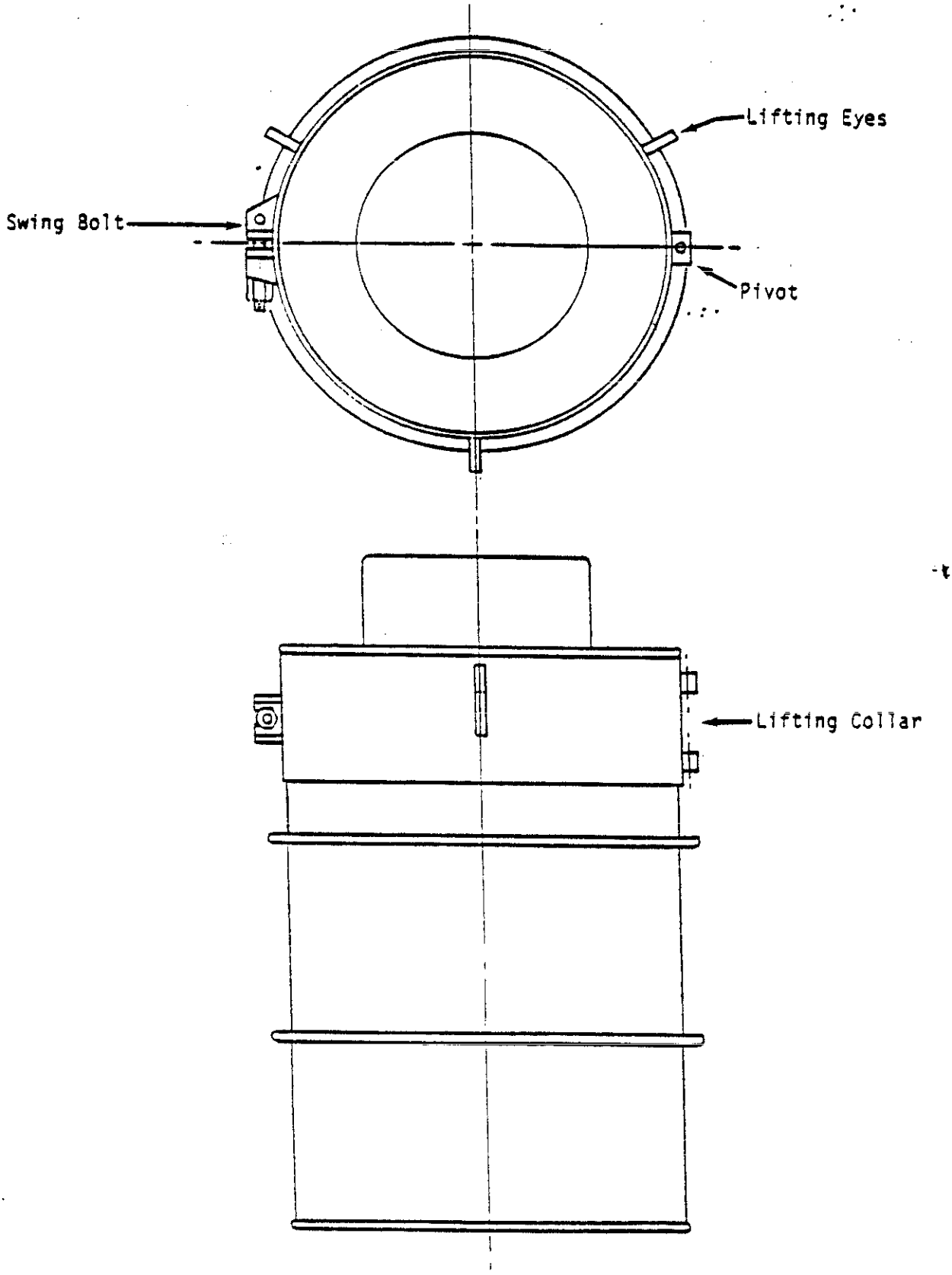


Figure 6.3 Drum Lifting Collar

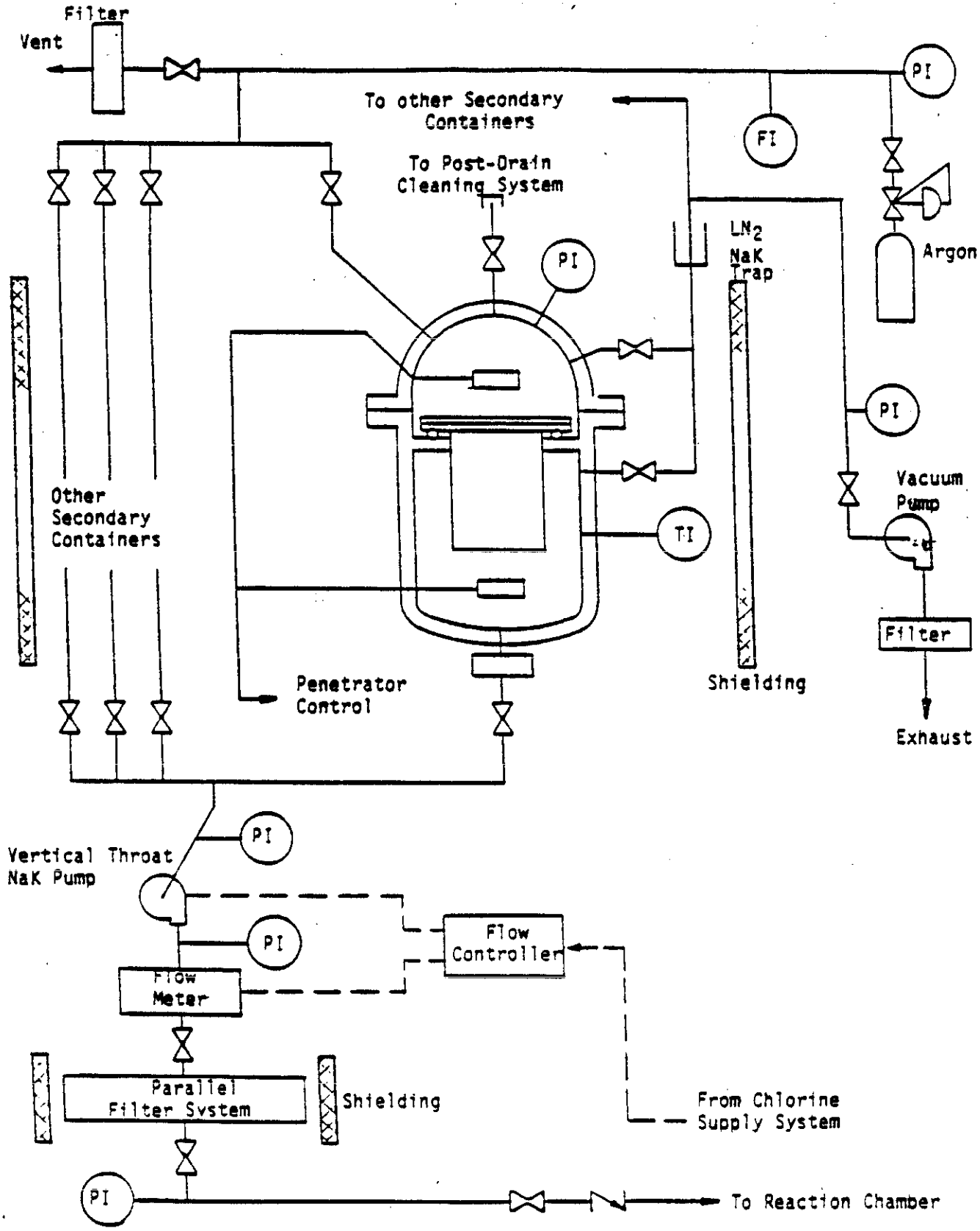


Figure 6.4 Piping and Instrumentation Diagram

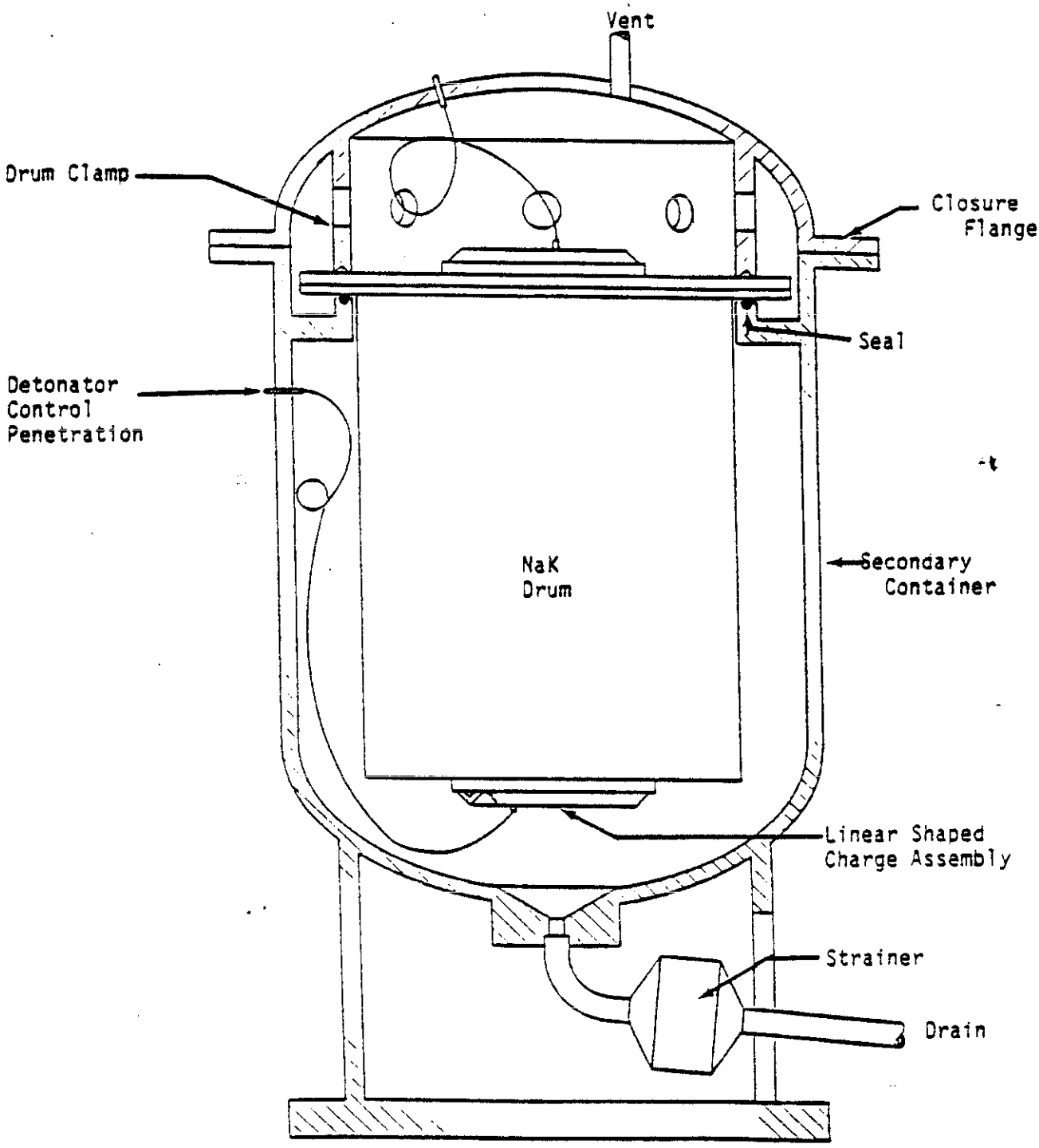


Figure 6.5 Secondary Container Assembly
(Shaped Charge Penetrator)

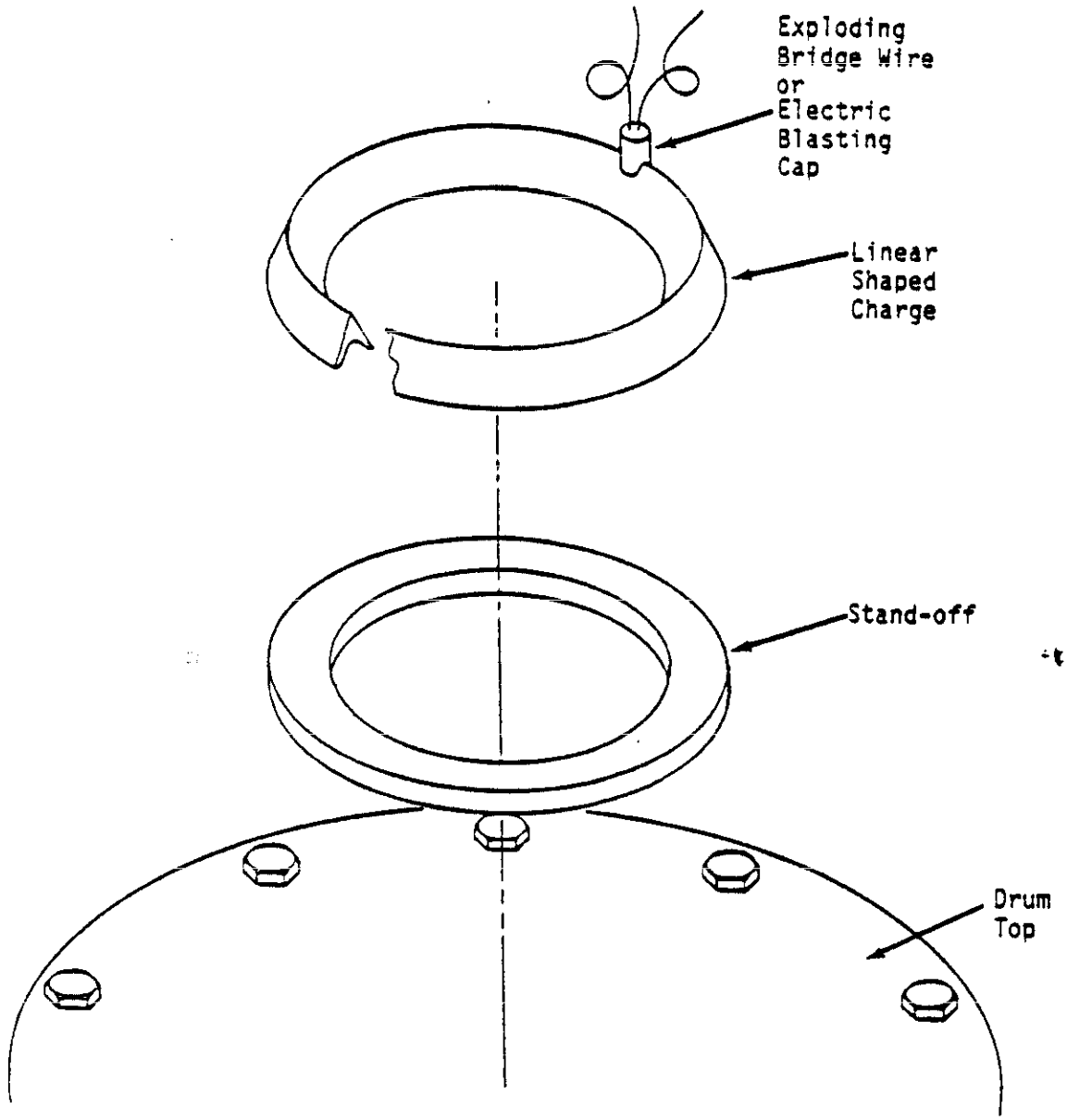


Figure 6.6 Shaped Charge Penetrator Detail

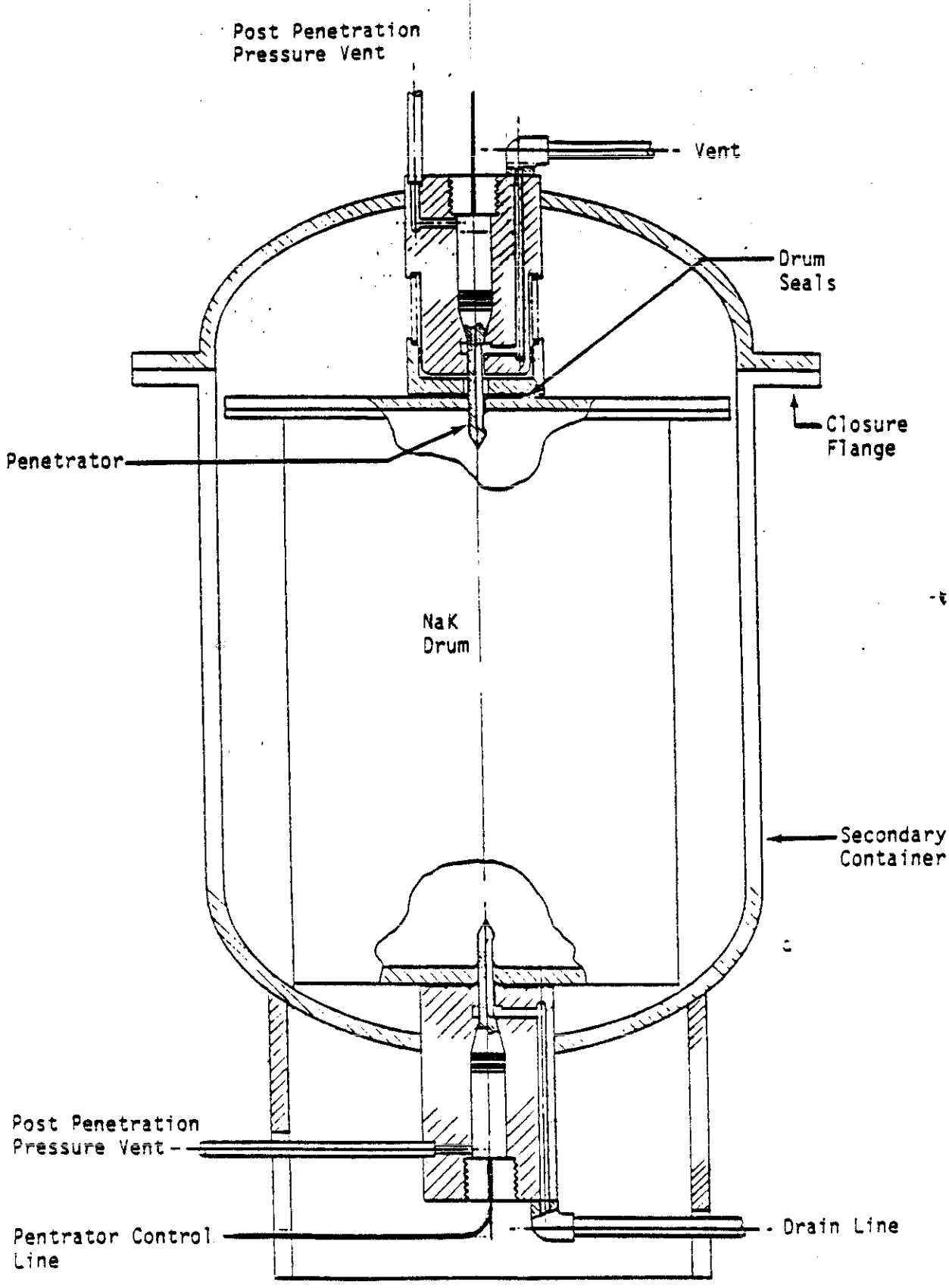


Figure 6.7 Secondary Container Assembly
(Driven Penetrator)

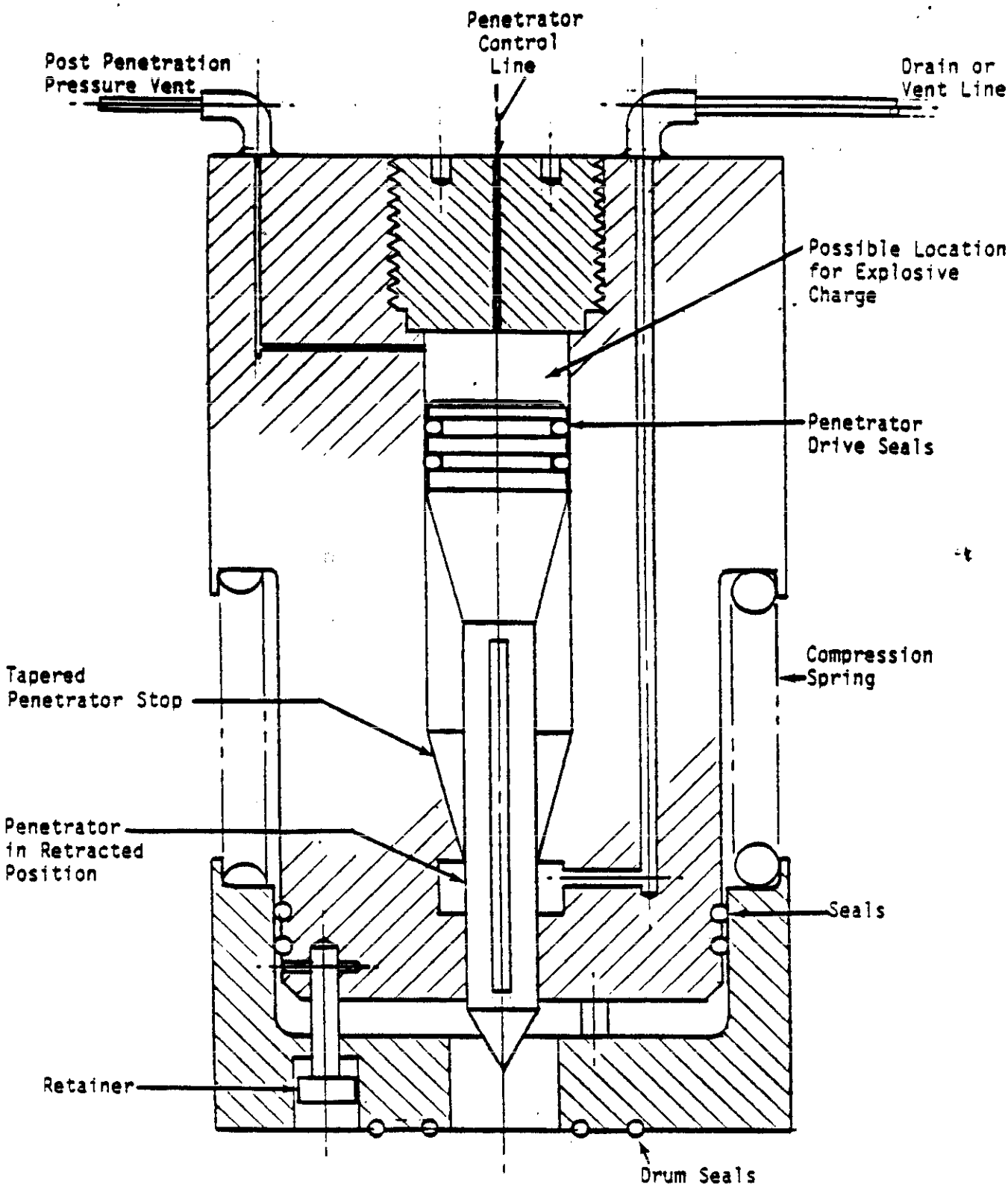


Figure 6.8 Driven Penetrator Detail

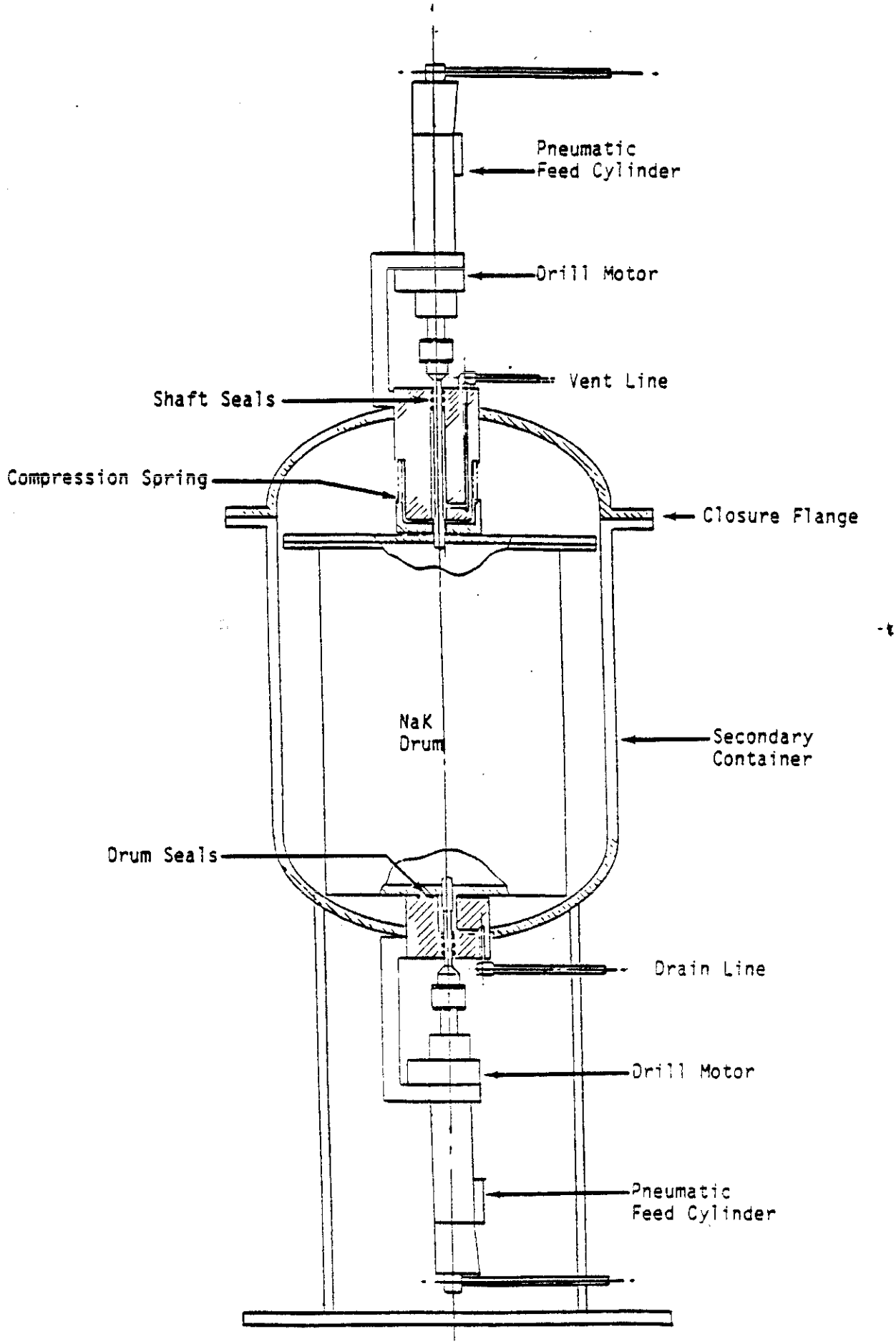


Figure 6.9 Secondary Container Assembly
(Drill Type Penetrator)

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev. 4-78)

PROJECT FILE NO 015094

EDF SERIAL NO NAK009

FUNCTIONAL FILE NO

DATE June 24, 1987

ENGINEERING DESIGN FILE

PROJECT/TASK

SUBTASK NaK Drum Container and Penetrator

EDF PAGE NO 1 OF 6

SUBJECT PROOF-OF-PRINCIPLE TEST REPORT

ABSTRACT

This EDF contains the results of Proof-of-Principle tests on seals and penetrators which could be used in the final design of the NaK Drum Container and Penetrator systems. The following report sections are included:

1.0 INTRODUCTION
2.0 TEST EQUIPMENT
3.0 TESTING AND DATA
4.0 DISCUSSION AND CONCLUSIONS

The testing conducted on the equipment described herein has demonstrated effective penetration with leakages of less than 5×10^{-7} scc/sec (helium). This information can be used to validate final designs.

