DOE/ORO-2182

Type B Accident Investigation Board Report

May 8, 2004, Exothermic Metal Reaction Event During Sodium Transfer Activities East Tennessee Technology Park Oak Ridge, Tennessee

June 2004

Oak Ridge Operations Office
U.S. Department of Energy

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INDEPENDENT REPORT

This report is an independent product of the Type B Accident Investigation Board (Board) appointed by Gerald Boyd, Manager, Oak Ridge Operations Office, U.S. Department of Energy. The Board was appointed to perform a Type B investigation of the accident and prepare an investigation report in accordance with DOE O 225.1A, *Accident Investigations*.

The discussion of the facts, as determined by the Board, and the views expressed in this report are not necessarily those of the U.S. Department of Energy and do not assume and are not intended to establish the existence of any legal causation, liability, or duty at law on the part of the U.S. Government, its employees or agents or contractors, their employees or agents or subcontractors at any tier, or any other party.

This report neither determines nor implies liability.

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RELEASE AUTHORIZATION

On May 17, 2004, I appointed a Type B Accident Investigation Board to investigate the May 8, 2004, exothermic metal reaction accident that occurred during sodium transfer activities at the East Tennessee Technology Park. The responsibilities of the Accident Investigation Board have been satisfied with respect to this investigation. The analyses and the identification of the contributing causes, the root cause, and the Judgments of Need resulting from this investigation were performed in accordance with DOE O 225.1A, *Accident Investigations*.

I accept the report of the Accident Investigation Board and authorize release of this report for general distribution.

Gerald Boyd, Manager
Oak Ridge Operations Office

Date Accepted: 8/12/04

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TABLE OF CONTENTS

TABLES

FIGURES

ACRONYMS

ALARA	As Low As Reasonably Achievable
AMESH	Assistant Manager for Environment, Safety, Health, and Emergency Management
AU	Assets Utilization
BJC	Bechtel Jacobs Company LLC
BNFL	BNFL Inc.
BOA	Basic Ordering Agreement
Board	Accident Investigation Board
CAP	Corrective Action Plan
CFR	Code of Federal Regulations
Commodore	Commodore Advanced Sciences, Inc.
COO	Chief Operating Officer
COR	Contracting Officer's Representative
Corporate HASP	*Corporate Health and Safety Plan*
CROET	Community Reuse Organization of East Tennessee
DMC	Document Management Center
DOE	Department of Energy
DOT	Department of Transportation
EAL	Emergency Action Level
EH	Office of Environment, Safety and Health
EH-1	Assistant Secretary for the Office of Environment, Safety and Health
EM	Environmental Management
E-mail	Electronic Mail
EMHA	Emergency Management Hazard Analysis
EMHS	Emergency Management Hazard Survey
EOC	Emergency Operations Center
ERO	Emergency Response Organization
ES&H	Environment, Safety, and Health
ETTP	East Tennessee Technology Park
Exothermic Reaction	Exothermic Metal Reaction
FWENC	Foster Wheeler Environmental Corporation
HASP	Health and Safety Plan
ISM	Integrated Safety Management
ISMS	Integrated Safety Management System
IT	IT Corporation
NRC	Nuclear Regulatory Commission
NQA-1	NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations Office

ACRONYMS (continued)

ORO Manual 110	ORO Manual 110, *Oak Ridge Operations Organization Manual*
OSHA	Occupational Safety and Health Administration
PA	Public Address
PPE	Personal Protective Equipment
PSS	Park Shift Superintendent
PWSS	Public Warning Siren System
QAP	Quality Assurance Program
RRAs	Roles, Responsibilities, and Authorities
SAIC	Science Applications International Corporation
SWSA	Solid Waste Storage Area
TEMA	Tennessee Emergency Management Agency
Tetra Tech	Tetra Tech, Inc.
Toxco	Toxco, Inc.
UT-Battelle	UT-Battelle, LLC
Y-12	Y-12 National Security Complex

EXECUTIVE SUMMARY

The Event

On May 8, 2004, at approximately 11:00 am, an exothermic metal reaction (exothermic reaction) accident occurred during heating of surplus activated sodium shields at the East Tennessee Technology Park (ETTP). The work activities were being conducted by personnel of Commodore Advanced Sciences, Inc. (Commodore), a teaming partner with Toxco, Inc. (Toxco). Toxco is a sublessee of the Community Reuse Organization of East Tennessee (CROET) at ETTP and a contractor to the U.S. Department of Energy (DOE) Oak Ridge Operations Office (ORO) under a Task Order for a materials disposition Basic Ordering Agreement (BOA). Toxco's and Commodore's operations were being conducted on a parcel of land at ETTP known as ED-2 (see Figure 1-2).

Commodore personnel were heating sodium metal on May 8, 2004, at the Toxco facility. The sodium metal was contained in an aluminum shield that was 11 feet in diameter and 2.5 feet thick. The shield was constrained by a concrete cradle and four angle iron supports. This configuration was being heated to transfer the material into a Department of Transportation (DOT)-approved container for shipment. The heating process took place in an engineered steel structure described as a "hot box" that was constructed for this purpose. The heating process commenced on May 5, 2004. On May 8, at approximately 10:00 am, as Commodore continued to heat the sodium, personnel standing nearby heard a "pop" and a "whoosh" sound, which was followed approximately an hour later by visual observance of liquid sodium leaking from the hot box. The operators implemented emergency procedures and attempted to stop the flow of sodium by building a dam with an appropriate extinguishing agent, but their efforts were unsuccessful. The sodium subsequently contacted standing rainwater, and an exothermic reaction occurred. Toxco contacted the ETTP Park Shift Superintendent (PSS) and reported that they had a sodium fire at their facility. The PSS dispatched the ETTP Fire Department, Security, and Health Physics personnel to the incident scene.

By 2:00 pm, roadblocks had been established on local access roads, and the adjacent waterway had been secured and blocked. The Emergency Operations Center was declared operational at 2:47 pm. At 3:38 pm, the National Response Center was notified that a reportable quantity of sodium (10 pounds) had been released. Field Monitoring Teams were dispatched to perform field monitoring and environmental sampling to determine the nature and extent of the chemical release at ETTP. The exothermic reaction was allowed to continue until a thick crust of reacted metal had formed and further reaction ceased. Recovery actions began on the afternoon of May 9, 2004.

The ORO Manager, after evaluating the conditions associated with this accident, requested that a Type B Accident Investigation be conducted in accordance with DOE O 225.1A, *Accident Investigations*. The Accident Investigation Board (Board) convened on May 17, 2004, and began investigating the circumstances involving the exothermic reaction to

determine the causal factors associated with the accident and identify Judgments of Need to prevent recurrence.

Background

Commodore is a teaming partner with Toxco, who is a sublessee under one of the CROET leases with ORO and is performing work at the parcel of land known as ED-2 at ETTP. In addition to the subleasing arrangement, Toxco is also a contractor to ORO under a Task Order for a materials disposition BOA. However, this contractual relationship was not understood by all organizational elements due to the work being performed under a BOA and the fact that Toxco was also leasing property through CROET at ETTP. This unique arrangement created confusion, with the result that the Toxco contract was not being managed as a contract with appropriate DOE oversight. The Teaming Agreement between Toxco and Commodore further confused the situation and prevented full flowdown of requirements from the contract or from the sublease.

Bechtel Jacobs Company LLC, (BJC) is the prime contractor to ORO Environmental Management at ETTP. As part of BJC's contractual responsibilities to ORO, BJC's role is one of support to ORO Assets Utilization (AU) rather than a lead role with regard to reindustrialization. However, under the prime contract, BJC has responsibility for environmental restoration, decontamination and decommissioning, and waste treatment and disposal activities. The disposal activities can include dispositioning material through ORO AU.

On January 12, 2000, the Secretary of Energy issued a moratorium on the release of volumetrically contaminated metals into general commerce. The shield in this accident is subject to this moratorium because the shield material, including the aluminum, is activated. This was the first time AU had attempted to disposition volumetrically contaminated metal by executing a contract to transfer the metal to an Nuclear Regulatory Commission (NRC) licensee. Toxco is an NRC Agreement State licensee. The shields were transferred to Toxco for disposition without DOE stipulating controls to preclude release of the metal to general commerce.

Results and Analysis

The accident has resulted in the identification of a number of deficiencies in the ORO safety management systems. Although Toxco was not required to comply with Integrated Safety Management (ISM) under the Task Order, Toxco had written an Integrated Safety Management System description. Therefore, the Board elected to conduct the investigation and document the results and analysis in terms of ISM.

The Contributing Causes of the accident are as follows:

1. ORO line management responsible for project management and contract administration of Toxco's contract did not implement their responsibilities for the sodium heating operations.

2. ORO, BJC, and CROET did not develop a formal program plan that integrates all the management and assessment activities of each organization that affects subleases.

3. ORO's and BJC's feedback processes were inadequate to identify management deficiencies, DOE Order compliance, and communication of information critical to designing the sodium transfer process and understanding the nature and extent of the contamination.

Conclusions

The Board concludes that this accident was preventable. The accident highlighted weaknesses in the five core functions of ISM. The direct cause of the accident was the failure of the secondary containment, which allowed the sodium to escape the hot box and resulted in an exothermic reaction.

The Board identified one Root Cause for this accident: ORO management responsible for the preparation and execution of the lease with CROET and the contract with Toxco did not fully implement their responsibilities, resulting in an accident and evacuation of the public.

The Board's conclusions and the Judgments of Need identified are provided in Table ES-1.

Table ES-1. Conclusions and Judgments of Need

Conclusions	Judgments of Need
The rupture of the sodium shield upon heating was caused by the combination of overfilling in 1971 and the stress induced by the concrete cradle The failure of the secondary containment resulted in the hot box leaking sodium. The nature of this failure cannot be ascertained until the hot box door is opened when recovery operations are resumed.	**JON-1a**: ORO Environmental Management needs to lead the Accident Recovery Team, in conjunction with Toxco and Commodore, to perform an evaluation of the exact failure mode of the primary and secondary containment. **JON-1b**: ORO needs to ensure the results of the evaluation are communicated to all line managers responsible for this and all future sodium and metal recovery operations.
Although the scope of work was adequately defined in contract documents, technical information that was crucial to understanding the nature and extent of the contamination and volume of sodium in the shields was not provided to Toxco or Commodore. AU did not have effective mechanisms in place to identify the information on the nature, extent, and character of the sodium shields.	**JON-2**: ORO needs to implement a formal process for identifying, communicating, and disseminating technical information crucial for work processes on all materials disposition activities.

Table ES-1. Conclusions and Judgments of Need (continued)

Conclusions	Judgments of Need
Both Toxco and Commodore failed to effectively analyze all the hazards associated with the scope of work. This failure was partially attributable to a lack of important technical information about the work to be performed. ORO, CROET, and the ETTP Site Safety Council review the tenant HASPs, but none of these organizations have the authority to approve the HASPs.	**JON-3**: ORO and CROET need to establish and implement a formal process to ensure that sublessees' Health and Safety Plans (HASPs) are reviewed, are commensurate with the hazards, and are approved.
Commodore and Applied Reactor Technology failed to adequately design and/or install the silicone gasket system for the hot box door. Toxco failed to define and flow down the appropriate requirements to its teaming partner, especially with regard to safety requirements and expectations.	**JON-4**: ORO needs to ensure that all contractual requirements (Occupational Safety and Health Administration; DOT; NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*; and DOE directives) flow down to the work and are fully implemented for all contracts and subleases.
The corrective actions implemented by ORO to address tenant issues identified by the Office of Oversight were inadequate. ORO failed to ensure that Roles, Responsibilities, and Authorities (RRAs) were defined between AU and the Assistant Manager for Environment, Safety, Health, and Emergency Management and between AU and the Assistant Manager for Environmental Management. AU management failed to ensure that the Facilities and Materials Reuse Division's responsibilities were fully implemented for the Statement of Work in the contract. AU's ES&H responsibilities are not adequately defined, and confusion exists such that the responsibilities for ES&H oversight cannot be effectively implemented.	**JON-5**: ORO needs to ensure that AU defines their organizational interfaces with the Assistant Manager for Environment, Safety, Health, and Emergency Management and the Assistant Manager for Environmental Management and that AU executes their responsibilities for ensuring that ES&H requirements are included in contracts and subleases and that these requirements are effectively implemented.

Table ES-1. Conclusions and Judgments of Need (continued)

Conclusions	Judgments of Need
Communication, dissemination, and use of lessons learned from previous ORO Type B Accident Investigations were inadequate.	**JON-6**: ORO and BJC need to evaluate their lessons learned programs to ensure that lessons from accident investigations are screened and disseminated to the responsible organizations for use in planning work to promote accident prevention across ORO.
AU and the Contracting Officer for the Toxco contract did not provide feedback or consequences to Toxco for violating the terms and conditions of its contract with ORO after the DOT enforcement action. Toxco does not have a quality assurance program that is compliant with NQA-1, which is a contract requirement.	**JON-7**: ORO needs to establish and implement a formal mechanism to ensure that the terms and conditions of contracts are effectively implemented by all contractors.
No requirements exist for preparing, reviewing, approving, and maintaining Emergency Management Hazard Surveys and Emergency Management Hazard Analyses and the associated Emergency Action Levels for sublessees at ETTP. Commodore's workers did not have required training per Title 29 Code of Federal Regulations, Part 1910.157, *Portable Fire Extinguisher*, and failed to fully implement Commodore's fire emergency procedure.	**JON-8**: ORO and CROET need to establish a policy and requirements to ensure that lessees participate in the ETTP hazard identification and analysis process for emergency management.
The BOA and associated Task Order process is not understood by all organizations involved in this accident.	**JON-9**: ORO needs to establish and fully implement a formal mechanism to ensure that the BOA/Task Order process is defined and managed as a contract across all activities.
CROET failed to document the RRAs of CROET personnel with regard to safe execution of tenant operations. Commodore's managers with responsibility for the work being conducted did not enforce Commodore's corporate safety requirement to develop a site-specific HASP or to perform an activity hazards analysis.	**JON-10**: ORO needs to develop and implement a process to ensure that the terms and conditions of all leases/subleases are effectively implemented at all levels.

Table ES-1. Conclusions and Judgments of Need (continued)

Conclusions	Judgments of Need
BJC failed to define the RRAs of the Reindustrialization organization as required under ISM.	**JON-11a**: BJC needs to define and fully implement RRAs for its Reindustrialization organization. **JON-11b**: ORO needs to develop and implement a formal mechanism to ensure BJC fully implements its RRAs for the Reindustrialization organization.
AU failed to meet the intent of the Secretary of Energy's moratorium on release of volumetrically contaminated metals into general commerce.	**JON-12**: ORO needs to develop and implement a formal process to ensure that transfers of volumetrically contaminated metals to licensees include controls on the end use of activated metals in accordance with Secretarial policies.
ORO's oversight of tenant organizations at ETTP is not formal.	**JON-13**: ORO needs to develop and implement an oversight process for all leased properties.

1.0 INTRODUCTION

1.1 Background

On May 8, 2004, employees of Commodore Advanced Sciences, Inc. (Commodore), were conducting activities to heat surplus sodium-filled shields at the East Tennessee Technology Park (ETTP). While conducting these activities, an exothermic metal reaction (exothermic reaction) occurred when the sodium came in contact with standing rainwater, resulting in evacuation of ETTP and a nearby neighborhood and implementation of the *United States Department of Energy Oak Ridge Reservation Emergency Plan*. No injuries were sustained from this accident.

On May 11, 2004, U.S. Department of Energy (DOE) Oak Ridge Operations Office (ORO) management categorized the accident as a Type B. On May 17, 2004, the ORO Manager formally appointed a Type B Accident Investigation Board (Board) to investigate the event in accordance with DOE O 225.1A, *Accident Investigations* (see Appendix A). This report documents the facts of the accident and the conclusions of the Board.

The organizations involved in this event were ORO; Bechtel Jacobs Company LLC (BJC); the Community Reuse Organization of East Tennessee (CROET); Toxco, Inc. (Toxco); and Commodore. A brief description of each organization is provided below.

Department of Energy Oak Ridge Operations Office

ORO is a diverse office with key missions in Science and Technology, Environmental Management (EM), Assets Utilizations (AU), and Uranium Programs. In addition, ORO manages three service centers that support ORO and/or other DOE sites/locations: the Financial Service Center, the National Electronics Recycling Center, and the Materials Recycle Service Center(s). Personnel from matrix support organizations located in Oak Ridge, Tennessee, support these programs and service centers. In addition, ORO provides support to the national security programs at the Y-12 National Security Complex (Y-12).

Bechtel Jacobs Company LLC

BJC is a prime contractor for ORO's EM Cleanup Program, which includes work at ETTP, Y-12, and the Oak Ridge National Laboratory (ORNL). This contract with ORO (DE-AC05-98OR22700) includes environmental restoration, decontamination and decommissioning, and waste treatment and disposal activities. The mission at ETTP is environmental cleanup and reindustrialization/reuse of the assets (i.e., facilities, equipment, materials, utilities, and trained workforce). This mission is being accomplished by cleaning up the site through the BJC contract.

Community Reuse Organization of East Tennessee

In 1996, ORO's reindustrialization initiative went into effect at ETTP, with efforts focusing on restoration of the environment, decontamination and decommissioning of the facilities,

and management of legacy wastes. CROET was created to move the ETTP resources toward private management quickly and efficiently. The organization leases the Federally owned properties from DOE and subleases them to private industries. Leasing arrangements have included bartering arrangements, trading for such services as decontamination and decommissioning, providing short-term markets for recycled materials, and traditional leases. As a right-to-work state, the State of Tennessee provides further incentives for leasing the ETTP facilities, such as tax credits, exemptions, deductions, financing incentives, and accelerated depreciation of machinery and equipment.

Subsidiaries of CROET handle the actual leasing activities. For example, the Heritage Railroad Corporation handles the railroad and right of way at ETTP, providing tenants with on-site rail spur service and the general public with excursion train rides, and the Horizon Center leases space at a new 1,000-acre greenfield site near ETTP. The Heritage Center handles the ETTP leases. In some cases, private businesses locating at ETTP rehabilitate the space in a building for reduced lease rates and make use of the existing equipment and other assets, such as cranes and machine tools, to reduce their operating costs.

Toxco, Inc.

Toxco was formed in May 1984 as a Nevada corporation. Toxco's scope of work from 1984 to 1991 was as an environmental company involved in site surveys, site assessments, field trials, on-site remediation, design activities, site closures, and verification studies. In 1991, Toxco opened an operating facility for battery recycling and recovery in Trail, British Columbia, and moved the focus of the company's efforts to that facility. In 1992, Toxco patented a process for recycling lithium batteries and purchased a facility in Baltimore, Maryland, in 1998 to process recovered lithium. The facility became operational in 1999.

In July 1999, Toxco subleased land from CROET at ETTP to process scrap metal. Toxco's facility at ETTP has various contracts with scrap generators in the area to handle and process suspect radiologically contaminated materials under a Radioactive Materials License from the State of Tennessee. In addition, Toxco has a Basic Ordering Agreement (BOA) with ORO to recycle material from sites within the DOE complex.

Commodore Advanced Sciences, Inc.

Commodore is a wholly-owned subsidiary of Commodore Applied Technologies, Inc., which is a public company focused on solving environmental problems by providing proprietary environmental technologies and services. Commodore was founded in 1977 as an engineering and management firm, and it specializes in the investigation, remediation, and management of hazardous and radioactive mixed waste sites. Commodore also has a Teaming Agreement with Toxco to disposition the sodium contained in the shields. Commodore subcontracted with Applied Reactor Technology to design the "hot box" that was used to melt the sodium.

1.2 Facility Description

ETTP is located approximately five miles west of Oak Ridge, Tennessee. ETTP, formerly known as the K-25 Site, was a gaseous diffusion plant for uranium enrichment during and after World War II. The plant was shut down in the 1980s, and its mission was changed to environmental cleanup and site closure. ETTP contains over 500 buildings and structures that must be decontaminated, decommissioned, and either demolished or transferred for private sector use before site closure is completed.

In 1996, ORO announced a plan to reindustrialize a large portion of ETTP by transitioning it into a commercial industrial park. According to the plan agreed to by the DOE Office of EM, certain buildings would be leased to private companies, thereby accelerating the pace of cleanup and reducing the associated costs. ORO partnered with CROET to conduct the reindustrialization effort at ETTP.

DOE and CROET have entered into lease agreements that allow CROET to sublease portions of government-owned property and/or facilities at ETTP. Under these leases, CROET has been allowed to sublease property and facilities to other companies, agents, or representatives to promote economic development. The property subleased by CROET consists of 19.4 acres of DOE-owned land at ETTP. (See Figure 1-1.) On July 28, 1999, CROET subleased approximately 10 acres of land plus an area containing the temporary facility K-1313-D (7,500 square feet) to Toxco. The accident site is located on this parcel of land, which is known as ED-2. (See Figure 1-2.)

Toxco and Commodore signed a Teaming Agreement on March 28, 2003, for Commodore to handle the heating process and dispose of the sodium. In September 2003, Toxco proposed to transport approximately 54 containers (identified as "shields") filled with surplus DOE sodium metal (weighing approximately 110,000 pounds) from ORNL to the K-1313-D facility on the ED-2 parcel. The sodium would be extracted from the shields using a heating method and transferred to Department of Transportation (DOT)-approved containers for shipment off site.

1.3 Scope, Conduct, and Methodology

The Board began its activities on May 17, 2004, and completed its investigation on June 18, 2004. The scope of the Board's investigation was to identify all relevant facts; analyze the facts to determine the direct, contributing, and root causes of the event; develop conclusions; and determine Judgments of Need that, when implemented, should prevent recurrence of the incident. See Figure 1-3 for an explanation of accident investigation terminology. The investigation was performed in accordance with DOE O 225.1A, *Accident Investigations*, using the following methodology:

- Facts relevant to the accident were gathered through interviews and reviews of documents and evidence.

- The accident scene was inspected, and photographs were taken of the scene.

- The facts were analyzed to identify the causal factors using event and causal factors analysis, barrier analysis, root cause analysis, and change analysis.

- Judgments of Need for corrective actions to prevent recurrence were developed to address the causal factors of the event.

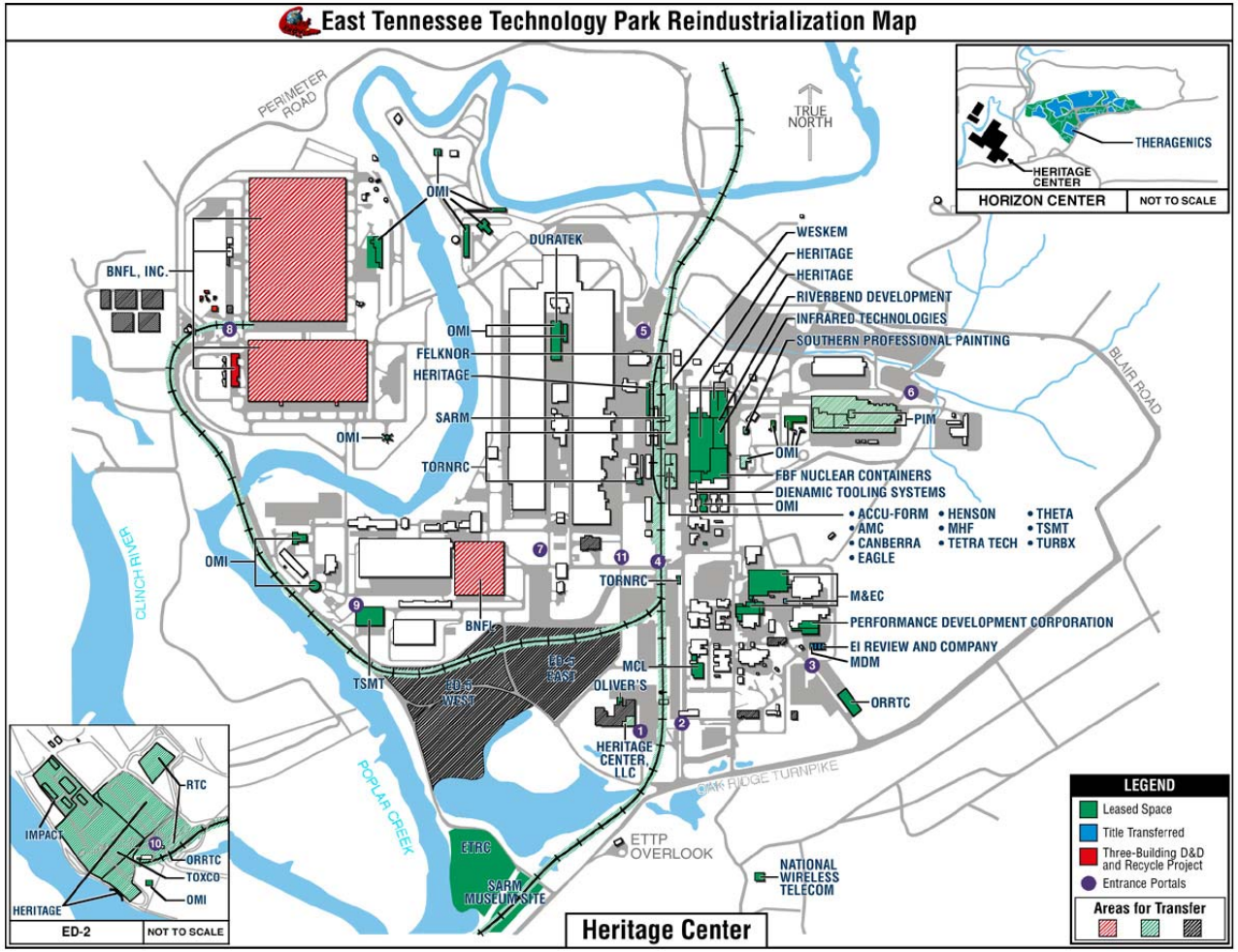

Figure 1-1. Leased Space at the East Tennessee Technology Park

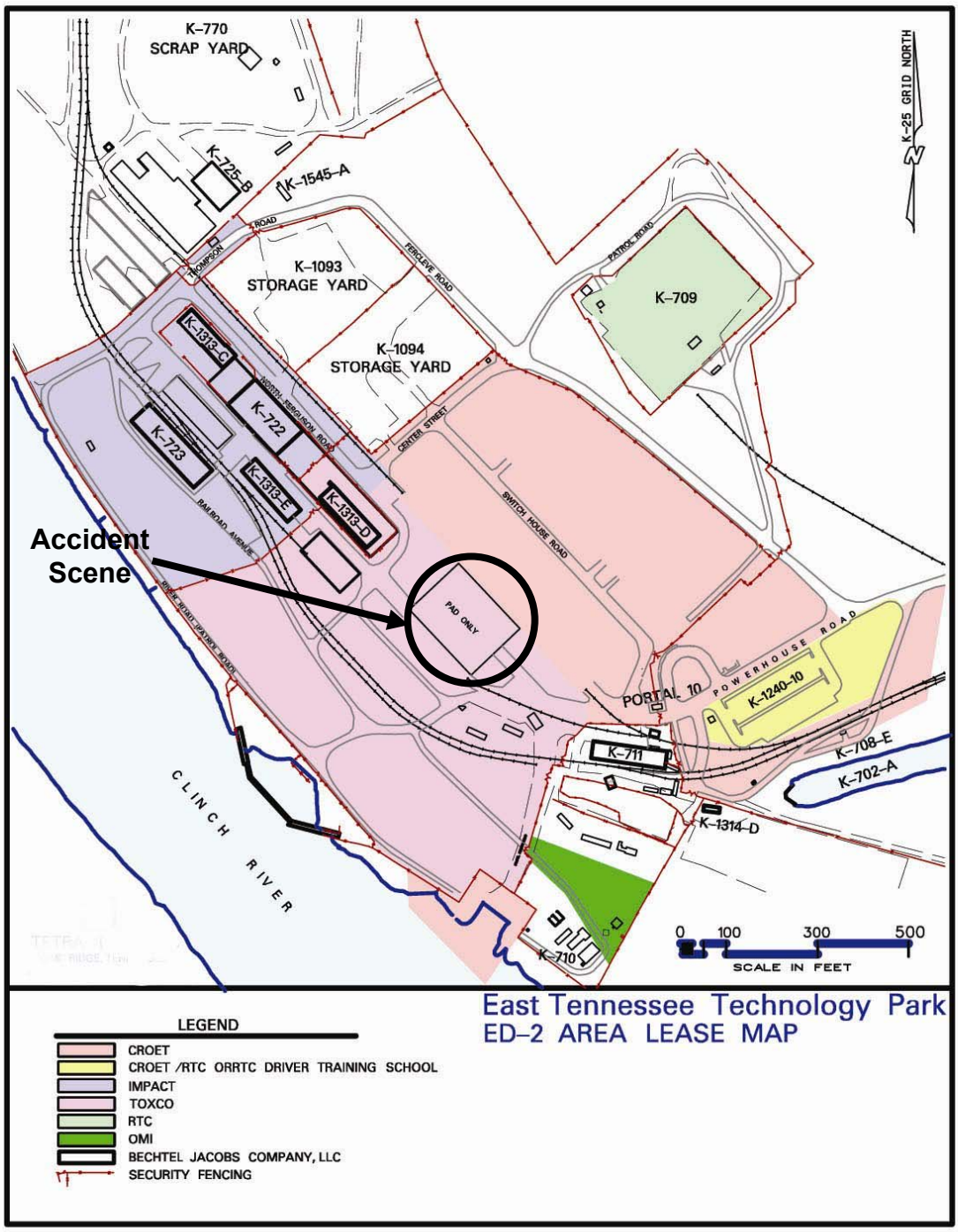

Figure 1-2. East Tennessee Technology Park ED-2 Area Lease Map

Accident Investigation Terminology

A **causal factor** is an event or condition in the accident sequence that contributes to the unwanted result. There are three types of causal factors: **direct cause(s)**, which is the immediate event(s) or condition(s) that caused the accident; **root cause(s)**, which is the causal factor that, if corrected, would prevent recurrence of the accident; and the **contributing causal factors**, which are the causal factors that collectively with the other causes increase the likelihood of an accident but which did not cause the accident.

