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INFORMAL REPORT

FINAL

FUNCTIONAL AND OPERATIONAL DESIGN REQUIREMENTS FOR DECONTAMINATION AND DECOMMISSIONING OF THE EBR-I MARK-II NAK

(Project File No. 015163)

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FUNCTIONAL AND OPERATIONAL DESIGN REQUIREMENTS FOR DECONTAMINATION AND DECOMMISSIONING OF THE EBR-I MARK-II NaK

(PROJECT FILE NO. 015163)

SEPTEMBER 28, 1987

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FUNCTIONAL AND OPERATIONAL DESIGN REQUIREMENTS FOR DECONTAMINATING AND DECOMMISSIONING OF THE EBR-I MARK-II NaK

1. INTRODUCTION

Approximately 180 gal of sodium/potassium (NaK) eutectic liquid metal were severely radioactively 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 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 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 amount of radioactive material contained in the NaK (Appendix A) is estimated to be less than 30 g. The NaK may also contain some nonradioactive core debris.

This document presents the Functional and Operational Requirements (F&ORs) for the D&D of the contaminated NaK and the ARVFS bunker site.

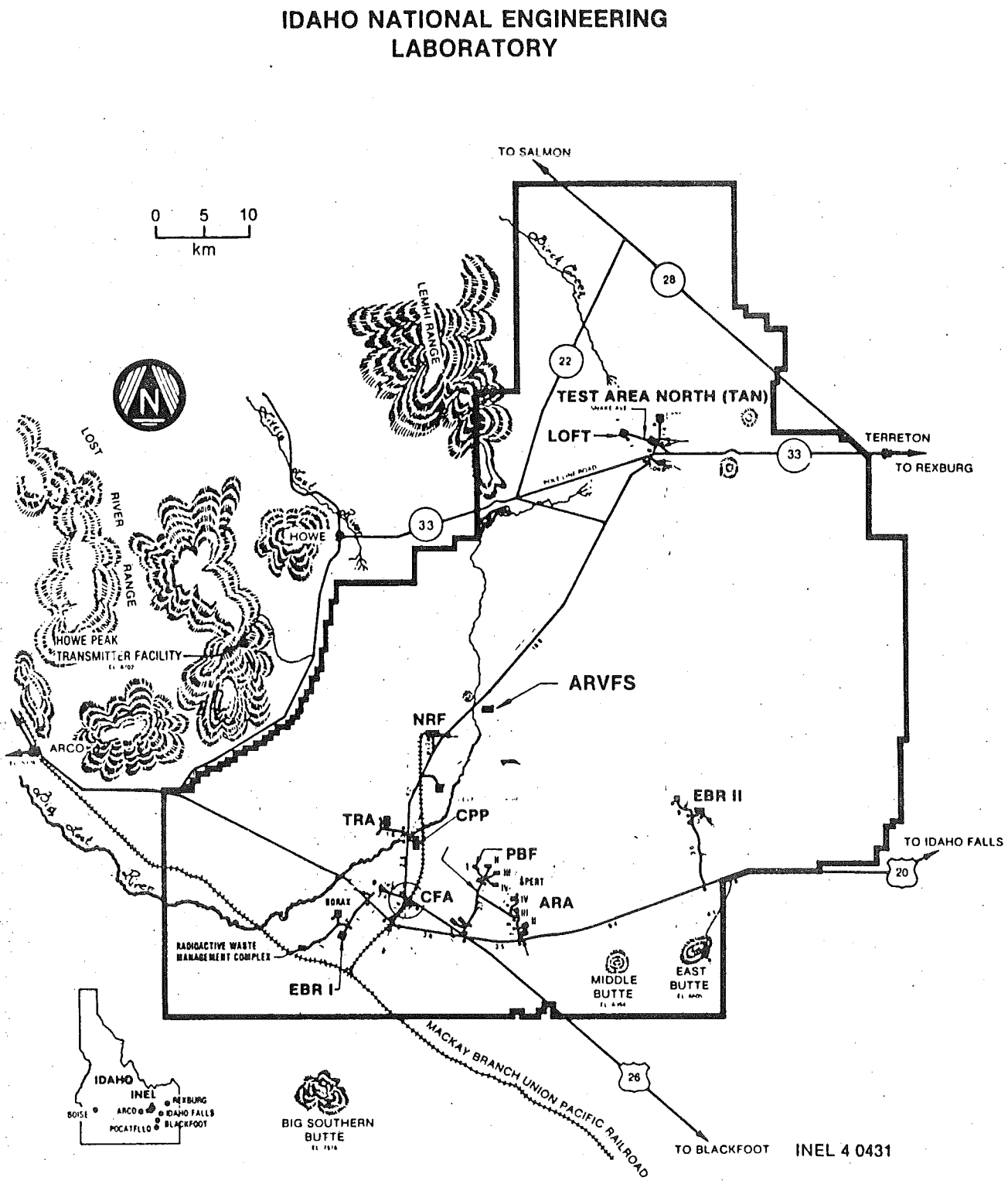

Figure 1. Map of INEL showing the location of ARVFS.