DISTRIBUTION (COMPLETE PACKAGE)

F. E. Stoll, D. M. LaRue, B. W. Brown, E. V. Mobley, T. W. Ferns, J. H. Southwick

DISTRIBUTION (COVER SHEET ONLY) PROJECT EDF FILE LOG, EDF SERIAL NO LOG

R. H. Meservey

AUTHOR	DEPT	REVIEWED	DATE	APPROVED	DATE
D. L. Crandall	E320	[signature]	6/23/87	[signature]	6/24/87

ENGINEERING DESIGN FILE

PROJECT/TASK

SUBTASK NaK Drum Container and Penetrator

ABSTRACT

1.0 INTRODUCTION

This EDF reports the results of Proof-of-Principle tests conducted to develop information about penetrators and penetrator shaft seals necessary to complete detailed design of NaK Drum Container and Penetrator systems. Successful performance of seals and penetrators is considered essential to safe disposal of the contaminated NaK. The final container and penetrator systems will penetrate the storage drums and prevent the release of NaK and/or radioactive contamination. This Proof-of-Principle Testing was conducted per the Test Specification ES 51128 dated 04-29-87.

2.0 TEST EQUIPMENT

Figure 1 is a schematic diagram of the test setup. Photos of the system are identified with numbers from 87-312-1-1 to 87-312-1-12. The objects specifically under test are the seals and cutters. Bearings and the drive shaft are indirectly tested as they affect the performance of the seals and cutters.

The seals tested in this program are of two types, Parker nitrile rubber seal #A51 1870100021 and this same seal with the polymer expansion ring replaced by a metal wire coiled expansion ring.

The cutter system is of special design but is based on the J+L Industries Multi-Tool system for "E" type blades (Pilot Holder #EH32, Pilot #'s EX20 and EX25, and "E" type blades in 2 in., 2-1/2 in. and 3 in. sizes). This tool system was selected because it turns the displaced material, for 3 inch diameter, almost entirely into chips leaving no significant plug to interfere with the subsequent penetration in the drum bottom. The changes from the standard tool are as follows:

1. A new tool holder was developed which carries the requisite 1 in. pilot drill and all three "E" cutters so that a 3 in. hole can be cut with one pass. Through development testing (not specifically required in ES 51128) Stainless Type 17-4 material was selected shaped and hardened to approximately Rockwell 45(C) by heating to 900°F followed by gradual cooling in air. The pilots are machined integral with the tool holder.

2. The pilot drill (mounted in the new tool holder) is made by shortening the shank of an entirely hardened centering and spotting drill, Series SPD 1 in. diameter with 1-1/4 in. flute length. Shortening is needed to minimize the overall length of the tool.

ABSTRACT

3. The "E" blades were modified to incorporate a 10° angle relative to a line normal to the cutter shaft. This modification minimizes the thickness of the rings left after penetrations.

This cutting tool will be defined by EG&G drawing number 423330.

The bearings are journal type Kamatics KARON #KRJ16-SB-020. They are special high load bearings and were selected to minimize the spacing between bearings and in turn reduce the overall height of the drilling system.

The shafting is Thomson Industries hardened and ground round way 1.0 in. nominal diameter (.999 actual diameter). The coupons in the test rig are approximately one foot below the lower bearing and the bearings are spaced 4 inches apart.

3.0 TESTING AND DATA

3.1 Seal Leakage Tests. The shaft seals were tested with the cutter shaft stationary, rotating, translating, and rotating plus translating during penetration of a 1/2 in. thick mild carbon steel coupon. The shaft was turned at 80 rpm and the feed rate was set at .0022 inches per revolution. No lubricant of any type was used on the shaft or penetrator. The leak rate varied between 3×10^{-7} and 5×10^{-7} standard cubic centimeters per second (scc/sec) of helium across a one atmosphere pressure difference. The leak rate was not dependent on mode (i.e., translating vs. translating plus rotating) and seemed to vary more as a function of seal position along the axis of the shaft. The leak testing was conducted with the seals reversed (put in to hold pressure out) using a Vacuum Instrument Corporation Model MD-180 leak checking instrument. The calibration of the instrument was confirmed using a calibrated standard leak at 3.9×10^{-8} scc/sec helium. The inside of the observation chamber was evacuated and maintained at a vacuum between 20 and 50 microns during leak testing. Higher micron readings were assumed to occur as a result of heating of the coupon during drilling. Leak testing of the observation chamber revealed leaks which were repaired except for those at the glass lighting ports and observation port. These were sealed with duct seal and carefully checked before testing.

Three incidents occurred during this testing which are worthy of note and are detailed as follows:

1. After fabrication of the observation chamber, gross leaks were identified using a fluid leak testing agent. This fluid rapidly promoted rusting of the Thompson Roundway shaft at the interface with the bearings. Disassembly cleaning and polishing of the shaft was necessary.

ABSTRACT

2. During penetration at the 2-1/2 in. diameter cutter, an eccentric motion was established which resulted in visible flexing of the seal and bearing cartridge as it was mounted in the top of the observation chamber. However, no appreciable change in the leak rate occurred. The capacity for the seal and bearing system to handle the associated loads without failure or leakage, supports selection of these components for use in subsequent design.

3. The seal and bearing cartridge incorporates a cylindrical seal retainer. This seal retainer seized to the shaft twice during operation of the penetration system due to insufficient radial clearance. Each time, stainless steel was transferred from the retainer onto the Thompson Roundway. This necessitated careful removal of the stainless steel and repolishing of the shaft, however, no extra leakage could be attributed to these repairs. This seizing problem was finally cured by providing approximately .015 in. radial clearance between the shaft and the seal retainer.

   The second failure provided an opportunity to replace the standard Parker #A51 18701000 21 seal with the similar seal incorporating a metal expansion ring. No difference in sealing or wear performance was detected between the two types of seals.

The bearings were measured following the testing. The upper bearing was found to have a maximum of .0005 inches of wear, the lower bearing was found to have a maximum of .0007 inches of wear; relative to the newly installed dimension. The two sets of seals were examined after the testing. The lower seal in each case showed some minor abrasion damage to the sharp edge of the sealing lip. This is believed to be due to the assembly process and apparently had little or no affect on the performance.

3.2 Cutter Tests. The cutter system as described in Section 2.0 was used to cut two each, 1/2 in. thick mild carbon steel and 1/16 in. thick 300 series stainless steel coupons. The cutter was turned at 80 rpms with the feed set on .0022 inches per revolution. The coupons incorporated shallow dams on the upper surfaces around the cutter penetrated area and cups beneath the cutter penetrated area to retain NaK at the cutting interface. Approximately 30 cubic centemeters of NaK were poured onto the cutter-coupon interface during the penetration operation on each coupon. The observation chamber was maintained filled with argon gas with a slight positive pressure to prevent any air in leakage. In each test, the coupons were successfully penetrated, and after NaK removal, had an appearance similar to coupons penetrated without the presence of NaK. The cutter system showed minimal wear similar to that produced by penetration testing without NaK.

ABSTRACT

Following testing, the test assembly was cleaned of NaK using steam and water mist. All the NaK used in the testing was reacted at the ARA 4 (building 616) test location.

Two incidents occurred during this testing which are worthy of note and are detailed as follows:

1. During cutting at the 2 inch and 3 inch diameters, stoppages occurred due to torque requirements in excess of the boring bar motor capacity. Several factors may have contributed to this stoppage including; limited motor power (1-1/2 HP), long power supply cords and the fact that the bar is not designed to provide the high axial thrust. Short retraction and restart were all that was required to complete penetration.

2. The changeout between the third and fourth coupon was accomplished without chip removal or NaK cleaning. Limited air in leakage reacted with some NaK on chips resulting in a yellow product assumed to be KO_2. Greater care was exercised by personnel during observation of the subsequent coupon cutting operation due to the potential for K-KO_2 reaction. However, no significant reaction took place between the yellow substance and fresh NaK introduced in the final cutting operation.

4.0 DISCUSSION AND CONCLUSIONS

Based on experience in the testing program, care should be taken to protect the cutter shaft against corrosion from leak checking fluids or water. A stainless cutter shaft might be considered as an alternate.

The opportunity to test two different seals showed no particular advantages for either one. On this basis, the less expensive and readily available standard seal should be used.

The cutter design developed and used in this test program appears completely acceptable for penetrating multiple 1/2 in. carbon or sheet stainless steel layers, when operated at 80 rpms and .0022 (inches per revolution) feed. The bearings of the size and type used with a spacing of 4 inches or greater will work to support the cutter shaft allowing the seals to maintain containment.

The 1-1/2 HP motor appears to be barely adequate for drive power with the present cutter design. Torque and thrust requirements should be predicted by analysis and a drive system of greater power selected for use in subsequent design.

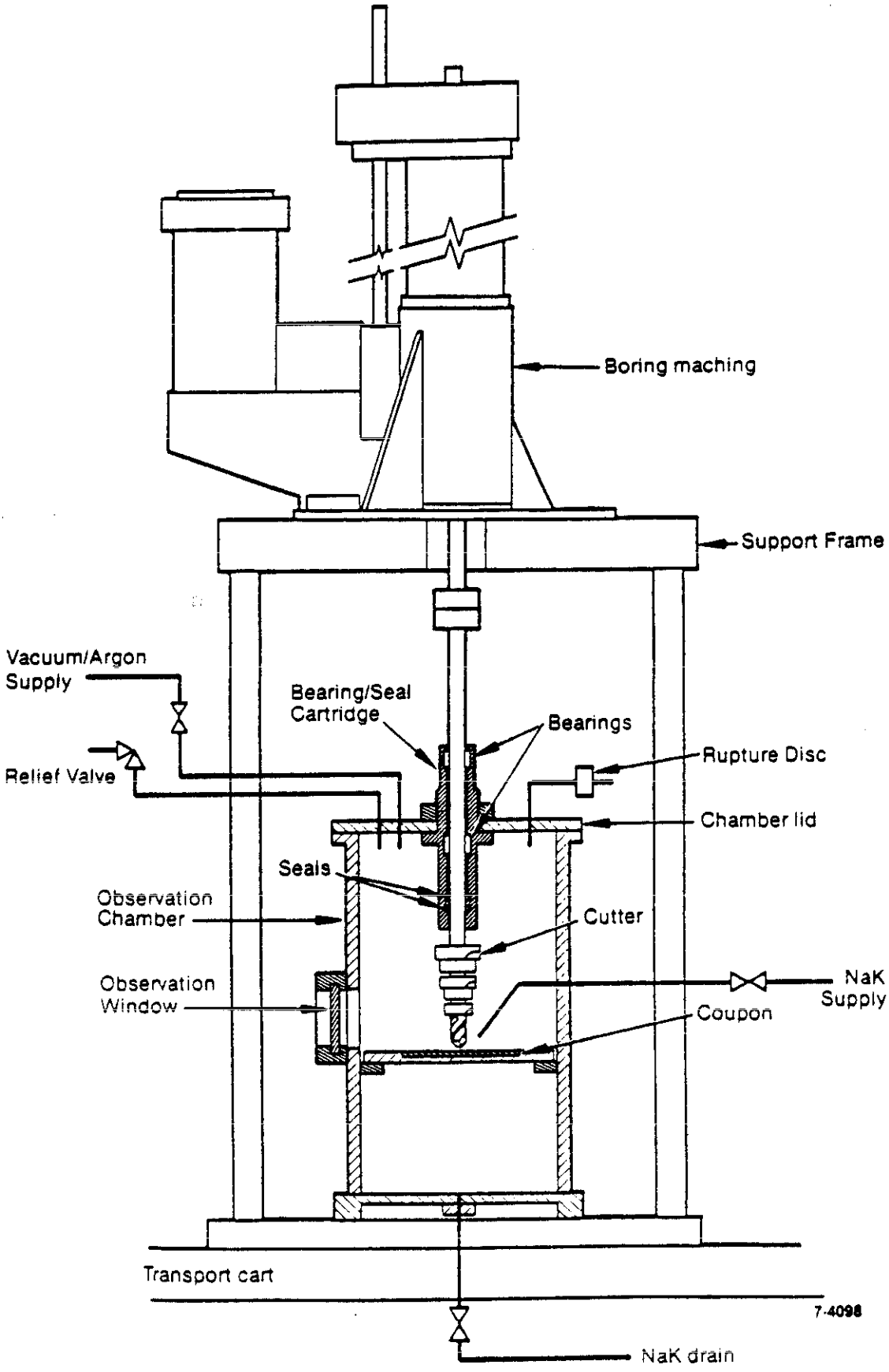

Boring maching
Support Frame
Vacuum/Argon Supply
Bearing/Seal Cartridge
Bearings
Rupture Disc
Relief Valve
Chamber lid
Seals
Observation Chamber
Cutter
Observation Window
NaK Supply
Coupon
Transport cart
7-4098
NaK drain

Figure 1

APPENDIX E

PROCESS SELECTION

APPENDIX E

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev 4-78)

PROJECT FILE NO. 3KNOPNAKO

EDF SERIAL NO. NAK001

FUNCTIONAL FILE NO. 3KNOPNAKE

ENGINEERING DESIGN FILE

PROJECT/TASK Nak Disposal - EBR I

DATE 1/3/86

SUBTASK Engineering

EDF PAGE NO. ___ OF ___

SUBJECT

PROCESS SELECTION

ABSTRACT

This EDF addresses the selection of a process to chemically deactivate the EBR-I Mark-II radioactively contaminated Nak stored at ARVFS Bunker.

The conclusion reached by this EDF is that the processing of the Nak with chlorine is the best process option. The major concerns in performing this selection were:

1. Safety
2. Environmental impact
3. Final waste form stability
4. Final waste form volume
5. Cost

DISTRIBUTION (COMPLETE PACKAGE)

M. Dolenc, R. Green, J. Browder, D. La Rue, D. Suciu, R. Meservey

DISTRIBUTION (COVER SHEET ONLY) PROJECT EDF FILE LOG, EDF SERIAL NO. LOG

AUTHOR	DEPT	REVIEWED	DATE	APPROVED	DATE
D M LaRue	EEPM		Jan 85		

1. INTRODUCTION

Four containers of contaminated Sodium/Potassium (NaK) are stored in an underground bunker at the ARMY Reentry Vehicle Site (ARVFS). The NaK was originally used as primary reactor coolant in the EBR-I. During November 1955 this NaK was radioactively contaminated during the testing of the EBR-I Mark II fuel. During this testing, Uranium (238) was being transmuted to Plutonium (239) when the core overheated. It is unknown as to how much of the Uranium had been transmuted and how much of this material was released into the NaK during the core failure. In addition, a 10.5 gram foil sample of Plutonium was being tested inside the reactor; this sample was lost and believed to be contained in the NaK. Estimates have been made that the NaK contains about 16 grams of radioactive material. No documentation for this estimate has been found. The NaK also probably contains some non-radioactive fuel rod debris.

This NaK coolant, estimated volume is 200 gal (maximum), was removed from the reactor and placed into two 55 gal Mine Safety Appliance Research (MSAR) drums and two containers fabricated from pipe. Each container was pressurized with an argon blanket gas. These containers were then placed in a storage pit at the EBR-I site until 1974. During 1974, these drums were removed from this storage pit, and then placed into a steel dumpster. The dumpster was filled with sand and the package transferred to the ARVFS bunker.

A bunker inspection was performed in August 1979 to characterize the external condition of the NaK containers. Most of the sand was removed from around the containers and radiation and physical measurements were taken. No contamination external to the containers or in the removed sand was found. The containers/drums were not moved or lifted during this inspection activity: therefore, no information exists on the condition of the bottoms of these containers. Vermiculite was added to the dumpster to a depth of approximately 12 in. above the drums. The sheet metal dumpster lid was replaced and the package located inside the bunker for continued storage.

Inspection of the NaK storage containers in 1979 verified that the integrity of the containers had not been breached. However, the smaller of the fabricated containers did have some rust on its lower outer surface. Based on these inspection results, it can be assumed that no significant external deterioration of the containers has occurred during their storage. Although the external condition of the containers has been verified, uncertainties exist regarding the overall integrity of the containers since corrosion could be occurring inside the

containers. In particular, the fabricated containers are of concern since design and construction information on these two containers cannot be located.

There is also some concern that the NaK may contain Potassium Superoxide, KO_2, which if present, could present significant problems during the handling of these containers.

Radiation data for the NaK containers and dumpster taken in August of 1979 are summarized in Table 1. The isotopic curie quantities that were calculated (during 1979) to be present in the EBR-I NaK are presented in Table 2. Figure 1 presents the radiation levels measured for these drums prior to their relocation to the bunker in 1974. Comparison of the 1974 measurements with the 1979 measurements shows a significant discrepancy. Further complicating this issue was the known miscalibration of the radiation meter used during the 1979 inspection. Due to the significance of the radiation hazard associated with these drums, and the inability to reinspect the drums prior to their processing in 1988, the 1979 readings will be used for engineering. This should be sufficiently conservative for personnel safety. (See references 1 & 2)

2. Process Evaluation Considerations

In selecting a proposed process for the chemical deactivation and stabilization of the radioactively contaminated NaK eutectic solution from EBR-I, the following process scheme characteristics were of prime importance:

1) Safety (both chemically and radiologically)
2) Potential of adverse environmental impact during processing
3) Final Waste Form Stability
4) Final Waste Form Volumes
5) Cost (operational and equipment)

Also of concern, although to a lesser degree than the characteristics listed above were the following considerations:

1) Service Requirements (water, power, etc.) at processing site
2) Could the NaK be processed at or near its present location.
3) Rate of Processing
4) Simplicity of Process Scheme

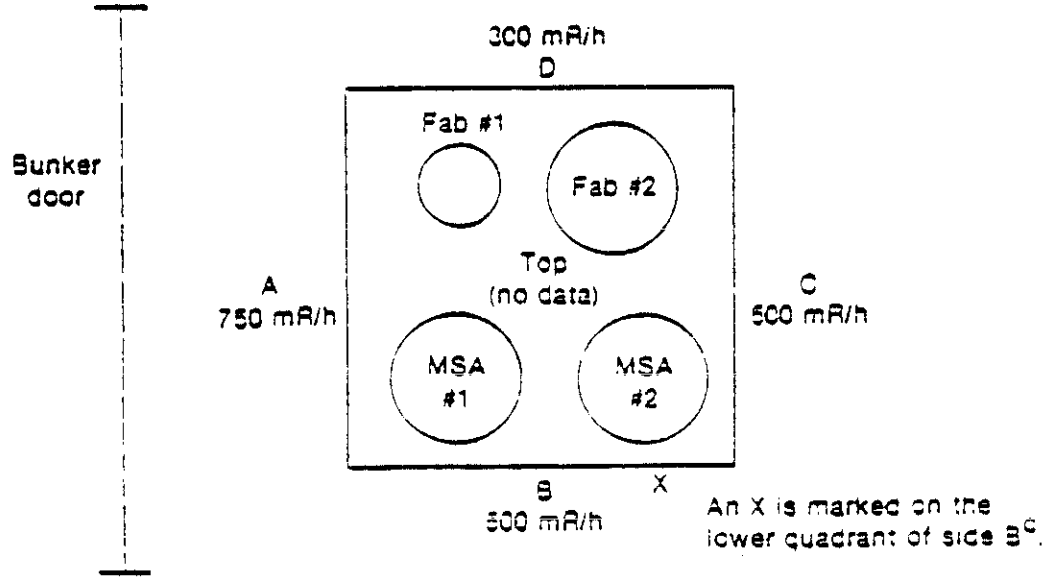
In performing the evaluation, consideration was given to methods which have been employed in the past. In addition, other potential chemical methods were also investigated.

TABLE 1. RADIATION DATA FOR NaK STORAGE CONTAINERS AND DUMPSTER
1979

	CONTAINERS			
	Top of Container @ Contact (R/hr)	Container Height (ft)	Elevation[a] (ft)	Maximum Radiation Reading
MSA #1	1.6	3	1.5	40.0 R/h
MSA #2	2.0	3	1.0	23.3 R/h
Fab #1	0.2	2.2	1.0	16.7 R/h
Fab #2	0.5	3	0.5	16.7 R/h

a. Elevation where the maximum radiation reading was taken, measured downward from container top flange.

DUMPSTER[b]



b. Maximum readings at contact with sides A, B, C, D.

c. Hot spot marked X reading 1.5 R/h.

NEL 4 0453

TABLE 2. ISOTOPIC CURIE QUANTITIES CALCULATED TO BE PRESENT IN THE EBR-II NaK IN SEPTEMBER 1979

Isotope	Curie Value
Sr-90	7.12 +1[a]
Y-90	7.12 +1
Zr-93	4.21 +3
Tc-99	1.74 -2
Ru-106	1.59 -5
Rh-106	1.59 -5
Sn-121m	6.79 -3
Sb-125	1.27 -2
Te-125	2.95 -4
Cs-135	1.92 -3
Cs-137	7.20 +1
Ba-137m	6.63 +1
Pm-147	6.84 +0
Sm-151	2.79 +0
Pu-239	6.16 -1
Pu-240	1.13 -1
Pu-241	1.174 +0

a. $7.12 + 1 = 7.12 \times 10^{1}$

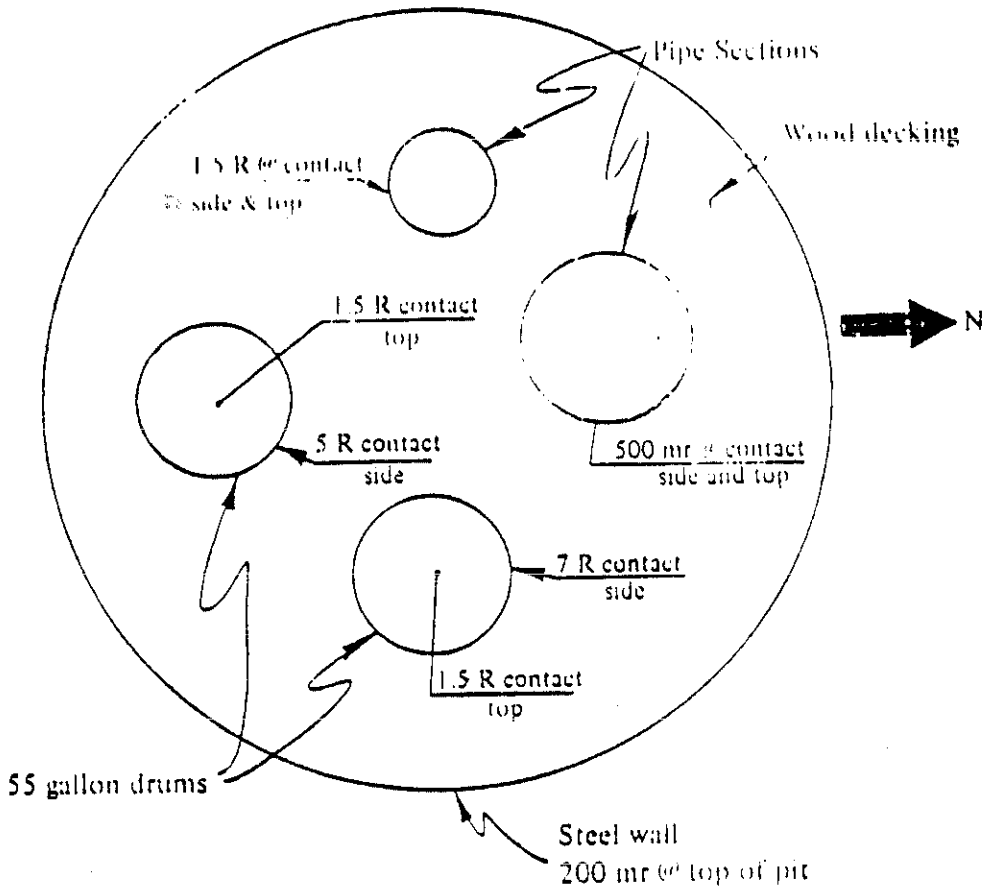


Fig. 1. NaK Storage Pit Radiation Survey

3. PROCESSES INVESTIGATED

In the discussion below, brief descriptions of the various processing scenarios investigated are presented. This list does not include all the process schemes conceived during this exercise; it contains only those schemes not rejected off-hand because of safety, complexity, or cost.