Event and causal factors analysis includes charting, which depicts the logical sequence of events and conditions (causal factors that allowed the accident to occur), and the use of deductive reasoning to determine the events or conditions that contributed to the accident.

Barrier analysis reviews the hazards, the targets (people or objects) of the hazards, and the controls or barriers that management systems put in place to separate the hazards from the targets. Barriers may be physical or administrative.

Change analysis is a systematic approach that examines planned or unplanned changes in a system that caused the undesirable results related to the accident.

Figure 1-3. Accident Investigation Terminology

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2.0 THE ACCIDENT

2.1 Event Description and Chronology of Events

Commodore personnel were using the hot box to heat a shield consisting of sodium metal encased in an aluminum shell on May 8, 2004, on the property that Toxco subleased from CROET located at ETTP in Oak Ridge, Tennessee. The shield was being heated to liquefy the sodium for transfer to DOT-approved containers for shipment. The heating process began on May 5, 2004, in a hot box constructed for this purpose and continued through the morning of May 8. At approximately 10:00 am on May 8, as the sodium was being heated, Commodore personnel standing nearby heard a "pop" and a "whoosh" sound. At approximately 11:00 am, this was followed by additional noise and visual observance of material leaking from the hot box near the bottom of the side entrance door. The Commodore operators attempted to build a dam with Class D extinguishing agent to keep the flow of sodium from reaching the standing rainwater on the ground, but their efforts were unsuccessful. The sodium subsequently contacted standing rainwater, and an exothermic reaction occurred. At 11:24 am, Toxco personnel contacted the ETTP Park Shift Superintendent (PSS) and reported that they had a sodium fire at their facility. The ETTP Fire Department, Security, and Health Physics personnel were dispatched to the scene. Figure 2-1 provides an overview of the accident scene.

Figure 2-1. Overview of the Accident Scene

At 11:33 am, the PSS notified ORO and advised neighboring tenants at ETTP to shelter in place. At approximately 12:21 pm, the PSS notified the City of Oak Ridge, Roane County, and the Tennessee Emergency Management Agency (TEMA) of the incident. The Public Warning Siren System (PWSS) was activated at 1:12 pm, and a Public Address (PA) announcement was made for personnel at ETTP to remain in place and await further instructions. At 1:37 pm, the Emergency Operations Center (EOC) was activated, and an Operational Emergency was declared at 1:42 pm.

By 2:00 pm, roadblocks had been established on local access roads, and the Clinch River had been secured and access blocked. The EOC was declared operational at 2:47 pm. At 3:38 pm, the National Response Center was notified that a release of a reportable quantity of sodium (10 pounds) had been exceeded. Field Monitoring Teams were dispatched to perform field monitoring and environmental sampling to determine the nature and extent of the chemical release at ETTP. The exothermic sodium reaction was allowed to continue until a thick crust of reacted metal formed, which smothered the reaction. Recovery actions began on the afternoon of May 9, 2004.

Table 2-1 provides the events leading up to the accident on May 8, 2004.

Table 2-1. Event Chronology

Date	Time	Event
4/1971		The ORNL Physics Division developed requirements for the sodium shields. These requirements stipulated that the shields were to be solid material with no voids.
6/1971		The sodium shields were filled at the Molten Salt Reactor Experiment Facility at ORNL. The shields were cooled from the bottom.
6/1971–5/2004		The sodium shields were located outside in various locations for 33 years.
2/1995		Dupont prepared a training program for Commodore.
4/26/1996		DOE and CROET executed the original real estate lease for the ED-2 parcel.
10/17/1996		Commodore employees completed the prerequisites to participate in on-the-job training specific to sodium handling.
9/1997		The DOE Office of Oversight issued a report on the facility disposition programs at ETTP.
9/15/1997		The real estate lease between ORO and CROET for the ED-2 parcel was revised and replaced in its entirety.

Table 2-1. Event Chronology (continued)

Date	Time	Event
1999 (exact date unknown)		ORO and BJC requested EH-4 from the Headquarters Office of Environment, Safety and Health (EH) for approval to free release the shields using the As Low As Reasonably Achievable (ALARA) process as allowed by DOE 5400.5*, Radiation Protection of the Public and the Environment*.
7/28/1999		CROET and Toxco signed the original sublease.
1/12/2000		The Secretary of Energy issued a moratorium on the release of volumetrically contaminated metals (referred to in this report as the Secretary of Energy's moratorium).
2/14/2000		The Secretary of Energy issued a memorandum entitled "Release of Materials for Re-use and Recycle."
4/3/2000		ORO approved ORR 150B.2, *U.S. Department of Energy Oak Ridge Reservation Emergency Management Program Implementing Procedures (EPIP)*.
4/28/2000		ORO issued ORR 150B.2, *U.S. Department of Energy Oak Ridge Reservation Emergency Management Program Implementing Procedures (EPIP)*.
7/13/2000		The Secretary of Energy issued a memorandum entitled "Release of Surplus and Scrap Materials."
7/21/2000		The EH-412 organization issued *Frequently Asked Questions on the Suspension on Release for Recycling of Metal from Radiation Areas*.
10/2000		The DOE Office of Oversight issued a report on safety and health programs at ETTP.
1/19/2001		The Secretary of Energy issued a memorandum entitled "Managing the Release of Surplus and Scrap Materials."
2/6–7/2001		ORO AU performed an audit of Toxco to determine the company's qualifications regarding award of the materials disposition BOA.
2/22/2001		ORO transmitted the audit report to Toxco with a request for a Corrective Action Plan (CAP) to address the identified deficiencies.
3/1/2001		Toxco submitted its CAP for the deficiencies identified in the ORO audit report.
3/9/2001		ORO notified Toxco of its qualification acceptance to bid on work under the materials disposition BOA.

Table 2-1. Event Chronology (continued)

Date	Time	Event
10/1/2001		BJC received a DOT exemption to ship 45 sodium-filled shields one way from ORNL to Waste Control Specialists in Andrews, Texas.
3/22/2002		BJC performed an annual radiation/contamination survey of the 7831-D pad at the Solid Waste Storage Area (SWSA)-5. The survey report states, "7831-D is a posted Fixed Contamination Area."
4/4/2002		DOE released draft DOE Guide 441.1-XX, Control and Release of Property with Residual Radioactive Material for use with DOE 5400.5, *Radiation Protection of the Public and the Environment*, for use and comment.
6/2002		ORO signed the *Tennessee Multi-Jurisdictional Emergency Response Plan for the Department of Energy Oak Ridge Reservation*.
11/15/2002		The ORO AU Safety Advocate wrote a letter to CROET with the subject "Health and Safety Plan Requirement for All Lessees."
12/16/2002		ORO issued a BOA (DE-AK05-01OR22876) to Toxco for materials disposition.
1/27/2003		BJC tasked Tetra Tech, Inc. (Tetra Tech), to conduct an engineering study on the sodium shields (Work Release 23900-BA-ES008, WR 0943).
3/14/2003		ORO issued the *Oak Ridge Reservation Emergency Plan*, Revision 0.
3/18/2003		BJC performed an annual radiation/contamination survey of the 7831-D pad at SWSA-5. The survey report states, "7831 D is a posted Fixed Contamination Area."
3/28/2003		Toxco and Commodore signed a Teaming Agreement.
3–4/2003		BJC performed its review and comment process on the Tetra Tech engineering study on the sodium shields.
4/2003		ORO held three bidders conferences in mid-April to discuss disposition of the sodium shields with companies approved to work under the materials disposition BOA.
3/31 & 4/1/2003		A required BOA audit of Toxco was performed. The overall audit effort was managed by AU, with support from DOE subcontractor personnel.
4/12/2003		The BJC Document Management Center (DMC) assigned number BJC/OR-1399 to the Tetra Tech engineering study on the shields.

Table 2-1. Event Chronology (continued)

Date	Time	Event
4/17/2003		The Tower Shielding Reactor Shields Meeting was held, which included in attendance the BJC Radiological Control Manager and representatives from BJC Projects, BJC Reindustrialization, and ORO Procurement and Contracts. The purpose of the meeting was to discuss potential disposition paths for the sodium shields.
4/30/2003		Tetra Tech issued its engineering study on the sodium shields as a final report to BJC (BJC/OR-1399, *Sodium and Lithium Hydride [sic] Shields Engineering Study for the Tower Shielding Facility, Oak Ridge National Laboratory, Oak Ridge, Tennessee*).
5/15/2003		BJC performed a radiological survey (BJC-MVHI-108375) on a Sea-Land container containing some of the shields. This survey indicates that the inside of Sea-Land container RM2-0368 meets the criteria for a Contamination Area.
6/16/2003		Toxco submitted its bid for work under the materials disposition BOA.
6/16–9/11/2003		The Procurement and Contracts Division requested the AU Project Manager to review the Toxco bid. AU performed the requested review.
7/17/2003		The BJC Project Manager signed off on the "Subcontractor Submittal Status Sheet" to accept the final Tetra Tech report (BJC/OR-1399).
		Westinghouse Safety Management Solutions Mid-America LLC submitted *Nuclear Engineering Analysis of TSF Shields* (WSMS-CRT-03-0076, Revision 0) to BJC.
9/11/2003		The ORO Contracting Officer responded by letter to an inquiry from Toxco.
9/29/2003		DOT issued an exemption (DOTE-133221) to Toxco to move the sodium shields from ORNL to ETTP.
9/30/2003		ORO tasked Toxco with disposition of the sodium shields via a Task Order under the materials disposition BOA (DE-AT05-03OR22982).
		ORO approved the *Oak Ridge Reservation Emergency Plan*, Revision 1.0, which has an effective date of November 14, 2004.
11/1–2/2003		Toxco shipped four large shields from ORNL to ETTP. The shipment was not in compliance with DOT regulations.

Table 2-1. Event Chronology (continued)

Date	Time	Event
11/2/2003		BJC performed a radiological survey as the shields were moved from SWSA-5 to ED-2 at ETTP. The survey states, "Area is posted as FCA."
11/4/2003		Applied Reactor Technology designed the hot box to melt the sodium and contain the liquid sodium in the event of a shield failure.
11/11/2003–3/25/2004		BJC performed multiple radiological surveys in the area of the Well Drillers Steam Cleaning Area of SWSA-5. The surveys state the area is posted as a Radioactive Materials Area.
11/12–17/2003		At AU's request, the Transportation Safety Engineer from the ORO Office of Assistant Manager for Environment, Safety, Health, and Emergency Management (AMESH) performed a review of the noncompliant Toxco shield shipment.
1–4/2004		Commodore and Applied Reactor Technology constructed the hot box.
1/20/2004		The BJC Melton Valley Project sent an electronic mail message (e-mail) with an early version of the Tetra Tech report to Toxco; however, the attachments to the report were not included in the e-mail.
3/1–4/29/2004		The installation of the building was altered to raise the hot box above the ground to prevent water intrusion.
3/8/2004		The main BJC DMC sent an e-mail to the point of contact for the BJC DMC at ORNL to ask if the number BJC/OR-1399 was still needed.
~3/15/2004		The ORO AU organization contacted Process Engineering Associates to conduct a review of the Toxco/Commodore setup.
3/26/2004		BJC performed a radiological survey of the SWASA-5 7831-D pad, location number 452. In the "Description" block, the survey record states that the survey was an "Annual Routine Contamination And Radiation for a posted FCA/Frisk."
~4/29/2004		BJC Emergency Response personnel visited the Toxco jobsite at ETTP and were briefed on the planned sodium transfer activities.
4/29–30/2004		Toxco and Commodore hosted meetings to present the proposed sodium transfer activities. The ORO AU Safety Advocate attended and documented his conclusions in an e-mail message to the ORO ETTP Project Closure Director.

Table 2-1. Event Chronology (continued)

Date	Time	Event
4/29–5/5/2004		Process Engineering Associates and an ORO AU Project Manager conducted a limited review of the Toxco/Commodore system and personnel.
5/4/2004		The hot box door was closed and sealed.
5/5/2004	~Noon	Commodore personnel completed the "Pre-System Startup Checklist."
	~1:00 pm	Commodore began heating the sodium shield.
	1:00–3:00 pm	Commodore entered the hot box to change the location of a thermocouple. The hot box door was closed and resealed.
	3:00 pm	The heaters were energized for the second time.
	Late	Commodore increased the heaters' setpoint to 225°F.
5/6/2004		Commodore increased the heaters' set point to 250°F.
5/7/2004	7:00 am	Commodore increased the heaters' setpoint to 300°F.
		BJC personnel reported a PA system outage in the Toxco facility area.
		BJC updated the *Compensatory Measures for Facilities with Inadequate Public Address System* to include the Toxco facility.
		BJC personnel reported that contingencies were now in place (i.e., contact by telephone via the PSS).
5/8/2004	12:01 am	Commodore increased the heaters' setpoint to 339°F.
		Eberline Services received a solid sodium sample (TOX-01) from Toxco.
	~10:00 am	Commodore personnel and the Applied Reactor Technology Engineer standing near the hot box heard a "pop" and a "whoosh" sound from the hot box.
		Black smoke came from the hot box.
		Power was terminated to the heaters and thermocouples.
	11:00–11:24 am	Commodore operators noticed liquid sodium coming from under the hot box door.
		The operators attempted to stop the flow of sodium by building a dam using a Class D extinguishing agent. The sodium contacted standing rainwater, causing an exothermic reaction.
	11:24 am	The Commodore operators failed to control the exothermic sodium reaction and evacuated to the gate.
		Toxco personnel called 911 to report a sodium fire at their facility.

2.2 Sodium Properties and Hazards

Metallic sodium is a soft, malleable solid. The untarnished surface is silvery white and lustrous; however, sodium rapidly tarnishes (oxidizes) in the air to a dull gray color. When sodium is heated above its melting point (207.5°F, 97.5°C) in an inert atmosphere, it becomes a very fluid, silvery liquid. Compared with most metals, liquid sodium has a low surface tension and viscosity. It also has a relatively low density, high heat capacity, and good neutron radiation stability. It is essentially noncorrosive when in contact with many structural alloys, including aluminum. For this reason, sodium is usually more advantageous than other liquid metal for heat transfer applications.

Physical Properties of Sodium

Appearance: Soft, malleable, silvery white solid

Atomic Number:	11
Atomic Weight:	22.997
Boiling Point:	883°C; 1,621°F
Electrical Resistivity, microhms/cm, 100°C:	9.65
Heat of Fusion @ 97.5°C, 207.5°F, cal/g:	27.2
Btu/lb:	48.96
Heat of Vaporization @ 883°C; 1,621°F, cal/g:	1,005
Btu/lb:	1,809
Melting Point:	97.5°C, 207.5°F

Density:

	Temperature °C	°F	Density g/cm³
Solid	0	32	0.9721
	97.5	207.5	0.9519
Liquid	97.5	207.5	0.9287
	100	212	0.928
	145	293	0.916
	250	482	0.891
	400	752	0.859
	600	1,112	0.809
	800	1,472	0.757

Lb per cubic foot, solid at 97.5°C, 207.5°F: 59.4
Lb per gallon, liquid at 97.5°C, 207.5°F: 7.75
Volume Change on Fusion (Solidification): 2.4% of solid volume
Coefficient of Thermal Expansion: 39.4 x 10^{-6} in/in/°F

Sodium oxidizes readily in air with a yellow flame and produces white monoxide (Na_2O) fumes. Further heating in air produces yellow sodium peroxide (Na_2O_2). Sodium is best known for its reaction with water, where it forms sodium hydroxide and hydrogen. This reaction is vigorous, and if oxygen or air is also present, the heat of the reaction can ignite the hydrogen-oxygen mixture and cause an explosion in a confined space. The sodium hydroxide fumes produced by the reaction of sodium with water are hazardous because skin contact can cause burns.

Sodium metal has an autoignition temperature of approximately 250°F, depending on conditions. Melting and liquid transfer operations are usually performed below 250°F to avoid potential ignition. Inert gas blanketing of sodium is usually done with nitrogen to prevent autoignition. Should an exothermic sodium reaction occur, use of a Class D dry-chemical-type extinguishing agent such as Met-L-X is recommended.

2.3 Evaluation of the Failed Sodium Shield

The sodium shields used for experiments at the Tower Shielding Facility are shown in Figure 2-2. They were constructed of ½-inch-thick Type 5083 aluminum alloy with welded seams. The shields are 11 feet in diameter and 2.5 feet thick or 5.0 feet thick (deep). The shields were constructed with a concrete support base (cradle) that is approximately 14 feet

long and 2.5 or 5.0 feet thick. The volume of the shield that was being processed (a 2.5-foot-thick shield) is 237 cubic feet, and it contained approximately 14,000 pounds of sodium when the heat transfer process began. The combined shield and cradle were covered with a matching concrete cap that was removed before transport to ETTP and subsequent heating.

Figure 2-2. Large Sodium Shields

The concrete was used to minimize the neutron leakage from the sodium shields during the Tower Shielding Facility's experiments and to hold the shield in place. There are two 2 1/2-inch fill caps in the top of the shield and a single 1-inch drain cap in the bottom. Two 3-inch angle iron supports are located at the 6-inch and 5-foot levels of the faceplates of the shield and are connected to the concrete cradle. Commodore chose a 2.5-foot-thick shield (IE 40113) for processing on May 5, 2004.

In 1971, the ORNL Neutron Physics Division assembled the equipment to fill the shields with sodium metal in the Molten Salt Reactor Experiment Facility. A support jig and heating assembly were strapped to the flat faces of the shield before filling to support the 11-foot-diameter surface and to heat the shields to 250^{o}F. The heaters were also used to control the cooling of the liquid sodium after it was added to the shield.

The filling procedure states that the 2.5-foot-thick shield was filled with 33.15 drums (55-gallon drums) of molten sodium, each drum containing 420 pounds of sodium metal. When the shield had been filled with 32.17 drums, it was allowed to cool to 212^{o}F. An additional 0.16 drums of sodium were added to compensate for the shrinkage caused by the cooling. The sodium was allowed to solidify from the bottom up by sequentially deactivating the heating elements. Once the sodium had solidified at 208^{o}F, an additional 0.82 drums of sodium were added to fill the void space created by the sodium solidifying. The intent of this procedure was to ensure that the shield was uniformly filled with sodium metal. A void

space extending 16 inches below the top was created by the solid sodium cooling to room temperature. The void space was, however, approximately one drum less in volume than if the shield had simply been filled with liquid sodium and allowed to cool.

The volume change when molten sodium solidifies is 2.43% of the solid volume. Heating the sodium from room temperature to 225°F produces a total volume expansion of 4.39% (see Figure 2-3). With the shield filled with approximately one drum of sodium in excess of the capacity of the shield to hold liquid sodium, pressure was created as the solid sodium was heated and melted. The coefficient of thermal expansion of sodium metal is 39.4 x 10^{-6} in/in/°F as compared to Type 5083 aluminum alloy, which is 13.2 x 10^{-6} in/in/°F. The difference in expansion in heating sodium to its melting temperature (208°F) results in a pressure increase. The Board had a structural analysis performed which indicates that the concrete support cradle and iron supports bolted to the face of the concrete cradle restrained the aluminum shield, causing the probable failure point to be the interface between the shield and the concrete. A stress analysis representation of the restrained shield in the concrete cradle is shown in Figure 2-4 on the following page.

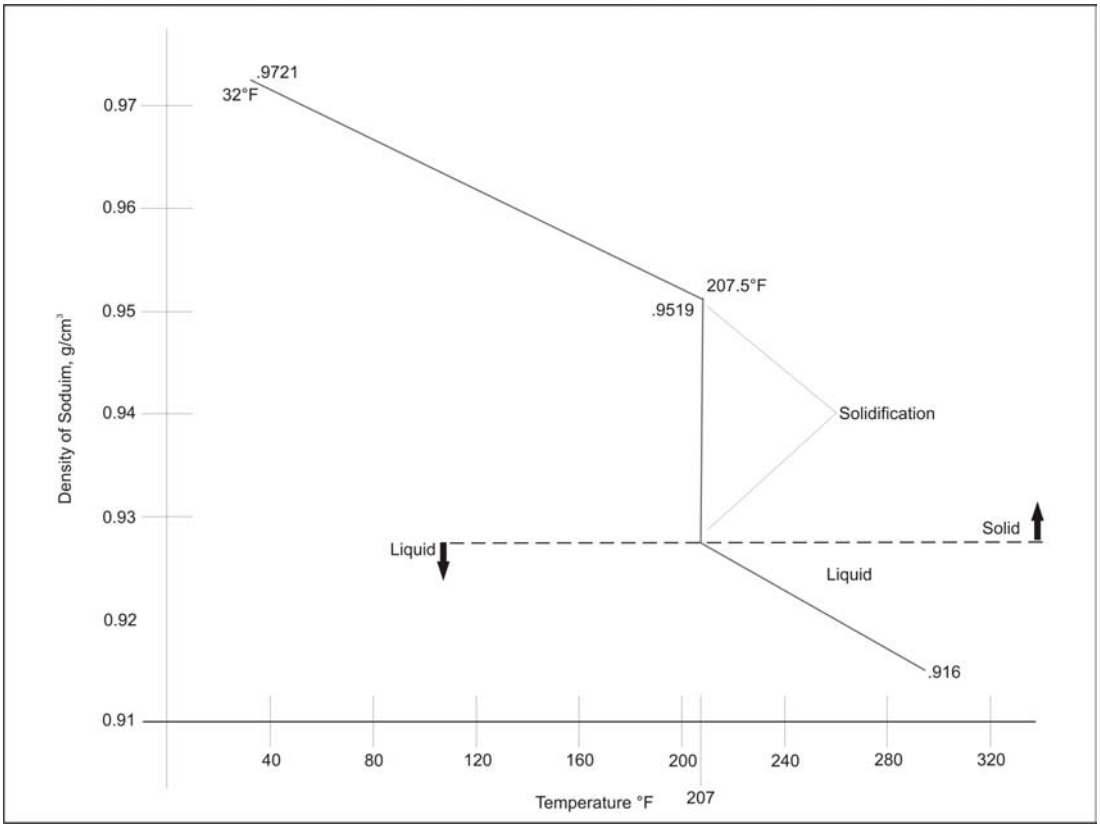

Figure 2-3. Sodium Density as a Function of Temperature

The unrestrained shield should have contained the sodium, although it would have bulged significantly. The void space in the top of the shield was not adequate to accommodate the

expansion of the melting sodium due to the extra drum of sodium that was added during filling.

The Board concludes that the rupture of the sodium shield upon heating was caused by the combination of overfilling in 1971 and the stress induced by the concrete cradle.

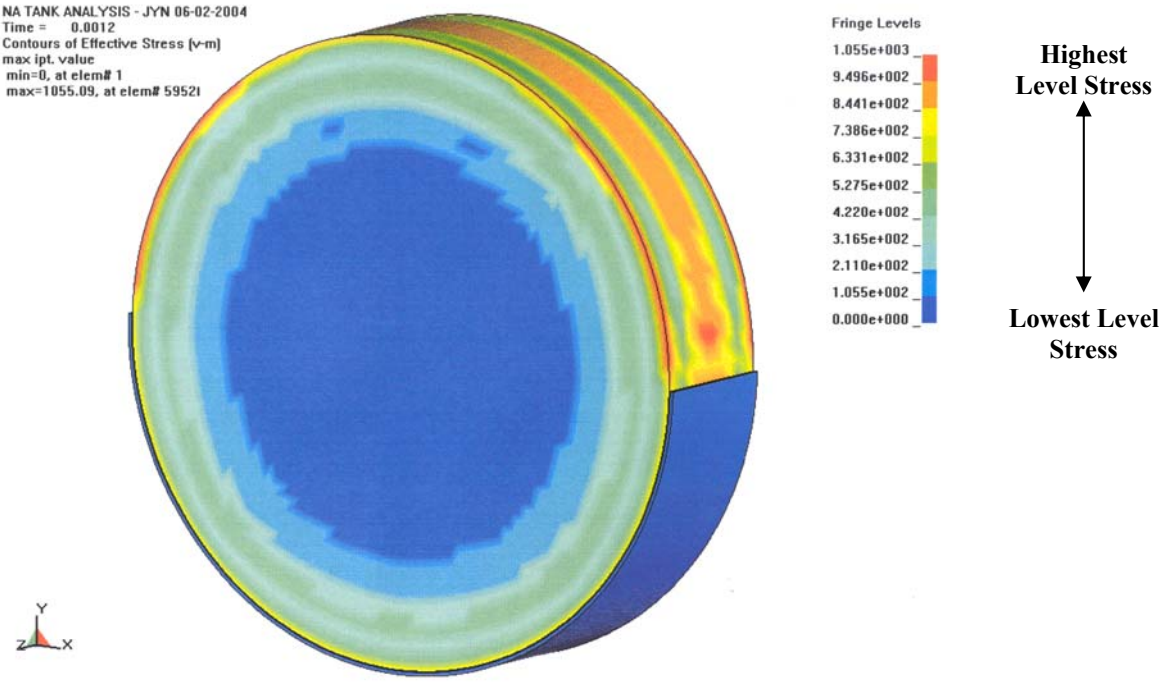

Figure 2-4. Stress Model of the Failed Sodium Shield

The hot box heating process was initiated on May 5, 2004, and continued with incremental increases in temperature until the time of the accident. The hot box had been elevated onto a platform (referred to by Commodore as a scale) because of the concern over standing water resulting from the rainy weather. Despite the insulation provided under the floor, Commodore encountered difficulty in heating the lower portion of the hot box with the radiant heaters positioned in the upper portion of the hot box. The cooler weather during the night also dropped the measured temperature in the lower section of the shield. This resulted in thermal cycling of the lower quadrant of the shield, as indicated by the thermocouples placed in the shield. The thermal cycling would result in a pressure variation in the shield. The structural analysis indicates that the thermal cycling did not contribute to the shield failure, but it may have indirectly contributed to the accident.