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

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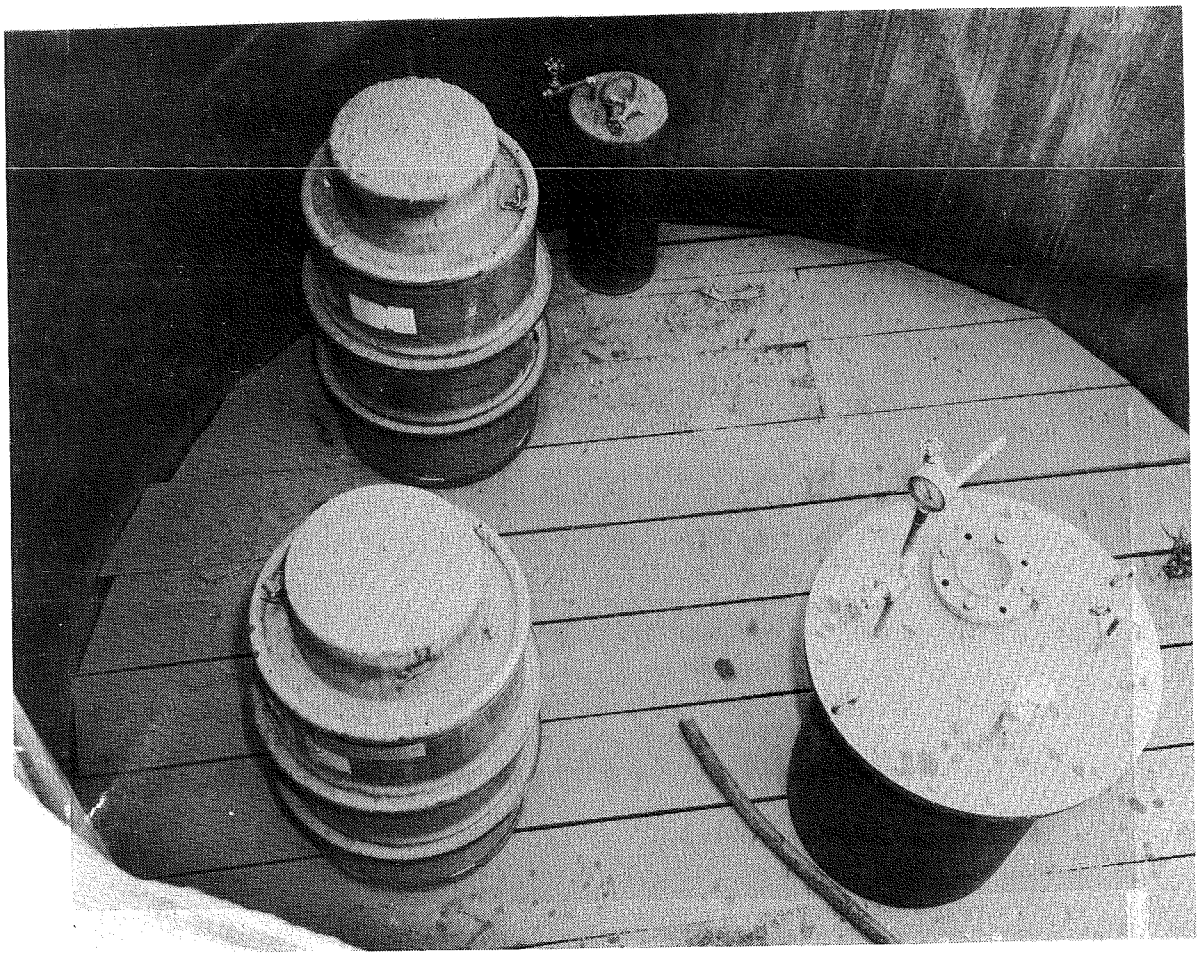

Figure 3. Four containers of contaminated NaK in storage pit at the INEL EBR-I site from 1955 to 1974. 73-3533

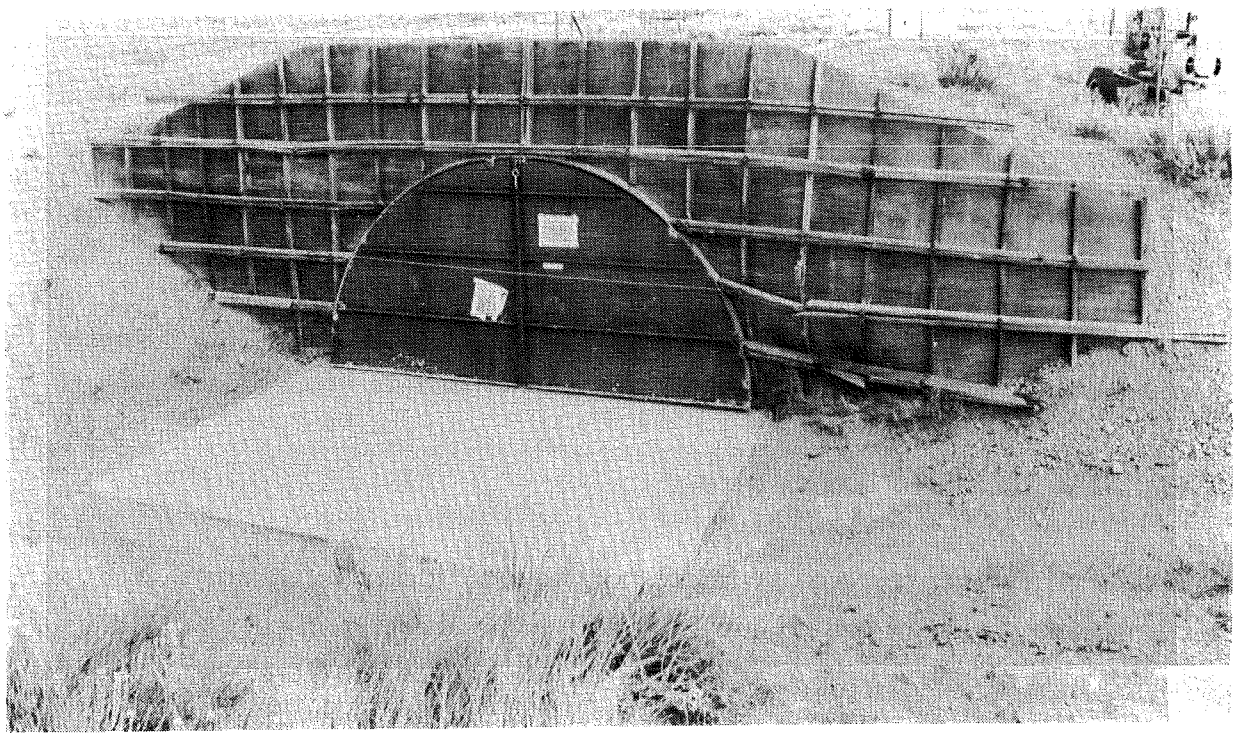

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Figure 4. AVRFS bunker.

2. PROJECT OBJECTIVES

The objectives of this project are as follows:

1. Chemically deactivate the NaK.

2. Dispose of the radioactively 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; and they 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 ARVFS NaK, which is now considered a significant potential hazard, will be removed from the Surplus Facilities Management Program priority listing of projects.

3. FACILITY DESCRIPTION

3.1 Physical

The physical description of the NaK containers and of the 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 knowledge exists as to the internal condition of the NaK containers. Several attempts over the years since the 1955 incident have been unsuccessful in locating engineering drawings for the two fabricated NaK containers. 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 inches 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 does not have electrical or water service. However, a 132-kva line runs past the site, 1/4 mile to the east and USGS water well 17 is 1/2 mile to the west. 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.