3.1 Steam/Nitrogen Reaction

This process has been used successfully to chemically deactivate liquid sodium and NaK, in some cases where the NaK was radioactively contaminated. (See Reference 3 and 4). The process uses the fact that Na and K will react with water to form hydroxides

$$2\ NaK_2 + 6\ H_2O \longrightarrow 2\ NaOH + 4\ KOH + 3\ H_2\uparrow$$

along with hydrogen gas. The water (water vapor), in significant dilution with nitrogen, is passed over the metal to be reacted. The nitrogen serves two functions: (1)the NaK-water reaction is exothermic and the nitrogen conducts a portion of the heat of reaction away from the reactants to maintain reasonable working temperatures; and (2) the hydrogen generated can present a significant explosion hazard with air, therefore the nitrogen serves as a diluent to maintain the hydrogen concentration below explosion limits when it is vented from the system.

The hydroxides generated by this process are neutralized with mineral acids (e.g., sulfuric acid) prior to disposal. The off-gas is vented through a filter (HEPA) to prevent the introduction of radioactive material into the atmosphere. Figure 2 illustrates this process in schematic form.

3.2 Oxygen Reaction

This process has also been successfully employed to chemically deactivate Sodium. (See Reference 5). In this process, warm air, with a small amount of moisture to catalyze the reaction, is slowly passed over the sodium to oxidixe it. A small amount of hydrogen is produced in this reaction, but this is maintained below the combustion limits by maintaining a low partial pressure of water in the reactant gas stream. The Sodium Oxide can be stored in its solid form or it can be further stabilized by reacting with

water to form sodium hydroxide. This can then be reacted with mineral acids to form salt solutions. The advantage of this system is that smaller quantities of hydrogen are formed during the reaction.

$4\ Na + O_2 \longrightarrow Na_2O$

$K + O_2 \longrightarrow KO_2$

This process is illustrated in Figure 3.

This process is not as attractive when processing Potassium containing liquid metal solutions. The Potassium preferentially reacts with the Oxygen to form Potassium Superoxide. (See Reference 6). This superoxide can then spontaneously react with sodium to form sodium and potassium oxides. The rate and exotherm of this reaction is similar to thermite reactions. and although not explosive in the normal sense. can produce sufficient thermal energy to penetrate the vessel containing the reactants, or release sufficient energy to produce a thermal explosion. (See Reference 7).

3.3 Reaction with Alconols

Alconols are mildly acidic and will react with alkali metals to form alkoxides. The relative acidity of the alcohols is tertiary < secondary < primary < methanol. The reaction rate between the alkali metal and the alconol is ennanced with the presence of a small amount of water due to the formation of hydronium ions in the solution. The reactions with alconols produce Hydrogen:

$2\ ROH + 2Na \longrightarrow 2\ RONa + H_2\uparrow$

R is a paraffin chain

A flow scheme for this reaction is scnematically illustrated in Figure 4. (See Reference 8). A safety concern would be the presence of KO_2 which could react violently with the organic chain of the alconol.

3.4 Reaction with Sulfur

The alkali metals react with Sulfur to form ionic molecules. i.e., soluble in water.

$2Na + S \longrightarrow Na_2S$

$4Na + 2S \longrightarrow Na_4S_2$

$6Na + 3S \longrightarrow Na_6S_3$

$2K + S \longrightarrow K_2S$

$4K + 2S \longrightarrow K_4S_2$

In this reaction scheme, the Sulfur would be in the molten state (slightly greater than 120 C) within the reactor vessel. The NaK would be slowly introduced into the vessel to react with the Sulfur. Due to density considerations ($NaK < Na_2S < S$) the reactor would have to be agitated. Upon completion of the processing of the NaK, the vessel would be allowed to cool, solidifying the Sulfur and Sulfide mixture, and then disposed. This process is illustrated in Figure 5.

3.5 Reaction with Acids

The alkali metals react vigorously with all acids. The acids which were considered in this investigation were:

Sulfuric
Hydrochloric
Nitric
Hydrogen Sulfide
Ammonia

In all of these systems, Hydrogen is produced. Due to the concerns associated with the handling of these fluids, there is no advantage of these reaction schemes over the reaction with water vapor, also acidic to alkali metals.

3.6 Reaction with Halogens

The halogens (Fluorine, Chlorine, Bromine, and Iodine) are very reactive with the alkali metals and react to form ionic salts, e.g., NaCl.

Fluorine and Chlorine are gasses at standard conditions, Bromine is a liquid, and Iodine is a solid. Due to the significant exotherm for these reactions, the halogens should be diluted in an inert gas. This condition therefore restricts Bromine and Iodine from being strongly considered.

In this reaction scheme, the NaK would be slowly sprayed into a dilute atmosphere of Fluorine or Chlorine.

$$2\ Na + Cl_2 \longrightarrow 2\ NaCl$$
$$2\ K + Cl_2 \longrightarrow 2\ KCl$$

The diluting gas should be Helium or Argon, other gasses, e.g., nitrogen, would react in this system to form compounds not as stable as the desired final products.

Fluorine or Chlorine would be slowly injected into the reaction vessel to maintain the desired partial pressure. At the completion of the processing of the NaK, the small amount of residual halogen gas would be vented through an absorbant, e.g., water; the vessel purged with Helium, and then the entire system could be disposed.

Depending upon the process flow rates, it may be necessary to provide some form of cooling for the reaction vessel.

Figure 6 illustrates this process.

4. CHARACTERIZATION OF PROCESSES

The discussion below briefly describes the characteristics of the investigated processes. This discussion is primarily aimed at addressing the process considerations outlined in Section II of this EDF.

4.1 Steam/Nitrogen Reaction

This process is illustrated in Figure 2.

4.1.1 Safety

This process has been successfully used to process NaK with radioactive contamination present. The safety concerns, i.e., Hydrogen, caustic handling, and heat of reaction, have been safely monitored and controlled. The control system required for the safe operation of this process does present a substantial cost penalty, but not an unaffordable one. Real time and chromatographic (GC) analytical equipment is required to monitor the radiation and explosion hazards. The system for handling the NaK requires no additional equipment when compared to the other processing options.

The process safety considerations must also address the handling of caustic and acids if the product is to be neutralized prior to storage.

4.1.2 Cost (Operational and Equipment)

The system represents a moderately high total equipment cost; the major cost items are:

Nitrogen Heater
Steam Generator
Gas Moving Equipment
HEPA Filter
Gas Sampling and Analytical Equipment

Operational costs should be slightly higher due to the energy requirements for steam generation, gas heating, and gas moving equipment. Sufficient water would be required for the processing and neutralization steps. Manpower costs would probably be comparable to the other proposed systems.

4.2.3 Final Waste Form Stability

The hydroxides generated under this process are corrosive and, due to the long half-lives of the radionuclide contamination, the product should be neutralized with acid prior to long term storage.

4.2.4 Final Waste Form Volumes

The volume of radioactive wastes generated by this process are fairly high. The SIG Sodium deactivation produced approximately 2000 gal of liquid waste in the processing of about 80 gal of sodium. (See Reference 3). This suggests that the final amount of liquid waste from processing the EBR-I NaK would be approximately 3000-5000 gal.

During the processing, the following components would become contaminated and would have to be either decontaminated or wasted:

Nitrogen Heater, Gas Compressor, NaK Pump, NaK Storage Tank, Demister, and HEPA Filter.

4.1.5 Potential of Environmental Impact

The potential for environmental impact during the processing is considered to be of moderate concern. The possible sources of contamination are gas circulation line leaks, compressor or pump leaks, and possible HEPA filter failure.

4.1.6 Other Considerations

Due to the amount of power and water required for the process, it may not be practical to process the NaK at its present location. The rate of the processing should be about average when compared to the other processing options.

This process scheme is fairly complicated when compared to some of the other process options.

4.2 Oxygen Reaction

This process is illustrated in Figure 3.

4.2.1 Safety

The only major safety concern for this system when compared to the other process options is the high probability of formation of potassium superoxide. This superoxide would remain in the system, unless it reacted (potentially violently). For this reason, although this is a viable process for sodium, it does not appear to be viable for the processing of NaK.

Further discussion of this process is unnecessary.

4.3 Alcohol Process

This process is illustrated in Figure 4.

4.3.1 Safety

A similar process is routinely used to clean Sodium containers in industry. The process should work safely for cleaning NaK components and containers with the careful selection of the alcohol to be used. Since the off-gas produced will be rich in Hydrogen, the same safety considerations and safety equipment costs would be required as in the Steam/Nitrogen process option.

The process does present a significant safety concern if applied to the processing of the EBR-I NaK. There is considerable concern, although no positive evidence, that the EBR-I NaK contains Potassium Superoxide. If present, this compound can be anticipated to attack the C-C and C-H bonds of the alcohol, and if significant quantities of the

superoxide are present, an explosive mixture could be generated within the reactor. Prior to using this process, determination must be made as whether or not superoxide is present.

There would be a significant cost and schedule penalty associated with the sampling of the NaK containers to determine the presence of superoxide, and since this process option appears to offer no unique advantages over the other processing options, continued investigation of the alcohol process is unwarranted.

4.4 Reaction with Sulfur

This process is illustrated in Figure 5.

4.4.1 Safety

There is no evidence that this reaction scheme has been used in the past to process sodium or sodium-potassium mixtures. The reaction is known to proceed at a reasonable rate in the presence of a catalyst, e.g., iron.

A significant safety advantage of this concept over some of the other process options is that no gaseous reaction product is formed. There are only two significant safety concerns associated with this concept (in addition to the NaK handling concerns). These are:

1) the need for 150 lb steam and the potential of sulfur leakage and subsequent fires. Molten sulfur is routinely handled in the chemical and petroleum industries on a very safe basis, and it is therefore felt that these safety concerns are not prohibitive. It is suggested that if this process is the one chosen, that an outside A/E, e.g., Matthew Hall Engineering, Inc, Houston, Texas, with experience in sulfur systems be used. Sulfur piping and valving systems are very difficult to design due to freezing and plugging problems.

2) The potential of uncontrollable reactions between KO_2 and Sulfur if appreciable quantities of KO_2 were to enter the reactor.

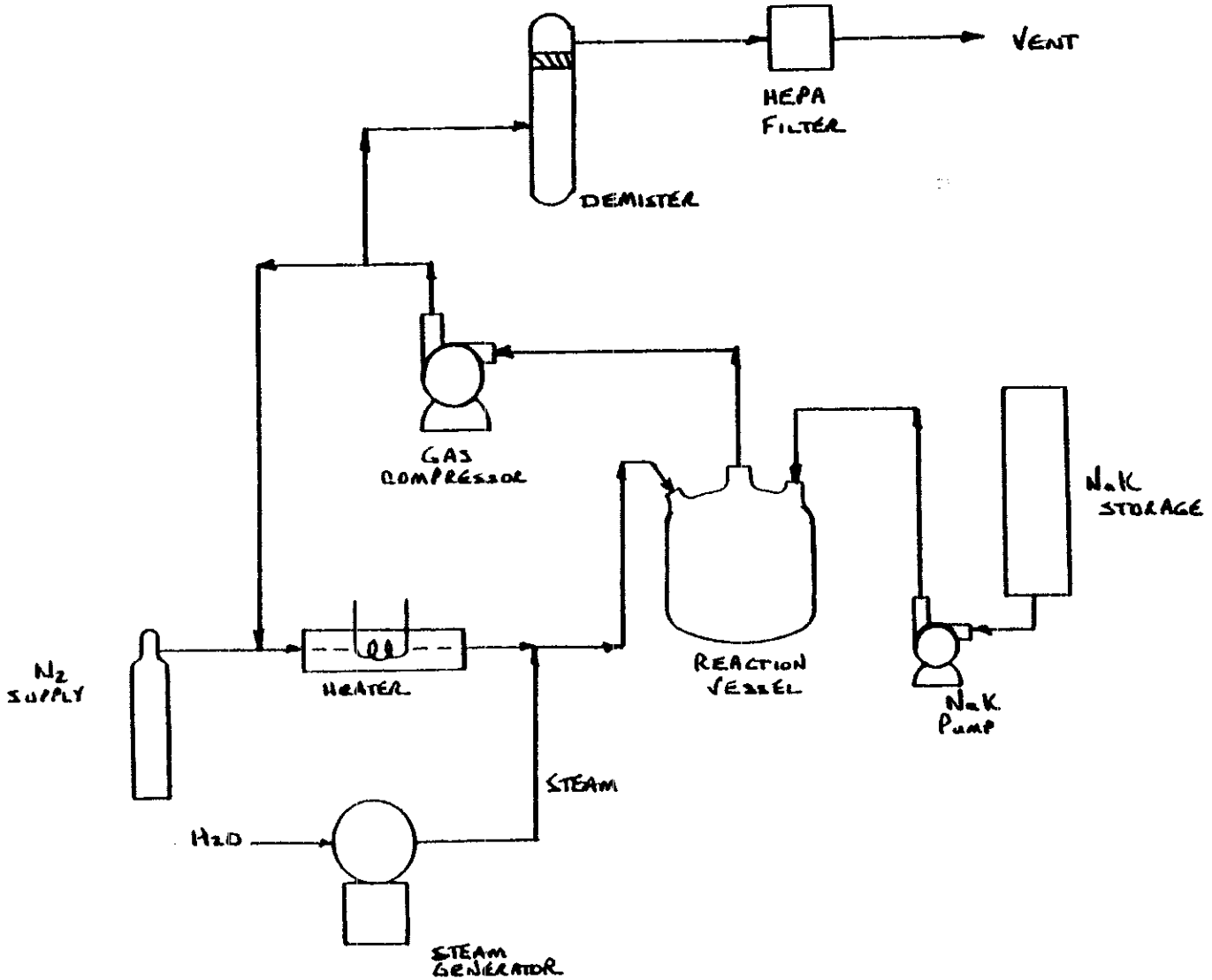


FIGURE 2 STEAM/NITROGEN PROCESS

4.4.2 Cost (Operational and Equipment)

This system represents a moderately high total equipment cost; the major cost items for thisprocess are:

Reactor Vessel (150 lb jacketed and agitated)
Sulfur Storage and Piping System
150 lb Steam Boiler

Operational costs will be higher than other options due to the fuel costs for the steam generator. Manpower costs would probably be comparable to the other proposed systems.

4.4.3 Final Waste Form Stability

The solid material generated, K_2S and Na_2S and S. are all stable chemicals and should not present a significant hazard in long term storage.

4.4.4 Final Waste Form Volumes

The final waste volume should be no greater than two to three times the initial NaK volume. This volume increase is primarily due to the need to process the NaK in excess sulfur.

The equipment to be D & D'd or wasted after the processing would be the NaK storage tank and the NaK pump and piping.

4.4.5 Potential of Environmental Impact

The potential for environmental impact during the processing is considered to be of low-moderate concern. The potential sources for radioactive material entering the environment are from leaks in the NaK storage, pump, and transfer lines. The chance of Sulfur leaking is low and would not be of consequence unless a catastrophic leak occurred.

4.4.6 Other Considerations

This process could be operated at the NaK's present site, but it would require the use of a packaged 150 lb steam boiler. This