Commodore made an initial inspection of the interior of the hot box on May 20, 2004, using a borescope inserted through an existing electrical conduit port in the side of the hot box. Seven inspections were made, with three inspections on each side parallel with the sodium shield faces and one inspection in the end opposite the door. The videotape of the inspections shows sodium on the floor of the hot box, primarily on the east side. The pattern of the flow indicates that the breach probably occurred in the 3 to 4 o'clock position of the

east side of the shield in contact with the concrete support cradle. Figure 2-5 on the following page is a borescope photograph of the probable shield failure area. The quantity of sodium that leaked from the shield was estimated to be about half of the 14,000 pounds loaded into the shield. The exact nature and location of the shield failure can only be determined after recovery has been completed and the vessel can be analyzed.

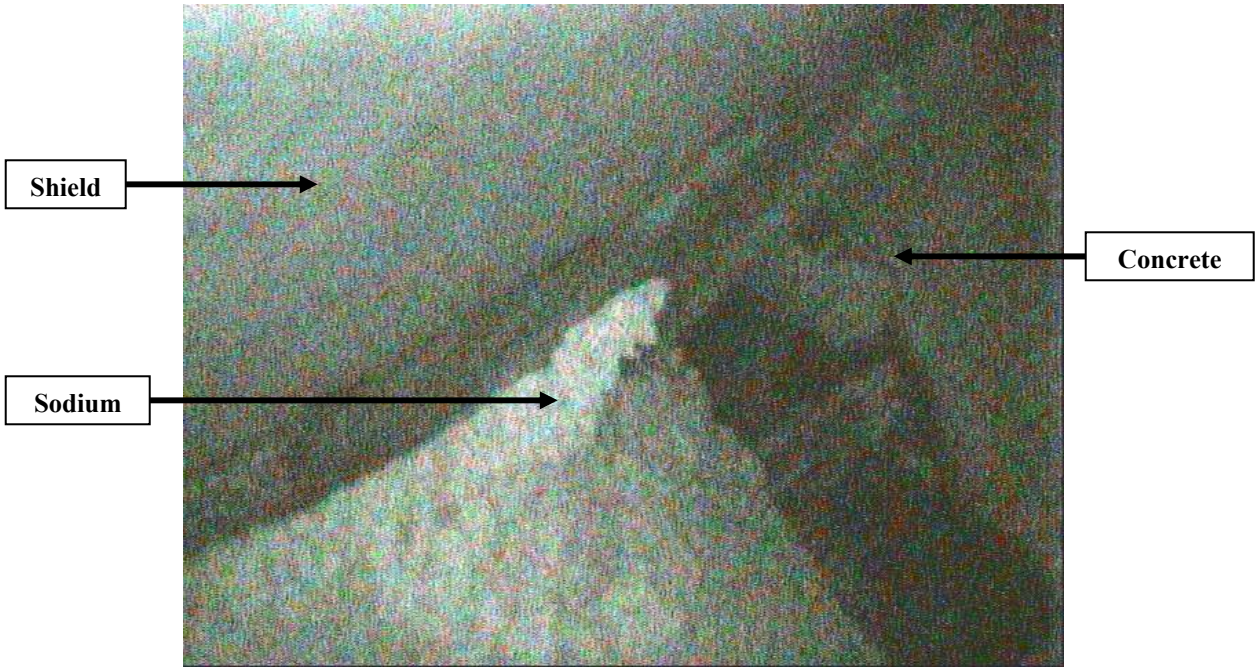

Figure 2-5. Borescope Photograph of the Failed Shield Area

Black smoke was observed coming from the hot box immediately following the shield failure. Safety evaluation research (NUREG-0968) performed in support of the Clinch River Breeder Reactor reported that copious quantities of black smoke were generated whenever liquid sodium contacted concrete. The shields had been stored outside without any weather protection, so the concrete cradles were saturated with water. Additional water was likely present between the aluminum shield and the concrete saddle. Heating to 200^{o}F should have removed much (but not all) of the water, thus minimizing the potential of an explosive reaction between the sodium and the concrete. The Applied Reactor Technology Engineer standing nearby during the heating process reported a popping sound at the time of the apparent breach of the shield.

The Board concludes that an exothermic sodium reaction with water did not contribute to the failure of the shield inside the hot box.

2.4 Failure of the Secondary Containment

During processing of liquid sodium, a secondary containment has always been used to contain the liquid in case the primary container fails for any reason. A "catch pan"

arrangement was used when the shields were filled at the Molten Salt Reactor Experiment Facility in 1971.

Secondary containment was built into the Commodore hot box by welding 30-inch, 12-gauge steel sheets to the walls and floor around the periphery. However, Commodore determined that future use of the hot box would require a side access door so that a forklift could be used to lift the smaller shields in and out of the hot box. For this reason, a double door was made part of the secondary containment in the hot box. The door has a removable center post and the bottom door threshold can be removed to facilitate use of the forklift. The integrity of the door's threshold was to be ensured by placing a bead of silicone rubber caulk around the door's sealing surfaces. To be effective, the silicone caulk is applied and allowed to cure for 12 hours to form a resilient rubber gasket. The silicone rubber is rated to withstand 400^{o} F. Commodore considered this adequate to contain the molten sodium long enough for it to solidify. This was consistent with a small, or limited, release during failure of a shield. The actual catastrophic breach of the shield far exceeded the anticipated cooling effect of the floor. Commodore planned to evaluate the integrity of the resulting rubber gasket after every entry into the hot box. The operators opened the hot box door on the first day of heating (May 5, 2004) to reposition a thermocouple. The Commodore heating procedure states that the rubber gasket is to be inspected and repaired if necessary before closing the door.

The accident was initiated when liquid sodium seeped under the center of the door. This occurred an estimated hour after the failure of the shield. The door gasket had contained a one-foot-deep pool of liquid sodium before failing. Power to the heaters had been turned off, and the secondary containment appeared to be working properly. Styrofoam insulation boards had been placed around the bottom exterior of the hot box to reduce the increased heat loss created after the hot box was elevated. The Styrofoam in the front of the hot box door was found to be smoldering, which was the first indication that something was amiss. A small flow of molten sodium, approximately one foot wide, flowed slowly under the door and onto the 12-inch-wide steel ledge (the scale) in front of the doors. The operators implemented emergency procedures and attempted to stop the flow of sodium by building a dam using the Class D extinguishing agent. They were aware of the potential for ignition if the sodium flowed off the ledge and onto the damp ground. There was also water on the ledge of the scale that would react with the sodium. The Commodore operators were unable to contain the flow or the subsequent exothermic reaction, so they evacuated the area, and Toxco personnel notified the PSS.

The sodium reacted from 11:24 am until approximately 2:00 pm. The exothermic reaction continued until a thick crust of reacted material had formed and further reaction ceased. Intermittent plumes of white monoxide fumes/smoke (Na_2O) were emitted by the exothermic reaction on a cycle of every 20 to 40 minutes. Yellow sodium peroxide (Na_2O_2) was formed during the exothermic reaction, along with the sodium hydroxide (NaOH). A blue color in the reaction was also reported but never explained. The remnants of the exothermic sodium reaction are shown in Figure 2-6 on the following page. The Board estimates that approximately 400 pounds of sodium leaked from the hot box.

The last smoke from the exothermic reaction was noted at 2:00 am on the morning of the next day. The EOC was disbanded at 1:05 pm on May 9, 2004. During the initial recovery efforts, mineral oil was sprayed on the sodium residue, which promptly ignited and burned. The second recovery effort involved using liquid nitrogen to cool the hot box door and freeze any sodium still reacting.

The Board concludes that the failure of the secondary containment resulted in the hot box leaking sodium. The nature of this failure cannot be ascertained until the hot box door is opened when recovery operations are resumed.

Figure 2-6. Remnants of the Exothermic Sodium Reaction

3.0 FACTS AND ANALYSIS

3.1 Analysis By Integrated Safety Management Core Function

DOE utilizes Integrated Safety Management (ISM) as a framework to evaluate the causes of accidents. The Board recognizes that ORO has not made ISM a requirement for CROET sublessees such as Toxco. However, the Board elected to conduct the investigation and document the results in terms of ISM due to the fact that Toxco has an Integrated Safety Management System (ISMS) description. In addition, the use of ISM ensured that a thorough review of the accident was performed to provide the maximum benefit to all parties involved and to facilitate development of lessons learned to prevent recurrence.

3.1.1 Define the Scope of Work

Effective work execution begins with the preparation of a well-defined scope of work that translates mission and requirements into terms that those who are to accomplish the work clearly understand. The scope of work must provide adequate detail to support the hazards analysis and the development of controls at the task level. To fulfill its responsibilities, line management must determine the work to be performed and be accountable for understanding it as completely as possible.

The materials disposition BOA and associated Task Order define the scope of work to be performed and provide some basic information about the shields. This information was adequate to convey to Toxco that the shields were known to be activated and, therefore, potentially radioactive. From prebid through award, the Statement of Work in the Task Order indicates that the shields' contents are activated with up to 1 pCi/g of Sodium-22. In addition, it indicates that the aluminum shells of the shields are activated with an unspecified quantity of Cobalt-60.

However, preaward discussions between the AU Facilities and Materials Reuse Division and Toxco conveyed to Toxco AU's conviction that the shields were not radioactive. Toxco subsequently lowered its bid, and the Facilities and Materials Reuse Division accepted responsibility for disposition should Toxco find any radioactive material. This information was also sufficient to enable a process designer to determine the size of the facility needed to process (heat) the shields. More detailed technical information (information that was crucial to thoroughly understand the work and plan a successful sodium transfer campaign) was available to DOE and BJC. However, this additional information was not provided to Toxco or Commodore prior to the accident.

Prior to the BOA between DOE and Toxco, the BJC Melton Valley Project was to have disposed of the shields. As part of that task, the responsible BJC Melton Valley Project Manager recognized the need to research and collect pertinent historical technical information. To address this need, a BJC subcontract was awarded to Tetra Tech to locate all available technical documentation regarding the shields and prepare a report compiling that information. The final Tetra Tech report (BJC/OR-1399, *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge National Laboratory,*

Oak Ridge, Tennessee) includes lists of available shield drawings, a report of an ALARA analysis of the shields completed in 1999, and copies of the procedures developed and used in 1971 to fill the large sodium shields. The procedures indicate that an excess of sodium was placed in the shields during the filling operations. This existing condition, if unrecognized, would lead to an overpressure condition inside the shields when they were heated.

During early 2003 and concurrent with BJC's efforts to compile technical information about the shields, BJC proposed to ORO the idea of using the materials disposition BOA and associated Task Order to dispose of the shields. DOE, with the assistance of BJC, hosted several bidders conferences to solicit interest in the work and provide information regarding the shields to interested vendors. The BJC Reindustrialization Account Executive coordinated and facilitated these bidders conferences and worked closely with the BJC Melton Valley Project Manager to do so. Some technical information regarding the shields was provided during these conferences and via formal and informal correspondence pertaining to the Task Order.

However, neither the other prospective bidders nor Toxco were advised of the existence of the Tetra Tech report during the process of selecting and awarding the Task Order. Although BJC personnel interviewed by the Board stated their conviction that Toxco had been provided with a copy of the final Tetra Tech report at various meetings and interactions during the process of transferring the shields to Toxco, no evidence exists to document these claims. The Board did find one instance when a draft version of the report (dated April 2003) was provided by e-mail to the Toxco Vice President in January 2004, but this version lacked the appendices included in the final report that contain the filling procedures. In addition, this communication happened during the context of shipping some of the shields to the Toxco facility at ETTP and not during any discussion regarding technical information on the shields. The Toxco Vice President advised the Board that he had not opened the attachment to the e-mail that contained the draft Tetra Tech report. Subsequent to the accident, the BJC Reindustrialization Account Executive provided a March 2003 version of the Tetra Tech report (including the appendices) and four drawings to Commodore on May 20, 2004.

The Board concludes that although the scope of work was adequately defined in contract documents, technical information that was crucial to understanding the nature and extent of the contamination and the volume of sodium in the shields was not provided to Toxco or Commodore.

3.1.2 Analyze the Hazards

Sodium presents unique hazards to workers and the environment, and controls are necessary to ensure the material can be safely processed. The hazards and related controls are further complicated when the sodium and/or its container might also be volumetrically contaminated with radioactive material.

The failure to provide important technical information about the shields contributed to an incomplete hazard identification and analysis process. Toxco and Commodore developed procedures and systems to control the sodium hazards, and Toxco had existing radiological control procedures in place to control the shields until they could be determined to be nonradioactive through sampling and analysis. However, since the overpressurization hazard created while heating the shields was not recognized, no controls were identified to address this hazard. The hazard associated with overpressurization was further exacerbated by the presence of the concrete saddle. The large shields are stenciled with the warning "LIFT IN CRADLE ONLY---USE LIFTING FIXTURE" (see Figure 3-1).

Figure 3-1. Warning Stenciled on the Large Shields

Toxco and Commodore adhered to this warning while rigging the shields into the hot box for heating. The concrete saddle was left in the hot box under the shield during heating to stabilize the shield. Commodore and Applied Reactor Technology personnel, unaware that an overpressurization condition would exist in the shield during heating, did not recognize that the saddle would exert a restraining force on the shield as it expanded due to the expansion of the melting sodium, thus causing a stress concentration to occur. A stress analysis of the restrained shield (see Section 2.3) indicates that the concrete saddle caused stress concentrations at the aluminum/concrete interface point that likely led to the failure of the shield.

In addition, the hazard identification and assessment process used by Toxco and Commodore was ineffective. The Board reviewed Commodore's *Corporate Health and*

Safety Plan (Corporate HASP), the Toxco *Site Specific Health and Safety Plan* (HASP), and the Toxco ISMS description for the Toxco jobsite at ETTP. None of these documents address the specific scope of work associated with the sodium processing campaign performed at the Toxco jobsite. Each CROET sublessee is required to submit a HASP for the work to be performed by the tenant. BJC has provided guidance to CROET as to what such HASPs should contain and what they should address (Reindustrialization Business Practice IOM-RI-BP-15, *Preparation of Lessee Health and Safety Plans*, Revision 0, dated June 2, 2000). The BJC guidance cautions that changes in a lessee's operations may require revisions to the HASP. In addition, the Toxco ISMS description stipulates that specific HASPs are be developed for projects that differ from the general site activities, requires that each operation be analyzed for the hazards identified to be present on the job, and provides criteria for performing a hazards analysis and approving a HASP. Finally, the Commodore Corporate HASP also stipulates that a task-specific HASP is required to perform work on DOE property.

The Board determined that no task-specific hazard analysis had been conducted for the work performed the day of the accident. Although Toxco had a site HASP and had conducted a superficial hazard identification and evaluation as required by its sublease with CROET, both Toxco and Commodore failed to follow their existing corporate commitments and BJC's guidance to conduct a task-specific hazard analysis for the sodium processing campaign. Processing reactive sodium by heating, melting, cooling, and solidification was well beyond the normal scope of work performed by Toxco at its jobsite. While Toxco relied on Commodore to provide the requisite expertise to perform the sodium transfer function, Toxco failed to ensure that the necessary task-specific hazard analysis was in place prior to allowing Commodore to begin work. Similarly, Commodore lacked radiological work practice expertise and experience and relied on Toxco to provide that necessary expertise, but Commodore also failed to ensure the necessary task-specific hazard analysis was performed. The Board notes that the Teaming Agreement signed in March 2003 between Toxco and Commodore fails to identify the party responsible for hazards identification and analysis. This omission likely contributed to the failure to conduct a task-specific hazard analysis. Each entity in the Teaming Agreement relied on the other's hazard analysis, without verifying to confirm it had been done, or done properly.

The Board concludes that both Toxco and Commodore failed to effectively analyze all the hazards associated with the scope of work. This failure was partially attributable to a lack of important technical information about the work to be performed.

3.1.3 Develop and Implement Controls

Controls for processing liquid sodium typically include the following:

- Use of an inert atmosphere
- Special training, Personal Protective Equipment (PPE), and portable firefighting equipment (Class D extinguishing agent) for the workers
- Work procedures and worker training

- Controls on the temperature of the sodium
- Means to prevent the molten sodium from contacting water or moist air

Controls for any radioactive hazards present in the shields included PPE, radiological surveys, sampling, postings, procedures, and worker training.

Although unaware of the overpressurization hazard, Commodore anticipated the potential failure of the shields during heating. Commodore contracted with Applied Reactor Technology to design the hot box and the ancillary power, heating, sensing, and control systems to heat the sodium in the shields to a molten state and drain it from the shields. The Board notes that the Applied Reactor Technology Engineer who designed the hot box and assisted in its construction lacked sodium-processing expertise but had designed similar processing systems and containments for Commodore for several years. Commodore was to provide the necessary sodium expertise to produce a satisfactory design.

The hot box design included insulated walls and floor designed to retain a heated atmosphere and provisions to inert the atmosphere with nitrogen during heating. The hot box was designed, or expected, to rest on the ground. The design also included a pan-shaped secondary containment (also referred to as the bathtub) to retain the full capacity of sodium from the larger shields should the shield integrity fail during heating. The secondary containment was designed as an integral part of the hot box, and it was originally to be constructed entirely of carbon steel with welded seams at all joints. However, during construction and fabrication of the hot box, Commodore and Applied Reactor Technology elected to modify the design to allow access into the secondary containment to facilitate loading the smaller-sized shields into the hot box with a forklift. This modification changed one wall of the secondary containment to incorporate a double door with a removable threshold and center post. The modified design relies on silicone caulk to form a resilient rubber gasket and seal the hot box door to retain the nitrogen cover gas during the heating cycle and to retain any molten sodium in the secondary containment until the sodium cools and solidifies. During the accident, the shield failed and released molten sodium into the secondary containment. The silicone door gasket then failed to function and released liquid sodium from the hot box into the environment. This release led to the exothermic reaction that constituted the accident.

Commodore and Applied Reactor Technology also developed the procedure to heat the shields, collect the molten sodium into DOT-compliant containers (55 gallon drums), and allow it to solidify within those containers. Emergency response procedures were also developed. Commodore trained its workers and provided PPE appropriate for the hazards, as well as Class D extinguishers at the worksite. However, the procedure to heat the shields was not developed with an awareness of the overpressurization hazard of the shields and, therefore, did not include provisions for relieving pressure as the shields were heated.

Since the accident scene is still in recovery phase, the Board was unable to gain access to the hot box and inspect the condition of the silicone gasket. The gasket obviously failed to perform and released molten sodium to the environment during the accident. However, it is not currently possible to determine if that failure was due to an inadequate design, to

inadequate installation, or both. The Board determined that the Applied Reactor Technology Engineer did not conduct any reviews of the silicone caulk for incompatibilities with hot sodium and relied on Commodore to specify the caulk to be applied. Commodore relied only on the temperature rating of the caulk (400°F) to retain any molten sodium and did not evaluate the caulk for compatibility with hot sodium. The Board reviewed the specifications of the silicone caulk material that was used and found no material incompatibilities between molten sodium and the silicone caulk.

The Board concludes that Commodore and Applied Reactor Technology failed to adequately design and/or install the silicone door gasket system.

3.1.4 Perform the Work Within the Controls

Commodore looked upon this first shield processing evolution as a "pilot" process and expected to identify procedure and design improvements to be implemented during subsequent processing campaigns. As a result, Commodore operators, working in close consultation with the design engineer and Commodore management, modified the procedure during processing. In like manner, Commodore and Applied Reactor Technology modified the design of the secondary containment during fabrication.

During installation of the processing system at the Toxco jobsite, Commodore and the Applied Reactor Technology Engineer noted the presence of standing water on the ground as the result of the recent heavy rains. This condition persisted over several days, throughout much of the installation process. Concerned about the potential for a problem should any molten sodium come into contact with the standing rainwater, a decision was made to raise the hot box onto a platform (the scale) approximately one foot off the ground. In addition, a tent structure was built over the installation to protect the operation from rainwater.

Commodore personnel installed the silicone gasket in the door of the hot box prior to starting the heating process. Commodore personnel also inspected the shields prior to commencing heating. During preparations to conduct the heating cycle, Commodore tested the integrity of the secondary containment by "float testing" to ensure the integrity was adequate. The Board could not ascertain how this testing was performed.

During heating, the recorded thermocouple readings indicated significant drops in the recorded temperatures of the thermocouples located in the bottom of the shield. Operators noted this occurring during the night hours of Wednesday and Thursday when the local air temperatures dipped into the 50s and 60s. The operators and the Applied Reactor Technology Engineer attributed these lower-than-expected thermocouple readings to the higher-than-expected amount of convective heat loss through the floor as a result of the change to the installation of the hot box. In an attempt to compensate for the heat loss and increase the temperature of the sodium in the lower portion of the shield, operators increased the setpoint of the hot box heaters several times, up to 339°F by the early morning of the accident. This setpoint was 114°F above the temperature specified in the approved heating procedure, and it was applied to the hot box and shield for approximately the last 10 hours

prior to the accident. Although no evidence was provided to the Board by Commodore to indicate that the increases in the temperature setpoint were evaluated, the Board's sodium expert determined that the changes would not have affected the outcome.

After the shield was placed into the hot box, Commodore sampled the sodium and provided the sample to Toxco in a glass container. The Board was unable to determine if the sampling was performed under proper radiological controls. The sodium in the sample was immersed or otherwise covered with oil. Toxco accepted the sample and transferred it to a local radiochemistry laboratory for analysis, where the sample was analyzed by gamma spectroscopy. This sampling evolution was undertaken to determine if the sodium could be released from radiological controls. Once the sample results were analyzed, Toxco determined that the sodium no longer needed to be controlled as a radioactive material. Subsequent operations with the shield were conducted without radiological controls.

The Board notes the sample information provided by Toxco indicates that normal quality assurance/quality work control procedures had not been performed on the sample and that it was only counted for 30 minutes. In addition, portions of the sample data report are identical to the data report provided for the analysis of several personnel lapel (breathing zone) samples taken after the event. Toxco could not explain these discrepancies to the Board's satisfaction, and the Board's Health Physics Advisor expressed concerns about the sample protocol apparently used by Toxco.

Without having access to the hot box, the Board could not ascertain the exact failure mode of the shield. Without this information, the impact of the higher heating temperatures cannot be determined. Similarly, it is not possible to determine the impact of the change in hot box installation (raising it off the ground and possibly inducing unexpected heat loss through the hot box floor). It is clear that the low thermocouple temperature readings in the lower portion of the shield led to the heating period of the shield continuing longer than planned or expected. This may have been the result of heat loss through the floor due to the elevated position of the hot box relative to the ground. The higher heat introduced to the hot box in an attempt to overcome this problem, coupled with stress concentration in the shield caused by the restraining influence of concrete saddle and the longer time at these higher temperatures, may have led to the failure of the aluminum shield container. However, the Board could not determine this with certainty.

The Board concludes that the work was not performed within the established controls. Specifically, the installation of the hot box was changed, and the heaters' setpoint for the hot box was set higher than allowed by the approved procedure. However, the Board could not draw a conclusion regarding the contribution of these changes on the accident.

3.1.5 Provide Feedback and Continuous Improvement

ORO's feedback and improvement mechanisms for DOE contractors include assessment and corrective action processes and lessons learned processes. ORO does not require CROET to ensure that lessons learned are disseminated to tenant organizations.

Assessment and Corrective Action Processes

In 1997, the Office of Oversight conducted a Safety Management Evaluation at ETTP that included a review of the tenants. The report concluded the following:

- ORO needs to clarify DOE's safety roles, responsibilities, authorities, and accountability for tenants at ETTP.

- The Reindustrialization Program needs to be implemented in a more controlled, systematic manner to ensure identification of Environment, Safety, and Health (ES&H) requirements.

- The Reindustrialization Program needs to be implemented in a more controlled manner to ensure effective oversight.

Since 1997, ORO has taken many actions to address issues pertaining to tenants at ETTP. For example, ORO was organized so that the AU organization receives program direction directly from the Chief Operating Officer, a process for Consultation and Assist Visits was implemented to foster safety at tenant facilities, and ORO Manual 110, *Oak Ridge Operations Organization Manual* (ORO Manual 110), was revised, in part, to clarify ORO's responsibilities and authorities for tenant activities.

During its investigation, the Board identified deficiencies in defining and implementing responsibilities and authorities to ensure safety oversight; clearly defining, flowing down, and implementing safety requirements for the tenants' activities; and overseeing Toxco/ Commodore to ensure safe operations.

The Board concludes that the corrective actions implemented by ORO to address tenant issues identified by the Office of Oversight were inadequate.

Lessons Learned and Feedback Processes

The Board reviewed the communication, dissemination, and use of lessons learned and the feedback mechanisms associated with the disposition of sodium shields. ORO Manual 110 states that development and implementation of an effective lessons learned program for AU is the responsibility of the Technical Oversight and Implementation Division.

The Board searched for information and reports pertaining to the sodium shields and sodium operations that were available to ORO. The following reports obtained by the Board were readily available and contain information that would have been useful to Toxco and Commodore in understanding the nature, extent, and character of the shields:

- *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge, Tennessee* prepared by Tetra Tech and issued in April 2003

- *Nuclear Engineering Analysis of Shields* prepared by Westinghouse Safety Management Solutions Mid-America LLC in July 2003

- *ALARA Evaluation of Proposed Metals Recycling of Sodium Hydride Shields at the Tower Shielding Facility Located at ORNL* produced in 1999 by Science Applications International Corporation (SAIC)

These reports were not made available to Commodore prior to the design of the sodium transfer process. Commodore was provided with a copy of the *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge, Tennessee* on May 19, 2004. After reviewing the report, the Commodore President contacted the Board and stated that he would have modified the sodium transfer process based on the information contained in the report.

The Board concludes that AU did not have effective mechanisms in place to identify the information on the nature, extent, and character of the sodium shields.

Since 1999, eight Type B Accident Investigations have been conducted of contractors performing work for ORO, not counting the two investigations in May 2004. The root causes of these accidents are shown in Table 3-1 on the following page. The Board identified deficiencies in ISM during this investigation, including deficiencies in the ISM core functions that contributed to the accident on May 8, 2004

An objective of the DOE Accident Investigation Program is to prevent recurrence of accidents. To achieve this objective, accidents are investigated and the systemic causal factors of the accidents are identified so that lessons learned from the investigation can be developed, communicated, disseminated, and used to prevent recurrence. Lessons learned from accidents are intended to be used to prevent similar accidents from happening across the DOE complex, regardless of the organizational structure, contract mechanism, or work activity. To ensure application and use of lessons learned, mechanisms must be established and fully implemented to promote accident prevention.