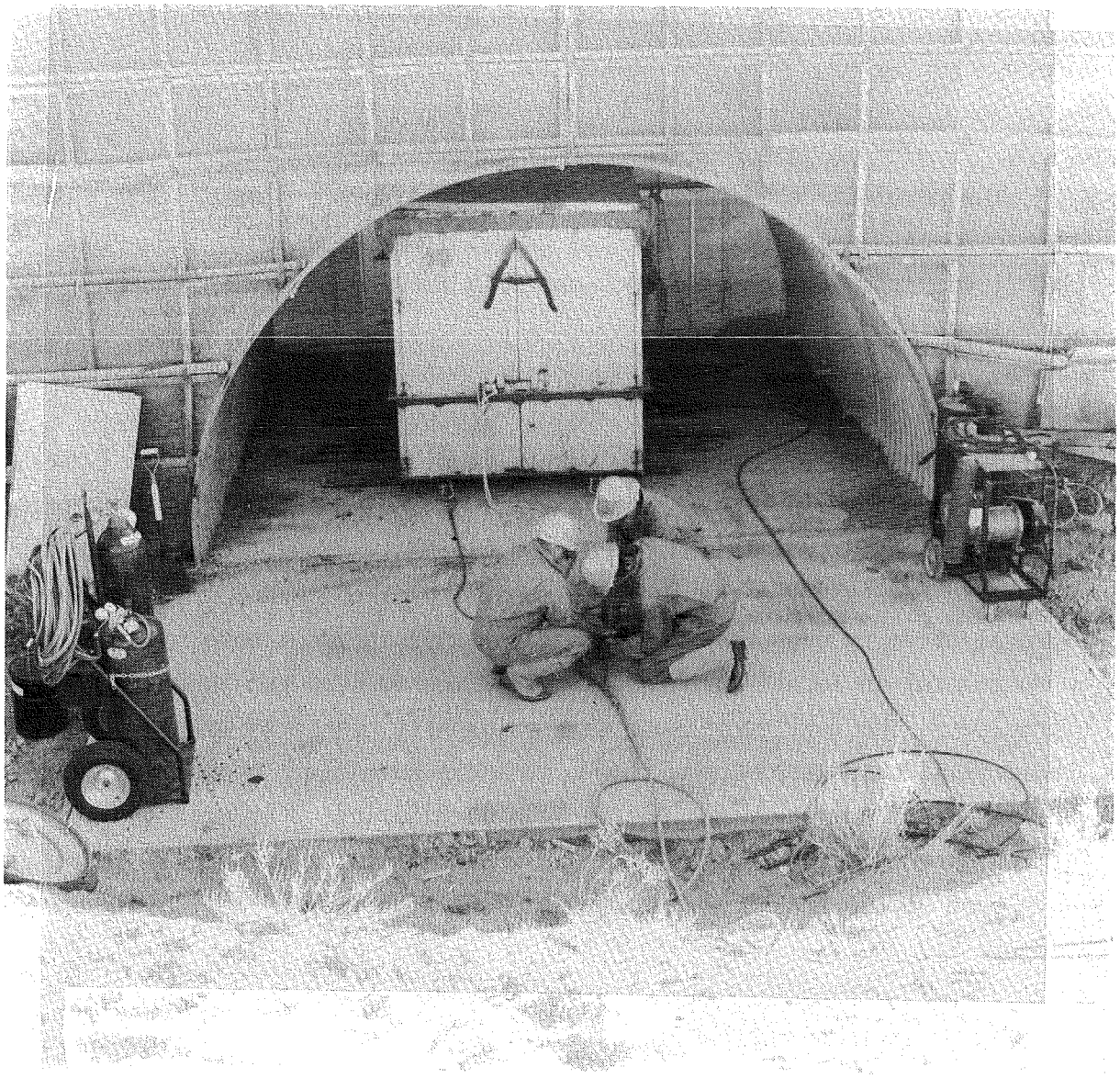

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Figure 5. Dumpster containing NaK drums and containers in ARVFS bunker.

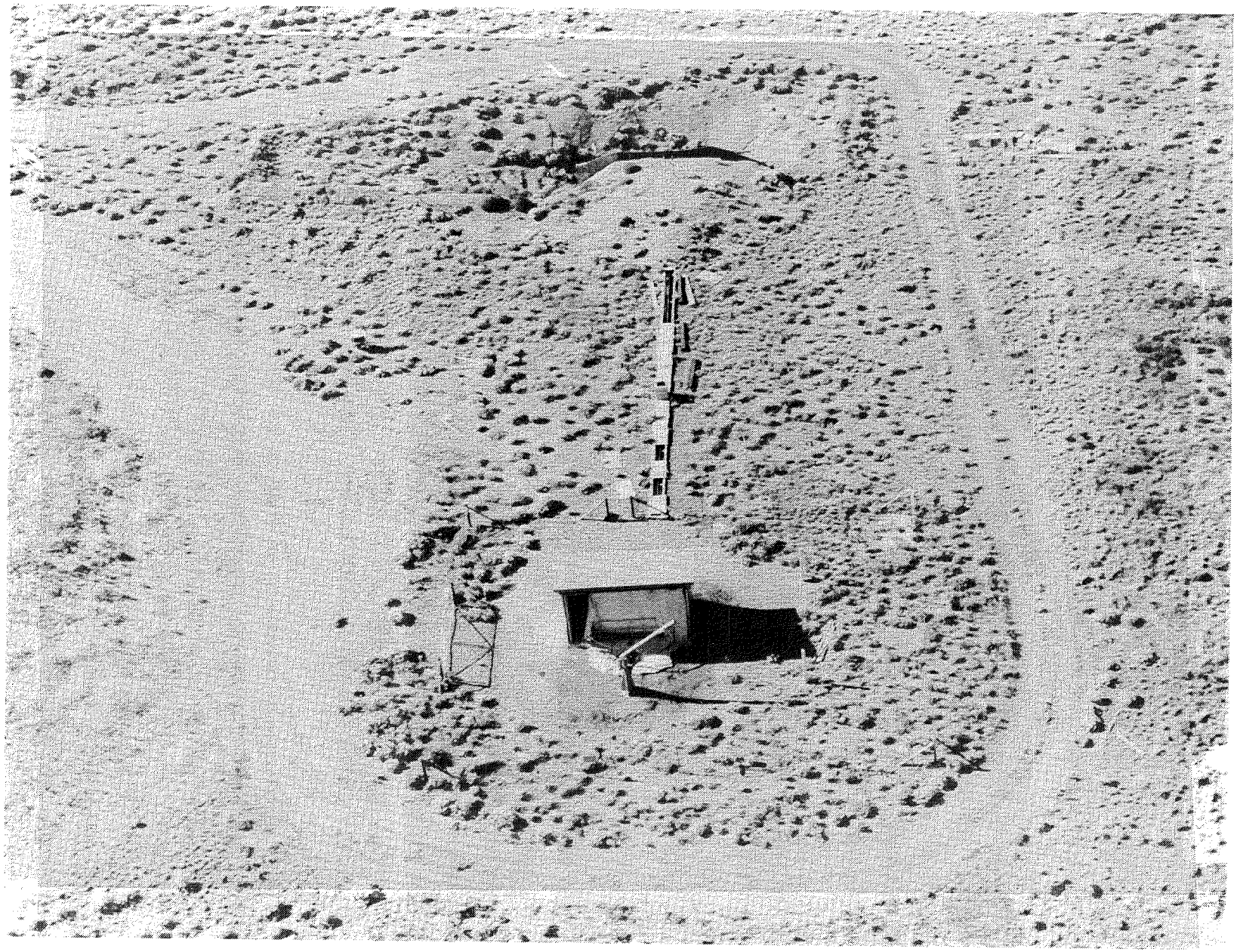

Figure 6. Aerial view of ARVFS looking to the west. 83-574-11-3

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

The cylindrical test pit is an open-top vessel made of 1/4 inch A-36 structural steel. It has an inside diameter of 12 feet and is 16 feet 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). The hand operated crane, located in front of the shed, has since been removed and excessed. The metal shed is 9 by 17 feet and about 8 feet high. The open side has been covered with a wood frame and plastic cover.