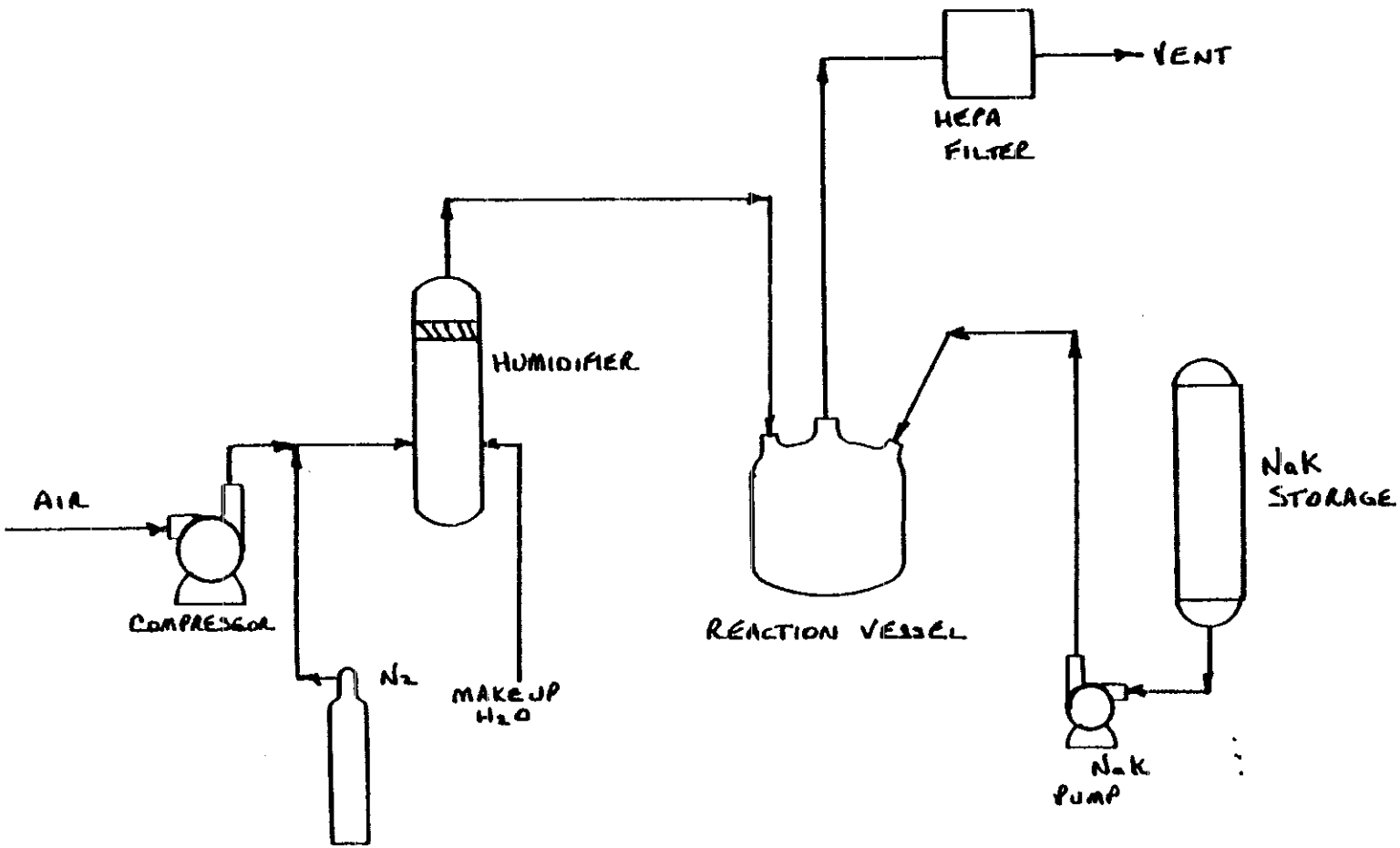


FIGURE 3 OXYGEN PROCESS

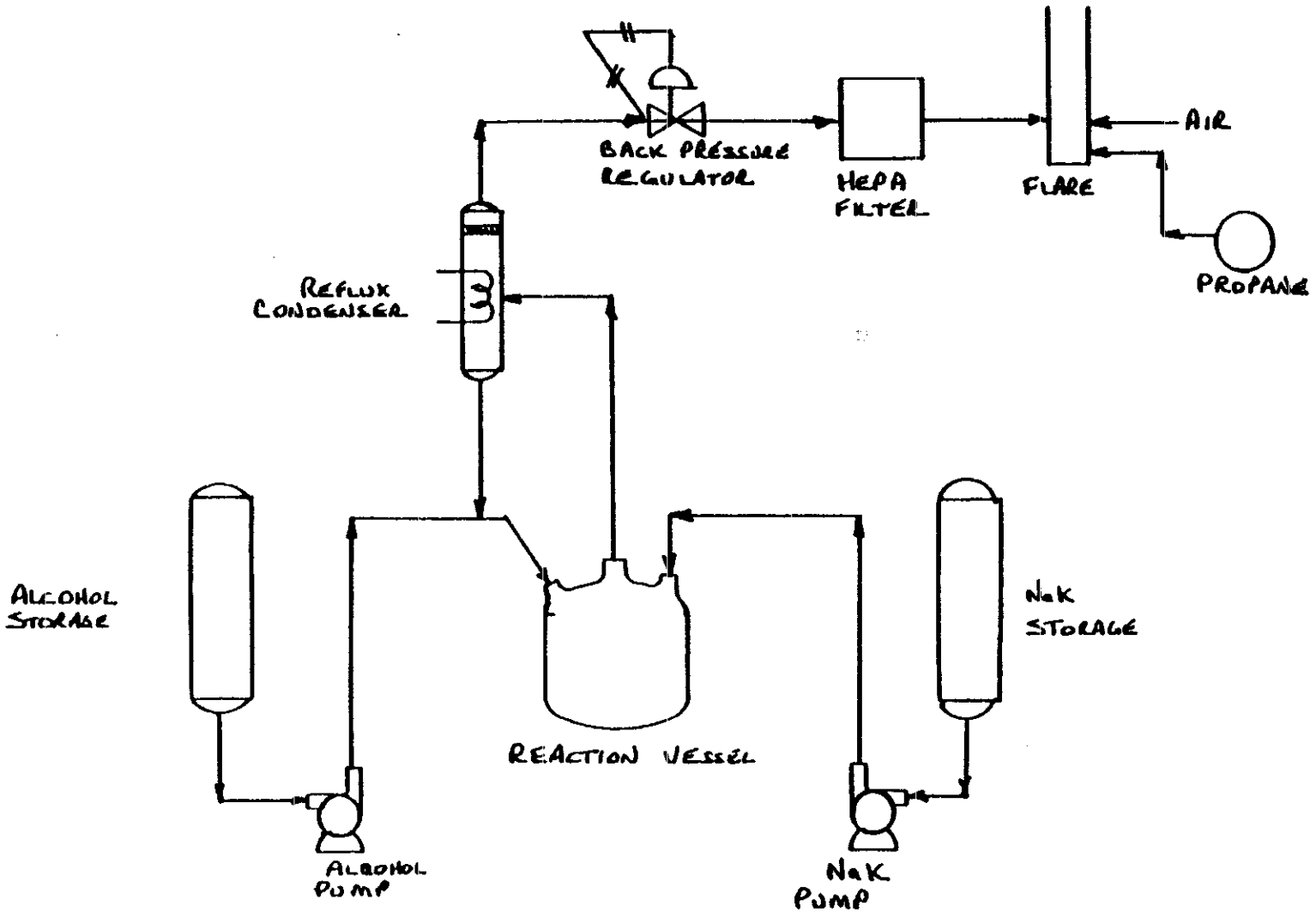


FIGURE 4 ALCOHOL PROCESS

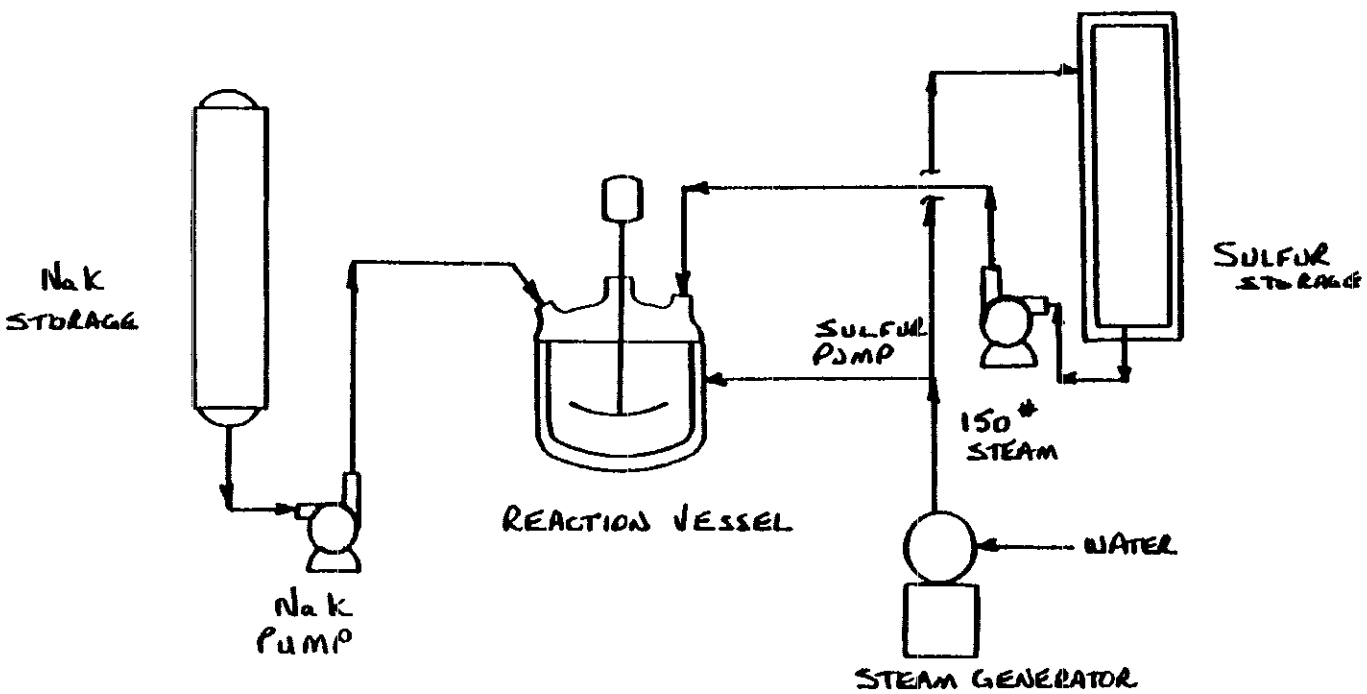


FIGURE 5 SULFUR PROCESS

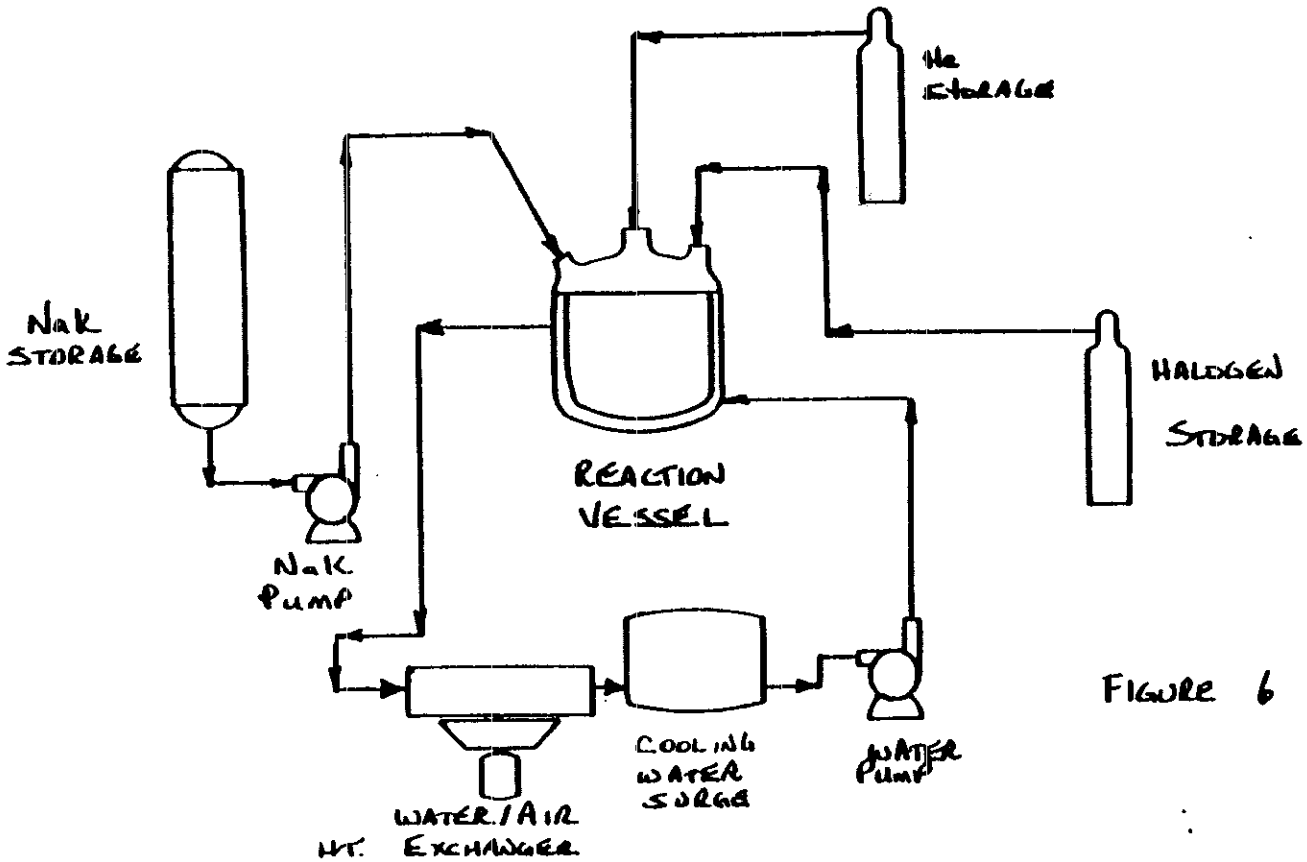


FIGURE 6 HALOGEN PROCESS

processing scheme is less complex than some systems considered, but the piping and Sulfur storage systems would require that these systems be wasted to prevent a substantial waste volume from being generated if they were to be cleaned.

4.5 Reaction with Acids

Since there is no distinct advantage of operating with acid over the Steam/Nitrogen process, and since the equipment costs for acid handling would require higher overall costs, this process will not be considered to be a viable option.

4.6 Reaction with Halogens

This process is illustrated in Figure 6.

There are distinct advantages of using Chlorine over the case where Fluorine is the considered reactant. These advantages are:

- Materials of construction costs
- The lower chemical reactivity of Chlorine compared to Fluorine
- Package chlorinators are available at a reasonable cost which would mean a lower design and construction cost.

For these reasons, Chlorine will be considered a better option than Fluorine, and will be compared to the other process options in the following discussion.

4.6.1 Safety

Although chlorine is a very reactive and a strong pulmonary irritant, it is used routinely and safely due to its industrial and public health importance.

Chlorine is extremely irratating to the mucous membrane of the eyes at 3ppm and the respiratory tract. It combines with moisture to liberate nascent oxygen and form hydrochloric acid. Both these substances, if present in quantity, cause inflammation of the tissues with which they come in contact. If the lung tissues are attacked, pulmonary edema may result. A concentration of 3.5 ppm produces a detectable odor; 15 ppm causes immediate irratation of the throat.

Concentrations of 50 ppm are dangerous for even short exposures. 1000 ppm may be fatal, even when the exposure is brief. Because of its intensely irritating properties, severe industrial exposure seldom occurs, as the workman is forced to leave exposure area before he can be seriously affected. In cases where this is impossible, the initial irritation of the eyes and mucous membrane of the nose and throat is followed by cough, a feeling of suffocation, and later, pain and a feeling of constriction in the chest. If exposure has been severe, pulmonary-edema may follow, with rales being heard over the chest. It is a common air contaminant. (See Reference 9)

Fire hazard: Chlorine can react to cause fires or explosions upon contact with many substances which are combustible with air if the proper concentrations of reactants are present.

The reaction between NaK and chlorine gas has a similar exotherm and free energy of formation as the reaction between NaK and oxygen. The mechanisms for the reaction of oxygen and the reaction of chlorine with NaK are undoubtably different, but it is still highly probable that a controlled reaction scheme can be demonstrated, and therefore this reaction should offer no greater safety hazard then the combusting of NaK or reacting NaK with steam. Indeed, since no Hydrogen is released in this reaction scheme, the overall explosion hazard of this process should be less than the Steam/Nitrogen process.

4.6.2 Cost (Operational and Equipment)

The equipment costs for this system should be lower than the other viable process options. Since there is no off-gas, there is no need for gas heating, gas moving, or gas filtration equipment.

The major capital equipment items will be the NaK storage and metering system, the reactor/final containment, and the Chlorine gas metering equipment. Chlorine storage can be provided from rental bottles.

The operational costs should be as low as or lower than the other options since no process heating is required. Manpower costs would probably be comparable to the other options.

4.6.3 Final Waste Form Stability

The salts generated by this process, NaCl and KCl, are very stable and common compounds; and, in a dry environment, of no significant corrosion problem.

4.6.4 Final Waste Form Volume

The process will generate the smallest quantity of waste of the considered process options. The salt generated will be approximately 70 % of the original NaK volume. The reactor vessel will serve as the final containment for the waste. The only equipment to be disposed of, other than the reactor, is the NaK storage, pump, feed system, and the present NaK containers.

4.6.5 Potential of Environmental Impact

There is no significant probability of environmental impact with any of the processes considered if proper control and monitoring systems are employed. Since no gaseous products are released from this reaction scheme, the probability of adverse environmental impact with this process can be assumed lower than those processes which produce a gaseous byproduct.

4.6.6 Other Considerations

Since this process has not been used in this manner before, there is a slightly greater risk in the successful operation than that compared with the steam/nitrogen process. To overcome this risk differential, some laboratory work will be required to bring the reactor design confidence level to that of the other process options. The cost of this laboratory work, over and above the laboratory work associated with the other processes, should be less than $ 200 K. This expense would be more than offset in equipment cost savings alone.

5. Evaluation of Processes and Selection

In the evaluation of the processes, certain project objectives were considered of prime importance. These

objectives, in their decreasing importance are:

1) The ability to safely process the NaK with a minimal chance of exposure of manpower to chemical or radioactive hazard

2) Potential of adversely impacting the environment during the processing

3) Confidence in the process's ability to react with all the NaK to remove all chemical hazard, i.e., to prevent the inclusion of unreacted NaK in the solid and liquid products formed

4) Final waste form stability

5) Final waste form volume

6) Overall cost of system and processing

Although this ranking is somewhat subjective, sensitivity analysis of the results indicates that reordering of the above objectives does not significantly impact the process selected.

In addition to these prime objectives, other process characteristics were rated to select the process. These characteristics, in the decreasing order of their importance, are:

1) The ability to field operate the system

2) The overall process simplicity

3) The service requirements (water, power, etc.)

4) Rate of processing the NaK

Finally, the potential downside characteristics of the processes were rated. These characteristics, in the decreasing order of their potential adverse impacts on meeting the project objectives, are:

1) Impact if there were a catastrophic equipment failure

2) Ability to further treat the process products if this were to be required at a future date due to changes in disposal requirements

3) Uncertainties in construction and operation

4) Uncertainties in design

5.1 Results of Evaluation

The results of the individual process evaluations are presented in Tables 3-1 through 3-6.

5.2 Process Ranking and Selection

Table 4 presents the summary from the individual evaluations. From this table, it can be seen that the processing of the NaK with Chlorine has significant advantages over the other processes investigated.

The major competitors with this process are the Sulfur process and the Steam/Nitrogen process.

In making this assessment, since the Chlorine system is untried, the scoring was performed with some concern about the Chlorine systems performance. It is this reviewer's belief, that these concerns can be dissipated with proper laboratory testing, and if the evaluation was again performed after this laboratory work, the Chlorine process would be ranked substantially higher than the other process options.

6. Conclusions

The processing of the NaK with Chlorine clearly offers substantial advantages over the other processing options investigated. Among these advantages are: cost; safety; simplicity; and final waste form volume.

Due to the untried nature of this process, some laboratory testing is requisite. This testing will not adversely impact schedule or cost of the project. The final cost of completing the project, including the indicated laboratory work, should still be lower than the other processing options investigated.

The laboratory effort will be primarily aimed at quantifying the following engineering data needs:

1) Reaction rates as a function of concentrations to define safe reaction parameters

2) Required NaK droplet size to prevent inclusion of unreacted NaK in the salts formed

3) Overall reaction heat-transfer rates to allow for reactor design.

PROCESS STEAM/NITROGEN PROCESS SCORING SHEET TABLE 3-1

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	6	54	There has been one major incidence of explosion. Requires more handling
COST	4	3	12	Higher Costs for equipment and Instrumentation
FINAL WASTE FORM STABILITY	6	8	48	STABLE AFTER Neutralization
FINAL WASTE FORM VOLUME	5	2	10	Produces Largest Quantity of WASTES
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	9	72	
CONFIDENCE IN SUCCESSFULLY PROCESSING NUK	7	10	70	Has been operated successfully at INEL and Elsewhere
SERVICE REQUIREMENTS	1.0	7	7	
FIELD OPERATION	2.0	5	1	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	4	6	Most Complex of process options
UNCERTAINTIES IN DESIGN	-.05	2	-1	
IMPACT IF CATASTROPHIC EQUIP FAILURE	-2.0	8	-16	Potential of explosion
ABILITY TO FURTHER TREAT WASTE FORM IF NECESS.	-1.5	4	-6	WASTE form would contain a lot of water
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	1	-1	

TOTAL SCORE 260

PROCESS Oxygen — PROCESS SCORING SHEET — TABLE 3-2

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	0	0	Produces KO_2 - Potential for uncontrolled Reaction
COST	4	5	20	
FINAL WASTE FORM STABILITY	6	0	0	KO_2 would be an Acceptable Waste
FINAL WASTE FORM VOLUME	5	5	25	
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	7	56	
CONFIDENCE IN SUCCESSFULLY PROCESSING NUC	7	2	14	
SERVICE REQUIREMENTS	1.0	8	8	
FIELD OPERATION	2.0	8	16	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	7	10.5	
UNCERTAINTIES IN DESIGN	-.05	3	-1.5	
IMPACT of CATASTROPHIC EQUIP FAILURE	-2.0	2	-4	
Ability to Further Treat WASTE FORM if NECESS.	-.15	8	-12	
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	2	-2	

TOTAL SCORE 134

PRO is Alcohol — PROCESS SCORING SHEET — TABLE 3-3

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	2	18	May cause reaction with KO_2 and Alcohol
COST	4	5	20	
FINAL WASTE FORM STABILITY	6	6	36	
FINAL WASTE FORM VOLUME	5	3	15	
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	6	48	Some potential for explosion
CONFIDENCE IN SUCCESSFULLY PROCESSING NUC	7	3	21	
SERVICE REQUIREMENTS	1.0	7	7	
FIELD OPERATION	2.0	8	16	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	7	10.5	
UNCERTAINTIES IN DESIGN	-.05	1	-0.5	
IMPACT of CATASTROPHIC EQUIP FAILURE	-2.0	10	-20	High Fire danger
ABILITY TO FURTHER TREAT WASTE FORM if NECESS.	-.15	2	-3	
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	8	-8	

TOTAL SCORE 164

PROCESS Sulfur — PROCESS SCORING SHEET — TABLE 3-4

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	7	63	Some concern over Sulfur handling
COST	4	6	24	
FINAL WASTE FORM STABILITY	6	8	48	
FINAL WASTE FORM VOLUME	5	8	40	
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	7	56	
CONFIDENCE in SUCCESSFULLY PROCESSING NWK	7	8	56	
SERVICE REQUIREMENTS	1.0	4	4	
FIELD OPERATION	2.0	6	12	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	6	9	
UNCERTAINTIES IN DESIGN	-.05	8	-4	
IMPACT if CATASTROPHIC EQUIP FAILURE	-2.0	7	-14	
ABILITY to FURTHER TREAT WASTE FORM if NEEDED	-1.5	8	-12	SULFUR WOULD BE PRESENT IN SOLID FORM
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	7	-7	

TOTAL SCORE 279

PROCESS ACIDS — PROCESS SCORING SHEET — TABLE 3-5

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	4	36	Concentration of hydrogen would be high.
COST	4	3	12	
FINAL WASTE FORM STABILITY	6	8	48	
FINAL WASTE FORM VOLUME	5	4	20	
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	6	48	
CONFIDENCE IN SUCCESSFULLY PROCESSING NWLC	7	9	63	
SERVICE REQUIREMENTS	1.0	8	8	
FIELD OPERATION	2.0	8	16	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	8	12	
UNCERTAINTIES IN DESIGN	-.05	6	-3	Materials
IMPACT if CATASTROPHIC EQUIP FAILURE	-2.0	6	-12	
ABILITY TO FURTHER TREAT WASTE FORM if NECES.	-1.5	8	-12	
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	5	-5	

TOTAL SCORE 235

PROCESS CHLORINE — PROCESS SCORING SHEET — TABLE 3-6

CHARACTERISTIC	WT.	SCORE	TOTAL VALUE	COMMENTS
SAFETY	9	8	72	
COST	4	9	36	Should be least costly of systems
FINAL WASTE FORM STABILITY	6	8	48	
FINAL WASTE FORM VOLUME	.5	9	45	LEAST WASTE of All options
ENVIRONMENTAL CONCERNS (PROBABILITY of NON-IMPACT)	8	9	72	
CONFIDENCE IN SUCCESSFULLY PROCESSING NUK	7	7	49	WILL REQUIRE LAB WORK to INCREASE CONFIDENCE LEVEL
SERVICE REQUIREMENTS	1.0	9	9	
FIELD OPERATION	2.0	8	16	
RATE OF PROCESSING	0.5	8	4	
SIMPLICITY	1.5	8	12	
UNCERTAINTIES IN DESIGN	-.05	8	-4	WILL REQUIRE MORE LAB TIME to "remove" UNCERTAINTIES
IMPACT if CATASTROPHIC EQUIP FAILURE	-2.0	7	-14	Some potential for fire
ABILITY to Further Treat WASTE FORM if NEEDED	-.15	2	-3	
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1.0	8	-8	NEW process concept

TOTAL SCORE 334

TABLE 4 PROCESS SCORING SUMMARY

	STEAM/ N_2	OXYGEN	ALCOHOL	SULFUR	ACIDS	CHLORINE
SAFETY	54	0	18	63	36	72
COST	12	20	20	24	12	36
FINAL WASTE FORM STABILITY	48	0	36	48	48	48
FINAL WASTE FORM VOLUME	10	25	15	40	20	45
ENVIRONMENTAL CONCERNS (PROBABILITY OF NON-IMPACT)	72	56	48	56	48	72
CONFIDENCE IN SUCCESSFULLY PROCESSING NAK	70	14	21	56	63	49*
SERVICE REQUIREMENTS	7	8	7	4	8	9
FIELD OPERATION	1	16	16	12	16	16
RATE OF PROCESSING	4	4	4	4	4	4
SIMPLICITY	6	10.5	10.5	9	12	12
UNCERTAINTIES IN DESIGN	-1	-1.5	-0.5	-4	-3	-4
IMPACT IF CATASTROPHIC EQUIP. FAILURE	-16	-4	-20	-14	-12	-14
ABILITY TO FURTHER TREAT WASTE FORM, IF NEC.	-6	-12	-3	-12	-12	-3
UNCERTAINTIES IN CONSTRUCTION & OPERATION	-1	-2	-8	-7	-5	-8
TOTAL	260	124	164	279	235	334
RANKING	3	6	5	2	4	1

* SEE SECTION 4.6.6 (RANKING WILL BE CONSIDERABLY HIGHER AFTER LABORATORY WORK)

REFERENCES:

1) EDF 2701 (3KKBJ00E1) EBR-I Mark-II NaK/Bunker Inspection R.D. Turner, 9-11-79.

2) Planning Document for Removal of NaK Drums from EBR-I Storage Pit to ARVFS Bunker (Actual title unknown, document was photocopied without copying title page).

3) Decontamination and Decommissioning of the EBR-I Complex Final Report, July 1975, ANCR-1242, UC-70.

4) S1G Reactor Vessel Decommissioning Project-Final Report, EG&G Internal Technical Report, PG-WM-83-031, Sept. 1983.

5) Disposal of Radioactive Sodium Waste, McPheeters, C.C., Wolson, R.D., (Argonne National Lab, IL) Sept. 1978, ANL-78-87.

6) Telecon with Jack Bicenouse, Mine Safety Appliances, Advanced Systems Division, Evans City, PA. Dec. 19.1985.

7) An Explosion Hazards Analysis and Evaluation of the Eutectic Soultion of Sodium and Potassium (NaK) and Potassium Superoxide (KO_2) - WIS-6-74, Cook Associates, Inc., Feb 1974. Subcontract to Aerojet Nuclear Company, S-1306.

8) Sodium-NaK Engineering Handbook, Volume 1, Sodium Chemistry and Physical Properties. O. J. Foust, editor, Gordon and Breech Science Publishers, Inc., NY, NY, 1972.

9) Dangerous Properties of Industrial Materials, Sixth Edition N. Irving Sax, Van Nostrand Reinhold Company, NY, NY, 1984.

APPENDIX F

REACTION MODEL

APPENDIX F

EG&G Idaho, Inc.

FORM EG&G-2631 (Rev. 4-78)

ENGINEERING DESIGN FILE

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK007

FUNCTIONAL FILE NO. 3KNOPNAKE

PROJECT/TASK NaK Disposal/EBR-1

DATE July 30, 1986

SUBTASK Engineering

EDF PAGE NO. 1 OF 11

SUBJECT

REACTOR MODELING

ABSTRACT

This EDF addresses modeling of the NaK/chlorine reaction within the reactor vessel, as well as the modeling of the entire process. A Fortran code was developed for the reactor model, and ASPEN was used for the flowsheet. Major findings of this study were that the process is limited to NaK flowrates which allow for the inside wall temperature to be below the fusion point of KCl. The heat transfer from the vessel was found to be most sensitive to vessel diameter, and the thermal conductivity and density of the salt deposit. Laboratory experiments are planned to further characterize these parameters.

DISTRIBUTION (COMPLETE PACKAGE): M. R. Dolenc, R. H. Meservey, D. L. Crandall, D. M. LaRue, B. G. Schnitzler, B. W. Brown, R. C. Green, D. P. Halls, J. L. Liebenthal, J. M. Espinoza

DISTRIBUTION (COVER SHEET ONLY): PROJECT EDF FILE LOG, EDF SERIAL NO. LOG

AUTHOR	DEPT.	REVIEWED	DATE	APPROVED	DATE
B. W. Brown	E210				7/30/86

I. INTRODUCTION

Approximately 180 gal of contaminated sodium/potassium (NaK) are currently stored in a bunker at the ARVFS. Plans for stabilizing this NaK have been made, with the most promising method being reaction of the NaK with chlorine gas. Such a process would result in a solid product (NaCl and KCl) which is chemically stable. The selection of this process was previously described in EDF NAK001.

II. MODEL DESCRIPTION

A computer program has been written which models the reaction of NaK and Cl_2 inside a cylindrical reaction vessel, shown in Figure 1. The model used is a transient, one-dimensional heat conduction finite difference scheme with boundary conditions being the reaction heat flux on the interior, and convective heat transfer on the exterior. The number of nodes is user-specified, as is the position of the salt/steel interface node. At the interface, thermal diffusivity of the salt and steel are both used.

Nodal spacing through the salt matrix increases with time. The salt is assumed to adhere to the steel shell, with the deposit thickness a function of reactant flowrate and deposit density. As the deposit increases in thickness, the distance between nodes increases for the fixed number of nodes in the salt.

Backward differencing is used for numerical stability. The time step is specified by the user. The following equations represent the heat balance for the reactor inside surface, an interior node, and the reactor outside surface.

$$QA_1\ t - kA_2(T_{1,k+1}-T_{2,k+1})\ t/(r_2-r_1) = C_pV_1(T_{1,k+1}-T_{1,k})$$

$$kA_i(T_{i,k+1}-T_{i,k+1})\ t/(r_i-r_{i-1}) - kA_{i+1}(T_{i,k+1}-T_{i+1,k+1})\ t/(r_{i+1}-r_i) = C_pV_i(T_{i,k+1}-T_{i,k})$$

$$kA_n(T_{n-1,k+1}-T_{n,k+1})\ t/(r_n-r_{n-1}) - hA_{n+1}(T_{n,k+1}-T_f)\ t = C_pV_n(T_{n,k+1}-T_{n,k})$$

where Q = heat flux from chemical reaction
A = area
k = thermal conductivity
n = number of nodes
T = temperature
t = time
r = radius
ρ = density
C_p = heat capacity
V = volume
h = heat transfer coefficient (convective), outside
T_f = coolant temperature
subscripts i,1,2,3,...n - refer to node number
k - refers to time step considered

Solution of the temperature profile requires solving N equations in N unknowns, where N is the number of nodes. A tridiagonal matrix solver is used to solve for the unknown temperatures. This routine is better-suited to the problem due to the sparse matrix involved.