The Board concludes that communication, dissemination, and use of lessons learned from previous ORO Type B Accident Investigations were inadequate.

The contract (Task Order) for disposition of the 54 sodium shields has a "Performance Based Statement of Work" section that requires Toxco to process the bulk sodium materials within 180 days from taking possession in accordance with all applicable laws, including the Occupational Safety and Health Administration (OSHA) and DOT, and to have a quality assurance program that is compliant with NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*, dated 2000 (NQA-1). During the conduct of this investigation, the Board identified noncompliances with OSHA and DOT regulations. For example, DOT brought an enforcement action against Toxco for noncompliant shipment of the shields, which resulted in a civil penalties being paid by Toxco. In addition, Toxco does not have a Quality Assurance Program (QAP) that is compliant with NQA-1. Appendix E

includes the report from the review of the Toxco QAP that was performed by two ORO Senior Quality Assurance Engineers.

Toxco violated the terms and conditions of its contract with ORO, and even after DOT brought an enforcement action against Toxco, AU management did not follow-up to ensure that Toxco was qualified to perform all tasks within the scope of work in the contract.

The Board concludes that AU and the Contracting Officer for Toxco did not provide feedback or consequences to Toxco for violating the terms and conditions of its contract with ORO after the DOT enforcement action.

Table 3-1. Root Causes of ORO Type B Accident Investigations Since 1999

Accident	Root Cause	Organization(s)	Event
12/17/2003 ETTP BNFL Inc. (BNFL) Employee Foot Injury	BNFL failed to implement an effective work planning process.	BNFL	Worker Injury
4/8/2003 ORNL Foster Wheeler Environmental Corporation (FWENC) Electrical Arc Blast	FWENC management ineffectively administered the change control process.	FWENC	Electrical Arc Blast
2/18/2003 ETTP BJC PPE Ignition Incident	BJC's and the subcontractor's work control process was inadequate.	BJC and Subcontractor	Multiple Events Requiring Investigation
6/27/2002 ETTP BNFL Exothermic Metal Reaction Event	BNFL's management systems and processes were not effective in preventing the tube bundle reaction and ensuring appropriate emergency response	BNFL	Multiple Events Requiring Investigation
9/7/2001 ORNL UT-Battelle, LLC (UT-Battelle) Burn Injury	ORO did not ensure that the contractor implemented the various components of ISM. The hazards of the tunnel washer were not evaluated, and the specific requirements applicable to the tunnel washer were not clear.	UT-Battelle	Worker Injury
11/15/2000 ORNL BJC Subcontractor Fall During Decontamination and Decommissioning Activity	The subcontractor failed to identify and analyze the hazards associated with the defective ladder and the level of PPE being worn while climbing the ladder	BJC and Subcontractor	Worker Injury

Table 3-1. Root Causes of ORO Type B Accident Investigations Since 1999 (continued)

Accident	Root Cause	Organization(s)	Event
10/2000 Portsmouth Site UT-Battelle Injury Resulting from Violent Exothermic Reaction at X-701B Site	1. UT-Battelle, BJC, and IT Corporation (IT) management failed to analyze the hazards for all field activities, which resulted in inadequate development and implementation of control measures for and knowledge of the potential hazards. 2. UT-Battelle, BJC, IT, and the two IT subcontractors on-site project personnel failed to implement the hazard controls and requirements stated in the project documents. 3. ORO, UT-Battelle, BJC, and IT management did not establish clear roles and responsibilities for the planning, execution, and oversight of the project. 4. ORO, UT-Battelle, BJC, and IT management did not establish or ensure a safety culture that implements ISM and encourages personnel to stop and re-enter the analysis phase when a change or unexpected condition arises.	UT-Battelle, BJC, IT, and Subcontractors	Worker Injury
3/26/1999 ETTP BNFL Worker Injury	Failure to implement the requirements of Enhanced Work Planning	BNFL	Worker Injury

3.1.6 Emergency Preparedness

Two BJC site procedures (BJC-EP-3022, *Preparation/Maintenance of Emergency Management Hazards Surveys, Hazards Assessments and Emergency Action Levels*, Revision 2, and ETTP-3514, *ETTP Protective Action Decision Making*) provide requirements for preparing, reviewing, approving, and maintaining Emergency Management Hazard Surveys (EMHSs) and Emergency Management Hazard Analysis (EMHAs) and the associated Emergency Action Levels (EALs). These site procedures also provide the requirements for development and issuance of protective action direction to on-site personnel and recommendations to off-site emergency management officials during emergency events. However, leased facilities are not subject to these requirements. There are no facility-specific or discretionary EALs are in place for accidents involving the sodium

operation at the Toxco jobsite. The PSS used the *Operational Emergency Categorization and Classification Guide* for declaring the Operational Emergency and the *Emergency Response Guide Book* that provides the Emergency Response Protective Guide-2 for sodium.

Two key, applicable BJC emergency management procedures (*Reindustrialization Business Practices for Tenant Regarding Emergency Preparedness and Response*, Revision 1, dated April 29, 2002, and BJC-EP-3022, *Preparation/Maintenance of Emergency Management Hazards Surveys, Hazards Assessments and Emergency Action Levels*, Revision 2) do not require sublessees like Toxco to use similar requirements for the preparation, maintenance, and use of hazard surveys and hazard assessments, even though the hazardous materials were present at the Toxco jobsite in quantities that could potentially pose a serious threat to the safety of the workers and the public.

The EMHS process assists with the identification of hazardous materials in buildings/ facilities in quantities that pose a serious threat to the safety of the workers and the public. Screening thresholds were not defined for the hazardous material (sodium) at the Toxco jobsite, and no criteria were established for determining if a quantitative analysis or EMHA was needed.

The Board concludes that no requirements exist for preparing, reviewing, approving, and maintaining EMHSs and EMHAs and the associated EALs for sublessees at ETTP.

The BJC document IOM-RI-LF-02-360-BP-12, *Reindustrialization Business Practices for Tenant Regarding Emergency Preparedness and Response*, Revision 1, dated April 29, 2002, describes how emergency preparedness and response are handled for lessees at ETTP and the requirement for portable fire extinguisher training. The Board requested but did not receive training records that show that Commodore workers have completed training in accordance with Title 29 Code of Federal Regulations (CFR) 1910.157, *Portable Fire Extinguisher*. On the day of the accident, Commodore workers attempted to extinguish the exothermic reaction without also pulling the fire alarm, which was inconsistent with Commodore's fire emergency procedure.

The Board concludes that Commodore's workers did not have required training per 29 CFR 1910.157, Portable Fire Extinguisher, and failed to fully implement Commodore's fire emergency procedure.

3.2 Management Systems

3.2.1 Contract Requirements

Basic Ordering Agreement

A BOA was signed between ORO and Toxco on December 16, 2002 (DE-AK05-01OR22876). Article 4, "Site-Specific Terms and Conditions," of the materials disposition BOA with Toxco states, "The Contractor agrees that the organization placing an order (task)

under this BOA reserves the right to incorporate its own local site-specific terms and conditions relative to Environmental, Safety and Health considerations as well as FAR, Agency-specific regulations, or other applicable regulations and laws." In addition, Section E.1 of the BOA states, "Inspection and acceptance of all items delivered under this BOA shall be accomplished by the federal organization issuing the order." Section E.2 defines "services" as "includes services performed, workmanship, and material furnished or utilized in the performance of services." Appendix A, "Statement of Work For Materials Disposition, ESH&QA . . .," states that the ES&H and quality assurance requirements will likely vary with each Task Order, depending on what work (if any) will be performed on the government's site.

Although a BOA is not in itself a contract (as mandated by Federal Acquisition Regulation 16.703), ORO issued a specific Task Order under the materials disposition BOA to Toxco on September 30, 2003. The ORO Office of Chief Counsel determined that acceptance of the Task Order, which also invokes the BOA, formed a contractual relationship between ORO and Toxco. This contractual relationship was not understood by multiple organizations in ORO; BJC, which is ORO's prime contractor for EM and which has reindustrialization support responsibilities in its contract Statement of Work; CROET, who subleased the property to Toxco; Toxco, who was required to receive, transport, process, and disposition the sodium shields; and Commodore, who was a teaming partner with Toxco to process the sodium. This confusion resulted in the Toxco contract not being managed as a contract. ORO AU personnel believed their responsibilities ended when the title to the sodium shields transferred to Toxco at the time the shields were moved from ORNL to ED-2 at ETTP (as stipulated by the Task Order).

The Board concludes that the BOA and associated Task Order process is not clearly understood by all organizations involved in this accident.

Task Order

The Statement of Work in the Toxco Task Order (DE-AT05-03OR22982) states, "Contractor shall provide the following service: Disposition of 54 containers of sodium located at the Oak Ridge National Laboratory." The Task Order also stipulates that the contractor will have a QAP that is compliant with NQA-1. In addition, to prequalify to bid on the BOA that covered this Task Order, the bidders were required to have a QAP that is in compliance with NQA-1. Two ORO Senior Quality Assurance Engineers reviewed Toxco's QAP. The scope of the review was to determine if Toxco's QAP, Revision 3, dated December 29, 2003, is compliant with NQA-1. The reviewers determined through examination of Toxco's documents that only Requirement 16, "Corrective Action," which is addressed in Section 17 of the QAP, is fully met. Requirements 1, 2, 4, 6, 7, 8, 9, 12, 17, and 18 are considered to be minimally acceptable against the basic requirements of NQA-1. A large contributor to the minimal acceptance is the pervasive use of "may," "may be," "generally include," and "may include" instead of "shall" or "will," which allows too much flexibility in meeting the basic requirements. Seven basic requirements (Requirements 3, 5, 10, 11, 13, 14, and 15) of NQA-1 are not adequately addressed in the Toxco QAP.

Appendix E contains the full report detailing the approach and results of the NQA-1 review of the Toxco QAP.

AU conducted an audit at Toxco on February 6–7, 2001. The objective of the audit was to verify that Toxco could meet the current contractual requirements outlined in the BOA Request for Proposal and operate in a safe and compliant manner. The report states, "Adherence to ASME NQA-1 requirements applies to tasks under this DOE Basic Ordering Agreement (BOA) as radioactively contaminated scrap materials may be received and processed by ToxCo. The audit team evaluated procedures and implementation for effectiveness in complying with NQA-1 requirements. As the Scope of Work for this facility is somewhat limited as is current activities, a graded approach was taken to evaluate practical implementation of necessary requirements." However, the report does not state what activities affect quality or what the controls would need to be using the graded approach. Deficiencies were noted as a result of the review, and AU requested a CAP from Toxco. Toxco provided the CAP by letter dated March 1, 2001. The AU Facilities and Materials Reuse Division reviewed the CAP, performed a verification visit, and concluded that the audit findings had been satisfactorily answered. This information was forwarded to Toxco by the ORO Contracting Officer on March 9, 2001, and is Toxco's approval as a BOA bidder. However, a review of the CAP indicates that Toxco's implementation of the corrective actions extended three months past the date of the ORO letter approving their CAP. NQA-1, Part 1, "Introduction," states that the application of these requirements should be fostered in a manner consistent with the relative importance of the item or activity that could affect quality." In addition, "Activities affecting quality include siting, designing, procuring, fabricating, handling, shipping, receiving, storing, cleaning, erecting, installing, inspecting, testing, operating, maintaining, repairing, refueling, modifying and decommissioning."

The Board concludes that Toxco does not have a QAP that is compliant with NQA-1, which is a contract requirement.

The Task Order states, "Title to the materials shall pass to the contractor upon removal from ORNL." AU personnel involved with the BOA and the associated Task Order stated it was their belief that ORO's responsibility ended when Toxco crossed the ORNL boundary with the sodium shields. The Task Order also stipulates that the contractor will survey, analyze, decontaminate (if required), recover, and disposition the materials at its "off-site facility." Toxco's off-site facility in this case was the DOE property at ETTP that had been leased to CROET and subsequently subleased to Toxco. With the title transfer and the belief that Toxco's activities were officially considered off site because they were under a sublease arrangement, AU personnel believed they had no responsibilities associated with the conduct of work under the Task Order other than normal responsibilities for a sublessee at ETTP.

The Board concludes that the misconception about ORO's responsibility ending with title transfer led to AU personnel not instituting their Roles, Responsibilities, and Authorities (RRAs) for this contract as stipulated in ORO Manual 110.

In the Task Order's "Performance-Based Statement of Work," Toxco is required to process the bulk sodium materials within 180 days from taking possession (Section B.1) in compliance with all applicable laws and regulations (Section B.2) and to dispose of all waste associated with the transportation and recovery of the material. Toxco took possession of the four large shields on November 1 and 2, 2003, and transported them to ETTP. Subsequent shipments of shields occurred early in 2004; however, there are still several shields located at ORNL that Toxco has not taken possession of. No documentation was provided by AU to indicate any directions/actions taken against Toxco for failure to comply with this 180-day requirement. In fact, interviews with AU personnel indicated that the requirement of 180 days was placed in the Task Order to help ensure that Toxco would take action to disposition the material rather than leave it in a storage area. Facilities and Materials Reuse Division personnel stated that as long as the AU organization was convinced that some action toward the goal of disposition was being taken, the performance standard was being met.

Toxco moved four large shields from ORNL to its facility at ETTP on November 1–2, 2003. Toxco's shipments were not made in compliance with DOT's hazardous materials safety regulations. DOT brought an enforcement action against Toxco for the noncompliant shipments, which resulted in a civil penalty being paid by Toxco. The contract states that work will be performed in accordance with all applicable Federal and state regulations.

The Board concludes that Toxco did not meet the criteria in the "Performance Based Statement of Work" to "process the bulk sodium materials within 180 days from taking possession" and failed to comply with Federal regulations during performance of the transportation task.

In order to accomplish the sodium transfer from the shields to DOT-approved shipping containers, Toxco signed a Teaming Agreement with Commodore on March 28, 2003. This Teaming Agreement stipulates that Commodore will comply with all applicable government regulations. However, the "applicable government regulations" are not clearly documented in the Teaming Agreement. In addition, there is no specific requirement in the Teaming Agreement to flow down DOE contract requirements to Commodore for work conducted within the stated scope of work.

The Board concludes that Toxco failed to define and flow down the appropriate requirements to its teaming partner, especially with regard to safety requirements and expectations.

3.2.2 Lease Requirements

CROET Lease With DOE

DOE and CROET's current lease agreement (REORDOER-1-97-0506) for the ED-2 parcel (which is a representative example of these lease agreements) states the terms and conditions whereby the lease or sublease(s) can be terminated by DOE. These conditions include (1) failure to comply with terms and conditions of the lease, (2) mission changes, and (3) failure

to comply with approved environmental documentation. Section 8 of the lease authorizes the lessee to sublease to sublessee(s) who will assume all of the duties and obligations of the lessee under this lease. In Section 38 of the lease, the lessee is also directed to comply with OSHA regulations, specifically 29 CFR, and have a HASP. There are no specific requirements (other than the language in Section 8 previously mentioned) for CROET to flow down safety requirements**.**

CROET Sublease with Toxco

CROET entered into a sublease with Toxco on July 28, 1999, to lease property at ETTP (Sublease 9912HER-03). In Section 1 of the sublease, CROET stipulates that the sublessee has thoroughly reviewed ". . . the terms of the Lease that affect the Sublessee's rights to and obligations arising from use of the premises are acceptable to Sublessee." Section 3 of the sublease identifies the terms and conditions whereby DOE or CROET may terminate the sublease, and these are similar to the conditions in the CROET lease with DOE for the property. Other than the vague language contained in Section 1, there are no specific flowdown requirements cited in the sublease. Specifically, there are requirements stipulated to comply with OSHA regulations; however, the requirement to submit a HASP is not evident. The language in the sublease is very confusing, which makes it hard to determine exactly what is intended to flow down to the sublessee.

Toxco Teaming Agreement With Commodore

Toxco entered into a Teaming Agreement with Commodore on March 28, 2003, which delineates the responsibilities of each company with respect to the work to be accomplished. Section 1.9 under Article 1 "Proposal Preparation and Submission," states that "The parties shall comply with all applicable government regulations in performance of their obligations hereunder." No other requirements are flowed down in the agreement. Interviews with Toxco personnel indicated that the statement in Section 1.9 is intended to be all inclusive and appropriately flow down all of the requirements placed on Toxco as a resident at ETTP. However, since the sublease between CROET and Toxco is not clear with regard to Toxco's specific responsibilities under the CROET lease, the understanding of the flowdown of requirements in this Teaming Agreement is further removed.

The Board concludes that the requirements and the subsequent flowdown of those requirements in leases and subleases involving ORO, CROET, and sublessee(s) at ETTP are confusing and should be revised to specifically stipulate the appropriate flowdown requirements that are expected, especially with regard to safety requirements and expectations.

3.2.3 Roles, Responsibilities, and Authorities

Oak Ridge Operations Office

ORO's RRAs are defined by four key documents: ORO Manual 110; ORO M 100, *Management System Description*; ORO M 411.1-1E, *Manual of Safety Management*

Functions, Responsibilities, and Authorities, Level II, for Oak Ridge Operations; and individual position descriptions. Contained in these documents are AU's line responsibilities and accountabilities for identification of the appropriate safety requirements in contract documents which, when implemented, ensure the safe execution of the assigned scope of work. Under the contract (Task Order) with Toxco, the Facilities and Materials Reuse Division has the responsibility to ensure that the NQA-1 requirements covered by the contract flow down to Toxco and for ensuring that such requirements are implemented for activities within the scope of work. AU is also responsible and accountable for verifying all contract performance, including verifying that all Federal, state, and local regulations and all contract-specific requirements are implemented.

The ORO organization manual (ORO Manual 110) states that the line organization has the lead for ES&H, with AMESH providing support. The Board was not provided any additional documentation that further defines the ES&H roles and responsibilities between these two ORO organizational elements. In the absence of defined relationships between AU and AMESH for day-to-day execution of assigned work, AU has the opportunity (but no mandate) to call upon AMESH for support in meeting its ES&H responsibilities, including conducting assessments to provide feedback to the ORO Manager, Chief Operating Officer, and AU line managers regarding the effectiveness of ES&H activities. AU has exercised that opportunity by requesting AMESH's support of the OSHA-like Consultation and Assist Visits. The Consultation and Assist Visit process is organizationally structured; however, the process has not been fully implemented, is confused within ORO regarding enforcement, and has resulted in the ineffective implementation of safety in the AU line organization. Figure 3-2 shows the organizational relationships between ORO, CROET, Toxco, and Commodore for the work being conducted on the day of the accident.

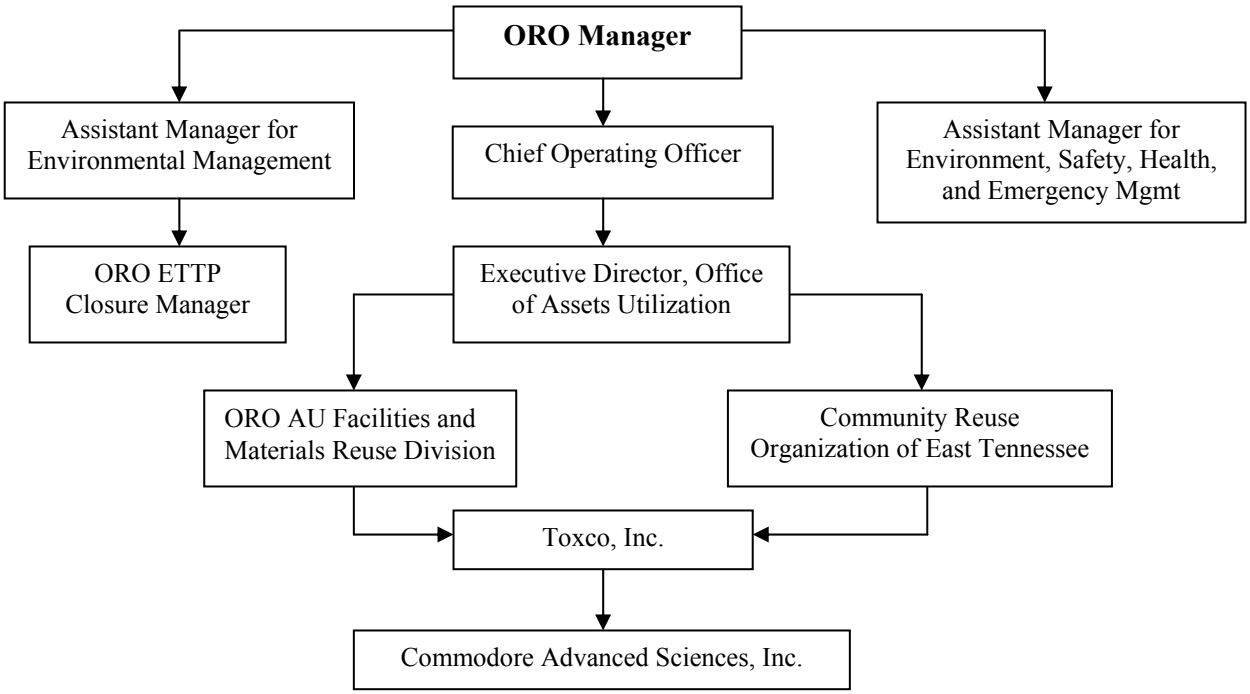

Figure 3-2. Organization Chart for Work Performed by Commodore

In addition, AU has the opportunity to call on EM Facility Representatives to conduct walkthroughs and assessments of operations and to identify hazards and incidents of noncompliance with standards, guidelines, and approved safety bases/authorization basis documents and potential problems areas where a more thorough inspection is warranted. In addition, the Facility Representatives can be called upon to monitor changes to the facility from construction, maintenance, and temporary modifications. To date, the EM Facility Representatives have not been officially requested to support AU's reindustrialization mission.

As stated in the contract section of this report (Section 3.2.1), AU failed to ensure that Toxco complied with all requirements of the contract (Task Order) Statement of Work. The analysis of Toxco's QAP performed by two ORO Senior Quality Assurance Engineers determined that Toxco's quality assurance documentation only fully meets 1 requirement out of the 18 NQA-1 requirements. The line organization (the Facilities and Materials Reuse Division Contracting Officer's Representative [COR]) is responsible and accountable for ensuring that all contract terms and conditions are fully implemented. However, the organizations involved in this accident did not understand that a contractual relationship existed.

ORO EM has a prime contract with BJC for the accelerated closure of ETTP. In accordance with the Statement of Work for the closure contract, BJC provides support to the AU organization's mission for reindustrialization. The RRAs are not clear between EM and AU with regard to the AU reindustrialization mission as defined in EM's accelerated closure contract.

The Board concludes that ORO failed to ensure clear RRAs between AU and AMESH and between AU and EM.

The Board concludes that AU management failed to ensure that the Facilities and Materials Reuse Division's responsibilities were fully implemented for the Statement of Work in the contract.

Community Reuse Organization of East Tennessee

DOE and CROET entered into a lease for the ED-2 parcel on September 15, 1997. CROET and Toxco entered into a sublease on July 28, 1999, for the ED-2 parcel. Operations Management International provides safety and health support to CROET and the tenants at ETTP by assigning its ES&H Director (referred to as the CROET health and safety representative) to support CROET and tenant activities. However, no documentation was provided to the Board that delineates these responsibilities. Basically, CROET has the responsibility to flow down the requirements in the leases to the sublessees and to ensure the requirements are implemented, including ensuring that each tenant has a HASP. The Board notes that AU is the DOE lead for ensuring flowdown and implementation of requirements.

The Board concludes that CROET failed to document the RRAs of CROET personnel/ representatives with regard to safe execution of tenant operations.

Bechtel Jacobs Company LLC

The BJC Reindustrialization organization is comprised of a Reindustrialization Manager who reports directly to the BJC Vice President and General Deputy Manager, and three subtier organizations (Regulatory Affairs, Account Executives, and Planning and Controls). The current BJC Reindustrialization organization chart is dated March 29, 2004, and was approved by the Acting Manager, BJC Reindustrialization. The organization is fully staffed by individuals who are on loan from various BJC matrix organizations. Each employee has a position description with regard to his or her responsibilities under the functional area in the matrix organization. The Board requested but was not provided with formal documentation describing the BJC Reindustrialization organization's mission, objectives, charter, or purpose. Specific RRAs associated with the BJC Reindustrialization organization do not exist.

The Board concludes that BJC failed to define the RRAs of the Reindustrialization organization as required under ISM.

Toxco, Inc.

Toxco has specific responsibilities under its CROET sublease and under the ORO contract (Task Order). Toxco failed to comply with all the requirements of the contract (see Section 3.2.1 above). Toxco and Commodore have a Teaming Agreement. According to this agreement, Toxco is responsible and accountable for the following:

- BOA qualifications
- Radiological decontamination services
- Radiological engineering and health physics
- Metals decontamination and declassification
- Securing supplies of metals and metal materials
- Performing classified work for government agencies

Toxco has a documented Hazardous Communication Plan and a site-specific HASP. Toxco is responsible and accountable for overall safety at the jobsite. In addition, Toxco has a QAP. The QAP states, "Specific plans and methods of accomplishment are presented in Project Work Plans for a particular project." No Project Work Plan covering the contract scope of work was provided to the Board. No other formal documentation was provided to the Board that delineates the roles and responsibilities for carrying out the contract (Task Order), the sublease requirements, or the Teaming Agreement.

The Board concludes that Toxco's RRAs for safe disposition of sodium are not clearly defined.

Commodore Advanced Sciences, Inc.

The Teaming Agreement between Toxco and Commodore states that Commodore is responsible and accountable for conducting activities with regard to the following:

- Handling sodium materials
- Disposing of sodium materials
- Personnel trained to handle sodium material
- Processing sodium materials

Commodore has a Corporate HASP which requires that a site-specific HASP be prepared. The site-specific HASP is to be developed based on the framework outlined in the Corporate HASP and on an activity hazard analysis. During the conduct of the investigation, the Commodore President and the Chief Executive Officer of Commodore Applied Technologies, Inc., told the Board that they expected their employees working at ETTP to follow Toxco's HASP.

Commodore's *Safe Work Plan #6, Emergency Plan* states that potential emergency situations and swift response to those emergencies are the responsibility of all field team members, and the plan further states that the Project Supervisor is in charge of all treatment activities and is the lead Commodore safety representative. The Project Supervisor has the authority to stop any Commodore-related activity posing an immediate threat to health and/or the environment. The Commodore Project Manager is responsible for ensuring that operations involving sodium transfer equipment system are conducted safely and that personnel are aware of potential emergencies situations. Thus, the Commodore Project Manager was responsible for all sodium transfer activities on the day of the accident.

The Board concludes that the Commodore managers with responsibility for the work being conducted did not enforce Commodore's corporate safety requirement to develop a site-specific HASP or to perform an activity hazards analysis.

Oversight to Ensure Safety of ETTP Tenants

Oversight of the tenants' activities at ETTP is covered through the responsibilities of the ORO AU organization (with support from the BJC Reindustrialization organization), CROET, the ETTP Site Safety Council, and the tenants. ORO Manual 110 contains responsibilities for the Assistant Manager for AU; however, that position has been abolished and replaced by the Executive Director position. The only document that delineates responsibilities under this position is contained in a position description. A comparison of responsibilities in the position description against the responsibilities listed in ORO Manual 110 for the Assistant Manager for AU appears comparable. Yet, instead of reporting to the ORO Manager, the AU Executive Director reports directly to the Chief Operating Officer (COO), who provides program direction and policy for AU's missions. However, the ORO Manager indicated to the Board that the actual reporting path of the AU Executive Director was to the Manager. The COO serves as the COR for the Reindustrialization portion of the BJC prime contract.