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

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 the 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 on reactant materials present.

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.

Figure 7. Metal shed covering test pit. 83-476-2-9

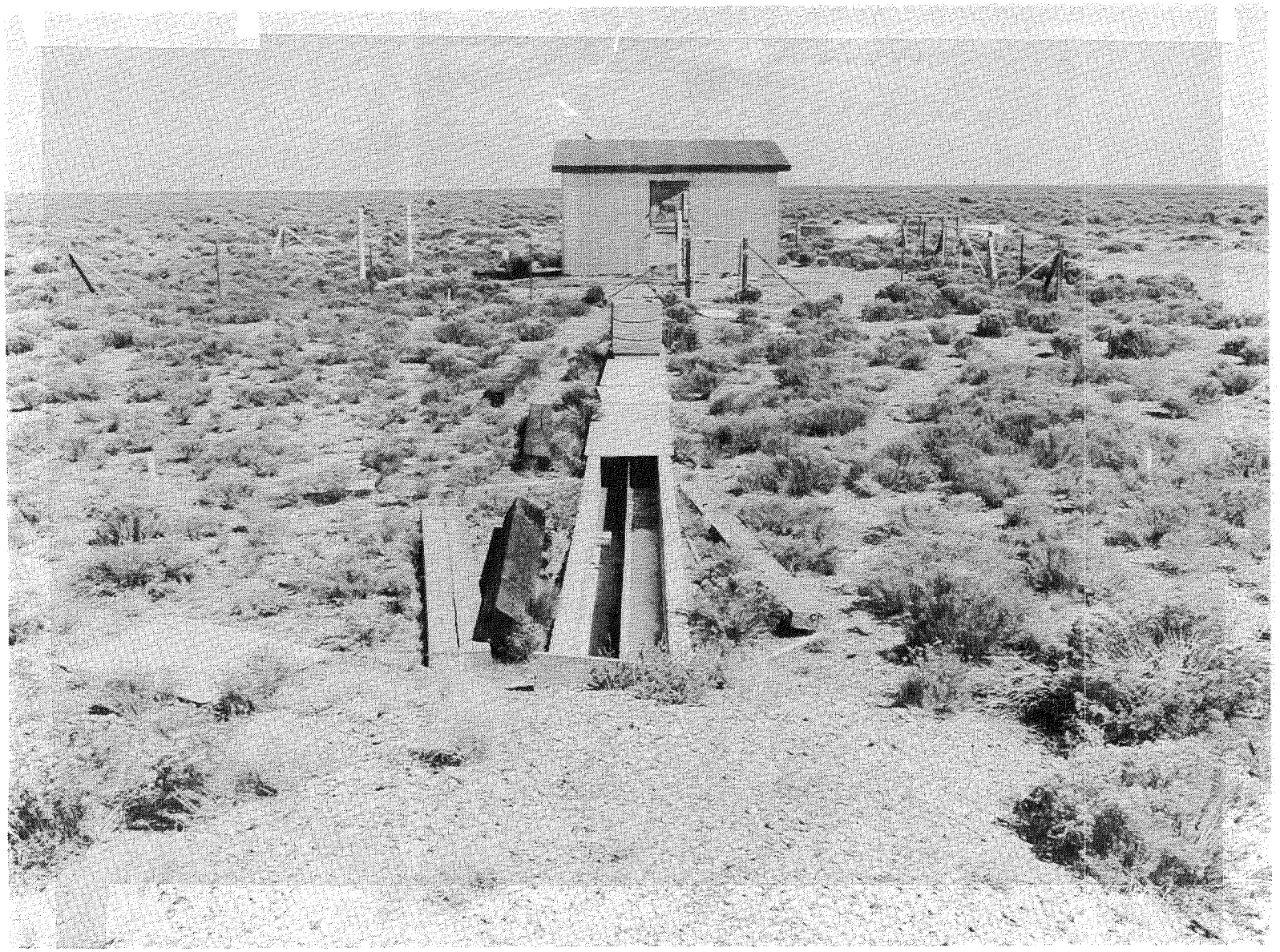

Figure 8. Metal shed and cable trench at ARVFS looking east. 83-476-2-8

It is possible that air has leaked into one or more of the containers since their original containment. If air has entered the containers, oxygen would have reacted with the potassium present to form potassium superoxide, potassium peroxide, and potassium oxide. The sodium would have reacted to form sodium oxide. The sodium and potassium oxides, which are essentially inert, could have crystallized in such a manner that the KO_2 and KO would become isolated from the bulk of the NaK. This isolation could be broken with movement or vibration of the containers. If the superoxides are present, they could react as described in previous paragraphs if brought into sudden and immediate contact with the NaK.

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 EDF's 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 on 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.

4. FUNCTIONAL REQUIREMENTS

This project consists of building a processing system to chemically deactivate the EBR-I Mark-II NaK with chlorine gas to produce sodium chloride (NaCl) and potassium chloride (KCl) salts. The processing system shall include the necessary equipment to enclose the NaK containers and remotely penetrate the NaK containers to allow for the processing of NaK. In support of the process system will be equipment for handling the drums prior to NaK processing and equipment for reducing and handling of the system components after processing is completed.

The processing system shall be designed so that, at the completion of the NaK processing, the system can be dismantled and chemically deactivated of any residual NaK before its disposal as radioactively contaminated equipment. The system shall 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.

The final phase of this project will be to D&D the ARVFS bunker area and return it to a contamination/radiation free area. The degree of general area restoration (i.e. cable trench, shed, and pit removal) will be determined later in the project.

Because of the radiological hazard associated with this project, the processing system shall be remotely/automatically controlled and operated to the degree reasonably possible.

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

5. OPERATIONAL REQUIREMENTS

The process system operating and control parameters cannot be specified at this time. These parameters will be generated during design using information derived from empirical work performed in FY-1987.

Once initiated, the NaK processing involving a single drum will be continuous (24 hr/day) until the processing of the NaK in that drum is complete . The system shall therefore be designed for continuous operation. Should an unlikely event occur requiring system shutdown, design provisions shall be incorporated to allow for safe shutdown and restart.

At the completion of the NaK processing, all equipment associated with the processing shall be removed from the ARVFS area. All radionuclide contaminants shall be removed from the ARVFS area thereby eliminating any radiation exposure to the general public or INEL personnel. All hazardous materials shall be removed from the ARVFS area and dispositioned as required according to the specific hazard involved.

The following subparagraphs address the general operational and equipment requirements that can be identified at this point in the project.

5.1 Ancillary Systems

There are no services available at the ARVFS bunker site.