The inside radius of the salt deposit is solved using a Newton-Raphson iteration method on the function

$$A\ r^3 + B\ r^2 + C\ (V't/3.14 - fHR^2) = 0$$

where r = inside radius of deposit
V' = NaK volumetric flowrate
t = time
H = reactor height
R = reactor radius
f = fraction of H (vertically) that deposit accumulates 0.0-1.0

The constants A, B, and C are determined according to the assumption concerning the deposit growth as follows

Deposit on	A	B	C
walls only	0	1	1/Hf
walls, 1 end	1	fH-R	1
walls, 2 ends	1	H/2-R	1/2

When the interface node number is set to 1, it is assumed that the deposit accumulates in the bottom of the reactor and that the heat flux is transferred through the steel shell. This option can be used to evaluate heat transfer through the steel wall without the insulating effect of a salt layer.

Both laminar and turbulent flow is regimes are acommodated for a liquid coolant if the reaction vessel is jacketed. Convective and radiative heat transfer are allowed when air is used as the coolant.

When a liquid coolant is used, the heat transfer coefficient is dependent on the flowrate of fluid through the exterior shell. It is assumed that the coolant temperature remains constant. However, if the reactor shell temperature exceeds 200 ^{o}F, boiling becomes the assumed mode of heat transfer; the coolant temperature is assumed constant at 200 ^{o}F and the heat transfer coefficient becomes independent of the coolant flowrate.

Gas temperature inside the reactor is calculated from an energy balance, which assumes that the heat of reaction is transferred to the walls entirely by radiation. This technique overpredicts the gas temperature, and is therefore conservative, because some heat transfer will also occur due to convection and condensation (heat of fusion) of salt on the solid boundary. Gas temperature is used to calculate reactor pressure from the ideal gas equation of state. The actual reactor volume (reduced by wall deposits) is used in calculating reactor pressure.

The program uses 31 input variables to describe the reactor geometry, coolant characteristics, NaK and salt physical properties, reactor operation variables, and reactor heat transfer. A sample of the program input and output is attached.

Most of the parameters required by the model are available in the literature. These parameters, however, can only serve as initial estimates for properties such as density and thermal conductivity because of gas inclusions in the solid deposit which will likely occur due to the processing method. It will be necessary to obtain empirical data for density, thermal conductivity, heat capacity of the resultant salt deposit, flame temperature, and to determine if fractional conversion (NaK inclusions in the salt) may be a problem.

Parametric calculations were made to determine the sensitivity of the predictions on several variables. These variables were heat capacity, thermal conductivity, and density of the salt deposit, emissivity of the gas and exterior of the reactor vessel, cooling option (water or air cooled), reactant flowrate, vessel diameter, and vessel wall thickness. The results of these calculations are discussed below.

III. MODELING RESULTS

The input flowrate of NaK was found to be limited mainly by the reactor temperature. If the inside wall temperature exceeds the salt melting point (1043 ^{o}F), deposition on the walls will cease and molten salt will accumulate at the bottom of the reactor. The flowrate must be kept low enough that heat can be conducted through the reactor walls such that the inside wall temperature is below the salt melting temperature. Although the model allows calculations for wall temperature values in excess of the salt melting point, the results discussed below are only for those cases in which the temperature was below the melting point.

Figure 2 shows the predicted final inside wall temperature for various NaK input flowrates and values for deposit thermal conductivity. For the conditions represented by these predictions, the maximum allowable flowrate of NaK is 6-8 lb/h. Figure 3 shows predicted temperature for a range of flowrates and deposit density values, and also suggests an upper bound of 6-8 lb/h for the range of other variables considered. This upper limit on NaK input flowrate indicates that at least 7-9 days will be required for processing the 180 gal of NaK (4 ft diameter vessel).

The thermal conductivity of the deposit is a major factor affecting the heat transfer process. Values of 0.20, 0.25, and 0.30 Btu/h.ft.^{o}F were used in the calculation for thermal conductivity, with 0.28 being the literature value for a solid crystal. Predicted final inside wall temperature increases about 100 ^{o}F for every 0.05 Btu/hr.ft.^{o}F decrease in thermal conductivity, as shown in Figure 2.

The density of the salt deposit is also a major factor affecting heat transfer through the deposit to the inside of the reactor vessel. The maximum density possible is about 128 lb/ft^3, which is that of pure NaCl (135 lb/ft^3) and KCl (124 lb/ft^3) in the proportions in this project (NaK: approximately 0.33/0.67 mol sodium/mol potassium or 0.33(135) + 0.67(124) => 128 lb/ft^3). However, it is anticipated that inclusions of gas, or a granulated crystal, will reduce the density somewhat. Calculations were made for density values of 110, 90, and 70 lb/ft^3 to account for the possibility of up to 45 % porosity in the salt deposit. Figure 3 shows that predicted inside wall final temperature increases about 150 ^oF for a decrease in density of 20 lb/ft^3.

Three values of heat capacity of the salt deposit were used: 0.15, 0.21 (literature value), and 0.25 Btu/lb.^oF. Essentially no effect on final predicted temperature was observed for this range of heat capacity.

The choice of cooling option, whether air-cooled by radiation and convection, or water-cooled, either boiling or constant temperature, had very little effect on the predicted final inside wall temperature. As shown in Figure 2, for a NaK flowrate of 8 lb/h, the predicted final inside wall temperature decreased from 836 to 810 ^oF when a boiling water bath (200 ^oF) was used for external cooling. However, at lower flowrates (2 lb/hr NaK), the calculated inside wall temperature was actually higher with the water bath. This is because the assumed bath temperature (200 ^oF) is actually higher than the temperature which would otherwise be attained by the bare reactor shell. The choice of a boiling water bath, therefore, offers little advantage from a heat transfer standpoint. A water jacket may be desirable to ensure that the outside wall temperature is kept within certain limits, however, such as the 140 ^oF OSHA standard. The predicted final inside wall temperature decreased from 810 ^oF to 786 ^oF for circulating water (70 ^oF) at a rate of 300 gph, which would also make this option questionable from a heat transfer point of view.

Very little effect was observed on the predicted final inside wall temperature for a variation in exterior emissivity from 0.50 to 0.90. This is attributed to the fact that the outside shell temperature was low enough (about 200 ^{o}F) that radiation, being a function of temperature to the fourth power, had a negligible effect on the total heat transfer.

The predicted outside shell temperature was observed to be relatively constant, from about 200 to 220 ^{o}F. This temperature was maintained for a wide variety of NaK input flowrates, exterior wall emissivity, cooling options (water or air), and values for salt deposit thermal conductivity and density.

Differential thermal expansion between the salt deposit and the steel shell could lead to situations which only experiments can identify. Initial estimates are that a salt deposit will expand up to 100 times that of the 1" thick steel shell. This is attributed to the higher coefficient of thermal expansion, the greater temperature rise, as well as the greater thickness of the salt. This greater expansion will undoubtedly lead to fracture of the salt deposit, resulting in either the flaking and attrition of the deposit, or the sealing of the resulting cracks with additional deposition. Laboratory experiments will characterize this issue more fully.

The final vessel pressure (proportional to gas temperature) was predicted to be a function of both NaK flowrate and assumed gas emissivity. Pressure is also dependent somewhat on salt deposit density, with higher pressures resulting from lower salt density due to decreased reactor volume. Pressure increased about 1 atm for each 2 lb/hr increase in NaK flowrate, and increased about 1.5 atm when the gas emissivity was decreased from 0.5 to 0.1, as shown in Figure 4.

The effect of reactor inside diameter on predicted final inside wall temperature is shown in Figure 5. The increased surface area with larger diameters provided better heat dissipation, and allowed higher flowrates of NaK. Whereas a 4 ft vessel diameter allowed a NaK input flowrate of about 8 lb/h, a rate of 25 lb/h could be allowed with a 6 ft vessel

diameter. By using a 6 ft diameter vessel, the 180 gal of NaK could be processed in as little as 2-3 days.

Vessel wall thickness was also used as a parameter in calculating temperature profiles through the salt deposit and steel reactor shell. The wall thickness has a very negligible effect on predicted temperature profiles, with final temperature increasing only about 1.3 ^{o}F for each inch of additional steel wall thickness.

The vessel pressure is proportional to the amount of material which is present in the gas phase. The gas inventory depends on the fractional conversion of chlorine in the process (assumed to be 1.00 for these calculations), and the initial partial pressure of inert gases present in the reactor. The parametric calculations were made for an inert gas partial pressure of 1.0 atm. Decreasing the initial inert gas partial pressure would decrease the final predicted pressure proportionally.

The predicted temperature of the gas (which determines the vessel pressure) as it is calculated by the model, is not substantially greater than the predicted inside wall temperature, the gas temperature being about 100 ^{o}F higher than the wall temperature (depending on assumed gas emissivity). Therefore, the inside wall temperature is a fair approximation of the inside gas temperature.

A second set of parametric calculations was performed to determine the effect of no salt deposit on the inside wall temperature. This was done in order to bound the heat transfer process if the products either did not deposit on the wall or in some way fell off. The salt deposit was allowed to collect at the bottom of the reactor, but not on the reactor walls. The heat flux from the exothermic reaction was assumed to be evenly distributed on the inside surface of the steel shell.

In most cases, the predicted final inside wall temperature was independent of salt deposit physical properties. The exception was a slight dependence on salt density; lower values for density produced larger volumes of deposit on the bottom of the reactor, which in turn made for

smaller surface area of steel shell above the deposit. The net effect was slightly higher temperatures at lower values of salt density.

Reactor inside diameter also affected the predicted inside temperature of the steel shell. Figure 6 shows that temperature decreased 30-40 ^{o}F for a 6 inch increase in inside diameter.

Figure 6 also demonstrates another interesting result of these calculations, which is that permissible flowrates were significantly higher when no salt deposit was covering the steel shell. The previous limit on flowrate was determined from the melting point of the salt deposit on the inside surface. This temperature was extremely sensitive to flowrate due to the insulating properties of the salt deposit. As the deposit grew thicker, the temperature increased in part due to the increase in insulation. When no deposit covered the steel shell, the heat was conducted much more effectively to the outside of the reaction vessel, where it was dissipated to the environment. Much higher reactant flowrates were possible because of the enhanced heat transfer.

IV. FLOWSHEET MODELING

The entire flowsheet, including the reactor, was modeled using ASPEN, a process simulation model. Flowsheets for 6 and 8 lb/hr of NaK are shown in Figures 7 and 8, respectively. Copies of the ASPEN computer runs are attached.

Liquid chlorine is supplied through standard-size cylinders, each containing 150 lb of chlorine (10 cylinders required). The temperature of the chlorine is kept constant with a water jacket. The chlorine is pumped to an expansion valve, where the pressure is reduced and the liquid partially flashes to vapor. A heat exchanger is used to completely vaporize the mixture by raising the temperature. The gaseous chlorine is then allowed to enter the reactor.

Liquid NaK is pumped from secondary containers (described in EDF NAK006) into the reaction vessel. A dispersion mechanism, such as a spray nozzle, will be used in order to uniformly distribute the NaK. A constant surface to volume ratio for the droplets will be maintained as the NaK flowrate is varied. This will prevent any pressure transients attributed to unsteady reaction rates.

Water is used primarily to cool the reactor, and is circulated through a loop which includes the reaction vessel where heat is absorbed and a cooling tower where heat is rejected. The water is also used to keep the liquid chlorine cool and to vaporize the sub-cooled liquid/vapor mixture.

There is a possibility that potassium superoxide (KO_2) is present in the NaK containers due to air infiltration during the 30 years of storage. The solid contaminants will be filtered to avoid being introduced into the reactor. Calculations with a thermochemical equilibrium program suggest that chlorine has a much greater affinity for potassium and sodium than for oxygen. It is thought that potassium oxides reacting with chlorine will induce no pressure transients not already associated with the NaK/Cl_2 reaction. Laboratory experiments will be preformed to confirm this.

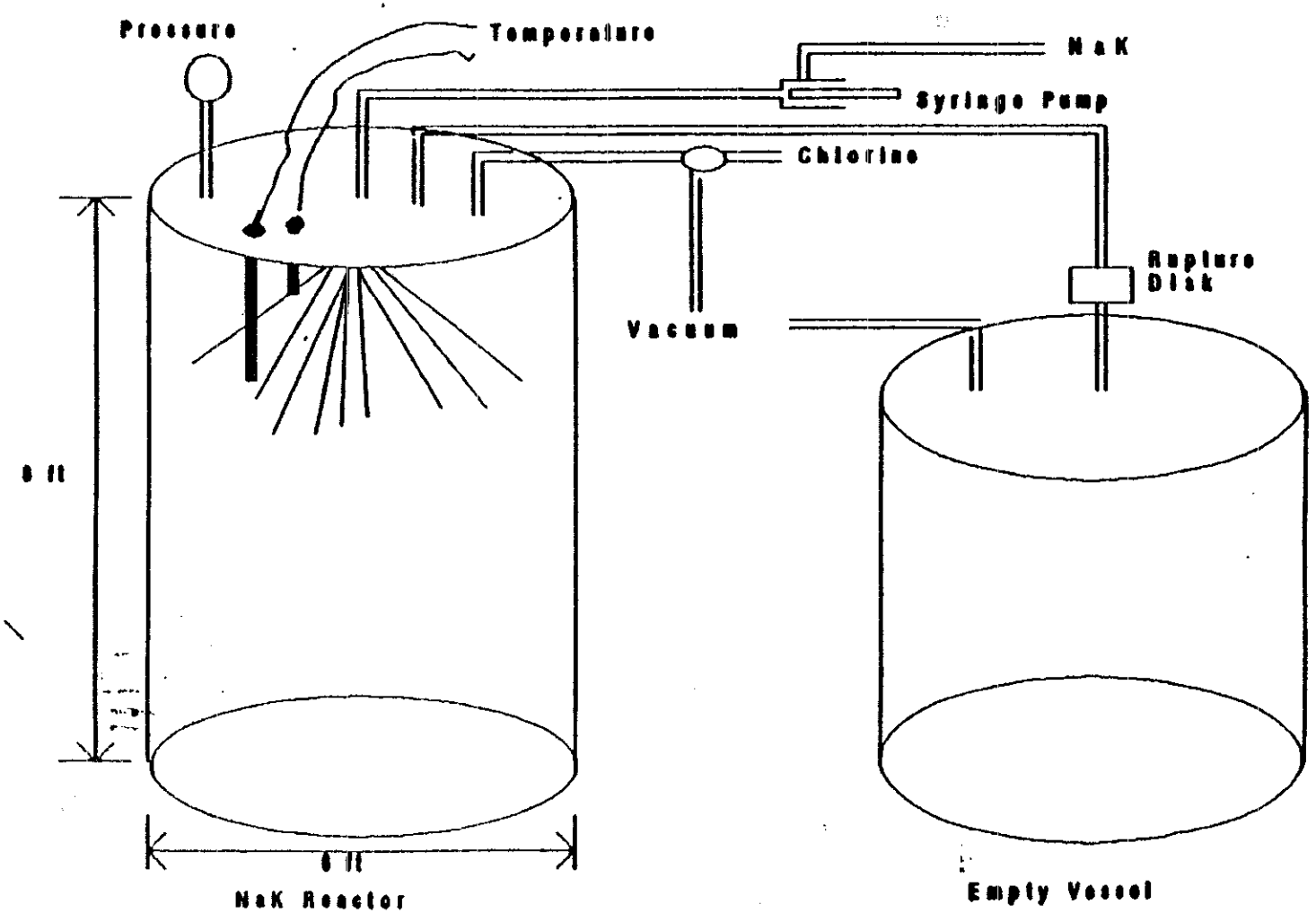
V. CONCLUSIONS

It was found that the reactor inside wall temperature was the factor which limited the NaK processing time. Major variables affecting the temperature are NaK input flowrate, salt deposit density and thermal conductivity, and reaction vessel diameter. Variables which have less noticeable effects on processing time are salt deposit heat capacity, gas emissivity, reactor shell emissivity, cooling mode, and vessel wall thickness. Minimum processing time for 180 gal of NaK is 2-3 days for a 6 ft diameter vessel, and 7-9 days for a 4 ft diameter vessel. As little as 12 hours are necessary to process the NaK if the deposit collects on the bottom of the reactor.

Results of the parametric calculations indicate that laboratory experiments are necessary to obtain data which can only be estimated at present. Accurate values for thermal conductivity and density of the deposit, as well as reaction temperature and pressure, are essential to the prediction of reactor performance. It is also necessary to determine if the salt deposit will adhere to the reactor walls, or if it will collect at the bottom of the reactor.

Figure 1

Proposed Reactor Configuration



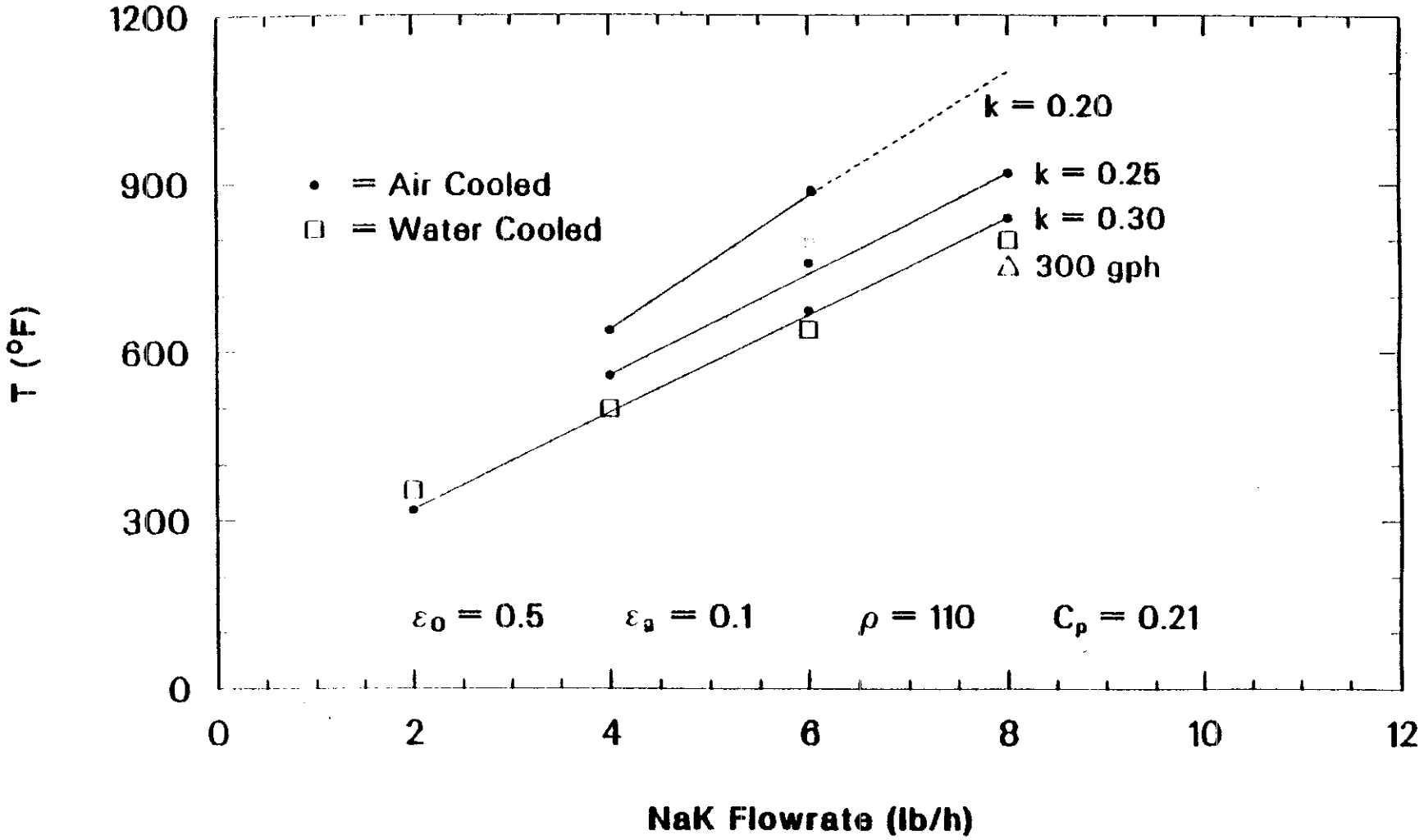


Fig. 2 Effect of salt deposit thermal conductivity, cooling method, and NaK flowrate on predicted final inside wall temp..

BWB0786-01

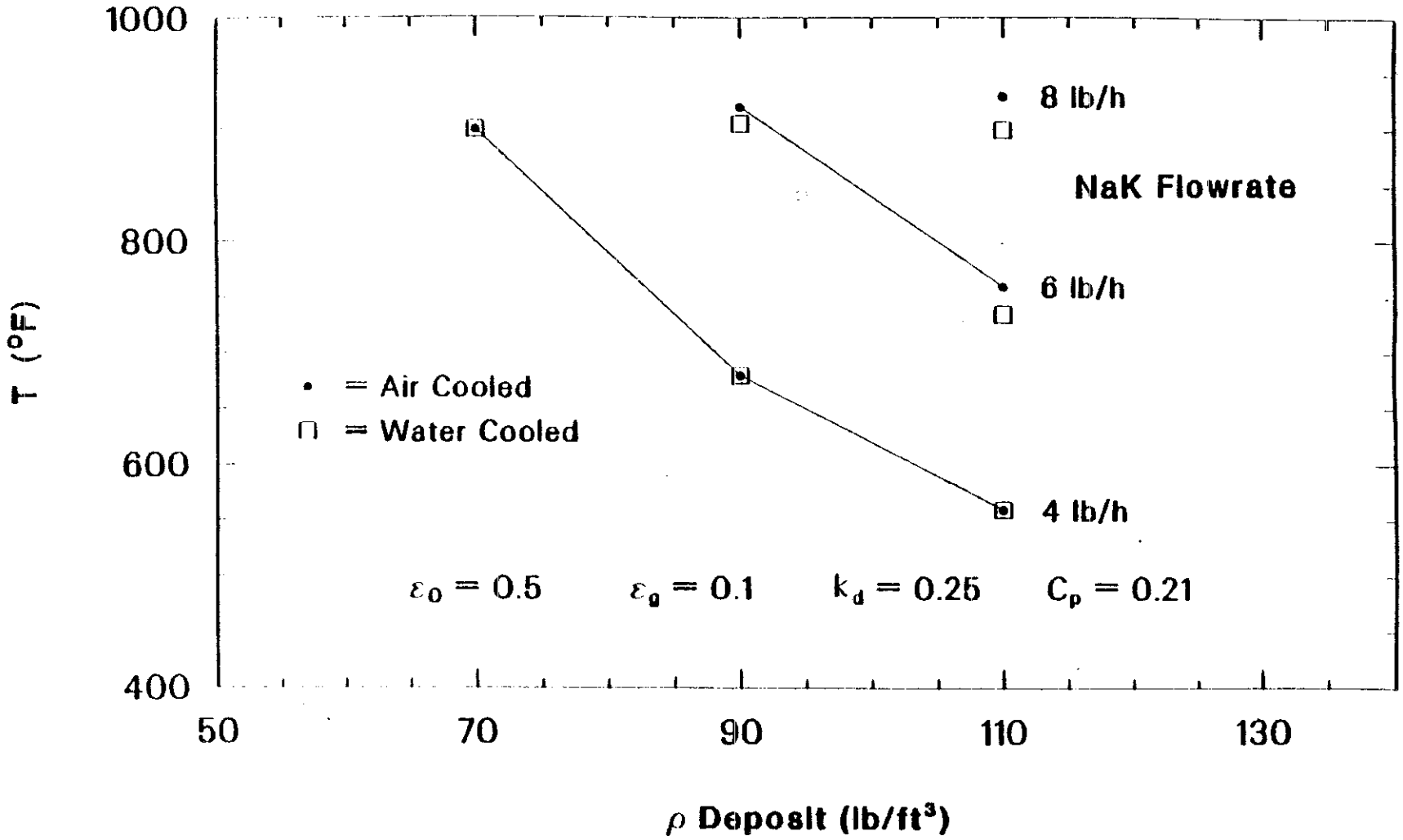


Fig. 3 Effect of salt deposit density on predicted final inside wall temperature ($T_{steel} \sim 200$ °F).