The three divisions in AU (Reindustrialization, Technical Oversight and Implementation Division, and Facilities and Materials Reuse) have varied safety responsibilities. The Reindustrialization Division has overall responsibility for the reindustrialization of ETTP. The Safety Advocate resides in the Reindustrialization Division. Per ORO Manual 110, the

Reindustrialization Division defines, clarifies, and formalizes roles and responsibilities with matrix organizations to ensure safety and maximize the effectiveness of matrix support. In carrying out this role, the Reindustrialization Division uses support from BJC to coordinate the program and from AMESH to help staff the Consultation and Assist Visits conducted at tenant organizations. The Reindustrialization Division also coordinates with the Technical Oversight and Implementation Division in identifying and analyzing hazards to ensure adequate controls are implemented and to properly categorize facilities. Based on comments from the CROET health and safety representative and the AMESH subject matter experts, the conduct of the Consultation and Assist Visits has not been as rigorous and comprehensive as a full OSHA compliance review.

The Technical Oversight and Implementation Division is responsible for performing ES&H audits and reviews of vendors and contractors engaged in asset recovery operations to ensure compliance with all applicable laws and regulations. However, during interviews with AU personnel, there was considerable confusion as to the intent of the ES&H audits for Toxco because it was the understanding of the AU staff and management that Toxco's work was being performed under a lease. One of the AU Project Managers stated the ES&H audits were intended to determine ES&H compliance but that he was not a safety expert. However, the Team Leader for the Technical Oversight and Implementation Division stated that the audits are not really ES&H audits, but instead the reviews are intended to focus on the real estate and its condition (i.e., whether the tenant had damaged DOE's property during its operations). The Safety Advocate in the Reindustrialization Division also indicated that the ES&H audits, as they relate to the Technical Oversight and Implementation Division's responsibilities, are not compliance audits for identifying ES&H compliance issues.

The Facilities and Materials Reuse Division is responsible for managing the National Program for Metals Recycling, including materials inventory and characterization, transportation, processing, marketing, and commercialization of reuse/recycling activities. In addition, the Facilities and Materials Reuse Division is responsible for ensuring that the contractor-executed functions are carried out in a manner that protects Federal and contractor personnel and the general public against ES&H hazards arising from the performance of contract functions.

The Board concludes that AU's ES&H responsibilities are not adequately defined and that confusion exists such that the responsibilities for ES&H oversight cannot be effectively implemented.

DOE's strategy for safety and health oversight of leased/subleased property at ETTP was initiated May 9, 1997, in a point paper recommending that the ORO Manager implement an oversight program that would be structured after the OSHA Assistance and Consultation Program, with a few modifications. This strategy has continued over the years with a series of memorandums of understanding/agreement being rewritten as individuals in management roles have changed. Prior to August 2000, the ORO ETTP Site Manager was responsible for (1) providing safety oversight in the form of Consultation and Assist Visits and providing information from these visits to CROET for its information and appropriate action, (2) providing a DOE representative to the ETTP Site Safety Council and fulfilling DOE's

responsibilities as outlined in the Council's charter, and (3) providing an occasional presence in DOE-leased space to maintain a general awareness of lessees' activities and be available to help coordinate any safety assistance that might benefit the site occupants. On August 28, 2000, the ORO ETTP Site Manager informed AU that the Site Office would no longer carry out these responsibilities due to staffing level changes.

As a result of the transfer of responsibilities, AU continued the Consultation and Assist Visits with matrix support from AMESH, as needed. A schedule of visits was established whereby all tenant organizations would be reviewed each year. The AU Safety Advocate is responsible for coordinating the Consultation and Assist Visits. However, for about one year preceding the accident, the Safety Advocate was on numerous details and unable to perform all the responsibilities of that position. A member of AMESH has been fulfilling the role of coordinating the Consultation and Assist Visits with continued support from the subject matter experts in AMESH. The purpose of the Consultation and Assist Visits is stated as ". . . to assess the effectiveness of a tenant's occupational safety practices and accident prevention program." Based on statements from the CROET health and safety representative and the AMESH subject matter experts, the conduct of the Consultation and Assist Visits has not been adequate to assess the effectiveness of the tenants' safety programs. OSHA standards contain many requirements for private industry to maintain written procedures, training, and other records to help ensure a safe and healthful workplace. However, during the Consultation and Assist Visits, AMESH personnel have not been permitted to review procedural documentation. In some cases, they have been restricted from inspecting certain areas by the tenant, and this has been accepted by AU. This information was confirmed by the CROET health and safety representative.

Over the years, there has been some confusion among and between ORO organizations as to what constitutes a Consultation and Assist Visit, such as whether it is consultation and assistance or whether it is an OSHA-type inspection. The AU personnel interviewed stated that the Consultation and Assist Visits are tailored after OSHA's Assistance and Consultation Program. However, a review of the Department of Labor/OSHA Consultation and Assistance Program indicates a much different approach than the Consultation and Assist Visits conducted by AU. OSHA's consultative services include a full safety program review to identify safety and health hazards and suggestions for cost-effective hazard solutions. This no-cost service is designed to assist employers in developing or enhancing safety and health management systems. However, OSHA's consultative services are not initiated until a company requests a specific safety/health service.

AU personnel use the Consultation and Assist Visits to exercise their responsibility to ensure safe operations at tenant facilities, but this has not been successful due to the limitations placed on the reviewers performing the visits. In 1996, OSHA elected not to enforce its jurisdiction in ETTP tenant facilities because they are on DOE property, and it was agreed that DOE would have jurisdiction on its own property. However, on July 26, 2000, the DOE Headquarters Assistant Secretary for EH issued a letter to the Assistant Secretary of Labor for Occupational Safety and Health that transmitted signed copies of the *Privatization Memorandum of Understanding*. The memorandum of understanding applies to privatized facilities on DOE sites (1) that have been leased to private business sector enterprises which

are not conducting activities for or on the behalf of DOE and (2) where there is no likelihood that any employee exposure to radiation from DOE sources will be 25 millirems per year or more. When DOE determines that any privatized facilities meet the above two criteria and documents that decision to the Department of Labor, then OSHA will have jurisdiction over that facility/operation. This approach to transfer oversight jurisdiction to OSHA has been in place for four years, but it has not been used by ORO. However, it should be understood that the Toxco work which resulted in this accident was on behalf of DOE, so the *Privatization Memorandum of Understanding* would not apply.

The Board concludes that ORO's oversight of tenant organizations at ETTP is not formal.

Under the DOE lease with CROET for parcel ED-2, dated September 15, 1997, Section 38 covers occupational safety and health requirements. The lessee is required to comply with applicable OSHA standards and provisions, specifically 29 CFR. The lessee also, as a minimum, must maintain a HASP that identifies the "mitigative measures and controls for hazards that do not present an unacceptable risk [sic] to employees, site personnel, or visitors." The lease further stipulates that DOE may require a safety council in which DOE will participate for the purpose of providing assistance and consultation and representing DOE's interests in conducting safe operations. Section 8 of the lease authorizes the lessee to sublease to sublessee(s) who will assume all of the duties and obligations of the lessee under this lease. Specific safety and health requirements, however, are not discussed in the sublease between CROET and Toxco or in the Teaming Agreement between Toxco and Commodore. The only ES&H requirement that is specifically flowed down to CROET's sublessees is Condition 8 regarding environmental documentation or subsequent documentation that expands those parameters as set forth in Condition 12(c) of the lease, which is the Comprehensive Environmental Response, Compensation and Liability Act 120(h) report.

Through interviews and review of documentation, the Board determined that there was an understanding at all levels in the leasing process that sublessees were required to have a HASP. The ORO and BJC Reindustrialization Account Executives are responsible for addressing the standard and unique characteristics of each lease arrangement. BJC documents this process through several Business Practice documents that include requirements for the lessees to comply with OSHA requirements and prepare HASPs to meet certain requirements, and these Business Practices stipulate the review of those HASPs. These BJC documents are (1) IOM-RI-LF-02-360-BP-12, *Reindustrialization Business Practice for Tenants Regarding Emergency Preparedness and Response*, dated April 29, 2002, and (2) IOM-RI-BP-15, *Reindustrialization Business Practice – Preparation of Lessee Health and Safety Plans*, dated June 2, 2000. On November 15, 2002, the AU Safety Advocate sent a letter to CROET reaffirming the requirement that each lessee must submit a HASP. The letter states that all HASPs are required to meet the intent of the attached ETTP HASP guidance document. The letter further states that the AU Safety Advocate and the ETTP Safety Council would review the HASPs.

Toxco's HASP, Section III, "Work Site Safety Requirements," requires maintenance of safety records and documentation to include 29 CFR (OSHA) records such as the OSHA

200 Log, inspection documentation (as required) and documentation of employee training (as required). Other subsections include general requirements for radiological protection, fitness for duty, emergency exit plans, and PPE. Hazards for the jobsite at ETTP were evaluated in a job hazards analysis, and a checklist was provided delineating those hazards. A global statement is made that all employees are trained with regard to each hazard identified. However, under "Chemical Hazards," the only item checked is "Flammable." There is no indication in Toxco's HASP that reactive chemicals such as sodium will be on the jobsite. Furthermore, no mechanism exists in the Teaming Agreement to flow down the HASP requirements to Commodore.

The Board concludes that ORO, CROET, and the ETTP Site Safety Council review the tenant HASPs, but none of these organizations has the authority to approve the HASPs.

3.2.4 Moratorium/Suspension on Release of Surplus Metals for Recycling

Moratorium

On January 12, 2000, DOE Headquarters issued a press release stating that DOE had just placed a moratorium on release of DOE's volumetrically contaminated metals. Volumetrically contaminated metal has radioactive contaminants distributed throughout its mass. This action was taken due to concerns with the management of materials released from DOE facilities and concerns from the public that contaminated metals would enter commercial scrap metal processes used to manufacture consumer goods.

The January 12, 2000, press release by DOE was followed by a memorandum from the Secretary of Energy dated February 14, 2000, that is entitled "Release of Materials for Re-Use and Recycle." This memorandum states that the moratorium remains in effect at least until the Nuclear Regulatory Commission (NRC) makes a decision regarding whether to proceed with a Rulemaking that would set national standards for the release of solid materials. To date, the NRC has not established national standards for the release of these materials, and the moratorium is still in effect. The shield in the accident is comprised of activated metal and is, therefore, volumetrically contaminated and subject to the moratorium.

Suspension

The moratorium was upheld in the subsequent memorandums issued by the Secretary of Energy on July 13, 2000, and January 19, 2001. The memorandum issued by the Secretary of Energy on July 13, 2000, suspended the unrestricted release for recycling of metals from radiological areas within DOE facilities. In addition, the Secretary's January 19, 2001, memorandum directed further action in the following four areas:

- Improvement of the Department's release criteria and monitoring practices
- Expansion of efforts to promote reuse and recycling within the DOE complex

- Improvement of the Department's management of information about material inventories and releases
- The accelerated recovery of sealed sources

The suspension is to remain in effect until improvements in DOE's release criteria and information management are developed and implemented. The suspension is still in effect.

The purpose of the suspension is to prevent the release of large quantities of scrap metals with detectable levels of residual radioactivity from entering commerce for unrestricted recycle until the Department completes a re-evaluation of its procedures and policies regarding scrap metals. This suspension prohibits release of material for recycle if it is (or has been) stored in a Radiological Area as defined by 10 CFR 835.2. The suspension does not apply to volumetrically contaminated metal unless it was stored in a Radiological Area and, therefore, had the potential to also become surface-contaminated material.

The Board reviewed a number of radiological surveys and determined that, since prior to the suspension and until early 2003, none of the shields were stored in a Radiological Area. The large shield in the hot box on the day of the accident had never been in a Radiological Area.

Nine of the sodium shields involved in the Toxco Task Order for sodium shield disposition were moved from a Radiological Material Area into a Sea-Land container that is identified as a Contamination Area by BJC radiological surveys conducted February through May 2004. These shields are part of the 54 shields to be dispositioned by Toxco, but they had not been transferred to Toxco as of the date of the accident. These shields are subject to both the moratorium and the suspension.

Based on the evidence provided, the Board concludes that the shield in the hot box on the day of the accident was not subject to the Secretary of Energy's suspension, but it was subject to the Secretary of Energy's moratorium.

DOE Directive and Guidance to Implement the Moratorium and Suspension

The release of volumetrically contaminated material by DOE is governed by DOE 5400.5, *Radiation Protection of the Public and the Environment*, Chapter II, dated January 17, 1993. Although this Order is archived and has not been converted to the current three-digit Order system in the DOE Directives System, it is in effect and ORO's property release programs are subject to the responsibilities and authorities in this Order. This Order is also in the BJC contract with ORO.

The Order defines "Release of Property" as ". . . the exercising of DOE's authority to release property from its control after confirming that residual radioactive material (over which DOE has authority) on the property has been determined to meet the authorized limits and guidelines for residual radioactive material in Chapter IV or any other applicable radiological requirements. There may be instances in which DOE or other authority will impose restriction on the management and/or use of the property if the residual radioactive material guidelines of Chapter IV are not met or if other applicable Federal, State, or local

requirements cause the imposition of such restrictions." "Residual Radioactive Material" means "any radioactive material which is in or on soil, air, equipment, or structures as a consequence of past operations or activities."

Chapter II of DOE 5400.5 addresses release of materials and equipment with volumetric contamination in Paragraph II.5.c(6), which states, "No guidance is currently available for release of material that has been contaminated in depth, such as activated material . . . Such materials may be released if criteria and survey techniques are approved by EH-1."

In April 2002, EH-41 (formerly EH-412) issued a draft guide (DOE G 441.1-XX, Control and Release of Property With Residual Radioactive Material for use with DOE-5400.5, *Radiation Protection of the Public and the Environment*) for use and comment. Guidance for implementing DOE 5400.5 requirements for the release of property has been provided by EH-41 over the past ten years through individual memoranda, guidance documents and handbooks, and modeling and analysis tools. A principal objective of DOE G 441.1-XX is to integrate the key elements of these individual guidance sources into one document as a principal resource for DOE and contractor personnel.

This guidance is still in draft and, if finalized, is only guidance as to "suggested nonmandatory approaches for meeting requirements. Guides <u>are not</u> requirements documents and <u>are not</u> construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual."

As stated in DOE 5400.5, approval for DOE release of volumetrically contaminated metals must be made by the Assistant Secretary for EH (EH-1); however, DOE 5400.5 does not require EH-1's approval for transfers to an NRC licensee. This decision can be made at the field program level (e.g., ORO AU), and it requires DOE to ensure that the licensee is qualified to accept the material under their license.

Disposition Path and Compliance with the Moratorium

On April 17, 2003, a meeting was held with BJC, prospective bidders under the materials disposition BOA, and DOE to discuss the disposition options for the shields. The Board interviewed the BJC Radiological Control Manager who was present at the meeting. He recalled that there was discussion concerning DOE or BJC free-releasing the shields, since it was felt that there was sufficient justification to support a request to EH-1 and that the request could be approved based upon the significant decay of the activation products. However, this path was not given further consideration because the process would be too time consuming, and approval would have to come from EH-1 and could not be done locally.

Volumetrically contaminated metal is subject to the Secretary of Energy's moratorium and can be released from DOE's control for unrestricted use under the requirements in DOE 5400.5. The nonmandatory guidance in draft DOE G 441.1-XX stipulates that ALARA/dose-based derived authorized limits be established, reviewed, and approved by DOE Field Elements in coordination with the Program Office and submitted to EH-4 for

approval by EH-1. It further states that the submittal should be made at least 45 working days in advance of the required implementation date and that EH will respond within 30 days if there are any problems or concerns with the submittal. This process ensures that the Secretary's concerns for release of these metals into general commerce are addressed.

The consensus of the group in the 2003 meeting was that disposition of the shields would be left to an NRC licensee. Transferring volumetrically contaminated metal to an NRC licensee for release into commerce is not strictly prohibited under DOE 5400.5. However, it is the opinion of EH-41 that the disposition path used by AU to disposition the shields is not within the intent of the Secretary of Energy's moratorium, and although it is not necessarily a violation of DOE 5400.5, given the volumetric moratorium, this path should not be used unless adequate controls are placed on the material's end use.

The Team Leader for the AU Facilities and Materials Reuse Division told the Board that he made the decision to transfer the shields to an NRC licensee, and his decision was based on the fact that the shields had not been in a Radiological Area and were, therefore, not subject to the suspension. In his testimony to the Board, the BJC Account Executive stated, "The intent of this Task Order was to disposition the shields to an NRC-licensed company because BJC and DOE were not going to go through a free-release campaign." The Facilities and Materials Reuse Division Director told the Board that all of his division's activities are "vetted" by EH-41, but that in the case of the shields, EH-41 was not consulted because this was not seen as a precedent-setting case.

The Statement of Work in the Task Order for disposition of the shields states, "The contractor will survey, analyze, decontaminate [if required], recover, and disposition the materials in accordance with the contractor's radioactive materials possession license, if applicable, and other applicable regulatory requirements." The Statement of Work cautions the contractor that the steel shells are subject to the "Secretary of Energy's moratorium [sic]" regarding the release of surplus and scrap metals, but it is silent as to the aluminum shells and the Secretary's moratorium for release of volumetrically contaminated metals. The Statement of Work, Section D, does require the contractor to report the quantities of materials received, processed, recycled/reused, and dispositioned (by disposal method) for the Annual Mass Balance Report. The Annual Mass Balance Report is used to track DOE's release of metals and account for their use. DOE's ability to track the shields released into general commerce would end when the material was released from Toxco's control.

The September 11, 2003, memorandum from the Team Leader of the Facilities and Materials Reuse Division to the Contracting Officer provided the following evaluation: "ToxCo holds a license issued by the State of Tennessee to receive, process, and release materials from radiological control. All material will be surveyed, processed, and released by ToxCo at their site in accordance with their license criteria."

In Toxco's Radioactive Materials License amendment request to the State of Tennessee, Toxco states that "non-activated aluminum materials that may be released will be released in accordance with ToxCo's unrestricted release procedure and in accordance with the DOE restrictions on recycle of materials that may be contaminated." DOE did not indicate in the

Statement of Work that the material was subject to the Secretary of Energy's moratorium; therefore, no restrictions were placed on the material by DOE. By allowing all material to be released in accordance with Toxco's license, all restrictions on the end use of the material were removed, and all of the metal had the potential to be used in general commerce (e.g., used in consumer products).

Toxco's teaming partner, Commodore, does not have a Radioactive Materials License and, therefore, would only be able to accept sodium that was free released to it by Toxco. The Commodore President told the Board that it was the company's intention to "either accept the sodium for unrestricted recycling based on its demonstrated nonradioactive (and therefore not regulated as radioactive) nature or to use it for treatment activities at sites that could accept it under their own radiological licenses." When Commodore priced the work, consideration was given to both possibilities. Based on the extremely low radioactive concentration in the shields, the opportunity exists for all of the sodium and metal shells to meet free-release criteria under Toxco's license.

Once the contract (Task Order) was chosen as the vehicle for shield disposition, none of the evidence provided to the Board indicates that any more consideration was given to the Secretary of Energy's moratorium or the fact that the activated shields were subject to it. Subsequent decisions by BJC and AU were based on evaluating whether or not the shields were subject to the Secretary of Energy's suspension memorandum prohibiting unrestricted release of surface-contaminated material for recycle.

From prebid through award, the Statement of Work in the Task Order indicates that the shields' contents are activated with up to 1 pCi/g of Sodium-22. In addition, it indicates that the aluminum shells of the shields are activated with an unspecified quantity of Cobalt-60.

During the course of the Task Order award, the AU Facilities and Materials Reuse Division contacted Toxco to clarify issues relating, in part, to Toxco's ability to release the metal without restriction. Based on the information provided by AU, Toxco made decisions consistent with the expectation that the material would not be contaminated. Toxco modified its offer to DOE from $996,500 to $596,000. Part of the price adjustment was based on assurances from AU that the material was not radioactive, and if it were found to be radioactive, DOE would be responsible for the material.

Two months prior to the award of the Task Order, a BJC-commissioned technical report (*Nuclear Engineering Analysis of TSF Shields*) was issued in final form that characterized the 11- by 5-foot sodium shields as having up to 0.0008 pCi/g of Sodium-22 and activation products in the aluminum up to 0.0314 pCi/g. This information was not included in the Statement of Work in the Task Order, and Toxco personnel indicated they had never seen this information.

In a July 31, 2003, response to a modification request, Toxco modified its bid to include the condition that "DOE and/or their contractors will have responsibility for disposing of all activated sodium found within 30 days of notification that activated sodium is found." No mention was made of activation levels within the shield containers themselves.

Toxco was never informed that the metals are subject to the Secretary of Energy's moratorium on the release of volumetrically contaminated metals. Toxco was initially told that the material was subject to the Secretary of Energy's suspension but was later told that the material was not subject to the suspension because the material had not been in a Radiological Area. The Task Order places no restrictions on the end use of the metals and states that the materials are to be dispositioned in accordance with Toxco's license, which allows for unrestricted release. Under this disposition path, the sodium and the shields could be used in general commerce (e.g., made into consumer products).

Tennessee is an NRC Agreement State, and Toxco has its license from Tennessee. Toxco has been tasked under the materials disposition BOA on two other occasions to free release surface-contaminated metals from various locations. The sodium shields task was the first task awarded to Toxco that dealt with volumetrically contaminated metal. The Board could not determine if Toxco has a full understanding of the differing release criteria between surface-contaminated metal and volumetrically contaminated metal.

Following DOE 5400.5 for release of volumetrically contaminated metal with EH-1 approval would have resulted in the following:

- Appropriate DOE review to ensure compliance with the Secretary of Energy's moratorium

- Appropriate communication of the radiological characteristics of the material to the licensee

- DOE's obligations for end use of the material ending with the property title transfer

The decision to transfer the material to an NRC licensee shifted the approval authority for disposition of the sodium shields from EH-1 to the Team Leader of the AU Facilities and Materials Reuse Division.

AU transferred volumetrically contaminated metal to an NRC licensee without stipulating controls to prevent release into general commerce or informing them that the metal is subject to the Secretary of Energy's moratorium. This practice is not consistent with the intent of the Secretary's moratorium. AU also told the licensee that the material was not radioactive. These actions allowed the opportunity for the NRC licensee to release the metal into general commerce, which is not within the intent of the Secretary's moratorium. This action also left DOE liable for recourse if Toxco failed to adequately characterize the metal for release under its license and enforcement actions were taken against Toxco.

Toxco and Commodore both had the clear intent to use the metal without restriction after it was verified that the material was "not radioactive." Disposition of the sodium shields by DOE release under the Order would have provided for a property transfer that appropriately identified and communicated to Toxco the hazards present with the shields so that appropriate controls and work planning could have been established and implemented.

The Board concludes that AU failed to meet the intent of the Secretary of Energy's moratorium for release of volumetrically contaminated metals into general commerce.

3.3 Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. For an accident to occur, there must be a hazard that comes into contact with a target because the barriers or controls were not in place, not used, or failed. A hazard is the potential for unwanted energy flow to result in an accident or other adverse consequence. A target is a person or object that a hazard may damage, injure, or fatally harm. A barrier is any means used to control, prevent, or impede the hazard from reaching the target, thereby reducing the severity of the resultant accident or the adverse consequence. The results of the barrier analysis are used to support the development of the causal factors. Appendix B, Table B-1, contains the barrier analysis.

3.4 Change Analysis

Change is anything that disturbs the "balance" of a system that is operating as planned. Change is often the source of deviations in system operations. Change can be planned, anticipated, and desired, or it can be unintentional and unwanted. Change analysis examines the planned or unplanned changes that caused the undesired results or outcomes related to the accident. This process analyzes the difference between what is normal (or "ideal") and what actually occurred. The results of the change analysis are used to support the development of the causal factors. Appendix C, Table C-1, contains the change analysis.

3.5 Events and Causal Factors Analysis

An events and causal factors analysis was performed in accordance with the DOE Workbook *Conducting Accident Investigations*. The events and causal factors analysis requires deductive reasoning to determine which events and/or conditions contributed to the accident. Causal factors are the events or conditions that produced or contributed to the occurrence of the accident, and they consist of direct, contributing, and root causes.

The direct cause is the immediate events or conditions that caused the accident. The contributing causes are the events or conditions that, collectively with the other causes, increased the likelihood of the accident but which did not cause the accident. Root causes are the events or conditions that, if corrected, would prevent recurrence of this and similar accidents. *The direct cause of the accident was the failure of the secondary containment, which allowed the sodium to escape the hot box and resulted in an exothermic reaction.* A summary of the Board's causal factors analysis is presented in Appendix D, Table D-1, and it is followed by the "Events and Causal Factors Chart."

4.0 CONCLUSIONS AND JUDGMENTS OF NEED

Judgments of Need are the managerial controls and safety measures determined by the Board to be necessary to prevent or minimize the probability or severity of a recurrence. These Judgments of Need are linked directly to causal factors, which are derived from facts and analyses and form the basis for corrective action plans and which are the responsibility of line management. Table 4-1 contains the Board's conclusions and the Judgments of Need.

Table 4-1. Conclusions and Judgments of Need

Conclusions	Judgments of Need
The rupture of the sodium shield upon heating was caused by the combination of overfilling in 1971 and the stress induced by the concrete cradle The failure of the secondary containment resulted in the hot box leaking sodium. The nature of this failure cannot be ascertained until the hot box door is opened when recovery operations are resumed.	**JON-1a**: ORO EM needs to lead the Accident Recovery Team, in conjunction with Toxco and Commodore, to perform an evaluation of the exact failure mode of the primary and secondary containment. **JON-1b**: ORO needs to ensure the results of the evaluation are communicated to all line managers responsible for this and all future sodium and metal recovery operations.
Although the scope of work was adequately defined in contract documents, technical information that was crucial to understanding the nature and extent of the contamination and volume of sodium in the shields was not provided to Toxco or Commodore. AU did not have effective mechanisms in place to identify the information on the nature, extent, and character of the sodium shields.	**JON-2**: ORO needs to implement a formal process for identifying, communicating, and disseminating technical information crucial for work processes on all materials disposition activities.
Both Toxco and Commodore failed to effectively analyze all the hazards associated with the scope of work. This failure was partially attributable to a lack of important technical information about the work to be performed. ORO, CROET, and the ETTP Site Safety Council review the tenant HASPs, but none of these organizations have the authority to approve the HASPs.	**JON-3**: ORO and CROET need to establish and implement a formal process to ensure that sublessees' HASPs are reviewed, are commensurate with the hazards, and are approved.

Table 4-1. Conclusions and Judgments of Need (continued)

Conclusions	Judgments of Need
Commodore and Applied Reactor Technology failed to adequately design and/or install the silicone gasket system for the hot box door. Toxco failed to define and flow down the appropriate requirements to its teaming partner, especially with regard to safety requirements and expectations.	**JON-4**: ORO needs to ensure that all contractual requirements (OSHA, DOT, NQA-1, and DOE directives) flow down to the work and are fully implemented for all contracts and subleases.
The corrective actions implemented by ORO to address tenant issues identified by the Office of Oversight were inadequate. ORO failed to ensure RRAs were defined between AU and AMESH and between AU and EM. AU management failed to ensure that the Facilities and Materials Reuse Division's responsibilities were fully implemented for the Statement of Work in the contract. AU's ES&H responsibilities are not adequately defined, and confusion exists such that the responsibilities for ES&H oversight cannot be effectively implemented.	**JON-5**: ORO needs to ensure that AU defines their organizational interfaces with AMESH and the Assistant Manager for EM and that AU executes their responsibilities for ensuring ES&H requirements are included in contracts and subleases and that these requirements are effectively implemented.
Communication, dissemination, and use of lessons learned from previous ORO Type B Accident Investigations were inadequate.	**JON-6**: ORO and BJC need to evaluate their lessons learned programs to ensure that lessons from accident investigations are screened and disseminated to the responsible organizations for use in planning work to promote accident prevention across ORO.
AU and the Contracting Officer for the Toxco contract did not provide feedback or consequences to Toxco for violating the terms and conditions of its contract with ORO after the DOT enforcement action. Toxco does not have a QAP that is compliant with NQA-1, which is a contract requirement.	**JON-7**: ORO needs to establish and implement a formal mechanism to ensure that the terms and conditions of contracts are effectively implemented by all contractors.