Office, control room, lunchroom, and restroom space shall be provided by the short term rental of a trailer. The control trailer will be located behind an earthen berm and sufficiently far from the processing area to ensure minimal radiological exposure to operating personnel. Human wastes will be stored temporarily on site during operations and then transported to Central Facilities Area (CFA) for waste treatment.

Potable and service water shall be brought in and stored at the ARVFS site.

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

During all operations, the ARVFS bunker area will be closed to all but necessary personnel. The road to the bunker will be posted with American Protective Services (APS) personnel to ensure that unnecessary personnel are not permitted in the area.

5.2 NaK Drum Handling Equipment

The drums containing the NaK will be removed from the ARVFS bunker and placed into secondary containment. This operation shall be accomplished using existing INEL mobile cranes and rigging equipment where possible. To reduce the possibility of a superoxide/NaK reaction, vibration and shock to the NaK containers shall be minimized during the drum handling phase.

5.3 Secondary Containment

The secondary containment vessel(s) will house the NaK containers. The vessel(s) will be evacuated and then purged with argon gas prior to remote penetration of the NaK containers. The vessel(s) shall provide a sealable and leak tight enclosure for controlling the gas environment around the NaK containers during the NaK processing. The vessel(s) shall be designed to enclose a potential potassium superoxide/NaK thermite type reaction to prevent contaminated materials from being introduced into the environment. Because of the potential of superoxide/carbon reactions, the vessel(s) shall be free of all grease and oil and shall not use any organic components (e.g. gasketing materials, wire insulation). Vessel material selection must take into account the chlorine gas environment the vessel will be subjected to.

The secondary containment vessel(s) will interface with the drum handling equipment, the vacuum system, the air, argon, and chlorine systems, the drum penetration system, the NaK filtering system, and the NaK metering system. The vessel(s) shall be temperature and pressure monitored during the NaK processing.

5.4 Vacuum System

The vacuum system shall provide the capability to evacuate air, argon, chlorine gas or any combination of these gases from the secondary containment vessel(s), the metering system, and the reaction vessel. The evacuated gases shall be filtered prior to being vented through a vessel/tank containing a sodium hydroxide (NaOH) solution. The gases that will then be exhausted to the atmosphere will be air, argon, oxygen, and hydrogen.

5.5 Air, Argon, and Chlorine Systems

The air system shall provide the capability to meter/control air flow. The system shall be designed to feed the required amount of air to the secondary containment(s), the filtering system, the metering system, and the reaction vessel.

The argon system shall provide the capability to meter/control argon gas flow. The system shall be designed to feed the required amount of argon to the secondary containment(s), the filtering system, the metering system, and the reaction vessel.

The chlorine injection system shall provide the capability to vaporize liquid chlorine and meter/control gaseous chlorine flow. The chlorine injection system shall be designed to feed the required amount of chlorine gas to the secondary containment(s), the filtering system, the metering system, and the reaction vessel within a time span of one minute.

5.6 Drum Penetration System

The drum penetration system includes equipment required to remotely penetrate the NaK drum and allow the NaK to drain out of the drum. This operation will be accomplished inside the argon filled secondary containment. Proof of principle testing for this system was completed in FY-87 and is documented in EDF NAK009 (Appendix D).

5.7 NaK Filtering System

The NaK filtering system shall be capable of removing particulate material (size to be determined) from the liquid NaK prior to the NaK being introduced into the reaction vessel. The filtering medium shall be redundant to avoid clogging and the system shall be capable of filtering all 180 gal of NaK with the consideration that the filtering medium may not be accessible once processing begins. The system will interface with the secondary containment(s), the metering system, and the reaction vessel. Portions of the system that come in contact with the NaK must also be capable of functioning in the argon and chlorine environments that will be present.

5.8 NaK Metering System

The NaK metering system shall be capable of measuring a given quantity (amount to be determined) of NaK and delivering that quantity to the reaction vessel. The system shall be remotely operable and capable of processing the 180 gal of NaK. The system will interface with the filtering system and the reaction vessel. Portions of the system that come in contact with the NaK must also be capable of functioning in the chlorine environment that will be present.

5.9 NaK Reaction Vessel

The NaK reaction vessel shall provide the containment necessary to safely confine the chemical reaction between the NaK and chlorine gas. The vessel shall be capable of handling the processing of all 180 gal of NaK without loss of structural integrity. The vessel shall be designed so that after the NaK processing, when it is filled with processed salts and grout, it will be capable of being shipped to and acceptable for burial at WIPP. The vessel shall have the necessary penetrations and connections to interface with the argon and chlorine systems, the vacuum system, and the metering system. The reaction vessel shall be instrumented for internal temperature and pressure with these conditions remotely monitored and recorded at the temporary control facility. External heating and cooling of the vessel shall be provided. The attachments to the vessel for this heating and cooling shall be removed prior to shipment of the vessel to WIPP.

5.10 Grouting System

The grouting system shall provide the capability to inject a grout into the secondary containment(s), the filtering system, and the reaction vessel. The system shall be remotely operated with hands on contact with contaminated/radioactive equipment minimized.

5.11 Electrical Power, Lighting, and Process Control

Electrical power shall be provided by portable electric generators. Power shall be available for process operations, control trailer requirements, and area lighting. Power generation shall be redundant with immediate backup capability should failure to the primary system occur. Battery backup may be necessary depending on the control systems designed and how critical the need for uninterrupted power may be.

Temporary/portable area lighting shall be provided. This lighting shall be adequate to provide a safe working environment when natural light is not available.

The NaK system processing will be controlled (manually/automatically) from a microprocessor system located in the control trailer.

5.12 Building/Civil

The process equipment shall be housed in a temporary building/shed. The building/shed shall be adequate to provide protection against normal wind, rain, and dust conditions.

The immediate grounds have previously been disturbed. Current mounds/piles of dirt may have to be moved to provide appropriate work areas. Earthen berm(s) shall be formed for shielding purposes for the control trailer and any other work areas as required.

5.13 Safety Equipment

Continuous air monitoring (CAM) and remote area monitoring (RAM) equipment shall be used in the area of the processing equipment. The quantity, type, and location of these components shall be specified by EG&G Safety (Health Physics).

Chlorine and caustic metal detection equipment shall be used in the area of the processing equipment. The quantity, type, and location of these components shall be determined during design.

Fire fighting equipment for NaK, chlorine, and general fires shall be provided during operations. Fire fighting equipment shall be specified during design by EG&G Idaho Safety and the INEL Fire Department. Personnel training required shall be provided by these two organizations.

Two way radio communications shall be available in the control trailer at all times when personnel are present in the work area. Communications made will be to notify INEL organizations, should an emergency occur that requires assistance (e.g. ambulance service).

6. 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.

7. 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 personnel, Quality, Safety, Procurement, Planning and Budgets, Security, and Radioactive Waste Management Complex (RWMC).