BWB0786-02

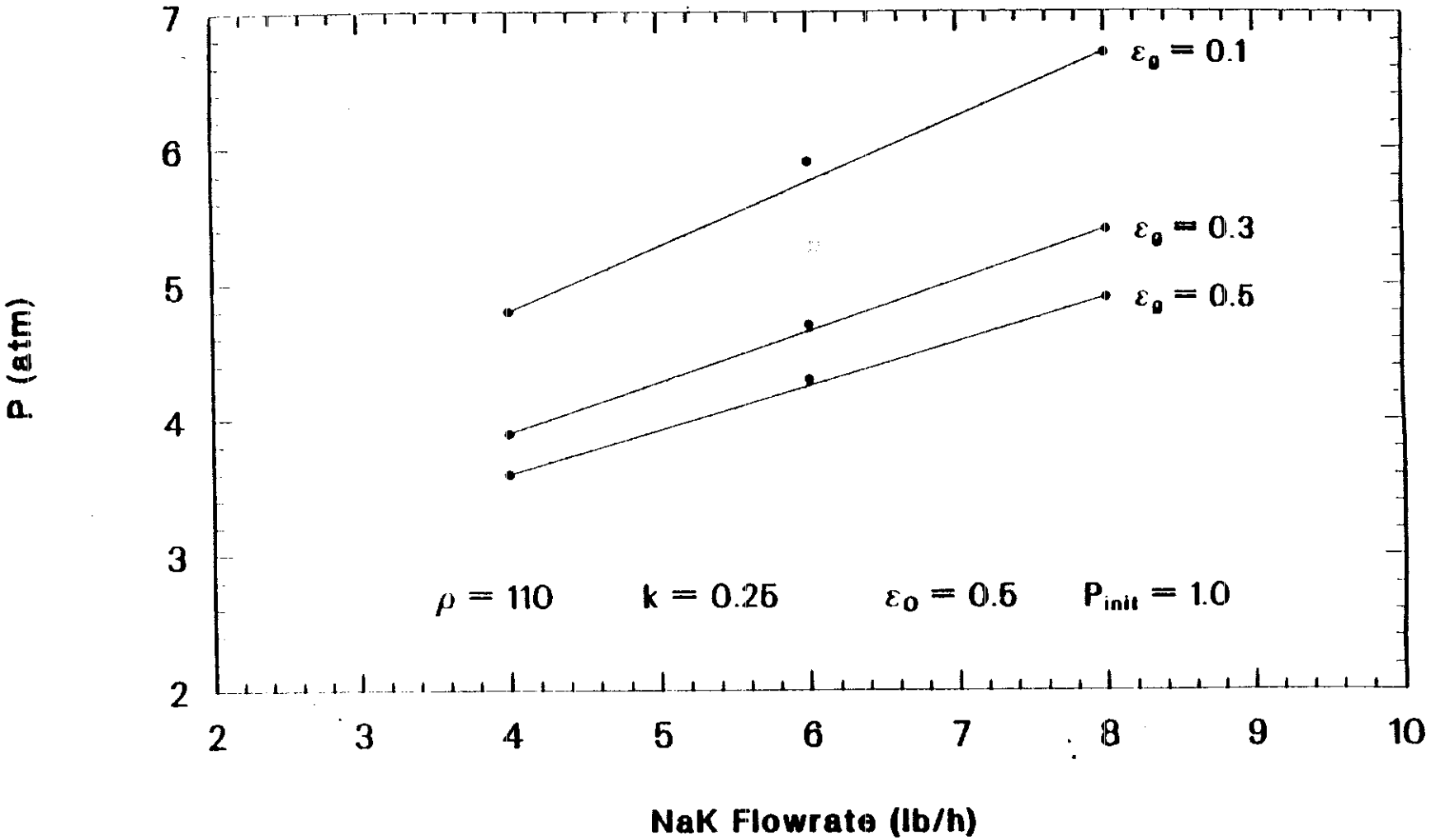


Fig. 4 Effect of gas emissivity and NaK flowrate on predicted final inside pressure.

BWB0786-03

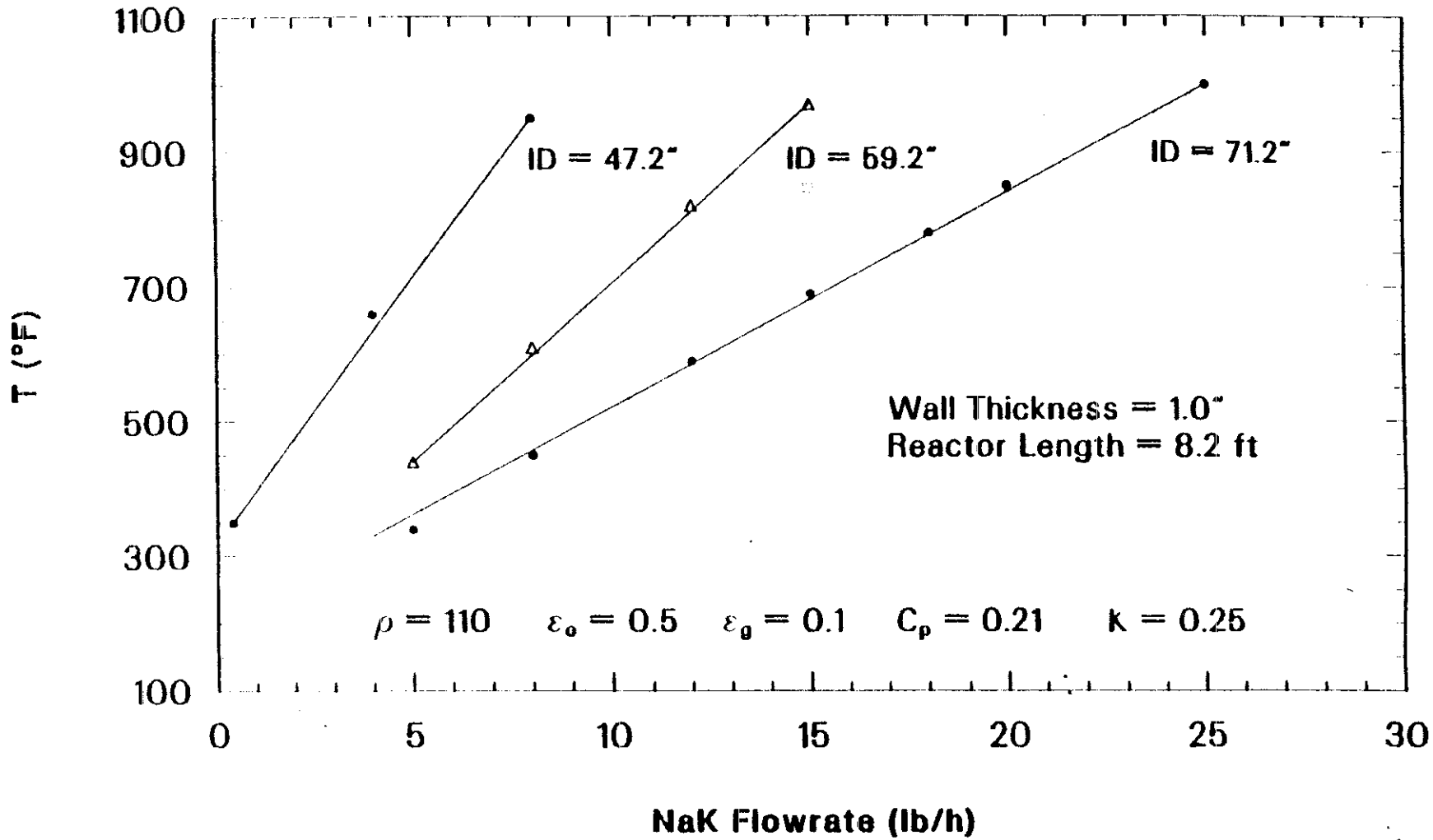


Fig. 5 Effect of reactor inside diameter and NaK flowrate on predicted final inside wall temperature.

BWB0786-04

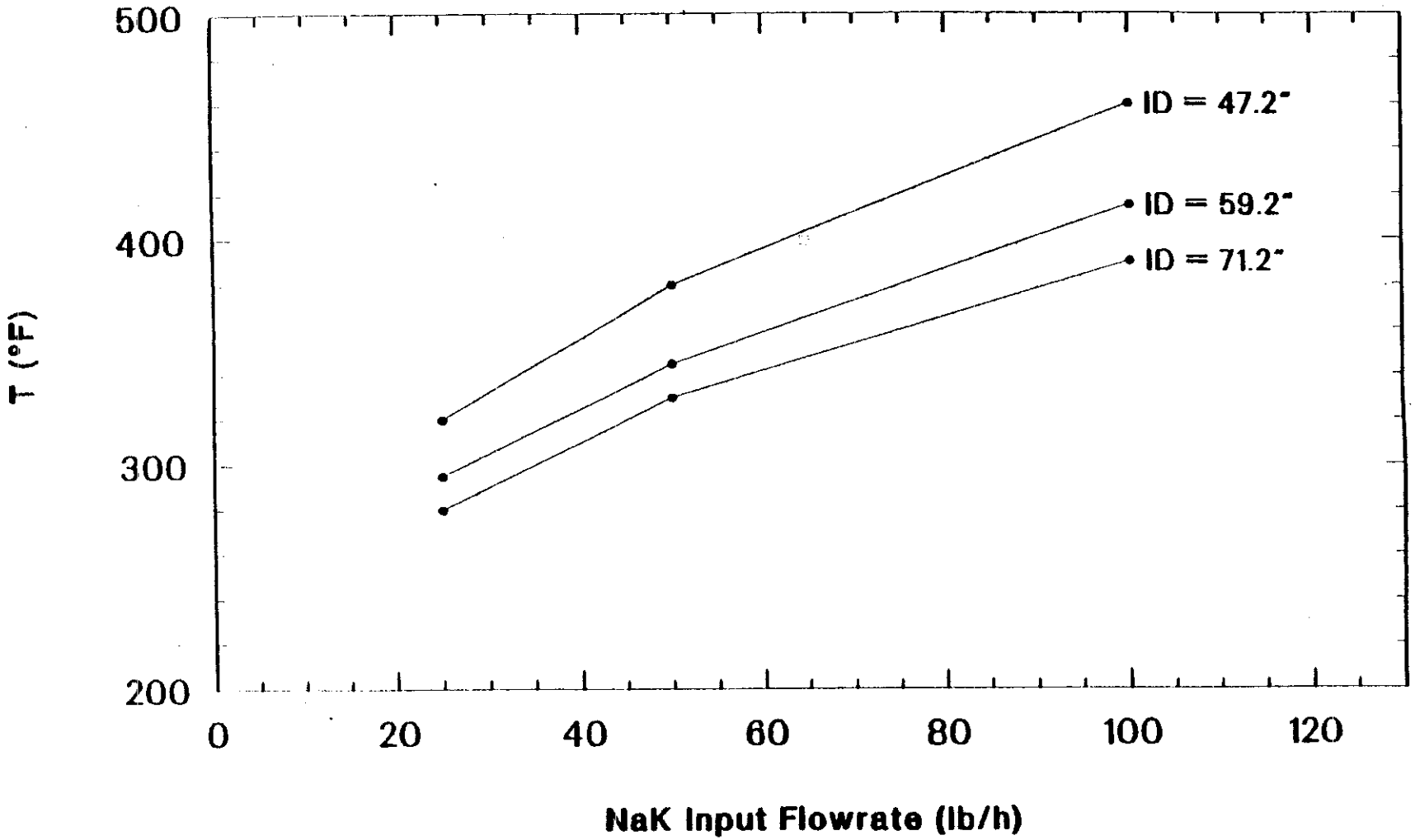
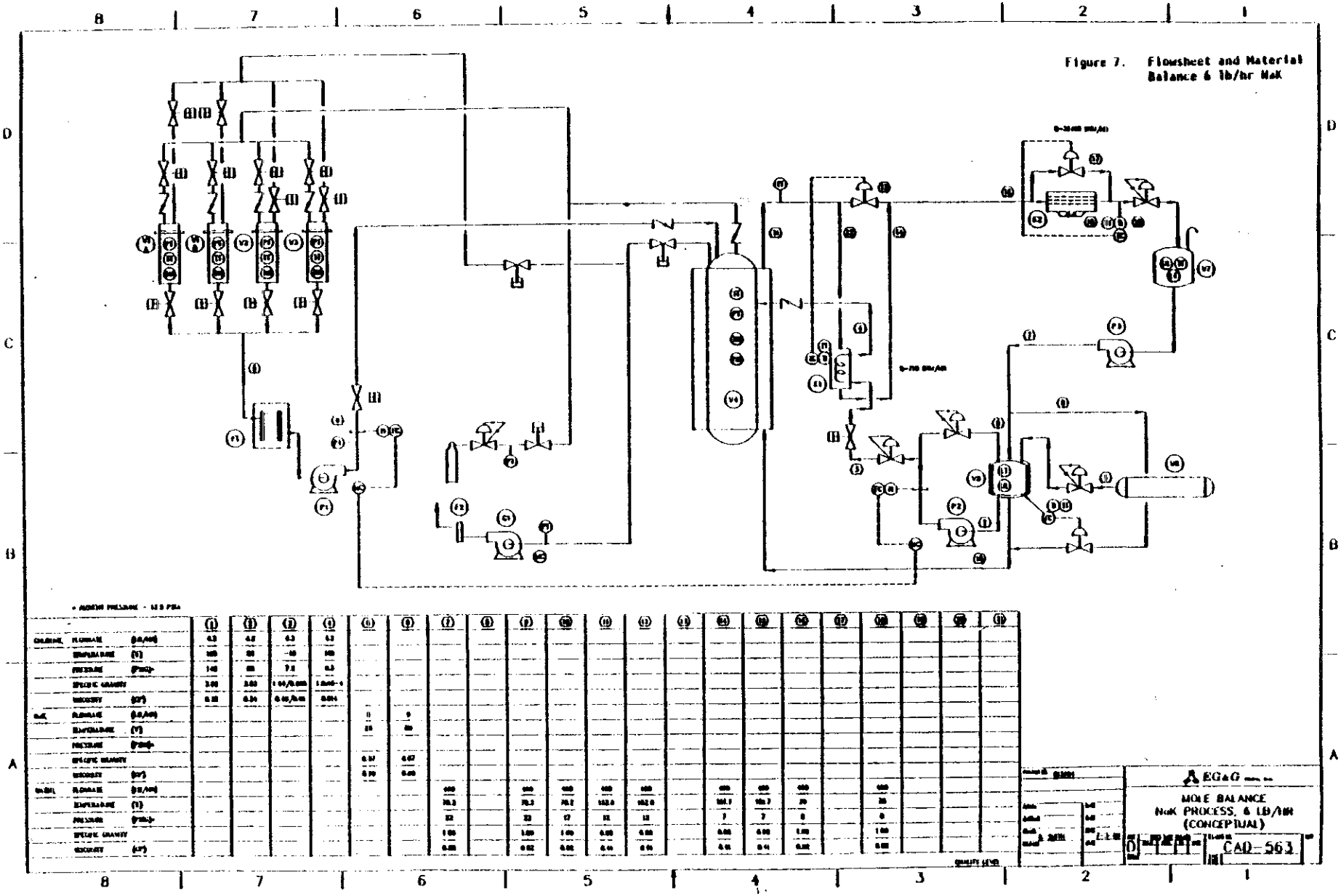


Fig. 6 Effect of reactor inside radius and NaK flowrate on predicted final inside wall temperature, no deposit on walls.

BWB0786-05

Figure 7. Flowsheet and Material Balance 6 lb/hr NaK

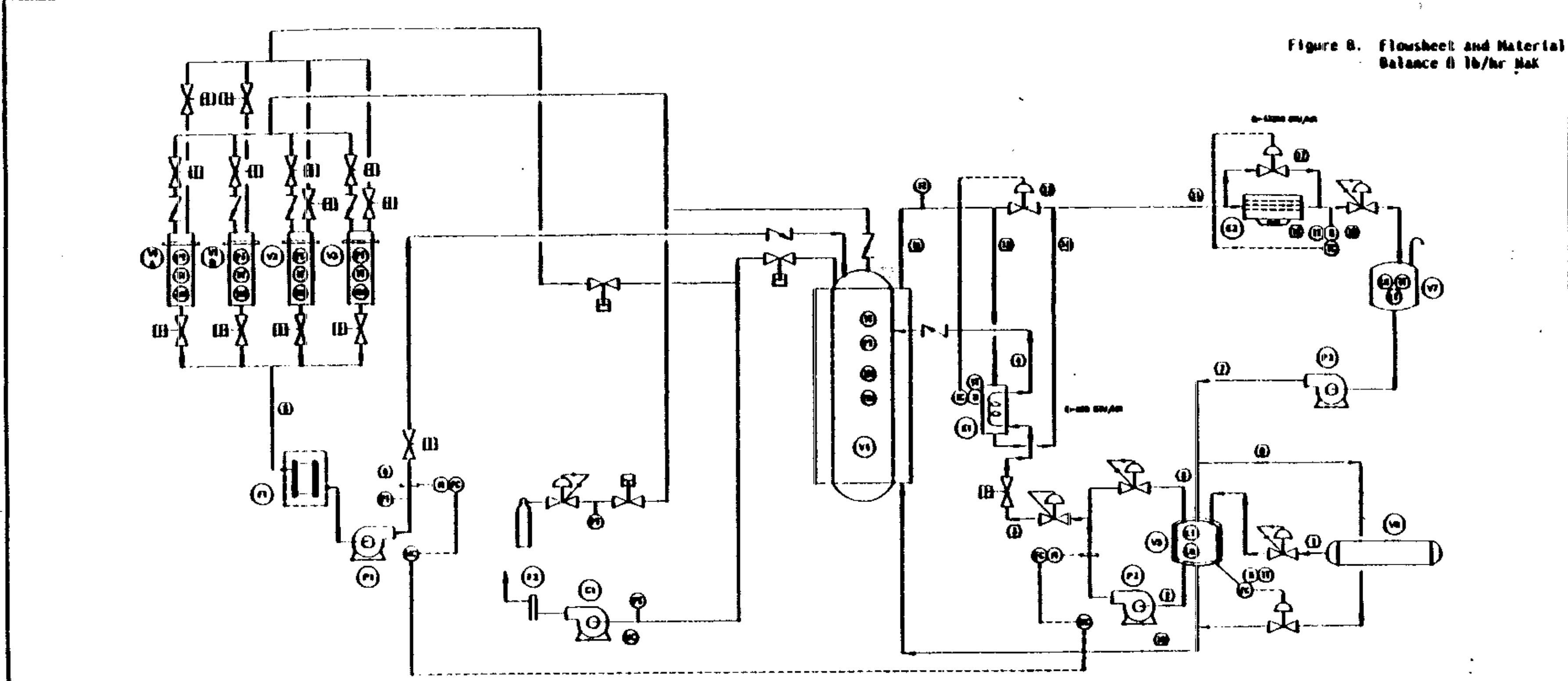


EG&G

MOLE BALANCE
NaK PROCESS, 6 LB/HR
(CONCEPTUAL)

CAD-563

Figure 8. Flowsheet and Material Balance 8 lb/hr NaK



• AMBIENT PRESSURE - 14.5 PSIA

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
[illegible]	FLOWRATE	(LB/HR)	[illegible]	[illegible]	[illegible]	[illegible]																	
	TEMPERATURE	(F)	[illegible]	[illegible]	-40	[illegible]																	
	PRESSURE	(PSIG)	[illegible]	[illegible]	[illegible]	[illegible]																	
	SPECIFIC GRAVITY		[illegible]	[illegible]	[illegible]	[illegible]																	
	VISCOSITY	(CP)	[illegible]	[illegible]	[illegible]	[illegible]																	
[illegible]	FLOWRATE	(LB/HR)					[illegible]	[illegible]															
	TEMPERATURE	(F)					[illegible]	[illegible]															
	PRESSURE	(PSIG)																					
	SPECIFIC GRAVITY						[illegible]	[illegible]															
	VISCOSITY	(CP)					[illegible]	[illegible]															
WATER	FLOWRATE	(LB/HR)							400		400	400	400	400		400	400	400		400			
	TEMPERATURE	(F)							[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]			
	PRESSURE	(PSIG)							[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		7	7	0		0			
	SPECIFIC GRAVITY								1.00		1.00	1.00	[illegible]	[illegible]		[illegible]	[illegible]	1.00		1.00			
	VISCOSITY	(CP)							[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]			

EG&G

MOLE BALANCE
NaK PROCESS, 8 LB/HR
(CONCEPTUAL)

CAD-564

```
ASPEN PLUS(TM) IS A PROPRIETARY PRODUCT OF ASPEN TECHNOLOGY, INC.
(ASPENTECH), CAMBRIDGE, MASSACHUSETTS, AND MAY BE USED ONLY UNDER
AGREEMENT WITH ASPENTECH OR THROUGH NETWORK SERVICES LICENSED BY
ASPENTECH. ASPEN PLUS(TM) IS A TRADEMARK OF ASPENTECH. THE ASPEN
PLUS COMPUTER SOFTWARE SYSTEM IS USED FOR FLOWSHEET SIMULATION.

--- INPUT-ECHO-ES ---

>>ORIGINAL RUN                                  JULY 2, 1986
 INPUT FILE: JCLINPUT                          TUESDAY
 OUTPUT POP-NAK1      VERSION:  1              5:02:32 P.M.

     1  TITLE 'NAK REACTOR FLOWSHEET'
     2  DESCRIPTION "THIS MODELS THE NAK-REACTOR, WATER COOLANT"
     3  ;
     4  IN-UNITS ENG  POWER='BTU/HR'
     5  OUT-UNITS ENG
     6  ;
     7  HISTORY MSG-LEVEL PROPERTIES=2
     8  ;
     9  COMPONENTS CL2 CHLORINE / H2O WATER
    10  ;
    11  ;-----FLOWSHEET-----
    12  ;
    13  FLOWSHEET
    14    BLOCK JACKET1 IN=H2OWARM CL2COLD   OUT=H2OCOOL CL2WARM
    15    BLOCK PUMP1   IN=CL2WARM           OUT=CL2HI
    16    BLOCK FLASH   IN=CL2HI             OUT=CL2FLASH
    17    BLOCK HEATX1  IN=H2OHOT CL2FLASH OUT=RADIN CL2VAP
    18    BLOCK PUMP2   IN=H2OIN   OUT=H2OWARM
    19    BLOCK JACKET2 IN=H2OCOOL   OUT=H2OHOT
    20    BLOCK RADIATOR IN=RADIN   OUT=OUT
    21  ;
    22  ;-    STREAM DATA
    23  ;
    24  STREAM CL2COLD PRES=160. TEMP=100.  MASS-FLOW=4.2
    25         MOLE-FRAC CL2 1.0
    26  STREAM H2OIN PRES=12.5 T=70.        MASS-FLOW=400.
    27         MOLE-FRAC H2O 1.0
    28  ;
    29  ;-    UNIT OPERATIONS
    30  ;
    31  BLOCK JACKET1 HEATX
    32        PARAM T-COLD=80. PRES-HOT=-5.
    33        FEEDS HOT=H2OWARM COLD=CL2COLD
    34        PRODUCTS HOT=H2OCOOL COLD=CL2WARM
    35        HEAT-TR-COEF U=50.
    36    -   PROPERTIES  SYSOP12/ SYSOP3
    37        FLASH-SPECS CL2WARM NPHASE=1 PHASE=2
    38  BLOCK PUMP1 PUMP
    39        PARAM PRES=105.
    40        PROPERTIES SYSOP3
    41  BLOCK FLASH HEATER
    42        PARAM P=20.   DUTY=0.0
    43  BLOCK HEATX1 HEATX
    44        PARAM   T-COLD=100. PRES-HOT=-5 PRES-COLD=-7.
    45    -   FEEDS    HOT=H2OHOT COLD=CL2FLASH
    46        PRODUCTS HOT=RADIN   COLD=CL2VAP
    47        HEAT-TR-COEF U=50
    48        PROPERTIES SYSOP12/ SYSOP3
    49        FLASH-SPECS CL2VAP NPHASE=1 PHASE=1
    50  BLOCK PUMP2 PUMP
    51        PARAM PRES=34.5
    52        PROPERTIES SYSOP12
    53  BLOCK JACKET2 HEATER
    54        PARAM DUTY=33000. PRES=-5.
    55    -   PROPERTIES SYSOP12
    56  BLOCK RADIATOR HEATER
    57        PARAM TEMP=70.0  PRES=-7.
    58    -   PROPERTIES SYSOP12
    59  ;
    60  PROP-SET SET1 MU SG       PHASE=V L
    61  STREAM-REPORT
    62    STANDARD OPTIONS=MASS-FRAC
    63    SUPPLEMENTARY OPTIONS=MASS-FLOW PROPERTIES=SET1
    64  RUN-CONTROL MAX-TIME=1000
    65  ;
    66  ;     PHYSICAL PROPERTY DATA
    67  ;
    68  PROPERTIES SYSOP3 / SYSOP12
    69  ;

 SIMULATION STARTED     MODULE USED: NAK1     CREATION:  7/02/86 17:02:32
 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

>>CURRENT RUN

 INPUT FILE: JCLINPUT                          JULY 3, 1986
 INPUT POP : NAK1      VERSION:  1             MONDAY
 OUTPUT POP: NAK2DT    VERSION:  1             10:24:13 A.M.

     1  TITLE 'NAK REACTOR FLOWSHEET, 6 L3/HR NAK'
     2  DESCRIPTION "THIS MODELS THE NAK REACTOR, WATER COOLANT"
     3  ;
     4  STREAM CL2COLD PRES=160. TEMP=100.  MASS-FLOW=6.3
     5         MOLE-FRAC CL2 1.0
     6  ;
     7  ;     UNIT OPERATIONS
     8  ;
     9  BLOCK JACKET2 HEATER
    10        PARAM DUTY=33000. PRES=-5.
    11        PROPERTIES SYSOP12
    12  BLOCK JACKET1 HEATX
    13        PARAM T-COLD=80.   PRES-HOT=-5. PRES-COLD=100.
    14    -   FEEDS    HOT=H2OWARM COLD=CL2COLD
    15    -   PRODUCTS HOT=H2OCOOL COLD=CL2WARM
    16        HEAT-TR-COEF U=50.
    17    -   PROPERTIES SYSOP12/ SYSOP3
    18    -   FLASH-SPECS CL2WARM NPHASE=1 PHASE=2
```