Table 4-1. Conclusions and Judgments of Need (continued)

Conclusions	Judgments of Need
No requirements exist for preparing, reviewing, approving, and maintaining EMHSs and EMHAs and the associated Emergency Action Levels for sublessees at ETTP. Commodore's workers did not have required training per 29 CFR 1910.157, *Portable Fire Extinguisher*, and failed to fully implement Commodore's fire emergency procedure.	**JON-8**: ORO and CROET need to establish a policy and requirements to ensure that lessees participate in the ETTP hazard identification and analysis process for emergency management.
The BOA and associated Task Order process is not understood by all organizations involved in this accident.	**JON-9**: ORO needs to establish and fully implement a formal mechanism to ensure that the BOA/ Task Order process is defined and managed as a contract across all activities.
CROET failed to document the RRAs of CROET personnel with regard to safe execution of tenant operations. Commodore's managers with responsibility for the work being conducted did not enforce Commodore's corporate safety requirement to develop a site-specific HASP or to perform an activity hazards analysis.	**JON-10**: ORO needs to develop and implement a process to ensure that the terms and conditions of all leases/subleases are effectively implemented at all levels.
BJC failed to define the RRAs of the Reindustrialization organization as required under ISM.	**JON-11a**: BJC needs to define and fully implement RRAs for its Reindustrialization organization. **JON-11b**: ORO needs to develop and implement a formal mechanism to ensure BJC fully implements its RRAs for the Reindustrialization organization.
AU failed to meet the intent of the Secretary of Energy's moratorium on release of volumetrically contaminated metals into general commerce.	**JON-12**: ORO needs to develop and implement a formal process to ensure that transfers of volumetrically contaminated metals to licensees include controls on the end use of activated metal in accordance with Secretarial policies.
ORO's oversight of tenant organizations at ETTP is not formal.	**JON-13**: ORO needs to develop and implement an oversight process for all leased properties.

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5.0 BOARD SIGNATURES

6/18/04

Robert A. Crowley, PE
DOE Accident Investigation Board Chairperson
U.S. Department of Energy
Office of Facility Safety

6/18/04

Rowland Felt, Ph.D.
DOE Accident Investigation Trained Board Member
U.S. Department of Energy
Office of Facility Safety

6/18/04

Jenny Mullins
DOE Accident Investigation Deputy Board Chairperson
U.S. Department of Energy
Oak Ridge Operations Office

6/18/04

Danny Punch, PMP
DOE Accident Investigation Board Member
U.S. Department of Energy
Ohio Field Office

6/18/04

W. Don Seaborg, PE
DOE Accident Investigation Board Member
U.S. Department of Energy
Oak Ridge Operations Office

Donald K. Wierwille 6/18/2004

Donald K. Wierwille, PE
DOE Accident Investigation Board Member
U.S. Department of Energy
Oak Ridge Operations Office

Dana M. Willaford 6/18/04

Dana Willaford
DOE Accident Investigation Board Analyst
U.S. Department of Energy
Oak Ridge Operations Office

6.0 BOARD MEMBERS, ADVISORS, AND STAFF

Board Members

Chairperson	Robert A. Crowley, Safety Engineer, DOE EH
Member	Rowland Felt, Nuclear Materials Specialist, DOE EH
Member	Jenny Mullins, Occupational Safety and Health Manager, DOE ORO
Member	Danny Punch, Project Manager, Main Hill Project, DOE Ohio
Member	W. Don Seaborg, Supervisory General Engineer, DOE ORO
Member	Donald K. Wierwille, Team Leader, Melton Valley Remediation Team, DOE ORO
Analyst	Dana Willaford, Transportation Safety Engineer, DOE ORO

Advisors

Advisor	Ivan Boatner, Lead General Attorney, DOE ORO
Advisor	Richard Hammond, Senior Staff Engineer, Engineering Analysis and Technology Engineering, BWXT Y-12, LLC
Advisor	J. Mitch Hicks, Health Physicist, Paducah Site, DOE ORO Environmental Management
Advisor	Dean Little, Acting Section Leader of Compatibility and Compliance, BWXT Y-12, LLC
Advisor	Jacob Neal, Engineer, Engineering Analysis and Technology Engineering, BWXT Y-12, LLC
Advisor	Donna R. H. Riggs, Senior Quality Assurance Engineer, DOE ORO
Advisor	Jack A. Weese, Senior Quality Assurance Engineer, DOE ORO

Technical and Administrative Support

Coordinator/Technical Editor	Karen Brown, Quality Assurance Specialist III, Parallax, Inc.
Administrative Support	Melisa Hart, Administrative Assistant II, Critique
Court Reporter	Joan Roberts

Appendix A – Appointment of Type B Accident Investigation Board

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DOE F 1325.8
(3/96)

United States Government **Department of Energy**
Oak Ridge Operations Office

memorandum

DATE: May 17, 2004

REPLY TO
ATTN OF: SE-32:Mullins

SUBJECT: **TYPE B INVESTIGATION – UNCONTROLLED EXOTHERMIC SODIUM REACTION - EAST TENNESSE TECHNOLOGY PARK, OAK RIDGE, TENNESSEE**

TO: Robert A. Crowley, Office of Facility Operations Support, EH-24, HQ/FORS

You are hereby appointed Chairperson of the Accident Investigation Board (Board) to investigate the subject incident that occurred near Building K-722, which is located at the East Tennessee Technology Park, in Oak Ridge, Tennessee. You are to perform a Type B Investigation of this incident and prepare an investigation report. The report shall conform to requirements detailed in the Department of Energy (DOE) Order 225.1A, *Accident Investigation,* and DOE G 225.1A-1, *Implementation Guide for Use with DOE 225.1A, Accident Investigations*. The Board will be comprised of the following members:

Jenny Mullins, Assessment & Emergency Management Division, SE-32, Deputy Chairperson
Don Seaborg, Environmental Management, Operations, EM-98, Member
Rowland Felt, Office of Facility Operations Support, EH-24, Accident Investigator
Don Wierwille, Melton Valley Closure Project, EM-92, Member
Danny Punch, Ohio Field Office, OH, Member
Dana Willaford, Nuclear Safety Division, SE-33, Analyst

Ivan Boatner, Office of Chief Counsel, will serve as the legal liaison. The scope of the Board's investigation is to include, but is not limited to, identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the incident; developing conclusions; and determining judgments of need that, when implemented, should prevent the recurrence of the incident. The Board will focus on and specifically address the role of DOE, the tenant organizations and their subcontractors, and safety management systems, including emergency preparedness.

If additional resources are required to assist you in completing this task, please let me know and it will be provided. You and members of the Board are relieved of your other duties until this assignment is completed.

The Board is to provide my office with weekly reports on the status of the investigation but will not include any findings or arrive at any premature conclusions until an analysis of all the causal factors have been completed. Draft copies of the factual portion of the investigation report will be submitted to my office, the Community Reuse Organization of East Tennessee (CROET), and its tenant for factual accuracy review prior to the report finalization.

The final investigation report should be provided to me by June 18, 2004. Any delay to this date shall be justified and forwarded to this office. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report. If you have any questions, please contact me at (865) 576-4444 or Robert Poe, of my staff, at (865) 576-0891.

Gerald G. Boyd
Manager

cc:
Jessie H. Roberson, EM-1, HQ/FORS
Paul M. Golan, EM-2, HQ/FORS
Patrice M. Bubar, EM-3, HQ/FORS
Milt D. Johnson, SC-1, HQ/FORS
Raymond J. Hardwick, EH-2, HQ/FORS
Rowland Felt, EH-24, NE-ID
Robert J. Brown, M-3, ORO
Steven L. Wyatt, M-4, ORO
Robert W. Poe, SE-30, ORO
Larry W. Clark, AU-60, ORO
Stephen H. McCracken, EM-90, ORO
Don Seaborg, EM-98, ORO
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Ivan Boatner, CC-10, ORO
Jennifer Fowler, CC-10, ORO
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Margaret Marks, Ohio Field Office
Jenny Mullins, SE-32, ORO
Dana Willaford, SE-32, ORO
Brenda Hawks, SE-32, ORO
Jorge Ferrer, SE-33, ORO

Appendix B – Barrier Analysis

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Table B-1. Barrier Analysis

Barrier	Purpose	Analysis/Effect on Accident
Primary Containment (Shield)	Contain the sodium during heating	The original design did not include lifecycle considerations and subsequent removal of the sodium from the shield. The shield was overstressed during heating and failed to contain the sodium. The sodium was released to the secondary containment.
Secondary Containment (secondary containment in the hot box); Door Gasket for the Secondary Containment	Contain heat and nitrogen during the heating/transfer process Contain the molten sodium in the event of a breach in the primary containment	The door cut through the secondary containment to allow the smaller shields to be placed inside the hot box with a forklift allowed sodium to be released to the outside environment when the door gasket failed. The sodium subsequently reacted with moisture, producing an uncontrolled exothermic reaction.
Characterization Documents for the Shields	Fully describe the containment shields and the properties of the sodium so that proper controls can be developed for the transfer process	No engineering drawings or shield descriptions were provided to Commodore personnel so that they could develop effective controls. Based on visual inspection, Commodore developed sketches of the shield, but the resulting hot box design was inadequate to ensure the containment of the liquid sodium during the heating process.
Emergency Plans (EPIP 4.4.15)	Establish emergency protocols for response to incidents involving sodium	No facility-specific or discretionary EALs were developed for accidents involving exothermic sodium reactions.
Procedure to Heat and Transfer the Sodium (Commodore *Work Instruction for Hotbox*, W9470-01, dated 4/30/2004)	Establish protocols to safely transfer the sodium from the shield into DOT-approved containers	The heating sequence was based on an assumption of adequate expansion volume within the shield. During sodium heating, pressure resulted that overstressed the shield, causing a failure and release of sodium to the secondary containment.
Class D Extinguishing Agent, such as Met-L-X	Cover the reactive surface of the sodium to prevent contact with the atmosphere	The available amount of extinguishing agent was insufficient to adequately cover the volume of material released from the hot box.

Table B-1. Barrier Analysis (continued)

Barrier	Purpose	Analysis/Effect on Accident
Expansion Volume Within the Shield	Allows for expansion of the sodium when heated	Adequate expansion volume was not present within the shield. The pressure of the expanding sodium forced a breach and released the sodium into the secondary containment.
Emergency Preparedness	Proper planning ensures that appropriate equipment and trained personnel are available for response	The hazard analyses for leased spaces at ETTP do not have the same rigor as those for on-site DOE contractor activities. The hazard analysis for the sodium heating activity was inadequate.
Lease/Sublease	The lease/sublease sets the terms, conditions, and requirements for safe operations in leased space	The terms and conditions were inadequate to address prefire planning and training. If the planning had been performed with more rigor, additional fire response equipment would have been available at the Toxco jobsite.
Prefire Plan	Provides the facility description and identifies the facility contents, the conditions and hazards, and the response and staging information	There was limited preincident planning for an exothermic reaction involving sodium.
Process Engineering Review of Toxco	The review benchmarks acceptable commercial practices for handling sodium	The review was less than comprehensive in that it was time-constrained and did not allow for an in-depth process review or design review.
Oversight	Oversight is performed to determine the effectiveness of a program using formal mechanisms that require results to be documented and reported to management having responsibility for corrective actions	Oversight of the acquisition and disposition process of the sodium shields was inadequate to ensure that (1) the requirements were clearly defined in the Task Order, (2) the mechanisms were in place to flow down the requirements to the work being performed by Commodore, and (3) the design was adequate to ensure containment of sodium during a failure of the shield.
Quality Assurance Program	Ensure that services affecting quality are accomplished by incorporating special controls, equipment, tools, and skills to meet Toxco's quality objective to achieve safe transfer of the sodium from the shield	An effective QAP might have (1) identified problems with the design of the hot box to act as secondary containment, (2) provided inspection during installation of the sealant material on the hot box door to assure its intended function, and (3) ensured that the appropriate requirements were identified and included in all acquisition documents.

Appendix C – Change Analysis

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Table C-1. Change Analysis

Normal "Ideal"	Actual	Analysis
ORO's roles and responsibilities for oversight of the BOA and the associated Task Orders are fully implemented.	ORO's roles and responsibilities for oversight of the BOA and its associated Task Orders were not implemented.	ORO's oversight of the BOA and associated Task Orders was inadequate to ensure the following: • Identification of the appropriate requirements for safe disposition of the sodium and the aluminum shields • Flowdown of NQA-1 requirements to both Toxco and Commodore and full implementation of NQA-1 by both companies • All Federal, state, and local regulations were implemented • All BOA- and Task Order-specific requirements were implemented Inadequate oversight of the BOA and the associated Task Order resulted in acceptance of the "graded approach" to implementing NQA-1 for disposition of the sodium and the aluminum shields, acceptance of the graded approach to implementing safety requirements for disposition of the sodium and the aluminum shields, and failure to identify the AU organization's responsibility for implementing the Statement of Work and understanding all of the tasks associated with the Statement of Work.
Application of the silicone material to form a gasket and seal the hot box door contains the liquid sodium.	The silicone gasket applied to the hot box door failed to contain the liquid sodium.	Application of the silicone gasket to seal the hot box door and/or the silicone's properties failed to contain the liquid sodium inside the secondary containment. The liquid sodium breached the gasket and escaped the secondary containment, causing an exothermic reaction when it encountered standing rainwater.
The secondary containment contains the liquid sodium when the shield ruptures.	The secondary containment failed to contain the liquid sodium when the shield ruptured.	The design of the secondary containment included a door, and the door failed to contain the liquid sodium.
The liquid volume of the sodium equals the volume of the shield.	The liquid volume of the sodium exceeded the volume of the shield because of the addition of liquid sodium to fill the void created by cooling and solidification of the sodium.	During heating, the sodium expanded to exceed the volume of the shield. The stresses created during heating exceeded the ultimate strength of the aluminum shield.

Table C-1. Change Analysis (continued)

Normal "Ideal"	Actual	Analysis
The shield is not in the concrete cradle when it is heated.	The shield was in the concrete cradle when it was heated.	By confining the aluminum shield with its concrete cradle during heating, the ultimate strength of the aluminum shield was exceeded at approximately the 3 or 4 o'clock position on the shield near the interface with the concrete cradle. The failure of the aluminum shield released the liquid sodium.
ORO's safety RRAs for Toxco's leased property are understood and fully implemented.	ORO's safety RRAs for Toxco's leased property were not understood.	ORO personnel had an incomplete understanding of their safety RRAs that resulted in the following: • Confusion with regard to their authority to conduct OSHA-like inspections on Toxco's leased property • Inadequate implementation of responsibilities for oversight of Toxco's work activities on leased property • Confusion with regard to line management responsibility for work performed on Toxco's leased property by Commodore on the day of the accident The inadequate emergency planning resulted in a lack of sufficient extinguishing agent being available to stop the flow of liquid sodium before it contacted standing rainwater or to smother the resulting exothermic reaction. The emergency response was inappropriate for the magnitude of the accident.
Feedback mechanisms are in place and effectively identify and communicate safety-related information relative to shield processing to Commodore.	No feedback mechanisms were in place to effectively identify and communicate safety-related information about shield processing to Commodore.	The feedback and improvement mechanisms were inadequate to communicate the following information to Commodore: • *Nuclear Engineering Analysis of Shields*, prepared by Westinghouse Safety Management Solutions Mid-America LLC in July 2003 • BJC/OR-1399, *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge National Laboratory, Oak Ridge, Tennessee*, dated April 2003, produced by Tetra Tech on the procedures used to fill the shields in 1971 • Shield leaking issues identified in the 1990s • Issues at the Molten Salt Reactor Experiment Facility related to draining the sodium

Table C-1. Change Analysis (continued)

Normal "Ideal"	Actual	Analysis
Feedback mechanisms are in place and effectively identify and communicate safety-related information relative to shield processing to Commodore. (continued)	No feedback mechanisms were in place to effectively identify and communicate safety-related information about shield processing to Commodore.	• *ALARA Evaluation of Proposed Metals Recycling of Sodium Hydride Shields at the Tower Shielding Facility Located at ORNL*, produced in 1999 by SAIC The feedback mechanisms were not in place to ensure effective identification and communication of safety-related information to Commodore.
An issues management mechanism is established, implemented, and improved to effectively correct identified issues to prevent recurrences.	ORO's issues management mechanisms were inadequate to effectively correct issues involving ETTP tenants.	The Office of Oversight identified issues associated with tenants during a 1997 Safety Management Evaluation at ETTP. ORO developed and implemented corrective actions in response to the review. During the course of this investigation, the Board identified the same issues with ORO, Toxco, and Commodore that were identified by the Office of Oversight. The issues identified by the Office of Oversight in 1997 were not effectively corrected by ORO to prevent recurrence.
Lessons learned from previous accidents at ETTP are applied to the work conducted under the BOA and associated Task Orders	Lessons learned from previous accidents at ETTP are not applied to work conducted under the BOA and associated Task Orders	Lessons learned from previous Type B Accident Investigations at ETTP were not applied in planning the disposition of the sodium shields, resulting in deficiencies in responsibilities and authorities and in work control.
An in-depth design review is conducted of the secondary containment for "planned" shield failure	No in-depth design review was conducted of the secondary containment for planned shield failure	No in-depth design review was conducted of the secondary containment, even though Commodore anticipated a shield failure and release of sodium. An in-depth design review of the secondary containment would have identified that the integrity of the secondary containment was compromised when a door, a removable threshold and center post, and a silicone gasket were constructed as part of the secondary containment.
Toxco is not a tenant at ETTP but has a contract with ORO.	Toxco is a tenant at ETTP with an ORO contract.	ORO had a contract with Toxco that required Toxco to complete a scope of work at Toxco's off-site license facility. However, Toxco's off-site licensed facility is DOE property at ETTP that has been subleased to Toxco by CROET. Both the contract and the sublease have separate terms and conditions that are administered by two separate AU organizations.

Table C-1. Change Analysis (continued)

Normal "Ideal"	Actual	Analysis
Toxco is not a tenant at ETTP but has a contract with ORO. (continued)	Toxco is a tenant at ETTP with an ORO contract.	The Facilities and Materials Reuse Division performs contract administration. Lease policy, management, and administration is the responsibility of the Reindustrialization Division through the AU Executive Director, who is also the local program representative between ORO and CROET. The local ORO program representative is responsible for "the complete charge of the administration of activities under the lease and shall exercise full supervision and general direction" for DOE's interests. During the course of the Board's investigation, all AU management and staff stated that the Statement of Work in the contract was complete when title to the sodium shields was transferred to Toxco at the gate of ORNL.
Release of volumetrically contaminated metal by bill of sale	Transfer of volumetrically contaminated metal by contract	• Volumetrically contaminated metal is subject to the Secretary of Energy's moratorium. • For volumetrically contaminated metal, DOE G 441.XX stipulates the following: o ALARA/dose-based derived authorized limits be established, reviewed, and approved by DOE Field Elements in coordination with the Program Office o The limits must be submitted to EH-4 for approval by EH-1. o This process ensures that the Secretary's concerns for release into general commerce of these metals are addressed. • Use of a contract to transfer volumetrically contaminated metal to a licensee for free release is not strictly prohibited under the current guidance. o It is viewed by EH-4 as not consistent with the intent of the moratorium. o Adequate controls must be placed on the use of the material.

Table C-1. Change Analysis (continued)

Normal "Ideal"	Actual	Analysis
Release of volumetrically contaminated metal by bill of sale (continued)	Transfer of volumetrically contaminated metal by contract	• Use of a contract for free release of volumetrically contaminated metal obligates DOE to: o Ensure adequate controls are stated in the terms of the contract. o Manage the contract to final disposition of the metal, rather than at the point of property transfer. • During the course of the award, Toxco was assured that the sodium was not contaminated. Little mention was ever made as to the activation levels within the aluminum shields. Based on this information, Toxco made decisions consistent with dealing with a nonradioactive material, as it was their expectation that the material would meet those criteria. • Toxco was never informed that the metal was subject to the Secretary of Energy's moratorium on the release of volumetrically contaminated metal. To the contrary, Toxco was initially told that the material was subject to the suspension on metal and was later told that it was not because the material had not been in a Radiological Area. • Toxco is an NRC licensee and has been tasked under the BOA to free release surface-contaminated metals under two prior Task Orders. This was the first Task Order given to Toxco that dealt with volumetrically contaminated metal. The Board could not determine if Toxco has a full understanding of the differing release criteria between surface-contaminated metal and volumetrically contaminated metal. • Following the DOE G 441.1-XX guidance to release the volumetrically contaminated metal would have resulted in the following: o Appropriate DOE review to ensure compliance with the moratorium o Appropriate communication of the hazards to the licensee o DOE's obligations for end use of the material ending with property title transfer

Table C-1. Change Analysis (continued)

Normal "Ideal"	Actual	Analysis
Implementation of DOE 5400.5 requires ORO to analyze the material and establish authorized limits for release of volumetrically contaminated material ORO's authorized limits and release process are approved by EH-1	The authorized limits required by DOE 5400.5 for release of volumetrically contaminated material were not established ORO's authorized limits and release process were not sent to EH-1 for approval	BJC's failure to fully implement DOE 5400.5 under its contract resulted in authorized limits for release of volumetrically contaminated material not being established and provided to ORO for submittal to EH-1 for approval. BJC failed to perform the necessary ALARA/dose analysis to derive the authorized limits for release, and ORO failed to obtain the required approval from EH-1.

Appendix D – Events and Causal Factors Analysis

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Table D-1. Events and Causal Factors Analysis

CC No.	Contributing Causes	Discussion	Related JONs
CC-1	ORO line management responsible for project management and contract administration of Toxco's contract did not implement their responsibilities for the sodium heating operations.	ORO line management responsible for project management and contract administration for work conducted within the Toxco's scope of work did not fully implement their responsibilities for the sodium heating operations the day of the accident. During the conduct of the investigation, the Board identified the following deficiencies: <u>Contract Administration Responsible for Toxco's Contract</u> • Failed to hold Toxco accountable for DOT violations. • Failed to hold Toxco accountable for the time delay to remove and process the metal consistent with the terms and conditions of the contract • Failed to recognize that issuing of a Task Order under the authority of a BOA is a contract that legally binds both parties to perform activities per the BOA and Task Order • The COR gave assurance to Toxco that there was no radioactive contamination in the shield when in fact it was contaminated • Failed to communicate and enforce the appropriate Secretarial policy applicable to the scope of work • Failed to ensure the ISM core functions and guiding principles were implemented for the work associated with sodium heating activities on the day of the accident • Failed to provide a clear scope of work to a process engineer for evaluating the equipment and procedure for transferring the sodium • Failed to provide adequate information to perform the scope of work	1, 2, 3 4, 5, 7, 9 11, 12

Table D-1. Events and Causal Factors Analysis (continued)

CC No.	Contributing Causes	Discussion	Related JONs
CC-1	ORO line management responsible for project management and contract administration of Toxco's contract did not implement their responsibilities for the sodium heating operations. (continued)	<u>AU Line Organizations Responsible for Sodium Heating Operations</u> • Failed to ensure mechanisms were in place to flow down NQA-1 requirements to the workers performing the heating operations on the day of the accident • Failure to ensure a mechanism was in place to determine appropriate requirements were identified, including the Secretary of Energy's moratorium for dispositioning volumetrically contaminated metals • Failure to ensure walkdowns were conducted in a formal manner to ensure identification and correction of issues and feedback to management • Failure to ensure processes were in place to evaluate the design of the hot box • Failed to ensure effective corrective actions were taken to correct quality assurance issues identified in 2001	
CC-2	ORO, BJC, and CROET did not develop a formal program plan that integrates all the management and assessment activities of each organization that affects subleases.	Although ORO, BJC, and CROET use some formal and informal processes to accomplish the Reindustrialization Mission for subleases like Toxco, the lack of a formal program plan to integrate the management and assessment functions and activities of all three organizations led to the following deficiencies: • RRAs for lessees performing work under DOE contracts are not clearly defined • Organizational interfaces are not clearly defined among and between ORO, BJC, and CROET • No mechanism exists to identify appropriate requirements for work being conducted by lessees where title has not been transferred from DOE to CROET	3, 4, 5 8, 10, 13

Table D-1. Events and Causal Factors Analysis (continued)

CC No.	Contributing Causes	Discussion	Related JONs
CC-2	ORO, BJC, and CROET did not develop a formal program plan that integrates all the management and assessment activities of each organization that affects subleases. (continued)	• Feedback and improvement mechanisms have not been developed with sufficient rigor to provide feedback on sublessees' performance, such as (a) compliance with Toxco's ISM requirements and (b) compliance with the health and safety requirement for a site-specific HASP	
CC-3	ORO's and BJC's feedback processes were inadequate to identify management deficiencies, DOE Order compliance, and communication of information critical to designing the sodium transfer process and understanding the nature and extent of the contamination.	BJC's feedback and improvement processes were inadequate to identify the following deficiencies: • RRAs for BJC Reindustrialization activities were undefined • Information in the custody of BJC crucial to design the sodium transfer process was not communicated to Toxco • Shield characterization information in the custody of BJC was not communicated to Toxco ORO's feedback and improvement processes were inadequate to identify the following deficiencies: • Lessons learned from previous Type B Accident Investigations at ETTP were not effectively communicated, disseminated, and used • Information on the nature, extent, and character of the sodium shields was not included in the Statement of Work • Corrective actions to address tenant issues identified by the 1997 Office of Oversight review were inadequate to prevent recurrence • RRAs were not defined between AU and AMESH and between AU and EM • The AU Facilities and Materials Reuse Division's responsibilities were not fully implemented for the Statement of Work in the Toxco contract • AU did not stipulate controls in the contract necessary to meet the intent of the Secretary of Energy's moratorium	2, 4, 5 6, 11