8. SITUATIONS REQUIRING SPECIAL CONSIDERATION OR ATTENTION

8.1 Access and Security Access

The ARVFS bunker is located in a portion of the INEL not under special access control. During operations, INEL security will control road access to the bunker area to restrict entrance except to necessary personnel.

8.2 Reaction Vessel

It is anticipated at this time that the reaction vessel will be procured from an outside vendor. The finalization of the vessel requirements, envelope and specification must proceed quickly and with priority in order to have the least impact on the project schedule.

8.3 Quality Level

All components for this project are quality level B. Special quality inspection instructions may be required for certain components. These requirements will be specified during design and included in the appropriate procurement packages.

8.4 Long Lead Items

Procurement time for the reaction vessel is anticipated to be three to twelve months. No other items are anticipated to require more than two months to procure.

8.5 Safety Items

Special considerations should be given to location of all safety related equipment. In particular, since the processing will not take place in a containment facility, all radiological and hazardous materials detection equipment should be located to accommodate the prevailing wind patterns.

The NaK processing will be continuous (24 hr/day) once the processing of a container has begun. Special attention must be given to area lighting to cover the process area, operator routes, and potential emergency routes, should an emergency arise.

The NaK processing will be performed during the time of year when historically the weather is fair and dry. This will be done to minimize the consequences should the unlikely incident of a NaK leak occur. However, because of the remoteness of the area and lack of permanent services, abnormal weather conditions could cause some work delays.

9.0 APPLICABLE DESIGN CODES AND STANDARDS

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

9.1 Department of Energy Codes (Manuals)

1. DOE Order 5480.1, 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

9.2 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

9.3 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. American National Standards Institute, ANSI-C2, "National Electric Code (NEC)"

9. American National Standards Institute, ANSI-C2, "National Electric Safety Code"

10. Uniform Building Code (UBC)

11. American Society of Testing and Materials (ASTM)

9.4 Other

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

2. EG&G Idaho Inc., Safety Manual

3. OSHA 29 CFR 1926.901

4. 18 USC, Chapter 40

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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 Technical 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.

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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.

APPENDIX A

EDF
RADIOLOGICAL HAZARDS

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

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.

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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 periphery. 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.

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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

EDF
CHEMICAL HAZARDS

EG&G Idaho, Inc.

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

ENGINEERING DESIGN FILE

PROJECT FILE NO. 3KNOPNAKO

EDF SERIAL NO. NAK002

FUNCTIONAL FILE NO. 3KNOPNAKE

DATE 1/21/86

PROJECT/TASK NaK Disposal - EBR-II

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.

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AUTHOR	DEPT.	REVIEWED	DATE	APPROVED	DATE
D. M. LaRue	E&PM	John L. Rebentisch	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.

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APPENDIX C

EDF
EXPOSURE ESTIMATES

EG&G Idaho, Inc.

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

ENGINEERING DESIGN FILE

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK004

FUNCTIONAL FILE NO. SRA-10-86

DATE March 31, 1986

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

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AUTHOR	DEPT.	REVIEWED	DATE	APPROVED	DATE
S. R. Adams	S&E Programs	James D. Bailey	4/1/86	DMC for 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	Shielding thickness required to remain in compliance with the EG&G Administrative Dose Guides	
Container (minutes)	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.

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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}

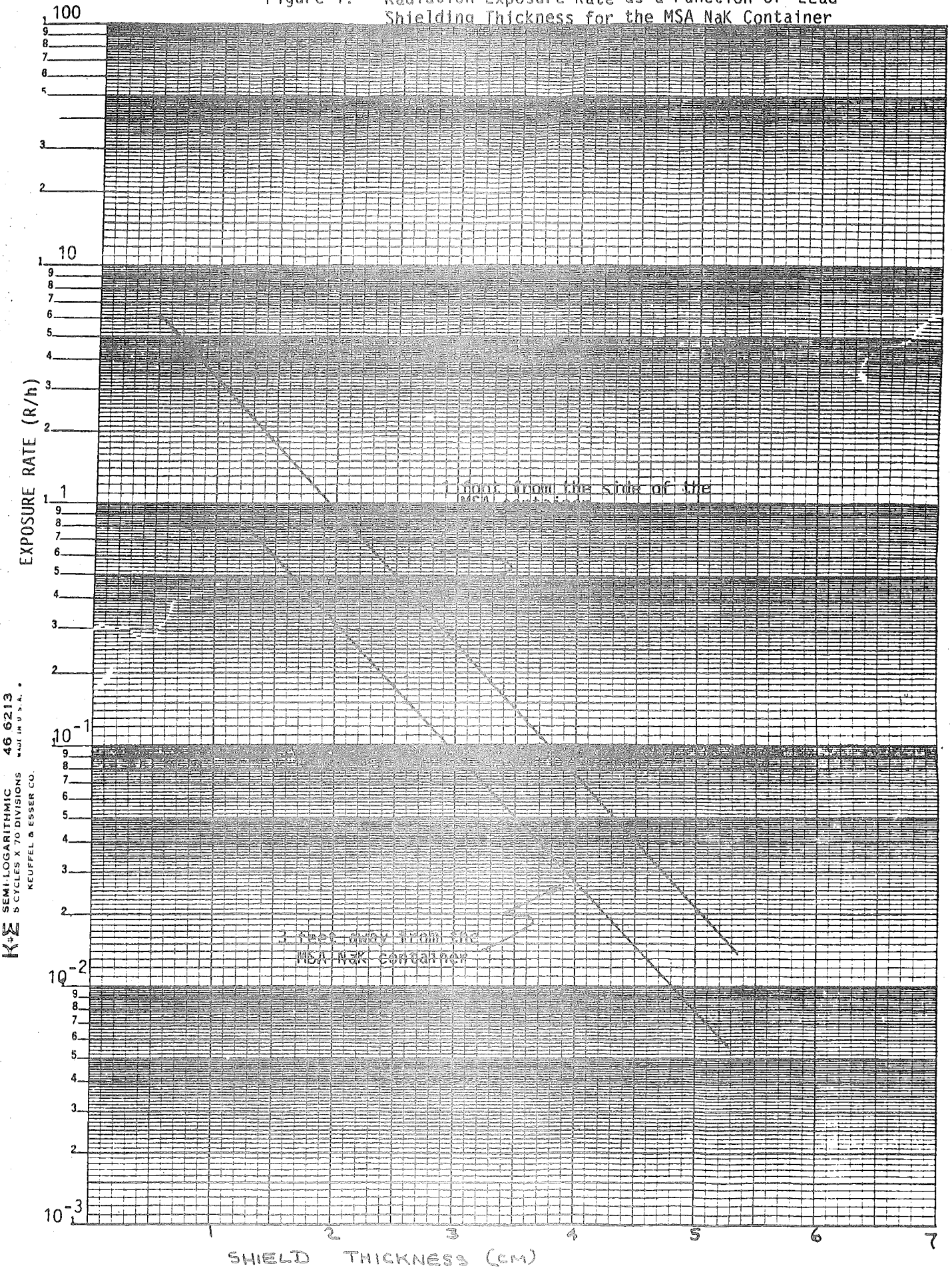
Table 2. Radiation Exposure Rates in the Vicinity of the NaK Containers (R/hour)