TABLE OF CONTENTS

RUN CONTROL INFORMATION

TYPE OF RUN: EDIT
INPUT FILE NAME: JCLINPUT
INPUT PROBLEM DATA FILE NAME: NAK1 VERSION NO. 1
OUTPUT PROBLEM DATA FILE NAME: NAKEDT VERSION NO. 1
CALLING PROGRAM NAME: NAK1
SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

DESCRIPTION

THIS MODELS THE NAK REACTOR, WATER COOLANT

BLOCK STATUS

ALL UNIT OPERATION BLOCKS WERE COMPLETED NORMALLY

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
CL2COLD	----	JACKET1	H2OIN	----	PUMP2
H2OCOOL	JACKET1	JACKET2	CL2WARM	JACKET1	PUMP1
CL2HI	PUMP1	FLASH	CL2FLASH	FLASH	HEATX1
RADIN	HEATX1	RADIATOR	CL2VAP	HEATX1	----
H2OWARM	PUMP2	JACKET1	H2OHOT	JACKET2	HEATX1
OUT	RADIATOR	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
JACKET1	H2OWARM CL2COLD	H2OCOOL CL2WARM
PUMP1	CL2WARM	CL2HI
FLASH	CL2HI	CL2FLASH
HEATX1	H2OHOT CL2FLASH	RADIN CL2VAP
PUMP2	H2OIN	H2OWARM
JACKET2	H2OCOOL	H2OHOT
RADIATOR	RADIN	OUT

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
PUMP2 JACKET1 PUMP1 FLASH JACKET2 HEATX1 RADIATOR

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
CL2	0.888500E-01	0.888500E-01	0.000000E+00
H2O	22.2037	22.2037	0.000000E+00
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2926	22.2926	0.000000E+00
MASS(LB/HR)	406.300	406.300	0.000000E+00
ENTHALPY(BTU/HR)	-0.273364E+07	-0.273296E+07	-0.249729E-03

COMPONENTS

ID	TYPE	FORMULA	NAME OR ALIAS
CL2	C	CL2	CHLORINE
H2O	C	H2O	WATER

BLOCK: JACKET1 MODEL: HEATX

INLET HOT STREAM:	HZOWARM
INLET COLD STREAM:	CL2COLD
OUTLET HOT STREAM:	HZOCOOL
OUTLET COLD STREAM:	CL2WARM
PROPERTY OPTION SETS HOT SIDE:	SYSOP12
COLD SIDE:	SYSOP3
FREE WATER OPTION SETS HOT SIDE:	SYSOP12
COLD SIDE:	SYSOP12
SOLUBLE WATER OPTIONS HOT SIDE:	ORGANIC OPTION SET
COLD SIDE:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2926	22.2926	0.000000E+00
MASS(LB/HR)	404.300	404.300	0.000000E+00
ENTHALPY(BTU/HR)	-0.273355E+07	-0.273356E+07	0.355067E-06

*** INPUT DATA ***

FLASH SPECS FOR HOT SIDE:
TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:
ONE PHASE FLASH SPECIFIED PHASE IS LIQUID
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

COUNTERCURRENT HEAT EXCHANGER WITH SPECIFIED COLD OUTLET TEMPERATURE

COLD STREAM OUTLET TEMPERATURE (F)	80.0000
HOT STREAM PRESSURE DROP (PSI)	5.00000
COLD STREAM OUTLET PRESSURE (PSI)	100.0000
OVERALL HEAT TRANSFER COEFFICIENT (BTU/HR-SQFT-R)	50.0000

*** RESULTS ***

HOT STREAM INLET TEMPERATURE (F)	70.1601
HOT STREAM OUTLET TEMPERATURE (F)	70.2489
COLD STREAM INLET TEMPERATURE (F)	100.0000
COLD STREAM OUTLET TEMPERATURE (F)	80.0000
EXCHANGER HEAT DUTY (BTU/HR)	-30.8716
HEAT TRANSFER AREA (SQFT)	0.034309

BLOCK: PUMP1 MODEL: PUMP

INLET STREAM(S):	CL2WARM
OUTLET STREAM:	CL2HI
PROPERTY OPTION SET:	SYSOP3
FREE WATER OPTION SET:	SYSOP12
SOLUBLE WATER OPTION:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.888500E-01	0.888500E-01	0.000000E+00
MASS(LB/HR)	6.30000	6.30000	0.000000E+00
ENTHALPY(BTU/HR)	-699.354	-699.107	-0.352262E-03

*** INPUT DATA ***

REQUIRED EXIT PRESSURE (PSI)	105.000
PUMP EFFICIENCY	MISSING
DRIVER EFFICIENCY	1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE (CUFT/HR)	0.078722
PRESSURE CHANGE (PSI)	5.00000
FLUID POWER (HP)	0.236260-04
BRAKE POWER (HP)	0.968216-04
ELECTRICITY (KW)	0.721999-04
PUMP EFFICIENCY USED	0.29566
NET WORK (HP)	-0.968216-04

BLOCK: FLASH MODEL: HEATER

INLET STREAM(S):	CL2HI
OUTLET STREAM:	CL2FLASH
PROPERTY OPTION SET:	SYSOP3
FREE WATER OPTION SET:	SYSOP12
SOLUBLE WATER OPTION:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.888500E-01	0.888500E-01	0.000000E+00
MASS(LB/HR)	6.30000	6.30000	0.000000E+00
ENTHALPY(BTU/HR)	-699.107	-699.107	0.266404E-08

*** INPUT DATA ***

TWO PHASE PQ FLASH	
SPECIFIED PRESSURE PSI	20.0000
SPECIFIED HEAT DUTY BTU/HR	0.0
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

BLOCK: FLASH MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	F	-16.081
OUTLET PRESSURE	PSI	20.000
VAPOR FRACTION		0.17914

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
CL2	1.0000	1.0000	1.0000	1.0000

BLOCK: HEATX1 MODEL: HEATX

INLET HOT STREAM:	H2OHOT	
INLET COLD STREAM:	CL2FLASH	
OUTLET HOT STREAM:	H2OIN	
OUTLET COLD STREAM:	CL2VAP	
PROPERTY OPTION SETS	HOT SIDE:	SYSOPL2
	COLD SIDE:	SYSOPP3
FREE WATER OPTION SETS	HOT SIDE:	SYSOPL2
	COLD SIDE:	SYSOPL2
SOLUBLE WATER OPTIONS	HOT SIDE:	ORGANIC OPTION SET
	COLD SIDE:	ORGANIC OPTION SET

*** MASS-AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2926	22.2926	0.000000E+00
MASS(LB/HR)	406.300	406.300	0.000000E+00
ENTHALPY(BTU/HR)	-0.270056E+07	-0.270056E+07	0.179931E-08

*** INPUT DATA ***

FLASH SPECS FOR HOT SIDE:
TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:
ONE PHASE FLASH SPECIFIED PHASE IS VAPOR
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

BLOCK: HEATX1 MODEL: HEATX (CONTINUED)

COUNTERCURRENT HEAT EXCHANGER WITH SPECIFIED COLD OUTLET TEMPERATURE

COLD STREAM OUTLET TEMPERATURE (F)	100.0000
HOT STREAM PRESSURE DROP (PSI)	5.00000
COLD STREAM PRESSURE DROP (PSI)	7.00000
OVERALL HEAT TRANSFER COEFFICIENT (BTU/HR-SQFT-R)	50.0000

*** RESULTS ***

HOT STREAM INLET TEMPERATURE (F)	152.876
HOT STREAM OUTLET TEMPERATURE (F)	151.105
COLD STREAM INLET TEMPERATURE (F)	-16.0812
COLD STREAM OUTLET TEMPERATURE (F)	100.0000
EXCHANGER HEAT DUTY (BTU/HR)	713.295
HEAT TRANSFER AREA (SQFT)	0.14367

BLOCK: PUMP2 MODEL: PUMP

INLET STREAM(S):	H2OIN
OUTLET STREAM:	H2OWARM
PROPERTY OPTION SET:	SYSOPL2
FREE WATER OPTION SET:	SYSOPL2
SOLUBLE WATER OPTION:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.000	400.000	0.000000E+00
ENTHALPY(BTU/HR)	-0.273297E+07	-0.273289E+07	-0.323439E-04

*** INPUT DATA ***

REQUIRED EXIT PRESSURE (PSI)	34.5000
PUMP EFFICIENCY	MISSING
DRIVER EFFICIENCY	1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE (CUFT/HR)	6.41976
PRESSURE CHANGE (PSI)	22.0000
FLUID POWER (HP)	0.010272
BRAKE POWER (HP)	0.034742
ELECTRICITY (KW)	0.025907
PUMP EFFICIENCY USED	0.29566
NET WORK (HP)	-0.034742

BLOCK: JACKET2 MODEL: HEATER

INLET STREAM(S):	H2OCOL		
OUTLET STREAM:	H2OHOT		
PROPERTY OPTION SET:	SYSOP12		
FREE WATER OPTION SET:	SYSOP12		
SOLUBLE WATER OPTION:	ORGANIC OPTION SET		

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.000	400.000	0.000000E+00
ENTHALPY(BTU/HR)	-0.273286E+07	-0.269986E+07	-0.120726E-01

*** INPUT DATA ***

TWO PHASE PQ FLASH		
PRESSURE DROP	PSI	5.00000
SPECIFIED HEAT DUTY	BTU/HR	33,000.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	F	152.88
OUTLET PRESSURE	PSI	24.500
VAPOR FRACTION		0.00000E+00

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	0.16867

BLOCK: RADIATOR MODEL: HEATER

INLET STREAM(S):	RADIN
OUTLET STREAM:	OUT
PROPERTY OPTION SET:	SYSOP12
FREE WATER OPTION SET:	SYSOP12
SOLUBLE WATER OPTION:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.000	400.000	0.000000E+00
ENTHALPY(BTU/HR)	-0.270058E+07	-0.273297E+07	0.118543E-01

*** INPUT DATA ***

TWO PHASE TP FLASH		
SPECIFIED TEMPERATURE	F	70.0000
PRESSURE DROP	PSI	7.00000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

BLOCK: RADIATOR MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	F	70.000
OUTLET PRESSURE	PSI	12.500
HEAT DUTY	BTU/HR	-32398.
VAPOR FRACTION		0.00000E+00

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	0.30390E-01

CL2COLD H2OIN H2OCOOL CL2WARM CL2HI

STREAM ID	CL2COLD	H2OIN	H2OCOOL	CL2WARM	CL2HI
FROM :		PUMP2	JACKET1	JACKET1	PUMP1
TO :	JACKET1		JACKET2	PUMP1	FLASH
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: MASS FRAC					
CL2	1.0000	0.0	0.0	1.0000	1.0000
H2O	0.0	1.0000	1.0000	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0889	22.2037	22.2037	0.0889	0.0889
LB/HR	6.3000	400.0000	400.0000	6.3000	6.3000
CUFT/HR	0.0811	6.4196	6.4196	0.0797	0.0787
STATE VARIABLES:					
TEMP F	100.0000	70.0000	70.2689	80.0000	80.1535
PRES PSI	160.0000	12.5000	29.5000	100.0000	105.0000
VFRAC	0.0	0.3	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-7523.7150	-1.2309+05	-1.2308+05	-7871.1720	-7868.3993
BTU/LB	-106.1083	-6832.4369	-6832.1411	-111.0085	-110.9694
BTU/HR	-668.4823	-2.7330+06	-2.7329+06	-699.3538	-699.1075
ENTROPY:					
BTU/LBMOL-R	-17.8954	-39.2068	-39.1988	-18.5094	-18.5057
BTU/LB-R	-0.2524	-2.1763	-2.1759	-0.2610	-0.2610
DENSITY:					
LBMOL/CUFT	1.0953	3.4587	3.4587	1.1287	1.1285
LB/CUFT	77.6777	62.3076	62.3091	80.0258	80.0204
AVG MW	70.9060	18.0150	18.0150	70.9060	70.9060

CL2FLASH RADIN CL2VAP H2OWARM H2OHOT

STREAM ID	CL2FLASH	RADIN	CL2VAP	H2OWARM	H2OHOT
FROM :	FLASH	HEATX1	HEATX1	PUMP2	JACKET2
TO :	HEATX1	RADIATOR	----	JACKET1	HEATX1
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: MASS FRAC					
CL2	1.0000	0.0	1.0000	0.0	0.0
H2O	0.0	1.0000	0.0	1.0000	1.0000
TOTAL FLOW:					
LBMOL/HR	0.0889	22.2037	0.0889	22.2037	22.2037
LB/HR	6.3000	400.0000	6.3000	400.0000	400.0000
CUFT/HR	3.7460	6.5390	40.6720	6.4194	6.5428
STATE VARIABLES:					
TEMP F	-16.0812	151.1046	100.0000	70.1601	152.3755
PRES PSI	20.0000	19.5000	13.0000	34.5000	24.5000
VFRAC	0.1791	0.0	1.0000	0.0	0.0
LFRAC	0.8209	1.0000	0.0	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-7868.3993	-1.2163+05	159.6828	-1.2308+05	-1.2160+05
BTU/LB	-110.9694	-6751.4428	2.2520	-6832.2139	-6749.6596
BTU/HR	-699.1075	-2.7006+06	14.1878	-2.7329+06	-2.6999+06
ENTROPY:					
BTU/LBMOL-R	-18.1432	-36.6445	0.5541	-39.2019	-36.5926
BTU/LB-R	-0.2559	-2.0341	0.0078	-2.1761	-2.0312
DENSITY:					
LBMOL/CUFT	0.0237	3.3956	0.0022	3.4588	3.3937
LB/CUFT	1.6818	61.1712	0.1549	62.3107	61.1379
AVG MW	70.9060	18.0150	70.9060	18.0150	18.0150

OUT

STREAM ID	OUT
FROM :	RADIATOR
TO :	
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: MASS FRAC	
CL2	0.0
H2O	1.0000
TOTAL FLOW:	
LBMOL/HR	22.2037
LB/HR	400.0000
CUFT/HR	6.4198
STATE VARIABLES:	
TEMP F	70.0000
PRES PSI	12.5000
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.2309+05
BTU/LB	-6832.4369
BTU/HR	-2.7330+06
ENTROPY:	
BTU/LBMOL-R	-39.2068
BTU/LB-R	-2.1763
DENSITY:	
LBMOL/CUFT	3.4587
LB/CUFT	62.3076
AVG MW	18.0150

CL2COLD H2OIN H2OCOOL CL2WARM CL2HI

STREAM ID	CL2COLD	H2OIN	H2OCOOL	CL2WARM	CL2HI
FROM :			JACKET1	JACKET1	PUMP1
TO :	JACKET1	PUMP2	JACKET2	PUMP1	FLASH
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LB/HR					
CL2	6.3000	0.0	0.0	6.3000	6.3000
H2O	0.0	400.0000	400.0000	0.0	0.0
STREAM PROPERTIES:					
*** VAPOR ***					
MU CP					
CL2	MISSING	MISSING	MISSING	MISSING	MISSING
H2O	MISSING	MISSING	MISSING	MISSING	MISSING
SG	MISSING	MISSING	MISSING	MISSING	MISSING
*** LIQUID ***					
MU CP					
CL2	0.3189	MISSING	MISSING	0.3361	0.3360
H2O	MISSING	0.8171	0.8152	MISSING	MISSING
SG	3.9186	1.0001	1.0001	3.9321	1.2844

CL2FLASH RADIN CL2VAP H2OWARM H2OHOT

STREAM ID	CL2FLASH	RADIN	CL2VAP	H2OWARM	H2OHOT
FROM :	FLASH	HEATX1	HEATX1	PUMP2	JACKET2
TO :	HEATX1	RADIATOR	----	JACKET1	HEATX1
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: LB/HR					
CL2	6.3000	0.0	6.3000	0.0	0.0
H2O	0.0	400.0000	0.0	400.0000	400.0000
STREAM PROPERTIES:					
*** VAPOR ***					
MU					
CP					
CL2	0.0110	MISSING	0.0139	MISSING	MISSING
H2O	MISSING	MISSING	MISSING	MISSING	MISSING
SG	0.0049	MISSING	1.8031-04	MISSING	MISSING
*** LIQUID ***					
MU					
CP					
CL2	0.4625	MISSING	MISSING	MISSING	MISSING
H2O	MISSING	0.4123	MISSING	0.8159	0.4070
SG	1.4403	0.9819	MISSING	1.0002	0.9813

OUT

STREAM ID	OUT
FROM :	RADIATOR
TO :	----
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: LB/HR	
CL2	0.0
H2O	400.0000
STREAM PROPERTIES:	
*** VAPOR ***	
MU	
CP	
CL2	MISSING
H2O	MISSING
SG	MISSING
*** LIQUID ***	
MU	
CP	
CL2	MISSING
H2O	0.3171
SG	1.0001

```
      ASPEN PLUS(TM) IS A PROPRIETARY PRODUCT OF ASPEN TECHNOLOGY, INC.
      (ASPENTECH), CAMBRIDGE, MASSACHUSETTS, AND MAY BE USED ONLY UNDER
      AGREEMENT WITH ASPENTECH OR THROUGH NETWORK SERVICES LICENSED BY
      ASPENTECH. ASPEN PLUS(TM) IS A TRADEMARK OF ASPENTECH. THE ASPEN
      PLUS COMPUTER SOFTWARE SYSTEM IS USED FOR FLOWSHEET SIMULATION.

--- INPUT-ECHO(ES) ---

>>ORIGINAL RUN                                  JULY 2, 1986
  INPUT FILE: JCLINPUT                         TUESDAY
  OUTPUT POP: NAK1 ----VERSION:= 1 ----        5:02:32 P.M.

    1   TITLE 'NAK REACTOR FLOWSHEET'
    2   DESCRIPTION "THIS MODELS THE NAK REACTOR, WATER COOLANT"
    3   ;
    4   IN-UNITS ENG  POWER='BTU/HR'
    5   OUT-UNITS ENG
    6   ;
    7   HISTORY MSG-LEVEL PROPERTIES=2
    8   ;
    9   COMPONENTS CL2 CHLORINE / H2O WATER
   10   ;
   11   ;-----FLOWSHEET-----
   12   ;
   13   FLOWSHEET
   14     BLOCK JACKET1 IN=H2OWARM CL2COLD   OUT=H2OCOOL CL2WARM
   15     BLOCK PUMP1   IN=CL2WARM           OUT=CL2HI
   16     BLOCK FLASH   IN=CL2HI             OUT=CL2FLASH
   17     BLOCK HEATX1  IN=H2OHOT CL2FLASH OUT=RADIN CL2VAP
   18     BLOCK PUMP2   IN=H2OIN     OUT=H2OWARM
   19     BLOCK JACKET2 IN=H2OCOOL   OUT=H2OHOT
   20     BLOCK RADIATOR IN=RADIN    OUT=OUT
   21   ;
   22   ;     STREAM DATA
   23   ;
   24   STREAM CL2COLD PRES=160. TEMP=100.  MASS-FLOW=4.2
   25          MOLE-FRAC CL2 1.0
   26   STREAM H2OIN PRES=12.5 T=70.        MASS-FLOW=400.
   27          MOLE-FRAC H2O 1.0
   28   ;
   29   ;     UNIT OPERATIONS
   30   ;
   31   BLOCK JACKET1 HEATX
   32        PARAM T-COLD=80. PRES-HOT=-5.
   33        FEEDS HOT=H2OWARM COLD=CL2COLD
   34        PRODUCTS HOT=H2OCOOL COLD=CL2WARM
   35        HEAT-TR-COEF U=50.
   36        PROPERTIES SYSOP12/ SYSOP3
   37        FLASH-SPECS CL2WARM NPHASE=1 PHASE=2
   38   BLOCK PUMP1 PUMP
   39        PARAM PRES=109.
   40        PROPERTIES SYSOP3
   41   BLOCK FLASH HEATER
   42        PARAM P=20.   DUTY=0.0
   43   BLOCK HEATX1 HEATX
   44        PARAM  T-COLD=100. PRES-HOT=-5 PRES-COLD=-7.
   45        FEEDS    HOT=H2OHOT COLD=CL2FLASH
   46        PRODUCTS HOT=RADIN   COLD=CL2VAP
   47        HEAT-TR-COEF U=50.
   48        PROPERTIES SYSOP12/ SYSOP3
   49        FLASH-SPECS CL2VAP NPHASE=1 PHASE=1
   50   BLOCK PUMP2 PUMP
   51        PARAM PRES=34.5
   52        PROPERTIES SYSOP12
   53   BLOCK JACKET2 HEATER
   54        PARAM DUTY=33000. PRES=-5.
   55        PROPERTIES SYSOP12
   56   BLOCK RADIATOR HEATER
   57        PARAM TEMP=70.0  PRES=-7.
   58        PROPERTIES SYSOP12
   59   ;
   60   PROP-SET SET1 MU SG      PHASE=V L
   61   STREAM-REPORT
   62     STANDARD OPTIONS=MASS-FRAC
   63     SUPPLEMENTARY 1 OPTIONS=MASS-FLOW PROPERTIES=SET1
   64   RUN-CONTROL MAX-TIME=1000
   65   ;
   66   ;     PHYSICAL PROPERTY DATA
   67   ;
   68   PROPERTIES SYSOP3 / SYSOP12
   69   ;

  SIMULATION STARTED     MODULE USED: NAK1     CREATION:  7/02/86 17:02:32
  SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

>>CURRENT RUN

  INPUT FILE: JCLINPUT                         JULY 8, 1986
  INPUT POP : NAK1     VERSION:  1             MONDAY
  OUTPUT POP: NAKEOT   VERSION:  1             9:41:53 A.M.

    1   TITLE 'NAK REACTOR FLOWSHEET, 8 LB/HR NAK'
    2   DESCRIPTION "THIS MODELS THE NAK REACTOR, WATER COOLANT"
    3   ;
    4   STREAM CL2COLD PRES=160. TEMP=100.  MASS-FLOW=8.4
    5        MOLE-FRAC CL2 1.0
    6   ;
    7   ;     UNIT OPERATIONS
    8   ;
    9   BLOCK JACKET2 HEATER
   10        PARAM DUTY=44000. PRES=-5.
   11        PROPERTIES SYSOP12
   12   BLOCK JACKET1 HEATX
   13        PARAM  T-COLD=80.   PRES-HOT=-5. PRES-COLD=100.
   14        FEEDS    HOT=H2OWARM COLD=CL2COLD
   15        PRODUCTS HOT=H2OCOOL COLD=CL2WARM
   16        HEAT-TR-COEF U=50.
   17        PROPERTIES SYSOP12/ SYSOP3
   18        FLASH-SPECS CL2WARM NPHASE=1 PHASE=2
```

TABLE OF CONTENTS

RUN CONTROL INFORMATION

TYPE OF RUN: EDIT

INPUT FILE NAME: JCLINPUT

INPUT PROBLEM DATA FILE NAME : NAK1 VERSION NO. 1

OUTPUT PROBLEM DATA FILE NAME: NAKEDT VERSION NO. 1

CALLING PROGRAM NAME: NAK1

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

DESCRIPTION

THIS MODELS THE NAK REACTOR, WATER COOLANT

BLOCK STATUS

ALL UNIT OPERATION BLOCKS WERE COMPLETED NORMALLY

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
CL2COLD	----	JACKET1	H2OIN	----	PUMP2
H2OCOOL	JACKET1	JACKET2	CL2WARM	JACKET1	PUMP1
CL2HI	PUMP1	FLASH	CL2FLASH	FLASH	HEATX1
RADIN	HEATX1	RADIATOR	CL2VAP	HEATX1	----
H2OWARM	PUMP2	JACKET1	H2OHOT	JACKET2	HEATX1
OUT	RADIATOR	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
JACKET1	H2OWARM CL2COLD	H2OCOOL CL2WARM
PUMP1	CL2WARM	CL2HI
FLASH	CL2HI	CL2FLASH
HEATX1	H2OHOT CL2FLASH	RADIN CL2VAP
PUMP2	H2OIN	H2OWARM
JACKET2	H2OCOOL	H2OHOT
RADIATOR	RADIN	OUT