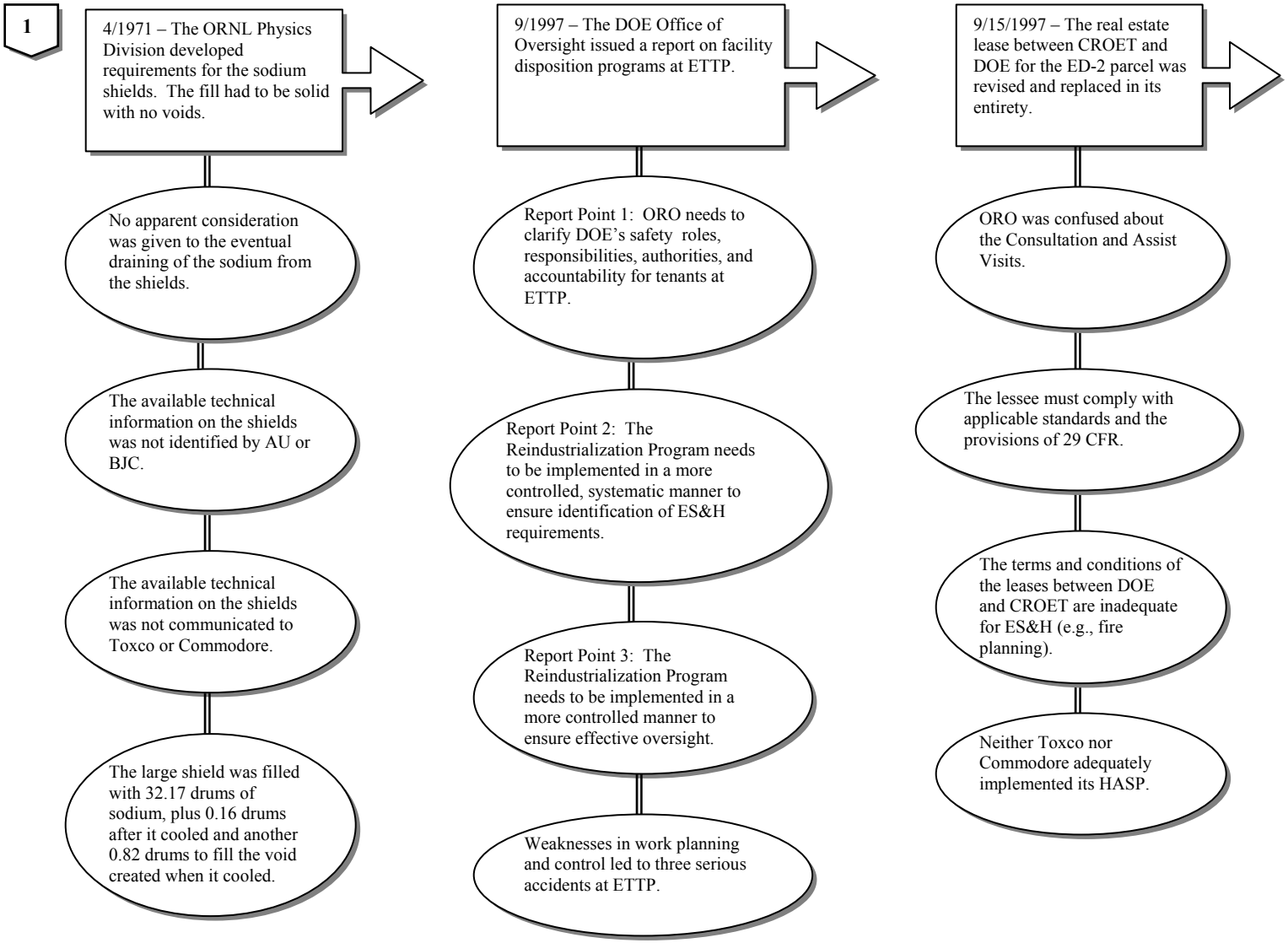
Table D-1. Events and Causal Factors Analysis (continued)

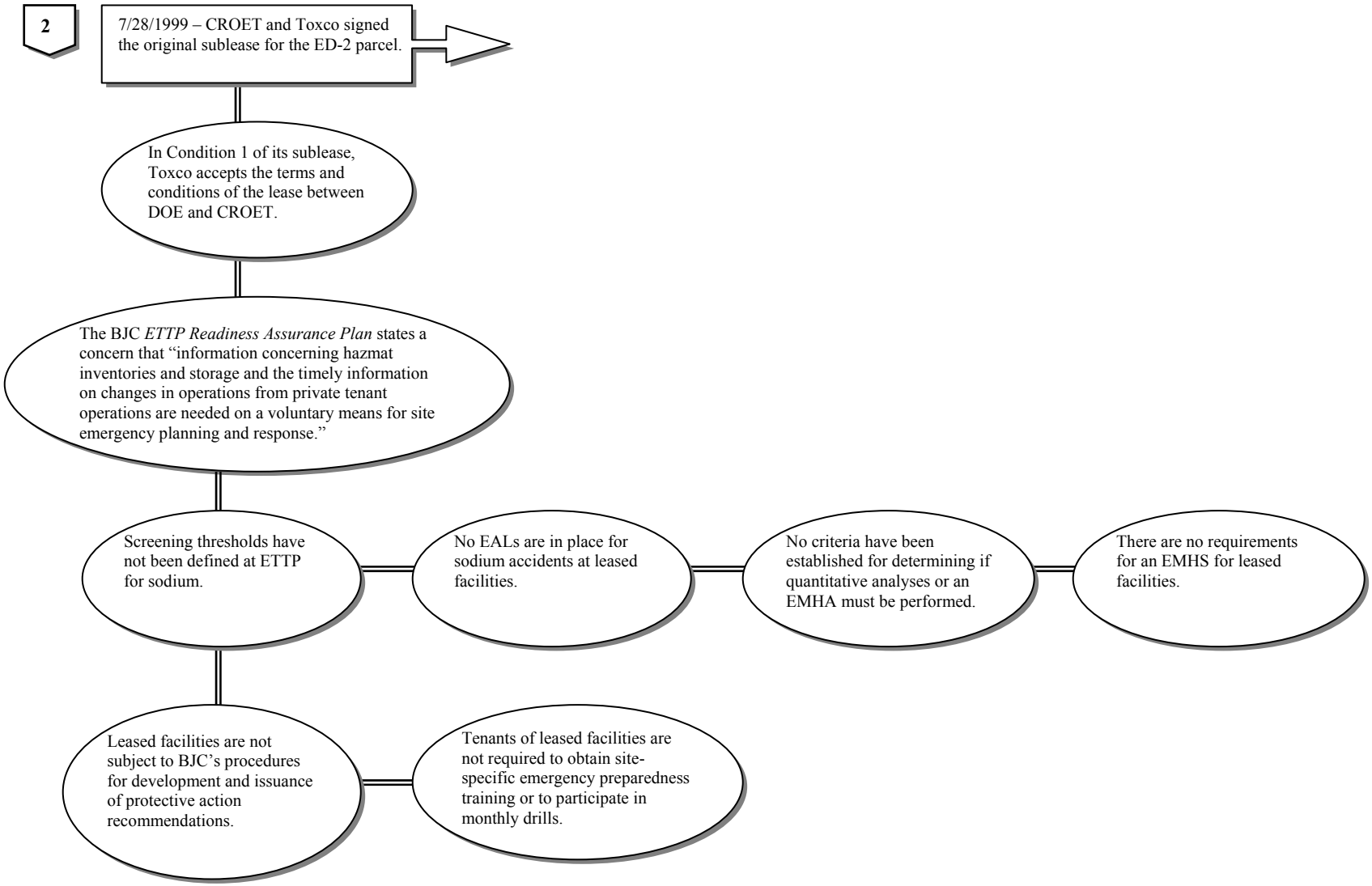
CC No.	Contributing Causes	Discussion	Related JONs
Root Cause	ORO management responsible for the preparation and execution of the lease with CROET and the contract with Toxco did not fully implement their responsibilities, resulting in an accident and evacuation of the public.	ORO line management responsible for project management and contract administration of Toxco's contract did not implement their responsibilities for the sodium heating operations. ORO, BJC, and CROET did not develop a formal program plan that integrates all the management and assessment activities of each organization that affects subleases. ORO's and BJC's feedback processes were inadequate to identify management deficiencies, DOE Order compliance, and communication of information critical to designing the sodium transfer process and understanding the nature and extent of the contamination.	1, 2, 3, 4 5, 6, 7 8, 9, 10 11, 12, 13

Causal Factors Identified in the Events and Causal Factors Analysis

A – No ORO policy was in place for leased property.	I – CROET failed to provide effective oversight to ensure the sublessees implemented the requirements in the subleases.	P – Toxco's feedback and improvement mechanisms were inadequate to ensure implementation of ISM.
B – AU failed to ensure that contract requirements were implemented.	J – The AU COR, the Contracting Officer, and the AU Executive Director failed to ensure that Toxco implemented the DOT requirements.	Q – Toxco failed to ensure that the requirements in the BOA were implemented.
C – AU failed to provide the best available technical information in the Statement of Work for the Task Order.	K – The RRAs between AU and AMESH were not clearly defined.	R – BJC failed to comply with DOE 5400.5 requirements on releasing activated metals.
D – The secondary containment in the hot box was inadequate.	L – ORO failed to adequately evaluate Toxco's ability to perform transportation tasks under the contract.	S – AU failed to ensure that the requirements of the Secretary of Energy's moratorium on releasing activated metals were included in the BOA and associated Task Order.
E – Toxco's work planning was inadequate to execute the Statement of Work in the Task Order.	M – ORO failed to adequately define BJC's reindustrialization responsibilities under the Task Order.	T – The BJC Reindustrialization organization failed to define its RRAs as required by ISM.
F – The shield overpressurized during heating.	N – BJC failed to provide radiological characterization and design data on the shields to ORO.	U – AU failed to ensure that that RRAs were defined for the BJC Reindustrialization organization.
G – The AU COR and the Contracting Officer failed to adequately define the requirements for design review in the Statement of Work in the Task Order.	O – ORO's feedback and improvement mechanisms were inadequate to ensure that the BOA, the BJC contract, and the CROET lease requirements were implemented.	V – The Headquarters Office of Corporate Performance Assessment failed to provide adequate oversight of the implementation of release of activated metals in accordance with DOE 5400.5.
H – The AU COR, the Contracting Officer, and the AU Executive Director failed to ensure that NQA-1 requirements were implemented.		