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



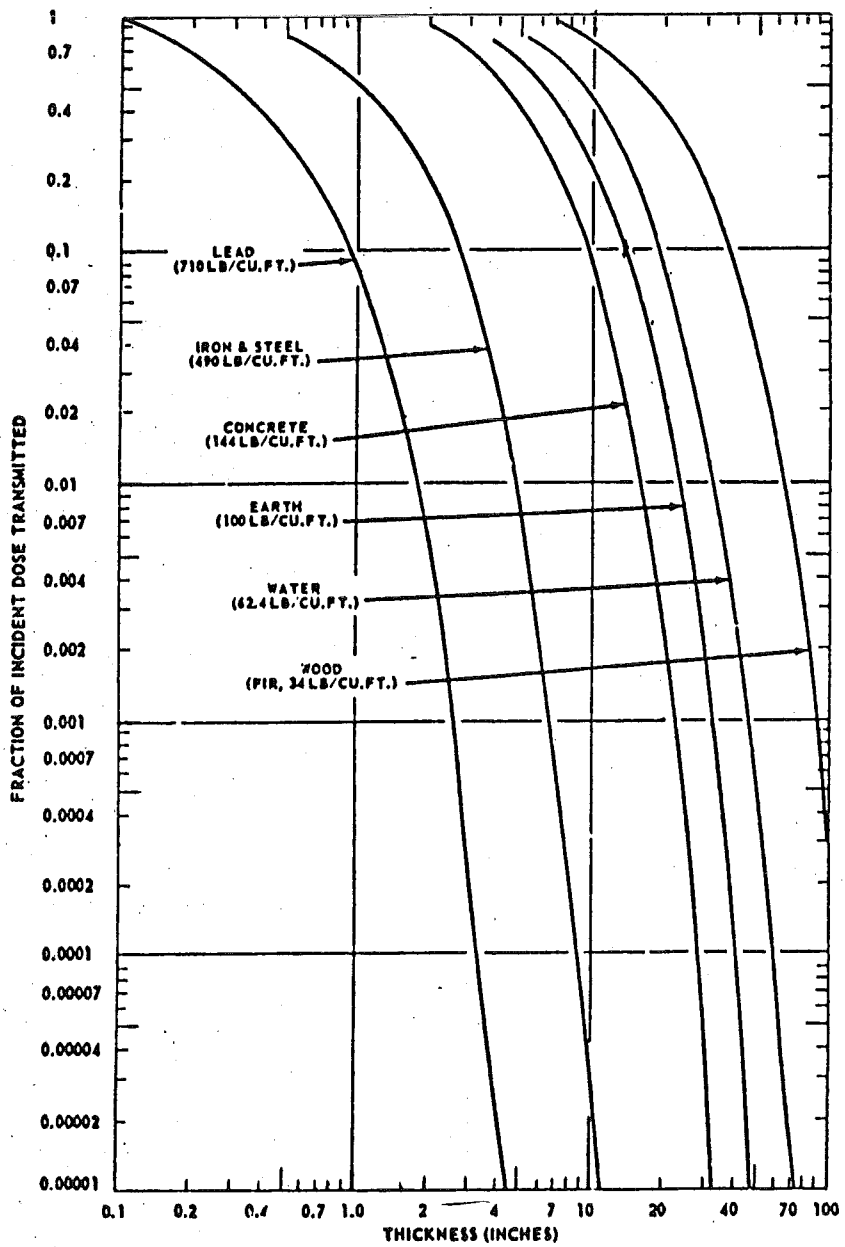
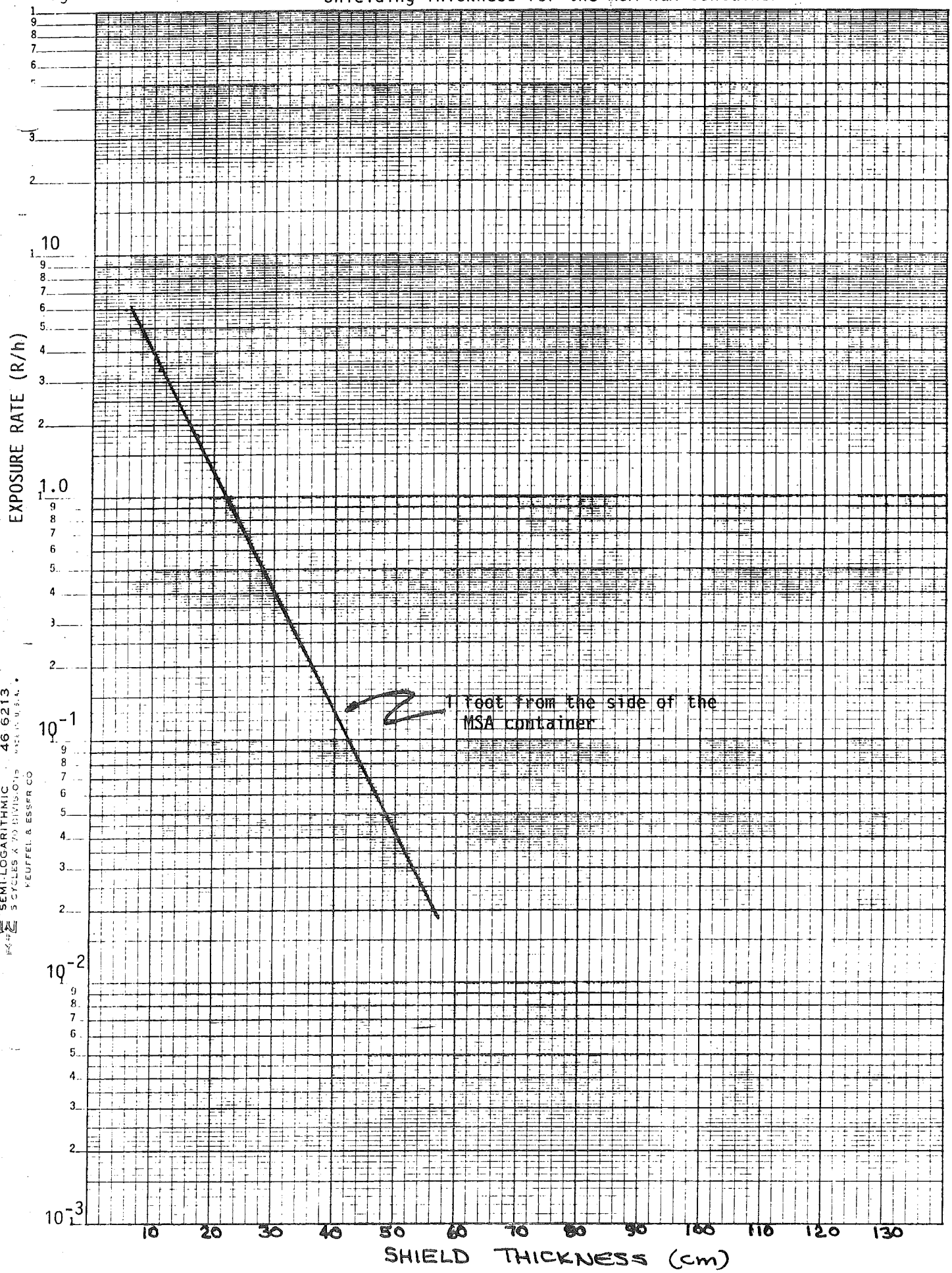