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
PUMP2 JACKET1 PUMP1 FLASH JACKET2 HEATX1 RADIATOR

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
CL2	0.118467	0.118467	0.000000E+00
H2O	22.2037	22.2037	0.000000E+00
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.3222	22.3222	0.000000E+00
MASS(LB/HR)	408.400	408.400	0.000000E+00
ENTHALPY(BTU/HR)	-0.273387E+07	-0.273296E+07	-0.332943E-03

COMPONENTS

ID	TYPE	FORMULA	NAME OR ALIAS
CL2	C	CL2	CHLORINE
H2O	C	H2O	WATER

BLOCK: FLASH MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	F	-16.081
OUTLET PRESSURE	PSI	20.000
VAPOR FRACTION		0.17914

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
CL2	1.0000	1.0000	1.0000	1.0000

BLOCK: HEATX1 MODEL: HEATX

INLET HOT STREAM:	H2OHOT	
INLET COLD STREAM:	CL2FLASH	
OUTLET HOT STREAM:	RADIN	
OUTLET COLD STREAM:	CL2VAP	
PROPERTY OPTION SETS	HOT SIDE:	SYSOP12
	COLD SIDE:	SYSOP3
FREE WATER OPTION SETS	HOT SIDE:	SYSOP12
	COLD SIDE:	SYSOP12
SOLUBLE WATER OPTIONS	HOT SIDE:	ORGANIC OPTION SET
	COLD SIDE:	ORGANIC OPTION SET

*** MASS-AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.3222	22.3222	0.000000E+00
MASS(LB/HR)	408.400	408.400	0.000000E+00
ENTHALPY(BTU/HR)	-0.268978E+07	-0.268978E+07	0.778663E-08

*** INPUT DATA ***

FLASH SPECS FOR HOT SIDE:
TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:
ONE PHASE FLASH SPECIFIED PHASE IS VAPOR
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

BLOCK: HEATX1 MODEL: HEATX (CONTINUED)

COUNTERCURRENT HEAT EXCHANGER WITH SPECIFIED COLD OUTLET TEMPERATURE

COLD STREAM OUTLET TEMPERATURE (F)	100.0000
HOT STREAM PRESSURE DROP (PSI)	5.00000
COLD STREAM PRESSURE DROP (PSI)	7.00000
OVERALL HEAT TRANSFER COEFFICIENT (BTU/HR-SQFT-R)	50.0000

*** RESULTS ***

HOT STREAM INLET TEMPERATURE (F)	180.385
HOT STREAM OUTLET TEMPERATURE (F)	178.025
COLD STREAM INLET TEMPERATURE (F)	-16.0812
COLD STREAM OUTLET TEMPERATURE (F)	100.0000
EXCHANGER HEAT DUTY (BTU/HR)	951.060
HEAT TRANSFER AREA (SQFT)	0.14745

BLOCK: PUMP2 MODEL: PUMP

INLET STREAM(S):	H2OIN
OUTLET STREAM:	H2OWARM
PROPERTY OPTION SET:	SYSOP12
FREE WATER OPTION SET:	SYSOP12
SOLUBLE WATER OPTION:	ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.300	400.300	0.000000E+00
ENTHALPY(BTU/HR)	-0.273297E+07	-0.273289E+07	-0.323439E-04

*** INPUT DATA ***

REQUIRED EXIT PRESSURE (PSI)	34.5000
PUMP EFFICIENCY	MISSING
DRIVER EFFICIENCY	1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE (CUFT/HR)	6.41976
PRESSURE CHANGE (PSI)	22.0000
FLUID POWER (HP)	0.010272
BRAKE POWER (HP)	0.034742
ELECTRICITY (KW)	0.025907
PUMP EFFICIENCY USED	0.29566
NET WORK (HP)	-0.034742

BLOCK: JACKET2 MODEL: HEATER

INLET STREAM(S): H2OCOOL
OUTLET STREAM: H2CHOT
PROPERTY OPTION SET: SYSOP12
FREE WATER OPTION SET: SYSOP12
SOLUBLE WATER OPTION: ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.000	400.000	0.000000E+00
ENTHALPY(BTU/HR)	-0.273285E+07	-0.268885E+07	-0.161004E-01

*** INPUT DATA ***

TWO PHASE PQ FLASH
PRESSURE DROP PSI 5.00000
SPECIFIED HEAT DUTY BTU/HR 44,000.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE F 180.39
OUTLET PRESSURE PSI 24.500
VAPOR FRACTION 0.00000E+00

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	0.31643

BLOCK: RADIATOR MODEL: HEATER

INLET STREAM(S): RADIN
OUTLET STREAM: OUT
PROPERTY OPTION SET: SYSOP12
FREE WATER OPTION SET: SYSOP12
SOLUBLE WATER OPTION: ORGANIC OPTION SET

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	22.2037	22.2037	0.000000E+00
MASS(LB/HR)	400.000	400.000	0.000000E+00
ENTHALPY(BTU/HR)	-0.268980E+07	-0.273297E+07	0.157987E-01

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE F 70.0000
PRESSURE DROP PSI 7.00000
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

BLOCK: RADIATOR MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE F 70.000
OUTLET PRESSURE PSI 12.500
HEAT DUTY BTU/HR -43177.
VAPOR FRACTION 0.00000E+00

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
H2O	1.0000	1.0000	1.0000	0.30390E-01

CL2COLD H2OIN H2OCOOL CL2WARM CL2HI

STREAM ID	CL2COLD	H2OIN	H2OCOOL	CL2WARM	CL2HI
FROM :			JACKET1	JACKET1	PUMP1
TO :	JACKET1	PUMP2	JACKET2	PUMP1	FLASH
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: MASS FRAC					
CL2	1.0000	0.0	0.0	1.0000	1.0000
H2O	0.0	1.0000	1.0000	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.1185	22.2037	22.2037	0.1185	0.1185
LB/HR	8.4000	400.0000	400.0000	8.4000	8.4000
CUFT/HR	0.1081	6.4198	6.4198	0.1050	0.1050
STATE VARIABLES:					
TEMP F	100.0000	70.0000	70.2747	80.0000	80.1535
PRES PSI	160.0000	12.5000	29.2000	100.0000	105.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-7523.7150	-1.2309+05	-1.2308+05	-7871.1770	-7868.3993
BTU/LB	-106.1083	-6832.4369	-6832.1154	-111.0085	-110.9694
BTU/HR	-891.3097	-2.7330+06	-2.7328+06	-932.4718	-932.1433
ENTROPY:					
BTU/LBMOL-R	-17.8934	-39.2068	-39.1979	-18.5094	-18.5057
BTU/LB-R	-0.2524	-2.1763	-2.1758	-0.2610	-0.2610
DENSITY:					
LBMOL/CUFT	1.0955	3.4587	3.4587	1.1287	1.1285
LB/CUFT	77.6777	62.3076	62.3089	80.0288	80.0204
AVG MW	70.9060	18.0150	18.0150	70.9060	70.9060

CL2FLASH RADIN CL2VAP H2OWARM H2OHOT

STREAM ID	CL2FLASH	RADIN	CL2VAP	H2OWARM	H2OHOT
FROM :	FLASH	HEATX1	HEATX1	PUMP2	JACKET2
TO :	HEATX1	RADIATOR	----	JACKET1	HEATX1
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: MASS FRAC					
CL2	1.0000	0.0	1.0000	0.0	0.0
H2O	0.0	1.0000	0.0	1.0000	1.0000
TOTAL FLOW:					
LBMOL/HR	0.1185	22.2037	0.1185	22.2037	22.2037
LB/HR	8.4000	400.0000	8.4000	400.0000	400.0000
CUFT/HR	4.9947	6.5990	54.2293	6.4194	6.6046
STATE VARIABLES:					
TEMP F	-16.0812	178.0251	100.0000	70.1601	180.3854
PRES PSI	20.0000	19.5000	13.0000	34.5000	24.5000
VFRAC	0.1791	0.0	1.0000	0.0	0.0
LFRAC	0.8209	1.0000	0.0	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-7868.3993	-1.2114+05	159.4828	-1.2308+05	-1.2110+05
BTU/LB	-110.9694	-6724.4932	2.5530	-6832.2159	-6722.1155
BTU/HR	-932.1433	-2.6898+06	18.9171	-2.7329+06	-2.6888+06
ENTROPY:					
BTU/LBMOL-R	-18.1432	-35.8667	0.5541	-39.2019	-35.8001
BTU/LB-R	-0.2559	-1.9909	0.0078	-2.1761	-1.9872
DENSITY:					
LBMOL/CUFT	0.0237	3.3647	0.0022	3.4588	3.3618
LB/CUFT	1.6818	60.6149	0.1549	62.3107	60.5636
AVG MW	70.9060	18.0150	70.9060	18.0150	18.0150

OUT

STREAM ID	OUT
FROM :	RADIATOR
TO :	
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: MASS FRAC	
CL2	0.0
H2O	1.0000
TOTAL FLOW:	
LBMOL/HR	22.2037
LB/HR	400.0000
CUFT/HR	6.4198
STATE VARIABLES:	
TEMP F	70.0000
PRES PSI	12.5000
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.2309+05
BTU/LB	-6832.4369
BTU/HR	-2.7330+06
ENTROPY:	
BTU/LBMOL-R	-39.2068
BTU/LB-R	-2.1763
DENSITY:	
LBMOL/CUFT	3.4587
LB/CUFT	62.3076
AVG MW	18.0150

CL2COLD H2OIN H2OCOOL CL2WARM CL2HI

STREAM ID	CL2COLD	H2OIN	H2OCOOL	CL2WARM	CL2HI
FROM :	JACKET1	PUMP2	JACKET2	JACKET1	PUMP1
TO :					FLASH
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LB/HR					
CL2	8.4000	0.0	0.0	8.4000	8.4000
H2O	0.0	400.0000	400.0000	0.0	0.0
STREAM PROPERTIES:					
*** VAPOR ***					
MU					
CP					
CL2	MISSING	MISSING	MISSING	MISSING	MISSING
H2O	MISSING	MISSING	MISSING	MISSING	MISSING
SG	MISSING	MISSING	MISSING	MISSING	MISSING
*** LIQUID ***					
MU					
CP					
CL2	0.3189	MISSING	MISSING	0.3361	0.3360
H2O	MISSING	0.3171	0.8150	MISSING	MISSING
SG	3.9186	1.0001	1.0001	3.9321	1.2844

CL2FLASH RADIN CL2VAP H2OWARM H2OHOT

STREAM ID	CL2FLASH	RADIN	CL2VAP	H2OWARM	H2OHOT
FROM :	FLASH	HEATX1	HEATX1	PUMP2	JACKET2
TO :	HEATX1	RADIATOR	----	JACKET1	HEATX1
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: LB/HR					
CL2	8.4000	0.0	8.4000	0.0	0.0
H2O	0.0	400.0000	0.0	400.0000	400.0000
STREAM PROPERTIES:					
*** VAPOR ***					
MU					
CP					
CL2	0.0110	MISSING	0.0139	MISSING	MISSING
H2O	MISSING	MISSING	MISSING	MISSING	MISSING
SG	0.0049	MISSING	1.8031-04	MISSING	MISSING
*** LIQUID ***					
MU					
CP					
CL2	0.4622	MISSING	MISSING	MISSING	MISSING
H2O	MISSING	0.3415	MISSING	0.8159	0.3361
SG	1.4403	0.9730	MISSING	1.0002	0.9721

OUT

STREAM ID	OUT
FROM :	RADIATOR
TO :	
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: LB/HR	
CL2	0.0
H2O	400.0000
STREAM PROPERTIES:	
*** VAPOR ***	
MU	
CP	
CL2	MISSING
H2O	MISSING
SG	MISSING
*** LIQUID ***	
MU	
CP	
CL2	MISSING
H2O	0.8171
SG	1.0001

1. JACKET RADIUS = 25.60 inches
2. REACTOR RADIUS, OUTSIDE = 24.60 inches 3 INSIDE = 23.60 inches
4. VESSEL HEIGHT = 3.200 ft
5. COOLANT FLOW RATE = 120.0 gal/hr 6 TEMP = 70.00 F
7. COOLANT DENSITY = 62.400 lb/ft3
8. COOLANT VISCOSITY = 1.000 cpoise
9. COOLANT THERMAL CONDUCTIVITY = 0.340 Btu/hr ftF
10. COOLANT PRANDTL NUMBER = 7.000
11. NUMBER OF NODES = 10. 12 INTERFACE NODE NUMBER = 7.
13. TIME STEP = 1.000 hour 14 PRINT FREQUENCY = 10.000 hours
15. N&K FLOWRATE = 6.000 lb/hr
16. DENSITY, N&K = 52.88 17. NaCl = 135.10 18. KCl = 123.80 lb/ft3
19. SALT DEPOSIT DENSITY = 110.00 lb/ft3
20. SALT DEPOSIT HEAT CAPACITY = 0.21 Btu/lb.F
21. SALT THERMAL CONDUCTIVITY = 0.25 Btu/hr ft.F
22. STEEL DENSITY = 502.20 lb/ft3
23. STEEL HEAT CAPACITY = 0.12 Btu/lb.F
24. STEEL THERMAL CONDUCTIVITY = 9.41 Btu/hr.ft.F
25. N&K HEAT OF REACTION = 5462. Btu/lb
26. INERT GAS PARTIAL PRESSURE =1.00 atm 27. C12 CONVERSION = 1.00
28. SALT DEPOSITION OPTION = 2 1=SIDES ONLY, 2=SIDES+1END, 3=SIDES+2ENDS
29. SALT DEPOSITION FRACTION = 0.000 FRACT OF HT
30. HEAT TRANSFER OPTION = 1.00 (0=1=emiss to air,1=liquid)
31. GAS EMISSIVITY = 0.30

			NODE NUMBER									
TIME (hr)	R1 (ft)	PRESS (atm)	1	2	3	4	5	6	7	8	9	10
			TEMPERATURE (F)									
0.0	1.9667	1.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
10.0	1.9526	2.8	212.3	208.9	205.6	202.3	199.0	195.7	192.4	191.4	190.3	189.3
20.0	1.9384	2.8	233.0	226.2	219.5	212.8	206.1	199.5	192.8	191.8	190.8	189.8
30.0	1.9241	2.9	253.9	243.7	233.5	223.3	213.2	203.1	193.0	192.0	191.0	190.0
40.0	1.9096	2.9	275.4	261.5	247.7	234.0	220.3	206.7	193.2	192.2	191.2	190.2
50.0	1.8950	3.0	297.3	279.6	262.2	244.9	227.6	210.4	193.4	192.4	191.4	190.4
60.0	1.8802	3.1	319.7	298.2	276.9	255.9	235.0	214.2	193.6	192.6	191.6	190.6
70.0	1.8652	3.1	342.6	317.2	292.0	267.1	242.5	218.0	193.9	192.8	191.8	190.8
80.0	1.8501	3.2	366.1	336.5	307.4	278.6	250.1	221.9	194.1	193.0	192.0	191.0
90.0	1.8348	3.3	390.1	356.3	323.1	290.3	257.9	225.9	194.3	193.2	192.2	191.2
100.0	1.8194	3.4	414.7	376.6	339.1	302.2	265.8	229.9	194.5	193.4	192.4	191.4
110.0	1.8037	3.5	439.9	397.3	355.4	314.3	273.6	234.0	194.7	193.6	192.6	191.6
120.0	1.7879	3.6	465.8	418.5	372.1	326.7	282.0	238.1	194.9	193.9	192.8	191.8
130.0	1.7718	3.7	492.3	440.2	389.2	339.3	290.3	242.3	195.1	194.1	193.0	192.0
140.0	1.7556	3.8	519.5	462.4	406.7	352.2	298.0	246.6	195.3	194.3	193.2	192.2
150.0	1.7391	3.9	547.5	485.2	424.5	365.3	307.5	250.9	195.5	194.5	193.4	192.4
160.0	1.7225	4.0	576.2	508.5	442.7	378.7	315.9	255.4	195.7	194.7	193.6	192.6
170.0	1.7056	4.1	605.6	532.4	461.4	392.4	325.3	259.9	196.0	194.9	193.8	192.8
180.0	1.6885	4.2	635.9	556.9	480.5	406.4	334.4	264.4	196.2	195.1	194.1	193.0
190.0	1.6711	4.4	667.1	582.1	500.1	420.7	344.0	269.1	196.4	195.3	194.3	193.2
200.0	1.6535	4.5	699.2	607.9	520.1	435.3	353.8	273.8	196.6	195.5	194.5	193.4
210.0	1.6357	4.7	732.2	634.5	540.6	450.3	363.8	278.6	196.8	195.7	194.7	193.6

NAK VOLUME EXCEEDS 180 GALLONS

APPENDIX G

COST ESTIMATE DETAILS

EG&G Idaho, Inc.

Detailed Cost Estimate CONCEPTUAL (Type of estimate, ie., conceptual, Title I, etc.)

Date 2-25-86

Page 1 of 6

Project or Description ARVFS Nat DEP

Location INEL Requested By D.M. LARAE

SOURCE OF ESTIMATE
(E) Engr Est.
(V) Vendor
(P) Pur Order
(H) Handbook Ref

Prep By A.R. MILLARD

Chk'd/Appr'd By

FORM EG&G 668 (Rev 12-78)

SUMMARY SHEET 2000 ACCT.

Acct No.	Description	Source	Material Quantity & Units	Mat'l Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
SUB	TOTALS PAGE # 2					974		15,334	38,200		53,534
SUB	TOTALS PAGE # 3					430		17,630	45,600		63,230
SUB	TOTALS PAGE # 4					540		22,140	35,400	55,000	112,540
SUB	TOTALS PAGE # 5					160		6560	20,000		26,560
SUB	TOTALS PAGE # 6					208		8528	170,400		178,928
	TOTAL LABOR & MAT'L COST					1712		70,192	309,600	55,000	434,792
	SITE CRAFT PRODUCTIVITY FACTOR @ 25% OF 1712 = 428 X 41										17,548
	SITE PLANNING & SCHEDULING (SUPERVISION) @ 20% CRAFT LABOR 428 X 43 =										18,404
	TOTAL CONSTRUCTION COST OF 2000 ACCT										470,744
										USE	470,000

EG&G Idaho, Inc

FORM EG&G 568A
(Rev. 12-82)

DETAILED COST ESTIMATE (CONT. SHEET)

Project or Description ARVES Nat DED

Date 2-12-86

	Description	Material Quantity & Units	Material Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
7000	PRESSURE TRANSMITERS	8 EA	1000		64	41	2624	8000		10,624
	WIRING & PIPING	8 EA	200		40	41	1640	1600		3240
	TEMP. TRANSMITERS	10 EA	1200		80	41	3280	12,000		15,280
	WIRING	10 EA	200		50	41	2050	2000		4050
	TEMP ALARM	4 EA	1000		24	41	984	4000		4984
	WIRING	4 EA	200		20	41	820	800		1620
	LEVEL TRANSMITTER	2 EA	2000		16	41	656	4000		4656
	WIRING	2 EA	200		16	41	656	400		1056
	LEVEL ALARM	2 EA	1200		16	41	656	2400		3056
	WIRING	2 EA	200		16	41	656	400		1056
	PRESSURE SWITCH	1 EA	1200		8	41	328	1200		1528
	WIRING & PIPING	1 EA	200		8	41	328	200		528
	TEMPERATURE SWITCH	1 EA	1000		8	41	328	1000		1328
	WIRING	1 EA	200		8	41	328	200		528
	SUB TOTAL				374		15,334	38,200		53,534

EG&G Idaho, Inc

FORM EG&G 588A
(Rev. 12-82)

DETAILED COST ESTIMATE (CONT. SHEET)

Project or Description ARVES NaK R&D

Date 2-12-86

	Description	Material Quantity & Units	Material Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
7000	ELECT. OPER. VALVES	17 EA	1200		50	41	2050	29,400		22,450
	WIRING	17 EA	200		80	41	5280	3400		6,680
	PRESSURE OPERATED VALVES	8 EA	1600		24	41	984	12,800		13,784
	PIPING	8 EA	200		64	41	2624	1600		4224
	CHECK VALVES	7 EA	300		24	41	984	2100		3084
	PROCESS PIPING									
	1" SS	100 LF	11		40	41	1640	1100		2740
	½" SS	40 LF	10		20	41	820	400		1220
	FLOW INDICATORS	2 EA	1200		16	41	656	2400		3056
	PIPING & WIRING	2 EA	200		32	41	1312	400		1712
	CHLORINE PIPING	ALLOW	500		40	41	1640	500		2140
	COOLANT WATER PIPING	ALLOW	500		40	41	1640	500		2140
	SUB TOTAL				430		17,630	45,600		63,230

EG&G Idaho, Inc

FORM EG&G 588A
(Rev. 12 82)

DETAILED COST ESTIMATE (CONT. SHEET)

Project or Description ARMS NAK DED

Date 7-18-86

Page 4 of 6

	Description	Material Quantity & Units	Material Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
7000	RAMS & CAMS	ASSUME:	SITE	SPARES	CAN	BE	USED			
	OUTLETS	ALLOW	200		40	41	1640	200		1840
	CHLORINE & CAUSTIC METAL	DETECTION	SYSTEM	EQUIP-	ASSUME:	—				
	SAME as RAMS & CAMS									
	OUTLETS	ALLOW	200		40	41	1640	200		1840
	FIRE FIGHTING EQUIP	ASSUME:	SITE	SPARES						
	ELECTRIC GENERATOR	2EA	ALLOW						2000	2000
	CONTROL ROOM	1EA	ALLOW						5000	5000
	REST ROOM	2EA	ALLOW						1000	1000
	AREA LIGHTING	ALLOW							1000	1000
	POTABLE WATER	ALLOW							1000	1000
	PROCESS CONTROL SYSTEM	ALLOW							10,000	10,000
	SKID's	ALLOW	FOR	4	EA				35,000	35,000
	CONTROL PANEL w/INST.	ALLOW	35,000		460	41	18,860	35,000		53,860
	SUB TOTAL				540		22,140	35,400	55000	112,540

EG&G Idaho, Inc

FORM EG&G 588A
(Rev. 12-82)

DETAILED COST ESTIMATE (CONT. SHEET)

Project or Description ARVFS NaK PED

Date 7-21-86

	Description	Material Quantity & Units	Material Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
700	VACUUM PUMP FILTER	1EA	2000		16	41	656	2000		2656
	NaK FILTER	3EA	3000		48	41	1968	9000		10968
	NaK PUMP	1EA	2000		16	41	656	2000		2656
	CHLORINE PUMP	1EA	2000		16	41	656	2000		2656
	WATER PUMP	1EA	500		16	41	656	500		1156
	VACUUM PUMP	1EA	1000		16	41	656	1000		1656
	CHLORINE VAPORIZER	1EA	2000		16	41	656	2000		2656
	WATER COOLER	1EA	1500		16	41	656	1500		2156
	SUBTOTAL				160		6560	29000		26560

EG&G Idaho, Inc

FORM EG&G 588A
(Rev. 12-84)

DETAILED COST ESTIMATE (CONT. SHEET)

Project or Description ARVES NaK R&D

Date 7-21-86

	Description	Material Quantity & Units	Material Unit Cost	Unit Labor Hours	Total Labor Hours	Labor Rate	Labor Cost	Material Cost	Other Cost	Total Cost
3000	SECONDARY CONTAINMENT	YEA	27,000		32	41	1312	108,000		109,312
	NaK REACTOR	LEA	44,000		16	41	656	44,000		44,656
	CHLORINE SURGE TANK	LEA	15,000		16	41	656	15,000		15,656
	WATER SURGE TANK	LEA	3400		16	41	656	3400		4056
	TRANSPORT FROM ASSEMBLY AREA TO R&D AREA	ALLOW			48	41	1968			1968
	FIELD WELDING	ALLOW			80	41	3280			3280
	SUBTOTAL				208		8528	170,400		178,928
4000	CLEAR & GRUB	ALLOW							20,000	20,000

EG&G Idaho, Inc

FORM EG&G 107 (10/83)

ESCALATION SHEET

Project or Description ARVES NAT RED

Location INEL Requested By R. M. LARUE

Date 7-23-86

Page 1 of 1

Prep. By AR MILLWARD

Chk'd/Appr'd By

Fiscal Years	86	87	88	89	90	91
Calendar Years	88	87	88	89	90	91
Total Period						
Title I, II			USE	4 %		
Title III			USE	5 %		
Construction Period						
Labor						
Material and Subcontracts						
Equipment						
Indirects						
PM						
CM						
FE						

TIME NOW

Equipment	3.7	4.7	5.2	5.2	5.5	5.4
Material	3.7	4.7	5.2	5.2	5.5	5.4
Labor	4.1	5.6	6.0	6.1	6.4	6.2
Indirects	4.1	5.6	6.0	6.1	6.4	6.2
I. II.	4.6	5.6	6.0	6.2	6.3	6.2
III.	4.6	5.6	6.0	6.2	6.3	6.2
PM—CM—FE	4.6	5.6	6.0	6.2	6.3	6.2