Figure D-1. Events and Causal Factors Chart


1
4/1971 – The ORNL Physics Division developed requirements for the sodium shields. The fill had to be solid with no voids.
No apparent consideration was given to the eventual draining of the sodium from the shields.
The available technical information on the shields was not identified by AU or BJC.
The available technical information on the shields was not communicated to Toxco or Commodore.
The large shield was filled with 32.17 drums of sodium, plus 0.16 drums after it cooled and another 0.82 drums to fill the void created when it cooled.
9/1997 – The DOE Office of Oversight issued a report on facility disposition programs at ETTP.
Report Point 1: ORO needs to clarify DOE's safety roles, responsibilities, authorities, and accountability for tenants at ETTP.
Report Point 2: The Reindustrialization Program needs to be implemented in a more controlled, systematic manner to ensure identification of ES&H requirements.
Report Point 3: The Reindustrialization Program needs to be implemented in a more controlled manner to ensure effective oversight.
Weaknesses in work planning and control led to three serious accidents at ETTP.
9/15/1997 – The real estate lease between CROET and DOE for the ED-2 parcel was revised and replaced in its entirety.
ORO was confused about the Consultation and Assist Visits.
The lessee must comply with applicable standards and the provisions of 29 CFR.
The terms and conditions of the leases between DOE and CROET are inadequate for ES&H (e.g., fire planning).
Neither Toxco nor Commodore adequately implemented its HASP.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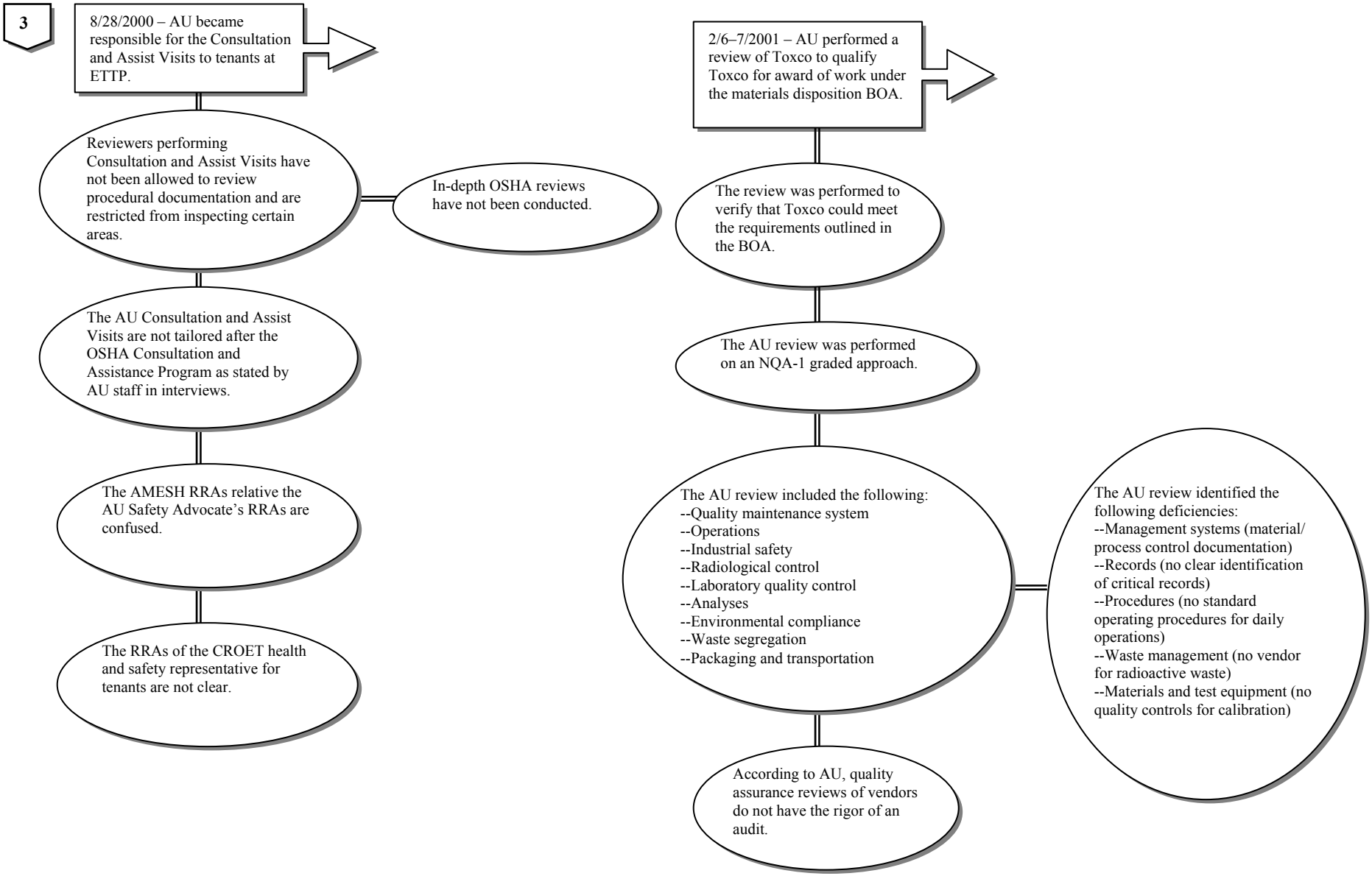
7/28/1999 – CROET and Toxco signed the original sublease for the ED-2 parcel.
In Condition 1 of its sublease, Toxco accepts the terms and conditions of the lease between DOE and CROET.
The BJC *ETTP Readiness Assurance Plan* states a concern that "information concerning hazmat inventories and storage and the timely information on changes in operations from private tenant operations are needed on a voluntary means for site emergency planning and response."
Screening thresholds have not been defined at ETTP for sodium.
No EALs are in place for sodium accidents at leased facilities.
No criteria have been established for determining if quantitative analyses or an EMHA must be performed.
There are no requirements for an EMHS for leased facilities.
Leased facilities are not subject to BJC's procedures for development and issuance of protective action recommendations.
Tenants of leased facilities are not required to obtain site-specific emergency preparedness training or to participate in monthly drills.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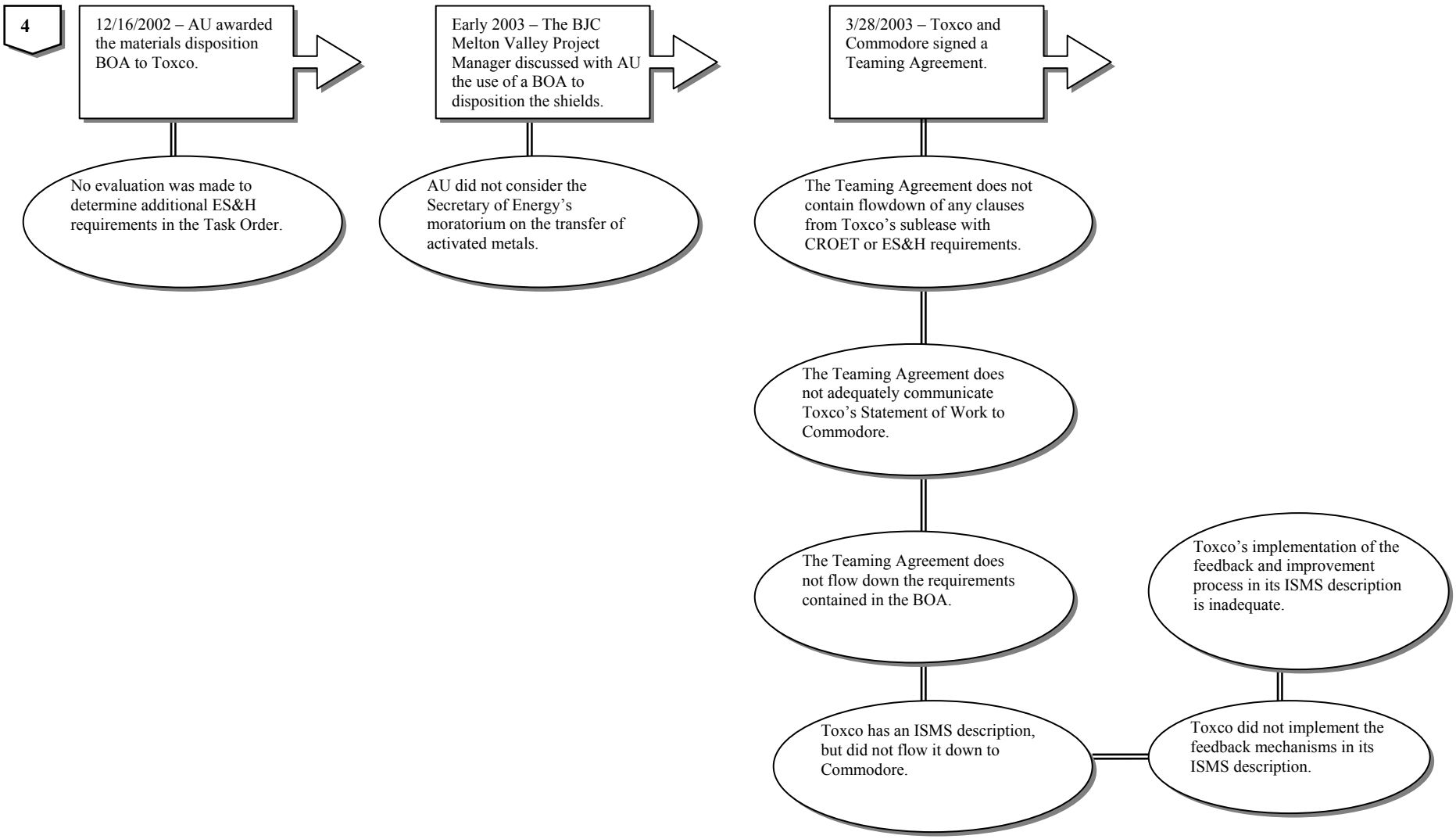
8/28/2000 – AU became responsible for the Consultation and Assist Visits to tenants at ETTP.
Reviewers performing Consultation and Assist Visits have not been allowed to review procedural documentation and are restricted from inspecting certain areas.
In-depth OSHA reviews have not been conducted.
The AU Consultation and Assist Visits are not tailored after the OSHA Consultation and Assistance Program as stated by AU staff in interviews.
The AMESH RRAs relative the AU Safety Advocate's RRAs are confused.
The RRAs of the CROET health and safety representative for tenants are not clear.
2/6–7/2001 – AU performed a review of Toxco to qualify Toxco for award of work under the materials disposition BOA.
The review was performed to verify that Toxco could meet the requirements outlined in the BOA.
The AU review was performed on an NQA-1 graded approach.
The AU review included the following:
--Quality maintenance system
--Operations
--Industrial safety
--Radiological control
--Laboratory quality control
--Analyses
--Environmental compliance
--Waste segregation
--Packaging and transportation
The AU review identified the following deficiencies:
--Management systems (material/ process control documentation)
--Records (no clear identification of critical records)
--Procedures (no standard operating procedures for daily operations)
--Waste management (no vendor for radioactive waste)
--Materials and test equipment (no quality controls for calibration)
According to AU, quality assurance reviews of vendors do not have the rigor of an audit.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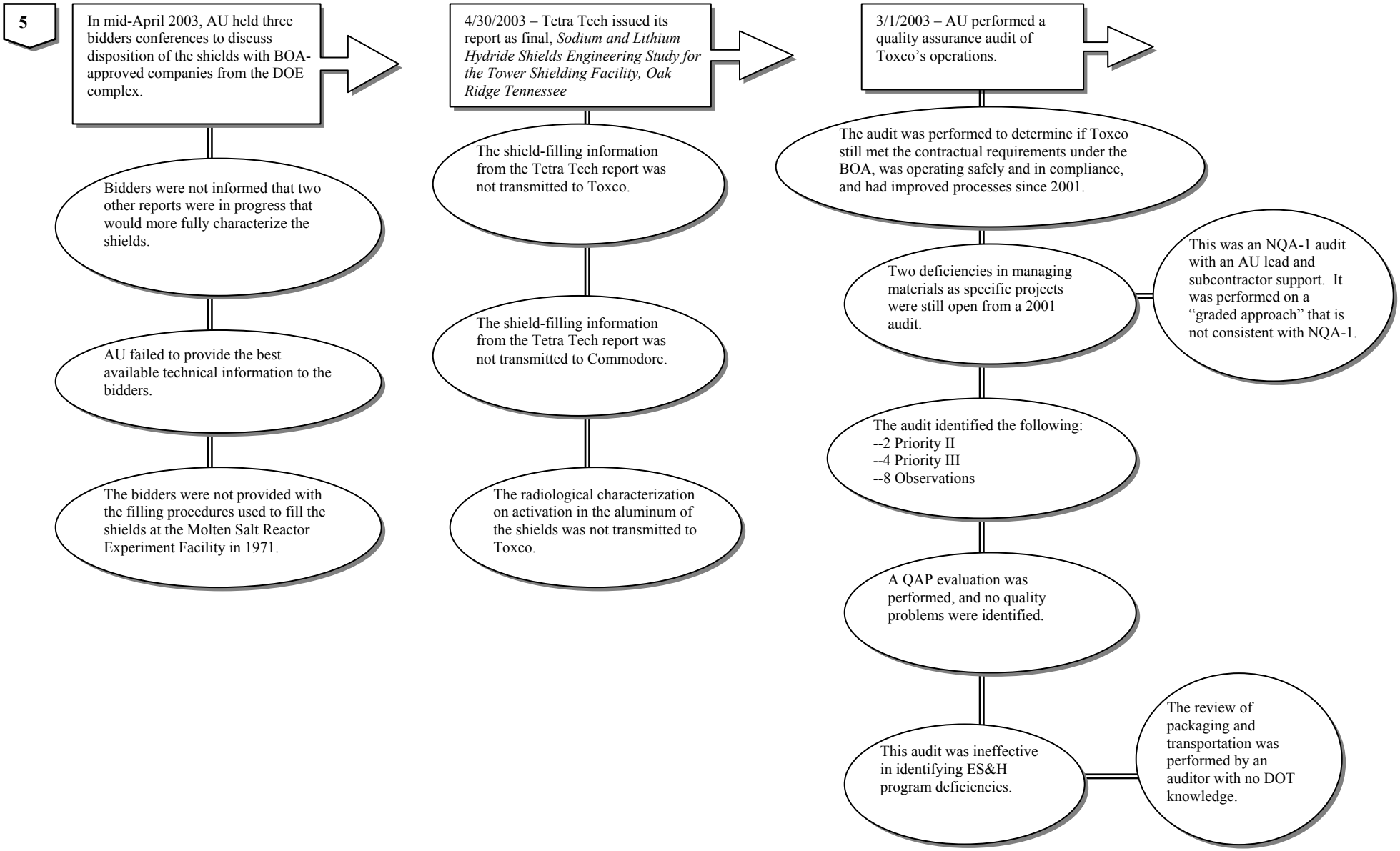
12/16/2002 – AU awarded the materials disposition BOA to Toxco.
Early 2003 – The BJC Melton Valley Project Manager discussed with AU the use of a BOA to disposition the shields.
3/28/2003 – Toxco and Commodore signed a Teaming Agreement.
No evaluation was made to determine additional ES&H requirements in the Task Order.
AU did not consider the Secretary of Energy's moratorium on the transfer of activated metals.
The Teaming Agreement does not contain flowdown of any clauses from Toxco's sublease with CROET or ES&H requirements.
The Teaming Agreement does not adequately communicate Toxco's Statement of Work to Commodore.
The Teaming Agreement does not flow down the requirements contained in the BOA.
Toxco's implementation of the feedback and improvement process in its ISMS description is inadequate.
Toxco has an ISMS description, but did not flow it down to Commodore.
Toxco did not implement the feedback mechanisms in its ISMS description.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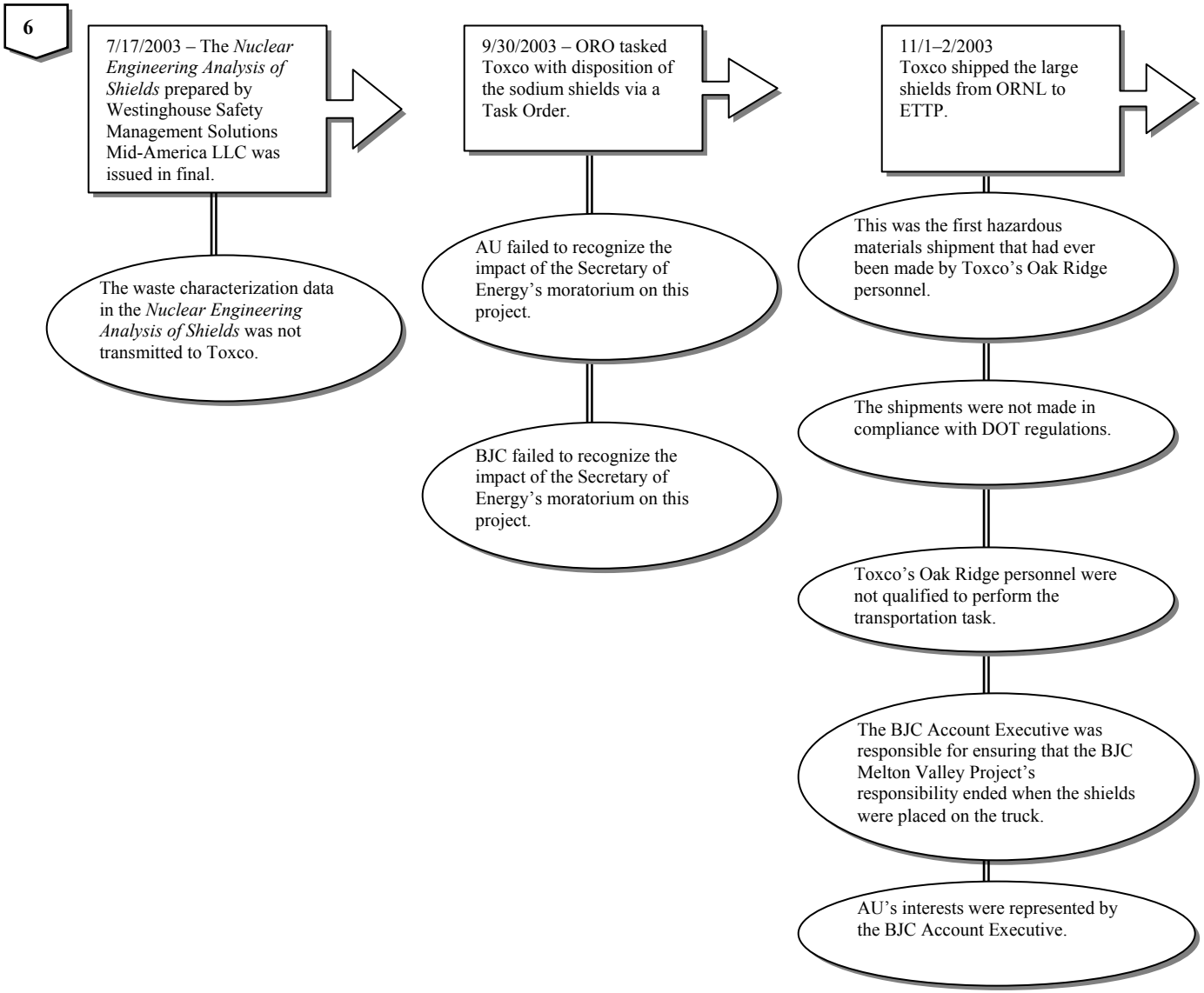
In mid-April 2003, AU held three bidders conferences to discuss disposition of the shields with BOA-approved companies from the DOE complex.
Bidders were not informed that two other reports were in progress that would more fully characterize the shields.
AU failed to provide the best available technical information to the bidders.
The bidders were not provided with the filling procedures used to fill the shields at the Molten Salt Reactor Experiment Facility in 1971.
4/30/2003 – Tetra Tech issued its report as final, *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge Tennessee*
The shield-filling information from the Tetra Tech report was not transmitted to Toxco.
The shield-filling information from the Tetra Tech report was not transmitted to Commodore.
The radiological characterization on activation in the aluminum of the shields was not transmitted to Toxco.
3/1/2003 – AU performed a quality assurance audit of Toxco's operations.
The audit was performed to determine if Toxco still met the contractual requirements under the BOA, was operating safely and in compliance, and had improved processes since 2001.
Two deficiencies in managing materials as specific projects were still open from a 2001 audit.
This was an NQA-1 audit with an AU lead and subcontractor support. It was performed on a "graded approach" that is not consistent with NQA-1.
The audit identified the following:
--2 Priority II
--4 Priority III
--8 Observations
A QAP evaluation was performed, and no quality problems were identified.
This audit was ineffective in identifying ES&H program deficiencies.
The review of packaging and transportation was performed by an auditor with no DOT knowledge.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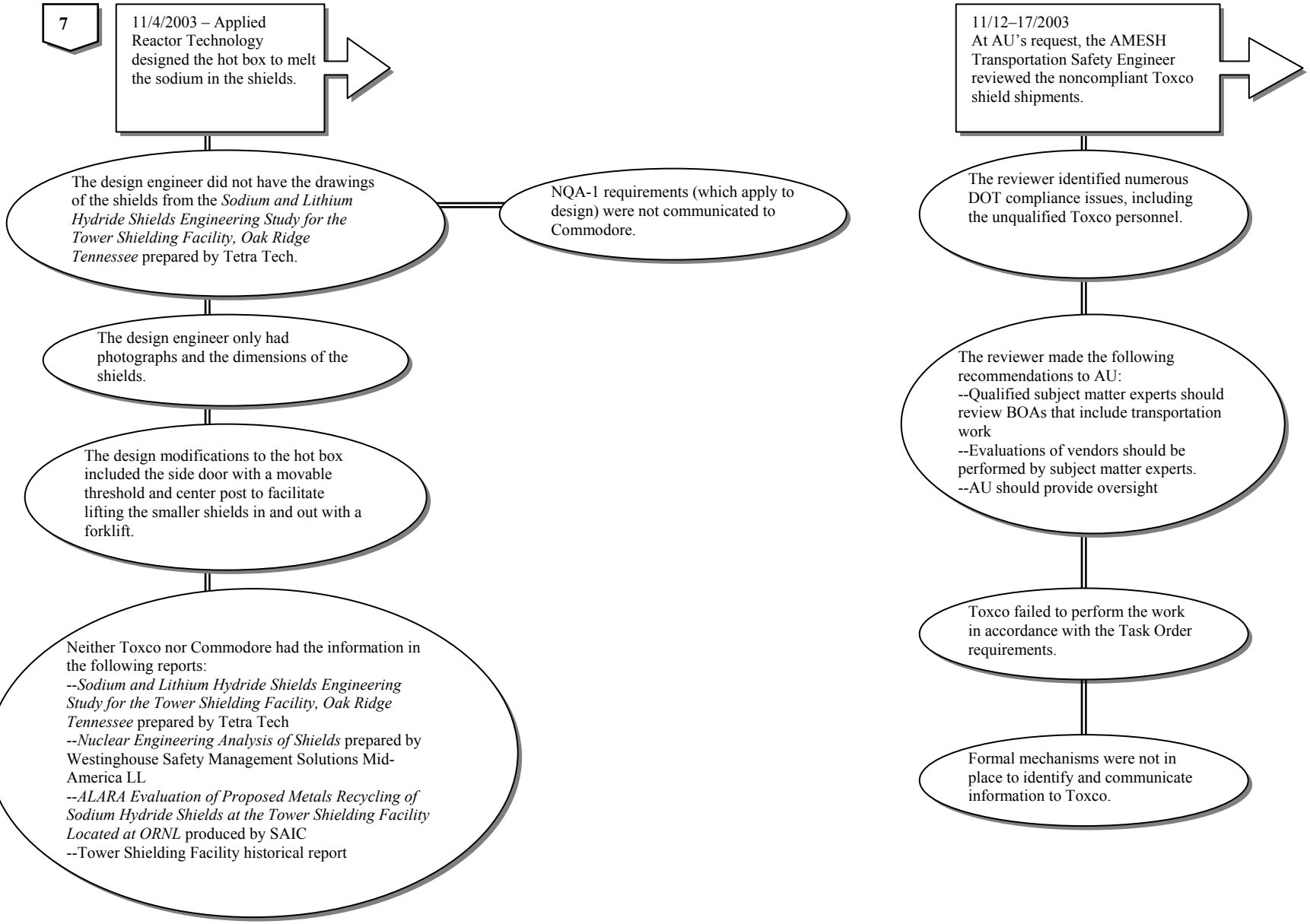
7/17/2003 – The *Nuclear Engineering Analysis of Shields* prepared by Westinghouse Safety Management Solutions Mid-America LLC was issued in final.
The waste characterization data in the *Nuclear Engineering Analysis of Shields* was not transmitted to Toxco.
9/30/2003 – ORO tasked Toxco with disposition of the sodium shields via a Task Order.
AU failed to recognize the impact of the Secretary of Energy's moratorium on this project.
BJC failed to recognize the impact of the Secretary of Energy's moratorium on this project.
11/1–2/2003
Toxco shipped the large shields from ORNL to ETTP.
This was the first hazardous materials shipment that had ever been made by Toxco's Oak Ridge personnel.
The shipments were not made in compliance with DOT regulations.
Toxco's Oak Ridge personnel were not qualified to perform the transportation task.
The BJC Account Executive was responsible for ensuring that the BJC Melton Valley Project's responsibility ended when the shields were placed on the truck.
AU's interests were represented by the BJC Account Executive.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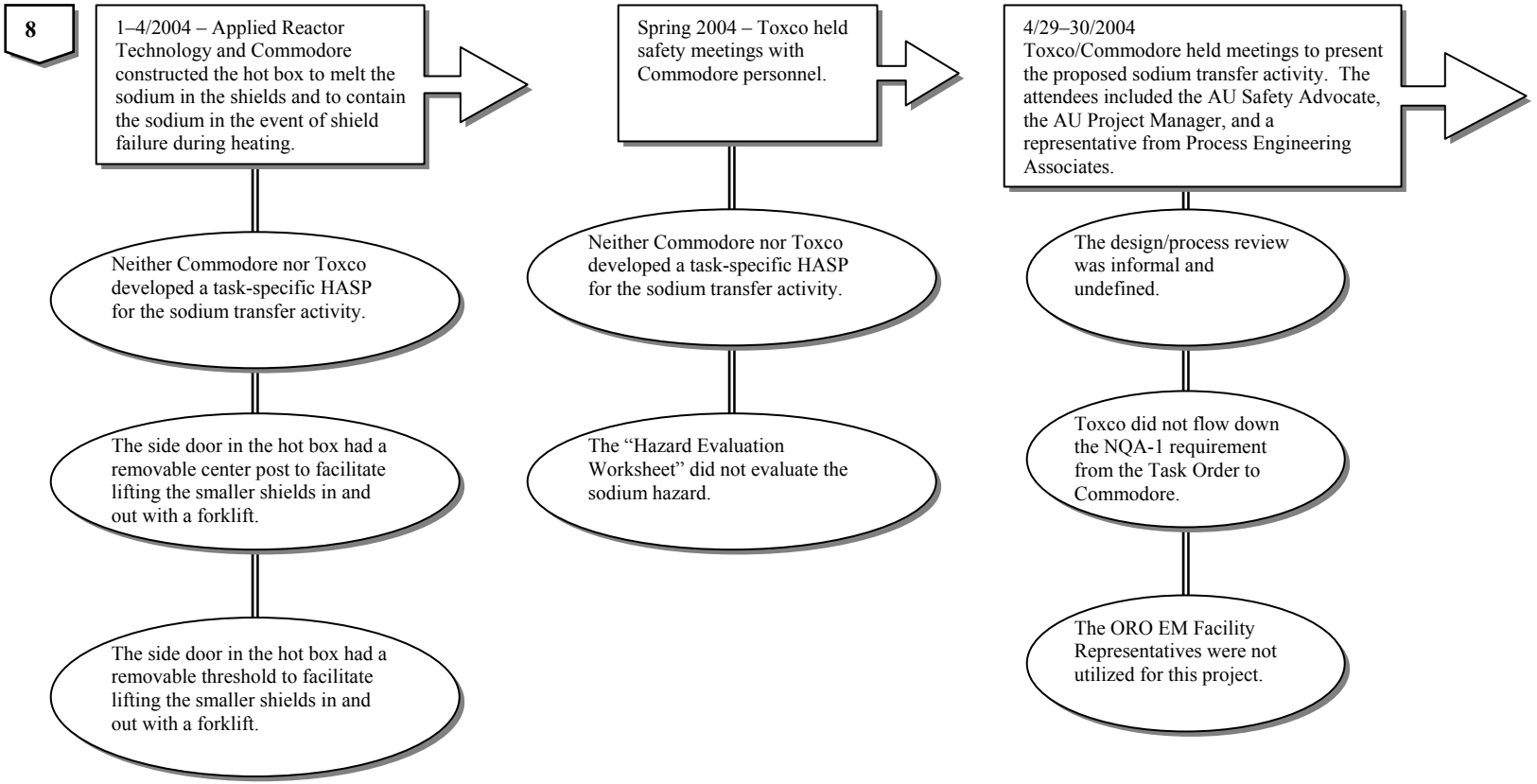
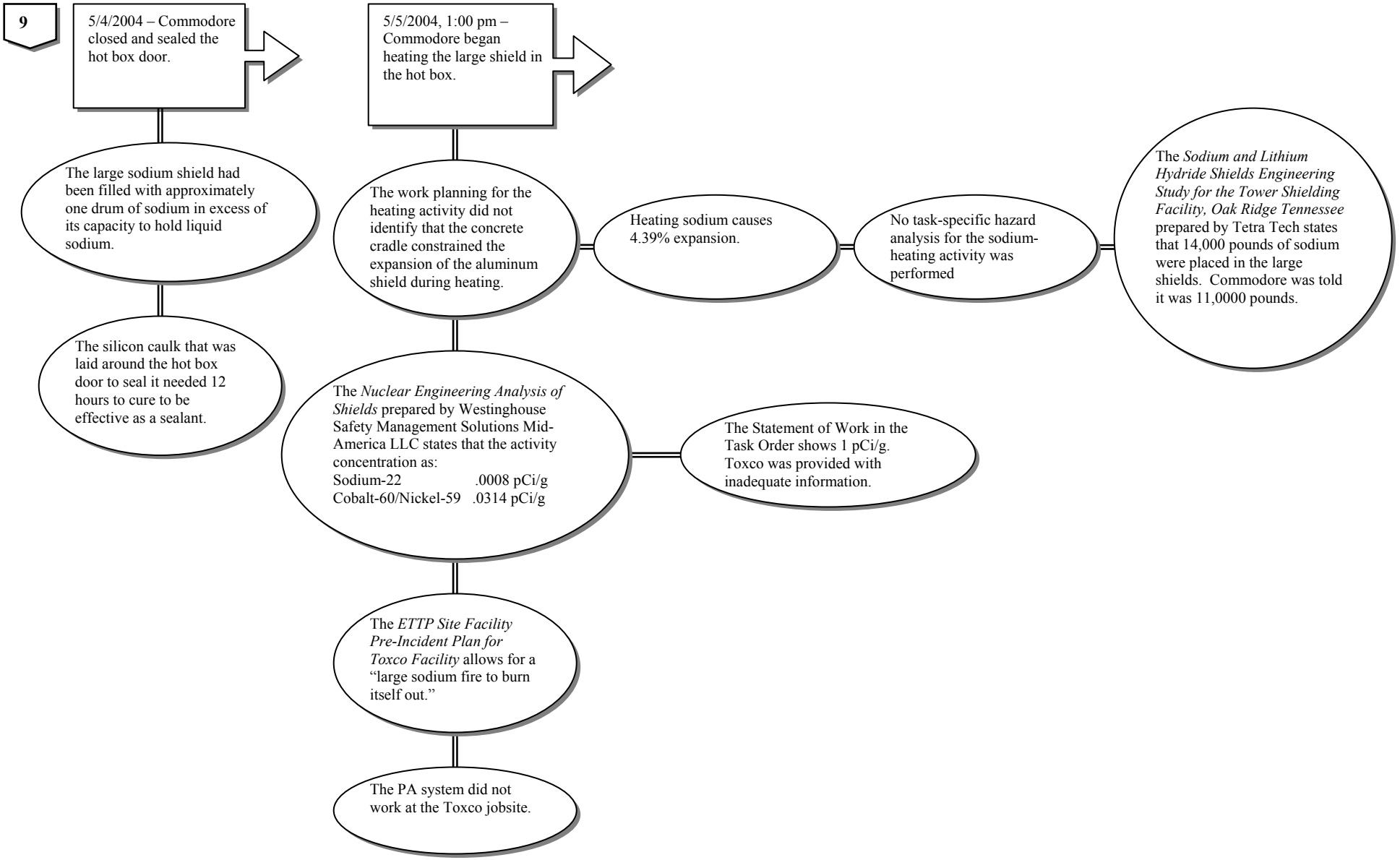
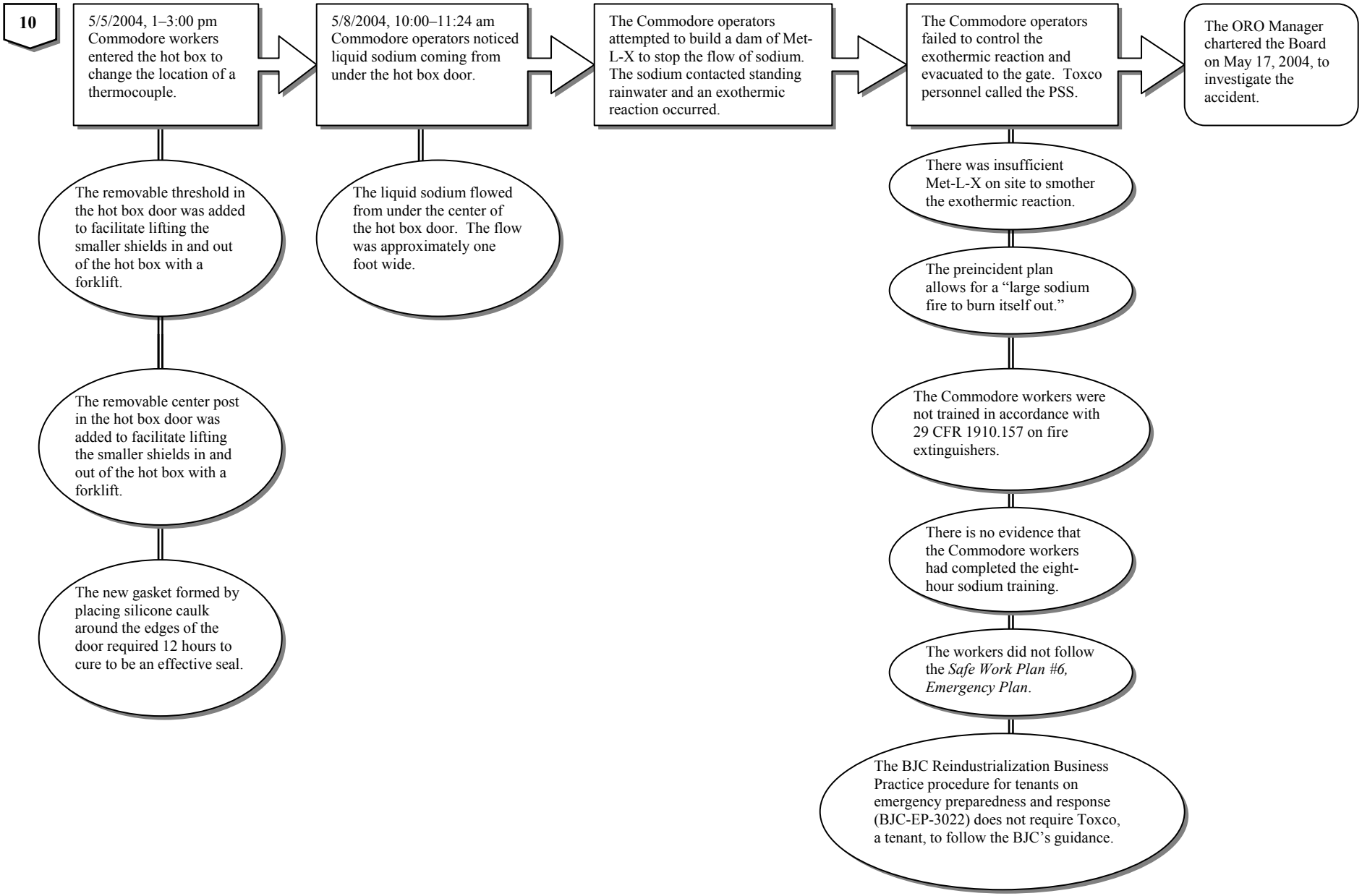
11/4/2003 – Applied Reactor Technology designed the hot box to melt the sodium in the shields.
The design engineer did not have the drawings of the shields from the *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge Tennessee* prepared by Tetra Tech.
NQA-1 requirements (which apply to design) were not communicated to Commodore.
The design engineer only had photographs and the dimensions of the shields.
The design modifications to the hot box included the side door with a movable threshold and center post to facilitate lifting the smaller shields in and out with a forklift.
Neither Toxco nor Commodore had the information in the following reports:
--*Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge Tennessee* prepared by Tetra Tech
--*Nuclear Engineering Analysis of Shields* prepared by Westinghouse Safety Management Solutions Mid-America LL
--*ALARA Evaluation of Proposed Metals Recycling of Sodium Hydride Shields at the Tower Shielding Facility Located at ORNL* produced by SAIC
--Tower Shielding Facility historical report
11/12–17/2003
At AU's request, the AMESH Transportation Safety Engineer reviewed the noncompliant Toxco shield shipments.
The reviewer identified numerous DOT compliance issues, including the unqualified Toxco personnel.
The reviewer made the following recommendations to AU:
--Qualified subject matter experts should review BOAs that include transportation work
--Evaluations of vendors should be performed by subject matter experts.
--AU should provide oversight
Toxco failed to perform the work in accordance with the Task Order requirements.
Formal mechanisms were not in place to identify and communicate information to Toxco.


8
1–4/2004 – Applied Reactor Technology and Commodore constructed the hot box to melt the sodium in the shields and to contain the sodium in the event of shield failure during heating.
Neither Commodore nor Toxco developed a task-specific HASP for the sodium transfer activity.
The side door in the hot box had a removable center post to facilitate lifting the smaller shields in and out with a forklift.
The side door in the hot box had a removable threshold to facilitate lifting the smaller shields in and out with a forklift.
Spring 2004 – Toxco held safety meetings with Commodore personnel.
Neither Commodore nor Toxco developed a task-specific HASP for the sodium transfer activity.
The "Hazard Evaluation Worksheet" did not evaluate the sodium hazard.
4/29–30/2004
Toxco/Commodore held meetings to present the proposed sodium transfer activity. The attendees included the AU Safety Advocate, the AU Project Manager, and a representative from Process Engineering Associates.
The design/process review was informal and undefined.
Toxco did not flow down the NQA-1 requirement from the Task Order to Commodore.
The ORO EM Facility Representatives were not utilized for this project.


9
5/4/2004 – Commodore closed and sealed the hot box door.
5/5/2004, 1:00 pm – Commodore began heating the large shield in the hot box.
The large sodium shield had been filled with approximately one drum of sodium in excess of its capacity to hold liquid sodium.
The work planning for the heating activity did not identify that the concrete cradle constrained the expansion of the aluminum shield during heating.
Heating sodium causes 4.39% expansion.
No task-specific hazard analysis for the sodium-heating activity was performed
The *Sodium and Lithium Hydride Shields Engineering Study for the Tower Shielding Facility, Oak Ridge Tennessee* prepared by Tetra Tech states that 14,000 pounds of sodium were placed in the large shields. Commodore was told it was 11,0000 pounds.
The silicon caulk that was laid around the hot box door to seal it needed 12 hours to cure to be effective as a sealant.
The *Nuclear Engineering Analysis of Shields* prepared by Westinghouse Safety Management Solutions Mid-America LLC states that the activity concentration as:
Sodium-22 .0008 pCi/g
Cobalt-60/Nickel-59 .0314 pCi/g
The Statement of Work in the Task Order shows 1 pCi/g. Toxco was provided with inadequate information.
The *ETTP Site Facility Pre-Incident Plan for Toxco Facility* allows for a "large sodium fire to burn itself out."
The PA system did not work at the Toxco jobsite.


10
5/5/2004, 1–3:00 pm Commodore workers entered the hot box to change the location of a thermocouple.
5/8/2004, 10:00–11:24 am Commodore operators noticed liquid sodium coming from under the hot box door.
The Commodore operators attempted to build a dam of Met-L-X to stop the flow of sodium. The sodium contacted standing rainwater and an exothermic reaction occurred.
The Commodore operators failed to control the exothermic reaction and evacuated to the gate. Toxco personnel called the PSS.
The ORO Manager chartered the Board on May 17, 2004, to investigate the accident.
The removable threshold in the hot box door was added to facilitate lifting the smaller shields in and out of the hot box with a forklift.
The removable center post in the hot box door was added to facilitate lifting the smaller shields in and out of the hot box with a forklift.
The new gasket formed by placing silicone caulk around the edges of the door required 12 hours to cure to be an effective seal.
The liquid sodium flowed from under the center of the hot box door. The flow was approximately one foot wide.
There was insufficient Met-L-X on site to smother the exothermic reaction.
The preincident plan allows for a "large sodium fire to burn itself out."
The Commodore workers were not trained in accordance with 29 CFR 1910.157 on fire extinguishers.
There is no evidence that the Commodore workers had completed the eight-hour sodium training.
The workers did not follow the *Safe Work Plan #6, Emergency Plan*.
The BJC Reindustrialization Business Practice procedure for tenants on emergency preparedness and response (BJC-EP-3022) does not require Toxco, a tenant, to follow the BJC's guidance.

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Appendix E – Review of the Toxco Quality Assurance Plan

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Toxco Quality Assurance Plan Review

June 4, 2004

Scope

The purpose of this review was to determine if the *Toxco Incorporated, East Tennessee Park Site, Quality Assurance Plan* (QAP), Revision 3, dated December 29, 2003, is compliant with the national standard American Society of Mechanical Engineers NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications* (NQA-1), dated 2000.

Approach

The review was conducted based on a document review only, since interviews were not an option. The reviewers individually reviewed the QAP against the basic statement for each of the 18 NQA-1 requirements. The reviewers came to agreement on the adequacy of the document. Based on Sections 3 and 10 of the QAP, a request was made for the Project Work Plan and/or the Quality Assurance Project Plan in order to determine the project-specific quality requirements. Neither document was provided.

Results

The reviewers determined through examination of documents that only Requirement 16, "Corrective Action," which is addressed in Section 17 of the QAP, is fully met. Requirements 1, 2, 4, 6, 7, 8, 9, 12, 17, and 18 are considered as minimally acceptable against the basic requirements of NQA-1-2000. A large contributor to the minimal acceptance is the pervasive use of "may," "may be," "generally include," and "may include" instead of "shall" or "will," which allows too much flexibility in meeting the basic requirements.

The following seven basic requirements of ASME NQA-1-2000 were not adequately addressed in the Toxco QAP.

NQA-1-2000 Requirement 3, "Design Control," "100 Basic"

- "Design interfaces shall be identified and controlled. Design adequacy shall be verified. Design changes shall be governed by control measures . . . "
    - Section 4.0 of the Toxco QAP does not address interfaces, adequacy verifications, or change control for the selection and review for suitability of application of materials, equipment, and processes at the Toxco facility.

NQA-1-2000 Requirement 5, "Instructions, Procedures, and Drawings," "100 Basic"

- "Activities affecting quality and services shall be prescribed by and performed in accordance with documented instructions, procedures, or drawing that include or reference appropriate quantitative or qualitative acceptance criteria for determining that prescribed results have been satisfactorily attained."
    - Section 6.0 of the Toxco QAP makes the use of acceptance criteria for activities affecting quality optional.

NQA-1-2000 Requirement 10, "Inspection," "100 Basic"

- "Inspection results shall be documented."
    - Section 11.0 of the Toxco QAP does not address the requirement for documenting inspection results.

NQA-1-2000 Requirement 11, "Test Control," "100 Basic"

- "Tests required to . . . verify conformance of an item . . . to specified requirements, or to demonstrate satisfactory performance for service shall be planned and executed."
    - Section 12.2, "Requirements," of the Toxco QAP states that "Test control programs do not directly apply to Toxco's quality program." However, Section 12.3, "Scope," states that "When applicable and practicable, Toxco will perform testing of a supplied service or product." These statements are contradictory.

NQA-1-2000 Requirement 13, "Handling, Storage, and Shipping," "100 Basic"

- "Handling, storage, cleaning, packaging, shipping and preservation of items shall be controlled to prevent damage or loss and to minimize deterioration."
    - Section 14.0 of the Toxco QAP is limited to control of material. The standard also applies to control of items used in operations affecting quality.

NQA-1-2000 Requirement 14, "Inspection, Test, and Operating Status," "100 Basic"

- "Status indicators shall also provide for indicating the operation status of systems and components . . ."
    - Section 15.0 of the Toxco QAP section 15 is limited to material status. The standard also applies to status of systems and components.

NQA-1-2000 Requirement 15, "Control of Nonconforming Items," "100 Basic"

- "Controls shall provide for identification, documentation, evaluation, segregation when practical, and disposition of nonconforming items, and for notification to affected organizations."
    - Section 16.0 of the Toxco QAP does not address documentation, evaluation, disposition, or notification concerning nonconforming items.