FIGURE 2

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 FA2 CONTAINER #2, TOP OF THE CONTAINER
 $INPUT NEXT=1,
 IGEOM=9,NSHLD=2,JBUF=1,
 WEIGHT(055)=.4822,
 WEIGHT(082)=14.38,
 WEIGHT(084)=14.38,
 WEIGHT(141)=4.6E-3,
 WEIGHT(206)=8.35E-4,
 WEIGHT(269)=6.34E-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 EAE 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(386)=3.69E-3,WEIGHT(403)=.087,
 WEIGHT(419)=1.79E-3,
 IGEOM=7,NSHLD=2,JRUF=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
 $INPUT NEXT=4,X=104.3,$END
```

```
          2
R/H FROM CONTAMINATED NAK IN FAB 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)=8.35E-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)=6.92E-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-3,
 IGEOM=9,
 NSHLD=2,JPUF=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                                                    1
          9                7.3
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 USA 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)=.0004,
 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
```

```
R/H FROM CONTANINATED NAK IN MSA CONTAINER, SIDE OF CONTAINER
 $INPUT NEXT=1,
 IGEOM=7,NSHLD=2,JBUF=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
9 7.3 1

```
R/H AT 1 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=61.,$END
R/H AT 3 FT FROM THE SIDE OF THE CONTAINER
 $INPUT NEXT=4,X=122.,$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

EDF
CONTAINER/PENETRATOR PROOF OF PRINCIPLE

EG&G Idaho, Inc.

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

ENGINEERING DESIGN FILE

PROJECT FILE NO. 015094

EDF SERIAL NO. NAK009

FUNCTIONAL FILE NO

DATE June 24, 1987

PROJECT/TASK

SUBTASK NaK Drum Container and Penetrator

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	[illegible]	6/23/87	[illegible]	6/24/87

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.

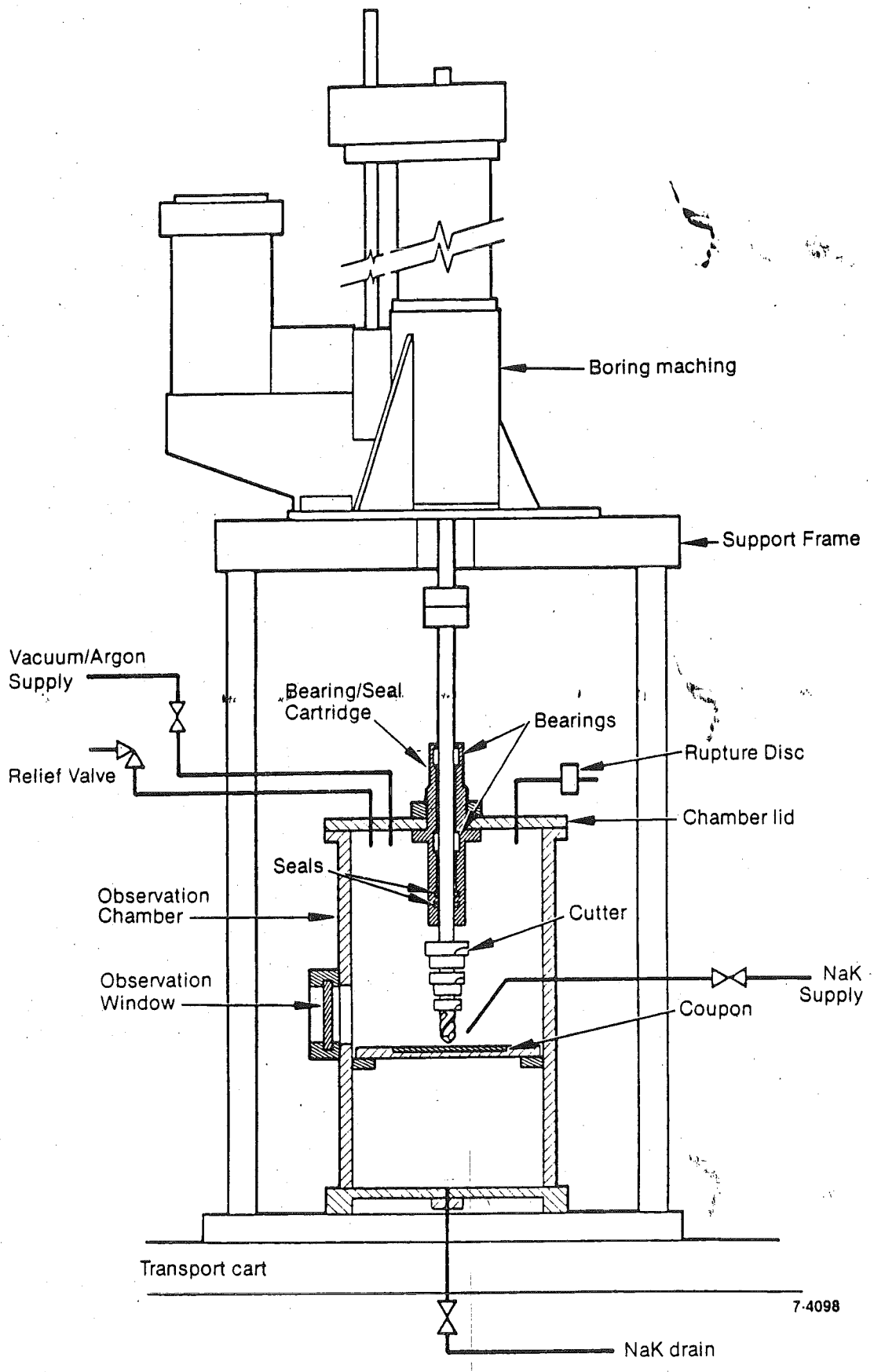

Boring maching
Support Frame
Vacuum/Argon
Supply
Bearing/Seal
Cartridge
Bearings
Rupture Disc
Relief Valve
Chamber lid
Seals
Observation
Chamber
Cutter
Observation
Window
NaK
Supply
Coupon
Transport cart
7-4098
NaK drain

Figure 1